Y & M Anjuman Khairul Islam's

POONA COLLEGE

OF ARTS, SCIENCE AND COMMERCE

(Affiliated to Savitribai Phule Pune University) ID No. PU/PN/ASC/023/1970

ACTIVITY REPORT

(2022 - 2023)

I. Basic Details:

Name of The Activity- Faculty and students Exchange under MOU.			
Date	**Faculty**	**Department/ Committee**	**Coordinator Name & Phone no.**
11th March to 13th March	BBA	Department of BBA	Prof.Deepika Kininge 9405555695
Time	Venue	Activity for class/ group student number	Extracurricular
	BBA	08	

II. Brief Information about the Activity -Criterion no :- 3.5.1

Topic/ Subject of the activity	**Faculty and students Exchange under MOU.**
Objective for conducting the activity	• The objectives for a faculty and student exchange program at a college is multifaceted, aiming to foster academic growth, cultural understanding, and collaboration. • **Academic Enrichment:** • **Cultural Exchange and Understanding:** • **Knowledge Exchange:** • **Personal Growth:**
Methodology	Participative Learning
Outcome	student exchange programs have fulfilled the objectives that aim to foster academic, cultural, and personal development.

III. Proofs attached: letters/ student list of participation/ certificate/ document/photos/ any other

AKI's Poona College of Arts Science and Commerce
DEPARTMENT OF BBA

REPORT

Visit to Damodar College of Commerce and Economics Margoa,Goa

GOA VISIT (3 Days and 2 Nights)
(11th March to 13th March 2023)

(Under Faculty and Student Exchange Program with Damodar College of Arts Science and Commerce, Verna, GOA)

Department of BBA along with 06 BBA students and 2 Faculty organized Study tour and Faculty student Exchange Program in collaboration with Damodar College of Arts Science and Commerce, Verna, GOA from 11th March to 13th March under in pursuance of MOU signed between Damodar College ,Goa and Poona College. Faculties of BBA presented research paper @Damodar College and Student enjoyed Mgt games and Cultural Activities on GOAN culture org by Dept of BBA of Damodar College.

Prof.Deepika AND Prof.Sonali Kamble (BBA Dept.Poona College) visited Damodar College

Goa on 11th March 2023 along with 05 BBA Students

Dr.Rodney D'silva welcomed BBA faculties and students of BBA

Principal Dr.Priti Malya of Damodar College GOA welcomed BBA Faculty and Students.

BBA faculties and Students of Damodar College organized program for BBA students of Poona College.

Ms Deepika Kiringe
BBA Dept.

50

Golden Jubilee Celebrations

Vidya Vikas Mandal's

SHREE DAMODAR COLLEGE

OF COMMERCE & ECONOMICS

Affiliated to Goa University

Accredited by NAAC at 'A' Grade with CGPA of 3.03 on a 4 point scale

Margao - Goa

Department of Commerce & Management

in collaboration with

Directorate of Higher Education (DHE), Government of Goa

Shree Damodar College of Commerce & Economics V.V.M'S. MARGAO GOA

Certificate

This is to certify that ~~Prof./Dr./Mr./~~Ms.

Deepika Abhijeet Kininge

of Poona College of Arts, Science & Commerce, Pune

has presented a research paper titled A Comparative Study of Marketing Strategies and Consumer Satisfaction of Ayurvedic Medicinal Products with Allopathic Medicinal Products in Pune at the National Conference on

'Emerging Global Practices in Finance & Management'

organised by the Department of Commerce & Management in collaboration with Directorate of Higher Education (DHE), Government of Goa, held on 11th March, 2023

Prof. Prita D. Mallya
Professor and Principal

Dr. Shami Pai
HoD, Commerce & Management

Dr. Sheetal Arondekar & Mr. Gajanan Haldankar
Conference Coordinators

Attendance Sheet

Date of Activity: 11th March to 13th March 2021 **Time:**

Activity Name: Activity under MOU. **Coordinator Name:** Deepika Kinige

Department : BBA Faculty Student Exchange Program between Poona College & Damodar College, Goa.

Number of Participants: 06 student + 02 faculty

Sr.No	Name	Class	Roll No	Sign of Participant
1	Nirupam Bansode	TYBBA	6359	Nirupam
2	Shaikh Mohd. Sohel [illegible]	TYBBA	6373	[illegible]
3	Sameer Abdulla Shaikh	TYBBA	6365	[illegible]
4	Mohammed Ahsan	SYBBA	6188	[illegible]
5	Fidaa Tamboli	SYBBA	6151	[illegible]
6	Pradhumn Bhorge	TYBBA	6360	[illegible]
7.	Deepika Abhijeet Kinige	Coordinator	BBA	[illegible]
8.	Sonali S. Kamble	Faculty	BBA	[illegible]

Signature of Coordinator

PROJECT REPORT

ON

A STUDY ON E- FILING OF TAX RETURN – INCOME TAX WITH A CASE STUDY OF CAFE ADDA IN AURANGABAD

SUBMITTED TO

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(ADVANCED ACCOUNTING & TAXATION)

OF

SAVITRIBAI PHULE PUNE UNIVERSITY

SUBMITTED BY

ANSARI SHIFA KHATOON ASIF

Roll No-5901

MCOM II SEM IV

UNDER THE GUIDANCE OF

DR. SYED HAMED HASHMI

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

CAFE ADDA

Azad Chowk Rd, Rahemania Colony, Kiradpura, Aurangabad Maharashtra
431001

Mobile Number - +91 84848 84855

This is to certify that -**Ansari Shifa Khatun Asif** of **MCOM Part II, SEM 4,** and Roll No. 5901 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of **Savitribai Phule Pune University** in our organization.

During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavours.

CAFE ADDA
Prop. Ausaf Khan
8484884855

Authorized Signature

PROJECT REPORT

ON

A STUDY OF TAX AUDIT REPORT OF CORPORATE AND NON-CORPORATE ASSESSEES

IN

YASH PLAST PRIVATE LIMITED PUNE

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

ADVANCED ACCOUNTING AND TAXATION.

SUBMITTED BY

CHIKODI MOHAMMAD FAWAAZ MOHSIN

Roll No- 5982

UNDER THE GUIDANCE OF

DR. SYED HAMED HASHMI

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

YASH PLAST

Mfg. : In All Types of Plastic Moulding & Scrap Dealing

Sr. No. 15 A, Shed No. 5, Dhorewadkar Industries, Nanded - Phata, Pune - Sinhagad Road,
Pune - 411041. Tel. [redacted]

This is to certify that **CHIKODI MOHAMMAD FAWAAZ MOHSIN** of MCOM Part II, SEM 4, and **Roll No-5902** of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.
During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish him all the best in his future endeavors.

The candidate has completed his internship in our organization from 1st January 2023 to 31st March 2023.

YASH PLAST

A PROJECT ON

"A Case Study of e-filing of Tax Returns of GST in Alfasahat Air Conditioning Systems at MSK & Associates Pune"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(Advance Accounting & Taxation)

SUBMITTED BY

UNAES ZAKARIYA KOKATE

Roll No-5903

UNDER THE GUIDANCE OF

Dr. Syed Hamed Hashmi

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

Mr. Mohammed Sadique Khan
M.B.A (Fin), M.Com, G.D.C.A, B.Com, D.T.L, G.S.T.P
CSC VLE for Ministry of Electronics and Information Technology, Government of India New Delhi
BC for Bank of India
Prop. MSK & Associates
Founder of counttax.com
GSTP No. : 271800007293GP

www.counttax.com

Counttax

MSK ASSOCIATES

One Stop Solution for All Your Financial & Legal Services

(M) : 738 7786 729 (O) : 963 7387 786
Email us : mskassociates1@gmail.com / counttax.com@gmail.com ; For queries mail us at ce.mskassociates@gmail.com

Date: 04/04/2023

TO WHOM SO EVER IT MAY CONCERN

This is to certify that **Mr. Unaes Zakariya Kokate** of MCOM Part II, SEM 4, and Roll No. **5903** of **AKI's Poona College of Arts, Science and Commerce** has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable. We wish **Mr. Unaes Zakariya Kokate** him all the best in his future endeavours.

He has completed his internship for a period from **01st January 2023 to 31st March 2023.**

MSK & Associates
Mohammed Sadique Khan
G.D.C.A, M.B.A (Fin), M.Com, B.Com, D.T.L
(M) +917387786729
Pune

For MSK & Associates

Prop. Mohammed Sadique Khan
M.B.A (Fin), G.D.C.A, M.Com, B.Com, D.T.L

A PROJECT ON

"A CASE STUDY ON TAX PLANNING OF INDIVIDUAL ASSESSEES HAVING INCOME FROM BUSINESS WITH RESPECT TO INCOME TAX ACT 1961, AT MSK & ASSOCIATES

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(Advance Accounting & Taxation)

SUBMITTED BY

SAQLAIN SHOEB SHAIKH

Roll No-5904

UNDER THE GUIDANCE OF

Dr. Syed Hamed Hashmi

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

Mr. Mohammed Sadique Khan
M.B.A (Fin), M.Com, G.D.C.A, B.Com, D.T.L, G.S.T.P
CSC VLE for Ministry of Electronics and Information Technology,
Government of India New Delhi
BC for Bank of India
Prop. MSK & Associates
Founder of counttax.com
GSTP No. : 271800007293GP1

www.counttax.com

Counttax

MSK ASSOCIATES

One Stop Solution for All Your Financial & Legal Services

(M) : 738 7786 729 (O) : 963 7387 786

mail us : mskassociates@gmail.com / counttax.com@gmail.com : For queries mail us at ss.mskassociates@gmail.com

Date:03/04/2023

TO WHOM SO EVER IT MAY CONCERN

This is to certify that **Mr. Saqlain Shoeb Shaikh** of MCOM Part II, SEM 4, and Roll No. **5904** of **AKI's Poona College of Arts, Science and Commerce** has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable. We wish **Mr. Saqlain Shoeb Shaikh** him all the best in his future endeavours.

He has completed his internship for a period from **01st January 2023 to 31st March 2023**.

MSK & Associates
Pune

For MSK & Associates

Prop. Mohammed Sadique Khan
M.B.A (Fin), G.D.C.A, M.Com, B.Com, D.T.L

Shop No 2, Gulmohar Habitat Phase II, Salunke Vihar Road, Nr Aarzoo Café, Wanawadi, Pune 411040.

"COMPUTERIZED ACCOUNTING SYSTEM AT KOKATE ROADLINES"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(ADVANCED ACCOUNTING & TAXATION)

SUBMITTED BY

REHAN JAMIL KHAN

Roll No-5905

UNDER THE GUIDANCE OF

DR.HAMED HASHMI

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

KATE ROADLINES
OWNER & TRANSPORT CONTRACTORS

Shop No. A-5, Vardhaman Garden, Katraj-Mumbai by pass,
Katraj, Pune - 411046, Maharashtra
Tel. : 020 - 24368351 Mob. : 9822063761
Email : milindkd009@yahoo.co.in, kokate.roadlines123@gmail.com
web : www.kokateroadlines.com
GSTIN No. : 27AJLPK4392D1Z2 • PAN NO. : AJLPK4392D

This is to certify that REHAN JAMIL KHAN of MCOM Part II, SEM 4, and Roll No. 5905 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish him all the best in his future endeavours.

Authorized Signature with Stamp KOKATE ROADLINES PUNE-46

29.03.2023

"A study of Computerized Accounting System in Future Chip Technologies Pune"

A PROJECT REPORT SUBMITTED

TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(Advance Accounting & Taxation)

SUBMITTED BY

SADIKA FAIZ AHMED INAMDAR

Roll No-5907

UNDER THE GUIDANCE OF

Dr. Syed Hamed Hashmi

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE-1

2022-2023

Future Chip Technologies

Head Office : 13/293, Ram Society, Phulenagar, Behind R.T.O. Office, Alandi Road, Pune - 411 006.
Pune Branch : 928, Sadashiv Peth, Near Sadhana Trust Office, Pune - 411 030.
Mumbai Branch : Near Girnar Building, Mumbai-Pune Highway, Khapoli, Dist. Raigad - 410 203.
Cell : 98901 41705 | 96659 99705 | **Email :** ramakantbhujbal@gmail.com | www.futurechiptech.com

TO WHOM IT MAY BE CONCERN

This is to certify that **Miss. SADIKA FAIZAHMED INAMDAR** of M.COM. Part II (SEM-IV), and Roll No.-5907 of **AKI's Poona College of Arts, Science and Commerce, Pune** has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University, Pune in our organization.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by her is highly appreciable.

We wish her all the best in her future endeavors.

She has completed her Internship for period from 01/01/2023 to 31/03/2023

Mr. Bhujbal Ramakant
Director
Future Chip Technologies,
409, Shaniwar Peth, Pune-30

FUTURE CHIP TECHNOLOGIES PUNE

A PROJECT ON

"A STUDY OF COMPUTERIZED ACCOUNTING SYSTEM IN B K TOUGHENED GLASS PVT LTD PUNE"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(Advance Accounting & Taxation)

SUBMITTED BY

Siyam Imtiyaz Parkar

Roll No- 5908

UNDER THE GUIDANCE OF

Dr. Syed Hamed Hashmi

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

TUFF

CIN : U74900PN2012PTC14405

B K TOUGHENED GLASS PRIVATE LIMITED
Gat No. 380, Kanifnath Mandir Road, Bopgaon, Tal. Purandar, Dist. Pune Pin – 412301
Office : 9087720436, Email : bktoughenedglass@gmail.com

TO WHOMSOEVER IT MAY CONCERN

This is to certify that **Siyam Imtiyaz Parkar** of MCOM Part II, SEM 4, and Roll No. **5908** of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavors.

He has completed his Internship for period from 01/01/2023 to 31/03/2023

B K TOUGHENED GLASS PVT. LTD. BOPGAON

PROJECT REPORT ON

"A STUDY OF E-FILING OF TAX RETURN"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(ADVANCE ACCOUNTING & TAXATION)

SUBMITTED BY

KANNAUJIYA SUJEET MISHRILAL

Roll No- 5909

UNDER THE GUIDANCE OF

Dr. Syed Hamed Hashmi

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

Mohammad Asad
Chartered Accountant (B.com)
Cell : 9975775774
Email : ca.mohammadasad@gmail.com

Mohammad Asad & Co.
Chartered Accountants

Ref # : Date :

Date: 18/03/2023

TO WHOM SO EVER IT MAY CONCERN

This is to certify that **Mr. Kannaujiya Sujeet Mishrilal** of MCOM Part II, SEM 4, and Roll No. **5909** of **AKI's Poona College of Arts, Science and Commerce** has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

He has completed his internship for a period of **01-12-2022 to 28-02-2023**.

We wish **Mr. Kannaujiya Sujeet Mishrilal** him all the best in his future endeavours.

Best Regards

For Mohammad Asad & Co.

Proprietor

Date:18/03/2023

A PROJECT ON

"A study on Accounting System of Global Tour and Travel Business in Pune"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR

THE DEGREE OF MASTER OF COMMERCE

ADVANCE ACCOUNTING

ANDTAXATION

SUBMITTED BY

SANIYA MUSTAFA CHOUDHARY

ROLL NO- 5910

UNDER THE GUIDANCE OF

DR. SAYED HAMED HASHMI

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

GLOBAL TRAVELS

: 27ASOPS3848L1ZT

Helpline No: 020-40026508

This is to certify that **CHOUDHARY SANIYA MUSTAFA** of MCOM Part II, SEM 4, and **Roll No. 5910** of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish her all the best in her future endeavours.

The candidate has completed her internship in our organization from 1st January 2023 to 31st March 2023.

Authorized Signature with Stamp

For Global Travels

Proprietor

Shop No.7, Graffiti arcade, Opp Jehangir Hospital, Pune.
Maharashtra, Pin:411001, Email: [illegible]
Contact No: 020-26162894-95 40026508

"COMPUTATION OF TOTAL INCOME WITH RESPECTIVE INDIVIDUAL RESPONDENT"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(Advance Accounting & Taxation)

SUBMITTED BY

Pal Punam Premshankar

Roll No-5911

UNDER THE GUIDANCE OF

Dr. Syed Hamed Hashmi

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

VARSHA JAWALKAR & ASSOCIATES
CHARTERED ACCOUNTANTS

Date:-10/03/2023

TO WHOMESOEVER IT MAY CONCERN

This Is TO Certify That Miss Punam Premshankar Pal a Student Of a Mcom Master Of Commerce Pune University . Has Sucessfully Completed 3(three) Months (From 1 December 2022 To28 Feb2023)Long Intership Programme At This Firm. During The Period Of His Intership Programme With Us. She Was Found Punctual. Hardworking And Inquisitve.

Her Associataion With Us Was Very Benifical And We Her All The Best In Her Futura Endeavors

Authorizes Signatory
CA Varsha Jawalkar -Ghule

Address : 4th Floor, Saikrupa Building, Pune Solapur Road, Manjari Bk, Tal. Haveli, Dist. Pune
Contact No : 9604590093 | Email : ca.varshajawalkar@gmail.com

PROJECT REPORT

ON

A STUDY ON AN ACCOUNTING AND TAX PLANNING OF NEW PARVIN DRESSES PARTNERSHIP FIRM KHADKI PUNE

SUBMITTED TO

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(ADVANCED ACCOUNTING & TAXATION)

OF

SAVITRIBAI PHULE PUNE UNIVERSITY

SUBMITTED BY

SHAIKH SAINA MURTUZA

Roll No-5912

MCOM II SEM IV

UNDER THE GUIDANCE OF

DR. SYED HAMED HASHMI

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

NEW PARVIN DRESSES

Shop No. 16, Ambemata Estate, 8/9 New Bazar, [illegible], Pune-[illegible]
Mobile Number - +91 9822834260, +91 [illegible]

This is to certify that Saina Murtuza Shaikh of M.COM Part II, SEM 4, and Roll No. 5912 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University on our organization.

During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavors.

Duration of project work: 1 February to 15 April.

Murtuza

For New Parvin Dresses

Proprietor

Authorized Signature

2022-2023

"A STUDY OF GST IMPLEMENTATION AND IT'S EFFECTS ON SALES"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT

FOR THE

DEGREE OF MASTER OF COMMERCE

(Advance Accounting & Taxation)

SUBMITTED BY

SINGH ANKITA KUMARI BRAJESH KUMAR

Roll No-5914

UNDER THE GUIDANCE OF

Dr. Syed Hamed Hashmi

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

AMP & ASSOCIATES
CHARTERED ACCOUNTANTS

TO WHOMSOEVER IT MAY CONCERN

This is to certify that ANKITA BRAJESH SINGH of M.com Part II , SEM-4 Roll No.5914 of Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, she was sincere, hardworking and showed keen interest to learn. The involvement and sustained efforts put by student are highly appreciable.

We wish her all the best for her future endeavor.

For AMP & Associates
Chartered Accountants

AMP & ASSOCIATES
FRN No. 137099W
CHARTERED ACCOUNTANTS

CA.Mihir S Sanghvi
Partner
M.No.145407
Date-
Pune

92 B, Khalate Sadan, Nr. Bank of Maharashtra, Parvati, Pune - 411009. M. : +91 - 9422515955 / +91 - 9922318941

"COST BUDGETING AT MAXGEN TECHNOLOGIES PVT. LTD"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(RECENT ADVANCES IN COST AUDITING & COST SYSTEM)

SUBMITTED BY

Ms. ZAINAB SAYYED

Roll No-5915

UNDER THE GUIDANCE OF

Dr. Riyasat Peerzade

DEPARTMENT OF COMMERCE, PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

Maxgen Technologies Pvt.Ltd

INTERNSHIP COMPLETION CERTIFICATE

This is to certify that Ms. Zainab Sayyed has successfully completed project work in the company under the esteemed guidance and technical support of Sr. Developers toward the fulfillment of the semester.

Project Name: Cost Budgeting

From – 27th Jan 2023 to 10th Feb 2023

She has successfully completed her internship. During the period she was sincere, hardworking & fully devoted to project.

We wish her all success to her future career.

For Maxgen Technology Pv

Salluna Kokate
Manager – Human Resources

Maxgen Technologies Pvt.Ltd.

"A STUDY OF ACTIVITY BASED COSTING METHOD AT TAMANNA HOTELS PRIVATE LIMITED., PUNE"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(ADVANCED COST ACCOUNTING & COST SYSTEM)

SUBMITTED BY

UMARMUKHTAR ASADIMRAN SHAIKH

ROLL NO -5921

UNDER THE GUIDANCE OF

Dr. RIYASAT PEERZADE

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

TAMANNA

This is to certify that Ummmukhar Asadimran Shaikh of M.COM Part II, (SEM- IV) and Roll No-5921 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 01/03/2023 to 18/03/2023 for the Academic Year 2022-2023.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish him all the best in his future endeavours.

Authorized Signature

This is a computerized generated document and does not require any stamp validation

Tamanna Hospitality Services Pvt. Ltd., Plot No. P - 10, Rajiv Gandhi Infotech Park, Phase - 1, MIDC, Hinjawadi, Pune 411 057.
Tel.: 020 - 66339888 / 22933164 / 66731900 Telefax : 020-22932127
Email : info@tamannahotels.com | Website : www.tamannahotels.com

"A STUDY OF BUDGETARY CONTROL SYSTEM AT BRITANNIA INDUSTRIES LIMITED."

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(ADVANCED COST ACCOUNTING & COST SYSTEM)

SUBMITTED BY

AFRIN TAUSIF SHAIKH

ROLL NO-5922

UNDER THE GUIDANCE OF

Dr. RIYASAT PEERZADE

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

BRITANNIA

TO WHOM IT MAY BE CONCERN

This is to certify that **Afrin Tausif Shaikh** of **MCOM Part II, SEM 4,** and Roll No. **5022** of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 27th January 2023 to 15th February 2023 for the academic year 2022-23.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish him all the best in his future endeavours.

Authorized Signature with Stamp

For Britannia Industries Limited

T.V. Thulsidass
Company Secretary
Membership No.: A20927

"STUDY OF WORKING CAPITAL MANAGEMENT AT ARTHVRITT CAPITAL SERVICES PRIVATE LIMITED"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

ADVANCED COST ACCOUNTING

SUBMITTED BY

KAITHAKODE UTHRA ADITHYAN

Roll No- 5923

UNDER THE GUIDANCE OF

DR. RIYASAT PEERZADE

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

ARTHVRITT CAPITAL SERVICES PVT. LTD.

COMPANY CERTIFICATE

This is to certify that **Kaithakode Uthra Adithyan** of **M.Com Part II, SEM 4,** and **Roll No. 5923** of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organizationfrom 27th January 2023 to 20th February 2023 for the academic year 2022-23.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish her all the best in his future endeavors.

Authorized Signature

For ARTHVRITT CAPITAL SERVICES PVT. LTD.

Director

+91-8291621577, +91-9024747384
info@arthvrittcapital.com
www.Arthvrittcapital.com
Office no. 1504, Goodwill Excellency, Sector 17, Vashi, Navi Mumbai 400703

AKI's POONA COLLEGE OF ARTS, SCIENCE AND COMMERCE

"A STUDY OF PROCESS COSTING AT KATRAJ DAIRY"

A PROJECT REPORT

SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(ADVANCE COST ACCOUNTING & COST SYSTEM)

SUBMITTED BY

SOBIYA SAMEER SHAIKH

Roll No-5925

UNDER THE GUIDANCE OF

DR.RIYASAT PEERZADE

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

PUNE ZILLHA SAHKARI DUDH UTPADAK SANGH MARYADIT
Katraj Dairy, Katraj Pune -411 046

Date:- 06/03/2023

INDUSTRIAL VISIT CERTIFICATE

This is to certify that **Miss. Sobiya Sameer Shaikh** the Students of Poona College of Arts, Science & Commerce, Camp, Pune - 411001 has visited to our Pune Zillha Sahakari Dudh Utpadak Sangh Maryadit Katraj Dairy, Katraj, Pune on 06/03/2023

6/3/23
Incharge Training Center

Pune Zillha Saha. Dudh
Utpadak Sangh Mar.
Pune-Satara Road,
Katraj Dairy, Pune-411046.

A Project Report on

"ACCOUNTING FOR TOURS AND TRAVELS BUSINESS

SABA TOURS AND TRAVELS"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

SUBMITTED BY

FAIZAN ARIF MULANI

Roll No-5927

UNDER THE GUIDANCE OF

Dr. Syed Hamid Hashmi

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

SABA
Tours & Travels

For All Types of CAB on HIRE
Salunke Vihar Road, Kondhwa Kamala,
Opp.Fakri Hill,Pune - 411 048.
Mob. : 5850334958 / 9371105496
E-mail : sabatoursandtravels@gmail.com

Ref. Date

This is to certify that FAIZAN ARIF MULANI of MCOM Part II, SEM 4, and Roll No. 5927 Of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest learns. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavours.

Thanking You,

For SABA TOURS AND TRAVELS

Proprietor

"A Study of Work Culture and Work Ethics at Treelink Network Pvt Ltd"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(BUSINESS ADMINISTRATION)

SUBMITTED BY

ABRAR AHMED SIDDIQUE

ROLL NO- 3947

UNDER THE GUIDANCE OF

DR. NASRIN KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

Treelink Network Private Limited

This is to certify that Abrar Ahmed Siddique of MCOM Part II, SEM 4, and Roll No.5942 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 02/02/2023 to 01/03/2023 for the academic year 2022-23 During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable. We wish him all the best in his future endeavors.

Authorized Signature with Stamp

Treelink ... Pvt. Ltd. Pune

A PROJECT REPORT ON

CUSTOMER SATISFACTION STRATEGIES AT BISMILLAH HAJ TOURS AND TRAVELS

SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(BUSINESS ADMINISTRATION)

SUBMITTED BY

SHAFIYA WAHID SAYEED

Roll No-5943

UNDER THE GUIDANCE OF

DR NASRIN PARVEZ KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

بسم الله حج ٹورس اینڈ ٹراولس

BISMILLAH

HAJ TOURS AND TRAVELS PVT. LTD.
Recognised by the Government of India

IATA

17th February 2023

This is to certify that Shafiya Wahid Sayyed of MCOM Part II, SEM IV, and Roll No. 5943 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 17 September 2022 to 17 February 2023 for the academic year 2022-2023

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable. We wish her all the best in her future endeavors.

Authorized Signature with Stamp

PUNE

Shop No 1, Abdul Hamid Heights, Opp. Aaina Masjid, 144 Nana Peth, Pune - 411002
020-26336482 99 22 99 87 01
Email Id : bismill@yahoo.co.in • www.bismillahhajtours.in

A STUDY ON 360 DEGREE PERFORANCE APPRAISAL AT LIFETIME NUMBER

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(BUSINESS ADMINISTRATION)

SUBMITTED BY

SHAISTA SHAIKH NASIR

ROLL NO -5944

UNDER THE GUIDANCE OF

DR. NASRIN KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLAGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022 - 22023

LIFE TYME
NUMBER

+91 8855999999
info@lifetimenumber.com
Sr No 13, Lane No. 5, behind Agarwal Sweet, Satav Plot, Amardip Pratishthan, Utkarsh Nagar, Hadapsar, Pune, Maharashtra 411028

This is to certify that Shaista Nasir Shaikh of MCOM Part II, SEM 4, and Roll No. 5944 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization. From 20/2/2023 to 20/3/2023 for the academic year 2022-2023.

During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavours.

Authorized Signature with Stamp

For LIFE TIME

Proprietor

21/03/2023

"WORK LIFE BALANCE IN AN ORGANISATION"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(BUSINESS ADMINISTRATION)

SUBMITTED BY

-FAIQUL INAMUL HAQ

Roll No-5945

UNDER THE GUIDANCE OF

-DR.NASRIN KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

Contact no.: 9970125786 Email ID: ahemadsayyed1271@gmail.com

DATE:03/03/2023

AB SOLUTIONS

Konark Indrayu Mall Office no.3249 Opposite to Satyanand Hospital Kondhwa Main Rd Kondhwa Khurd Pune 411048

This is to certify that Falqul Inamul Haq of MCOM Part II, SEM 4, and Roll No.5945 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 02/02/2023 to 01/03/2023 for the academic year 2022-23

During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavours.

AB SOLUTIONS
Konark Indrayu Mall, 2nd Floor, Office No. 3249, Opp. Satyanand Hospital, Above SBI Bank, Kondhwa Khurd Pune - 411048

Authorized Signature with Stamp

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

BUSINESS ADMINISTRATION

SUBMITTED BY

NITESH DATTATRAY PANCHAL

Roll No- 5946

UNDER THE GUIDANCE OF

Dr. NASRIN PARVEZ KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

OFFICE ADDRESS
[illegible]

Swaraj

This is to certify that **Nitesh Dattatray Panchal** of **MCOM** Part II, SEM IV, and **Roll No. 5946** of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 01/01/2023 to 01/03/2023 for the academic year 2022 to 2023

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable. We wish him all the best in his future endeavors.

For Swaraj Developers

Proprietor

Proprietor

Authorized Signature with Stamp

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

BUSINESS ADMINISTRATION

SUBMITTED BY

SOURAV KAILAS GAIKWAD

Roll No- 5947

UNDER THE GUIDANCE OF

Dr. NASRIN PARVEZ KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

OFFICE ADDRESS
Office No 4, [illegible] Heights Near PMT Bus Depot,
Behind Shreyash Garden, [illegible] Phata,
Wagholi, Pune - 412 207 Mob No : +91 [illegible]
e-mail : info@swarajdevelopersonline.com
website : www.swarajdevelopersonline.com

Swaraj

This is to certify that **Saurav Kailas Gaikwad of MCOM** Part II, SEM IV, and **Roll No. 5947** of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 01/01/2023 to 01/03/2023 for the academic year 2022 to 2023

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable. We wish him all the best in his future endeavors.

For Swaraj Developers

Proprietor

Authorized Signature with Stamp

A PROJECT REPORT ON

"A STUDY ON STRESS MANAGEMENT AMONG EMPLOYEES AT EMSPHERE TECHNOLOGIES Pvt. Ltd."

SUBMITTED BY

NUZHAT ASLAM SHAREEF

UNDER THE GUIDANCE OF

DR. NASRIN KHAN

SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

AWARD OF THE DEGREE OF

M.COM (BUSINESS ADMINISTRATION)

THROUGH

DEPARTMENT OF COMMERCE PG & RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

emsphere

emSphere Technologies Pvt. Ltd.
2nd Floor, Sapphire Chambers, Above Axis Bank, Baner Pune 411045

This is to certify that Nuzhat Azam Shareef of MCOM Part II SEM [illegible] and Roll No. [illegible] of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish her all the best in her future endeavours.

Ram Sonawane
[illegible] & Finance Manager

A STUDY OF STRESS MANAGEMENT RELATED TO THE WORK OF FACULTY MEMBERS IN COLLEGE

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

[Business Administration]

SUBMITTED BY

MR. MOHD UFAQUE RAFIQUE SHAIKH

Roll No-3950

UNDER THE GUIDANCE OF

Dr. Nasrin Parvez Khan

DEPARTMENT OF COMMERCE, PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

Anjuman Khairul Islam's

POONA COLLEGE
OF ARTS, SCIENCE & COMMERCE

- Affiliated to Savitribai Phule Pune University; ID No PU/PN/ASC/022/1970
- UGC - 2(f) & 12 (B) Status • DST - FIST Funded College
- Government of Maharashtra and Savitribai Phule Pune University Recognized Minority College

K. B. Hidayatullah Road, Camp, Pune - 411001 (MS) India
+91-20-2645 4243 2644 6218
principal@poonacollege.edu.in
www.poonacollege.edu.in

Professor Dr. Aftab Anwar Shaikh
M.Com, Ph.D (Busi. Admin.)
PRINCIPAL

+91 98220 31079
draanwarshaikh@gmail.com

TO WHOMSOEVER IT MAY CONCERN

This is to certify that MOHD UFAQUE RAFIQUE SHAIKH of MCOM part II, SEM-4, and Roll no.5950 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 10 October 2022 to 10 February 2023 for the academic year 2022-23.

During the training, the student was sincere, hardworking and showed a keen interest to learn.

The involvement and sustained effort put in by the student is highly appreciable.

We wish him all the best in his future endeavors.

Authorized Signature with Stamp

PRINCIPAL
Poona College of Arts, Science & Commerce
Camp, Pune-411001
Principal Office

AKI'S Poona College of Arts, Science & Commerce
Camp, Pune-411001

"E-RECRUITMENT SYSTEM AT INDIA TOURS AND TRAVELS PUNE"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

[Business Administration]

SUBMITTED BY

MS.TAMANNA BARKAT ALI ANSARI

Roll No-5951

UNDER THE GUIDANCE OF

Dr. Nasrin Parvez Khan

DEPARTMENT OF COMMERCE, PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

INDIA TOUR & TRAVELS

NEW SHIVAJINAGAR ST STAND, OLD MUMBAI PUNEROAD WAKDEWADI PUNE 411003

Importers & Distributors: Transport

Tel: 020 6160612
Cell: 8087088646
Mob: 9175202061

20/02/2023

PROJECT COMPLETION CERTIFICATION

This is to certify that Tamanna Ansari of MCOM Part II, SEM IV. and Roll No. 5951 of AK's Poona College of Arts. Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization India Tour and Travels From 27th Jan to 10th Feb-2023 for the academic year 2022-2023

During the training, the student was sincere. Hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish him all the best in his future endeavours.

For INDIA TOUR & TRAVELS

Proprietor

Authorized Signature with Stamp

A PROJECT REPORT ON

IMPACT OF CUSTOMER SATISFACTION STATERGY AT MASTER TRAVELS

SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(BUSINESS ADMINISTRATION)

SUBMITTED BY

FARAD ZAKIR SHAIKH

Roll No-5952

UNDER THE GUIDANCE OF

DR NASRIN PARVEZ KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

Master Travels

Haj-Umrah & Air Ticket

IATA

416, New Mangalwar Peth, Hazrat Yar Khan Complex, Wing A/5, 2nd Floor, Pune 411011. (M.S.) India
Mobile : 9890017809 / 7066063400 Tel.: (020) 26053117 | E-mail : mastertravels_haj@yahoo.com

Ref. No. *Date :*

Date: 21/03/2023

Ref no. /MT/086/23

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Ms. Farad Zakir Shaikh, Student of M. Com Final year, studying in Poona College of Arts Science & Commerce, has done the Project Work in the company on Master Travels, under the guidance of Mr. Farooque Qasim Shaikh in Master Travels. She was working on the Project from 01/01/2023 to 30/03/2023. During her Project Work, we found that she is a very Sincere Hardworking & Fully Voted to Assignment.

We wish her all the success to her Future Career.

MASTER TRAVELS PUNE

MASTER TRAVELS

FAROOQUE QASIM SHAIKH

"E-RECRUITMENT SYSTEM AT INDIA TOURS AND TRAVELS PUNE"

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

[Business Administration]

SUBMITTED BY

Mr. ANEESUL HAQUE KHAN

Roll No-5953

UNDER THE GUIDANCE OF

Dr. Nasrin Parvez Khan

DEPARTMENT OF COMMERCE, PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

INDIA TOUR & TRAVELS

NEW SHIVAJINAGAR ST STAND, OLD MUMBAI PUNEROAD WAKDEWADI PUNE 411003

Tel: 020 6150632

Importers & Distributors: Transport

Cell: 8087088646

Mob: 9175203061

20/02/2023

PROJECT COMPLETION CERTIFICATION

This is to certify that Aneesul Haque Khan of MCOM Part II. SEM IV. and Roll No. 5953 of AK's Poona College of Arts. Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization India Tour and Travels From 27th Jan to 10th Feb for the academic year 2022-2023

During the training, the student was sincere. Hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish him all the best in his future endeavours.

For INDIA TOUR & TRAVELS

Proprietor

Authorized Signature with Stamp

"*EMOTIONAL INTELLIGENCE AMONGST EMPLOYEES AT P S ENTERPRISES*"

A PROJECT REPORT SUBMITTEDTO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(Business Administration)

SUBMITTED BY-

SINGH PAHAL SUDHEER

Roll No- 5954

UNDER THE GUIDANCE OF

H.O.D DR. NASRIN KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

P S Enterprises

34, Market Yard, Pune-411037. Tel.: 020-24269499
www.ps-enterprises.co.in

17 Feb 2023

This is to certify that SINGH PAHAL SUDHEER of MCOM Part II, SEM 4, and Roll No. 5954 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 17 September 2022 to 17 February 2023 for the academic year 2022-23.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish her all the best in his future endeavors.

Authorized Signature with Stamp

For P. S. ENTERPRISES

PARTNER

Anjuman Khairul Islam's

POONA COLLEGE
OF ARTS, SCIENCE & COMMERCE

• Affiliated to Savitribai Phule Pune University: ID No. [illegible]
• UGC - 2(f) & 12 (B) Status • DST - FIST Funded College
• Government of Maharashtra and Savitribai Phule Pune University Recognized Minority College

K. B. Hidayatullah Road, Camp, Pune - 411001 (MS) India | +91-20-[illegible] [illegible] | principal@poonacollege.edu.in www.poonacollege.edu.in

Professor Dr. Aftab Anwar Shaikh
M.Com, Ph.D (Bust. Admin.)
PRINCIPAL

+91 [illegible]
[illegible]@gmail.com

PROJECT COMPLETION CERTIFICATE

This is to certify that the project report entitled **"A Study of Work Culture and Work Ethics at Treelink Network Pvt Ltd"**
In the subject Business Administration was prepared by **Azim Idris Shaikh** Class **M.COM -II (SEM- IV)** Roll No **[illegible]** for the academic year **2022-2023** under my guidance and supervision. This project report is based on original study work carried out by him such material as has been obtained from other sources has been duly acknowledged in the report. This project is submitted in partial fulfillment of requirement of the Master of Commerce and project work as per the Rules of Savitribai Phule Pune University.

Project Guide
Dr. Nasrin Khan

HOD
Dr. Nasrin Khan
Department of commerce

Exam Seat No. 20415

Date of Exam

External Examiner

Internal Examiner

Treelink Network Private Limited

This is to certify that Azim Idris Shaikh of MCOM Part II, SEM 4, and Roll No.5955 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 02/02/2023 to 01/03/2023 for the academic year 2022-23 During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable. We wish him all the best in his future endeavors.

Authorized Signature with Stamp

Pune

A Study on Talent Sourcing and Acquisition

At

"TVS Logistics Services Limited."

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(Business Administration)

SUBMITTED BY

Mr. Abdul Wajid Khan

Roll No.- 5008, M.Com-II, Sem-IV

UNDER THE GUIDANCE OF

Dr. Nasrin Parvez Khan

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

TVS Logistics Services Limited

Date: 08/06/2023

TO WHOMSOEVER IT MAY CONCERN
INTERNSHIP LETTER

This is to certify that **Abdul Wajid Khan** has successfully completed internship as **"Trainee"** under the assistance and guidance in connection with his Industrial Training at TVS Logistics Services Limited.

The details of the internship are as follows:

- Internship Position: Trainee
- Duration: 04/01/2023 to 03/06/2023

He was found sincere and hardworking during his tenure.
We wish him all the best for his future endeavors.

Regards,
TVS Logistics Services Ltd.

TVS Logistics Services Limited, Chakan, Mahalunge Ingale, Maharashtra 410501

A PROJECT REPORT ON

"A STUDY OF WORK LIFE BALANCE OF EMPLOYEES AT DIGITAL CONVERGENCE TECHNOLOGIES PVT. LTD"

SUBMITTED **TO**

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(BUSINESS ADMINISTRATION)

SUBMITTED BY

MOHAMMED RIYADH

Roll No-5961

UNDER THE GUIDANCE OF

DR NASRIN PARVEZ KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

DCT

8^{th} May 2023

TO WHOM SO EVER IT MAY CONCERN

This is to certify that **MOHAMMED RIYADH** of MCOM Part II, SEM (IV), Roll No. 5961 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 15th April to 1st May 2023 for the academic year 2022-23.

During the training, the student was sincere, hardworking, and showed keen interest to learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavours.

For Digital Convergence Technologies Pune Pvt Ltd

Authorised Signatory

go digital

Digital Convergence Technologies Pune Pvt. Ltd.

[illegible], Pune, Maharashtra [illegible]

The company was formerly known as [illegible] Pvt. Ltd

CIN: [illegible]

A PROJECT REPORT ON

HR CHALLENGES EMPLOYING GENERATION AT ACE VOYAGES INTERNATIONAL PVT LTD

SUBMITTED **TO**

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(BUSINESS ADMINISTRATION)

SUBMITTED BY

AFREEN ANWAR MEMON

Roll No-5962

UNDER THE GUIDANCE OF

DR NASRIN PARVEZ KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

YAGES

ACEVOYAGES INTERNATIONAL PVT. LTD.

INTERNSHIP CERTIFICATE

This is to certify that AFREEN ANWAR MEMON of M.COM part II, SEM 4, and Roll No 5962 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish him all the best in his future endeavours.

Acevoyages International Pvt. Ltd.

Authorised Signature with Stamp

Office No-117, 1st Floor, B-Wing, Pride Silicon Plaza, Senapati Bapat Road, Beside Chaturshringi Temple, Pune-411016.
info@acevoyagesinternational.com
www.acevoyagesinternational.com
[illegible]

A STUDY ON TRAINING AND DEVELOPMENT

At

"Direct B2B Media Enterprises."

A PROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE

DEGREE OF MASTER OF COMMERCE

(Business Administration)

SUBMITTED BY

Ms. Mohsina Mehmood Majawar

Roll No- 5964, M.Com-II, Sem-IV

UNDER THE GUIDANCE OF

Dr. Nasrin Parvez Khan

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

Direct B2B Media Enterprises

<u>To Whom It May Concern</u>

This is to certify that Ms. Mohsina Mehmood Mujawar of MCOM Part II, SEM 4, and Roll No. 5964 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 27th January to 10th February for the academic year 2022-23.

During the training, the student was sincere, hardworking and showed a keen interest learns. The involvement and sustained efforts put in by the student are highly appreciable.

We wish her all the best in her future endeavors.

For

Direct B2B Media Enterprises

Jasminshaikh

Jasmine Shaikh
Chief Executive Officer (CEO)

Office No: 308, Building The Core Lillinagar, NIBM, Pune-411048
Tel: +91 77706 97135,
www.directb2bmedia.com, Email: info@directb2bmedia.com

A PROJECT REPORT ON

TRAINING & DEVELOPMENT AT SUNRISE INSTRUMENTS PVT. LTD.

SUBMITTED **TO**

SAVITRIBAI PHULE PUNE UNIVERSITY

IN THE PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF COMMERCE

(BUSINESS ADMINISTRATION)

SUBMITTED BY

FIRDOUS ABDULGAFUR SHAIKH

Roll No-5966

UNDER THE GUIDANCE OF

DR NASRIN PARVEZ KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

CAMP, PUNE

2022-2023

powered by
ovations

SUNRISE INSTRUMENTS PVT. LTD.

"Sunrise House" Sr. No. 33/1 and Sr. No.37/1 to 4/3/1, Near Harsh Agro Pipes,
Tal- Haveli, Pisoli, Pune - 411048. Mob. no. 8888856795
Web Site : www.sunriseinstrument.com   Email : info@futuresol.com

Ref. No.:

Date : [illegible]

INTERNSHIP CERTIFICATE

This is to certify that **Shaikh Firdous AbdulGafur** of MCOM Part II, SEM 4, and Roll No. **5966** of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed a keen interest to learn. The involvement and sustained efforts put in by the student is highly appreciable.

We wish her all the best in his future endeavours.

Authorized Signature with Stamp

"A STUDY ON EMOTIONAL INTELLIGENCE AMONGST FEMALE EMPLOYEESWITH SPECIAL REFERENCETO XDBS PRIVATE LIMITED, PUNE"

APROJECT REPORT SUBMITTED TO

SAVITRIBAI PHULE PUNE UNIVERSITY

IN PARTIAL FULFILLMENTOF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF COMMERCE (BUSINESS ADMINISTRATION)

SUBMITTED BY
RAVEENA BASANTANI
ROLL NO- 5967

UNDER THE GUIDANCE OF
DR. NASRIN KHAN

DEPARTMENT OF COMMERCE PG AND RESEARCH CENTRE

AKI'S POONA COLLEGE OF ARTS, SCIENCE & COMMERCE
CAMP, PUNE

2022-2023

XDBS
BUSINESS INFORMATION SERVICES

Date: 10/03/2023

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Raveena Basantani of M.COM Part II, SEM 4, and Roll No. 3967 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization.

During the training, the student was sincere, hardworking and showed her keen interests learn. The involvement and sustained efforts put in by the student are highly appreciable.

The duration of the internship was from 01/01/2023 to 10/03/2023

We wish her all the best in her future endeavours.

Authorized Signature with Stamp
(Pinky Bachni, Marketing Manager)

XDBS

TRICON Management & Services (Pune) Private Limited

Deals in : Services, Consultancy, Supporting to the Banks & Financial Institutions for Recovery, Enforcement / [illegible], [illegible] & Various Purpose

To,

The Principal
Poona College of Arts Commerce & Science,
Camp, Pune-411001.

Subject : Internship Completion Certificate.

Dear Madam / Sir,

I am happy to inform you that following student of your College have successfully completed the " Sixty Hours Internship Programme" in this Organisation.

SR.NO.	NAME OF STUDENT	ROLL NO.	AADHAR NO.	SPECIAL SUBJECT
1.	Pratik Ramesh Dhawale	4873	7505 7567 7933	Banking & Finance

This student have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that this student will perform effectively in similar type of organizations.

I wish him every success in future endeavors.

Thank you,

Sincerely,

TRICON MANAGEMENT & SERVICES (PUNE) PVT. LTD. PUNE-6

(Rajesh H. Thakur)

Director.

Regd. & Head Off.: 6/44, Phulenagar, Nr. New R.T.O. Office, Alandi Road, Pune - 411006.
Cell : 9011033333 / 9011038915 / 9011038907 E-mail: triconmanagement@rediffmail.com

Country Club Hospitality & Holidays Limited

Koregaon Park Lane B/2, Near Rajvilas Society, Near O Hotel, Pune Pin 411001

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

AKIS's Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate.

Dear Madam/Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programmed 'in this organization.

Sr.No.	Name of the student	Roll No.	Aadhar Card No.	Special Subject
1.	Khan Ruhida Asif	4834	298927855772	Banking and Finance -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I am confident that these students will perform effectively in similar type of associates.

I wish them every success in future endeavors.

Thank you.

Sincerely,

PUNE

NAME & SIGNATURE

(AUTHORISED SIGNATORY)

EXCELLENT ENTERPRISES
Commerce Zone IT Park, Yerawada, Pune- 411006
Ph.(020) 64052378 Email : excellententerprises@gmail.com

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts, Science & Commerce
Camp , Pune- 411001

Subject: Internship Completion Certificate ——

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Sufiya Mohd. Rafique	4605	7305 3610 0480	Banking & Finance II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Excellent Enterprises

Sincerely,

Rahul S. Deshpande

Name & Signature

(Authorised Signatory)

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona College,

Pune .... (Place)

Subject: Internship Completion Certificate ----

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Sufiyan Shaikh	4809	--8440	Banking & fin
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

FREQUENCY COMPUTER INSTITUTE FCZ

Stamp

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

-------------- College,

-------------- (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Rafik Varted	4557		Bankg
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

PUNE-6 ... Pvt. Ltd.

Stamp of the company

Sincerely,

Name & Signature (Authorised Signatory)

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

.... College,

.... (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Sakara Khirchi	4919	46896148 4052	Banking and Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

STATE BANK OF INDIA

Sincerely,

Name & Signature

(Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,

The Principal,
Poona College,
Pune-Cam(p) (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Rukhsar Shaikh	4936	9417 7728 6217	Banking & Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisation.

I wish them every success in future endeavors.

Thank you.

MANAGER
Kondhwa Branch

Sincerely,

Name & Signature
(Authorised Signatory)

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

...Poona... College,

..Pune........ (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Akbar Momin	[illegible]	[illegible]	Banking & Finance-II
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

MD. RAFIQUE SHAIKH
ADMIN OFFICER

Name & Signature

(Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,

The Principal,
Poona College,
Pune (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Rizwannisa Khan	4890	[illegible]	Banking & Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

MD. RAFIQUE SHAIKH
ADMIN OFFICER
Name & Signature
(Authorised Signatory)

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

...Poona... College,

...Pune...... (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mehrunh Shaikh	4252	[illegible]	Banking and Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely

MD [illegible] SHAIKH

Name & Signature

(Authorised Signatory)

THE MUSLIM CO-OP. BANK LTD. HEAD OFFICE

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,
Poona College,
Pune (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Tehmeen Shaikh	4883	[illegible]	Banking & Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely

MD. RAFIQUE SHAIKH
ADMN(?) OFFICER

Name & Signature

(Authorised Signatory)

THE MUSLIM CO-OP BANK LTD.

Letter Head of the Internship Provider Organisation

To,

The Principal,
M.E.Poona College,
Pune (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Hallegondi Saba	4903		Banking & Finance II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you

MOULA ALI & COMPANY CHARTERED ACCOUNTANTS M. No.: 138699 PUNE 411006

Stamp

MOULA ALI & COMPANY CHARTERED ACCOUNTANTS M. No.: 138699 PUNE 411006

Sincerely,

Name & Signature (Authorised Signatory)

Moula Ali Company Salim Qazi

Letter Head of the Internship Provider Organisation

To,

The Principal,
[illegible] College,
Pune (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	[illegible]	4825	[illegible]	Banking and Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

MD. RAFIQUE SHAIKH
ADMN OFFICER

Name & Signature

(Authorised Signatory)

THE MUSLIM CO-OP BANK LTD.
ADM OFFICE

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona College,

Pune (Place)

Subject: Internship Completion Certificate ____

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Moaz Khan	4950		Banking & Finance
2.	Saad Khan	4807		Banking & Finance
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

...Poona... College,

...Pune... (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Rasul Baig	4833	4264-000-3755	Banking and Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

NASIR ... & SONS
... LPG,
... Pune,
Jalhind C... ...rpadi Gaon,
Pune 411 001.

Sincerely,

Farok Khan

Name & Signature

(Authorised Signatory)

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Letter Head of the Internship Provider Organisation

1. Name of the Student : KHAN MISBA
2. Name of the College : T.Y.B.Com.
3. Division and Roll Number : 'A' 4879
4. Address : 2277, New Modikhana, Camp, Pune
5. Contact Number : 9766939056
6. Email ID : Khanmisbah119@gmail.com
7. Special Subject : Banking & Finance II & III
8. Internship start date : 05th Dec, 2022
9. Internship end date : 15th Dec, 2022

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Date	Time		Total hours	Details of work done	Signature of officer	Signature of student
	From	To				
05/12/22	12:PM	6:PM	6 hr	Passing Journal Entries	[illegible]	Misbah
06/12/22	12:PM	6:PM	6 hr	Passing Journal Entries	[illegible]	Misbah
07/12/22	12:PM	6:PM	6 hr	Preparing Profit & Loss	[illegible]	Misbah
08/12/22	12:PM	6:PM	6 hr	Preparing Profit & Loss	[illegible]	Misbah
09/12/22	12:PM	6:PM	6 hr	Tally Balance Sheet		Misbah
10/12/22	12:PM	6:PM	6 hr	Tally Balance Sheet		Misbah
12/12/22	12:PM	6:PM	6 hr	learn Petty Cashbook		Misbah
13/12/22	12:PM	6:PM	6 hr	learn GST concepts		Misbah
14/12/22	12:PM	6:PM	6 hr	Filling GST		Misbah
15/12/22	12:PM	6:PM	6 hr	Filling GST.		Misbah

Scanned with OKEN Scanner

Date	Time		Total Hours	Details of work done	Signature of officer	Signature of student
	From	To				
	Total Hours					

Certified that ... Misba Khan .... (Name of the student) has satisfactorily completed the internship programme assigned to him.

Name & Signature of supervisor

Name & signature of manager

Name & signature of section in charge

Stamp of the company

M. No. 136899 PUNE

CHARTERED ACCO

Date :

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

.... College,

.... (Place)

Subject: Internship Completion Certificate ——

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Kalim Shaikh			
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

CloudAge
Pune 48.
Kondhwa Khurd

Stamp of the company

Name & Signature (Authorised Signatory)

Kalim Shaikh

Letter Head of the Internship Provider Organisation

To,

The Principal,
[illegible] College,
[illegible] (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Kiran Gurjar.	4905	[illegible]	Banking and Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

GANESH CHOUDHA
Mem. No. 147807
Chartered Accountants

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

.... College,

Pune........ (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	[illegible]	[illegible]	[illegible]	
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

For ALPIN TRADERS

Proprietor

Sincerely,

Name & Signature

(Authorised Signatory)

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,
Sarah Ali ... Commerce College,
.... (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Aman	4912	6901-3075-	Banking &
2.	Najmuddin		8027	Finances
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Chanda[illegible]ction
Hong Kong [illegible] 1016,
Deccan Gym[illegible] 411004,
Mobile - [illegible]

Sincerely,
Faruk Khan

Name & Signature

(Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,

The Principal,

.... College,

.... (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	ADNAN SAYYAD			
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)
ADNAN SAYYAD

Stamp of the company
HAYAT MEDICAL
EAST SIDE SHOP, GR. FL.,
SR. NO.10B/14A/18A/17B, PLOT NO.54,
GOLF CLUB ROAD, YERWADA,
PUNE-411006.

Letter Head of the Internship Provider Organisation

To,

The Principal,

.... College,

Pune.... (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Main Shaikh	4923	378961895	
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

For ALFIN TRADERS

Proprietor

Sincerely,

Name & Signature

(Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,

The Principal,

.... College,

.... (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Aasiyani kazi	4916	967371075 2279	Banking Finance II and III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

VERIFIED WITH ORIGINAL
For ICICI Bank Ltd.

Signature
Name of Bank Official
Employee Number

Sincerely,

Name & Signature

(Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,

The Principal,
AES Poona College College,
Pune (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Khan Anam Mukhtar	4842		Banking II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Burhani Computer Private Limited
Flat No. [illegible], Bhavani Peth,
Pune - 411002. Tel.: [illegible]
[illegible]

Stamp of the company

Sincerely,

Name & Signature (Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,

The Principal,

-------------- College,

-------------- (Place)

Subject: Internship Completion Certificate -----

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mustafa S [illegible]	4904		
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Soswaru Creations Tailoring Hub

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

Prathamesh Nagari Pathasanstha Bank

To,

The Principal,

Pragna College,

Kalyan (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Fatima Begum	4897	7557-4876-8329	Banking & finance II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

Scanned with OKEN Scanner

Letter Head of the Internship Provider Organisation

To,

The Principal,

A.K.I. Poona College,

Pune (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Afiya shaikh	4801		Banking & Finance I & II
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Name: MAJID KACHHI

Seal of the company

Letter Head of the Internship Provider Organisation

To,

The Principal,

.... College,

.... (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Anna Shaikh	4812		Banking & finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

For ALFIN TRADERS

Proprietor

Sincerely,

Name & Signature

(Authorised Signatory)

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

[illegible] College,

[illegible] (Place)

Subject: Internship Completion Certificate -----.

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Aiman Shaikh	4399	[illegible]	Banking & Finance-II[illegible]
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,
AKI's Poona College,
Pune (Place)

Subject: Internship Completion Certificate -----

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh zoya	4828	258223813469	Banking & Finance II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Kachhi

Name & Signature (Authorised Signatory)
Name: Majid Kachhi

Stamp of the company

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

PMI'S Poona College,

Pune (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Zeenat Shaikh	4806	732126579 73	Banking & Finance II & तृतीय
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

Letter Head of the Internship Provider Organisation

To,
The Principal,
POONA COLLEGE OF ARTS, SCIENCE AND COMMERCE College,
CAMP PUNE

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	SHOAIB NISAR SAYED	[illegible]	[illegible]	BANKING AND FINANCE
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

TANMAY BAG
Name & Signature

Letter Head of the Internship Provider Organisation

To,

The Principal,

Akis's poona College,

Puee (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir.

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Zaid ansari	4872	484363869566	Banking & finance 2 & 3
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform offectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

LPO and BPO Services Pvt
PUNE

Seal of the company

Letter Head of the Internship Provider Organisation

To,

The Principal,

.... College,

.... (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Sayyed Anam Aslam	4826	5793 4149 6059	Banking & finance II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Chandan Collection
Hong Kong Lane, Shop No. 1416,
Deccan Gymkhana, Pune 411004,
Mobile - 94220[illegible]

Sincerely,

Name & Signature (Authorised Signatory)

Chandan

Stamp of the company

Letter Head of the Internship Provider Organisation

To,

The Principal,

AKI' Poona College of Arts,Commerce & science,

pune

Subject: Internship Completion Certificate .

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	SONDE RIHAN RIYAZ	4874	612874608776	Banking and Finance II & III
2.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature
(Authorised Signatory)

Sajid Suraiya

Letter Head of the Internship Provider Organisation

To,

The Principal,

A.KI. Poona College,

Pune (Place)

Subject: Internship Completion Certificate —

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Warua Rafique	4864		Banking Finance II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Name: MAJID KACHHI

Stamp of the company

Dear Madam/ Sir,

Please provide your valuable feedback about the performance of the student on following parameters. Your feedback will enable us to make necessary changes in the internship process.

Thank you.

Coordinator- Internship Programme

Internship Programme feedback form

Sr. No.	Particulars		Details
1)	Name of the Supervisor/ Officer	:	Santosh Sahebrao Torade
2)	Department	:	
3)	Designation	:	Branch Manager
4)	Name of the Student	:	Shaikh Mohammed Zishan Riyaz
5)	Name of the College	:	AKI's Poona College of Arts, Commerce and Science
6)	Roll Number	:	4914
7)	Special Subject	:	Banking & Finance II & III

Part - A - Individual Ranking (Please tick the suitable checkbox)

No.	Parameter for feedback	Excellent	Very Good	Good	Satisfactory	Needs improvement
1)	Domain Knowledge			✓		
2)	Communication Skills				✓	
3)	Punctuality & Dedication			✓		
4)	Ability to work in teams			✓		
5)	Problem solving skills			✓		
6)	Quality of work done				✓	
7)	Effectiveness			✓		
8)	Efficiency			✓		
9)	Ability to take initiative			✓		
10)	Positive attitude		✓			
11)	Appearance		✓			
12)	Using full potential at work			✓		
13)	Work habits			✓		
14)	Honesty & Integrity		✓			
15)	Creativity			✓		

[illegible]

Letter Head of the Internship Provider Organisation

To,

The Principal,
[illegible] College,
Camp (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	[illegible]	4815		Banking & Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of Company

Roopchand Khandelwal & Co.

A-111/A-112, Kalpataru Plaza, 1st Floor, 224 Bhawani Peth,

To,

The Principal,

AKI'S Poona College of Arts, Science and Commerce College,

Pune (Place)

Subject: Internship Completion Certificate ……

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Gayatri Shapra	4957	8019 6554 4455	Banking & Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

ROOPCHAND KHANDELWAL & CO.
PUNE
M. No: 116037
FRN: 128395W
CHARTERED ACCOUNTANTS

@Khandelwal

Letter Head of the Internship Provider Organisation

To,

The Principal,

AKI's Poona College,

Pune (Place)

Subject: Internship Completion Certificate ----

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	AYMAN KACHHI	4813	5153 4799 5727	Banking & Finance II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

MKachhi

Name & Signature (Authorised Signatory)

Name: MAJID KACHHI.

MAHARASHTRA ... NO.

Nana Peth, Near Chacha ...

Pune 411002

Stamp of the company

Letter Head of the Internship Provider Organisation

To,

The Principal,
AKI3, Boom College,
...Pune... (Place)

Subject: Internship Completion Certificate ....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Venkatesh.	4817	5399087	Banking & Finance II & III
2.	Asmagam		36998	
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

Letter Head of the Internship Provider Organisation

To,

The Principal,
Akl Poona College,
Pune........ (Place)

Subject: Internship Completion Certificate ....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Aayesha Mulla	4819	685697858598	Banking and Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

HARA ENTERPRISES PUNE

Stamp of the company

Sincerely,

Name & Signature (Authorised Signatory)

Scanned with OKEN Scanner

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,
PKI POONA College,
PUNE (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Huzefa Sayyed	484		Banking & Finance II & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Stamp of the company

Name & Signature (Authorised Signatory)

Saundarya Nawa

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

AKI S poona College,

puna .... (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	MonIyar Ayan	6243	9955 9246 5056	Banking & Finance III & III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Burhani Computer Private Limited
Flat No. 103, 455, Bhavani Peth,
Pune - 411002 Tel.: 2633....
26340397 / ...

Stamp of the company

Sincerely,

Name & Signature (Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,

The Principal,

..Poona..... College,

..Pune....... (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Arif	4835	8728	Banking finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

MATRIX SOLUTION

Stamp of the company

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona College,

Pune (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mikail Peerzade	4863	1942	Banking & Finance
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

FCI

Stamp of the company

Name & Signature (Authorised Signatory)

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

AKI'S Poona College of Arts, Science and Commerce,

Pune.

Subject: Internship Completion Certificate.

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Sayyed Naved Ayaz	4810	7531 0893 0591	Banking& Finance II&III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Arshad Raza

Stamp of the company

GLOBAL BAKERS
S NO 45 BHAGYODAY NAGAR,
KONDHWA KHURD PUNE 48

Letter Head of the Internship Provider Organisation

To,

The Principal,

AKI Poona College,

Pune (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Tasmiya Tamboli	4869	33544780 3717	Banking & Finance
2.				II & III
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

MKachhi

Name & Signature (Authorised Signatory)

Name: MAJID KACHHI

Stamp of the company

Letter Head of the Internship Provider Organisation

To,

The Principal,

[illegible] College,

[illegible] (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	[illegible]	4801		banking & finance
2.	[illegible]	4801		banking & finance
3.	[illegible]	4801		banking & finance
4.	[illegible]	4801		–
5.	[illegible]	4801		–
6.	[illegible]	4801		–
7.	[illegible]	4801		–
8.	[illegible]	4801		–

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

For S. N. TRADER

Proprietor

Sincerely,

[illegible]

Name & Signature (Authorised Signatory)

Stamp of the company

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Letter Head of the Internship Provider Organisation

1. Name of the Student : Sayyed Afiya Sameer
2. Name of the College : T.Y.B.Com.
3. Division and Roll Number [A] 4832
4. Address : 390/1798 Babajan nagar near agarwal colony camp pune 411001
5. Contact Number : 9673760466
6. Email ID : Sayyedafiya2002@gmail.com
7. Special Subject : Banking II & III
8. Internship start date : 05th December, 2022
9. Internship end date : 24th December, 2022

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Date	Time		Total Hours	Details of work done	Signature of officer	Signature of student
	From	To				
05/12/22	12pm	6pm	40hrs	Tally ERP 9	Mkhli	Afiya
to	12pm	6pm	9hrs	ITR	Mkhli	Afiya
24/12/22	12pm	6pm	11hrs	BRC work	Mkhli	Afiya
				Bank Reconciliation Stat	Mkhli	Afiya

Date	Time		Total Hours	Details of work done	Signature of officer	Signature of student
	From	To				
5/2/22	10 am	6 pm	9 hours	Introduction of Tally	Mkalli	Afiya
6/2/22	10 am	6 pm	9 hours	How to open & close Tally	Mkalli	Afiya
7/2/22	10 am	6 pm	9 hours	Tally shortcut key	Mkalli	Afiya
8/2/22	10 am	6 pm	9 hours	Tally ERP 9.	Mkalli	Afiya
9/2/22	10 am	6 pm	9 hours	ROC work.	Mkalli	Afiya
10/2/22	10 am	6 pm	9 hours	Bank Reconciliation	Mkalli	Afiya
11/2/22	10 am	6 pm	9 hours	Basic Account how	Mkalli	Afiya
12/2/22	10 am	6 pm	9 hours	To Register ROC.	Mkalli	Afiya
13/2/22	10 am	6 pm	9 hours	What document	Mkalli	Afiya
14/2/22	10 am	6 pm	9 hours	Register How to	Mkalli	Afiya
15/2/22	10 am	6 pm	9 hours	Register	Mkalli	Afiya
Total Hours						

Certified that Afiya Sayyed (Name of the student) has satisfactorily completed the internship programme assigned to him.

Name & Signature of supervisor   Name & signature of manager   Name & signature of section in charge

Date :

MAHARASHTRA ... Peth, Near ... 411002

Stamp of the company

Mkalli

FEEDBACK FROM INTERNSHIP PROVIDER ORGANISATION

Dear Madam/ Sir,

Please provide your valuable feedback about the performance of the student on following parameters. Your feedback will enable us to make necessary changes in the internship process. Thank you.

Coordinator- Internship Programme

Internship Programme feedback form

Sr. No.	Particulars		Details
1)	Name of the Supervisor Officer	:	
2)	Department	:	
3)	Designation	:	
4)	Name of the Student	:	Sache Abiza
5)	Name of the College	:	Poona College
6)	Roll Number	:	4888
7)	Special Subject	:	Banking & finance

Part – A – Individual Ranking (Please tick the suitable checkbox)

No.	Parameter for feedback	Excellent	Very Good	Good	Satisfactory	Needs improvement
1)	Domain Knowledge	✓				
2)	Communication Skills		✓			
3)	Punctuality & Dedication	✓	✓			
4)	Ability to work in teams		✓			
5)	Problem solving skills		✓			
6)	Quality of work done		✓			
7)	Effectiveness		✓			
8)	Efficiency		✓			
9)	Ability to take initiative		✓			
10)	Positive attitude		✓			
11)	Appearance		✓			
12)	Using full potential at work		✓			
13)	Work habits		✓			
14)	Honesty & Integrity	✓	✓			

Letter Head of the Internship Provider Organisation

1. Name of the Student :Almaaf Shaikh

2. Name of the College :T.Y.B.Com.

3. Division and Roll Number :4540 div A

4. Address :Laxmi nagar yerwadapune

5. Contact Number :7066448055

6. Email ID : almashaikhashraf@gmail.com

7. Special Subject :banking and finance.

8. Internship start date :1/03/2023

9. Internship end date :12/03/2023

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Date	Time		Total Hours	Details of work done	Signature of officer	Signature of student
	From	To				
1/03/2023	2:00pm	11:00pm	9	Payroll team interaction		
2/03/202 3	2:00pm	11:00pm	9	Analysis of accounting data of the company		
3/03/202 3	2:00pm	11:00pm	9	Calculating the employee login hours		
4/03/202 3	2:00pm	11:00pm	9	Analysis of how to maintain employee data		
5/03/202 3	2:00pm	11:00pm	9	Training for refund process		
6/03/202 3	2:00pm	11:00pm	9	Training preparing salary sheet for employee		
7/03/202 3	2:00pm	11:00pm	9	Processing refund for customer		
8/03/202	2:00pm	11:00pm	9	Processing sodexo refund		

Certified that Pushpendra lakhami kushwah,, has satisfactorily completed the internship programme assigned to him,

Name & Signature of supervisor	Name & signature of manager	Name & signature of section in charge

Date :

Certified that Alim Arif Shaikh, has satisfactorily completed the internship programme assigned to him.

Madhura Bhosale

Name & Signature of supervisor

Name & signature of manager

Name & signature of section in charge

Date:

Letter Head of the Internship Provider Organisation

To,

The Principal,

---------------- College,

---------------- (Place)

Subject: Internship Completion Certificate ------

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Aman Gafur Mogal	4918	23849945 1348	Banking And Finance II And III
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

For Veera Enterprises

Proprietor

Stamp of the company

Name & Signature (Authorised Signatory)

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Letter Head of the Internship Provider Organisation

1. Name of the Student : NAHID MD. HANIF BAIG
2. Name of the College : T.Y.B.Com.
3. Division and Roll Number : "A" 4884
4. Address : kazmi nagar [illegible]
5. Contact Number : 8208849555
6. Email ID : nahidbaig049@gmail.com
7. Special Subject :
8. Internship start date :
9. Internship end date :

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Date	Time From	Time To	Total Hours	Details of work done	Signature of officer	Signature of student
					[signature]	[signature]
					[signature]	[signature]
					[signature]	[signature]
					[signature]	[signature]
					[signature]	[signature]

Date	Time		Total Hours	Details of work done	Signature of officer	Signature of student
	From	To				
Total Hours						

Certified that ———————————— (Name of the student) has satisfactorily completed the internship programme assigned to him.

Name & Signature of supervisor

Name & signature of manager

Name & signature of section in charge

Stamp of the company

Date :

Asif Pathan

M/S SHRINIWAS KADBANE & ASSOCIATES
CHARTERED ACCOUNTANTS
Flat No.403 A, 'C' Wing, Ashwini Paradise Society,
Bibwewadi, Pune-411037,
Contact: 91 – [illegible]
Email: kadbaneshriniwas@gmail.com

INTERNSHIP COMPLETION CERTIFICATE

Dt. 13-01-2023

To,
The Principal,
Poona College of Arts, Science & Commerce
Camp, Pune - 411001

Subject: Internship Completion Certificate.

Dear Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1	Saud Sayeed Lambe	4836		Banking and Finance II & III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.
I wish them every success in future endeavors.

Thank you.

Shriniwas Kadbane & Associates
Chartered Accountants

Shriniwas Kadbane & Asso. M. No. 611147 Pune Chartered Accountants

(CA Shriniwas S. Kadbane)
Proprietor
M. No.611147

1. Name of the Student : Oikare Kailas Tanaji
2. Name of the College : Poona College Arts Science & Commerce
3. Division and Roll Number : A (48/19)
4. Address : Sr. No 46/3A dattanagar ambegaon telco colony lane no 7
5. Contact Number : 9503437134
6. Email ID : kailasdikare1859@gmail.com
7. Special Subject : Banking & Finance
8. Internship start date : 23rd January ,2023
9. Internship end date : 3rd February,2023

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Date	Time		Total Hours	Details of work done	Signature of officer	Signature of student
	From	To				
23-01-23	11:00	3:00	5	Basic Training		Kailas
24-01-23	11:00	3:00	3	Basic Training		Kailas
25-01-23	10:00	2:00	4	Tally		Kailas
26-01-23	10:00	4:00	6	MS Excel		Kailas
27-01-23	10:00	3:00	5	Basic training		Kailas

28-06-23	10:00	3:00	5	Filing of Returns		Kailas
30-06-23	10:00	4:00	6	Bank Audit		Kailas
31-06-23	10:00	6:00	8	Bank Audit		Kailas
1-07-23	10:00	8:00	10	Bank Audit		Kailas
02-07-23	10:00	3:00	5	Filing of Returns		Kailas
03-07-23	10:00	3:00	5	Filing of Returns		Kailas

Certified that Dikare Kailas Tanaji has satisfactorily completed the internship programme assigned to him.

S.B. Mahendale

CA. Sarvesh Mahendale

Name & Signature of Supervisor

Name & Signature of Manager

SKYP & CO LLP

Stamp of the Company

Date : 03-07-2023

BANDARKAR & CO

Chartered Accountants

Abdus samad A S Bandarkar
ACA , M.Com (FRN. 152474W)

To,
The Principal,
AKI's POONA COLLEGE OF ARTS, SCIENCE AND COMMERCE,
Pune 411 001.

Subject: Internship Completion Certificate.

Dear Madam/ Sir,

I am happy to inform you that Mr. AVEES M SALEH MULLA, having Roll No: 4830, Adhaar No: 2781 8475 5791 and special subject: Banking and Finance, a student of your college has successfully completed the 'Sixty Hours Internship Programme' in this organisation.

The student has been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that this student will perform effectively in similar type of organisations.

I wish them every success in future endeavours.

Thank you.

Sincerely,

BANDARKAR & CO. Chartered Accountants

CA. Abdus samad A. S. Bandarkar
(Proprietor)
Date: 01/05/2023
Place: Pune

Address: Office No. F-4, Royal Plaza, 2122, Sardar V P Road, Opp. Thacker Apartment, Camp, Pune 411 001.
Email: ca.absamad@bandarkar.in
Phone: +91 78756 34622

STEAM Equipments
An ISO 9001 : 2015 Certified Company
CIN: U29119PN2004PTC019820

Steam Equipments Pvt Ltd
No-44, Tay Co.Op. Industrial Estate,
Kondhwa Budruk, Pune - 411048.
Phone: 020-26930968, 26930961
Email: sales@steamequipments.com
http://www.steamequipments.com

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

AKI Poona College of Arts Commerce and Science,

Pune

Subject: Internship Completion Certificate -----

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Sufiyan Irfan Galsulakr	4902	8140 2234 2065	Banking and Finance II&III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

STEAM EQUIPMENTS PVT. LTD. PUNE

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

CHIRAG ASSOCIATES

INDIRANAGAR PUNE

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Poonawala Hussain Mohammad	4802	449364241108	Banking and Finance –II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Shaikh Talha

Name & Signature

(Authorized Signatory)

Total Hours						

Certified that Kable Awwab Mohamed Hanif (Name of the student) has satisfactorily completed the internship programme assigned to him.

Appasaheb Pakar

Name & Signature of manager Name & signature section in charge Name & signature of supervisor of

Date :

INTERNSHIP COMPLETION CERTIFICATE

ICICI BANK LTD.

To,

The Principal,

AKI Poona College,

Camp Pune (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Kable Awwab	4875	65392752 7340	Banking & Finance II & III
2.				
3.				
4.				

Tech Mahindra

Date: 04-Jan-2022

Ref: 968975 /1955775/Pemit

Mr.. Arshad Arif Shaikh
PMC colony
room no 27 kasba peth kagdi Pura near PMC office (Maharashtra) - 411011
Phone No: 9284714622

Subject – Offer of Appointment

Dear Mr.. Arshad Arif Shaikh,

It is our pleasure to welcome you to Tech Mahindra Limited.

1. With reference to our discussions, we are pleased to offer you appointment in our Organization as Associate Customer Support on U1 band, operating out of our Pune office.

2. Your "Annual Total Cash Compensation" will be Rs. 175700. Please refer **Annexure-A** for details on the compensation and statutory deductions.

3. Your remuneration package is strictly confidential between you and here after, referred as The Company and should not be discussed with anyone nor divulged to anyone in any manner whatsoever.

4. Your employment with us will be governed by terms and conditions as specified in **Annexure-B.**

5. You are required to join on **04-Jan-2022** at the below mentioned location. The Offer stands withdrawn thereafter, unless the date is extended and communicated to you in writing.

6. On the date of joining, you are requested to report to **Sushant Pawar** at 9:30 AM to complete the joining formalities at **Tech Mahindra Limited, [Plot NO:01, Rajiv Gandhi Infotech Park, Phase:-3, Hinjewadi, Pune Special Economic Zone, Pune-411057, Maharashtra (India)]**. At the time of joining, you are expected to carry originals of the documents as per **Annexure – D** and submit the copies of the same to the HR Team.

7. Please note that this Offer is subject to your being given a clear background check either at the time of reporting/joining or thereafter depending upon our receipt of the background check report from the agency.

8. Kindly acknowledge acceptance of this Offer of Appointment by signing and returning the 'acceptance copy' to **Sushant Pawar latest by 04-Jan-2022.**

Letter Head of the Internship Provider Organisation

To,

The Principal,

AKI'S Pune College,

Pune, Maharashtra (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Arshad Arif	4895	[illegible]	Banking and Finance.
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

Wow Travels

Shop No 10 Capital Mall Kauser Baugh Kondhwa Khurd Pune
Mobile: 8380898801
[illegible]@gmail.com
website: www.wowtravel.in

1. Name of the Student : Shaikh Nadeem Farookh
2. Name of the College : T.Y.B.Com.
3. Division and Roll Number : (A) 4932
4. Address : Kondhwa Khurd
5. Contact Number : 7020249499
6. Email ID : nadeemshaikh@gmail.com
7. Special Subject : Banking & Finanance
8. Interrnship start date :01/01/2023
9. Internship end date :10/01/2023

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Date	TIME		Total Hours	Details of work done	Signature of officer	Signature of student
	From	To				
01/01/23	12:00	6:00	6	Sales Training		
02/01/23	12:00	6:00	6	Sales Training		
03/01/23	12:00	6:00	6	Product Knowledge		
04/01/23	12:00	6:00	6	Product Knowledge		
05/01/23	12:00	6:00	5	Backend Knowledge		
06/01/23	12:00	6:00	5	Backend Knowledge		
07/01/23	12:00	6:00	6	Clients Handling		
08/01/23	12:00	6:00	6	Clients Handling		
09/01/23	12:00	6:00	6	Clients with Clients		
10/01/23	12:00	6:00	6	Proceed the Work		

Certified that Mr. Shaikh Nadeem Farookh has satisfactorily completed the internship programme assigned to him.

Name & Signature of supervisor | Name & signature of manager | Name & signature of section in charge

CHIRAG ASSOCIATES

INDIRANAGAR PUNE

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	SHAIKH SUHANA FIROZ	4858	407670456487	Banking and Finance -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Pratiksha Nimbalkar

Name & Signature

(Authorized

Signatory)

[illegible]

Konark Mall Kondhwa Khurd, Pune, Maharashtra - 411048
Mobile - 9552319748
[illegible]
Website :- www.inamdarco.in

To,
The Principal,
AKI's Poona College
Camp Pune

Subject: Internship Completion Certificate ----

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Swaleha Sadique Shaikh	4933	[illegible]	Banking & Finance
2.	Ifra Altaf Shaikh	4818	[illegible]	Banking & Finance
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,
CMA Sayyed Inamdar
Name & Signature
(Authorized Signatory)

INAMDAR & CO. • COST ACCOUNTANTS • PUNE

Fivtech

FIVTECH AUTOMATION COMPANY

Phone- 8090060071 Gmail: fivtech.in@gmail.com

To,

The Principal
Poona College of Arts Commerce & Science,
Camp, Pune-411001.

Subject : Internship Completion Certificate.

Dear Madam / Sir,

I am happy to inform you that following student of your College have successfully completed the " Sixty Hours Internship Programme" in this Organisation.

Name of Student:- DUBEY VIMAL RAMESHCHANDRA
Roll No.:- 4803
AAdhar No. 361803572809
SPECIAL SUBJECT:- BANKING & FINANCE II & III

This student have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that this student will perform effectively in similar type of organizations.

I wish him every success in future endeavors.

Thank you,

FIVTECH AUTOMATION COMPANY

PROPRIETOR

Sincerely

(Ramesh Chandra Dubey)
Director.

Office No.- 49 Amba Bazar, Opp. Wonderland M.G Road Pune - 411001 | Hadapsar Pune - 411028

Shah Khandelwal & Jain Associates

Riverside Business Bay Wellesley Road, near RTO, Pune Maharashtra
4111001

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	[illegible] chottan shaikh	4911	[illegible]	Banking and Finance - II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

Partner: Rishabh Pathi

M.No. 168240

CHIRAG ASSOCIATES

INDIRANAGAR PUNE

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

1. Name of the Student :Shaikh Aadil Sharif
2. Name of the College : T.Y.B.Com.
3. Division and Roll Number : Div A, Roll No:4841
4. Address : Hadapsar gadital Pune
5. Contact Number :9359758368
6. Email ID : shaikhaadil623@gmail.com
7. Special Subject :Banking and Finance-II & III
8. Internship start date :Feb 1st,2023
9. Internship end date :Feb 16th,2023

LOG SHEET OF WORK PERFORMED DURING INTERNSHIP

Date	Time		Total Hours	Details of work done	Signature of officer	Signature of student
	From	To				
01-02-2023	12:00 PM	05:00 PM	5 HRS.	observation senior		
02-02-2023	12:00 PM	05:00 PM	5 HRS.	Convert client info. into Excel		
03-02-2023	12:00 PM	05:00 PM	5 HRS.	Excel Basic		
06-02-2023	12:00 PM	05:00 PM	5 HRS.	Observe Senior		
07-02-2023	12:00 PM	05:00 PM	5 HRS.	Basic Tally		
08-02-2023	12:00 PM	05:00 PM	5 HRS.	Basic Tally		
09-02-2023	10:00 AM	05:00 PM	5 HRS.	Send collective data to senior for [illegible]		
10-02-2023	10:00 AM	05:00 PM	5 HRS.			

13-02-2023	10:00 AM	05:00 PM	5 HRS.			
14-02-2023	10:00 AM	05:00 PM	5 HRS.			
15-02-2023	10:00 AM	05:00 PM	5 HRS.			
16-02-2023	10:00 AM	05:00 PM	5 HRS.			

Certified that Shaikh aadil Sharif (Name of the student) has satisfactorilycompleted the internship programme assigned to him.

Name & Signature of supervisor

Name & signatureof manager

Name & signature of section in charge

Date :

GREEN EXCEL EPC INDIA PRIVATE LIMITED
[illegible]
[illegible]
[illegible]
GSTIN : [illegible]

To,

The Principal,

AKI's Poona College of Arts, Science & Commerce.

Pune -411001

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following student of your college has successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Name of the Student	Roll Number	Aadhar Number	Special Subject
Rahil Yunus Shaikh	4804	581687142515	Banking & Finance

The student has been provided with adequate exposure and necessary hands on training pertaining to his special subject.

I am confident that the student will perform effectively in similar type of organisations.

I wish him every success in future endeavours.

Thank you.

Sincerely,

PUNE INDIA

Regreen Excel EPC India Pvt Ltd

MADINA BAKERY

Shop No.01, MADINA BAKERY,
2130,New Modikhana, Camp, Pune, Maharashtra -411001

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shubham Dasharath Bhundalkar	5119	-	Cost and Work Accounting – II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature
(Authorized Signatory)

MADINA BAKERY BHAVANI PETH PUNE

MADINA BAKERY

Shop No.01, MADINA BAKERY,
2130,New Modikhana, Camp, Pune, Maharashtra -411001.

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shubham Dasharath Bhandalkar	5119	-	Cost and Work Accounting –II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature
(Authorised Signatory)

MADINA BAKERY PUNE

SHREE DATTA BAKERY

Datta Chowk,Mundhwa, Pune, Maharashtra 411036.

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Aarbaj Shakir Aatar	5120	222935496431	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Shree Datta Bakery
Datta Chowk Mundhwa
Pune - 4110??
Mob - 9?

Aditya A...

Name & Signature

(Authorised Signatory)

INTEIRNSHIP COMPLETION CERTIFICATE

Arya interprise

To,

The Principal,
AKI's Poona College of Arts, Science and Commerce
PUNE

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Program' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Aadah Jamil	5123	89497846916	COST AND WORKS ACCOUNTING- II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Arya Khire

(Authorized Signatory)

Arya Enterprises
[illegible]
Mob. [illegible]

[Type here][Type here][Type here]

M. S. Engineering Works

Gym Equipments & Weightstack Manufacturer

To,

The principal,

AKI'S Poona College,

Camp, Pune.

Subject: **Internship Completion Certificate**

This is certify that Bhaijan Muskan Maksud student of 6th Sem of **T.Y.B.com** Roll no: **5102** has completed **60 hours internship.**

At **M. S. Engineering Works** from **2 February 2023 to 19 February 2023.**

At work he had proven satisfaction results and highly dependable. This is to certify also that he has no pending assignments in relation to his work , and so she is therefore cleared.

We wish them all the best for future endeavors.

M. S. Engineering Work

For Exellient Fab & Engg

(Proprietor)

ABDUL QADIR PATEL Proprietor

Bhaijan Muskan Maksud

Date: 6/5/23

SHREE DATTA BAKERY

Datta Chowk,Mundhwa, Pune, Maharashtra 411036.

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Abbas Nijam Sayyed	5104	697650676631	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Shree Datta Bakery
Datta Chowk Mundhwa
Pune - 411036
Mob - 9763987689

Name & Signature

(Authorised Signatory)

SHREE DATTA BAKERY

Datta Chowk,Mundhwa, Pune, Maharashtra 411036.

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Aayesha Iqbal Shaikh	5129	4816 9345 8556	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Shree Datta Bakery
Datta Chowk Mundhwa
Pune - 411036
Mob - 9761937889

Atiya Ansari

Name & Signature

(Authorised Signatory)

CITY CARS & COACHES

400,RASTA PETH BEHIND FATIMA BUILDING PUNE-411011

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	MAYURI AMBADAS DAULATABAD	3111	338879126062	Cost and Work Accounting - II & III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

CITY CARS & COACHES

Proprietor

Name & Signature

(Authorised Signatory)

GALAXIE INTERIOR SOLUTIONS

Survey no 10/13 Behind Dharmavat petrol pump, pisoli,

Pune, Maharashtra 411048

Email:-[illegible] , mobile no:-9673565786

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Noorbanu Hishamuddin Khan	5131	624335034961	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

GALAXIE INTERIOR SOLUTIONS

GALAXIE INTERIOR SOLUTIONS

Partner

Sunrise Bakery
सनराईज बेकर्स
Sadar Bazaar, New Modikhana, Pune Cantonment,
Pune, Maharashtra 411001

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that the following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No	Name of the Student	Roll Number	Aadhar No.	Special Subject
1.	Shaikh Zeenat Mukhtar	5146	4296 3896 7532	Cost and Work Accounting -II & III
2.	Ansari Sawleha Mohammad Shamshad	5103	2303 3934 5308	Cost and Work Accounting -II & III
3.	Pathan Arshin Noorkhan	5099	5957 6547 8706	Cost and Work Accounting -II & III
4.	Khan Sahida Noorulla	5072	9655 7736 9462	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.
I am confident that these students will perform effectively in similar type of organizations.
I wish them every success in future endeavors.

Thank you

Sincerely,

Name & Signature
(Authorised Signatory)

SUNRISE BAKERS
NEW MODIKHANA, 2130 CAMP,
PUNE - 411 001.

Sunrise Bakers The Cake Shop New Modikhana, 2130 Camp, pune – 411001
Email: sunrisebakers@gmail.com phone no : + 91 [illegible] / + 91 [illegible]

H.H.GYP STEEL

Gat No. 75 nr Fine Weigh Bridge, Moshi Road, Jadhavwadi,
Chikhli, Pune - 411014

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mohammad Hamza Jawaid Sheikh	5147	882526113176	Cost and Work Accounting - II & III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

H.H. GYP STEELS PUNE

Name & Signature

(Authorised Signature)

MS ENGINEERING WORKS

To,

The Principal,

Aki's Poona College,

Camp, Pune

Subject: **Internship Completion Certificate**

This is certify that **Ms/ DHTEKAR UMERA ASIF** student of 6th sem of TyBcom Roll no **5081** has completed 60 hours internship

At **Ms engineering works from** 2 February 2023 to 19 February 2023.

At work he had proven satisfaction results and highly dependable. This is to certify also that he has no pending assignments in relation to his work , and so she is therefore cleared.

We wish them all the best for future endeavors.

Ms engineering works

For M. S. Engineering Works

Proprietor

Proprietor

Abdul qadir patel

Dhotekar Umera Asif

Date:

LIVE CAKES

Sacred Heart Town, Wanaworie,Pune, Maharashtra -411040.

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Afrin Zulqarnain Qureshi	5143	881552328503	Cost and Work Accounting –II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

For LIVE CAKE

Proprietor

CloudAge

CloudAge,
C2/18, Brahma Industrial Estate,
Kondhwa NIBM Junction, Pune – 411048
Tel: +91 8087261598

01-05-2023

Internship Completion Letter

To,
The Principal,
Poona College,

Dear Madam/Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr.No	Name of Student	Roll no	Aadhar no	Special Sub
1	Sohail Baig	5339	324187694147	Marketing Management

We appreciate Sohail Baig contribution to our team and their willingness to learn and grow. Their dedication and positive attitude have been an asset to our company, and we are confident that they will continue to succeed in their future endeavors.

We wish Sohail Baig all the best in their future career and hope that they will stay in touch with our company.

Thank you.

Your Sincerely,

CloudAge Pune 48. Kondhwa Khurd

Haaris Zed
Hr Head- Human Resources

Shivom Industries Pvt. Ltd.

To,
The Principal,
AKI'S Poona College,
Camp, Pune

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr.no.	Name of the student	Roll no.	Aadhar no.	Special Subject
01	**Tejashree Ashok Shewale**	5094	622419280103	Cost and Works Accounting

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

For SHIVOM INDUSTRIES

Partner

Sincerely,

Near KF Bio Plant ,Manjari, Pune 412307

Email: Shivomindustries20212@gmail.com Phone: +91 9764113146

Shivom Industries Pvt. Ltd.

To,

The Principal,

AKI's Poona College,
Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Alka Rajkumar Nager	5062	650167449194	Cost and Works Accounting

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

For SHIVOM INDUSTRIES
Sincerely,

Partner

Near KF Bio, Manjari, Pune 412307

Email: Shivomindustries29212@gmail.comPhone:+9764113146

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona College,

Pune (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Safiya	5301	61859516 9ur	Marketing Manag-
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona College,

Pune (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Tamboli Saniya	5303	[illegible]	Marketing Management
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

MS ENGINEERING AND WORKS

To,

The Principle

Aki's Poona College.

Subject: internship completion certificate

This is certify that **Ms. SAYYED IRAM SHAFI** student of 4th Semester of **TYBCOM** Roll NO: **5082**

Has completed **40 hours** of internship.

At **MS ENGINEERING WORKS** FROM 2 February 2023 to 16 February 2023.

At work he had proven satisfied results and highly dependable. This is to certify also that he has no pending assignments in relation to his work, and so she is therefore cleared.

We wish them all the best for future endeavors.

MS ENINEERING AND WORKS

For M.S. Engineering World

PROPRIETOR Proprietor

Abdul Qadir Patel

SAYYED IRAM SHAFI

Date:

WOXMAN PVT LTD

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the ' Sixty Hours Internship Programme' in this organisation.

Sr. No	Name of the student	Roll No	Aadhar No.	Special Subject
1.	Vikas Jha	5057	[illegible]	Cost and Work Accounting - II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

MADINA BAKERY

Shop No.11, MADINA BAKERY,
2130,New Modikhana, Camp, Pune, Maharashtra -411001.

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Madani Manaf Khan	8114	467217333035	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

MADINA BAKERY

Name & Signature
(Authorised Signatory)

SalesGarners Marketing
5th floor office number 523 Clover Hills Plaza NIBM Road, Mohammadwadi, Pune
MOBILE: 9307444863
shafi@salesgarners.com
Website: www.salesgarners.com

To,
The Principal,
AKI'S Poona College
Camp Pune

Subject: Internship Completion Certificate ....

Dear Madam/ Sir,
I am happy to inform you that the following students of your college has successfully completed the "Sixty Hours Internship Programme" in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
-	Zohiya Iqbal Shaikh	5319	364413034163	Marketing
2				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar types of organizations. I wish them every success in future endeavors.

Thank you.
Sincerely,

Name & Signature
(Authorized Signatory)

M. S. Engineering Works

Gym Equipments & Weightstack Manufacturer

To,

The principal,

AKI'S Poona College,

Camp, Pune.

Subject: Internship Completion Certificate

This is certify that **Ms/ GHARATKAR URUSA IMRAN** student of 6th sem of **T.Y.B.com** Roll no: **5107** has completed **60 hours internship**.

at **M. S. Engineering Works** from **2 February 2023** to **19 February 2023.**

At work he had proven satisfaction results and highly dependable. This is to certify also that he has no pending assignments in relation to his work , and so she is therefore cleared.

We wish them all the best for future endeavors.

M. S. Engineering Work

For M. S. Engineering Works

Proprietor

(Proprietor)

ABDUL QADIR PATEL

GHARATKAR URUSA IMRAN

Date: 20- Feb- 2023

ARSYS Pvt.Ltd

LOTUS 703, KUMAR SURAKSHA HSG SOCIETY, PARGE NAGAR, OPP.OMKAR GARDEN, KONDHWA, PUNE-411048

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shikalgar Yashfeen Iftekhar	5068	501103537905	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

ARSYS PUNE

Name & Signature
(Authorised Signatory)

RAJDHANI BAKERY

Shop No.01, RAJDHANI BAKERY, Opp. Dinshaw Hall And Near Nishat Talkies.
New Nana Peth, Pune, Maharashtra -411001.

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Hamza Ayaz	5053	646545336363	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

RAJDHANI BAKERY PUNE

Name & Signature
(Authorized Signatory)

ARSYS PVT. LTD

LOTUS 703,KUMAR SURAKSHA HSG SOCIETY, PARGE , NAGAR, OPP OMKAR GARDEN, KONDHWA PUNE -411048

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mehwash Anis Tamboli	3066	387506016387	Cost and Work Accounting – II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

ARSYS
PUNE

Name & Signature
(Authorised Signatory)

HARIDAS MADHAVDAS SUGANDHI

451, Raviwar Peth Rd, next to ICICI Bank, Phadke Haud, Chowk, Pune, Maharashtra 411002

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mustakin Kamruddin Pirjade	5051	370844115478	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

HARIDAS MADHAVDAS SUGANDHI
451, Raviwar Peth, Pune-411 002. (India)
Telefax: +91 20 24458022
Email:hmsugandhi@gmail.com

Name & Signature
(Authorised Signatory)

Inamdar & Co.
Cost Accountants
Kevan's Mall Kondhwa Khurd, Pune, Maharashtra - 411048
Mobile - 9552319748
info@inamdarco.in
Website : www.inamdarco.in

To,
The Principal,
Aki's Poona College
Camp Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Nadaf Samshira Samiulbashir	5087	355143402190	Cost and Works Accounting

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Proprietor
INAMDAR & CO.
Firm No. 005401

Name & Signature
(AuthorizedSignatory)

PRECISE LASER TECH

SUKHSAGERNAGAR , PUNE MAHARASHTRA 411046

To,

The Principal,
AKI's Poona College of Arts, Science and Commerce
PUNE

Subject:InternshipCompletionCertificate

DearMadam/Sir,

Iamhappytoinformyouthatfollowingstudentsofyourcollegehavesuccessfully completedthe'SixtyHoursInternshipProgram'inthisorganization.

Sr.No.	Nameofthestudent	RollNo.	AadharNo.	SpecialSubject
1.	SHUBHAM MOHAN KHAIRE	5139	694250589332	COST AND WORKS ACCOUNTING- II & III

Thesestudentshavebeenprovidedwithadequateexposureandnecessaryhands-ontrainingpertainingtotheirspecialsubject.

Iamconfidentthatthesestudentswillperformeffectivelyinsimilartypeoforganizations.

Iwishthemeverysuccessinfutureendeavors.

Thankyou.

Sincerely,

Name &
Signature(AuthorizedS
ignatory)

Precise Laser Tech

[Type here][Type here][Type here]

DISHA LABELS AND BARCODE SOLUTION

W130/1 "S" Block,Near Indrayani Chowk, MIDC ,Bhosari , Pune, Maharashtra 411026

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Vinayak Suresh Nazare	5052	856249533809	Cost and Work Accounting –II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

TREELINK FURNITURE NETWORK

H & M Royal Society shop no 1 near talab factory, Pune.

Maharashtra 411048

Email:-treelinknetwork@gmail.com , mobile no:-8698320404

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Mohammad Moaz Naeemuddin	5105	259992846614	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

TREELINK FURNITURE NETWORK

Treelink Network Pvt. Ltd.
Pune

TUSHARWORK

Experts for Civil & Building Maintenance Job Painting Waterproofing, Tiles Plumbing & All Types of Chemical Waterproofing for W.C. Bathroom & Terrace, Swimming Pool, Coating & Injections.
S.No. 4, Kakade Nagar, Kondhwa Budruk, Pune 411 048.
Cell No. - 9560428017, 9930383546 Email ID : [illegible]@gmail.com

INTERNSHIPCOMPLETIONCERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject:InternshipCompletionCertificate

DearMadam/Sir,

Iamhappytoinformyouthatfollowingstudentsofyourcollegehavesuccessfully completedthe'SixtyHoursInternshipProgramed'inthisorganization.

Sr.No.	Nameofthestudent	RollNo.	AadharNo.	SpecialSubject
1.	Tushar Rahul Dahire	5154	264821906886	Cost and Work Accounting -II & III

Thesestudentshavebeenprovidedwithadequateexposureandnecessaryhands-ontrainingpertainingtotheirspecialsubject.

Iamconfidentthatthesestudentswillperformeffectivelyinsimilartypeoforganizations'.

Iwishthemeverysuccessinfutureendeavors.

Thankyou.

Sincerely,

Tushar Works
S. No. 4, Kakade Nagar,
Kondhwa Bk., Pune - 411048

Name & Signature(AuthorizedSignatory)

Vijaylaxmi Foods

Near Khadi Machine Chowk, Sanay Mehata Nagar Industrial Area, Kondhwa Budruk
Maharashtra Pune - 411048

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/Sir,

I am happy to inform youth at following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Farheen Shamsullaka Khan	5069	428756329448	Cost and Work Accounting - II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similarity be of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

VIJAYLAXMI FOODS
Signature
(Authorised Signatory)

New Empire Bakery

575, Sachapir St, Camp, Pune, Maharashtra 411001

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Ayeesha Azhar Khan	5855	497779914240	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

NEW EMPIRE BAKERY
575, SACHAPIR STREET,
CAMP, PUNE-411001.
PH 020-26340871
PHONE-PE: 1385306...

Sincerely,

Name & Signature

(Authorised Signatory)

SunriseBakersTheCakeShop

NewModikhana2130,CampPune,Maharashtra411001

INTERNSHIPCOMPLETIONCERTIFICATE

To,

ThePrincipal,

Poona College of Arts,Science & Commerce,Pune-01

Subject:InternshipCompletionCertificate

DearMadam/Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Nameofthestudent	Roll No.	Aadhar No.	SpecialSubject
1	Ansari Sawleha Mohammed Shamshad	5103	2303 3934 5308	Cost and Work Accounting - II& III
2	Pathan Arshin Noorkhan	5099	5657 6547 8706	Cost and Work Accounting -II& III
3	Khan Sahida Noorulla	5072	9655 7735 9453	Cost and Work Accounting -II& III
4	Abdul Kareem Nisar Shaikh	5128	3535 2179 0814	Cost and Work Accounting -II& III
5	Mohd. Alnazar Iqbal Shaikh	5138	7157 7468 7836	CostandWorkAccounting -II& III

These students have been provided with adequate exposure and necessary hands-training pertaining to their special subject.

I am confident that these students will perform effectively insimilar type of organisations.

I wish the mievery success infuture endeavors.

Thankyou.

Sincerely,

SUNRISE BAKERS
NEW MODIKHANA, 2130 CAMP,
PUNE - 411 001

TREELINK FURNITURE NETWORK

H & M ROYAL SOCIETY SHOP NO 1 NEAR TALAB

FACTORY Pune, Maharashtra 411040

Email:- treelinknetwork@gmail.com , mobile no:-8698320404

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mujawar Muskan Umar	5131	803682644768	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Thakur

TREELINK FURNITURE NETWORK

Treelink Network Pvt. Ltd. Pune

MUNDHWA BAKERY

KESHAVNAGAR CHOWK MUNDHWA PUNE 411036

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Parvej Liyakat Shaikh	5145	402386968016	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature
(Authorised Signatory)

MAGIC BAKERY

PROPRIETOR

Shivom Industries Pvt. Ltd.

To,

The Principal,

AKI's Poona College,
Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Anjali Rajkumar Nager	5078	721635499249	Cost and Works Accounting

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

For SHIVOM INDUSTRIES

Thank you.

Partner

Sincerely,

Near KF Bio, Manjari, Pune 412307

Email: Shivomindustries20212@gmail.com/Phone-+9764113346

Go Do Good Pvt. Ltd.

To,

The Principal,

Akl's Poona College,

Camp, Pune

Subject: Internship Completion Certificate

Dear Maam,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr.No.	Name of the student	Roll no.	Aadhar No.	Special subject
01	Jasmeen Harun Shaikh	5097	627514274476	Costs & Works Accounting II & III

This students have been provided with adequate exposure and necessary hands on training pertaining to their special subject.

I am confident that this students will perform effectively in similar type of organisations.

I wish her success in future endeavors.

Thank you.

GO DO GOOD PVT. LTD.

Sincerely,

Go Do Good Pvt. Ltd.

Sadhana Sadan, Sr. No. 12/1/A, Plot no.3 Trimbakeshwar Housing Society,
Mulik Nagar, Wadgaonsheri, Pune Mahrashtra 411014
Email: hello@go-dogood.com Phone: 7304401177

Better Precision Technology

TAMBOLI ENGINEERS PVT. LTD.

Manufacturing of Precision CNC Machined Components and
Jigs & Fixtures for Aerospace and Defence Application

To,

The Principal,

Poona College,

Camp, Pune.

Date :- 15.03.2023.

Subject: Internship Completion Certificate

Dear Madam/ Sir,

We are happy to inform you that following student of your college have successfully completed the 'Sixty Hours Internship Programme' in our organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Khan Nahira Ayaz	5108	549653927421	Cost & Work Accounting

Those students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

We are confident that this student will perform effectively in similar type of organizations.

We wish them every success in future endeavors.

Thank you.

For ,Tamboli Engineers Pvt. Ltd.

TAMBOLI ENGINEERS PVT. LTD. PUNE 411041

Nazir Bashir Tamboli

Managing Director

Regd Off. : S.No.171, Pune-Saswad Road, [illegible], Haveli, Pune 411041, Maharashtra, India.
Phone : +91 - 20 - [illegible] | Fax : +91 - 20 - [illegible]
E-mail : [illegible] Website : [illegible]
CIN : [illegible]

MS ENGINEERING WORKS

To,

The Principal,

AkI's Poona College,

Camp, Pune

Subject: **Internship Completion Certificate**

This is certify that Ms/ DHOTEKAR AYESHA MAQSOOD student of 6th sem of TyBcom Roll. no: 5085 has completed 60 hours internship

At Ms engineering works from 2 February 2023 to 19 February 2023.

At work he had proven satisfaction results and highly dependable. This is to certify also that he has no pending assignments in relation to his work , and so she is therefore cleared.

We wish them all the best for future endeavors.

For M. S. Engineering Works

Proprietor

Ms engineering works

Proprietor

Abdul qadir patel

Date:

Dhotekar Ayesha Maqsood

Date:

KABIRA **Clean Technologies**

To,

The Principal,

Aki's Poona College,

Camp, Pune

Subject: Internship Completion Certificate

Dear Maam,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr.No.	Name of the student	Roll no.	Aadhar No.	Special subject
01	Khan Farheen Khalilullah	5080	086004844256	Costs & Works Accounting II & III

This students have been provided with adequate exposure and necessary hands on training pertaining to their special subject.

I am confident that this students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Kabira Clean Technologies

Sadhana Sadan, Sr. No. 12/1/A, Plot no.3 Trimbakeshwar Housing Society,
Mulik Nagar, Wadgaonsheri, Pune Mahrashtra 411014
Email: hello@go-dogood.com Phone: 7304401177

Shalimar ENTERPRISES

DHANORI ROAD , BHAIRAV NAGAR , PUNE MAHARASHTRA 411047

To,

The Principal,
AKI's Poona College of Arts, Science and Commerce
PUNE

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Program' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Khan yasir asafai nazim	3127	3413 3300 6050	COST AND WORKS ACCOUNTING- II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature
(Authorized
Signatory)

SHALIMAR Sameer

[Type here][Type here][Type here]

INTERNSHIP COMPLETION CERTIFICATE

Contact Number:
9923364835
7823842099

THE MASTER SOFA

Address
S.no 38 khasa no 3/5/5,
Behind angraj dhaba,
pune, kondhwa-48

To,
The Principal,
AKI's Poona College
Camp, Pune

Subject: Internship Completion Certificate

Dear Madam

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization

The student have been provided with adequate exposure and necessary hands on training pertaining to their special subject.

I am confident that the student will perform effectively in similar type of organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject	
1.	Zainab Sayed	5113	[illegible]	Cost & Works Accounting - 2	

I wish them every success in future endeavors.
Thank you.

Sincerely,

For THE MASTER SOFA
Proprietor

Name & Signature
(Authorised Signatory)

OMEGA HEATERS

To,
The Principal,
AKI's Poona College of Arts Science and Commerce
Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

SR.NO.	NAME OF THE STUDENT	ROLL NO	AADHAR NO.	SPECIAL SUBJECT
01	SHAIKH FURQAAN RIYAZ	5079	737212495516	COST & WORKS ACCOUNTING II & III

These students have been provided with adequate exposure and necessary hands on training pertaining to his special subject

I wish them every success in future endeavors.

Thank you.

Sincerely, Omega Heaters

OMEGA HEATER IN PUNE

KOHINOOR BAKERY

Sastapur Bangla, TQ Basvkalyan Dist Bidar

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Sara Mukhtar Ahmed	5112	433541727339	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Kohinoor Bakery Bidar

Name & Signature

(Authorised Signatory)

GALAXIE INTERIOR SOLUTIONS

Survey no 10/13 Behind Dharmavat petrol pump, pisoli,

Pune, Maharashtra 411048

Email:-bnb.huzaifa@gmail.com , mobile no:-9673565786

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Ayesha Akhtar Shaikh	5134	486904113605	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

GALAXIE INTERIOR SOLUTIONS

NIRANJAN AUTO COMPONENTS PVT. LTD.
S BLOCK J 48 MIDC BHOSARI, PUNE411026

To,

The Principal,

AKI's Poona Collage,

Camp, Pune.

Subject: Internship Completion Certificate

Dear Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Patel Amaan Abdulgaffar	5075	408872087669	Cost and Works Accounting-II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavours.

Thank you.

Niranjan Auto Components Pune

Sincerely,

Niranjan Auto Components PVT. LTD

S.I. AND COMPANY

06/ No.43/44, Kausar Baugh Rd, Society, Kondhwa, Pune- 411048

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Atif Riyaz Ahmed Shaikh	5088	412824743046	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

MUNDHWA BAKERY

Keshavnagar Chowk, Mundhwa, Pune - 411036

To,

The Principal,

Poona College Of Arts

Science and Commerce

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Adnan Kanhalal Sutar	5003	8113 9077 3677	Cost and Work Accounting II-III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

MS ENGINEERING AND WORKS

To,

The Principle,

Azi's Poona College,

Camp, Pune

Subject: <u>Internship Completion Certificate,</u>

This is certify that **MS/ BAGWAN BUSHRA FEROZ** student of 6^{th} semester Tybcom roll no.5101

Has completed 60 hours internship.

At MS engineering works from 2 FEBRUARY 2023 TO 10 FEBRUARY 2023.

At work he had proven satisfaction results and highly dependable. This is to certify also That he has no pending assignments in relation to his work, and so she is therefore cleared. We wish them all the best for the best for future endeavors.

MS engineering works

BAGWAN BUSHRA FEROZ

DATE:

proprietor

Abdul qadir patel

RAJDHANI BAKERY

Shop No.01, RAJDHANI BAKERY, Opp. Dinshaw Hall And Near Nishat Talkies,
New Nana Peth, Pune, Maharashtra -411001.

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Fardeen Sameer Beediwala	5063	770699758217	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

RAJDHANI BAKERY PUNE

Name & Signature
(Authorised Signatory)

MSENGINEERINGWORKS

To,

ThePrincipal,

Aki's Poona

College,Camp, Pune

Subject:**InternshipCompletionCertificate**

This is certify that **Ms/ MominRahat Abdul Karim**student of **6th** **semof TyBcom**Rollno:**5142**hascompleted60hoursinternship

At**Msengineeringworksfrom**2February2023to19February2023.

At work he had proven satisfactionresults and highly dependable.This is to certify alsothathehas nopendingassignmentsinrelationtohis work,andsoheis thereforecleared.

Wewishthemallthe bestfor futureendeavers.

Msengineeringworks

For M. S. Engineering Works

Proprietor

Proprietor

Abdulqadirpatel

MominRahat Abdul-karim

Date:

PRIDE BAKERY

Sayyed Nagar Hadapser, Row No. 22/ A
Maharashtra Pune, 411028

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/Sir,

I am happy to inform you that following students of your college have successfully Completed the 'SixtyHours Internship Programme 'in this organisation.

Sr.No.	Nameofthestudent	RollNo.	AadharNo.	SpecialSubject
1.	Shaikh Aasam Dastagir	3110	677433330409	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wishthem every success in future endeavors.

Thank you.

Sincerely,

For BAKERS PRIDE

Proprietor

Name & Signature
(Authorised Signatory)

DISHA LABELS AND BARCODE SOLUTIONS

For Quality Barcode Solutions

ADDRESS-W-130, S Block, Near Sai Engg., Indrayani Nagar, Bhosari, MIDC, Pune - 411026, Maharashtra, India.
EMAIL: response@dishabarcode.com

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	RUTURAJ RAJU POL	5124	265497371130	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature(Authorised Signatory)
FOR DISHA LABELS & BARCODE SOLUTIONS

To,

The Principal,

AKI's Poona College of Arts, Science and Commerce,

Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following student of your college has successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	IRUM IMTIYAZ PASWARE	5070	444067484376	Cost & Works Accounting II & III

The student has been provided with adequate exposure and necessary hands-on training pertaining to the special subject.

I am confident that the student will perform effectively in similar type of organisations.

I wish her every success in future endeavors.

Thank you.

CLASSIC PROPERTIES PUNE

Sincerely,

Classic Constructions

J.K.S.Shaikh

CAKE STORY
DESSERTS

To,

The Principal,

AKI's Poona College,

Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following student of your college has successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	KHUSHI YOGESH AGARWAL	5054	2989 0384 2694	Cost and Works Accounting

The student has been provided with adequate exposure and necessary hands on training pertaining to their special subject.

I am confident that the student will perform effectively in similar type of organisations.

I wish her every success in future endeavors.

Thank you.

Sincerely,

Aniket Raut

Cake Story Desserts

Manager

KANHAIYA BAKERS
Survey No 1547/5, Munot Kamruti Building, Near Omkarya Ganapati Mandir, Dhayari, Tal- Haveli, Dist- Pune- 411041
Mob- 8759941010

Better Precision Technology

TAMBOLI ENGINEERS PVT. LTD.

Manufacturing of Precision CNC Machined Components and
Jigs & Fixtures for Aerospace and Defence Applications

Date :- 15.03.2023.

To,

The Principal,

Poona College,

Camp, Pune.

Subject: Internship Completion Certificate

Dear Madam/ Sir,

We are happy to inform you that following student of your college have successfully completed the 'Sixty Hours Internship Programme' in our organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Kafiya Asad Tamboli	5073	3265 2451 2394	Cost & Work Accounting

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

We are confident that this student will perform effectively in similar type of organizations.

We wish them every success in future endeavors.

Thank you.

Sincerely,

Tamboli Engineers Pvt. Ltd.

TAMBOLI ENGINEERS PVT. LTD. PUNE 411041

Nazir Bashir Tamboli

Managing Director

Regd Off.: S.No.171, Pune-Sinhagad Road, Nanded Phata, Dhayari, Haveli, Pune 411041, Maharashtra, India.
Phone : +91 - 20 - 24392433 / 2533 / 2633 | Fax : +91 - 20 - 24391948
E-mail : tamboliengg@gmail.com, sales_pune@tamboliengineers.co.in Website : www.tamboliengg.com
CIN : U00356PN2006PTC022255

Choudhary Carpet House

373,Nana Peth, Santh Kabir Chowk ,OPP. Modern Bakery Pune - 02

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the' Sixty Hours Internship Programme' in this organisation.

Sr. No	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Misba Feroz Khan	5074	888738553418	Cost and Work Accounting – II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

For Choudhary Carpet House

Proprietor

Name & Signature

(Authorised Signatory)

Choudhary Carpet House

Zenith
Bio Chemical
Industries Pvt. Ltd.

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Tauhid Sarafraz Inamdar	5092	415291104085	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Zenith Bio Chemical Industries Pvt. Ltd. Pune 411014

Harshali Karpe

Name & Signature
(Authorised Signatory)

Regd. Office :
Shri Ram Kunj, S. No. 49, 1st Floor,
Chandannagar, Kharadi, Pune - 411014,
Tel. No. : 9822774568, 9850032232

CIN No. U24100PN2015PTC155343

Factory Address :
Gate No. 1092, Bharat Gas Road,
At Post Sanaswadi, Tal. Shirur,
Dist. Pune - 412208

Email : zenithbci2015@gmail.com

HARIDAS MADHAVDAS SUGANDHI

451, Raviwar Peth Rd, next to ICICI Bank, Phadke Haud, Chowk, Pune, Maharashtra 411002

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Adhar No.	Special Subject
1.	Mahek zaheer faras	5121	547888809599	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

Contact Number
9923364835
7823842099

THE MASTER SOFA

Address
S.no.32 hisso no.3/5/5,
Behind angraj dhaba,
pune, kondhwa-48

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mohd Umair Chanda	5084	891063855411	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

For THE MASTER SOFA

Proprietor
Name & Signature
(Authorised Signatory)

SUJATA INDUSTRIES

Khadi-machine chock, Sujata Industries,Pune 411060

Maharashtra

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Abdussamad	5060		Cost and Work Accounting - II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

For SUJATA INDUSTRIES

Partner

Name & Signature

(Authorised Signatory)

SUJATA INDUSTRIES

Khadi machine chowk, Sujata industries,Pune 411060

Maharashtra

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Ismail A	5057	6818 1576 8525	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

For SUJATA INDUSTRIES

Partner

Name & Signature
(Authorised Signatory)

LIVE CARES

Sacred Heart Town, Wanaworie,Pune, Maharashtra -411040.

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Hepsiba Devaprasad Mamidi	5135	3232[illegible] 97	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

For LIVE CARES

Proprietor

VSPS ENTERPRISE

Adarsh nagar Colony No 7 Dighi Bhosari Road Dighi 411015

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Audhar No.	Special Subject
1.	Rohan Vasant Jadhav	5061	538613161792	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

Authorized Signatory

PURANDAR COCONUT BARFI & SWEETS

Jejuri MIDC, next to Jambhare ice factory, Jejuri, Pune, Maharashtra 412303

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Inamdar Akram Ayub	5098	243306352470	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

PURANDAR COCONUT BARFI

Name & Signature,
(Authorised Signatory)

JK ENTERPRISES

KOLHEWADI SHOP NO.2 NEARSK HOTEL CANARA BANK PUNE-24

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Amaan Abbas Shaikh	5065	644493950687	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

J.K. ENTERPRISES

Proprietor

VIKHAR ENTERPRISES

DHANORI ROAD , BHAIRAV NAGAR , PUNE MAHARASHTRA 411047

To,

The Principal,
AKI's Poona College of Arts, Science and Commerce
PUNE

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Program' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	SHAIKH MUNWAR JAVED	5067	258938149397	COST AND WORKS ACCOUNTING- II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature
(Authorized
Signatory)

[Type here] [Type here] [Type here]

DURVESH ENGINEERING WORKS

At/post khed shivapur taluka-haveli, dist-pune,near toll naka, pincode 412205, maharastra

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Saadaat Imtiyaz mujawar	5117	459609049966	Cost and Work Accounting -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

DURVESH ENGINEERING WORKS

Sincerely,

Name & Signature

(Authorised Signatory)

OMEGA HEATERS

To,
The Principal.
AKI's Poona College of Arts Science and Commerce
Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr.No.	Name of the student	Roll No.	Aadhar No.	Special Subject
01	Sayyed Umar Mushtaque	5125	467670564433	Cost & Works Accounting II & III

These students have been provided with adequate exposure and necessary hands on training pertaining to his special subject.

I am confident that this student will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Omega Heaters

OMEGA HEATER IN ★PUNE★

VERTEX COMMERCIAL SERVICES

5

Inamdar & Co.
Cost Accountants
Konark Mall Kondhwa Khurd, Pune, Maharashtra - 411048
Mobile - 9552319748
info@inamdar.co.in
Website :- www.inamdarco.in

To,
The Principal,
Akl's Poona College
Camp Pune

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	SHAIKH ALFIYA HUSAIN	5307	677128622471	Marketing Management
2.	ANJUM FIROZ KHAN	5408	687352716273	Marketing Management
3.	ZAID SHAIKH	5252	676908286361	Marketing Management
4.	SANIYA SIDDIQUE	5386	910546752013	Marketing Management
5.	MUZAMMIL ZAKIR INAMDAR	5310	608575539334	Marketing Management
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

CMA Sayyed Inamdar

Name & Signature

(Authorized Signatory)

Proprietor
INAMDAR & CO.
Firm No. 005401

VERTEX COMMERCIAL SERVICES

Office no 210, Mayur Trade Centre, Phase 2, Chinchwad Pune 411019
Zakir shaikh (Tax Consultant)
+91 7066532107

To,

The Principal,

AKI's Poona College

Camp Pune

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that Tabassum Tanvir Shaikh of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Tabassum Tanvir Shaikh	5333	382759701880	Marketing Management

She has been provided with adequate exposure and necessary hands-ontraining pertaining to their special subject.

I am confident that she will perform effectively in similar type of organizations.

I wish her every success in future endeavors.

Thank you

Vertex Commercial Services Pune 411019

Sincerely,

(Authorized Signatory)
Zakir Shaikh

AG FURNITURE

Undri Pisoli Road, Near Khadi Machine Chowk
Mobile: 8822488848
aandgfurniture2018@gmail.com
website: www.agfurniture.in

To,

The Principal,

Abi's Poona College,

Camp, Pune

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Mohammad Huzef Jameel	5347	901437971870	Marketing Management
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Shabbir Sayyed

Name & Signature

(Authorised Signatory)

For A&G Furniture

Proprietor

5

UST PIPES AND FITTINGS

272,Guruwar peth near dalal chowk Mominpura

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Khan Anas Salim	5358	705550117641	Marketing Management -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature
(Authorized
Signatory)

The Dream [illegible] Institute

Inmark Mall Kondhwa Khurd, Pune, Maharashtra - 411048
Mobile - 9552319748
[illegible]
Website :- www.inamdarco.in

To,

The Principal,

Aki's Poona College

Camp Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Swaleha Chaudhari	5313	523773330451	Marketing Management
2.	Khan Muaz Junaid	5376	[illegible]	Marketing Management
3.	Kaif Shaikh	5389	[illegible]	Marketing Management
4.	Nazeem Inamdar	5405	991922228321	Marketing Management
5.	Muskan sayyed	5304	[illegible]	Marketing Management
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

CMA Sayeed Inamdar

Name & Signature

(Authorized Signatory)

Proprietor
INAMDAR & CO.
Firm No. 005401

JYTE LOGISTICS PVT. LTD

Our Efforts Your Satisfaction....

Express Courier, Logistics, Cargo & CHA Clearance

Date – 01/03/2023

TO WHOM IT MAY CONCERN

This is to certify that Mr.Zaid Zahoor Chiplunkar, S/0- Mr.Zahoor Hajimiya Chiplunkar, a student of TYBCOM, Savitribai Phule Pune University Pune has successfully completed 03 (Three) months (From 3rd December, 2022 to 28th February, 2023) long internship program with our Company. During the period of his internship program with us he was found punctual and hardworking.

We wish him every success in his life.

For,
JYTE LOGISTICS PVT LTD

Kailash

JYTE LOGISTICS PVT. LTD

Authorised Signature

Office : Sr. No. 253/1A, Road No. 18, Khese Park, Behind Iwo Khese Bunglow, Lohgaon, Pune- 411047
Mobile : 9371655645 **Email** : ramdas@jytelogistics.com, **Website** : www.jytelogistics.in

ZiffyHealth

INTERNSHIP COMPLETION CERTIFICATE

15

To,

The Principal,

AKI's Poona College of Arts Commerce and Science College,

Pune 411014

Subject: Internship Completion Certificate

Dear Madam/Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organization.

Sr.No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Irshad Mustakin Khan	5378	559616471109	Marketing Management
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively similar type of organizations.

I wish them every success in future endeavours.

Thankyou.

Private Limited

Sincerely,

Rohil Patil

Name & Signature

(Authorized Signatory)

SPES™
MANNING SOLUTIONS LLP

INTERNSHIP LETTER

Date: 21st April 2023

To,

WHOMSOEVER IT MAY CONCERN

Subject: Internship Letter

Respected Sir/ Madam,

This letter certifies that Ms. Nabeela Shaikh a student of Aks Poona college of arts science and commerce, Hidayatulla Rd. Kabel Khana, Pune, Maharashtra 411002, Maharashtra, India has successfully completed his internship at Spes Manning Solutions LLP under the guidance of Mr. Ashok Murdikar for 10 days.

In the internship period her punctuality, hardworking nature, eagerness to learn and ability to understand and grasp concepts were the qualities that made her stand out and lead among the rest.

We wish her the very best in his future carrer.

Authorized Signatory

SPES Manning Solutions LLP
Pune

Ashok Murdikar

Manger,

SPES Manning Solutions LLP.

Address : Office No. 23A/24A, Yogesh House,
2nd Floor E Street, Camp, Pune - 411001.
Contact : (020) 30571441 E: info.spes.in Website : www.spes.in

Direct B2B Media Enterprises

Office No: 578, Building Number 29, Netaji Nagar, Wanowrie, Pune-411040 Tel: +91 8237100089

Date: 10th Dec.2022

To,
Employee Name: Shaikh Naziya,
Designation: Digital marketing Executive Department:
Marketing

Internship Completion Letter

Dear Sir/Ma'am,

This is an Internship Completion Certificate for **Ms. Naziya Shaikh** from DirectB2B Media

We state on record that **Naziya Shaikh** has successfully completed an internship project in the role of **Digital Marketer** at **Direct-B2B Media**, from 21st Nov 2021 to 09 Dec 2022 (15 Days).

During Internship, **Naziya** worked in " **Digital Marketing Sales** ". Her performance exceeded expectations and was able to complete the Internship successfully. We wish her all the best for her future career.

15

DIAMOND ENGINEERING WORKS

•Manufacturers & Suppliers•

285, Mangalwar Peth, Baraa Road, Pune - 411011 Tel. 020 - 39671450 [illegible]
Gat No 73, Jadhovwadi, Near River Residency Dehu Moshi Road, Chikli, Pune - 411054
Email : diamondengg1958@gmail.com

REF :

DATE :

To,

The Principal,

Poona college of Arts, Science & Commerce,

Camp, Pune – 411 001

Subject: Internship Completion Certificate-Aliya Naim Shaikh

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in our organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Aliya Naim Shaikh	C 5432	658894262396	Marketing Management

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish her every success in future endeavors.

Thank you.

Sincerely,

FOR DIAMOND ENGINEERING WORKS

Salim Adhoni

PARTNER

-S^B SAHYADRI ENTERPRISES

660 Guruwar Peth, Maharana Pratap Road, Pune - 411 042. / Mob. • 9850255134, 9922926886 ;

sahyadri4spices@gmail.com

Ref. No. **To Whom It May Concern**

This letter is to certify that **Moshin khan** has successfully completed his internship program of 10 days with **SAHYADRI ENTERPRISES**.

His internship tenure was from 15 Dec 2022 to 25 Dec 2022. He was working with Sales & Marketing And Billing Department He was actively & diligently involved in the projects and tasks assigned to him.

During the span, we found him punctual and hardworking person. His learning powers are good and he picks up swiftly. His feedback and evaluation proved that he learned keenly. Moreover, his interpersonal and communication skills are brilliant.

We wish him a bright future.

TechBiz Media

Marketing Agency

Office U61, UG Floor, Clover Hills Plaza, NIBM Road, Pune,

Maharashtra 411048, IN

Mobile-730792176

Website:-www.tbmoin.com

To,

The Principal,

Aki's Poona College

Camp Pune

Subject: Internship Completion Certificate

Dear Madam/Sir,

I am happy to inform you that following students of your college have successfully

Completed the 'Sixty Hours Internship Programme' in this organization.

Sr.No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	SHAIKH JUNED KAMAR	5412	895192895690	Marketing Management
2.				
3.				

These students have been provided with adequate exposure and necessary hands on training to their special subject.

I am confident that the se students will perform effectively in similarity of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorized Signatory)

TITANIC FIRE CORPORATION

(AN ISO 9001 - 2015 certified company)

[SALES & SERVICE OF FIRE FIGHTING EQUIPMENTS/AMC CONTRACTORS]
OFF/WORKS :- F/1, VISHAL AANGAN, PORWAL PARK, OFF TANK ROAD, OPP HP GAS GODOWN,
ALANDI ROAD, YERWADA, PUNE – 411006.
(MOBILE NO : 9850507468, 8007167286, 9168672399 – E.MAIL : [illegible])

To,

The Principal,

AKI's Poona College,

Camp, Pune.

Subject: Internship Completion Certificate –

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Sayyad Afaan Iqbal	5337	333936869733	Marketing Management
2.	Kazi Talha Anwar	5369	380634490859	Marketing Management
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

TITANIC FIRE CORPORATION
Sale & Service of Fire Fighting Equipments
Plot No. F, Vishal Aangan Porwal Park,
Off. Tank Road Opp. [illegible] Gas Godown
Mental Corner Alandi [illegible]

Sincerely,

Name & Signature (Authorised Signatory)

Scanned with OKEN Scanner

Vertedge Business Solutions LLP

TO

The Principal,

Aki's Poona College,

Camp, Pune

Subject: Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr No	Name of the student	Roll No	Aadhar No.	Special subject
01	Shaikh Adil Abdul Rashid	5390	347503895778	Marketing Management II & III

These students have been provided with adequate exposure and necessary handson training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Vertedge Business Solutions LLP

Vertedge Business Solutions LLP

Partner

Parmar Gallery, Office no 300 to 311, 3rd floor, Wanwadi, Pune, Maharashtra 411040

Email: info@vertedgebs.com Phone: +91 74985 65938

22

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona........ College,

..Camp....... (Place)

Subject: Internship Completion Certificate ....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Shifa	5311		Marketing management
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorised Signatory)

23

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,
The Principal,
Akis Azam College,
Camp Pune (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Uzma Sundke	5103	[illegible]	Marketing.
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature
(Authorised Signatory)

KK LIGHTS AND DECORATORS

To,

The Principal,

Poona College, of Arts,Science and Commerce

Camp, Pune

Subject: Internship Completion Certificate.

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Iftekar Nasir Khan	5416	466729515679	MARKETING MANAGEMENT

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these student will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

For K. K. Light Decorators & Mandap

Name & Signature

(Authorised Signatory) Proprietor

Konark puram Mall Kondhwa Khurd, Pune, Maharashtra - 411048
Mobile :8669331503
info@alpha00.in
Website :- www.alphaa.in

To,

The Principal, Aki's

Poona College

Camp Pune

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfullycompleted the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Khan sana Juned	5328	560127008606	Marketing Management
2.	Afsha inamdar	5392	975773530451	Marketing Management
3.	Ashraf Shaikh	5368	897632843760	Marketing Management
4.	Afreen Zuber shaikh	5468	991922228521	Marketing Management
5.	Khan sakib	5338	579786894642	Marketing Management
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-ontraining pertaining to their special subject.

I am confident that these students will perform effectively in similar type oforganizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorized Signatory)

NOORI MENHDI PRODUCTS

20-02-23

This is to certify that Taufir Javed Tamboli S/O Javed Tamboli. A Student of AKIS'S Poona Collage. Has Done Intership of Manufacturing and Managing the Business in my organiszation of 10 Days From (11-02-2023) to (20-02-2023) Working Hours – 9.00 to 3.00 Daily 6 Hours

I Wish Him Success in his Life

Date 20-12-2022

Place- Pune

Javed

Signature

Letter Head of the Internship Provider Organisation

For PREMIER SERVICES
Amol
Proprietor

To,
The Principal,
Poona College,
Pune (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	SHAIKH SOHAIL			
2.	AYAZ	5320	3460 8709	Marketing
3.			6347.	Management
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

For PREMIER SERVICES
Amol
Name & Sign Proprietor
(Authorised Signatory)

5 5

TAURUS

BPO services
Swargate, Shankarsheth rd, 399, Pune - 411042
Mobile - 8097519496

To,

The Principal,

Akl's Poona College

Camp Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Khalid Nabil Sayyed	6308	3031 7524 8614	MARKETING
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorized Signatory)

5

24

HARI OM REALTY

Associations Beyond Sales

Date :-

To Whomsoever It may Concern

Branch Address: Silver Estate Co-op. Hsg. Society, NIBM Road, Kondhwa, Pune -411048

Name of the Student: **Mr.Hadin Imran Sayyed**

Name of the Course: **Intern for Marketing Strategies**

About Hari Om Realty:

Our Company is a Real Estate Company. We makes people dreams by helping them to purchase their own homes. Hari Om Realty is a Proprietor Company. Our office is located in Moshi Area. Giving Proper Sales Service is our biggest strength which helps us to enhance our business through referral and satisfied customers.

Nature of Business

- Startegic Partner - Sale Selling of Projects
- Channel Partner
- Selling and Purchasing of Flats/ Plots
- Rentals
- Leasing of Offices/ Shops
- Pre Lease Offers

Following Work was done by Mr.Hadin Sayyed

- 10 Hours were given to survey the Project /Developers/competitors, find out competitors rate, specification and amenities. To know about Schools, Hospitals, Transportation, Hotels, Post Office, road connectivity to vicinity areas.

- 5 Hours training was given to compile competitive data and put it in Excel Format. This helps us to understand the product well and tackle customer queries and objections related to flats.

HARI OM REALTY • PUNE •

- 5 Hours training was given how to market the project on Media. Online platforms like Whatapp, Facebook, Micro Website have helped home buyers to view the project sitting home on one Click. Various online Paid application were shown how we can market our products such as Magic Bricks, 99 Acres, No Broker.com andHousing.com This have helped NRI customers to review the project and invest in real estate. Online platform have helped us in generating the leads.
- 5 hours training was given to Call the database, understand customer requirement, Explain the exact product which suits him.
- 10 hours training was given to him to communicate with the customer, Show him different projects, make him understand the market. Give details about home loan of different banks.
- 5 hours training was given to him to follow up with the customer and make him finalise the project which ever Customers likes.
- 5 hours training was given to him to coordinate with the Project Sales team and to brief about the customer requirement in their specific project.
- 5 hours training was given to him to act as a mediator between the Builder and the Customer. To make the situation a win win one for both the customer and builder. Take the customer to the site and show him the actual flat. Explain them the main amenities and interact with the customer.
- The whole above exercise was done to sell the flat and was to have knowledge of negotiation. 10 hours training was given to Mr. Hadin. The main focus was to build relationship with the customer and give such service to the customer that he refers more customer to us to make our organization grow.

Following the overall experience with Mr. Hadin, we found him more hard working, more sincere and honest. We wish him all the best for his future.

HARI OM REALTY * PUNE *

For Hari Om Realty

Authorized Signatory

Website : www.alkhalifatours.com

Al-Khalifa

Tours & Travels India Pvt. Ltd.

HAJ - UMRAH - ZIYARAT

AMIR SHAIKH 8669280314 7038109891
(Managing Director)
724, Chudamas Talim, Bhawani Peth, Opp. Navin Hind School Pune - 411 042. Email : amir@alkhalifatours.com

To,
The Principal,
POONA College,
PUNE-411001

Subject: Internship Completion Certificate —

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	HASHAM FEROZ MEMON	5332	N/A	MARKETING MANAGEMENT
2.	ARBAZ SIRAJ KHAN		N/A	

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely

Name & Signature
(Authorized signatory)

AL-KHALIFA TOURS & TRAVELS

(5)

Letter Head of the Internship Provider Organisation

To,

The Principal,

Abhi Poona College,

Pune.......(Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Saniya Tamboli	53871		Marketing Management
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

SAHARA ENTERPRISES PUNE

Stamp of the company

Sincerely,

Name & Signature (Authorized Signatory)

Wow Travels

Shop No 10 Capital Mall Kauser Baugh Kondhwa Khurd Pune
Mobile: [illegible]
[illegible]
website: www.wowtravel.in

To,

The Principal,

AKI's Poona College,

Camp, Pune

Subject: Internship Completion Certificate ……

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Tuttar Kamran Shabbir	5372	738302264935	Marketing Management
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

[illegible]

Name & Signature

(Authorised Signatory)

30

NCREDIBLE MARKETEER

Corporate Office: Office No. 404
Core,The Latitude NBM Pune -411048
tv@imarketeer.io

To,
The Principal,
POONA College,
PUNE-411001

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Ansari Sarik Nasim	5370	N/A	MARKETING MANAGEMENT
2.			N/A	

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely

Kaushik

Name & Signature

(Authorized signatory)

Dear Madam/ Sir,
Please provide your valuable feedback about the performance of the student on following parameters.
Your feedback will enable us to make necessary changes in the Internship process. Thank you.
Coordinator- Internship Programme

ABM
Dental Laboratory

ABM Dental Laboratory

A wing ,Ashwini Paradise,Bibewadi Kondhwa Rd.,Pune-37
MobileNo.- 848481
, email add.- abmdental24@gmail.com

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Mr **Shaikh Mustakaim Mukhtar** has successfully completed **2 weeks** of an internship program from **19th Jan 2023** to **30th Jan 2023** in the **Quality** department of our organization.

He was highly motivated and hardworking. He worked sincerely at his tasks and did a very good job.

Sincerely,

A.S. Mudgulkar

ABM DENTAL LABORATORY PUNE
ABM

EXALENZE BPO SERVICES Pvt. Ltd.

OFFICE 915, CLOVER HILLS PLAZA, NIBM UNDRI ROAD, PUNE, MAHARASHTRA 411048

Date: 15th Jan 2023

TO WHOMESOEVER IT MAY CONCERN

This is to certify that **Mr. Hussain Bohra** has successfully completed 2 weeks of his internship in Lease administration at **Exalenze BPO Services Pvt. Ltd (Terralenze Technologies PVT. LTD.)**, Pune from **19 De 2022 to 31st Dec 2022.**

During the internship he demonstrated good reading and communication skills with a self-motivated attitude to learn new things. His performance exceeded expectations and was able to complete the assigned task successfully on time.

We wish him all the best for his future endeavours.

Yours faithfully,

Exalenze BPO Services LLP

Authorized Signatory
(Mohamed Junaid)

TERRALENZE TECHNOLOGIES PVT. LTD.
KALYAN

Regd Office:
Exalenze BPO Services LLP
LLPIN : AAF-0011
D-118, First Floor, Regency Plaza,
Near Kalyan Ulhasnagar Border Gate, Ulhasnagar 421 001
Maharashtra, India T +91 0251-297 7587

Pune office:
Exalenze BPO Services LLP
Office 915, Clover Hill Plaza NIBM Undri Road,
Pune 411 048, Maharashtra, India
www.exalenze.com

MARIYA'S BIRDS FOOD STORE

10-02-23

This is to certify that Danish Akram Maniyar S/O Akram Maniyar. A Student of AKI'S Poona College. Has Done Intership of Accounting And Billing in my organisation of 10 Days From (1-02-2023) to (10-02-2023) Working Hours – 12.00 to 6.00 Daily 6 Hours

I Wish Him Success in his Life

Date 10-02-2023

Place- Pune

MARIYA'S BIRD FOOD STORE
Sr. No. [illegible] Opp. Al-Anam Building
Bopodi, Pune - 411 020.
Mob. - 6351682077

TAMBOLI SERVICES

Office Address: Shop No.1, Plot No.38, Sanjay Park, Pune 411032
Phone No: 9422518443 Email: tamboliservices321@gmail.com

Date: 17/02/2023

TO WHOM IT MAY CONCERN

This is to certify that Mr. Tamboli Mohd Umar Iftekhar, student of Poona College, has successfully completed a internship in the field of Document Analyzer and Uploader from 01/02/2023 to 17/02/2023 under the guidance of Salauddin Vakil.

During the period of his internship program with us, he had been exposed to different processes and was found diligent, hardworking and inquistive. His performance exceeded our expectations and he was able complete the given task on time.

We wish him every success in his life and career.

TAMBOLI SERVICES
Shop No.1, Plot No.38, Lane No.5D,
Mohammad Ali Chowk, Sanjay Park,
Pune 411032. MOB - 9422518443

Authorised Signature.

Office: 102, City Centre, Synagogue Street, Cantonment Camp, Pune - 411001. MH INDIA
Tel.: +91 20 48609777 / +91 80874 30793
Email : orangecommoditiesindia@gmail.com

Orange Commodities

Regd. Address : S. No. 52, Bldg. No. 2/8, Jai Jawan Society, Wanowrie, Pune - 411 040. MH INDIA

To,
The Principal
Poona college of Arts, Science & Commerce,
Pune

Subject – Internship Completion Certificate

Dear Sir/Madam,

I am happy to inform you that Mariya Mujahid Shaikh have successfully completed the "Sixty Hours Internship Programme" (in Business Administration - Special Subject) in this organisation.

She has been provided with adequate exposure and necessary hands on training pertaining to her special subject.

I am confident that she will perform effectively in similar type of organisation.

I wish her success in future endeavours.

Thank you

Sincerely

Mudassir Shaikh

Name & Signature

(Authorised Signatory)

Letter Head of the Internship Provider Organisation

To,
The Principal,
AKI'S Poona College
Arts, Commerce & Science
Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Iqbal Mubarak Babude	3535	[illegible]	Business Administration II & III

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

VIN loan Consultant Pvt Ltd

[illegible]

Date : 15/12/2022

[illegible] 2022

Subject – Internship Completion Certificate.

We [illegible] that **Iqbal Mubarak Babadu** has successfully completed an internship project in Sales Department with **VIN LOAN CONSULTANTS PVT LTD.**

The internship start date was **1st Dec 2022** and date **15th Dec 2022** and the location of the internship was in Pune. During this tenure, he has successfully met the objectives that were set at the beginning of the project.

He is a promising candidate and we wish him all the best for his future endeavours.

For VIN LOAN CONSULTANTS PVT LTD.

VIN LOAN CONSULTANTS PVT. LTD. ★ PUNE

DEEPALI DESHMUKH

(Human Resource Department)

+91 7066738614
+91 8390115443

vyankatraokarad@vinloanconsultants.com
karadvyankatesh44@gmail.com

Sr.No. 19 A3B, Shop No.51, 3rd Floor,
K.K. Market, Dhankawadi, Pune - 411043

www.vinloanconsultants.com

PBC Pharmaceuticals & Drug Store

Address: Lane no:3, Momin Building,Shop no:2, Meetha Nagar,Kondhwa,
Pune-48
Phone:9967378533

Date: 10/02/2023

TO WHOM IT MAY CONCERN

This is to certify that Mr.Ismail Ibrahim Desai, student of Poona College, has completed a internship in the field of Medical service from 01/02/2023 to 10/02/2023 under the guidance of Irfan Shaikh.

During the period of his internship program with us, he had been exposed to different processes and was found diligent, hardworking and inquisitive,time management,customer satisfaction.

We wish him every success in his life and career.

PBC PHARMACEUTICALS
Shop No. 02, Gr. Floor, Momin Bldg.
Mithanagar, Kondhwa Kd., Pune-48
I Shaikh

Authorised Signature:

Letter Head of the Internship Provider Organisation

To,

The Principal,

[illegible]........ College,

Camp........ (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Ismail Desai	5601	23910395 5400	Business Administr-ation
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Stamp of the company

Sincerely,

Name & Signature (Authorised Signatory)

Irfan Iqbal Shaikh

I. Shaikh

XPRESSBEES

Address: 83/84 Shivaji Nagar Old topkhana, Near Bhagwat Garage.
Phone:7972921151
Email:customercare@xpressbees.com

Date: 10/02/2023

TO WHOM IT MAY CONCERN

This is to certify that Mr.Ayaz Mumtaj Shah, student of Poona College, has completed a internship in the field of Courier service from 01/02/2023 to 10/02/2023 under the guidance of Bipin Gore.

During the period of his internship program with us, he had been exposed to different processes and was found diligent, hardworking and inquisitive,Time Management.

We wish him every success in his life and career.

Authorized Signature

TAMBOLI SERVICES

Office Address: Shop No.1, Plot No.38, Sanjay Park, Pune 411032
Phone No: 9422518443 Email: tamboliservices321@gmail.com

Date: 28/02/2023

TO WHOM IT MAY CONCERN

This is to certify that Ms. Ansari Nazrana Shamshad, student of Poona College, has successfully completed a internship in the field of Document Analyzer and Uploader from 13/02/2023 to 28/02/2023 under the guidance of Salauddin Vakil.

During the period of her internship program with us, she had been exposed to different processes and was found diligent, hardworking and inquistive. Her performance exceeded our expectations and she was able complete the given task on time.

We wish her every success in his life and career.

TAMBOLI SERVICES
Shop No.1, Plot No.38, Lane No.6D,
Mohammad Ali Chowk, Sanjay Park,
Pune 411032. MOB - 9422518443

Authorised Signature

AG FURNITURE

Undri Pisoli Road, Near Khadi Machine Chowk

Mobile: [illegible]

[illegible]@gmail.com

website: www.agfurniture.in

To,

The Principal,

Aki's Poona College,

Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

We are glad to inform that Miss. Qureshi Nashara Ashfaque from AG Furniture has successfully completed her internship from 1st January to 10th January 2023.

During her internship, she was exposed to the various activities in office assistant management and administration as assistant Admin.

We found her extremely inquisitive and hard working. She was very much interested to learn and also willing to put her best efforts and get in to the depth of the subject to understand it better.

Her association with us was very fruitful and we wish her all the best in her future endeavours.

Thank You

Sincerely,

Shahbaz Sayyed

For A&G Furniture

Proprietor

[illegible]

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona College,

Pune. (Place)

Subject: Internship Completion Certificate .....

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Abrar Shaikh	5604	3497 7385-4063	Business Administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

For AKBAR & CO.

Proprietor

Stamp of the company

AKBAR & CO.
Skin Merchant
1257/59, Bhawani Peth,
Pune - 411 002

AKBAR & CO

SKIN MERCHANT

1258 [illegible] peth Pune 02.

Mob: 99228[illegible]177

[illegible]

TO,

Akbar Sayyed.

Poona College of Arts Science and Commerce,

Camp, pune-01.

Subject- 60 Hours Internship Program.

DearSir,

I zaheeruddin SHAIKH, I'm writing this letter to inform you that, MR. MOHAMED ABRAR ZAHEERUDDIN SHAIKH will be doing Internship as a PURCHASE, SALES AND MARKETING under my guidance. He will be working 60 HOURS. 6 DAYS per day according to his convenience.

Zaheeruddin

05/05/23

Authorized Sign.

SAFAMOTORS
Where You Can Find The Right Car
Shopno-367, New Nana Peth Islampura, Pune-02,
Mob: 7385466004

TO,
Akbar Sayyed.
Poona College of Arts Science and Commerce,
Camp, pune-01.

Subject- 60 Hours Internship Program.

DearSir,
I ASAD SHAIKH, I'm writing this letter to inform you that, MR. MUAVIN MANSOOR SHAIKH will be doing Internship as a SALES AND MARKETING under my guidance. He will be working 60 DAYS. 6 HOURS per day according to his convenience.

Authorized Sign,

SYSTEM FINANCE

TO WHOMSOEVER IT MAY CONCERN

This is to certify that **Mr. Fardeen Abdulrauf Bagwan** has successfully completed 2 weeks of an internship program from 21 Dec 2022 to 30 Dec 2022 in the Quality department of our organization.

He was highly motivated and hardworking. He worked sincerely at his tasks and did a very good job.

Sincerely,

SYSTEM FINANCE

IQRA ENTERPRISES

Kashiwadi Bhawani Peth,Near 10 No Colony
Pune-411042 Maharashtra.

INTERNSHIP COMPLETION CERTIFICATE

To,
The Principal,
Poona College of Arts,
Science & Commerce,
Pune-01

Subject: Internship Completion Certificate

Dear Madam/Sir,

I am happy to inform you that following students of your college have successfully Completed the 'SixtyHours Internship Programme 'in this organisation.

Sr.No.	Nameofthestudent	RollNo.	AadharNo.	SpecialSubject
1.	Shaikh Arbaz Riyaz	5566	452829837403	Business administration –II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wishthem every success in future endeavors.

Thank you.

Sincerely,

IMRAN SHAIKH

Name & Signature
(Authorised Signatory)

IQRA ENTERPRISES

Kashiwadi Bhawani Peth,Near 10 No Colony
Pune-411042 Maharashtra.

LOGSHEETOFWORKPERFORMEDDURINGINTERNSHIP

1. Name of the student : Shaikh Arbaz Riyaz
2. Name of the College : T.Y.B.Com.
3. Divisionand RolNumber : Div D, Roll No:5566
4. Address : Kashiwadi bhawani peth near 10 no colony pune-411042
5. ContactNumber : 7410741328
6. EmailID : arbazshaikh03112012@gmail.com
7. SpecialSubject : Business administration -II & III
8. Internshipstartdate : December 01,2022
9. Internshipend date : December 15,2022

LOGSHEETOFWORKPERFORMEDDURINGINTERNSHIP

Date	Time From	Time To	TotalHours	Detailsof workdone	Signatureo fofficer	Signatureof student
01-12-2023	10:00 AM	02:00 PM	4 HRS.	Shop Visit and Information		Arbaz
02-12-2023	10:00 AM	02:00 PM	4 HRS.	Analysis the Machineries		Arbaz
03-12-2023	10:00 AM	02:00 PM	4 HRS.	Calculating the future profit by calculating invested money in business		Arbaz
04-12-2023	10:00 AM	02:00 PM	4 HRS.	Labour Management		Arbaz
06-12-2023	10:00 AM	02:00 PM	4 HRS.	Material used for demolition of scrap meterials		Arbaz
07-12-2023	10:00 AM	02:00 PM	4 HRS.	How to handle and collaborate with labours to get done the		Arbaz

UNDERTAKINGFROMSTUDENT

To,

The Manager(HR),

IQRA ENTERPRISES

Pune – 42

Subject:UndertakingFrom Student

Respected Madam/Sir,

I am a student of Poona College of Arts, Science And Commerce, Camp, Pune-01. I am studying insemester VI of T.Y.B.Com. I am going to join your esteemed organisation for my sixty hours internship programme during 01st December 2022-to 15th December 2022.

I assure that I will follow all the rules and instruction issued by you . I will be solely responsible for my behavior and performance during the internship period.

I will not disclose any information that is made available to me to anyone during or after the internship period.

I assure you that I will do my best and the internship opportunity provided to me will be a mutually rewarding experience.

Thank you.

Yours sincerely,

Arbaz Shaikh.

Arbaz

(Name & signature of the student)

Date:

Place:

UNDERTAKINGFROMSTUDENT

1. NameoftheStudent : Shaikh Arbaz Riyaz
2. Class :T.Y.B.Com.
3.DivisionandRollNumber : DIV D, Roll No: 5566
4.Presentaddress : Kashiwadi bhawani peth,near 10 no colony pune-411042
5.Permanentaddress : Kashiwadi bhawani peth,near 10 no colony pune-411042
6.ContactNumber :7418741328
7.ContactNumber(Parent) :9921603985
8.EmailID : arbazshaikh03112012@gmail.com

To,
The Principal,
PoonaCollege of Arts,
Science & Commerce,
Pune-01

Subject:UndertakingFrom Student

RespectedMadam/Sir,

I am studying in semester V/VI of T.Y.B.Com.I am going to join IQRA ENTERPRISES for my sixty hours' internship programme during 01st December 2022 to 15th December 2022

I assure that I will follow all the rules and instruction issued by the internshipproviding organisation. I will be responsible for my behaviour and performance during the internship period.

Thank you.

Sahida Shaikh.
सहीदा शेख

(Name&Signatureof parent)

Yours obediently,
Arbaz Shaikh.
Arbaz

(Name & signature of the student)

Date:

3C IT

Internship Certificate

This is to certify that Ms. Gajala Jamil Zari, T.Y.B.Com. Student at Poona College of Arts, Science & Commerce, Pune, has completed her Desktop Support Internship at 3C IT SOLUTIONS & TELECOMS (I) PVT. LTD. She worked under the guidance of Mr. Govind Sahu from 05th Jan to 20th Jan 2023.

Ms. Zari worked under 'Desktop Support Engineer'. As a part of the project, she understood how the Desktop Support Management works.

She is a self-motivated, hard worker that is always looking to learn new skills. Ms. Zari has done more than her role's responsibilities. We wish her all the best in all her future endeavors.

For 3C IT Solutions and Telecoms (I) Pvt Ltd

Govind Sahu

GM- Service & Operation.

ZAMZAM FURNITURE

THE COMPLETE FURNITURE DESTINATION

Date: 17-02-2023

TO WHOM IT MAY CONCERN

This is to Certify that Mr. Mohammad Shoaib Ajim Raj has done his internship in Production Manager in Zam Zam Furniture from 01/02/2023 to 17/02/2023 under the guidance of Zaid Sayyed.

During the time frame he has been a sincere and thoroughly professional employee. He had been exposed to different processes and was found diligent, hardworking and inquisitive.

We wish him every success in his life and career.

Zam Zam Trading
All Types Furniture Manufacturers
Kismat Project, Kondhwa Khurd,
Pune-48. Mob. 9823116812

Authorised Signature

Zam Zam Trading
All Types Furniture Manufacturer & Suppliers
Kismat Project, Kondhwa Khurd,
Pune-48. Mob. 9823116812

SUNSHINE FIELD PVT LTD

Address : Sr.no. 10 Kanauj nagar near Yusuf shah darga yerawada pune-06
Email : hamidshaikh0944@gmail.com
Contact: 7875677650

To,

The Principle,

Poona College of Commerce,

Subject: Internship completion certificate of Alfiya Shaikh

DEAR SIR,

I am happy to inform you that following student of your college have successfully completed the sixty hours of internship programmed in this organization

I have found her to be a hardworking and focused towards work who is always ready to learn new things. She performs excellent with well behavior and she is punctual at time to report before me day to day. she worked sincerely on his assignments and his performance was par excellence

I wish her best of luck for her further.

Sincerely,

Munawar Shaikh

SUNNEFIELDS PVT LTD

Thankyou

LIC

ASMA SAYYED

(Manager)

Ref no 12745863-35

This is to certify that **Sidra Kafil Sayyed D/O Kafil Sayyed**. A Student of **AKIS'S Poona Collage.** Had Done the Costumer Care Representive internship in our organization of 10 Days From (10-02-2023) to (20-02-2023) A short internship on **A STUDY ON CONSUMER PRECEPTION ABOUT LIFE INSURANCE** at this branch.

We wish her every succes in life

Date 21-02-2023

Place- Pune

LIC

Authorized Signature

HAKIMI HARDWARE

TO WHOMSOEVER MAY CONCERN

This is to certify that **Mr. Mohammed Hakim** has successfully completed 1 week of an internship program from 02 Feb 2023 to 10 Feb 2023 in the Sales department of our organization.

He was highly motivated and hardworking. He worked sincerely at his tasks and did a very good job.

HAKIMI HARDWARE
Riddhi Siddhi Aprt, Solapur Road
Vaiduwadi, Hadapsar PUNE

Sincerely,

Internship Training Certificate

This to certify that Shaikh Adil Haider Pursuing his B.Com in 3rd year has successfully completed internship at Rahil Cosmetics Bhawani Peth Near Janta Dairy 411002 from 02/04/2023 to 10/04/2023.

We found him sincere, hardworking, technically sound and oriented.
He worked well as a part of team during her tenure.

We take this opportunity thank him and wish him all the best for future.

Your Sincerely,
For Rahil Cosmetics.

Rafique Shaikh
Proprietor

FOR RAHIL COSMETICS

PROPRIETOR

MOB NO:- +91 9822280466

Suhaba Interior designs

Specialist in: Interior designing, Decorative interiors, Decorative exteriors
556, Bhavani Peth, Pune 411002

DATE:- 01/03/2023.

REF NO:-4508

This is to certify that Anubhav Kamble of BCOM Part II, SEM 6, and Roll No.5637 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 02/01/2023 to 01/02/2023 for the academic year 2022-23 During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavours.

SUHABA

Authorized Signature with Stamp

MOB NO:- +91 9923405482

Suhaba Interior designs

Specialist in: Painting, interior designing, Decorative interiors and exteriors

856, Bhavani Peth., Pune 411042

REF NO:-4508.

DATE:- 01/03/2023.

This is to certify that Toufiq shaikh of B.COM Part II, SEM 5, and Roll No.5605 of AKI's Poona College of Arts, Science and Commerce has successfully completed the internship work as per the guidelines of Savitribai Phule Pune University in our organization from 02/02/2023 to 01/03/2023 for the academic year 2022-23

During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavours.

SUHABA
Printing Contractor
All Type of Flat Bunglow
New Nana Peth, Near Palki Chowk, Pune
Mo: 7?23405482, 8?2?240?77
Prop. Fakhruddin I. Shaikh

Authorized Signature with Stamp

MADINA FOODS.

(10th April - 17th April 2023)

Dear Faiz Firoz Shaikh,

Over the past 40 hours of internship, You worked with our team of dedicated and hardworking individuals where you learnt about the food industry and customer service.

During the time at Madina Foods you have been able to gain hands-on experience in various areas of the business, including food preparation, customer service, and inventory management. You also had the opportunity to work with a diverse group of customers, and learned how to handle a variety of situations in a calm and professional manner.

Thank you for your continued hard work and dedication.

Sincerely,

Madina Foods.

MADINA FOODS
Shop No. 30, C. S. Market,
Camp, Pune-411 001.
Tel.-020-2633[illegible] - Parveez

Mudasil Shaikh

Sr Manager

Shop No 30 C-S Market Camp, Pune- 411001

ADRENALINE SPORTS

HOTEHT, UNDRI - 411060

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Arshad Mohammadhaseeb Miya	5660	881917020940	Business Administration - II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

FOR ADRENALINE SPORTS

Authorised Signatory

Name & Signature

(Authorised Signatory)

AM ENTERPRISES

Mr. Faris kasim Shaikh
Owner of AM Enterprises
Villaim Nagar Wakdewadi pune 05

Dear Faris kasim Shaikh

Sincerely,
AM Enterprises is a RTO Consultant & Services. Here we are doing all types of RTO works. We also have motor driving school. We collect work from RTO, also from private customer, Car sales company's, Online cars market,etc.

We provide this intership to Mr. Faris Kasim Shaikh who is student of Poona college of arts, commerce and science pune 01. For his educational purpose.

We hope this internship programme is easy, helpful and understanding for him for further studies.

Mr. Faris Kasim Shaikh

Date : 20/12/2022
Place : Pune

Mo : 9511720901
Office no : 8237231230
Email-id : amenterprises7121@gmail.com

Anil Mardikar & Co.
CHARTERED ACCOUNTANTS
[illegible] Madhunath Jadhav [illegible] 2nd Floor [illegible] Pune 411030 [illegible] Email [illegible]@gmail.com

TO,
THE PRINCIPAL,
POONACOLLEGE,
CAMP 411001

Subject : Internship Completion Certificate......

Dear Madam / Sir,

I am happy to inform you that following students of your college have successfully Completed the "Sixty Hours Internship Programme" in this or organization.

Sr.No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	AKASH ANIL JITKARE	5607	884240512521	Business Administration

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organization.

I wish them every success in future endeavors.

Thank you.

Name & Signature
(Authorised Signatory)

For ANIL MARDIKAR & CO.
Chartered Accountants

M.S.Jadhav

(CA. MADHUNATH S. JADHAV)
Partner
M. No. 150373

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona College,

Camp (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Afat Banerji	5668	279233391-2399	Business Administration 152
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

For, ADORN MEDIA LLP

Authorized Signatory

Stamp of the company

Sincerely,

Name & Signature (Authorised Signatory)

KARIM . TAMBOLI

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,

The Principal,

...Puna..... College,

....Pass..... (Place)

Subject: Internship Completion Certificate.......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Aman Bagwan	5635		Business Administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Jalkishan Enterprises
537 Market Yard, Gala No.5,
Pune-411037

Sincerely,

Name & Signature
(Authorised Signatory)

RIGHT MOVE
STAFFING SOLUTIONS PVT. LTD.

INTERNSHIP CERTIFICATE

This is to certify that Ms. Tejal Mohite has successfully completed her Internship program at Right Move staffing solutions Private Limited as a HR Recruiter.

Internship Duration- 01/12/2022 – 21/12/2022

During her tenure, she excelled in executing all assigned tasks and was competent and enthusiastic throughout.

We wish her great success in all of her future endeavours.

Right Move Staffing Solutions Pvt. Ltd.

Gurpreet Singh Walia

Director

RIGHT MOVE STAFFING SOLUTIONS PRIVATE LIMITED
T-313, Ashoka Mall, Next to Ranka Jewellers, Bund Garden Road, Pune - 411 001. (India)
Tel.: 020-41227397 Mob.: +91-9767030403 E-Mail : info@rightmoveconsultants.com
www.rightmoveconsultants.com CIN : U74999PN2018PTC177424

Makhuz.co

Gangadham Bibwewadi Lullanagar road, Pune, Maharashtra
Mobile - 7447810603

To,

The Principal,

Aki's Poona College

Camp Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that Aman Afzal Inamdar student of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

This student have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature

(Authorized Signatory)

RN
DEVELOPERS & PROMOTERS

RADHESHAWARI NAGAR PROMOTERS & DEVELOPERS

GAT NO 849-854, AT WAGHOLI, [illegible] ROAD, TALUKA HAVELI, DISTRICT-PUNE.
REG NO: PNA (4) / HSG / (TC) / 759/ 1995-96.
PH. NO.020-[illegible], Email:[illegible]@gmail.com

CERTIFICATE OF INTERNSHIP

This is to certify that **MRS. RUKSANA DARUWALA** student of **POONA COLLEGE OF ARTS, SCIENCE & COMMERCE Camp, Pune – 411001** having a **Roll no. 5633 Division D** has successfully completed the Internship Programme from **6th December to 28th December** in our organization **RADHESHWARI NAGAR PROMOTERS AND DEVELOPERS** at Wagholi Pune.

Radheshwari Nagar
Promoters & Developers

Partner

Signature Authorities

ADRENALINE SPORTS

HOTTUT, INDIA 411060

INTERNSHIP COMPLETION CERTIFICATE

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Azmat Amjad Shaikh	5655	657798804407	Business Administration -II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

FOR ADRENALINE SPORTS

Authorised Signatory

Name & Signature

(Authorised Signatory)

Inamdar & Co.
Konark Mall, Kondhwa Khurd, Pune, Maharashtra - 411048
Mobile - 9552319748
[illegible]
Website :- www.inamdarco.in

To,
The Principal,
Azi's Poona College
Camp Pune

Subject: Internship Completion Certificate ----

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Bangi Sualeha Mustufa	5608		Administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Proprietor
INAMDAR & CO.
Firm No. 005401

Name & Signature
(Authorized Signatory)

28 January 23

Internship Training Certificate

This to certify that Joel Joshua Sanjay Persuing his B.Com in 3rd year has successfully completed internship at Sr No 35 Plot no 43, 46 [illegible] , Kheliwadi, Katraj 411046 from 01/03/2023 to 31/03/2023.

We found him sincere, hardworking, technically sound and oriented.
He worked well as a part of team during his tenure.

We take this opportunity thank him and wish him all the best for future.

Your Sincerely,
For Satyam PVC Doors.

Sanjay Sonawne.
Proprietor

CAFE QUICK STORIES

CLOUD 9, NIBM ROAD, KONDHWA-411048

Date: 13th Jan 2023

TO WHOMESOEVER IT MAY CONCERN

This is to certify that Mr. **Afzan Rizwan Patrick** has successfully completed 2 weeks of his internship as Server at Cafe Quick Stories from **19 Dec 2022** to **31st Dec 2022**.

During the internship he demonstrated communication skills with a self motivated attitude to learn new things. His performance exceeded expectations and was able to complete the assigned task successfully on time.

We wish him all the best for his future endeavours.

Yours faithfully,

Authorised Signatory

(Tanvi Sayyed)

For Soulfully Hungry (OPC) Pvt. Ltd.

Director

tanvisayyed@gmail.com

www.cafequikstories.com

8390065556

SUNSHINE FIELD PVT LTD

Address - Sr.no.10 kamraj nagar near Yusuf shah darga yerawada pune 06
Email : hamidshaikh0944@gmail.com
Contact: 7875877050

To

The Principle,

Poona College of Commerce,

Subject: Internship completion certificate of ……

DEAR MADAM,

I am happy to inform you that following student of your college have successfully completed the sixty hours of internship programmed in this organization

SR.NO	NAME OF THE STUDENT	ROLL NO.	AADHAAR	SPECIAL SUBJECT
1	Taskira Penwale	5638		BUSINESS ADMINTRATION

The student has been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that the student will perform effectively in similar type of organizations.

I wish them every success in future endeavours

Thankyou
Sincerely,

Name and signature

SUNSHINE FIELDS PVT LTD

OM SAI ENTERPRISES

omsaienterprises@gmail.com
www.omsaigroup.in
@omsaienterprises

DECEMBER , 2022

Subject - Internship Completion Certificate

We state on record that **MD ABDULLAH MD RAHMATULLAH** has successfully completed an internship project in Sales Department with **OM SAI ENTERPRISES.**

The internship start date was **01 Dec 2022 &** end date **15 Dec 2022** and the location of the internship was in Pune. During this period , he has successfully met the objective that were set the beginning of the project .

He is a promising candidate and we wish him all the best for his future endeavors.

For, **OM SAI GROUP.**

For OM SAI ENTERPRISES

Proprietor

DHAIRYA CHAUDHARI
(Managing Director)

OM SAI ENTERPRISES
MOSHI PUNE

ACTIVE ELECTRICALS

MAYUR PANKH APARTMENTS, KONDHWA MAIN ROAD, KONDHWA, PUNE, MAHASHTRA 411048

Date: 15th Jan 2023

INTERNSHIP COMPLETION CERTIFICATE

This is to certify that Mr. Bilal Sadiqe Bagwan has successfully completed 2 weeks of his internship as a Salesman at **Active Electricals**, from 01 Jan 2023 to 09 Jan 2023.

During the internship he demonstrated good reading and communication skills with a self-motivated attitude to learn new things. His performance exceeded expectations and was able to complete the assigned task successfully on time.

We wish him all the best for his future endeavours.

Yours faithfully,

ACTIVE ELECTRICALS

Authorized Signatory
(Javed Shaikh)

ACTIVE Electricals
Mayurpankh Apts, Kondhwa Main Rd,
Opp. Sheetal Petrol Pump, Pune - 48.
Mob- 9823117861

DATE : 12/ 12/2022

Internership completion letter

To,

Swalehe Ishaque Shaikh

4th Floor, Flat no 416

Galaxy AS building

411048

Contact No- 7387865026

This is to Certify that Swalehe Ishaque Shaikh has done his internship in JK Events Planners , Pune-411 048, from 1/12/22 To 10/12/22

During the time frame he has been a sincere and thoroughly professional employee. Below are the key projects he has worked on successfully

JK EVENTS PLANNERS

For JK EVENTS PLANNERS

PROPRIETOR

MR. AKBAR SAYYED

DCC Infotech Pvt. Ltd.

[illegible]

Date - 31st Dec. 2022

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Ms. Pratiksha Laxman Pawar has done her internship in at DCC Infotech Pvt. Ltd., Pune, from 01st Dec. 2022 to 31st Dec. 2022.

She has worked on co-ordinating the Customers, Follow up of Customers.

During his internship she has demonstrated her skills with self-motivation to learn new skills.

Her performance exceeded our expectations and she was able to complete the project on time.

We wish her all the best for her upcoming career.

For DCC Infotech Pvt. Ltd.

Authorized Signature

DCC INFOTECH PVT. LTD.

A.B. XEROX Enterprises

Aashiyana Plaza, Shop No12, opp Poona College Bhawani Path, Pune 411042.
Phone 9422026193

To,

The Principal,

Poona College Arts Science Commerce,

Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Mohammed Alam Sarfaraz Alam Shaikh	5591	6624 7649 4302	Business Administration Paper II and III

These students have been provided with adequate exposure and necessary handson training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

A. B. Xerox
Shop No. 13, Aashiyana Apartment,
Opp. Poona College, Pune
Mob.: 9922676915

kangaroo kids

Dear Sir/Ma'am,

This is to update you that Saloni Aru was working as a intern in our school Kangaroo Kid's , Viman Nagar Branch and she completed her 6 months here .She is a very hardworking girl and we wish her a good luck for her future.

Thanks and Regards,

Priya Malhotra

Center Manager

Date : 1/09/22

Kangaroo Kids Viman Nagar
Pre School Day Care Activity Centre
Contact: 9145121888

Plot No 63, Parkland Society,
Sakore Nagar, Viman Nagar, Pune - 411014
9145121333, 9145121888
pune.vimannagar@kangarookids.co.in

INTERNSHIP COMPLETION CERTIFICATE

Letter Head of the Internship Provider Organisation

To,
The Principal,
AKI's Poona College,
Pune 411048

Subject: Internship Completion Certificate.

Dear Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Raj Mohammad Shoaib Ajim	5363	826277393111	Business Administration II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Zam Zam Trading
All Types Furniture [illegible]
Kausar Project, Kondhwa Khurd,
Pune-48. Mob. 9623116812

Stamp of the company

BEAUTY LIFE

Address: [illegible] Camp, Pune - [illegible]
Phone: [illegible] Email: [illegible]

Date: 17/02/2023

TO WHOM IT MAY CONCERN

This is to certify that Mrs. Hajra Nasir Baig, student of Poona College, has completed a internship in the field of Makeup artist assistant from 03/02/2023 to 17/02/2023 under the guidance of Snehal karnawat.

During the period of her internship program with us, she had been exposed to different processes and was found diligent, hardworking and inquisitive.

We wish her every success in her life and career.

Authorised Signature
BEAUTY LIFE
NEAR RAMAZAN
CAMP PUNE 01

DiZiLeads™
Management Solutions Pvt Ltd

DiZiLeads Management Solutions Pvt. Ltd.
Office No. 606/607, [illegible] Galaxia Mall, [illegible] Road,
[illegible], Pune – 411028
[illegible]

Date: 15th Feb 2023

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Mr. **Mohammed Rahim Khan** has successfully completed **2** weeks of an internship program from **19th Jan 2023** to **30th Jan 2023** in the **Quality** department of our organization.

He was highly motivated and hardworking. He worked sincerely at his tasks and did a very good job.

We wish him/her great success in his/her future endeavours.

Sincerely,

Authorized Signature

Strawberry Kids Pre-School

The First Step towards Success along with Happiness!

SUB : INTERNSHIP COMPLITION LETTER

We are glad to inform you that Miss. Anisa Gaus Khan from Strawberry Kids Pre-School has successfully completed her internship from 1st February to 31st March 2023.

During her internship, she was exposed to the various activities in office assistant management and administration as assistant Admin.

We found her extremely inquisitive and hard working. She was very much interested to learn and also willing to put her best efforts and get in to the depth of the subject to understand it better.

Her association with us was very fruitful and we wish her all the best in her future endeavours.

Strawberry Kids Pre-School
Principal

R. A. Dhumal
Principal

Strawberry Kids Pre-School
Kondhwa
Pune

Shivneri Nagar, Lane 1
Kondhwa, Pune 411048

+91 7038779295

strawberry.preschoolpune@gmail.com
www.StrawberrySchools.com

GLOBAL BAKERS

Address: Survey No.40, Lane No.6, Bhagyoday Nagar, Kondhwa, Pune – 48
Email: globalbakers@gmail.com
Phone: 9420064793

Date: 10/02/2023

TO WHOM IT MAY CONCERN

This is to certify that Mr. Ansari Mohd Fayaz Mohd Arshad, student of Poona College, has completed a internship in the field of Marketing from 01/02/2023 to 10/02/2023 under the guidance of Ajmal Raza.

During the period of his internship program with us, he had been exposed to different processes and was found diligent, hardworking and inquisitive.

We wish him every success in his life and career.

Authorised Signature

GLOBAL BAKERS
S.NO.40 BHAGYODAY NAGAR
KONDHWA KHURD,PUNE-48

India Lock & Key Maker

430 New Mangalwar Peth Near [illegible] Chowk Pune-11
Proprietor: Alim Shaikh
Contact no: [illegible]
Email id: [illegible]@gmail.com

DATE: 5/5/2023

To,

The Principal,

Azam's Poona College,

Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Shaikh Zaid Alim	5657	9431 3479 5842	Business Administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely, *For India Lock Key Maker*

A.Shaikh

Proprietor

Name & Signature (Authorized Signatory)

B NERKAR AND ASSOCIATES

Chartered Accountants

[illegible]

To,

The Principal

M.I.Y. Poona College

Camp, Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Programme' in this organization.

Sr. No	Name of the student	[illegible]	Aadhar No.	Special Subject
1.	Shaikh Moh[illegible] Hizaifa Hanif	5531	[illegible]245	Business Administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorized Signatory)

For B NERKAR AND ASSOCIATES

IQRA ENTERPRISES

All Types of Scrap Depot Sales & Purchase

Kashiwadi, Bhawani Peth, Opp. PMC Colony, Pune 42.
Mob : 9921603985 / [illegible]

Date :

Ref. No. :

IQRA ENTERPRISES

Kashiwadi, Bhawani Peth,

Opp. PMC Colony, Pune – 42.

TO WHOMSOVER IT MAY CONCERN

This is to certify that **Mr. Arbaz Shaikh,** has successfully completed his internship in the Organisation named **IQRA ENTERPRISES** from **1-Dec-22 to 15-Dec-22**.

During his tenure, we found him to be honest, dedicated, hardworking and well-behaved and his services were found to be satisfactory.

Name	: Imran Shaikh
Designation	: Owner (Supervisor)
Date	: 15th Dec'22

IQRA ENTERPRISES
Kashiwadi, Bhawani Peth,
Opp. PMC Colony No.10,
Pune - 42. Mo-9921603985

Techno5 Media Industries (I) Pvt.Ltd

210, The Capital, Kausar Baug NIBM Pune 411048

Email: [illegible]

Internship Certificate

This is to certify that Mr. Suhail Shaikh student of Azi's Poona College has completed internship in Learning Business Development Process with Techno5 Media Industries (PL, Pune)"

His internship started on 1st February 2023 to 10th February 2023.

During this period the student seem sincere and up to the mark.

We wish him all the best in all his future endeavors.

Place: Pune

Date:

IMRAN

Imran Khan

(HR – Manager)

TECHNO5

ALISA TRAVELS

[illegible] Peth Pune [illegible]@gmail.com / www.alisatravels.com

Date: 10/02/2023

TO WHOM IT MAY CONCERN

This is to certify that Mr. Ibaad Naim Shaikh student of Poona College, has completed a internship in the field of Travels service from 01/02/2023 to 10/02/2023 under the guidance of Sameer Shaikh. During the period of his internship program with us, he had been exposed to different processes and was found diligent, hardworking and inquisitive, Time Management. We wish him every success in his life and career.

ALISA TRAVELS
PUNE

Authorized Signature:

Website : www.alkhalifatours.com

Al-Khalifa

Tours & Travels India Pvt. Ltd.

HAJ - UMRAH - ZIYARAT

AMIR SHAIKH 8669280314 7038109891

(Managing Director)

724, Chudaman Talim, Bhawani Peth, Opp. Navin Hind School Pune - 411 042. Email : amir@alkhalifatours.com

Ref. No. Date :

Internship completion letter

To,
Kaif rauf Sayyed
?/ Salisbury park near
Yasin jug dargar madarasa building
2 floor pune-411 037
Contact No- 9834196466

This is to Certify that kaif Rauf Sayyed has done his internship in Jr. Accountant at **AL-KHALIFA TOURS AND TRAVEL IND.PVT.LTD** , office no 736 Shop no 2 Chudamantalim Bhawani peth Pune-411 042, from 02/12/2022 To 09/12/2022

During the time frame he has been a sincere and thoroughly professional employee. Below are the key projects he has worked on successfully

Al-Khalifa Tours & Travels Pvt. Ltd. Pune

Your Faithfully

NS ENTERPRISES

Address: [illegible]
Contact: [illegible]

Date:

Ref. No.: [illegible]

To,
The Principal,
AKI's Poona College of Arts,

Science & Commerce College.

Pune (Place)

Subject: Internship Completion Certificate ----

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the 'Sixty Hours Internship Program me' in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	KHAN HUZEFA SAEED	2620	[illegible]	BUSINESS ADMINISTRATION

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavors.

Thank you.

Digital & Seva Kendra
CSC

Name & Signature
(Authorised Signatory)

Maira Ads

Maira Ads - Your Digital Marketing Partner

Date: [illegible]

Ref. No.: [illegible]

EXPERIENCE CERTIFICATE

To Whomsoever It May Concern

This is to confirm that **Mr. FAHAD SHAIKH** worked as an "Social Media Marketing Executive" in Support Department, From **1st September, 2021 to 31 March 2023.**

During his tenure we found him sincere, dedicated and hard working.

Also we observe him dedicated and honest about his work.

We wish him success in his future endeavours.

For

Hr Team

MAIRA ADS

Authorized Signatory

Maira Ads Pune

[illegible]

To,

The Principal,

[illegible] College,

Pune (Place)

Subject: Intership Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Afraz Shaikh	56164	[illegible]	Business Administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

[illegible]

me of the company

Sincerely,

Name & Signature (Authorised Signatory)

[illegible]

Ashraf Sounds and Decorators

Office Address: [illegible]

Contact: [illegible] Email: [illegible]

Date: 11th FEB'23

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Afiaz Shaikh has done his/her internship in [Designation of internship] at [Ashraf Sounds and Decorators], Pune, from [02/02/23] to [10/02/23]

He has worked on a project titled Farewell'23. This project was aimed at Managing the party. As part of the project, he/she has Managed to execute the event.

During his internship he has demonstrated his skills with self-motivation to learn new skills. His performance exceeded our expectations and he was able to complete the project on time.

We wish him all the best for his upcoming career.

Authorized Signature

Ashraf Sounds and Decorators

[illegible]

MONDIAL BUSINESS PROCESS

Office Address: Brahma Estate Building 1st floor, near Jyoti hotel, Pune Kondhwa Phone No: [illegible]
Email : mondialprocess01@gmail.com

Date: 28/02/2023

SUBJECT: INTERNSHIP COMPLETION CERTIFICATE

This is to certify that Ms. Asfiya Rafique Shaikh, student of Poona College, has successfully completed a internship in the field of document analyzer and uploader from 13/02/2023 to 28/02/2023 under the guidance of Azim Shaikh.

During the period of her internship program with us, she had been exposed to different process and was found diligent, hardworking and inquisitive. Her performance exceeded our expectations and she was able complete the given task on time.

We wish them all the best for future endeavors.

Mondial Business Process

Proprietor

Authorised Signature

3C IT

Satyam®
DOOR

1 April 23

Internship Training Certificate

This to certify that Asmita Kalyan Jagtap Pursuing her B.Com in 3rd year has successfully completed internship at Sr.No 35 Plot no :43, 48 Jambulwadi , Kholewadi, Katraj 411046 from 01/03/2023 to 31/03/2023.

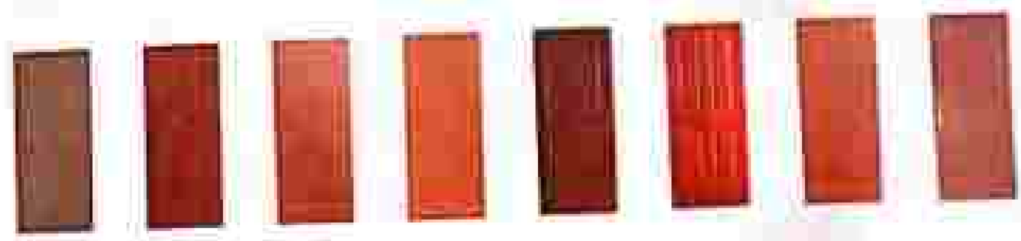
We found her sincere, hardworking, technically sound and oriented.
She worked well as a part of team during her tenure.

We take this opportunity thank her and wish her all the best for future.

Your Sincerely,
Satyam PVC Doors

For Satyam P.V.C. Doors
Proprietor

Kalyan Jagtap.
Proprietor



Internship Certificate

This is to certify that Ms. Asiya Fahim Khan, T.Y.B.Com. Student at Poona College of Arts, Science & Commerce, Pune, has completed her Desktop Support internship at 3C IT SOLUTIONS & TELECOMS (I) PVT. LTD. She worked under the guidance of Mr. Govind Sahu from 05th Jan to 20th Jan 2023.

Ms. Khan worked under 'Desktop Support Engineer'. As a part of the project, she understood how the Desktop Support Management works.

She is a self-motivated, hard worker that is always looking to learn new skills. Ms. Khan has done more than her role's responsibilities. She has always been keen on taking new tasks. We wish her all the best in all her future endeavors.

For 3C IT Solutions and Telecoms (I) Pvt Ltd

Govind Sahu

GM- Service & Operation.

INTERNSHIP COMPLETION CERTIFICATE

CHIRAAG ASSOCIATES
556, Gate no 5, Near Naya Bazar, 411037,
Market yard, Gultekadi, Pune

To,

The Principal,

AKIS Poona college of

Arts, Science and

Commerce Pune

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Ansari Salman	5816	[illegible]	Business administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Prakash Nimbalkar

Name & Signature

(Authorised Signatory)

Scanned with OKEN Scanner

CA CHIRAAG ASSOCIATES

Regd Address :556, Gate No. 5, Near Naya Bazaar, 411037, Market Yard, Gultekadi, Pune,
Maharashtra, Pune 411037
Email ID : chiraagassociates@gmail.com
Mobile No : 8551076639

CERTIFICATE OF COMPLETION

This certificate is awarded to SALIMUNNISA TABARAK ANSARI for successfully completing 60 hours of internship at CA CHIRAG ASSOCIATES from February 1, 2023 to February 10, 2023.

During the course of the internship, she demonstrated a strong work ethic, dedication to their assigned tasks, and a willingness to learn and grow. She worked collaboratively with other team members, took constructive feedback positively, and contributed to the overall success of the organization.

We wish her all the best in their future endeavours and hope that this internship experience has provided them with valuable skills and knowledge that will benefit them in their professional career.

Pratiksha Nimbalkar

Weanimates

WEANIMATES

Wanawrie Salunke Office no F/13 Super mall

Salunke vihar road Pune-411040

TO WHOMSOVER IT MAY CONCERN

This is to certify that Ms. Ayesha Sayyed was working at **Weanimates** as a **Research Analyst & Email Marketing** from **1st Feb'23** to **25th Feb'23.**

During her tenure, we found her to be honest, dedicated, hardworking and well-behaved and her services were found to be satisfactory.

Name : Sadique Shaikh.

Designation : Marketing Manager, Producer.

Date : 25th Feb'23.

Sadique

Weanimates

WEANIMATES

Wanwadie Salunke Office no F/11 Super mall

Salunke vihar road Pune-411040

TO WHOMSOVER IT MAY CONCERN

This is to certify that Ms. **Saadeka Tamboli** was working at **Weanimates** as a **Research Analyst & Email Marketing** from **1st Feb'23** to **25th Feb'23.**

During her tenure, we found her to be honest, dedicated, hardworking and well-behaved and her services were found to be satisfactory.

Name : Sadique Shaikh.
Designation : Marketing Manager, Producer.
Date : 25th Feb'23.

Sadique

HAKIMI HARDWARE

TO WHOMSOEVER MAY CONCERN

This is to certify that **Mr. Mohin Mulani** has successfully completed 1 week of an internship program from 02 Feb 2023 to 10 Feb 2023 in the Sales department of our organization.

He was highly motivated and hardworking. He worked sincerely at his tasks and did a very good job.

HAKIMI HARDWARE
Riddhi Siddhi Apt, Solapur Road
Vaidwadi, Hadapsar PUNE

Sincerely,

VIKAS PACKERS & MOVERS

CARGO SERVICES

SHOP NO. [illegible], COMMON SALE HALL, MARKET YARD, PUNE - 37. PHONE : [illegible] E-mail : vikas_packers@rediffmail.com

To,

The Principal,

Poona College of Arts,

Science & Commerce,

Pune-01

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organization.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Kan Ansarif Asif	5603	30857480572	Business Administration II & III

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organizations.

I wish them every success in future endeavers.

Thank you.

Sincerely,

For Vikas Packers & Movers

Proprietor

MUMBAI

[illegible]

HYDERABAD

[illegible]

BANGALORE

[illegible] Ring Road Bangalore

CHENNAI

[illegible] Chennai

Address: 83/84 Shivaji Nagar Old Topkhana, Near Bhagwat Garage.
Phone: 7972921151
Email: customercare@xpressbees.com

Date: 10/02/2023

TO WHOM IT MAY CONCERN

This is to certify that Mr. Ammar Athar Khatib student of Poona College, has completed a internship in the field of Courier service from 01/02/2023 to 10/03/2023 under the guidance of Bipin Garg.

During the period of his internship program with us, he had been exposed to different processes and was found diligent, hardworking and inquisitive, Time Management.

We wish him every success in his life and career.

Authorised Signature

NEW TAJ BAKERY

Ref. No.

Date: 05/05/2023

Mr. Ansari Aqib Altaf Hussain

~~Mr Ansari Mohd Altamash~~

~~Irfan Ahmed~~

Is working with our firm New Taj Bakery for the last one year

He has developed good relations with customers & good in keeping accounts.

Right now he is study in T.Y.Bcom Pune College in commerce section

He is very dedicated to his work and knows his responsibility

FOR NEW TAJ BAKERY

PARTNER/MANDATTEE

a College

i work as

3 for the

a keen

nt are

NEW TAJ BAKERY

Bhavani Peth, Pune 411 042

Ph. 26 35 26 52
26 35 26 51
Cell 9822052799
9890647773

Ref. No.

Date: 05/05/2023

Mr Ansari Mohd Altamash
Israr Ahmed

Is working with our firm New Taj Bakery for the last one year.
He has developed good relations with customers & good in keeping accounts.
Right now he is studying in T.Y. Bcom Poona College in Commerce section.
He is very dedicated to his work & knows his responsibility.

FOR NEW TAJ BAKERY

PARTNER/MANDATEE

EXCELLENT FABRICATION & ENGG. WORK

Industrial Fabrication & Engg. Works

To:

The principal

AKI'S Poona College,

Camp: Pune

Subject: Internship Completion Certificate

This is certify that **Ms/ Madiha Sameer Memon** student of 6th **sem** of **T.Y.B.com** roll no: **5554** has completed **60 hours** internship.

At **EXCELLENT FABRICATION AND ENGG. WORK** from **2 February 2023** to **19 February 2023**.

At work he had proven satisfaction results and highly dependable. This is to certify also that he has no pending assignments in relation to his work , and so she is therefore cleared.

We wish them all the best for future endeavors.

EXCELLENT FABRACTION

AND ENGG WORK

For Excell...

(Proprietor)

HUSAIN MEHBOOB SHAIKH

Taurus BPO Service

Date 10/03/2023

TO WHOM IT MAY CONCERN

This is to certify that **Mrs. Rosel Begum Bugga Khan** student of Poona College, has completed a internship in our organization Taurus BPO Services India LLP. As a designation Customer Service Associate in our Sales (Outbound) Department at Pune Centre from 20/02/2023 to 04/03/2023.

during the period of her internship program with us, she has been exposed to different processes and was found diligent, hardworking and inquisitive.

We thank her, for contribution and wish her success in future endeavours.

For Taurus BPO Service India LLP

Employee Name

Intermedia Cable Communication Pvt. Ltd.

[illegible]

JOINING LETTER

17th January, 2023.

To,
Mr. Mudassar Mukhtar Shaikh
1760/22 Babajan chowk,Dholpura,Gali no-23,411011

With reference to your application and subsequent interview you had with us the Management is pleased to appoint you as Net Executive w.e.f. **18th May, 2022.** Also note that your Temporary Employment can be terminated at any time before completion of a year at the discretion of the Management without assigning any reason therefore, without pay or pay in lieu of notice.

1. Please note that you will be paid consolidated service charges of **Rs.9,000/-** per month during the period.
2. You will carry out such duties and during such hours as shall be assigned to you from time to time by your Superiors.
3. You are liable to be transferred to any Department, Section at any time at the convenience of the Company, and at the same time you are liable to be transferred to any of our branches in Pune at the same terms and conditions of your original appointment.
4. At present you are required to attend your duties at following address. 1018, ICC Center, New Nana Peth, Pune 411002.
5. Please note that you shall be physically and mentally fit for your **assignment** work during this period.
6. You shall follow all safety rules and regulations of the company during this period.
7. You shall return in good condition, all tools instruments given to you for practical **Assignment** work in the Company on the last day of your working day in the company or money value of such unaccountable tools instruments will be recovered from your **Assignment** charges.
8. Please note that if you want to leave the job you have to complete notice period for 1 month, if any reason notice period is not completed by you then company is liable to an action against you.
9. At the time of joining duty please bring true copies of certificates, testimonials for our record Along with the originals for verification. Please also bring with you your recent passport Size Photograph.
10. Please sign & return duplicate copy of this letter in token of your acceptance of the Appointment on the above terms and conditions.
11. Employee will not work in similar field like cable service industry for 1 year from the date leaving our organization.

Thanking you
Mr.Prateek Khanna
Hr. Dept

HD

BroadBand Solutions

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WNS

Extending Your Enterprise

Date : 05th May 2023

Subject : internship completion

To Whomsoever it may concern,

This is to certify that MR. Ayaj Sadik Sayyed, a student of AKI's Poona College of Arts, Science and Commerce has completed him three month internship in the field of Insurance from 22nd November 2022 to 22nd February 2023.

During the period of his internship program with us, he had been exposed to different processes and found him extremely diligent, hard-working and inquisitive. He was interested to learn the functions of our core division and also willing to put him best efforts and get into depth of the subject to get the understanding of process.

We wish him all the best and phenomenal succes in him future endeavours.

[illegible]
Lead HR Executive
WNS Global Services (P) Ltd | [illegible]

WNS

ONE WNS ONE GOAL OUTPERFORM

Letter Head of the Internship Provider Organisation

To,

The Principal,

[illegible] College,

Pune (Place)

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	[illegible] Tamboli	5011		Business Administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

AASHA STEEL

Stamp of the Company

Name & Signature (Authorised Signatory)

Shahid Shaikh

INTERNSHIP COMPLETION CERTIFICATE

Letter head of the Internship provider organisation

To,

The principal

POONA COLLEGE,

PUNE.

Subject : Internship Completion Certificate......

Dear Madam/Sir

This is to certify that Ms. Firdos Begam T.Y.B.COM Student at Poona college of Arts ,science and commerce ,Pune has completed Internship in this organisation Healing and Health Clinic I am happy to inform you that following Student your College have successfully Completed the sixty hours Internship Programme' in this organisation.

This students have been provided with adequate exposure and necessary hands on training pertaining their special.

I am confident that this student will perform effectively in similar Type Of Organisation .

I wish them every success in future endeavours.

Thank you .

Sincerely,

Pathan

Name of signature

(Authorised Signatory)

Dr. Saara .S. Pathan

HEALING & HEALTH
Dr. Mrs. S. PATHAN
B.U.M.S. REG. [illegible]
Shop No.42, Bram[illegible] [illegible], NIBM Road,
Near Kausar Baugh, Kondhwa, Pune - 48

RIYA BAGS SALES & REPAIRS

38 M.G.Road Kamal chamber ,Next to bata,pune -411001

INTERNSHIP COMPLETION CERTIFICATE

To,

The principal,

Poona collage

Pune-

Sub-Internship completion certificate

Dear Sir/Madam,

This is to certify that Mr.singh Deepak sher T.Y.B.COM student at poona college of Arts ,Science and Commerce,Pune has completed internship in this organisation Riya Bags sales and repairs I am happy to inform you that following student your collage have successfully completed the sixty hours internship programs in this organisation .

This students have been provided with adequate exposure and necessary hands on training pertaining their specials.

I am confident that this student will perform effectively in similar type of Organisation .

I wish him very success in future endeavours.

Thank you

Sincerely

Kanahiyalal Soni

(Authorised Signatory)

RIYA BAGS
38, M.G. ROAD
CAMP, PUNE-411001
(M) 9860[illegible]

MOB NO:- +91 7711971971

COMPUMECH

Specialist in: second hand laptops selling laptop parts and chip level
Shop no 9, opp to Jim royal Kondhwa budruk pune 48

DATE:- 10/02/2023

REF NO:- 4508.

This is to certify that Hafeez Kadri of BCOM Part II, SEM 6, and Roll No.5647of AKI's Poona College of Arts, Science and Commerce has successfully completedthe internship work as per the guidelines of Savitribai Phule Pune University in our organization from 01/02/2023 to 10/02/2023 for the academic year 2022-23 During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavours.

COMPUMECH
PUNE

Authorized Signature with Stamp

MOB NO:- +91 9822789466

MOHAMMADI GLASS

Specialist in: Beveling, Polishing Etching, Decorative Mirrors
456, Bhavani Peth, Bharat Cinemas Compound, Pune 411042

REF NO:-4506

DATE:- 02/03/2023.

To whomsover it may concern,

This is to certify that **Mohammed Amin Munir** of TYB.com of AKI's Poona College of Arts, Science and Commerce has **successfully completed the internship work as per the guidelines in our organization from 02/02/2023 to 01/03/2023** for the academic year 2022-23.

During the training, the student was sincere, hardworking and showed a keen interest learn. The involvement and sustained efforts put in by the student are highly appreciable.

We wish him all the best in his future endeavors.

MOHAMMADI GLASS PUNE

Authorized Signature with Stamp

MAVEN BIZTECH

Date: 24th February 2023
Subject: Internship completion

To whomsoever it may concern,

This is to certify that Ms. Prema Shivapa Vachhe, a student of AKIs Poona College of Arts, Science and Commerce has completed her Internship in the field of Data Analytics from 10th February 2023 to 21st February 2023 under the able guidance of Ms. Farzin Khan.
During the period of her internship program with us, she had been exposed to different processes and we found her extremely diligent, hard-working and inquisitive. She was very much interested to learn the functions of our core division and also willing to put her best efforts and get into the depth of the subject to understand it better.

We wish her all the best and a phenomenal success in her future endeavours.

For Maven Biztech LLP

Maven Biztech LLP
Pune

Regards,
Somiya Mohammed
Sr. HR Generalist

Regards,
Farzin Khan
Assistant Ops Manager

9923480249

Natraj cafe

Breakfast | Lunch | Dinner

Date: 30 March 2023

Lane C, 37 B,

Ragvilas Society,

Koregaon Park,

Pune – 411001

Email – koveg987@gmail.com

TO WHOM IT MAY CONCORN

This to certify that Mr. Chandrashekhar Yadav student of Poona College, has completed a internship in the field of Restaurant and Hospitality from 21/03/2023 to 30/03/2023 under the guidance of Mr. Alok.

During the period of internship program with us, he had been exposed to different kind of works as a team, understand the nature of business, hospitality, interacting with guest time management.

We wish him every success in his life and career.

For NATRAJ FOOD

Raj Kumar

Proprietor

Authorized Signature

Igt Solutions

Mantri IT Park Vimanagar,

Pune, Maharashtra 411014

TO WHOMSOVER IT MAY CONCERN

This is to certify that **Mr. Musaib Majeed Yalal** has successfully completed her internship in the field of Customer care executive from **1-Dec-22 to 25-Dec-22**.

During her tenure, we found her to be honest, dedicated, hardworking and well-behaved and her services were found to be satisfactory.

Name	: Paras Chavan
Designation	: Team Leader.
Date	: 25th Dec - 22

Chavan

19

Website : www.alkhalifatours.com

Al-Khalifa

Tours & Travels India Pvt. Ltd.

HAJ - UMRAH - ZIYARAT

AMIR SHAIKH (Managing Director) 8669280314 7038109891

724, Chudaman Talim, Bhawani Peth, Opp. Navin Hind School Pune - 411 042. Email : amir@alkhalifatours.com

To,

The Principal,
POONA College,
PUNE-411001

Subject: Internship Completion Certificate ......

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully completed the "Sixty Hours Internship Programme" in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	HASHAM FEROZ MEMON	5332	N/A	MARKETING MANAGEMENT
2.	ARBAZ SIRAJ KHAN		N/A	
3.	Ayaan shafi bagwan	5336	N/A	ACCOUNT I NG PERSON

Theses

Sudent have been provided with adequate exposure and necessary hands- on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

AL-KHALIFA TOURS & TRAVELS

Sincerely

Name & Signature

(Authorized signatory)

MONDIAL BUSINESS PROCESS

Office Address: [illegible]
Email: [illegible]@gmail.com Phone No: [illegible]

Date: [illegible]

SUBJECT: INTERNSHIP COMPLETION CERTIFICATE

This is to certify that Mr. Asim Ali shaikh , student of Poona College, has successfully completed a internship in the field of document analyzer and uploader from 13/02/2023 to 28/02/2023 under the guidance of Asim Shaikh.

During the period of his internship program with us, he had been exposed to different process and was found diligent, hardworking and inquisitive. His performance exceeded our expectations and he was able complete the given task on time.

We wish them all the best for future endeavors.

Mondial Business Proc

Proprietor

Authorised Signature.

MAKHUZ.CO

Office Address: [illegible]
Email : [illegible]@gmail.com Phone No: [illegible]

Date: 01/01/2023

SUBJECT: INTERNSHIP COMPLETION CERTIFICATE

This is to certify that Mr. Ebad Abdul Rauf Shaikh, student of Poona College, has successfully completed a internship in all the field of the organization from 01/01/2023 to 17/01/2023 under the guidance of Inamul Hasan Shaikh.

During the period of his internship program with us, he had been exposed to different process and was found diligent, hardworking and inquisitive. His performance exceeded our expectations and he was able complete the given task on time.

We wish them all the best for future endeavors.

Authorised Signature

Letter Head of the Internship Provider Organisation

To,

The Principal,

Poona College,

Pune (Place)

Subject: Internship Completion Certificate

Dear Madam/ Sir,

I am happy to inform you that following students of your college have successfully Completed the 'Sixty Hours Internship Programme' in this organisation.

Sr. No.	Name of the student	Roll No.	Aadhar No.	Special Subject
1.	Kinjal Shaikh	5596	[illegible]	Business Administration
2.				
3.				
4.				
5.				
6.				
7.				
8.				

These students have been provided with adequate exposure and necessary hands-on training pertaining to their special subject.

I am confident that these students will perform effectively in similar type of organisations.

I wish them every success in future endeavors.

Thank you.

Sincerely,

Name & Signature (Authorised Signatory)

Stamp of the company

Stores

Park

Pune- 411032

Anjuman Khairul Islam's

POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

- Affiliated to Savitribai Phule Pune University: ID No. [illegible]
- Junior College Index No.: [illegible]
- Government of Maharashtra and Savitribai Phule Pune University Recognized Minority College
- UGC - 2(f) & 12 (B) Status • NAAC Re-accredited College • DST - FIST Funded College

K. B. Hidayatullah Road, Camp, Pune - 411001. (MS), India | [illegible] | [illegible] www.poonacollege.edu.in

Ref: PC/SC/Bot./Visit/ 354 /2022-23

Date: 17/11/2022

To,

Mr. Dilip Jadhav

Director,

A-One Biotech and Tissue Culture Laboratory,

(Horticultural Training Centre),

Talegaon, Pune – 411033

Subject: Regarding visit to you're a-One Biotech and Tissue Culture Laboratory, Talegaon on **24th November, 2022.**

Respected Sir,

As per our telephonic conversation, staff of Department of Botany would like to visit your esteemed A-One Biotech and A-One Biotech and Tissue Culture Laboratory (Horticultural Training Centre) on 24th November, 2022 with S.Y.B.Sc. (Botany) students. This visit is a part of curriculum that will educate students for techniques in Plant Tissue Culture and Horticulture. Staff and students will definitely get enriched with knowledge and information by this visit. We look forward for a positive reply

Yours Sincerely

Dr. Aftab Anwar Shaikh

Principal

Anjuman Khairul Islam's
POONA COLLEGE OF ARTS, SCIENCE & COMMERCE
• Affiliated to Savitribai Phule Pune University: ID No PU/PN/ASC/023/1975
• Junior College Index No.: J-11.15.004
• Government of Maharashtra and Savitribai Phule Pune University Recognised Minority College
• UGC - 2(f) & 12 (B) Status • NAAC Re-accredited College • DST - FIST Funded College
K. B. Hidayatullah Road, Camp, Pune - 411001. (MS), India
+91-20-2645 4283 / 2644 6215
principal@poonacollege.edu.in
www.poonacollege.edu.in

Date: 24/11/2022

To,
Mr. Dilip Jadhav
Director,
A-One Biotech and Tissue Culture Laboratory,
(Horticultural Training Centre),
Talegaon, Pune – 411033

Subject: Letter of Thanks.

Respected Sir,
The Staff and students of Department of Botany, Poona College appreciated and thank you for permitting us to your esteemed training centre. The visit has enriched our students with knowledge on cultivation of horticulture plants and entrepreneurship.

Thanking you

Yours Sincerely

Dr. Aftab Anwar Shaikh
Principal
Poona College of Arts, Science & Commerce
Camp, Pune-411001
Principal Office

Anjuman Khairul Islam's

POONA COLLEGE

OF ARTS, SCIENCE & COMMERCE

Camp, Pune – 411001 (Maharashtra)

(AFFILIATED TO SAVITRIBAI PHULE PUNE UNIVERSITY)

ACTIVITY REPORT

Academic Year: 2022-23

BASIC DETAILS			
Title of the Activity:			
Date	**Faculty**	**Department/ Committee**	**Coordinator Name & Phone No.**
24/11/2022	Science	Botany	Dr. Azfreen A. Ahmed
Time	**Venue**	**Activity for Class/Group**	**Nature: Co-curricular/ Extra-curricular/Extention/Outreach**
7.30 am – 5.30 pm	A-One Biotech and Tissue Culture Laboratory (Horticultural Training Centre), Talegaon, Pune	S.Y.B.SC. Botany	Co-curricular

BRIEF INFORMATION OF THE ACTIVITY	
Objectives	Hands on Training of making of pots in horticulture industries
Outcome	Students learn how to make a pot by different techniques in horticulture industries. They also learn that how propagation is done for getting multiple plants through tissue culture technique.
No. of Participants	33

DOCUMENTS ATTACHED: *Note: Please attach original documents. Photocopy (Xerox) will not be accepted.*		
Detailed Report	Geotagged Photos with Caption	Notice/Brochure
Attendance	Letters if any (Invitation/Thanks)	Any other relevant Documents (Recourse Person CV/Feedback)

DETAILED REPORT

Educational Visit to A-One Biotech, Talegaon

In charge: Dr. Aafreen A. Ahmed

No. of Beneficiaries: 33

Date: 24/11/2022 Time: 7.30 am to 5.30 pm

A-One Biotech Pvt. Ltd. Is a distributer of horti-micropropagated plants based in MIDC, Talegaon, Pune. The organization was established in 2005 by Mr. Dilip Jadhav (M.SC., Botany) with specialization in Plant Pathology after working for Ten years with Padamjee. His hard work is seen in the various successful tie-ups he has with several renowned companies such as Reliance Group, Government Projects such as beautification of Nasik Highway and Chatrapati Shivaji Maharaj International Airport, Mumbai etc.
Horticulture Training Center (HTC), situated I the campus of National Institute of Post Harvest Technology (NIIPHT), Talegaon imparts training in production of tissue culture plants and aeroponics.

The Department of Botany arranged a visit to a horticulture industry A-One Biotech and Horticulture Training Centre (HTC), at Talegaon Dabhade, Pune for SYBSC Botany students on 24/11/2022. All reached A-One Biotech by 11.00 am. Mr. Shelke, the manager received us, gave us a brief insights into the aims and objectives of A-One Biotech, its functional outgrowth in the past few years as a leading horticulture industry. He took students around the entire Polyhouse while explaining the kinds of plants nurtured there, their importance and need in the outside world. Students enquired about irrigation facilities, fertilizers used to maintain growth and the chemical control undertaken to keep away past and disease. Every query was answered in detail by Mr. Shelke. He trained the students for preparation of pots for vertical garden. He also explained the insights of tissue culture technique by taking the students to its unit.

The educational visit helped students experience the functioning of a duding industry- the Horticulture industry and Tissue culture industry. In all 33 students benefitted from the visit under the supervision of Dr. Aafreen Ahemd, and Dr. Rafik Shaikh

A gropu photo at A-One Biotech Industry, Talegaon (24/11/2023)

Mr. Shelke explaining students about Polyhouse and pot making (24/11/2023)

Students performing pot making technique (24/11/2023)

Anjuman Khairul Islam's

POONA COLLEGE

OF ARTS, SCIENCE & COMMERCE

Camp, Pune – 411001 (Maharashtra)

(AFFILIATED TO SAVITRIBAI PHULE PUNE UNIVERSITY)

IQAC

NAAC A+

AKI's Poona College of Arts, Science & Commerce, Pune-01

Attendance Sheet for Students

Date of Activity: 24th NOVEMBER 2022		Time Slot: 9:00 am to 6:30 pm	
Activity Name:	VISIT TO A-ONE BIOTECH PCL, TALEGAON, PUNE	Teacher Incharge:	Dr. [illegible] A. [illegible]
Organizing Dept/Committee: BOTANY			
Total Number of Students Attended: 33		Report Generated by: Dr. Anjum A. Ahmed	

Sr. No.	Name	Class	Mobile No.	Signature
1.	Madiha Jalil Khan	S.Y.B.Sc	[illegible]	[illegible]
2.	Tasmiya Javed Shaikh	S.Y.B.Sc	[illegible]	[illegible]
3.	Sadiya Mohd. Yusuf Tuge	S.Y.B.Sc	8637165092	Sadiya
4.	Fiza Nisar Shaikh	S.Y.B.Sc	8767367169	[illegible]
5.	Alfiya Ahesan Deshmukh	S.Y.B.Sc	[illegible]	[illegible]
6.	Fatima Shaikh	SY.BSc	8669806883	[illegible]
7.	Ala Khan	SY.BSc	9096885291	[illegible]
8.	Reshma Shaikh	SY.BSc	[illegible]	[illegible]
9.	Muskan Pathan	SY.BSc	[illegible]	Muskan
10.	[illegible] Shaikh	SY.BSc	[illegible]	[illegible]
11.	Rubina Nadaf	SY.BSc	8483098789	[illegible]
12.	Murtaza Ansari	SY.BSc	8087620023	Murtaza
13.	Misbah Ansari	SY.BSc	[illegible]	[illegible]
14.	Saniya Sameer Shaikh	SY.BSc	9876851766	[illegible]
15.	Nasreen Shaikh	SY.BSc	[illegible]	[illegible]
16.	Fusiha Sayed	SY.BSc	8669418191	[illegible]
17.	Afrina Pathan	SY.BSc	[illegible]	Pathan
18.	Ayan Shaikh	SY.BSc	8080354240	[illegible]
19.	Hasan Shaikh	SY.BSc	[illegible]	[illegible]
20.	Faizan Shaikh	SY.BSc	[illegible]	[illegible]
21	Trupti Chandaliya	SYBSc	[illegible]	[illegible]
22	Riya S Shelkar	SYBSc	[illegible]	[illegible]
23	Mahek S Shaikh	SYBSc	[illegible]	[illegible]
24	Ziya Sayyed	SYBSc	[illegible]	[illegible]
25	Lanchenla Thongam	SYBSc	[illegible]	[illegible]

Pg. No. 01 of 02 (Total Pages)

[illegible]
Signature of Faculty Incharge

Anjuman Khairul Islam's

POONA COLLEGE

OF ARTS, SCIENCE & COMMERCE

Camp, Pune – 411001 (Maharashtra)

(AFFILIATED TO SAVITRIBAI PHULE PUNE UNIVERSITY)

AKI's Poona College of Arts, Science & Commerce, Pune-01

Attendance Sheet for Students

Date of Activity: 24th NOVEMBER, 2022 | Time Slot: 8:00 am To 6:00 pm

Activity Name: VISIT TO A-ONE BIOTECH & TCL, TALEGAON, PUNE | Teacher Incharge: Dr. Nafisa A. Ahmad

Organizing Dept/Committee: BOTANY

Total Number of Students Attended: | Report Generated by: Dr. Nafisa A. Ahmad

Sr. No.	Name	Class	Mobile No.	Signature
26	Saniya Sameer Khan	SY BSc	[illegible]	[illegible]
27	Saniya Ayub Shaikh	SY BSc	[illegible]	[illegible]
28	Misbah Ayub Shaikh	SY BSc	[illegible]	[illegible]
29	Fazail Ur Rahman	SY BSc	[illegible]	[illegible]
30.	Mariya Javed Khan	S.Y.BSc	9760781968	Mariya
31.	Kazi Gohartaaz Abuzar	S.Y.BSc	[illegible]	[illegible]
32	Pathan Zeba Masood	S.Y.BSc	[illegible]	[illegible]
33	Rizwan Afia Ismail	S.Y.BSc	[illegible]	[illegible]

Pg. No. 02 of 02 (Total Pages)

Signature of Faculty Incharge

WEB CRYPT Technology

Office Address: [illegible]
Email: [illegible] Website: [illegible]

REF: INT-webcrypt[illegible]-2023

Date: 01/04/2023

TO WHOM IT MAY CONCERN

This is to inform that **Ms. Afsheen Irfan Shaikh** student of **AKI Poona College of Art, Commerce & Science** is pursuing her internship with our organization as a **Java Developer Intern**, the duration of internship is 6 months effective from 01st February 2023 **to 31st July 2023**. Currently she is associated with Java Developer team and learning various development processes.

Project Name: Web Based Smart Dream Homes

During the period of internship with us she was found punctual, hardworking and inquisitive.

As dictated by intellectual property and confidentiality policy of Webcrypt Technology Pune. She is unable to produce the source code of above mentioned project.

We wish her every success in life.

WEBCRYPT TECHNOLOGY
PUNE

YOURS SINCERELY,

HUMAN RESOURCE MANAGER

www.webcrypttechnology.com

Internship Certificate

This is to certify that **Mr. Dange Shoaib Rajekhan** a student of **A.K.I'S Poona College of Arts, Science, and Commerce, Camp, Pune**, was assigned a project titled "**HandWritten Digit Recognition ML** " from 6th Dec 2022 to 17th May 2023 and has partially completed his project with us.
He will continue working on till same till **15th June 2023**.

He was involved in ML development as a team member. During the period of project work with us, we found him sincere, obedient and hard-working.

We wish him all the best in his future endeavors.

Sincerely,
Internship Program Manager,
PHN Technology Pvt. Ltd.

PHN
Technology Pvt. Ltd.

Internship Certificate

This is to certify that **Mr. Juneid Majeed Bagwan** a student of **A.K.I'S Poona College of Arts, Science, and Commerce, Camp, Pune**, was assigned a project titled "**Movie Ticket Booking System**" from 6th Dec 2023 to 17th May 2023 and has partially completed his project with us.

He will continue working on till same till **15th June 2023**.

He was involved in front-end development as a team member. During the period of project work with us, we found him sincere, obedient and hard-working.

We wish him all the best in his future endeavors.

Sincerely,
Internship Program Manager,
PHN Technology Pvt. Ltd.

PHN
Technology Pvt. Ltd.

Internship Certificate

This is to certify that **Mr. Shaikh Alim Shahabuddin**, a student of **A.K.I'S Poona College of Arts, Science, and Commerce, Camp, Pune**, was assigned a project titled "**Student Result Management System**" from 6th Nov 2023 to 17th May 2023 and has partially completed his project with us. He will continue working on till same till **15th June 2023**.

He was involved in front-end development as a team member. During the period of project work with us, we found him sincere, obedient and hard-working.

We wish him all the best in his future endeavors.

Sincerely,
Internship Program Manager,
PHN Technology Pvt. Ltd.

Solitaire Business Hub 1 wing 5010,
Near Phoenix Mall, Viman Nagar,
Pune, Maharashtra, 411014

1800 309 2233

www.phntechnology.com

PHN
Technology Pvt. Ltd.

Internship Certificate

This is to certify that **Mr. Shaikh Sadik Abdul Razzak**, a student of **A.K.I'S Poona College of Arts, Science, and Commerce, Camp, Pune**, was assigned a project titled "**Audio Chat App**" from 6th Nov 2022 to 17th May 2023 and has partially completed his project with us. He will continue working on till same till **15th June 2023**.

He was involved in front-end development as a team member. During the period of project work with us, we found him sincere, obedient and hard-working.

We wish him all the best in his future endeavors.

Sincerely,
Internship Program Manager,
PHN Technology Pvt. Ltd.

PHN
Technology Pvt. Ltd.

Internship Certificate

This is to certify that **Mr. Hamza Shakil Mungaye**, a student of **A.K.I'S Poona College of Arts, Science, and Commerce, Camp, Pune**, was assigned a project titled "**E-learning website with ai chatbot** " from 5th Dec 2022 to 15th May 2023 and has partially completed his project with us. He will continue working on till same till **15th May 2023**.

He was involved in front-end development as a team member. During the period of project work with us, we found him sincere, obedient and hard-working.

We wish him all the best in his future endeavors.

Sincerely,
Internship Program Manager,
PHN Technology Pvt. Ltd.

PHN
Technology Pvt. Ltd.

Internship Certificate

This is to certify that **Mr. Aafan jameer Tamboli**, a student of **A.K.I'S Poona College of Arts, Science, and Commerce, Camp, Pune**, was assigned a project titled "**E-Worker**" from 6th Nov 2022 to 17th May 2023 and has partially completed his project with us. He will continue working on till same till **15th June 2023**.

He was involved in front-end development as a team member. During the period of project work with us, we found him sincere, obedient and hard-working.

We wish him all the best in his future endeavors.

Sincerely,
Internship Program Manager,
PHN Technology Pvt. Ltd.

Solitaire Business Hub E wing 5010,
Near Phoenix Mall, Viman Nagar,
Pune, Maharashtra, 411014

1800 209 2288

www.phntechnology.com

Internship Certificate

This is to certify that **Mr. Altamash Ashpak Tamboli**, a student of **A.K.I'S Poona College of Arts, Science, and Commerce, Camp, Pune**, was assigned a project titled "**Automation Testing**" from 21th May 2022 to 17th May 2023 and has partially completed his project with us. He will continue working on till same till **17th June 2023**.

He was involved in front-end development as a team member. During the period of project work with us, we found him sincere, obedient and hard-working.

We wish him all the best in his future endeavors.

Sincerely,
Internship Program Manager,
PHN Technology Pvt. Ltd.

Profecia Links Consulting Pvt. Ltd.

...challenging limits..

Date: 15/04/22

This is to certify that **Mr. Fareed Muslim Shaikh** student of MSC (CS) from "**AKI Poona college of Arts Commerce and Science**" has successfully completed his internship as Software Developer Intern at **Profecia links Pvt Ltd**, Pune.

He worked on a project titled "**Ara**". With Ara, a low-code platform for any business application and framework is a software-as-a-service product that can be hosted in the cloud or on-premises. With the fundamental principle of "Build by configuration not by code" various features can be built by an admin or business user without requiring a developer unless really needed. Building a new business functionality such as workflow management, CRM, and accounting can be done in a few days by a single person instead of months of team effort.

During his internship, he has demonstrated his skills with self-motivation to learn new skills. His performance exceeded our expectations and he was able to deliver the project on time.

Branch: MSC (CS)

Technologies: ReactJs, CSS, HTML5, Bootstrap
As advised by intellectual property and confidentiality policy of Profecia Links. We wish him all the

best for his upcoming career.

For Profecia Links,

Pratik Batra

Email: pbatra@profecialinks.com

Reg. Off: 02nd Floor, Above
Jijamata Bank,
Karvenagar, Pune 411052
www.ssptechnosys.com

SSP TECHNOLOGY

REF: INT-SSP452-2023 **Date: 02/06/2023**

TO WHOM IT MAY CONCERN

This is to certify that **Ms. Muskan Nisar Shaikh,** student of M.Sc. (Computer Science) from **AKI'S Poona College of Arts Science And Commerce** has successfully completed a project on **"Municipal Corporation Online Complaint Handling Process"** as a partial fulfillment of requirement towards 04th semester of her M.Sc. (Computer Science) program.

Duration- 02nd February 2023 to 30th July 2023.

Technology- Java and MySQL.

During the period of internship with us she was found punctual, hardworking and inquisitive. As abided by intellectual property and confidentiality policy of SSP Technology Pune. She is unable to produce the source code of above mentioned project.

We wish her every success in life.

AUTHORIZED PERSON SIGN

SSP TECHNOLOGY PUNE

SSP TECHNOLOGY PUNE

[illegible]
Mobile No: +91- [illegible] Email: [illegible]
Website: [illegible]

REF: [illegible]-2022 Date: [illegible]

INTERNSHIP LETTER

This is to certify that Mr. Altaf Alam Shaikh, a student of **AKI's Poona College of Arts Science and Commerce, Pune** was assigned a Project titled **"Simple Key Realty Real Estate Business"** from **Dec 03, 2022 to May 15, 2023** and has partially completed his Project with us.

He was involved in Software Development and Analysis as Team Member. During the period of project work with us, we found him decent, obedient and hard working.

We wish him all the best in his future endeavours.

As abided by intellectual property and confidentiality policy of SSP Technology Pune.

We wish him every success in life.

[illegible]

AUTHORIZED PERSON SIGN

SSP TECHNOLOGY PUNE

Web Soft IT Solution

WEB SOFT IT SOLUTION

Office Address: 1st Floor, Office No -2, Building C-2, Manikmoti Complex, Near Jivandhara Hospital, Pune- Satara Road, Katraj Chowk, Pune- 411046.
Mobile No: +91-9579580670 E-mail: websoftitsolutionpune@gmail.com
Website: www.websoftitsolution.com

REF: Int-WS2011389-2022

INTERNSHIP CERTIFICATE

This is to certify that **Mr. Mohd Ayub Azmi** student from **"AKI Poona College of Science, Commerce & Arts, Pune"** has successfully delivered Internship on **"DevOps Toolchain For CI/CD"** as a partial fulfillment of requirement towards of him project.

University Name- Savitribai Phule Pune University, Pune.

Duration-5th December 2022 to 20th May 2023

As abided by intellectual property and confidentiality policy of WEBSOFT IT SOLUTION Pune.

We wish him every success in life.

AUTHORIZED PERSON SIGN

WEB SOFT IT SOLUTION PUNE

www.websoftitsolution.com

Web Soft IT Solution

WEB SOFT IT SOLUTION

Office Address: 1st Floor, Office No -2, Building C-2, Manikmoti Complex, Near Jivandhara Hospital, Pune- Satara Road, Katraj Chowk, Pune- 411046.
Mobile No: +91-8579980870 E-mail: websoftitsolutionpune@gmail.com
Website: www. websoftitsolution.com

REF: Int- WS2011389-2022

INTERNSHIP CERTIFICATE

This is to certify that **Mr. Saqueeb Aslam Attar** student from **"AKI Poona College of Science, Commerce & Arts, Pune"** has successfully delivered Internship on **"Web Development Lvl -1"** as a partial fulfillment of requirement towards of him project.

University Name- Savitribai Phule Pune University, Pune.

Duration-5th December 2022 to 30th May 2023

As abided by intellectual property and confidentiality policy of WEBSOFT IT SOLUTION Pune.

We wish him every success in life.

Websoft IT Solution

AUTHORIZED PERSON SIGN

WEB SOFT IT SOLUTION PUNE

Consociate

Date: 25/ 05/ 2023

TO WHOM IT MAY CONCERN

This is to certify that Mr. Abdul Rehman Abdul Gaffar Jakati, a student of M.Sc. (Master of Computer Science) from Poona College of Arts, Commerce and Science, Camp, Pune has successfully completed the development of the various project.

He has undergone Industrial training in this organization (ConsociateSolutions Private Limted) from 17th December 2022 to 16th May 2023. During this period, he has worked on Php and Javascript for development of projects.

During the period of his internship programme with us he was found punctual, hardworking and inquisitive.

As a part of company policy, source code of the project is intellectual property of the company. Hence, he is not liable to share the code of the project.

The overall rating for his performance during the project is V. Good. We wish him every success in life.

For, Consociate Solutions Private Limited.

Irfan Mukadam

Director.

Sacred World, Office #: 707, South Block, Wanwadi, Pune – 411048. TEL. 9004891465.

SGMS INFOTECH LLP

SGMS INFOTECH LLP
CIN : [illegible]
Email : [illegible]
Web : [illegible]
Contact : +91 [illegible]

Ref. No. : SGMS/2023/[illegible] Date : 26 / [illegible] / 2023

INTERNSHIP COMPLETION LETTER

This is to certify that **Mr. Saurabh Purushottam Lokale** Master of Computer Science Final year student of [illegible] College of Arts, Science and Commerce, Camp, Pune has successfully completed a Partial Project Titled **"Local Shipper E-Commerce Application"** in **Java** Technology with SGMS Infotech LLP, Akurdi, Pune as a part of his 4th semester project.

He has done his project during the period of 02nd January 2023 to 30th June 2023 in the completion of his project under the guidance of Mr. [illegible]

SGMS
PUNE

SGMS Infotech LLP

SGMS INFOTECH LLP

SGMS INFOTECH LLP
GIN: AA-8445
Email : [illegible]
Web : [illegible]
Contact : +91 [illegible]

Ref. No. : SGMS/2023/J00127

Date : 26 / 05 / 2023

INTERNSHIP COMPLETION LETTER

This is to certify that **Mr. Saipan Najmoddin Shaikh** Master of Computer Science Final year student of Poona College of Arts, Science and Commerce, Camp, Pune, has successfully completed a Partial Project Titled "**Ticket Master Travel Reservation System**" in **Java** Technology with SGMS Infotech LLP, Akurdi, Pune as a part of his 4th semester project.

He has done his project during the period of 02nd January 2023 To 30th June 2023 to the completion of his project under the guidance of Mr. Ritesh R. [illegible]

SGMS PUNE

SGMS Infotech LLP

SGMS INFOTECH LLP

SGMS INFOTECH LLP
CIN: AA-8449
Email: [illegible]
Web: [illegible]
Contact: +91 8275328828

Ref. No.: SGMS/2023/000126

Date: 26 / 05 / 2023

INTERNSHIP COMPLETION LETTER

This is to certify that **Mr. Gaurav Santosh Kathan** Master of Computer Science Final year student of Poona College of Arts, Science and Commerce, Camp, Pune, has successfully completed a Partial Project Titled "**Drug Awareness and Resistance Education**" in **Java** Technology with SGMS Infotech LLP, Akurdi, Pune as a part of his 4th semester project.

He has done his project during the period of 02nd January 2023 To 10th June 2023 to the completion of his project under the guidance of Mr. Ritesh R. Sarange.

SGMS INFOTECH LLP SGMS PUNE

SGMS Infotech LLP

CloudAge
Global Services Pvt. Ltd.

Internship Completion Certificate

TO WHOMSOEVER IT MAY CONCERN

02/06/2023

We hereby certify that Mohammed Aayat Kazi was an Intern of CloudAge Global Service Pvt.Ltd from 20/12/2022 to 01/06/2023.

Project assigned: Web developer

The project was successfully completed and we found Mohammed Aayat Kazi very sincere and result oriented.

We wish you all the best for your future endeavors.

Sincerely,

Haaris Zed
HR Head- Human Resources

www.callistomedia.com

C2/10, 2ND FLOOR, BRAHMA ESTATE COM. COMPLEX, NIBM Rd, Kondhwa, Pune, Maharashtra 411048

9764656435

CALLISTO media

May 25th 2023,

Internship certificate

This is to certify that **Mr. Shah Hamza Abdul Majid**, a student of A.K.I's Poona College of Arts, Science, Commerce, Camp, Pune was assigned as Project titled "Company Portfolio website" from 7th December 2022 to 7th June 2023 has partially completed this Project with us. He will continue working on the same till June 15th 2023.

He was involved in Software Development and Analysis as a Team Member. During the period of project work with us, we found him sincere, obedient and hard working.

We wish him all the best for his future endeavors.

Shaikh Salman

Sincerely,
Salman Shaikh
Project Manager

Ref: OmVSab IT Solution/HRD/2023

Certificate Of Completion

To whom it may concern,

This is to certify that **Mr.Abdul Razzak Khan** , student of final year MSC Computer Science from **A.K.I'S Poona College of Arts, Commerce and Science,Camp,Pune**, has completed internship Project in this Organization. During his training in team, he has completed work on project of "**Showroom ERP**" from 12th December 2022 to 12th May 2023 and has partially completed his project with us.

He will continue working on till same till 12th September 2023.

We wish him all the best for his future assignment and work.

Managing Director

For Omvsab IT Solution

Ref: OmVSab IT Solution/HRD/2023

Certificate Of Completion

To whom it may concern,

This is to certify that **Mr.Sohel Hamid Shaikh** , student of final year MSC Computer Science from **A.K.I'S Poona College of Arts, Commerce and Science,Camp,Pune**, has completed internship Project in this Organization. During his training in team, he has completed work on project of "**Gym Management ERP**" from 12th December 2022 to 12th May 2023 and has partially completed his project with us.

He will continue working on till same till 12th September 2023.

We wish him all the best for his future assignment and work.

Managing Director

For Omvsab IT Solution.

Date: - 30th May 2023

Project Completion Certificate

This is to certify that **Ms. Shaikh Nida Nisar, Student of Poona College of Arts, Science and Commerce, Pune,** has completed her project work in our organization under the esteemed guidance & technical support of Sr. Developers toward the fulfillment of the **MSC Computer Science, 4th Semester.**

Project name: **Online Shopping Store**

Technology: **Python with Django**

From- **06th March 2023 to 30th May 2023**

She has successfully completed her internship. During the period she was sincere, hardworking & fully devoted to project.

We wish her all success for her future career.

For Maxgen Technology Pvt Ltd

Maxgen Technologies Pvt. Ltd.

Dr. Mamta Yerawar

Manager – Human Resources

Date: - 30th May 2023

Project Completion Certificate

This is to certify that **Ms. Soleha Akbar Sayyed, Student of Poona College of Arts, Science and Commerce, Pune,** has completed her project work in our organization under the esteemed guidance & Technical support of Sr Developers toward the fulfillment of the **MSC Computer Science, 4th Semester.**

Project name: **Online Quiz Application**

Technology- **Python with Django**

From- **01st March 2023 to 30th May 2023**

She has successfully completed her internship. During the period she was sincere, hardworking & fully devoted to project.

We wish her all success for her future career.

For Maxgen Technology Pvt Ltd

Dr. Mamta Yerawar

Manager – Human Resources

Maxgen Technologies Pvt. Ltd.

Date: - 30th May 2023

Project Completion Certificate

This is to certify that **Ms. Ifra Patel, Student of Poona College of Arts, Science and Commerce, Pune,** has completed her project work in our organization under the esteemed guidance & Technical support of Sr. Developers toward the fulfillment of the **MSC Computer Science, 4th Semester.**

Project name: - **Online Furniture Store**

Technology- **Python with Django**

From- **06th March 2023 to 30th May 2023**

She has successfully completed her internship. During the period she was sincere, hardworking & fully devoted to project.

We wish her all success for her future career.

For Maxgen Technology Pvt Ltd

Maxgen Technologies Pvt Ltd

Dr. Mamta Yerawar

Manager – Human Resources

Date: 26th May 2023

INTERNSHIP COMPLETION CERTIFICATE

This is to certify that Ms. Hadiya Shaikh has successfully completed project work in the company under the esteemed guidance and technical support of Sr. Developers toward the fulfilment of the semester.

Project Name: Online Quiz Application
Technology - Python
From – 6th March 2023 To 1st August 2023

She has successfully completed her internship. During the period she was sincere, hardworking & fully devoted to project.

We wish her all success to her future career.

For Maxgen Technology Pvt Ltd

Sadhana Kokate
Manager – Human Resources

Maxgen Technologies Pvt Ltd

ROOTWARE Technologies
INDIA

TO WHOMSOEVER IT MAY CONCERN

Date: 24/05/2023

This is to certify that **Mr Mohammed Taher Electricwala** a student of A.K.I'S Poona College of Arts, Science and Commerce, Camp, Pune was assigned a project Title "BTC CHANNELS" from 5th January 2023 to 25th May 2023 and has partially completed his Project with us at Rootware Technologies, Pune. He will continue his internship till 30th June 2023

During the internship program, we found him sincere & hardworking.

We wish him success in future endeavors.

Yours Sincerely,

Date: 24/05/2023

Yogesha Shaik

TECHNOLOGIES PUNE 411040

For ROOTWARE TECHNOLOGIES
HUMAN RESOURCE

CERTIFICATE OF COMPLETION
OF
INTERNSHIP

This is to certify that

Danish Chandle

from

A.K.I'S POONA COLLEGE OF ARTS,SCIENCE & COMMERCE
Savitribai Phule University, Pune
has completed the internship program at Infosys Limited during

01 February 2023 – 13 May 2023

Satheesha B N.

Satheesha B Nanjappa
Vice President and Head, Global Education Center

Synergist Advance IT Solutions LLP

Office No-22, Raj Garden SN-43 BLD-D

Kondhwa, Khurd Pune-48

Internship Completion Certificate

TO WHOMSOEVER IT MAY CONCERN

15/05/2023

We hereby certify that Ganesh Ramadhar Jaiswal was an Intern of Synergist Advance IT Solutions LLP from 10/12/2022 to 9/05/2023.

Project assigned: Laptop Sales & Services.

The project was successfully completed and we found Ganesh Ramadhar Jaiswal very sincere and result oriented.

We wish you all the best for your future endeavors.

Sincerely,

(Chief Executive Officer)
Synergist Advance IT Solutions LLP, Pune

Anjuman Khairul Islam's

POONA COLLEGE
OF ARTS, SCIENCE & COMMERCE

[illegible]

DEPARTMENT OF MATHEMATICS

Date: 13/04/2023

NOTICE

Department of Mathematics in association with Internal Quality Assurance Cell (IQAC) would like to organize one day educational trip to Indian Institute Technology (IIT), Powai, Mumbai on 29/04/2023 for the students of F.Y./S.Y./T.Y. B.Sc. (Mathematics) and B.Sc (Computer Science). The objective to organize this educational trip is to help students to acquire practical knowledge about theories taught in classroom and to make aware about career opportunities in Mathematics through actual exposure to highly reputed educational institutes.

All the interested students are advised to submit their names along with undertaking form to coordinator on or before 20/04/2023.

Coordinator: Dr. Amjad Shaikh

Dr. Amjad Shaikh
Head
Department of Mathematics

Head Department of Mathematics
Anjuman Khairul Islam's
Poona College
of Arts, Science and Commerce,
Camp, Pune - 411001

Anjuman Khairul Islam's

POONA COLLEGE

OF ARTS, SCIENCE & COMMERCE

Camp, Pune – 411001 (Maharashtra)

(AFFILIATED TO SAVITRIBAI PHULE PUNE UNIVERSITY)

ACTIVITY REPORT

Academic Year: 2022-23

BASIC DETAILS			
Title of the Activity:			
Date	**Faculty**	**Department/ Committee**	**Coordinator Name & Phone no.**
29th April,2023	Science	Mathematics	Dr. Amjad Shaikh Mob No: 9890627303
Time	**Venue**	**Activity for Class/Group**	**Nature: Co-curricular/ Extra-curricular/Extension/Outreach**
One Day (6:30 am to 10:30 pm)	Indian Institute of Technology(IIT), Powai, Mumbai	F.Y/S.Y/T.Y.B.Sc (Maths) and F.Y/S.Y.B.Sc (Computer Science) 32 students	Co-curricular

BRIEF INFORMATION OF THE ACTIVITY	
Objectives	• To encourage and motivate students for higher studies in reputed institutes • To explore future prospect of mathematics and statistics • To explore renowned institutes in India
Outcome	Faculty members from department of mathematics, IIT, Mumbai interacted and guided students about further teaching and research opportunities and industrial applications of mathematics and statistics
No. of Participants	32 Students of S.Y/T.Y.B.Sc have participated and had an amazing experience. Students have learned and gained valuable information about further career opportunities in mathematics and pursuing higher studies at premier education institutes in India.

DOCUMENTS ATTACHED: *Note: Please attach original documents. Photocopy (Xerox) will not be accepted.*		
Detailed Report	**Geotagged Photos with Caption**	**Notice/Brochure**
Attendance	**Letters if any (Invitation/Thanks)**	**Any other relevant Documents (Recourse Person CV/Feedback)**

DETAILED REPORT

Educational Trip To IIT Mumbai

Department of Mathematics had organized an educational trip to IIT Mumbai, Powai on 29th April ,2023.

The HOD of the Mathematics department of IIT institute set the tone for the program which was followed by the felicitation of professors from the coordinator Dr. Amjad Shaikh head, department of Mathematics.

There was a student teacher interaction in which they discussed various career opportunity related with the field of Mathematics and Computer Science. They also discussed about different entrance exams like JAM, GATE, JEE etc. The session was very interesting and motivating and had a very beautiful interaction with JAM, Phd Scholars and PG students.

The HOD of Mathematics of IIT institute U.K Anandavardhan and professors Monika Bhattacharya & Dr. Ayan Bhattacharya guided them about various scopes and career opportunity in Mathematics.

Then we got a wonderful opportunity of visiting a massive library having numbers of various kinds on books, and easily access to e-books bounded with a lot of facilities.

Dr. Amjad Shaikh, Ms. Nida Kazi and Fareen Shaikh accompanied the trip.

GEOTAGGED PHOTOS WITH CAPTIONS

Dr. Amjad Shaikh Head Department of Mathematics felicitating professor of IIT Mumbai

Professors of IIT Mumbai interacting with students

Students of Poona college giving vote of thanks

Group Photo of IIT Mumbai

Amjad Shaikh <amjad.shaikh@[illegible]>

AKI's Poona College of Arts, Science & Commerce students' visit to IIT Bombay

ananth@math.iitb.ac.in <ananth@math.iitb.ac.in> Wed, Apr [illegible], 2023 at [illegible] PM
To: Amjad Shaikh <amjad.shaikh@poonacollege.edu.in>
Cc: PRO IIT Bombay <pro@iitb.ac.in>, Head Mathematics <head.math@iitb.ac.in>

Dear Dr. Shaikh,
This is to confirm that an interaction with some faculty and students of the mathematics department can be arranged on Saturday, Apr 29th, from 11:00 a.m. to 12:30 p.m.
A copy of this email is being sent to the PRO office, whose help you will need to get permission to enter campus, as well as to arrange a possible visit to the library.
Thank you for your patience.
Best wishes,
Ananth

Ananthnarayan H.
Associate Professor
Department of Mathematics
IIT Bombay
http://www.math.iitb.ac.in/~ananth
(022) 2576 [illegible]

>> ---------- Forwarded Message ----------
>> Subject: AKI's Poona College of Arts, Science & Commerce, Pune as part
>> of their educational tour
>> Date: Mon, 13 Mar 2023 11:24:[illegible] +0530
>> From: PRO IIT Bombay <pro@iitb.ac.in>
>> To: Head Mathematics <head.math@iitb.ac.in>
>> CC: office math office <office.math@iitb.ac.in>
>>
>>
>>
>> Dear Sir,
>>
>> Is 18th March possible for a visit to the Dept of Mathematics.
>>
>> Students of AKI's Poona College of Arts, Science & Commerce, Pune have
>> expressed their wish to visit the Dept of Mathematics.
>>
>> Regards,
>>
>> --
>>
>>
>>
>> [illegible]
>>
>> Falguni Banerjee Nag
>>
>> जनसंपर्क अधिकारी
>> Public Relations Officer,
>>
>> [illegible]
>> [illegible]

Head Department of Mathematics
Anjuman Khairul Islam's
Poona College
of Arts, Science and Commerce,
Camp, Pune - 411001

Date: 19/04/2023

To,

The Principal,

Poona College of Arts, Science and Commerce,

Camp, Pune.

Subject: Permission for Educational trip to Indian Institute Technology (IIT), Powai, Mumbai.

Respected sir,

Department of Mathematics in association with Internal Quality Assurance Cell (IQAC) would like to organize one day educational trip to Indian Institute Technology (IIT), Powai, Mumbai, on 29/04/2023 for the students of F. Y/S.Y./T.Y. B.Sc. (Mathematics) and B.Sc.(CS). The objective to organize this educational trip is to help students to acquire practical knowledge about theories taught in classroom and to make aware about career opportunities in Mathematics through actual exposure to highly reputed educational institutes. I assure you that our students will observe the rules and regulations that are prescribed by IIT for the visitors and will not disturb the functioning of the institute during visit. I also arrange for necessary permission and undertaking from parents/guardian as well as from students. Therefore, I am requesting you for your kind permission of educational trip to IIT, Powai, Mumbai.

Coordinator: Dr. Amjad Shaikh

Thanking You

Forwarded

19/4/2023

Head

Department of Mathematics

Poona College of Arts, Science and Commerce

Permitted

19/4/23

PRINCIPAL

Poona College of Arts, Science & Commerce

Camp, Pune 411001

Anjuman Khairul Islam's

POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

- Affiliated to Savitribai Phule Pune University [illegible]
- UGC: 2(f) & 12 (B) Status • DST-FIST Funded College
- Government of Maharashtra and Savitribai Phule Pune University Recognized Minority College

[illegible] Road, Camp, Pune - 411001 (MS) India | +91 20 2644 [illegible] | principal@poonacollege.edu.in www.poonacollege.edu.in

+91 [illegible]
[illegible]@gmail.com

Professor Dr. Aftab Anwar Shaikh
M.Com., Ph.D. (Busi. Admin.)
PRINCIPAL

Department of Mathematics
Educational Tour to IIT, Powai, Mumbai
List of Participants

Date: 26/04/2023

Following students of F.Y./S.Y./T.Y. B.Sc./B.Sc. (CS) are visiting the one day educational tour to Indian Institute of Technology (IIT), Powai, Mumbai on 29th April 2023

Sr. No.	Name of student	Sr. No.	Name of student
1	Shaikh Iqra Zakir	17	Khan Alfiha Asif
2	Shaikh Ayesha Nazir	18	Ansari Fatima
3	Qureshi Parvez Iqbal	19	Saquib Shaikh
4	Faraaz Shaikh	20	Afrid Raju Shaikh
5	Khan Hisbah	21	Iqra Baig
6	Shaikh Fida	22	Saniya Hussain Mulani
7	Khadija Zuber Shaikh	23	Mafaaz M. Shaikh
8	Munira Khan	24	Iptisam Juber Inamdar
9	Shaikh Midhat Fatima	25	Saniya Shaikh
10	Ilma Mansoor	26	Rumana Sayyed
11	Ansari Aatiqua	27	Zaid Asif Bagwan
12	Rawoot Iqra Moosa	28	Alfiha Khan
13	Ansari Sumaiyya	29	Shaikh Shahin
14	Shaikh Raheen Raees	30	Pathan Sajeda
15	Shaikh Shoaib	31	Shaikh Aliya
16	Shaikh Zuber Ejaz	32	Siddiqui Tashkeena

List of teachers accompanied:

1) Dr. Amjad Shaikh – Coordinator (9096627503)
2) Ms. Nida Kazi
3) Ms. Fareen Shaikh

Poona College of Arts, Science & Commerce, Camp, Pune-411001

Prof (Dr.) Aftab Anwar Shaikh

Principal

PRINCIPAL
Poona College of Arts, Science & Commerce
Camp, Pune-411001
Principal Office

Anjuman Khairul Islam's
POONA COLLEGE OF ARTS, SCIENCE & COMMERCE
[illegible]
Professor (Dr.) Aftab Anwar Shaikh
PRINCIPAL

Department of Mathematics
Educational Tour to IIT, Powai, Mumbai
List of Participants

Date: 29/01/2023

Attendance Sheet (F.Y, S.Y & T.Y B.Sc)

Sr. No.	Name of student	Class	Mobile no.	Sign	Sign
1	Shaikh Iqra Zakir	F.Y.B.Sc	8623096112 8623096112		
2	Khan Hindah	F.Y.B.Sc	7058960478 9890041867		
3	Shaikh Ayesha Nazir	F.Y.B.Sc	8888425485 9226959790		
4	Shaikh Fida Lateef	F.Y.B.Sc	8208215938 7498441301		
5	Farzan Zaheer Shaikh	F.Y.B.Sc	7666306291 9850910642		
6	Qureshi Parvez Iqbal	F.Y.B.Sc	8767563922 9028137866		
7	Khatija Zuber Shaikh	S.Y.B.Sc	9022182996 7598521993		
8	Hina Mansoor	S.Y.B.Sc	9548403317 9511993971		
9	Mariya Khan	S.Y.B.Sc	7756844965 9822401134		
10	Rasool Iqra Mosai	S.Y.B.Sc	8421619718 9763153012		
11	Ansari Aaliyaa Mahammad	S.Y.B.Sc	9552294238 9423586202		
12	Asma Mujawar	S.Y.B.Sc	7498442298 9225545738		
13	Deshmukh Fiza Tarik	S.Y.B.Sc	7020827795 9011358484		
14	Qureshi Sumaa Ismail	S.Y.B.Sc	7066919369 8010080024		
15	Nikita Subhash Kakade	S.Y.B.Sc	9834042798 9552302368		
16	Shaikh Misbah Fatima	S.Y.B.Sc	7219202139 9172215991		
17	Shaikh Zaheer	S.Y.B.Sc	7558209521 9028660061		

Anjuman Khairul Islam's

POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

Professor (Dr.) Aftab Anwar Shaikh

PRINCIPAL

Department of Mathematics

Educational Tour to IIT, Powai, Mumbai

List of Participants

Date: 29/04/2023

Attendance Sheet (F.Y.B.Sc (CS) and S.Y.B.Sc(CS))

Sr. No.	Name of student	Class	Mobile no.	Sign	Sign
1	Shaikh Afiya Hamim	F.Y.B.Sc (CS)	8830798194 9973703002		
2	Shaikh Rabiya Jameel	F.Y.B.Sc (CS)	7620981953 9970364253		
3	Saniya Husain Mulani	F.Y.B.Sc (CS)	7887978560 9860836286		
4	Iqra Asad Baig	F.Y.B.Sc (CS)	8767415348 8080158627		
5	Ayaan Shaikh	F.Y.B.Sc (CS)	9511668541 8830733707		
6	Mufasir Shaikh	F.Y.B.Sc (CS)	7875002149 9096757147		
7	Wajeed Abdul Waheed	F.Y.B.Sc (CS)	7620038004 8830522342		
8	Bagwan Zaid Asif	F.Y.B.Sc (CS)	8669627863 7276699398		
9	Roman Sameer Sayyad	F.Y.B.Sc (CS)	9834111577 9637668378		
10	Afud Shaikh	F.Y.B.Sc (CS)	9545992247 9822350142		
11	Saquib Shaikh	F.Y.B.Sc (CS)	8421116749 9067129020		
12	Shaikh Afiya Rafique	S.Y.B.Sc (CS)	9860813576 9822097915		
13	Pathan Sajeda Firoz	S.Y.B.Sc (CS)	7263847894 7083313845		
14	Tasleemaz Arshad	S.Y.B.Sc (CS)	9890200878 9960385754		

Dr. Amjad Shaikh (H.O.D)

Coordinator

FILE NO. TAR/2019/[illegible]

SCIENCE & ENGINEERING RESEARCH BOARD (SERB)

(A statutory body of the Department of Science & Technology, Government of India)

5 & 5A, Lower Ground Floor
Vasant Square Mall
Plot No. A, Community Centre
Sector-B, Pocket-5, Vasant Kunj
New Delhi-110070

Dated: 25-Nov-2019

ORDER

Subject: Financial Sanction under Teachers Associateship for Research Excellence (TARE) to Dr. Parvez Abdul[illegible] Shaikh, **Poona College Of Arts Science & Commerce , Camp, Pune, Pune, Maharashtra-411001** - under the mentorship of Dr. Rupesh S Devan, at **Indian Institute of Technology, Indore Khandwa Road, Simrol, Indore - 453552** - Release of 1st grant

Sanction of Science and Engineering Research Board (SERB) is hereby accorded to the above mentioned grant at a total cost of **Rs. 18,30,000/- (Rs. Eighteen Lakh Thirty Thousand Only)** for a duration of 36 months.
The date of start of the project will be 25 November 2019. The items of expenditure for which the total allocation of Rs. 18,30,000/- has been approved are given below:
The following budget is proposed for:

Poona College Of Arts Science & Commerce , Camp, Pune, Pune, Maharashtra-411001 (Parent)

Sl. No.	Budget Head	Amount
1	Fellowship	Rs. 0 (00/- per month (consolidated))
2.	Research Grant	Rs. 220,000/- per annum
3.	Overheads	Rs. 55,000/- per annum

Indian Institute of Technology, Indore Khandwa Road, Simrol, Indore - 453552 (Host)

Sl. No.	Budget Head	Amount
1.	Fellowship	Rs. 60,000 (on completion of 90 days mandatory attendance in the host institute every year)
2	Research Grant	Rs. 150,000/- per annum
3	Overheads	Rs. 25,000/- per annum

2. Sanction of the **SERB** is also accorded to the payment of **Rs. 2,75,000/-** (Rupees Two Lakh Seventy Five Thousand only) to **Poona College Of Arts Science & Commerce, Camp, Pune**, **Rs. 3,35,000/-** (Rupees Three Lakh Thirty Five Thousand only) to **Indian Institute of Technology, Indore Khandwa Road, Simrol, Indore - 453552** being the first installment of the grant for the year 2019-2020 for implementation of the said research project.

3. The expenditure involved is debitable to:

Fund for Science & Engineering Research (FSER)

This release is being made under Teachers Associateship For Research Excellence (TARE). (Condensed Matter Physics and Materials Science)

4. The Sanction has been issued to with the approval of the competent authority vide Diary No. **SERB/F/[illegible]/2019-2020** dated **25 November, 2019**

5. Sanction of the grant is subject to the conditions as detailed in Terms & Conditions available at website (www.serb.gov.in)

6. Overhead expenses are meant for the host institute towards the cost for providing infrastructural facilities and general administrative support etc. including benefits to the staff employed in the project.

7. As per rule 211 of GFR, the accounts of project shall be open to inspection by sanctioning authority/audit whenever the institute is called upon to do so.

8. The release amount of Rs. 2,75,000/- (Rupees Two Lakh Seventy Five Thousand only) will be drawn by the Under Secretary of the SERB and will be disbursed by means of RTGS transaction as per their Bank details given below.

Poona College of Arts Science & Commerce , Camp, pune, Pune, Maharashtra-411001 (Parent Institute) :

PFMS Unique Code	PCASC
Account Name	Principal A/C Poona College UGC Grant A/c
Account Number	[illegible]
Bank Name & Branch	Bank of Maharashtra Camp Branch, Camp, Pune-411001
IFSC/RTGS Code	MAHB0000[illegible]
Email address of PI	[illegible]@gmail.com
Email id of A/C Holder	[illegible]@gmail.com
Email address of concerned officer	[illegible]

The release amount of Rs. 3,35,000/- (Rupees Three Lakh Thirty Five Thousand only) will be drawn by the Under Secretary of the SERB and will be disbursed by means of RTGS transaction as per their Bank details given below

Evaluating the Potential of Lead-Free Nontoxic Cs_2BiAgI_6-Based Double Perovskite Solar Cell

Mohamed Alla, Vishesh Manjunath, Ekta Choudhary,* Manopriya Samtham, Siddhant Sharma, Parvez A. Shaikh, Mustapha Rouchdi, and Boubker Fares*

Recently, the efficiency of single-junction perovskite solar cells has been competing with the crystalline Si solar cells. However, the perovskite absorbers are toxic and susceptible to moisture. Herein, the performance of an environmentally benign and durable Cs_2BiAgI_6 light harvester using the 1D Solar Cell Capacitance Simulator (SCAPS-1D) software package is evaluated. The primary physical parameters, namely, defect and doping densities and thickness of the subsequent layers, are varied to achieve high efficiencies. The optimized Cs_2BiAgI_6-based double perovskite solar cells with three distinct hole-transporting layers (HTLs) (i.e., MoO_x, CuSCN, and spiro-OMeTAD) deliver a power conversion efficiency of ≈29% with AZnO as electron transport layer (ETL). Further, a variety of possible rear electrodes are explored, and their effect on the performance is estimated. For real-time examination of the Cs_2BiAgI_6-based double perovskite solar cells, the variation of power conversion efficiency (PCE) concerning the operating temperature is estimated. The thickness of the Cs_2BiAgI_6 light harvester layer and the bulk defect density are the key aspects in attaining high power conversion efficiencies in Cs_2BiAgI_6-based double perovskite solar cells.

1. Introduction

Accounting from high absorption coefficient ($>10^5$ cm^{-1}),[1] long charge diffusion length (>1 μm),[2] ease of processing, low recombination rates, etc.,[3,4] the power conversion efficiency (PCE) of single-junction thin film solar cells comprising perovskite light absorbers has witnessed a quantum jump from 3.8% to 25.6%, approaching the matured crystalline silicon solar cell at 26.7%.[5] Owing to the tunability of their crystal structure and optoelectronic properties, the perovskite light harvesters can be tailored into 2D perovskites, layered double perovskites, double perovskites, etc.[6,7] Despite these advances, the high-efficiency perovskite solar cells contain carcinogenic Pb^{2+}, and the crystal structure disintegrates when exposed to moisture, hindering their real-time implementation.[8,9] Various encapsulation techniques are experimented to address the poor stability of the perovskite absorbers.[10] However, the intense direct visible light absorption in perovskites originates from filled 6s orbitals at the valence band maximum and empty 6p orbitals at the conduction band minimum of the Pb cation.[11,12] Therefore, replacing the Pb atom in the crystal structure is crucial for achieving high efficiency. Thus, initially, Pb^{2+} was substituted with Ge^{2+} or Sn^{2+} cations, but the higher energy of 4s and 5s orbitals of Ge^{2+} and Sn^{2+} cations, respectively, produce oxidation centers in the crystal structure resulting in poor stability.[13] However, lately, several nontoxic lead-free lower dimension perovskites (0D and 2D) attained by heterovalent substitution of Pb^{2+} with Bi^{3+} or Sb^{3+}, and 3D double perovskites are studied for their suitability as a light harvester.[14,15] Nevertheless, a stable and nontoxic perovskite light harvester with optoelectronic properties akin to lead-containing 3D perovskites is yet to be unraveled. Among all the Pb-free alternatives, perovskites obtained by transmutation of M^{2+} cation with a combination of monovalent and trivalent cations result in 3D double perovskite with chemical formula $A_2M'M''X_6$, where A, M′, M″, and X are monovalent cation, monovalent metal ion, trivalent metal ion, and halogen, respectively. Thus, the unit cell is doubled, and a pair of M^{2+} cations are replaced with M^+ and M^{3+} cations and form the 3D double perovskite structure, which crystallizes in the cubic crystal system with $Fm\bar{3}m$ space group.[16] Though the 3D double perovskites possess relatively high indirect bandgap, yet several approaches, namely, M^{+} site doping,[17] dilute alloying,[18] and pressure-assisted bandgap tuning,[19] can be applied to reduce the bandgap toward panchromatic absorption. Further, depending on the M′ and M″ combination, the lead-free halide double perovskite can be classified as

M. Alla, M. Rouchdi, B. Fares
STCE Energy Research Center (ERC)
Faculty of Science
Mohammed V University in Rabat
Rabat B. P. 1014, Morocco

V. Manjunath, E. Choudhary, M. Samtham, S. Sharma, P. A. Shaikh
Department of Metallurgy Engineering and Materials Science
Indian Institute of Technology Indore
Khandwa Road, Simrol 453552, India
E-mail: phd1701105002@iiti.ac.in; phd1801151011@iiti.ac.in

E. Choudhary
Department of Physics
Indian Institute of Technology Indore
Khandwa Road, Simrol 453552, India

P. A. Shaikh
Department of Physics
Poona College of Arts, Science and Commerce
Pune, Maharashtra 411001, India

The ORCID identification number(s) for the author(s) of this article can be found under https://doi.org/10.1002/pssa.202200642.

DOI: 10.1002/pssa.202200642

1) nitrogen/alkali metals (M^{+} = Sb^{3+}, Bi^{3+} and M^{+} = N^{+}, K^{+}); 2) nitrogen family/transitional metals (M^{+} = Sb^{3+} and Bi^{3+} and M^{+} = Tl^{+}, In^{+}); 3) posttransitional/noble metals (M^{+} = In^{3+}, Ga^{3+} and M^{+} = Cu^{+}, Ag^{+}); and 4) nitrogen family/noble metals (M^{+} = Sb^{3+}, Bi^{3+} and M^{+} = Cu^{+}, Ag^{+}). Unlike the AMX_3 structure, in double perovskites, there is a need to consider a specific octahedral factor for each type of octahedron. However, for the tolerance factor, the average ionic radii of the M^{+} and M^{+} sites can be used. The theoretical conditions for a stable structure are $\mu > 0.41$ and $0.75 < t < 1$. The theoretical conditions for a stable structure are $\mu > 0.41$ and $0.75 < t < 1$.[20]

Consequently, the Pb atom can be replaced with Bi and Ag heterovalent substitution to form Cs_2BiAgI_6 double perovskite crystal structures. Moreover, $Cs_2BiAgCl_6$ and $Cs_2BiAgBr_6$ double perovskites are experimentally synthesized via solid-state reactions and solution processing. Such double perovskites crystallize into elpasolite structure (symmetric face-centered cubic double perovskite) with corner-sharing octahedra, with Cs in the middle of the cubic octahedral cavity. The centers of the octahedra are either occupied by Bi or Ag, alternating in a rock salt configuration rendering isotropic carrier transport properties.[21] Additionally, the Cs_2BiAgI_6 double perovskite having a relatively low bandgap is inorganic, environmentally benign, and can provide long-term stability. On the other hand, apart from the perovskite light absorber, two carrier-selective transport layers are required to achieve effective carrier extraction at both external terminals. The optoelectronic properties of electron and hole transport layers play a crucial role in attaining high performance. Among the compatible electron transport layers (ETLs), aluminum-doped zinc oxide (AZnO) is a promising n-type wide bandgap semiconductor (3.31 eV) with high transparency and excellent optoelectronic properties.[22,23] Several industrial processes, namely, spray coating, dip coating, screen printing, bar coating, etc.,[24,25] are developed to coat large-area conformal thin films. Further, owing to better band alignment and processability, molybdenum oxide (MoO_3),[26] copper thiocyanate (CuSCN), and spiro-OMeTAD have been extensively investigated for extracting holes toward the external terminal.[26] Additionally, producing high PCE solar cells requires precise tuning of thickness, doping, and bulk defect densities of the subsequent layers.[27,28] However, experimentally tailoring these properties and achieving high performance is a myriad task. Therefore, researchers use various software packages, namely, SILVACO ATLAS, wxAMPS, finite difference time domain method, etc. All these software programs generally solve basic semiconductor second-order differential equations by applying boundary conditions at the interfaces.[29] Among all the software packages, 1D Solar Cell Capacitance Simulator (SCAPS-1D) offers multijunction and heterojunction simulations.[30,31]

This study employs the SCAPS-1D software package to model and scrutinizes perovskite solar cells with a double perovskite light harvester and three distinct hole-transporting layers (HTLs). The modeled device structure, FTO/AZnO (ETL)/Cs_2BiAgI_6/(HTLs (MoO_3 or CuSCN or spiro-OMeTAD))/rear metal contact, is shown in **Figure 1**. The Cs_2BiAgI_6-based double perovskite solar cells are optimized in terms of thickness, bulk, and doping densities, with three distinct HTLs (i.e., MoO_3, CuSCN, and spiro-OMeTAD) and AZnO as ETL. Various

Figure 1. Schematic depicting the device structure of Cs_2BiAgI_6 double perovskite solar cells considered in the present study.

possible rear electrodes are selected, and the effect on the performance of the Cs_2BiAgI_6-based double perovskite solar cells is analyzed. Further, to assess the real-time application of Cs_2BiAgI_6-based double perovskite solar cells, the performance is also evaluated concerning the change in operating temperature. The present technique used for optimization can provide guidelines for experimental implementation and can be extended to other optoelectronic devices.

2. Device Modeling and Simulation Procedure

The planar double perovskite solar cell in n–i–p configuration is modeled as FTO/AZnO (ETL)/Cs_2BiAgI_6/HTLs (MoO_3 or CuSCN or spiro-OMeTAD)/rear metal contact (Figure 1). Owing to thermal stability and chemical inertness, fluorine-doped tin oxide (FTO) layered glass substrates are employed as transparent conducting substrates. Gold (Au) is chosen as the counter electrode for all simulations except for the simulations in which the work function of the counter electrode is varied. Global AM1.5 spectrum with an irradiation intensity of 1000 $W\,m^{-2}$ is used for all simulations.

In principle, the SCAPS-1D software solves the basic semiconductor equations which dictate the charge transport in the semiconductor.[32] However, various other additional requirements are needed to realistically simulate polycrystalline thin solar cells. Therefore, along with these semiconductor equations, SCPAS offers grading of all input parameters, namely, the type of recombination, defect levels (bulk and interfacial), charge type idealization, charge type (donor or acceptor), and valency (monovalent, divalent, or multivalent)), defect level distribution (Gaussian, single level, uniform, or combinations), optical properties (direct excitation of light), and contact properties (flat band or work function). Voltage, frequency, and operating temperature can also be controlled to perform reasonable computations. Therefore, the three underlying equations that regulate the carrier transport in semiconductors are listed below.

Poisson Equation (Equation (1))

$$\frac{d\varepsilon}{dx} = -\frac{d^2\Psi}{dx^2} = \frac{q}{\varepsilon}\left[p(x) - n(x) + N_D^+(x) - N_A^- + p_t(x) - n_t(x)\right] \tag{1}$$

where Ψ represents the electrostatic potential, q is the charge of an electron, ε denotes the dielectric constant of the material, p is the concentration of holes, n is the concentration of electrons, N_A^- indicates ionized acceptor density, N_D^+ signifies ionized donor density, n_t and p_t represent electron and hole traps, respectively, and x is the position coordinate.

Electron (Equation (2)) and hole (Equation 3) continuity equations

$$\frac{dn_p}{dt} = G_n - \frac{n_p - n_{p0}}{\tau_n} + n_p\mu_n\frac{dE}{dx} + \mu_n E\frac{dn_p}{dx} + D_n\frac{d^2 n_p}{dx^2} \tag{2}$$

$$\frac{dp_n}{dt} = G_p - \frac{p_n - p_{n0}}{\tau_p} + p_n\mu_p\frac{dE}{dx} + \mu_p E\frac{dp_n}{dx} + D_p\frac{d^2 p_n}{dx^2} \tag{3}$$

where G_p and G_n represent generation rates of hole and electron, p_n and n_p denote concentrations of hole and electron in the n and p region, respectively, p_{n0} and n_{p0} indicate equilibrium concentrations of hole and electron in the n and p region, respectively, τ_p and τ_n represent a lifetime of hole and electron, μ_p and μ_n denote the mobilities of hole and electron, E signifies the electric field, and D_p and D_n indicate the diffusion coefficient of holes and electrons. The carrier transport happening due to drift and diffusion for electrons (Equation (4)) and holes (Equation (5)) is expressed as

$$J_n(x) = qn\mu_n E + qD_n\frac{dn}{dx} = n\mu_n\frac{dE_{Fn}}{dx} \tag{4}$$

$$J_p(x) = qp\mu_p E - qD_p\frac{dp}{dx} = p\mu_p\frac{dE_{Fp}}{dx} \tag{5}$$

where E_{Fp} and E_{Fn} denote the hole's and electron's quasi Fermi levels. The physical and defect parameters used in the simulation of PSCs are tabulated in **Table 1**. Further, the series and shunt resistances are $5\,\Omega\,cm^{-2}$ and $1\,k\Omega\,cm^{-2}$, respectively.

3. Results and Discussion

The AZnO film is considered ETL in the present modeling. The AZnO accomplishes the following functionalities: 1) serves as the template for perovskite overlayer, 2) blinds UV radiation from striking the double perovskite over layer, 3) blocks hole transport, and 4) aids in dissociation of electron–hole pairs at the AZnO/double perovskite interface. Therefore, it is essential to optimize the thickness and donor doping density of the AZnO ETL. Experimentally, there are several scalable techniques to synthesize large area conformal AZnO thin films. Thus, the thickness of AZnO is varied from 30 to 180 nm, as shown in **Figure 2**a. Increasing thickness beyond 180 nm may lead to parasitic optical losses. Though the thickness of AZnO film is varied from 30 to 180 nm, the PCE remained constant (≈29.57%), originating from unaltered open-circuit voltage (V_{OC}) and short-circuit current density (J_{SC}). However, a minute variation in fill factor (FF) with increasing thickness of the AZnO can be ascribed to a minor increase in series resistance in the thicker AZnO films. Further, the donor doping density in the AZnO ETL is varied from 10^{15} to 10^{19} cm^{-3}, as shown in Figure 2b. With increasing donor doping concentration in AZnO ETL, the PCE and V_{OC} of the double perovskite solar cell remained constant. Marginal increase in the J_{SC} and decrease in FF at higher doping can be ascribed to an increase in carrier conductivity in the AZnO

Table 1. The physical parameters used as input to examine and optimize solar cells.

Parameters	FTO	AZnO	Cs_2BiAgI_6	Spiro-OMeTAD	CuSCN	MoO_3
Thickness [µm]	0.1	0.02[a]	0.50[a]	0.10[a]	0.03[a]	0.03[a]
Bandgap E_g [eV]	3.5	3.23	1.6	2.88	3.6	3.0
Electron affinity χ [eV]	4	4.33	3.90	2.05	1.7	2.2
Dielectric permittivity (relative)	9	8.12	6.5	3.0	10.0	12.5
Effective density of states in CB N_c [cm^{-3}]	2.2×10^{18}	4.1×10^{18}	1×10^{19}	2.2×10^{18}	2.2×10^{19}	2.2×10^{18}
Effective density of states in VB N_v [cm^{-3}]	1.8×10^{19}	8.2×10^{18}	1×10^{19}	1.8×10^{19}	1.8×10^{18}	1.8×10^{19}
Velocity of electrons (thermal) $V_{th,n}$ [cm s^{-1}]	1×10^7	1×10^7	1×10^7	1×10^7	1×10^7	1×10^7
Velocity of holes (thermal) $V_{th,p}$ [cm s^{-1}]	1×10^7	1×10^7	1×10^7	1×10^7	1×10^7	1×10^7
Mobility of electrons μ_n [cm^2 V^{-1} s^{-1}]	20	100	200	2×10^{-4}	100	25
Mobility of holes μ_p [cm^2 V^{-1} s^{-1}]	10	25	2	2×10^{-4}	2.5×10^{-3}	100
Shallow uniform donor density N_D [cm^{-3}]	2.1×10^{19}	$1 \times 10^{19[a,b]}$	0	0	0	0
Shallow uniform acceptor density N_A [cm^{-3}]	0	0	1×10^{15}	$1 \times 10^{18[a,b]}$	$1 \times 10^{18[a,b]}$	$1 \times 10^{18[a,b]}$
Density of defect N_t [cm^{-3}]	1×10^{15}	1×10^{15}	$1 \times 10^{15[a,b]}$	1×10^{15}	1×10^{15}	1×10^{15}
Reference	[33]	[34]	[35]	[36]	[38]	[40]

[a]The parameters used in the present study.

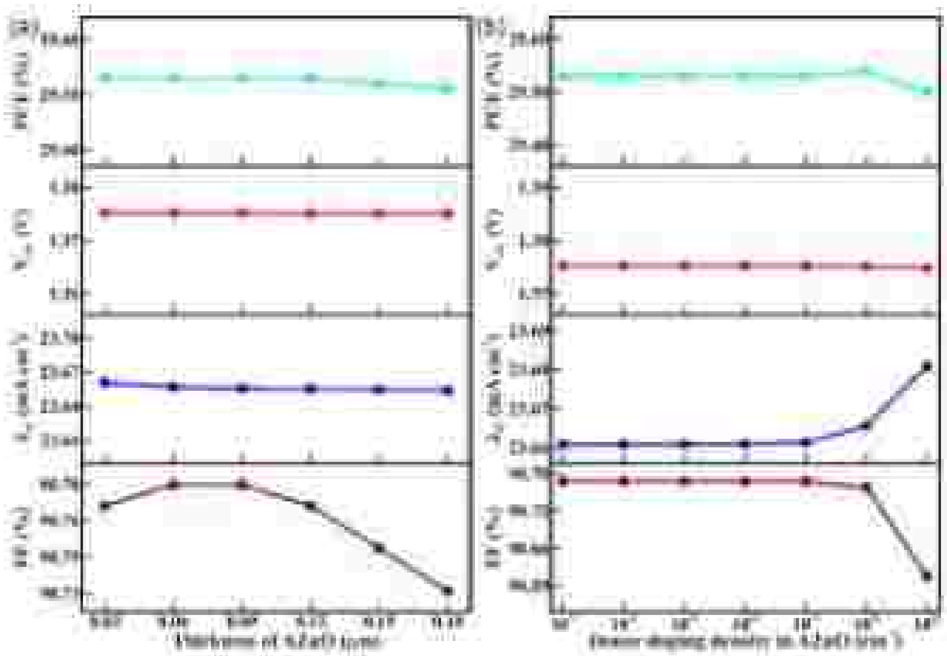

Figure 2. a) Thickness and b) donor doping density of AZnO layer-related deviation of solar cell parameters (with other parameters as tabulated in Table 1).

films. These results indicate that the Cs_2BiAgI_6 double perovskite-based solar cells are independent of the thickness and donor doping density in the AZnO ETL.

Furthermore, the thickness of the Cs_2BiAgI_6 double perovskite light harvester is varied from 100 to 900 nm, as shown in Figure 3a. As the thickness of the Cs_2BiAgI_6 double perovskite increases, the corresponding rise in the PCE of the Cs_2BiAgI_6 double perovskite-based solar cells increases, owing to the rise in J_{SC} resulting from higher photogeneration in the thicker Cs_2BiAgI_6 films. At the thickness of 900 nm, the Cs_2BiAgI_6 double perovskite-based solar cell delivers a PCE of ≈30%. The marginal decrease in V_{OC} and FF in thicker Cs_2BiAgI_6 films can be ascribed to higher recombination and a minor rise in series resistance, respectively. Besides the thickness, experimentally, the bulk defect density of the Cs_2BiAgI_6 double perovskite harvester varies depending on the synthesis protocol. The bulk defect density in the Cs_2BiAgI_6 double perovskite is varied from 10^{14} to 10^{18} cm^{-3}, as shown in Figure 3b. As the bulk defect density rises, a steady decrease in the PCE is observed (PCE declines from ≈29% to ≈16% when bulk defect density increases from 10^{14} to 10^{18} cm^{-3}), owing to the corresponding decline in the V_{OC}, J_{SC}, and FF. The decline in V_{OC}, J_{SC}, and FF can be associated to change in Fermi level, trap-assisted recombination, and an increase in resistance, respectively, in Cs_2BiAgI_6 films with high bulk defect density. These results illustrate the thickness and bulk defect density in the Cs_2BiAgI_6 double perovskite absorber plays a crucial role in achieving high performance.

To understand the effect of HTL thickness on the performance of Cs_2BiAgI_6 double perovskite solar cells, the thickness of HTL is varied from 30 to 180 nm (Figure 4a). Similar to the thickness of the ETL, the increase in thickness of the HTLs did not affect all the solar cell parameters. However, depending on the type of HTL, the PCE varied independently. Cs_2BiAgI_6 double perovskite solar cells with MoO_3 as HTL showed the highest efficiency of ≈29.53%, followed by CuSCN (≈29.37%) and spiro-OmeTAD (≈29.22%). Further, upon increasing the acceptor doping density from 10^{17} to 10^{19} cm^{-3}, the PCE and all other solar cell parameters remained constant for MoO_3 and CuSCN HTLs (Figure 4b). However, at higher doping concentrations, an increase in PCE of the Cs_2BiAgI_6 double perovskite solar cell with spiro-OMeTAD HTL is observed, ascribed to the rise in the FF of the solar cells. The increase in FF is associated with lower resistance in highly doped spiro-OMeTAD films.

The interfacial properties between the subsequent layers in the perovskite solar cells are crucial in achieving better performance.[13,14] Thus, the interfacial defect density at AZnO/perovskite and perovskite/MoO_3 is varied from 10^{10} to 10^{18} cm^{-3}, as shown in Figure 5a,b, respectively. As the interfacial defect density at AZnO/perovskite interface is increased from 10^{10} to 10^{18} cm^{-3}, the PCE steadily declines from ≈21% to 12%. This decline in PCE can be ascribed to a decrease in the V_{OC} and FF of the solar cells. However, the J_{SC} remains constant, but the V_{OC} and FF decrease due to interfacial losses originating change in band offset developed at the AZnO/perovskite interface. Conversely, when the defect density at the perovskite/MoO_3 is increased up to 10^{13} cm^{-3}, the PCE remains constant, indicating high defect tolerance of the perovskite/MoO_3 interface. Further, when the defect density increases beyond 10^{13} cm^{-3}, the PCE decreases owing to the decrease in J_{SC}. The decline in J_{SC} is attributed to the defect-assisted recombination losses at the perovskite/HTL interface.

Various rear contacts possessing distinct work functions are assessed for their applicability in Cs_2BiAgI_6-based double perovskite solar cells, as shown in Figure 6. However, the chemical

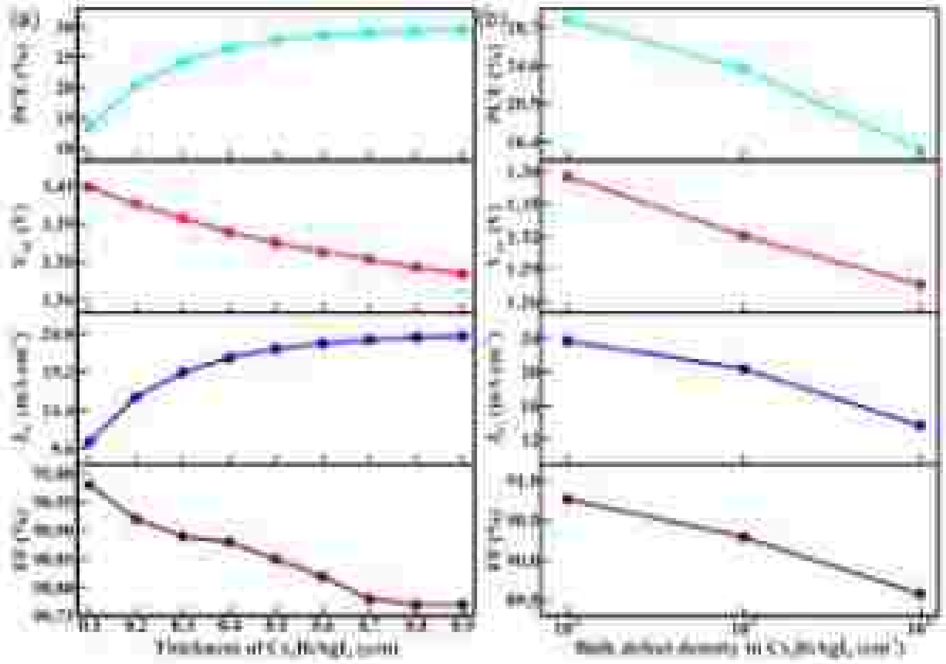

Figure 3. a) Thickness and b) bulk defect density of Cs_2BiAgI_6 double perovskite absorber-related deviation of solar cell parameters (with other parameters as tabulated in Table 1).

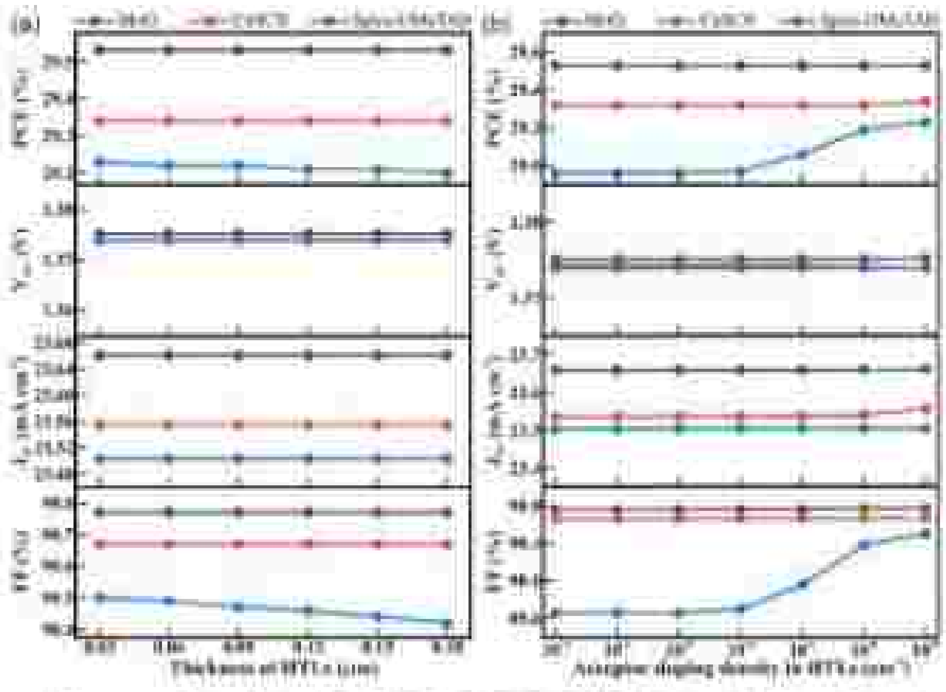

Figure 4. a) Thickness and b) acceptor doping density of HTL (MoO_3/CuSCN/Spiro-OMeTAD)-related deviation of solar cell parameters (with other parameters as tabulated in Table 1).

reactivity, conductivity, and processing directly influence the cost and performance of solar cells.[77] The work function of the rear contact directly impacts the performance of the solar cells. The PCE of the Cs_2BiAgI_6-based double perovskite solar cells increased with increasing the work function of the rear metal contact up to 5 eV. However, employing rear contacts having a work function beyond 5 eV had a minor change in the PCE. These results indicate even cost-effective carbon as counter electrodes can deliver ≈29% PCE.

Understanding the effect of operating temperature on the performance of solar cells is essential for real-time implementations.[78,79] Thus, the influence of operating temperature is

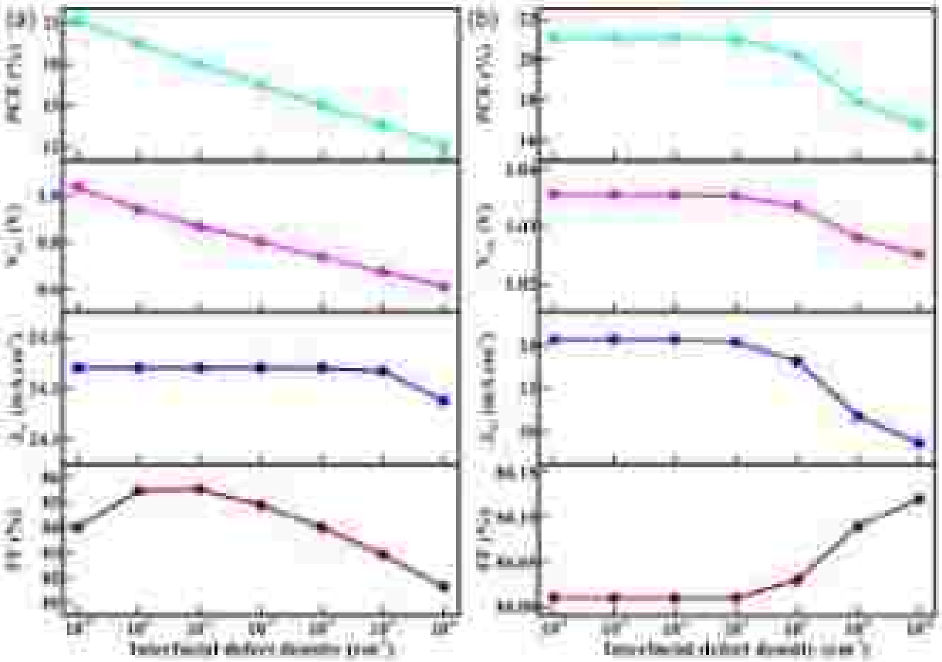

Figure 5. The solar cell parameter variation associated with the interfacial defect density changes at a) ETL/perovskite and perovskite/HTL interface.

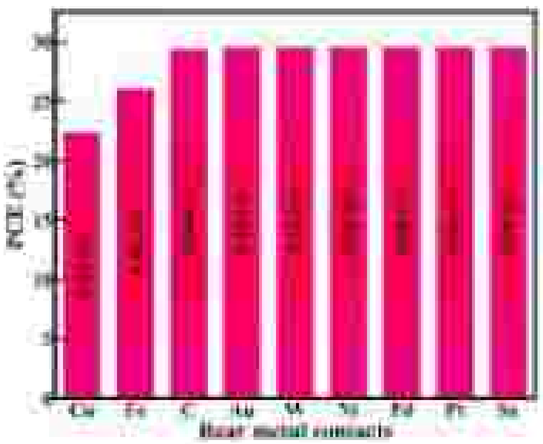

Figure 6. Contact electrode-related deviation in PCE (with other parameters as tabulated in Table 1).

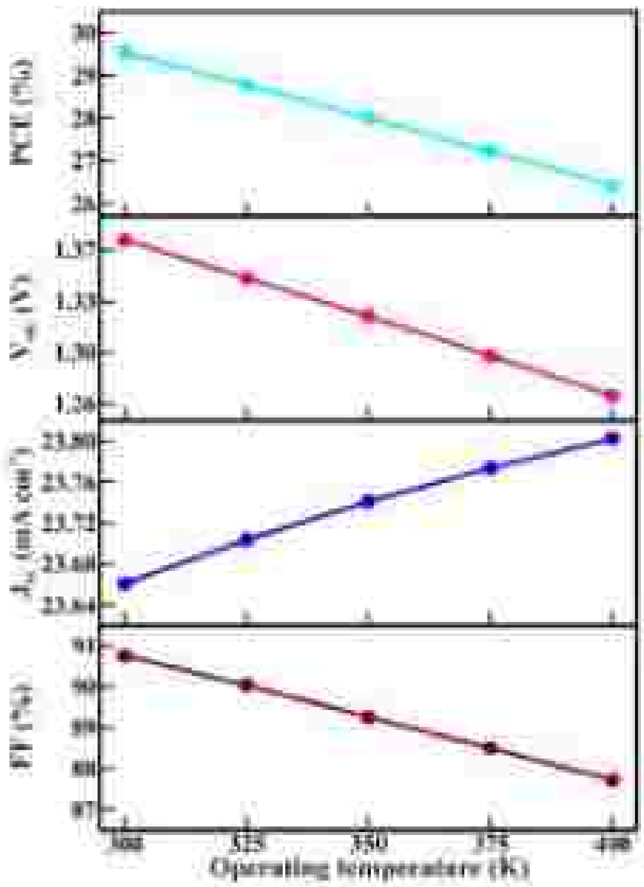

Figure 7. Operating temperature-related deviation solar cell parameters (with other parameters as tabulated in Table 1).

analyzed for temperatures ranging from 300 to 400 K, as shown in Figure 7. As the operating temperature rises from 300 to 400 K, a steady decline in the PCE is observed due to the reduction in V_{OC} and FF. The V_{OC} reduces due to an increment in the reverse saturation current in the Cs_2BiAgI_6 based double perovskite solar cell. However, the increase in J_{SC}, with an increase in the operating temperature, can be attributed to the thermal generation of electrons. Conversely, it is to be noted that, even when the operating temperature shoots to 400 K, the Cs_2BiAgI_6 based double perovskite solar cell delivered a PCE of ≈26%.

Evaluating the spectral response of the solar cells is essential in understanding the incident photon to electron conversion

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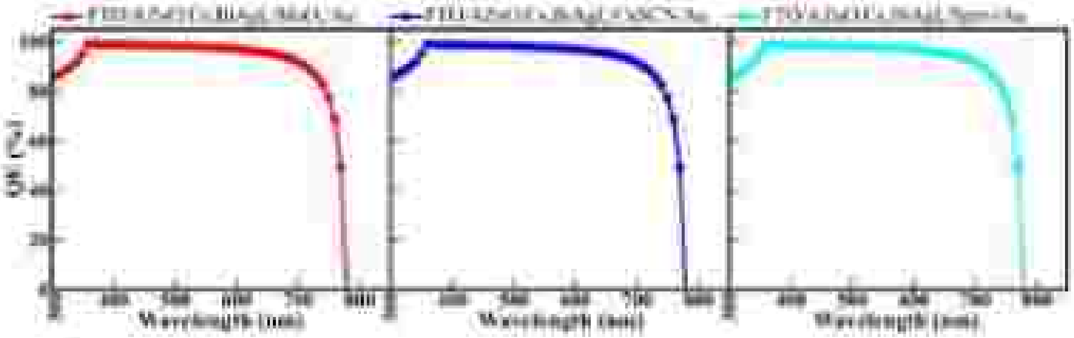

Figure 8. Quantum efficiency curves for the Cs_2BiAgI_6-based double perovskite solar cells comprising various HTLs (MoO_3/CuSCN/Spiro-OMeTAD).

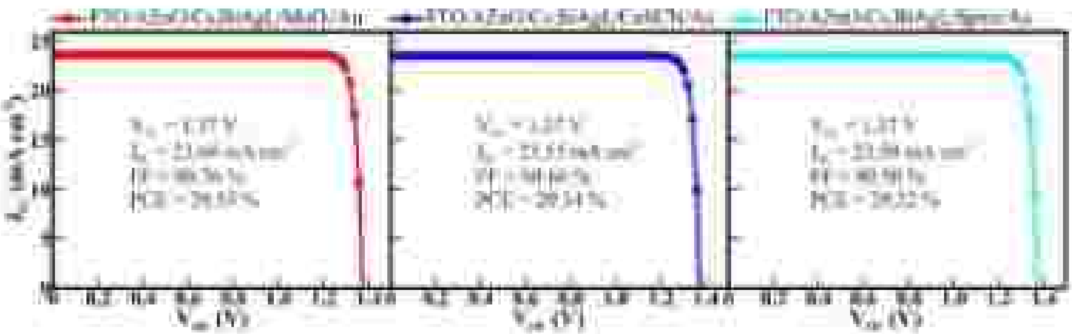

Figure 9. J–V curves for the Cs_2BiAgI_6-based double perovskite solar cells comprising various HTLs (MoO_3/CuSCN/Spiro-OMeTAD).

efficiency or quantum efficiency. The quantum efficiency of the Cs_2BiAgI_6-based double perovskite solar cells is shown in **Figure 8**. Cs_2BiAgI_6-based double perovskite solar cells with different HTLs showed a broad absorption in the complete visible range (300–800 nm). Further, the J–V curves of Cs_2BiAgI_6-based double perovskite solar cells with different HTLs are shown in **Figure 9**. The optimum solar cell parameters evaluated for all Cs_2BiAgI_6-based solar cells show high efficiency of ≈29%. The solar cells show V_{OC}, J_{SC}, and FF in the range of ≈1.37 V, ≈23 mA cm^{-2}, and ≈90%, respectively.

4. Conclusion

In conclusion, the theoretical potential of the Cs_2BiAgI_6 double perovskite light harvester is evaluated using the SCAPS-1D software package. Cs_2BiAgI_6 light harvesters are environmentally benign and render long term stability. The high efficiency solar cells are optimized based on the AZnO ETL and three different HTLs. Solar cells based on all three HTLs at optimized conditions delivered PCEs ≈29%. Compared to all the physical parameters varied in the optimization, the thickness and bulk defect density of the Cs_2BiAgI_6 double perovskite light harvester had the highest control over performance. The cheap and economical carbon electrodes could deliver a PCE of ≈29% in the modeled Cs_2BiAgI_6-based double perovskite solar cells. Further, even when the operating temperature shoots up to 400 K, the Cs_2BiAgI_6-based double perovskite solar cells delivered a PCE of ≈26%. Therefore, while experimentally fabricating Cs_2BiAgI_6 double perovskite solar cells, it should be noted that Cs_2BiAgI_6 perovskite is unstable. Hence, it is imperative to produce films with very low bulk defect density and prefer a practical rear contact. The present preliminary analysis accurately illustrates the factors which govern the PCE of Cs_2BiAgI_6 solar cells. The procedure employed in this assessment can provide guidelines for experimental implementation and be further expanded to examine additional light harvesters for optoelectronic applications.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Keywords

Cs_2BiAgI_6, double perovskite, lead-free, 1D Solar Cell Capacitance Simulator (SCAPS-1D), simulation, solar cells

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[1] T. Baikie, Y. Fang, J. M. Kadro, M. Schreyer, F. Wei, S. G. Mhaisalkar, M. Graetzel, T. J. White, *J. Mater. Chem. A* **2013**, *1*, 5628.
[2] M. M. Lee, J. Teuscher, T. Miyasaka, T. N. Murakami, H. J. Snaith, *Science* **2012**, *338*, 643.
[3] H. S. Jung, N.-G. Park, *Small* **2015**, *11*, 10.
[4] V. Manjunath, S. Bimli, P. Shaikh, S. Ogale, R. S. Devan, *J. Mater. Chem. C* **2022**, *10*, 15725.
[5] J. Jeong, M. Kim, J. Seo, H. Z. Lu, P. Ahlawat, A. Mishra, Y. G. Yang, M. A. Hope, F. T. Eickemeyer, M. Kim, Y. J. Yoon, I. W. Choi, B. P. Darwich, S. J. Choi, Y. Jo, J. H. Lee, B. Walker, S. M. Zakeeruddin, L. Emsley, U. Rothlisberger, A. Hagfeldt, D. S. Kim, M. Gratzel, J. Y. Kim, *Nature* **2021**, *592*, 381.
[6] S. Chand Yadav, A. Srivastava, V. Manjunath, A. Kanwade, R. S. Devan, P. M. Shirage, *Mater. Today Phys.* **2022**, *26*, 100731.
[7] H. Kim, K. A. Huynh, S. Y. Kim, Q. V. Le, H. W. Jang, *Phys. Status Solidi RRL* **2020**, *14*, 1900435.
[8] M. M. Tavakoli, Z. Fazel, R. Tavakoli, S. Akin, S. Satapathi, D. Prochowicz, P. Yadav, *Sol. RRL* **2022**, *6*, 2200106.
[9] V. Manjunath, P. K. Mishra, R. Dobhal, S. Bimli, P. M. Shirage, S. Sen, P. A. Shaikh, R. S. Devan, *ACS Appl. Electron. Mater.* **2021**, *3*, 4548.
[10] S. Ma, Y. Bai, H. Wang, H. C. Zai, J. F. Wu, L. Li, S. S. Xiang, N. Liu, L. Liu, C. Zhu, G. L. Liu, X. X. Niu, H. N. Chen, H. P. Zhou, Y. J. Li, Q. Chen, *Adv. Energy Mater.* **2020**, *10*, 1902472.
[11] A. H. Slavney, T. Hu, A. M. Lindenberg, H. I. Karunadasa, *J. Am. Chem. Soc.* **2016**, *138*, 2138.
[12] S. C. Yadav, V. Manjunath, A. Srivastava, R. S. Devan, P. M. Shirage, *Opt. Mater.* **2022**, *132*, 112676.
[13] Z. W. Xiao, W. W. Meng, J. B. Wang, Y. F. Yan, *ChemSusChem* **2016**, *9*, 2628.
[14] X. B. Kong, F. Q. Wu, F. Xu, S. K. Yang, B. Q. Cao, *Phys. Status Solidi RRL* **2021**, *15*, 2100134.
[15] Q. H. Chen, K.-M. Deng, Y. Shen, L. Li, *InfoMat* **2022**, *4*, e12303.
[16] J. N. Li, X. H. Meng, Z. H. Wu, Y. Y. Duan, R. X. Guo, W. D. Xiao, Y. S. Zhang, Y. K. Li, Y. L. Shen, W. Zhang, G. S. Shao, *Adv. Funct. Mater.* **2022**, *32*, 2112991.
[17] K. Z. Du, W. W. Meng, X. M. Wang, Y. F. Yan, D. B. Mitzi, *Angew. Chem., Int. Ed.* **2017**, *56*, 8158.
[18] A. H. Slavney, L. Leppert, D. Bartesaghi, A. Gold-Parker, M. F. Toney, T. J. Savenije, J. B. Neaton, H. I. Karunadasa, *J. Am. Chem. Soc.* **2017**, *139*, 5015.
[19] Q. Li, Y. G. Wang, W. C. Pan, W. G. Yang, B. Zou, J. Tang, Z. W. Quan, *Angew. Chem., Int. Ed.* **2017**, *56*, 15969.
[20] X. G. Zhao, D. Yang, J. C. Ren, Y. Sun, Z. Xiao, L. Zhang, *Joule* **2018**, *2*, 1662.
[21] M. R. Filip, S. Hillman, A. A. Haghighirad, H. J. Snaith, F. Giustino, *J. Phys. Chem. Lett.* **2016**, *7*, 2579.
[22] X. Y. Zhao, H. P. Shen, Y. Zhang, X. Li, X. C. Zhao, M. Q. Tai, J. F. Li, J. B. Li, X. Li, H. Lin, *ACS Appl. Mater. Interfaces* **2016**, *8*, 7826.
[23] J. Kruszynska, J. Ostapko, V. Ozkaya, B. Surucu, O. Szawcow, K. Nikiforow, M. Holdynski, M. M. Tavakoli, P. Yadav, M. Kot, G. P. Kolodziej, M. Wlazlo, S. Satapathi, S. Akin, D. Prochowicz, *Adv. Mater. Interfaces* **2022**, *9*, 2200575.
[24] S. Mandal, K. B. Dileep, G. Veerappan, E. Ramasamy, *Solar Energy* **2022**, *240*, 258.
[25] S. Maniarasu, M. K. Rajbhar, R. K. Dileep, E. Ramasamy, G. Veerappan, *Mater. Lett.* **2019**, *245*, 226.
[26] S. Sen, K. Bikas, J. S. Nam, A. Shawky, H. S. Lin, H. Nagaya, E. I. Kauppinen, R. Xiang, Y. Matsuo, I. Jeon, S. Maruyama, *Adv. Mater. Interfaces* **2022**, *9*, 2101311.
[27] V. Manjunath, S. Bimli, K. H. Parmar, P. M. Shirage, R. S. Devan, *Sol. Energy* **2019**, *193*, 387.
[28] V. Karthikeyan, S. Maniarasu, V. Manjunath, E. Ramasamy, G. Veerappan, *Sol. Energy* **2017**, *147*, 202.
[29] V. Manjunath, Y. K. Reddy, S. Bimli, R. J. Choudhary, R. S. Devan, *Mater. Today Commun.* **2022**, *32*, 104061.
[30] M. Alla, V. Manjunath, N. Chawki, D. Singh, S. C. Yadav, M. Rouchdi, F. Boubker, *Opt. Mater.* **2022**, *124*, 112044.
[31] M. Mottakin, K. Sobayel, D. C. Ismail, M. Shahiduzzaman, G. Muhammad, M. A. Ibrahim, M. Akhtaruzzaman, E. S. Hossain, *Phys. Status Solidi RRL* **2022**, *16*, 2200314.
[32] M. Alla, S. Bimli, V. Manjunath, M. Samiksha, A. Kassaoui, E. Choudhary, M. Rouchdi, F. Boubker, *Mater. Technol.* **2022**, *37*, 2963.
[33] D. K. Sarkar, A. K. M. Hasan, M. Mottakin, V. Selvanathan, K. Sobayel, M. A. Islam, G. Muhammad, M. Aminuzzaman, M. Shahiduzzaman, K. Sopian, M. Akhtaruzzaman, *Sol. Energy* **2022**, *243*, 275.
[34] K. Sobayel, M. Shahinuzzaman, N. Amin, M. R. Karim, M. A. Dar, R. Gul, M. A. Alghoul, K. Sopian, A. K. M. Hasan, M. Akhtaruzzaman, *Sol. Energy* **2020**, *207*, 479.
[35] Y. K. Reddy, V. Manjunath, S. Bimli, R. S. Devan, *Sol. Energy* **2022**, *244*, 75.
[36] I. Mosquera, L. Andrade, A. Mendes, *ChemSusChem* **2019**, *12*, 2186.
[37] F. Hanjun, M. Mallemgu, *Phys. Status Solidi RRL* **2021**, *15*, 2100211.
[38] A. Ait Abdelkadir, E. Oublal, M. Sahal, A. Gibaud, *Results Opt.* **2022**, *8*, 100257.
[39] S. Srivastava, A. K. Singh, P. Kumar, B. Pradhan, *J. Appl. Phys.* **2022**, *131*, 175001.
[40] S. Ahmed, F. Jannat, M. A. K. Khan, M. A. Alim, *Optik* **2021**, *225*, 165765.

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REVIEW

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Understanding the role of inorganic carrier transport layer materials and interfaces in emerging perovskite solar cells

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In the last decade, organic–inorganic hybrid and metal halide perovskite materials have shown tremendous tunability properties and capacity to harvest solar energy efficiently via conceptually new solar cell architectures. Presently, third-generation thin-film solar cells employing perovskite light absorbers produce a power conversion efficiency of ~25%, which is attributed to their exceptionally unique and device-worthy optoelectronic properties. Although the perovskite light absorbers play a main role in the harvesting process, the corresponding device architectures must contain either blocking layers such as electron and hole transport layers, which are crucial for the efficient and stable electronic functioning of the solar cell. Thus, understanding the functional significance of these transport layers and synergistically optimizing them with respect to the perovskite light absorbers is highly significant for further developments in this arena. Therefore, this review focuses and critically analyses the electron and hole transport layers used in perovskite solar cells, highlighting their functional significance and critical role. Their functionality basically originates from their crystal structure, chemistry, electronic and optical properties, and compatibility with the corresponding synthesis protocols of perovskites. Overall, this work aims at developing a comparative analysis and enhanced understanding of the transport of photogenerated charges across the active interfaces in the perovskite solar cells.

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1. Introduction

Renewable energy has shown great promise to combat the emerging energy demand globally, with its contribution to the energy sector increasing fairly rapidly. Among the renewable energy resources and their harvesting approaches, solar energy conversion into electrical energy has shown excellent promise towards sustainable development. Solar cells are devices that convert incoming light energy into usable electrical energy. Although a myriad of efforts has been undertaken in the past 30 years to achieve a high power conversion efficiency (PCE) through different solar cell designs and architectures, a knowledge gap still persists in the comprehensive understanding of how different material interfaces can affect the overall advancement of solar cell technology.

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Silicon-based solar cells are one of the earliest solar cells making use of crystalline silicon with a bandgap of 1.11 eV, which is well-positioned in the optimum range for broadband light absorption. At present, first-generation silicon solar cells continue to dominate this field, with significant progress being made towards a high photovoltaic conversion efficiency (PCE) due to the developed purification and fabrication technology and earth abundance of the required materials. Recently, the greater supply than demand has also reduced the costs of other materials, and thus the corresponding improved yields have reduced the projected price of photovoltaic technology. Moreover, over the years, various materials such as amorphous-Si, GaAs, CdTe/Se, PbSe/S, CIGS, and CZTS have been successfully deposited and optimized into thin films with required thickness and quality and are used as absorbers in second-generation solar cells to further address and combat related problems. The advantages of these second-generation solar cells include their low production cost, flexibility, and lightweightness.

During the last few decades, third-generation solar cells based on nanocrystals, polymers, sensitized dyes, organic–inorganic and inorganic halide perovskites have shown tremendous progress bringing a high degree of novelty and versatility in both the design of new materials and solar cell architectures. Specifically, the emerging perovskite solar cells (PSCs) have gained enormous interest in the last decade with the corresponding conversion efficiency (~25%) competing with their first-generation silicon counterparts. Also, the newly introduced perovskite/Si tandem cells have already delivered a remarkable efficiency of 29.5% (refer to the NREL website for more details).

Hybrid perovskites are molecularly assembled organic–inorganic compounds that absorb incoming light energy efficiently across a significant portion of the solar spectrum. They can be highly tuned to generate various desirable optical and

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optoelectronic properties. These organic–inorganic perovskite materials form the ABX_3 structure, where A represents an organic cation ($CH_3NH_3^+$, Cs^+, *etc.*), B represents a divalent metal (Pb^{2+}, Sn^{2+}, *etc.*) and X is a halogen (Cl^-, I^-, and Br^-). The size of these three ions is strictly confined by the tolerance factor (*t*) for a stable perovskite structure.[28] Moreover, the perovskite light absorbers possess a high absorption coefficient in the visible region (∼350 to 800 nm), high extinction coefficient (∼10^4 cm^{-1} at 550 nm), long charge diffusion lengths, and ease of processing, which have led to the fabrication of low-cost PSCs at room temperature consuming a lower amount of material.[29] These intrinsic properties of perovskite light absorbers can be tailored to meet the requirements by merely substituting the ions in perovskite materials.[30] However, compared to the perovskite light absorbers, the transport layers are equally important in the solar cell design to render high efficiency and stability.

Two different carrier-selective transport layers are required to achieve effective carrier extraction at both external terminals. These transport layers preferably perform selective charge carrier extraction (*i.e.*, n-type or p-type) by blocking the transport of the other (*i.e.*, p-type or n-type). The deposition of a p or n type transport layer on the light exposure side of the solar cell first, followed by an intrinsic layer results in the device configuration of the conventional negative–intrinsic–positive (n–i–p) and inverted positive–intrinsic–negative (p–i–n). Theoretically, both the (n–i–p) and (p–i–n) device architectures should give the same efficiency, but they differ due to their optical properties, transmittance in the UV-Vis-NIR region, material compatibility, and formation of an ohmic contact with the transparent side of the electrode. Additionally, the investigation of an inverted (p–i–n) architecture that alters optical behaviour was reported in the literature.[31] Generally, the recombination process involves both types of carriers present within the proximity of the charge diffusion pathway, where the extraction of particular types of charge carriers at different ends will reduce their recombination. However, various other qualities such as high conductivity for selected carrier types, reduction of the unfavourable effect at the interfaces, closely matching mobilities of the charge carriers across the interface and tuning of the bandgap for smooth charge transfer of the interfacial charge carrier-type selective transport layers contribute to the realization of high efficiency in PSCs.

In this review, we critically discuss and compare different possible inorganic transport layers (electrons and holes) mainly used for the PSCs. The functionalities, properties, and requirements of these transport layers to achieve efficient PSCs are the main focus. We primarily present, analyse, and discuss the developments pertaining to highly efficient inorganic electron transport layers (ETLs) composed of TiO_2, SnO_2, ZnO, and ternary metal oxides and hole transport layers (HTLs) composed of NiO_x, VO_x, CoO_x, CuO, CuI, and CuSCN. Further, the effect of the physical, chemical, and photoelectrical properties of these widely used inorganic transport layers on the performance of PSCs is discussed in depth. Finally, we also include a brief section on the most extensively used organic transport layers towards the end of this review article.

2. Importance of transport layers

The transport layers in PSCs perform specific functions similar to that in dye-sensitized solar cells (DSSCs) (Fig. 1). However, the term 'division of labour' has been widely used to understand the functionalities of each component in PSCs,[32] which include (i) perovskite light absorber: absorbs the majority of the solar spectrum and creates electron–hole pairs, (ii) transport layers: selectively dissociate the excitons generated in the light absorber, and (iii) electrodes: establish an electronic high-quality interface between the device and the external circuit with minimal resistance. Accordingly, the systematic synchronization of these basic components in terms of optical, chemical, structural, and electronic properties leads to a high performance in PSCs. The range of coverage, uniformity, and thickness of the transport layers depend on the employed coating technique. Notably, the interface at the transport layer/perovskite absorber plays a crucial role in the overall device performance. Depending on the structure of the employed transport layers, PSCs are classified into planar and mesoporous device architectures (Fig. 2). Theoretically, the device architecture with a larger charge diffusion length (L_d) than the thickness of the perovskite absorber (*t*) (*i.e.*, $L_d > t$) is identified as a planar device architecture, which is the opposite to the mesoscopic device architecture (*i.e.*, $L_d < t$). This structure is further divided into two configurations, namely,

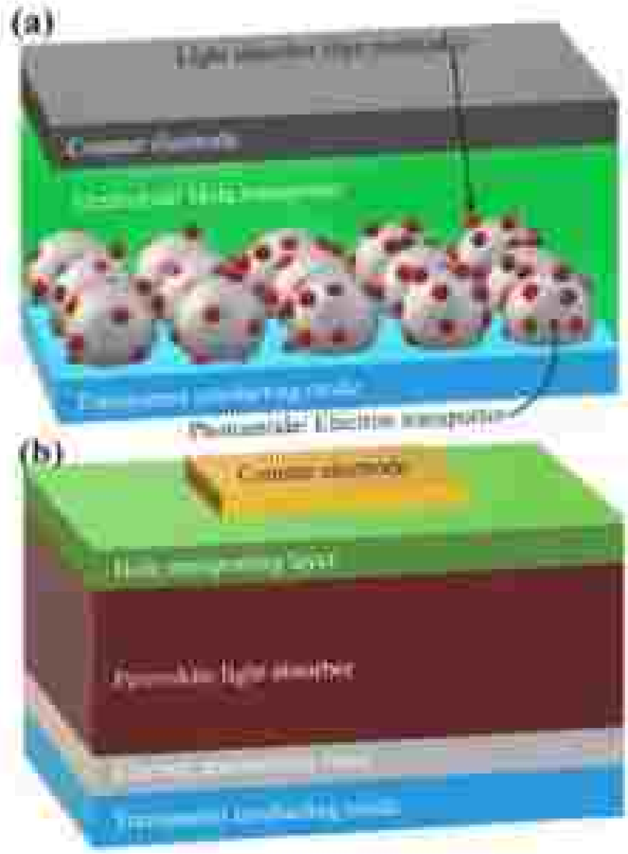

Fig. 1 Schematic representation of (a) dye-sensitized solar cell (*i.e.*, DSSC) and (b) perovskite solar cells (*i.e.*, PSC).

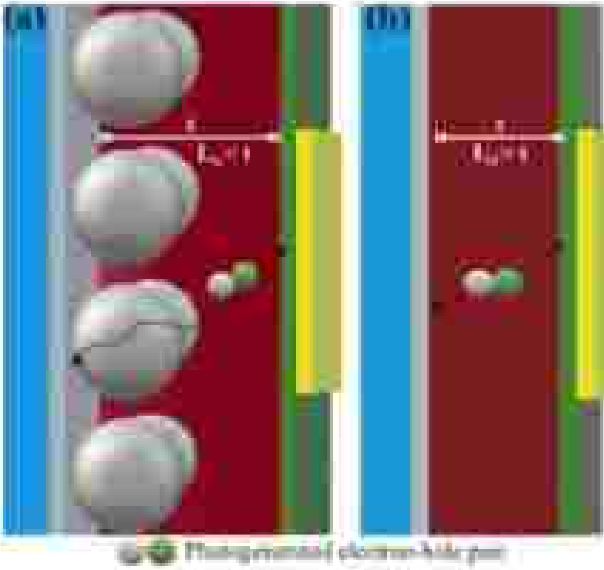

Fig. 2 Schematic of (a) mesoporous and (b) planar PSC.

regular planar with negative intrinsic positive (n–i–p) and inverted planar with positive intrinsic negative (p–i–n), to facilitate excellent optical transparency in the transport layer and allow maximum light illumination on the perovskite-like absorber.[33] Alternatively, the mesoporous structure demonstrates a large effective interface between the transport layer and perovskite, facilitating dissociation of the generated excitons, but lacks charge collection efficiency due to the grain boundary-assisted recombination.[34] The transport layers are found to guide the growth of the perovskite absorber, but the lattice mismatch between the perovskite and transport layers alters the charge transport. Also, chemical compatibility aspects such as stability and reactivity of the transport layer with the perovskite layer are equally important. Moreover, the transport layers optically protect the perovskite absorber from high-energy UV radiation, enhancing the device stability. Leijtens *et al.*[35] observed higher stability in mesoscopic PSCs sensitized with metal oxide than non-sensitized PSCs. The surface-adsorbed oxygen states of metal oxides possess deep trap sites for the injected electrons upon continuous exposure to the UV spectrum and may leak into the hole transport material. Furthermore, the presence of defects, interstitials, and impurities in the transport layer, and thereby at its interface with perovskite, strongly influences the charge mobility, transport, and recombination. The oxygen vacancies and interstitial atoms at the interface are known to create shallow or deep levels near the band edge, which form recombination centres.[36] Therefore, the selection of defect tolerant interfaces is a prerequisite for smooth charge transfer and to avoid charge recombination. The charge mobilities of the transport layers, when closely matched with the perovskite light absorber, drastically reduce the charge accumulation at the transport layer/perovskite interface and enhance the collection efficiency. Therefore, engineering of the transport layers by doping, fusing, or growing heterostructures is required to address these charge recombination issues.[37–41] Although a wide range of transport layers has been employed to efficiently transport electrons from the perovskite absorbers to the contacts, the bandgap and band alignment of the transport layers with perovskite light absorbers are fundamental prerequisites for the fabrication of a working device. Usually, wide bandgap semiconductors are employed to allow the maximum visible spectrum illumination on the perovskite films. Band alignment or band edge alignment guides the electrons through the transport layers to reduce the leakage of excited charges in the opposite direction. Besides these functionalities, the ease of processing, use of earth abundant materials, chemical stability, stability under light illumination, non-toxicity, and feasibility of real-time operation are the main concerns to realize the commercial availability of PSCs. Usually, the high processing temperature of metal oxides restricts the use of plastic substrates in PSCs. Overall, in the continuing search for ideal transport layers, different material systems with a wide range of approaches are discussed in the present review.

3. Role of interface and carrier transport in PSCs

3.1 Interfaces

When the perovskite layer absorbs light, the photo-generated charge carriers drift towards the respective interfaces (perovskite/ETL or perovskite/HTL) under the influence of the built-in electric field, where an ultrafast charge extraction process takes place. The efficient charge extraction depends on smooth charge transport through the interface, which is hindered by peculiar features related to the interface such as the surface energy of the two constituent layers, energy level alignment at the interface, interfacial layer, defects, mobile ions, trap states, charge recombination, and charge accumulation. These obstructions result in the recombination of charges, hysteresis effect, and light soaking in PSCs. Consequently, the precise control of these issues (discussed here and shown in Fig. 3) strongly influences the performance and stability of PSCs, which is discussed in detail in this review.

The understanding and investigation of the reasons for the recombination process in the perovskite layer and at the interface are imperative not only to control it but also to narrow the interface engineering schemes, which can be done with the help of a differential equation expressed as follows:

$$\frac{dp(t)}{d(t)} = -r_3 p^3 - r_2 p^2 - r_1 p \quad (1)$$

where p is the photo-induced charge carrier density, and r_1, r_2 and r_3 are trap-assisted (mono-molecular), interfacial (bimolecular), and auger recombination rate constants, respectively. The latter is negligible due to the wide bandgap nature of perovskite materials. The charge recombination in the perovskite is also significantly less for highly crystalline perovskite films. The dominant recombination is mainly due to the second-order, *i.e.*, interfacial (bimolecular), recombination arising from (i) structural defects in the perovskite layer emanating

Fig. 3 Schematic illustrating the importance of interfaces in PSCs.

from the lattice mismatch and thermal vibration, (ii) energy offset between the perovskite and transport layers, (iii) surface defects present in the transport materials such as ZnO and SnO_2 (ETL) and NiO (HTL), and (iv) difference in the charge carrier mobility of perovskite and transport layers.[38]

The charge dynamics, including extraction, transfer, and recombination of charge carriers, happens at the interface. Charge extraction is a very fast process and takes a few hundred picoseconds, which is significantly less than the lifetime of the charge carriers (around a few nanoseconds). Although the charge extraction process is hindered by the presence of PbI_2 at the surface of the perovskite, surface modification has become a prime requirement.[33,34] Furthermore, the hole traps resulting from the under-coordinated halide anions on the crystalline surface of $MAPbI_3$ thin films can induce significant charge accumulation at the perovskite/HTL interface.[35] These trap states existing at the interface can be eliminated by interface engineering to reduce the recombination rate and improve the charge transfer. Also, it has been perceived that the passivation of trap states can eradicate the hysteresis anomaly. Another obstruction for efficient charge extraction is the migration of ions present in the perovskite (MA^+, Pb^{2+}, and I^-) towards the interface, which can also affect the device performance. These ions have low activation barriers and ionic diffusion coefficients to move within the perovskite, especially when the device is exposed to light illumination.[36]

Another important feature is the energy level alignment at the interface, which is essential for smooth charge transportation. Generally, a band offset of -0.2 eV is required for efficient charge transfer at the perovskite/ETL interface. Further, the appropriate tailoring in the energy level alignment allows smooth charge transportation, which results in a higher short circuit current density (J_{SC}) and fill factor (FF). Also, an increase in the open circuit voltage (V_{OC}) can be achieved by optimum tailoring of the band alignment.[37]

Different approaches for interface engineering, including screening of alternative transport materials with different morphologies and surface modification to alter the charge carrier dynamics, have been attempted to improve the device performance, mainly V_{OC}, J_{SC}, and FF. Furthermore, the use of a mesoporous layer can affect the ion migration, producing a lower accumulation of charge carriers at the interface. The use of doped and composite transport materials, transport layer with different morphologies (one-dimensional and three-dimensional), and bi-layered mesoporous scaffolds can alter the mobility and band alignment of the transport layer, which will improve the device performance and stability. Additionally, different surface modifications and surface passivation techniques can and have been used to optimize the interface.

3.2 Charge carrier dynamics

The two main carrier characteristics of the transport layers that influence the performance of PSCs are mobility (μ) and conductivity (σ). The mobility of the carriers in the perovskite should be well-matched to that of the transport layers, *i.e.*, the mobility of carriers in the transport layers should be greater than or equal to that of the perovskite absorbers for smooth extraction from the perovskite absorber at the interface of the perovskite and transport layer. Conversely, charge accumulation occurs at the perovskite/transport layer interface when the mobility of the carriers in the transport layers is lower than that in the perovskite light absorbers, leading to interfacial recombination. Practically, the carrier mobility of a material depends on its processing methods, microstructures, morphology, and defect characteristics. The electron mobility in a semiconductor can be expressed as follows:

$$\mu = \frac{\tau}{m^*} \tag{2}$$

where μ, m^* and τ are the charge mobility ($cm^2\ V^{-1}\ s^{-1}$), effective mass, and characteristic time (s) of the charges in the transport layers, respectively.

Further, the charge conductivity of the transport layer should be comparable to that of the perovskite absorber to ensure lower charge recombination in the transport and achieve better performances in PSCs. The electrical conduction in a semiconductor is given by the following equation:

$$\sigma = nDE \tag{3}$$

where σ is the electrical conductivity ($S\ m^{-1}$), n is the free charge concentration based on the Boltzmann relation, D is the diffusion coefficient of charges, and E is the electric field ($V\ m^{-1}$). Thus, considering Einstein's equation, the electrical conductivities of the transport layers can be increased by either increasing the charge mobility (μ_e and μ_h for ETLs and HTLs, respectively) or concentration of free charges (n_e and n_h for ETLs and HTLs, respectively). Furthermore, the conductivity and mobility of the transport layers largely influence the series and shunt resistance of PSCs. Various reports suggest that the inclusion of low mobility transport layers at perovskite/transport layer interface results in dominant trap-assisted recombination losses, delivering poor device performances. Therefore, various research groups have used the doping strategy to enhance the carrier mobility in the transport layers, but doping results in other unfavourable issues such as parasitic absorption, dopant diffusion, and doping-induced degradation pathways. In addition, the concentration of dopants required to enhance the mobility in the semiconducting transport layers depends on their thickness and creates ambiguity in ascertaining the exact dopant that can work and its concentration. Le-Corre *et al.*[illegible] reported an alternative strategy to doping and found a different transport layer (with high mobility), namely, optimizing the thickness of the transport layers, which directly affected the fill factor (FF) of the PSCs. Further, to reduce the recombination of photogenerated charge carriers in the perovskite light absorbers, the mobility of electrons (μ_e) and holes (μ_h) should be balanced, *i.e.*, the ratio of μ_e and μ_h should be equal to one. Thus, Chen *et al.*[illegible] used the space-charge-limited current (SCLC) method and demonstrated the importance of choosing and grading the transport layers to achieve a μ_e and μ_h ratio of 1, which enhanced the performance of PSCs.

In general, the carrier transport in the perovskite layer is discussed based on the ideal space charge region, but some studies have reported changes in the semiconducting state (p, i, or n) of the perovskite absorber depending on its ionic composition. Subsequently, Byeon *et al.*[illegible] introduced the concept of dominant p–n junction depending on the type of ETL used. Electron-beam-induced current measurement (EBIC) and Kelvin probe force microscopy (KPFM) were used to analyse the electric field and charge densities. The EBIC measurements for devices based on a TiO_2 ETL showed a strong EBIC signal at the TiO_2/perovskite interface, unlike PSCs with a C_{60} ETL, showing a strong EBIC signal at the perovskite/spiro interface, as shown in Fig. 4. Specifically, the generated charges dissociate at the dominant junction with a strong built-in potential and are transferred to the corresponding transport layers. Further, the E-field inside the junction was measured by local contact potential differences (CPDs) with cross-sectional KPFM measurements. A strong E-field was observed at the TiO_2/perovskite interface for the TiO_2-based device, while the uniform distribution of a weak E-field was noticed at the $MAPbI_3$/spiro-MeOTAD interface and in the $MAPbI_3$ layer. On the contrary, a strong

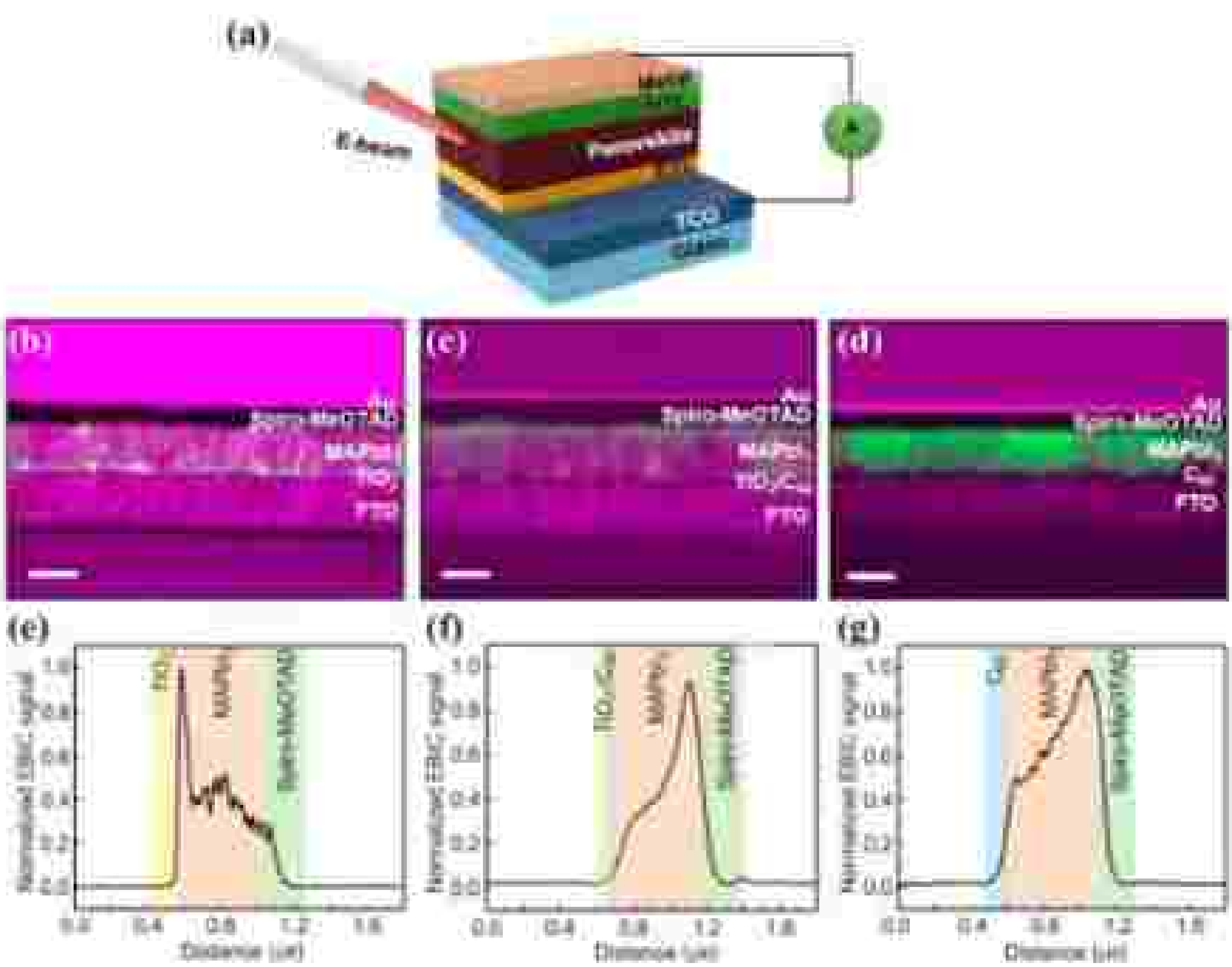

Fig. 4 (a) Schematics of electron beam induced current measurement setup. (b–d) Cross-sectional SEM images representing the EBIC signal in a bright green color and (e–g) their line profiles perpendicular to layers of TiO_2, TiO_2/C_{60} and C_{60}, respectively. The scale bars in SEM images are 500 nm.[illegible] Reprinted with permission from (ACS Energy Lett., 2020, 5, 2580–2589). Copyright (2020), the American Chemical Society.

E-field developed at the $MAPbI_3$/spiro-MeOTAD interface instead of the C_{60}/$MAPbI_3$ interface in the C_{60}-based device. This again corroborates that the choice of ETL decides the location to form the dominant p–n junction. The carrier density profiles obtained showed that holes were extensively amassed at the TiO_2 interface, and therefore, the net charge of the perovskite layer was also positive for the TiO_2-based device. However, the C_{60}-based device mainly showed electron accumulation at the spiro-MeOTAD interface rather than C_{60} (Fig. 5). The net charge of the entire perovskite layer was negative in the device comprised of C_{60} than that of TiO_2. Thus, the actual devices were not an ideal p–i–n solar cell, indicating a localized E-field at the specific interface with distinct transport layers. This further emphasizes the choice of transport layers as a key factor in controlling the carrier dynamics in the PSCs.

The semiconducting transport layers are vital components of high-performing PSCs, but these metal oxide transport layers usually possess inherent trap states. The UV active trap states in the semiconducting transport layers act as recombination centres, which directly impact the FF and short circuit current densities (J_{SC}) of the PSCs. Further, the recombination centres formed at the interface of the transport layer and perovskite absorber give rise to hysteresis in PSCs. Nimens *et al.*[45] emphasized that the fabrication method used to deposit the transport layers directly determines the trap density at the transport layer/perovskite interface. Further, besides the morphology of

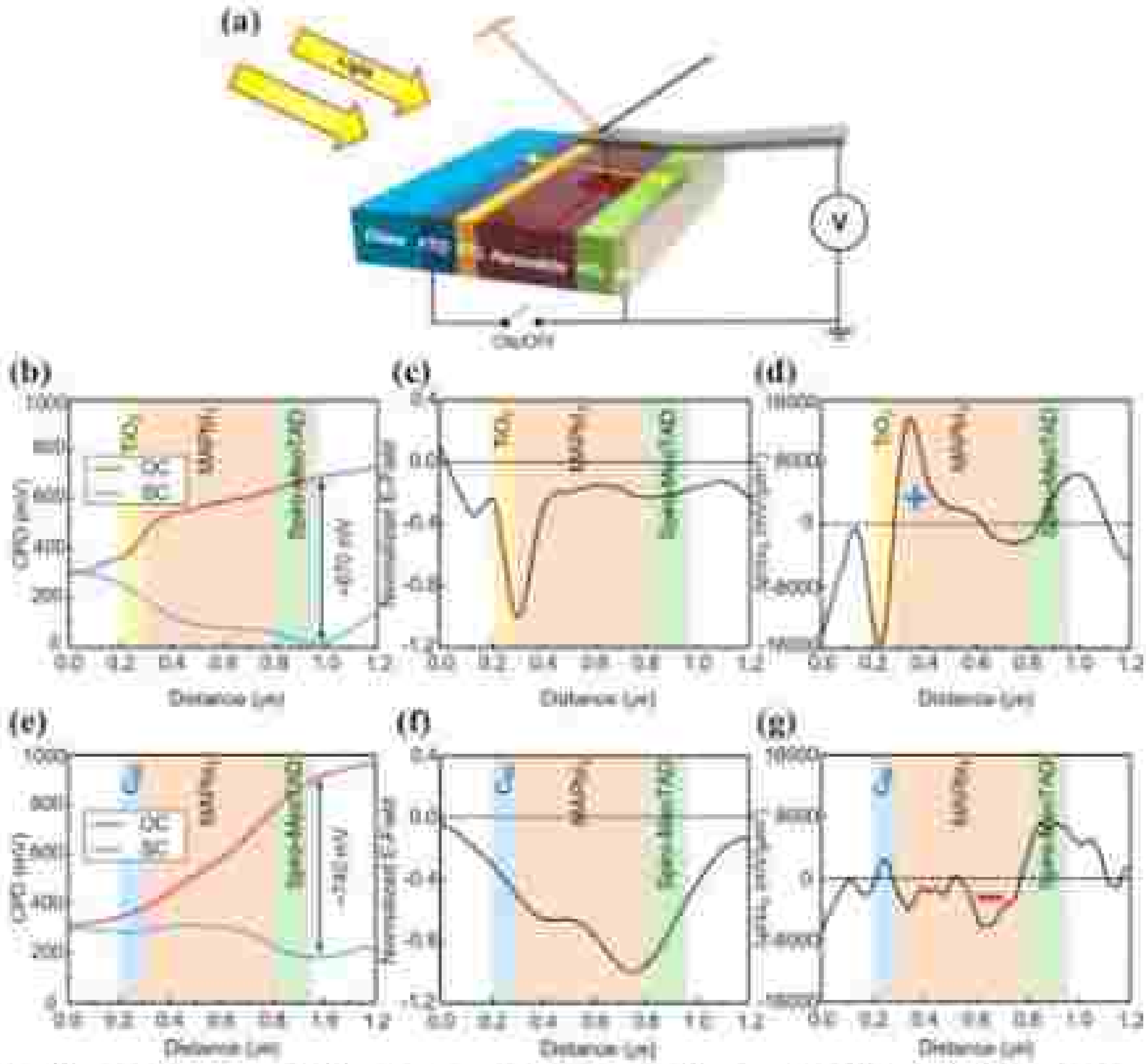

Fig. 5 (a) Schematic of cross-sectional Kelvin probe force microscopy measurement scheme. (b and e) Distribution of contact potential differences in OC (red line) and SC (blue line) condition and (c and f) normalized E-field distribution and OC conditions under illumination and (d and g) charge density profile evaluated from photo-potential difference between $V_{OC} - V_{SC}$ of TiO_2- and C_{60}-based PSCs, respectively. The arrows in (b) and (e) indicate the built-up V_{OC}. (OC: open circuit, SC: short circuit, V_{OC}: open circuit voltage, and V_{SC}: short circuit voltage).[44] Reprinted with permission from (ACS Energy Lett., 2020, 5, 2580–2589). Copyright (2020), the American Chemical Society.

the transport layers or the perovskite absorber films, the trap density obtained due to the fabrication process of the transport layer greatly controls the performance of PSCs.

Overall, the charge transfer dynamics compete at different timescales. The lifetime of photogenerated carriers in polycrystalline perovskite films ranges from 10–100 ns. With driving forces such as concentration gradient and built-in potential, the photogenerated carriers diffuse to the transport layer/perovskite interface and are selectively separated in a timescale of ~10 ns. Subsequently, the free carriers get collected through the transport layers at a typical timescale of ~10 μs. In the transport layers, before the carriers reach the electrode, the interfacial recombination competes with the carrier transport at the typical timescale of 1–1000 μs depending on the concentration of interfacial traps arising from their synthesis protocol, resulting in photocurrent and photovoltage loss.[43–44] Thus, by ensuring that the transport layers possess less traps at the transport layer/perovskite interface, the photovoltaic performance of PSCs can be significantly enhanced.

3.1 Density of states

The density of states (DOS) can help understand the distribution of the number of electron states per unit volume in the electronic band structure, which determines the optical properties and the V_{OC} of solar cells.[45,46] Interestingly, the atomic and electronic structure at the interface is the result of the combined effects of the surface structures of the independent constituent layers, giving rise to the solitary electronic structure, while forming the interface. Particularly, at the interface of the perovskite/transport layer, the atomic and electronic structure plays a pivotal role by affecting the lifetime and mobility of charge carriers.[47] Furthermore, the conduction band minimum and valence band maximum (mostly inorganic semiconductors) are analogous to the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) (mostly organic/polymer semiconductors). Fig. 6(a) shows the electronic structure, which is comprised of the vacuum energy level (E_{vac}), work function (WF), Fermi energy (E_F), bandgap (E_g), electron affinity (EA), and ionization energy (IE) for all organic/inorganic semiconductors. The position of these energy levels and their alignment at the junction plays a key role in the overall performance of electronic devices.[48]

The vacuum energy level is the energy of a stationary electron with zero kinetic energy located outside the surface of the material. The work function is the energy difference between the vacuum level and Fermi level (WF = E_{vac} − E_F), which depicts the energy barrier that restricts an electron from escaping the material. The Fermi energy represents the value at absolute zero temperature. The ionization energy (IE) refers to the energy difference between the vacuum level and valence band (VB) and depicts the minimum energy necessary to eliminate the electrons from the VB. Reciprocally, the energy gained by dropping an electron from the vacuum level to the conduction band (CB) is known as the electron affinity (EA) of the semiconductors. The distribution of DOS in the energy band can be better understood by splitting semiconductors into

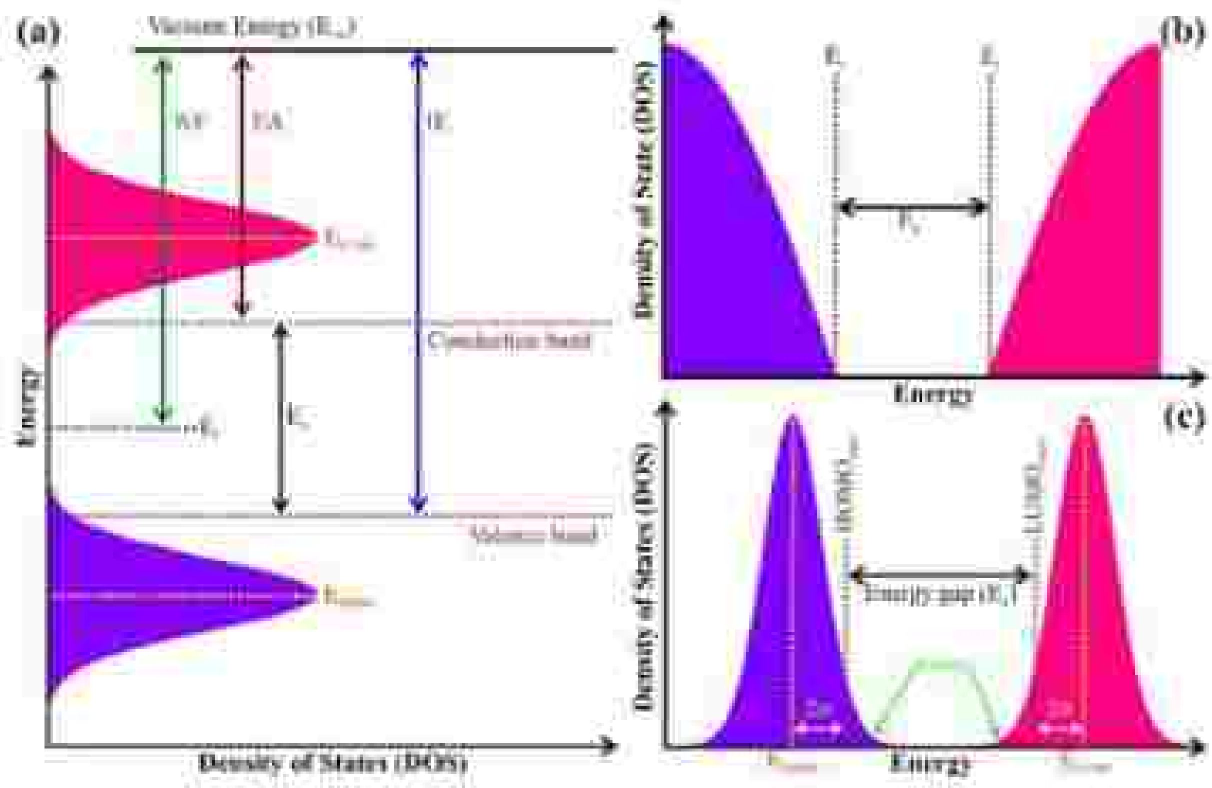

Fig. 6 Schematic of the electronic structure for (a) all organic/inorganic, (b) ordered (or crystalline), and (c) amorphous (or disordered) semiconductors.

two categories, i.e., ordered (single crystals and polycrystalline thin films) and disordered (amorphous materials) systems. In the case of ordered semiconductors, the localized charge carriers are at the band edges, and it shows a parabolic shape distribution of the DOS at the band edges, which can be represented as follows:[84]

$$g_c(E) \propto \sqrt{E - E_c} \tag{4}$$

$$g_v(E) \propto \sqrt{E_v - E} \tag{5}$$

where E_c and E_v are the conduction and valence band edges, respectively. This infers that there are no gap states in the forbidden gap of the semiconductor or the DOS is reduced to zero in the energy gap $E_v < E < E_c$. This results in the formation of sharp conduction and valence band edges, as shown in Fig. 6(b).[85]

In the case of disordered semiconductors such as amorphous and most organic semiconductors, the charge carriers have a poor degree of localization.[14] The weak localization at the band edges results in extended states, which progressively change to localized states, leading to the outgrowth of an extended state tail in the energy gap.[86,87] Therefore, the DOS is more appropriately described by the Gaussian or exponential distribution. Further, the Gaussian disorder model (GDM) was proposed to understand the charge carrier transport in disordered organic semiconductors, which gives the Gaussian density-of-state function, $g(E)$, as follows:

$$g(E) = \frac{N_0}{\sqrt{2\pi}\sigma}\exp\left\{-\frac{E^2}{2\sigma^2}\right\} \tag{6}$$

where N_0 is the density of states per unit volume, which is generally considered the density of the molecule, and σ is the width of the distribution. The extended states tailing from the Gaussian-distributed DOS are incapable of accurately defining clear bandgap and sharp band edges. Therefore, the energy gap is defined as the energy difference between $HOMO_{onset}$ and $LUMO_{onset}$ (Fig. 6(c)). Further details on determining the bandgap of disordered semiconductors can be found in previous studies.[58,88,89]

In PSCs, to locate the band edges at the interface, Chatterjee *et al.* used scanning tunneling microscopy, i.e., they recorded the tunneling current versus tip voltage of ultra-thin films of layers of PSCs subsequently coated over n-type silicon substrates. The differential conductance (dI/dV) of the thin films was calculated from the obtained data, which corresponds to the DOS. The spectra in Fig. 7 show the positive and negative voltages, denoted as the CB and VB levels, respectively, obtained with respect to the Fermi level. Further, the difference in the valence and conduction band levels (transport gap) is slightly lower than the optical bandgap due to trap states, which contributes to the tunneling current.[54] Moreover, the surface oxide states of the transport layer nanoparticles can be modified by ligands (silanes or thiols), which can alter the valence and conduction band edge levels by altering the density of states.[90]

Photoelectron yield spectroscopy (PYS) can also be further used to determine the work function of the transport layers. Yeo *et al.* tailored the work function of an NiO_x layer with lanthanum doping, which could alter the density of states owing to changes in the valence and conduction band levels.[38] It should also be noted that the lattice mismatch at the transport layer/perovskite influences the charge dynamics. Hu *et al.*[91] conducted a first-principles study on the $SnO_2/CsPbI_2Br$ heterojunction and showed that the SnO_2(110) surface is well-matched with the $CsPbI_2Br$ (100) surface due to their mismatch of 6.8%. The DOS at the interface was different from that in the bulk

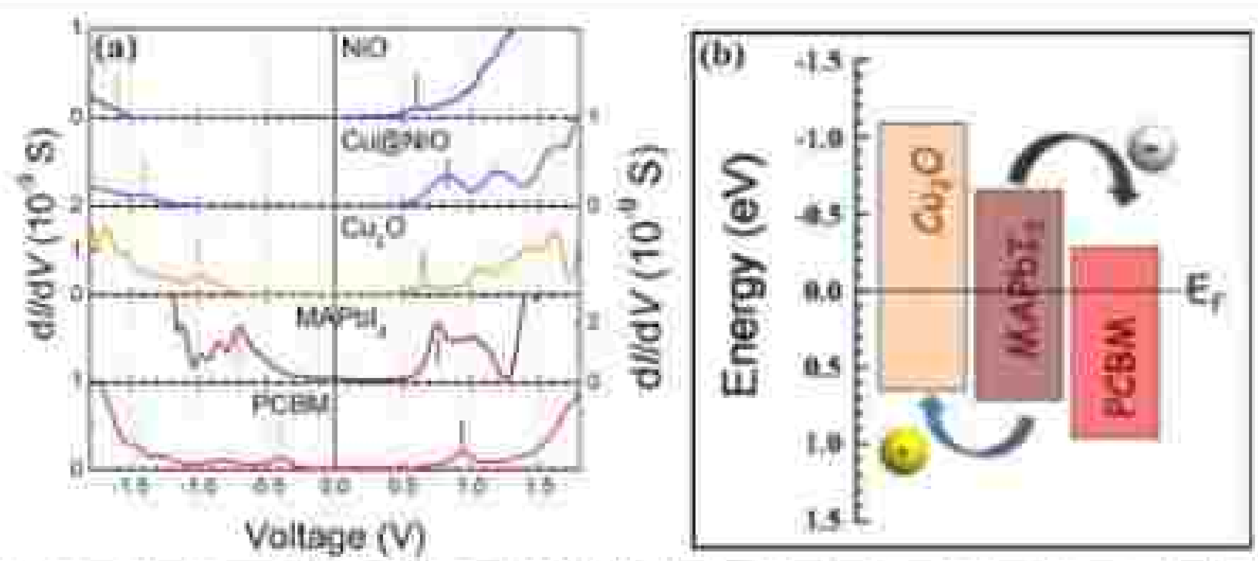

Fig. 7 (a) Differential conductance (dI/dV) plots of NiO, Cu@NiO, Cu_2O, $MAPbI_3$, and PCBM thin films. VB and CB edges of the materials and HOMO and LUMO levels of PCBM with respect to the Fermi energy are marked with vertical continuous and broken straight bars in the positive and negative voltage regions, respectively. (b) Schematic energy level diagram of $Cu_2O/MAPbI_3/PCBM$ heterojunction. The dashed line represents the Fermi energy after contact.[54] Reprinted with permission from (J. Phys. Chem. C, 2016, 120, 1428–1437). Copyright (2016), the American Chemical Society.

because of the corresponding variation in electronic states at the interface. Therefore, it should be noted that the EOS in PSCs depends on not only the bulk of the subsequent layers but also the interface; however, it can be tuned by controlled doping to adjust the band offsets and achieve a high V_{OC}.

4. Electron transport layer (ETL)

The bandgap and band alignment of the ETLs control and guide the electron transfer at the ETL/perovskite interface. ETLs, in the form of wide bandgap *n*-type semiconductors transparent to visible light, absorb in the UV wavelength range.[58] Moreover, they allow full visible radiance to strike the perovskite absorber, but this may not be true in inverted device architectures where light strikes through the hole transport layer (HTL) and transparent conducting substrates.[59] Typically, the bandgap values of the ETLs are higher than the perovskite absorbers utilized to fabricate PCSs. Therefore, the CB edge of the ETL should be at a lower potential than that of the perovskite absorber to guide the electrons through the ETL and reduce the leakage of excited charges in the opposite direction. In the *n*-type structure, the Fermi levels of the ETLs are close to the CB; hence, the probability of the VB electron movement from the perovskite to ETL is close to zero, and hence negligible (Fig. 8). Therefore, variety of ETLs has been explored to control the recombination process and accelerate the charge carrier recombination dynamics in search of efficient and stable photovoltaic performances. In this section, we discuss the important characteristics of various inorganic ETLs and their outstanding development in delivering excellent PCEs when combined with perovskite absorbers.

4.1. Inorganic ETLs

Inorganic ETLs, which are engineered into nanostructures for exploiting the nano-regime physical properties, increase the

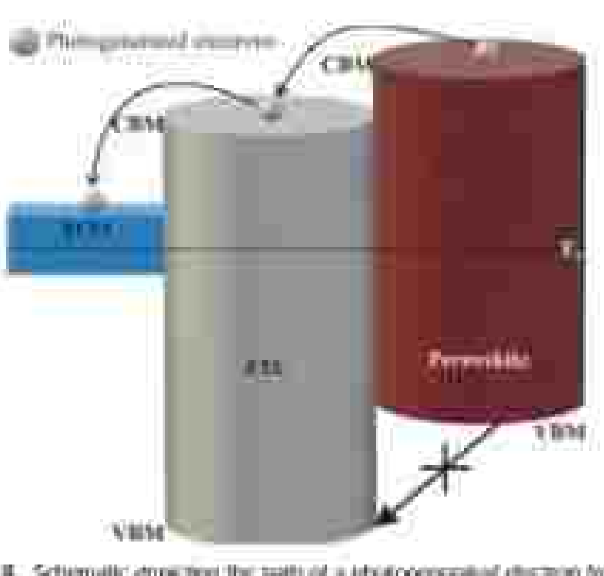

Fig. 8 Schematic depicting the path of a photogenerated electron from the perovskite light absorber to the external circuit. (CBM: conduction band minimum and VBM: valence band maximum.)

junction interface. Therefore, oxides of various metals such as titanium (Ti), tin (Sn), zinc (Zn), tungsten (W), barium (Ba), strontium (Sr), aluminium (Al), iron (Fe), and indium (In) have been explored for their performance as ETLs in PSCs.[60–66] The band structures of several promising inorganic ETLs are summarized in Fig. 9. The appearance of inorganic ETLs in various crystalline polymorphs and their ability to tailor the charge transfer dynamics are of special interest to the PV community. The objective is to look for cost-effective inorganic ETLs processible under ambient conditions. Furthermore, the ETLs can act as a prominent template for the overlaying perovskite layer in PSCs after engineering their phases and crystallinity. The synthesis, characterization, and significance of a few critical inorganic ETLs employed in PSCs are thoroughly discussed in this section.

4.1.1. Titanium dioxide (TiO_2).

TiO_2 is one of the fascinating electron transport materials widely used in the fabrication of PSCs due to its low processing cost, chemical stability, and non-toxic nature. Titanium oxide has several allotropic forms categorized as TiO_2 and Ti_nO_{2n-1} with different crystal structures, namely, monoclinic, triclinic, tetragonal, orthorhombic, rhombohedral, and hexagonal.[67,68] However, its most well-known forms are anatase (tetragonal structure, $I4_1/amd$ space group), brookite (orthorhombic structure, *Pbca* space group), and rutile (tetragonal structure, $P4_2/mnm$ space group), which are composed of a TiO_6 octahedral network through shared oxygen at the corners. The TiO_6 octahedra share both the corners and the edges to form the rutile and brookite-type crystal structures, but the sharing of only edges results in the formation of an anatase crystal structure. The chains of the edge-shared distorted TiO_6 octahedra run parallel to the *c*-axis and deliver the brookite phase. These distinct crystalline forms influence the electronic and electrochemical properties of TiO_2 nanostructures,[69–72] and hence play a crucial role in the performance of PSCs. In the nanocrystalline form, the anatase, brookite, and rutile phases are the most thermodynamically stable at crystalline dimensions of ≤11 nm, between 11 to 35 nm, and ≥35 nm, respectively.[73] Nevertheless, the synthesis of the brookite phase is most challenging because of its metastable nature.[74,75] Owing to the ease of processing of the anatase and rutile phases, they are more widely utilized than the brookite phase in solar cells.[76–78]

The wide adaptability of TiO_2 as photoanodes in DSSCs has promoted it as an interesting ETL material in PSCs.[79,80] TiO_2, which is an *n*-type wide bandgap semiconductor (i.e., E_g = 3.2 eV with CB edge level at −4.2 eV and VB edge level at −7.0 eV), is one of the most transparent materials to visible light and offers electronically favorable band edge alignment with most of the known perovskite absorbers. Usually, a compact TiO_2 film is used as the hole-blocking layer in PSCs. Various thin film growth techniques, namely, spin coating,[81] aerosol-assisted coating,[82] electrospinning,[83] sputtering,[84] atomic layer deposition (ALD),[85] hydrothermal growth,[86,87] spray coating,[88] and template-based synthesis,[89] have been employed for the synthesis of good-quality TiO_2 transport layers. However, hydrothermal synthesis is an attractive process for obtaining hierarchical nanostructures such as nano-dendrites,

Fig. 9 Schematic showing the band structures and the band alignment of various inorganic ETLs with a perovskite absorber.

which offer dual functions of significant light trapping and efficient electron collection (Fig. 10).[illegible] The 3D morphology efficiently extracts the photoelectrons from the perovskite absorber (*i.e.*, $MAPbI_3$) and reduces the electron transport length in the matrix to surmount the obstacle of short electron diffusion length. Further, finite difference time domain (FDTD) simulations revealed that the electron transport pathway in PSCs consisting of branched nano-dendrites assists in the photoelectron collection near the spiro-MeOTAD layer due to absorption of long-wavelength light. Moreover, the surface passivation of the 1D TiO_2 nanorods by atomically deposited TiO_2 nanoparticles offers excellent charge separation, controlling the back-flow reaction of the electrons excited from the perovskite absorber. This facilitates a low recombination rate with a conversion efficiency of 11.45%.[illegible] The secondary oxidation treatments at higher temperatures always contribute to the presence of defects/impurities (*i.e.*, residual carbon) and changing the band alignment at the interface. The impurities serve as unproductive quenching sites or charge recombination centres, effectively trapping the photogenerated electrons at the interface of the TiO_2 ETL and perovskite absorber, thereby curtailing the dramatically injected electron yield. However, the formation of defects or impurities was eliminated *via* UV-O_3 treatment without compromising the density of oxygen vacancies to gain competitive efficiency from the amorphous ALD-grown TiO_2 (*i.e.*, 9.97%) and compact TiO_2 (*i.e.*, 16.9%) ETLs.[illegible] Moreover, the uneven blocking layer of TiO_2 nanoparticles between the valleys and plateaus of F-doped SnO_2 induced unidentical electron transportation, and thereby the poor charge collection reduced the performance of the corresponding PSCs.[illegible]

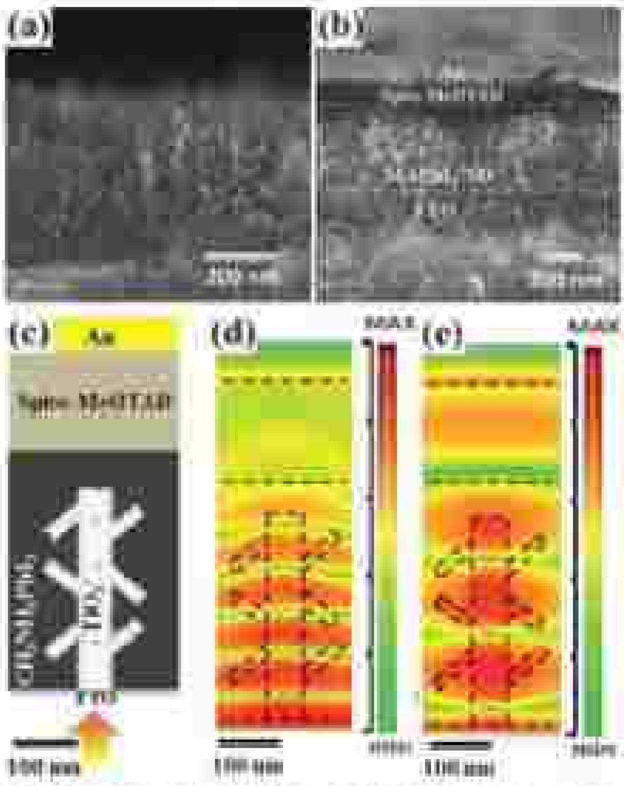

Fig. 10 Cross-sectional SEM images of (a) TiO_2 nanodendrites and (b) solar cell architecture comprised of TiO_2 nanodendrites. (c) Schematic of the FDTD simulation cells for perovskite : TiO_2 nanodendrites. FDTD-simulated EM energy density distribution in PSC after continuous electromagnetic waves passing through the perovskite : TiO_2 nanodendrites with wavelengths of (d) 400 nm and (e) 650 nm.[illegible]

Dharani et al.[illegible] introduced electrospun TiO_2 nanofibers as a photoanode, enabling a greater loading of perovskite materials and also lowering the trap-assisted recombination. Despite the more open structure and porous arrangement of the nanofibers, the poor PbI_2 conversion in $CH_3NH_3PbI_3$ was reported to

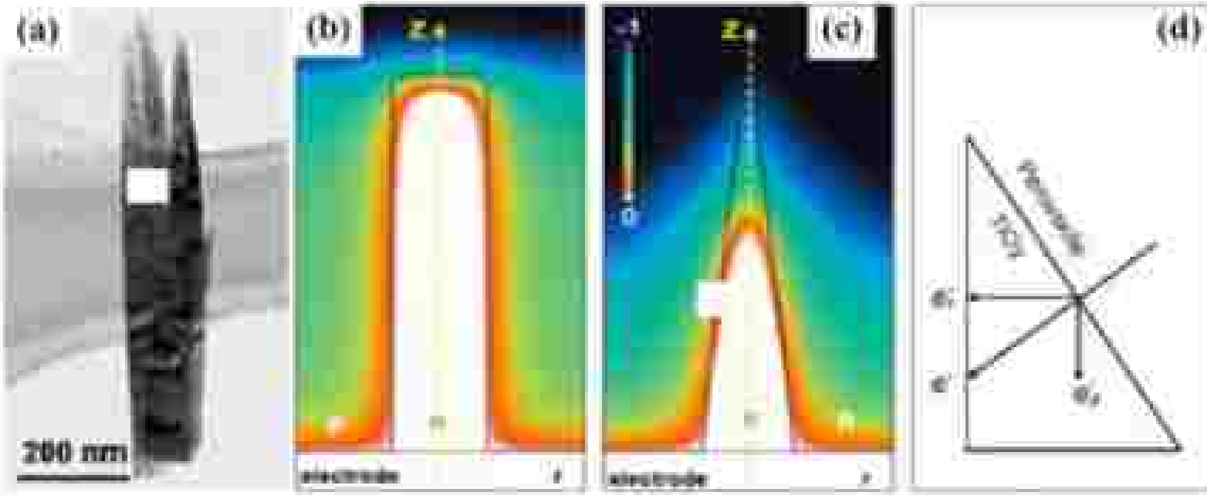

Fig. 11 (a) Low-magnification TEM image of TiO_2 nanocones. Electric potential contours for n-type (b) nanorod and (c) nanocone in the p-type matrix and (d) scheme of electron injection from perovskite to TiO_2 and transport within TiO_2. Note: e_r^- represents electron injection along the radial direction and e_a^- along the axial direction.[illegible] Reprinted with permission from (Nano Energy, 2015, **11**, 409–418). Copyright (2015), Elsevier.

impede the device efficiency.[illegible] The tapered nanocones of rutile TiO_2 oriented in the [001] direction exhibited superior efficiency than nanorods, irrespective of the variation in their length (Fig. 11).[illegible] The suppressed charge recombination due to the faster electron injection rate of the TiO_2 nanocones was beneficial for the charge separation at their interfaces with $CH_3NH_3PbI_3$, resulting in an enhancement in the efficiency. The two possible factors responsible for the faster electron transfer from the perovskite to nanocones are as follows: (i) larger surface to volume ratio of the nanocones improving the charge separation and (ii) decreased distribution of electrostatic potential for p–n junction, generating an electric field along the axial direction, which enabled enhanced electron transportation, while minimizing its trapping. Specifically, the driving force for the injection of electrons into the TiO_2 nanocone ETL and transport along the axial direction for the nanocone/perovskite systems was absent in the nanorods (Fig. 11(d)), which led to faster electron transfer from the perovskite to TiO_2 nanocones, suppressing the charge recombination. Likewise, highly ordered anti-reflecting titania nanotubes served as nanocontainers and ETL in $CH_3NH_3PbI_3$ PSCs and facilitated efficient charge collection/extraction, delivering an efficiency of 14.8% despite the relatively lower loading of $CH_3NH_3PbI_3$.[illegible]

It was shown by Xiao et al.[illegible] that nanoporous submicron TiO_2 spheres with high specific surface area ensure higher light scattering effect and better contact with the perovskite through infiltration, which caused higher light absorption and faster charge transport, respectively, delivering excellent stability against atmospheric moisture when the PSCs with 14.7% efficiency were exposed to the air. Similarly, the smaller leakage current and reduced transport resistance of opal-like mesoscopic TiO_2 ensured a high (18.2%) efficiency.[illegible] Further, as shown by Thambidurai et al.,[illegible] interface modification of a mesoporous TiO_2 ETL by $(OH)_x$ uplifted the conduction band of TiO_2, leading to better energy level alignment with the perovskite, thereby enhancing the optical absorption, reducing the carrier recombination, and rendering excellent electron transportation. Together, they led to a high PCE of 17.2%. The passivation of the perovskite/TiO_2 interface using poly(vinyl carbazole) (PVCz) and PCBM is a versatile and rational method to gain a PCE of around 21.1%. The PVCz-assisted homogeneous dispersion of PCBM in the mesoporous TiO_2 layer also prevented elution after the formation of the perovskite layer. The interface modification induced efficient charge transport to the TiO_2 ETL and efficiently reduced the carrier recombination at the ETL/perovskite interface.[illegible] Moreover, the introduction of a sodium sulfate (Na_2SO_4) passivation layer at the interface of the TiO_2 ETL and perovskite delivered an efficiency of 18.73%.[illegible]

Recently, Wang et al.[illegible] introduced the interface modification of TiO_2/perovskite by CsAc to reduce the interface defect density and the related carrier recombination. Even though the CsAc improved the affinity of the perovskite precursor to form a compact and highly crystalline perovskite layer by decreasing the Gibbs free energy for heterogeneous nucleation, the carbon as an HTL may have restricted the efficiency to 13.8%. Likewise, a robust and simple acid-treatment strategy was introduced to produce an amorphous TiO_2 buffer layer above the anatase TiO_2 surface as an ETL.[illegible] The acid treatment weakened the bonding of the zigzag octahedral chains in TiO_2 and formed an amorphous buffer layer by shortening the staggered octahedron chains. This led to the formation of oxygen vacancies in the amorphous TiO_2 ETL, and hence increased electron density, efficiently transferring electrons from the perovskite to ETL layer. Modification of the interlayer between the TiO_2 and perovskite layers by introducing air-stable n-type DMBI-doped PCBM was shown to significantly diminish the energy level offset at the interface, thereby delivering an efficiency of 20.1%.[illegible]

Nanocomposites of TiO_2 have also been explored to ensure the higher performance of PSCs based on them. Indeed, it was found that the PCE of 15% achieved using a TiO_2/graphene nanocomposite[97] further improved after replacing graphene with single-walled carbon nanotubes (SWCNTs).[106] However, the increased number of recombination sites due to higher loading of SWCNTs adversely affected the performance features. The composite of phosphotungstic acid (PW_{12}) and TiO_2 ETL down-shifted the conduction band edge and led to a well-aligned interface with the perovskite for excellent electron extraction.[107] Besides, metal oxides were also used as a substitute of carbon materials to form nanocomposites with TiO_2, but were found to be relatively inefficient as ETLs due to the inhibited recombination rate offered by impure phase formation.[108] Therefore, Y,[109] Ga,[109] Zr,[110] and Ru[111] doped and ZnN[112] and Er-Yb,[113] co-doped TiO_2 nanostructures have also been explored as ETLs to achieve longer carrier lifetimes and higher charge density at the ETL/perovskite interface. Moreover, hydrogen[114] and cadmium[115] have been utilized to alter the recombination resistance and charge carrier density of TiO_2 to further increase the collection efficiency. An Nb-doped TiO_2 ETL covered with an over-layer of TiO_2 nanorods was shown to reduce the interface transport resistance and capacitance, thereby delivering an efficiency of 18.83% due to electron injection from the CB of perovskite to Nb–TiO_2.[116]

Song et al.[117] doped a TiO_2 ETL with Na_2S in search of interface defect passivation and improved conductivity. The Na cations and S anions were observed to improve the conductivity and change the wettability of the TiO_2 layers, respectively. This was noted to improve the crystallinity of the perovskite layers and passivate defects at the ETL/perovskite interface. Recently, various anions of $TFSI^-$, Cl^-, F^-, and CO_3^{2-} of Li salts have been explored as ETLs for PSCs.[118] The first three anions of Li salts remain doped in TiO_2 to improve the electrical properties by one-order enhancement in electron mobility and reduced electron trap density of Li-doped TiO_2 ETLs. Conversely, the stronger chemical bonding between Li_2CO_3 and TiO_2 exhibits the deepest conduction band and delivers the maximum efficiency of over 23%. The high temperature firing at ∼450 °C required to gain the crystalline phase of pristine or doped TiO_2 nanostructures restricts the processing of the ETLs over plastic substrates. Alternatively, low-temperature processing to protect the plastic substrate, while gaining the desired crystalline phase of TiO_2 has been attempted to fabricate flexible PSCs. The plasma-enhanced atomic layer deposition of a compact TiO_2 layer at 80 °C on ITO-coated PEN flexible substrates[119] and e-beam evaporation of TiO_2 on PET substrates[120] have been found to be effective to fabricate wearable power devices, achieving a PCE of 13%. However, physical deposition methods, such as ALD,[119] e-beam evaporation[120] and sputtering,[121] are complex and demand high energy consumption to create a vacuum. Therefore, the use of solution methods such as spin coating[122] and solution dispersion[123] on flexible substrates was also attempted, but the PCE was limited to 10%. Consequently, further optimization of the solution-based processes at low temperature to gain dense and compact TiO_2 ETLs is essential to improve the PCE.

4.1.2. Tin oxide (SnO_2). Tin oxide can be synthesized in various chemical forms (i.e., SnO_2, SnO, Sn_2O_3, and Sn_3O_4) and crystalline phase forms (i.e., orthorhombic, tetragonal, cubic, and triclinic crystals).[93] Most importantly, being chemically stable, UV-resistant, and low-temperature processible (<200 °C), SnO_2 also supports high bulk electron mobility (i.e., 240 $cm^2 V^{-1} s^{-1}$), wide bandgap (i.e., 3.6–4.0 eV), and visible transparency.[124] Thus, considering its higher charge mobility and extended UV stability, it can potentially dethrone the lower charge mobility ETLs such as TiO_2. Recently, SnO_2 nanocrystalline films have been identified as both technically viable ETLs and antireflection films.[125] Various synthetic techniques such as ALD,[126] chemical bath deposition,[127] electrochemical deposition,[128] pulsed laser deposition (PLD),[129] e-beam evaporation,[130] and spray coating[131–133] have also been used to synthesize compact, uniform, and well-defined morphologies of SnO_2 ETLs. However, the solution processing of salts such as $SnCl_2$, $SnCl_4$, $SnCl_2·2H_2O$, and $SnCl_4·5H_2O$, followed by thermal decomposition,[125] is the most widely employed technique due to its easy scalability as an industrial tool to render well-defined morphologies of ETLs for PCSs. Moreover, the uniform layers of SnO_2 nanoparticles easily realized by an automated spray coating technique at lower processing temperature over 15 cm^2 active area was shown to deliver an improved charge lifetime at the ETL/perovskite interface and stable performance under self-life test for 1000 h.[133]

A thin layer of SnO_2 nanoparticles as the ETL delivered an efficiency of 21% in planar-structure PSCs,[134] but the development of PbI_2, a p-type material at the interface, led to a higher hole transfer rate than electron transfer rate. The reduced barrier at the perovskite/spiro-OMeTAD interface and passivation of the surface or grain boundary defects by PbI_2 were found to control the device performance. Moreover, SnO_2 was also studied with ZnO nanostructures to improve the PCE performance, where a hollow domed SnO_2 nanotube array was grown over ZnO nanorods as a sacrificial template (Fig. 13), but the PCE was still restricted to 12.1%, which could be due to sluggish electron transport from the hierarchical thicker shell layer of SnO_2 nanotubes, providing pinholes.[135] The pinholes caused surface current leakage and compromised the charge recombination processes at the interface. Therefore, the preparation of a smooth and compact bilayer structure of SnO_2 nanoparticles by filling the pin-holes reduced the oxygen-deficient regions, improved crystallinity, and diminished the dislocations, facilitating its efficacy as an ETL for PSCs. Indeed, the bilayer SnO_2 structure delivered a PCE of 16.84% due to the lowered electron trap density, enormously reduced contact resistance, and charge accumulation at the ETL/perovskite interface.[136]

Surface treatments with aqueous solutions of salts such as $TiCl_4$ have been explored to significantly retard the recombination process of SnO_2.[130] However, the inclusion of conducting materials in SnO_2 ETLs provides a better interface with the perovskite and control over the recombination process, and thus more attractive in the search for improved PCEs. The addition of a small amount of graphene quantum dots was shown to enrich the electronic properties of SnO_2, thereby aiding the delivery of a steady-state PCE of 20.23% with very little hysteresis via controlled electron transfer from graphene.[137]

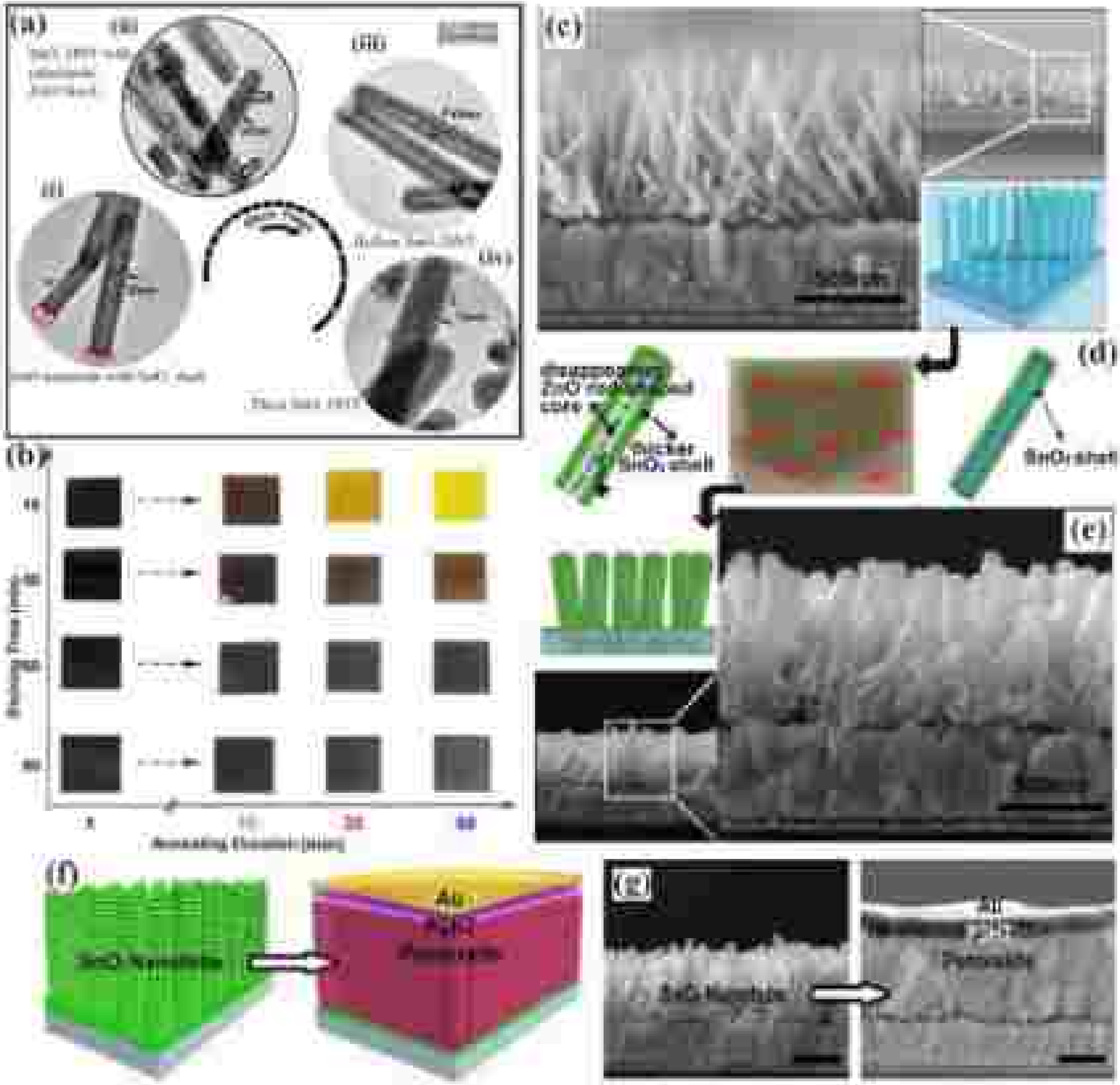

Fig. 12 (a) TEM images of time-dependent growth of SnO_2 DNTs under reaction time of (i) 15, (ii) 30, (iii) 60, and (iv) 90 min. (b) Spin-coated perovskite films over SnO_2 DNT/FTO/glass substrates at different reaction times. Schematic growth mechanism of (c) ZnO nanorods covered with discontinuous SnO_2 nanoparticles, (d) OH^- ions as by-product of SnO_2 can etch the ZnO nanorods, and (e) SnO_2 DNTs@ZnO nanorods. (f) Fabrication scheme of PSCs and (g) corresponding cross section of SnO_2 DNTs and SnO_2 DNT/perovskite/PTEH/Au device. The scale in black indicates 300 nm.[147] Reprinted with permission from (*Chem. Eng. J.*, 2017, **325**, 378–385). Copyright (2017), Elsevier.

The photogenerated electrons from graphene effectively fill the electron traps and improve the electron density in the conduction band (CB) of SnO_2, which collectively accounts for the reduced work function and improved conductivity of SnO_2. The reduced electron trap density and increased conductivity of the ETLs facilitated an enhancement in the electron extraction efficiency and reduced recombination at the ETL/perovskite interface. Further, the addition of graphene to mesoporous SnO_2 microspheres resulted in a relatively reduced charge transfer resistance (*i.e.*, faster electron extraction) and larger recombination resistance than the pristine SnO_2, consequently leading to the least interface potential loss and PCE of 17.00%.[137] Likewise, the inclusion of carbon nanotubes substantially increased the conductivity of the SnO_2 ETL by lowering the defect density, which improved the electron extraction and transport. This reduced the electron accumulation at the ETL/perovskite interface and significantly enhanced the PCE to 10.5%.[138]

Recently, You *et al.*[139] introduced a holistic approach to improve the performance of PSCs by virtue of charge carrier management. The SnO_2 ETL was developed with an ideal film coverage and thickness by tuning the chemical bath deposition protocol. Further, the decoupling of the passivation strategy between the bulk and the interface minimized the bandgap barrier and improved the charge carrier properties. Although control of the pH from most acidic (*i.e.*, 1) to 6 delivered thin uniform films to a distinct nanorod morphology, where the lower film coverage at the most acidic pH caused interfacial recombination, and the oxygen site defects at pH > 3 reduced the carrier lifetime by increasing the non-radiative recombination. The magic reaction at pH 1.5 exhibited ideal film coverage, morphology, and chemical composition and delivered a certified PCE of 25.2%. A high FF of 84.8% was identified to be responsible for the enhanced PCE, which improved the carrier mobility in the $CH_3NH_3PbBr_3$ active layer and excellent charge collection with the least parasitic losses from shunt/series resistances. Thus, the close association of charge carrier management with the FF and the V_{OC} can direct the improved performances of PSCs to reach the theoretical efficiency limit. Moreover, the resistance gradient across the edge and centre of the thin film influences the free carrier mobility to a considerable extent.[139] Hence, the realization of a uniform film with the controlled agglomeration of grains, which is feasible by adopting the rastering of multiple spray nozzles, can render an excellent ETL for PSCs.

Besides these efforts, doping strategies have been considered to improve the electron charge transfer, lower the charge recombination, and reduce the contact resistance at the SnO_2/perovskite interface. The downward shift of the CB or Fermi level and enhanced conductivity of the SnO_2 ETL after Li,[40] Mo,[141] Mg,[142] Cl,[143] Br,[144] KF,[145] $TaCl_5$,[146] ZrF_4,[147] and NH_4Cl,[148] doping expedited the injection and transfer of electrons, increased the effects of the doped ETLs/perovskite layers, and inhibited the charge recombination at the interface. Yang et al.[149] explored a Y-doped SnO_2 ETL in search of efficient PSCs. The Y doping promoted the homogeneous distribution of well-aligned SnO_2 nanosheets, which allowed better infiltration in and contact with the perovskite and improved electron transfer from the perovskite to SnO_2 nanosheet ETL. Moreover, after Y-doping, the uplifted band levels resulted in better energy level alignment and reduced charge recombination at the Y-SnO_2/perovskite interface. Moreover, the optimized 5 mol% doping of Nb in SnO_2 created better surface coverage with perovskite and yielded a PCE of 20.5% due to the reduced recombination centres and enhanced electron extraction at the interfacial contact.[150] The Cl-capping uplifted the band levels of the SnO_2 nanoparticle ETL and suppressed the non-radiative recombination with faster transfer of charge carriers. Moreover, Cl-capping created a hydrophobic surface for SnO_2, which reduced the trap density and suppressed the interfacial recombination of charges by dramatically increasing the grain size and crystallinity of the perovskites, delivering the hysteresis-free PCE of 18.1%.[151] In another study, nitrogen-doped graphene oxide (NGO) was introduced as an oxidizing agent for SnO_2 to control the oxygen defects. The altered oxidation state from Sn^{2+} to Sn^{4+} reduced the oxygen vacancies in SnO_2 in the composite of NGO-SnO_2 and efficiently extracted the charges and reduced the carrier recombination, thereby delivering a PCE of 16.55%.[152] Likewise, diluted CdS quantum dots improved the carrier mobility of SnO_2 and delivered a PCE of 20.78% by accelerating the charge extraction at the modified interface.[153]

Xia et al.[154] introduced the zwitterion sulfamic acid ($^{+}H_3N$-SO_3^{-}) between the SnO_2 ETL and the perovskite layer, in which the interfacial chemical bridge formed through the coordination bond via $-SO_3^{-}$ anions and electrostatic interactions via $-NH_3^{+}$, remedying the oxygen vacancies of SnO_2 and passivating the charged defects of the perovskites, respectively. This dipole alignment passivated the interfacial defects and offered barrier-free efficient charge transfer between SnO_2 and perovskites, leading to a PCE of 20.1%. Recently, the bi-directional functionalization via $-NH_2$ groups resulted in a PCE of 20.55%.[155] The chemical interface of $-NH_2$ groups expedited the charge transfer in the ETL and reduced the trap-state density in the perovskite.

Yu et al.[156] introduced the effect of molecular doping in an SnO_2 ETL on the overall performance of PSCs. The triphenylphosphine oxide (TPPO) molecule adopted n-type doping in SnO_2 to realize electron transfer from the R_3P^{+}–O^{-} σ bond to the peripheral Sn atoms rather than the atoms directly interacting at the surface, which produced delocalized electrons at the surface, leading to a reduced work function and increased conductivity (Fig. 13). Moreover, the significantly reduced energy barrier (i.e., 0.55 to 0.39 eV) after TPPO doping assisted the electron transfer and failed the charge accumulation at the interface, delivering a PCE of 20.69%. Similarly, graphdiyne doping in SnO_2 was employed to precisely engineer the interface due to heterogeneous perovskite nucleation, reducing the grain boundaries and defect density and leading to favourable C–O–π bond formation and band alignment. Consequently, this reduced the interfacial recombination and delivered a PCE of 20.74%.[157] In the future, molecular doping in the ETL can lead to achieving an excellent efficiency in PSCs, but the strong reducibility and stability under ambient conditions need be inspected thoroughly. Similarly, modulation of the perovskite crystallization process needs to be explored deeply to gain a deeper understanding of the process of realizing highly stable and crystalline perovskite films. Recently, it was shown that a $Ti_3C_2T_x$ quantum dot-modified SnO_2 ETL delivered a steady-state PCE of 22.1% with excellent charge extraction efficiency.[158]

4.1.2. Zinc Oxide (ZnO). Zinc oxide, an n-type semiconductor, offers high crystallinity at low processing temperature and favourable band alignment with hybrid perovskite. A direct bandgap of 3.2 eV, electron mobility of 205–300 $cm^2 V^{-1} s^{-1}$, and electron diffusion coefficient of 1.7×10^{-4} $cm^2 s^{-1}$ are the other major characteristics of ZnO, attracting researchers to explore it as a potential ETL to improve the performance of PSCs.[159–161] Various methods have been widely explored to process and coat ZnO films under an ambient atmosphere, and each method provides a unique way of controlling the structure, electronic properties, and surface defects,[162,163] which strongly affect the charge carrier transfer at the ZnO/perovskite interfaces. Furthermore, various morphologies (nanorods, nanosheets, nanofingers, and nano-flowers, etc.) of ZnO have been explored to improve the charge carrier collection efficiency at this interface. A simple and cost-effective approach to process the ZnO hole-blocking layer is repeated spin coating of a mixed solution of ethanol and zinc acetate as a precursor with intermediate drying to achieve the desired thickness. Son et al.[164] introduced the solution immersion method for the preparation of one-dimensional (1D) ZnO nanorods as an ETL in PSCs, which resulted in fast charge collection efficiency, leading to improved efficiency compared to that of TiO_2

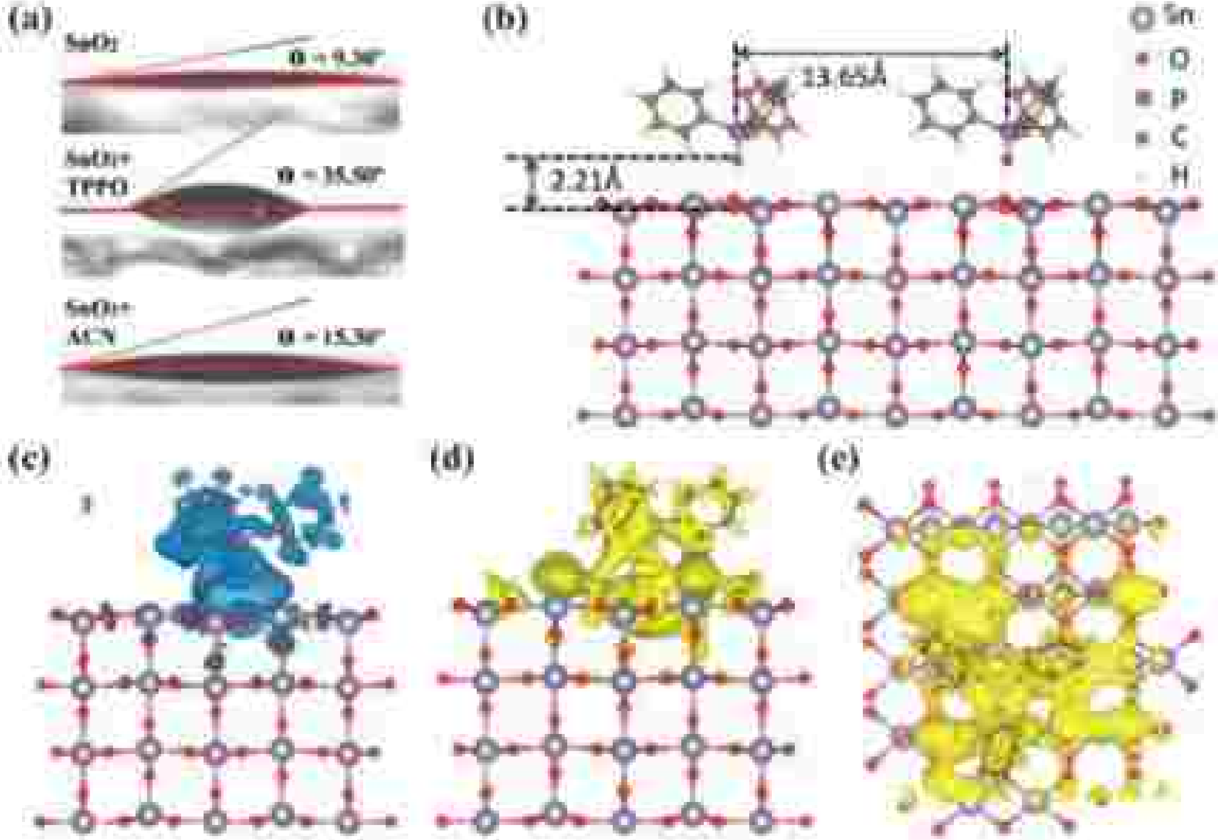

Fig. 13 (a) Surface contact angle of SnO_2, TPPO doped SnO_2, and acetonitrile treated SnO_2 on ITO substrate; the oxygen atom of TPPO (tetrahedral molecular connection with Sn atom leaving other three ends facing upward) delivered larger contact angle; (b) the side view of the relaxed model of TPPO absorbed $SnO_2(110)$ surface; charge density difference ($\Delta\rho$) of TPPO on $SnO_2(110)$ surface was evaluated at isovalue of 1.7×10^{-4} $|e|$ $Å^{-3}$; (c) blue indicates electron depletion, and (d) yellow indicates electron accumulation; (e) top view of charge density difference ($\Delta\rho$) of TPPO absorbed on $SnO_2(110)$, electron gain is indicated by yellow.[illegible] Reprinted with permission from *Adv. Mater.*, 2019, **31**, 1805944. Copyright (2019) John Wiley & Sons.

nanorods as the ETL. The single-crystalline 1D ZnO nanorods offered smooth charge transfer across the ZnO/perovskite interface due to the internal electric field along the *c*-axis, *i.e.*, common growth direction for ZnO nanorods and absence of grain boundaries.[illegible] The compact and uniform planar ZnO films indeed delivered relatively high-efficiency solar cells.

Tseng *et al.*[illegible] produced uniform ZnO films using RF sputtering under pure Ar and Ar + O_2 working gas to tune the surface electronic properties, which resulted in downshifting of the band structure, improving the electron injection and rendering an efficiency of ~15% combined with methylammonium lead iodide (*i.e.*, $MAPbI_3$). However, given that the high-energy ions used during sputtering damage the substrate and deteriorate the ZnO film quality, ALD has been utilized to obtain high-quality ZnO films.[illegible] The optimized thickness of 30 nm for ALD-grown ZnO films attained a high V_{OC} (*i.e.*, 0.97 V), FF (*i.e.*, 48%), and J_{SC} (*i.e.*, 18.15 mA cm^{-2}) of the PSCs. This study revealed a better excitation dissociation rate at the ZnO/perovskite interface, hinging on the exciton lifetime and photo-induced absorption strength. Nevertheless, an increase in thickness beyond 30 nm caused a high series resistance, and the performance of the PSCs decreased. Besides, the spray coating technique was also explored for the mass production of planar ZnO films over a larger area.[illegible] Hydrothermally grown 1D hexagonal ZnO nanorods exhibited high charge conduction due to their sparsely populated conduction band and showed a good agreement between the experimentally measured J_{SC} and integrated current density calculated from the external quantum efficiency.[illegible]

The two major drawbacks of ZnO ETLs are the severe charge recombination at the ZnO/perovskite interface due to the high density of surface defect states and their poor chemical stability due to the presence of hydroxyl groups and organic residue on the surface of ZnO, which deteriorate cell efficiency. Notably, the presence of volatile organic residue on the surface of ZnO enables the penetration of atmospheric water/oxygen at the ZnO/perovskite interface and degrades the perovskite, leading to the operational instability of PSCs.[illegible] Thus, this has stimulated researchers to investigate other possibilities of ZnO surface control to overcome the interface stability. The chemical behavior of the ZnO surface, which is basic in nature, is responsible for the deprotonation of the methylammonium cation to form methylamine through an acid–base reaction, which causes the perovskite to undergo thermal decomposition even in the absence of hydroxyl groups and residual organic ligand at the ZnO surface.[illegible] Density functional theory (DFT) calculations for the geometry optimization of the

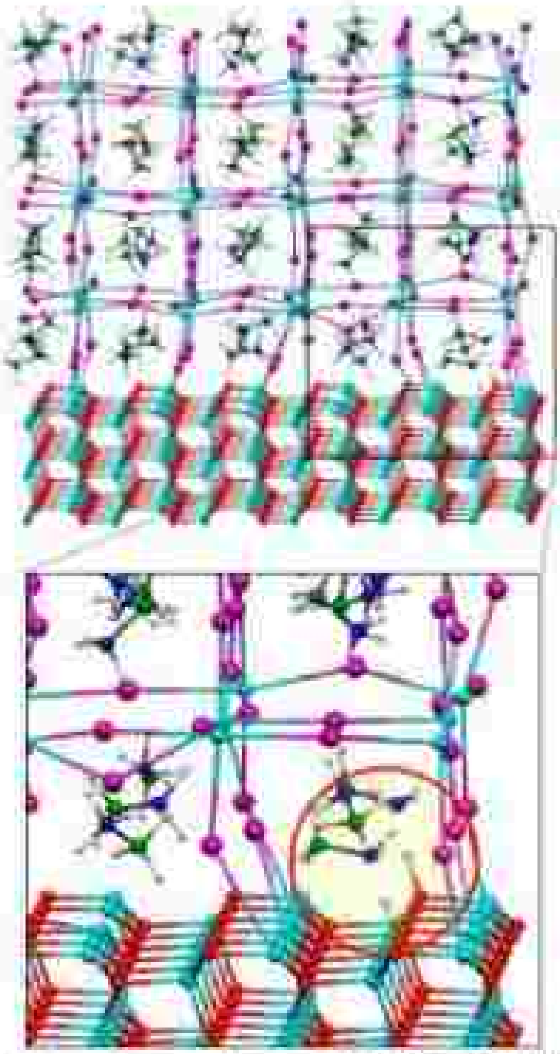

Fig. 14 Optimized geometrical structure of the ZnO ETL and $CH_3NH_3PbI_3$ perovskite (upper panel). The magnified structure of deprotonated methylammonium cations (lower panel) from the portion marked in the upper panel.[147] Reprinted with permission from (Chem. Mater., 2015, **27**, 4229–4236). Copyright (2015), the American Chemical Society.

ZnO/perovskite structure revealed that the deprotonation of the methylammonium ion (Fig. 14) is a constructive guide to develop PSCs capable of withstanding harsh temperature conditions.

Moreover, creative strategies such as doping and surface passivation of ZnO have been effectively used in search of its excellent performance as an ETL in PSCs. Both planar and nanostructured ZnO ETLs were doped with elements such as Mg,[illegible] Al,[illegible] Li,[illegible] and Sn[illegible] to develop low defect sites, larger surface area, and rapid electron extraction, which are some of the prerequisites for efficient ETLs. Besides, recently, the ZnO surface was modified with methylammonium chloride (MACl),[illegible] carbon nanotubes (CNTs),[illegible] and ethylene diamine tetraacetic acid (EDTA)[illegible] to eliminate the deprotonation ability and enhanced stability of the ZnO/perovskite interface was achieved.

Separately, the most widely studied optoelectronic material, aluminium-doped ZnO (*i.e.*, AZO), has been proposed as an ETL and transparent conducting electrode in PSCs, which also improves the thermal stability by decreasing the Lewis acid-base chemical reaction at the ZnO/perovskite interface.[illegible] A monolayer of Cs and Li-doped ZnO as the ETL in a PSC delivered a PCE of 18%, which is comparable to that of the well-accepted TiO_2. This is attributed to the increased electron density due to the decrease in trap density by reducing the oxygen vacancies at the ZnO surface.[illegible] The doping of indium facilitated the dense growth of ZnO:I nanopillars and led to a matching work function between the ETL and perovskite, which resulted in a PCE of around 18%.[illegible] The doping of ZnO[illegible] is a common and effective approach to fine-tune the position of the Fermi level (E_F) and band structure and increase the conductivity to avoid interface charge recombination by achieving an optimized CB edge difference between ZnO and perovskite. Alternatively, the surface passivation strategy helps to enhance the thermal stability during annealing,[illegible] improve the morphology of the perovskite layer,[illegible] and reduce the back electron transfer and charge recombination.[illegible] ZnO ETLs passivated with thin layers of MgO,[illegible] TiO_2,[illegible] Zn_2SnO_4,[illegible] Nb_2O_5,[illegible] SnO_2,[illegible] *etc.* were used to limit the degradation of the perovskite absorber due to the surface defects of ZnO at the perovskite/ZnO interface. The well-optimized passivation of ZnO with TiO_2 using the wet chemical approach of layer-by-layer absorption and reaction (LBLAR) method[illegible] achieved an efficiency of ~13.3% with better long-term stability compared to unpassivated ZnO nanorods (Fig. 15).[illegible]

Overall, the degradation and thermal decomposition of perovskite due to the ZnO surface hinder the long-term stability and outdoor applications of ZnO-based PSC devices. Therefore, more efforts by the broader research community are required to search for novel ways other than passivation that can stop the deprotonation of methylammonium and also provide smooth charge transfer across the ZnO/perovskite interface.

4.1.4. Ternary metal oxides. Ternary metal oxides with the perovskite structures of ABO_3 and A_2BO_4 are gaining more attention than binary metal oxides, given that they allow better tunability of the bandgap, work function, and conductivity by adjusting the relative ratio of cations.[illegible] $BaSnO_3$ (BSO) is a wide bandgap (*i.e.*, 3.2 eV) n-type transparent semiconductor with a perovskite structure similar to the photoactive layer. High-temperature processed BSO led to reduced charge recombination and charge transfer resistance at the BSO/perovskite interface, delivering PCEs close to 12%.[illegible] Additionally, one-dimensional BSO nanorods showed better electron conduction subject to direct pathways and less grain boundaries than nanoparticles.[illegible] Further, to gain atomic insights into the BSO/perovskite interface, first principal DFT calculations were performed by Guo *et al.*,[illegible] revealing large interface binding energies, favouring robust interface and charge transfer capability, which were shown to further improve with the doping depth of La in BSO. Moreover, theoretical studies also predicted the easy bandgap tuning of BSO by substituting La[illegible] or Sr[illegible] to produce optimal band alignment for improved device

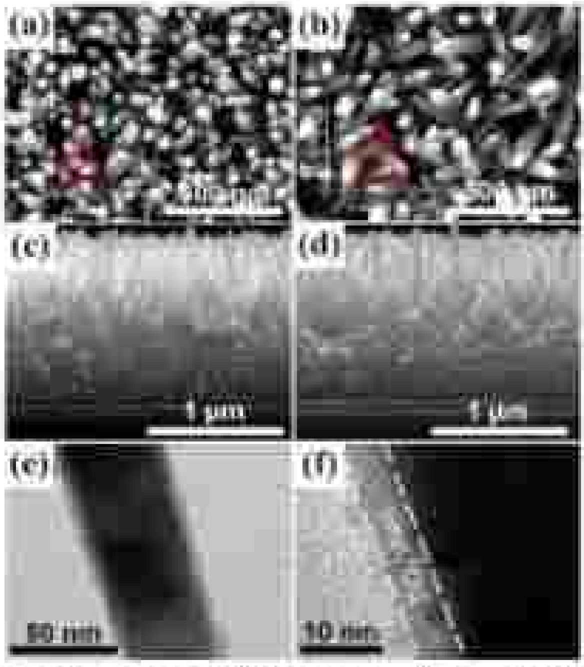

Fig. 15 SEM images of ZnO nanorods (a and c) without and (b and d) with TiO_2 passivation, depicting the top and cross-sectional views, respectively. (e) TEM and (f) HRTEM images of ZnO nanorod with TiO_2 passivation. The yellow dashed line in the HRTEM image marks the edge of the ZnO/TiO_2 nanorod.[196]

performance. Likewise, La-doping of BSO via the superoxide colloidal solution route was shown to yield improved electron mobility and optimal bandgap of BSO, which delivered an efficiency close to ~21% from the PSCs fabricated with a single cation lead triiodide. Recently, Zn doping also led to improved interfacial contact and reduced charge recombination at the interface of BSO.[200]

$SrTiO_3$ (STO), having high electron mobility and a slightly higher conduction band than TiO_2, has also been employed as the ETL for PSCs, giving a PCE of 10%.[201] This striking device performance was ascribed to the STO/perovskite interface with reduced charge recombination due to the high dielectric constant of STO and formation of a uniform photoactive layer with large crystals on STO, allowing complete surface coverage.[202] Unfortunately, the high-temperature processing, poor average J_{SC}, and inadequately studied STO/perovskite interface were limitations in the initial stage. However, Neophytou et al.[203] achieved a PCE of 19% from low temperature (150 °C)-processed STO as the ETL, which was attributed to the better optical transparency, reduced interfacial trap state density, improved electron transport, and efficient charge extraction. Despite the long term stability under UV light illumination, the conduction band edge of STO is unfavourable for the injection of electrons from the perovskite layers. Therefore, tuning of the CB position of STO by Nb doping, together with the removal of SrO phase segregated on the surface of Nb-doped STO, was shown to enable fast charge transfer at the interface, which collectively resulted in the highest PCE of 20.2%.[204] In parallel attempts to use STO as the ETL of PSCs, a variety of nanocomposites such as graphene/STO,[205] 3D self-branching of TiO_2/STO nanoparticles,[206] and Al_2O_3-graphene/STO[207] has been employed to achieve the highest PCE of close to 20.5%. Besides, $BaTiO_3$ (BTO), a ferroelectric material, has also been utilized as the ETL in PSCs owing to its spontaneous polarization, which drives the photogeneration of electrons to improve the transport and charge extraction.[209] The use of a mesoporous double layer of BTO/TiO_2[210] and ultrathin layer of BTO to modify the mesoporous TiO_2-perovskite interface[211] resulted in boosted charge extraction and reduced charge recombination. Also, doped ABO_3 perovskites such as Y-doped $SrSnO_3$[212] and La-doped $SrSnO_3$[213] have helped to achieve an efficiency close to 19%.

Ternary metal oxides besides the ABO_3 perovskite structure such as A_2BO_4 and $A_2B_2O_5$ have been scarcely studied as ETLs in PSCs. Among them, particularly, Zn_2SnO_4 (ZSO) is an up-and-coming alternative to TiO_2 in PSCs due to its comparable conduction band edge, higher electron mobility, much faster charge injection, and high electron diffusion efficiency, as observed by time and frequency-resolved spectroscopy.[214] Moreover, it provides negligible hysteresis and extraordinary stability with acid/base and polar molecules, and also enhances the crystallization of the perovskite layer. Its refractive index close to FTO permits high transmittance in the visible range. Furthermore, the use of ZSO as an ETL instead of ZnO plays a dual role by improving the crystallization of the perovskite without antisolvent treatment and providing increased stability without encapsulation.[215] Also, the use of ZSO/ZnO and ZSO/Al:ZnO nanocomposites as ETLs has resulted in better transmittance, electrical conductivity, and charge collection efficiency.[216,217] Amorphous ZSO films with extreme surface uniformity delivered an efficiency close to 20% in the presence of the FAMAPbI_3 perovskite light absorber.[84] In an attempt to overcome the differences in charge diffusion lengths between the perovskite and transport layers, a bulk heterojunction (BHJ) of a composite of ZSO nanoparticles and perovskite was also explored as the photoactive layer (Fig. 16). The enhanced charge collection efficiency, improved morphology of the perovskite layer with large crystal size, balanced charge carrier mobility, and reduced trap density of BHJ films helped to achieve an efficiency close to 21%.[218] Finally, a mesoporous layer of the $Zn_2Ti_3O_8$ perovskite structure was employed as an ETL in a PSC, resulting in a PCE of 17.2%.[219]

4.1.5. **Scaffolding technique**. The scaffolding technique has attracted attention due to its ability to exploit the long charge diffusion lengths of the perovskite light absorbers. The dielectric scaffolds offer a higher level of conduction band edge than the perovskite absorbers and prohibit the reverse electron transport from the perovskite, increasing the V_{OC} of PSCs.[220,221] Moreover, the implementation of insulating scaffolds is possible due to the long-range balanced electron and hole diffusion lengths of organic–inorganic perovskites. A mesoporous metal-oxide scaffold contributed to the electron–hole diffusion length of ~ >1 µm in a mixed halide ($CH_3NH_3PbI_{3-x}Cl_x$) and ~100 nm in triiodide ($CH_3NH_3PbI_3$) perovskite absorbers.[222] Lee et al.[223] demonstrated the use of a mesostructured

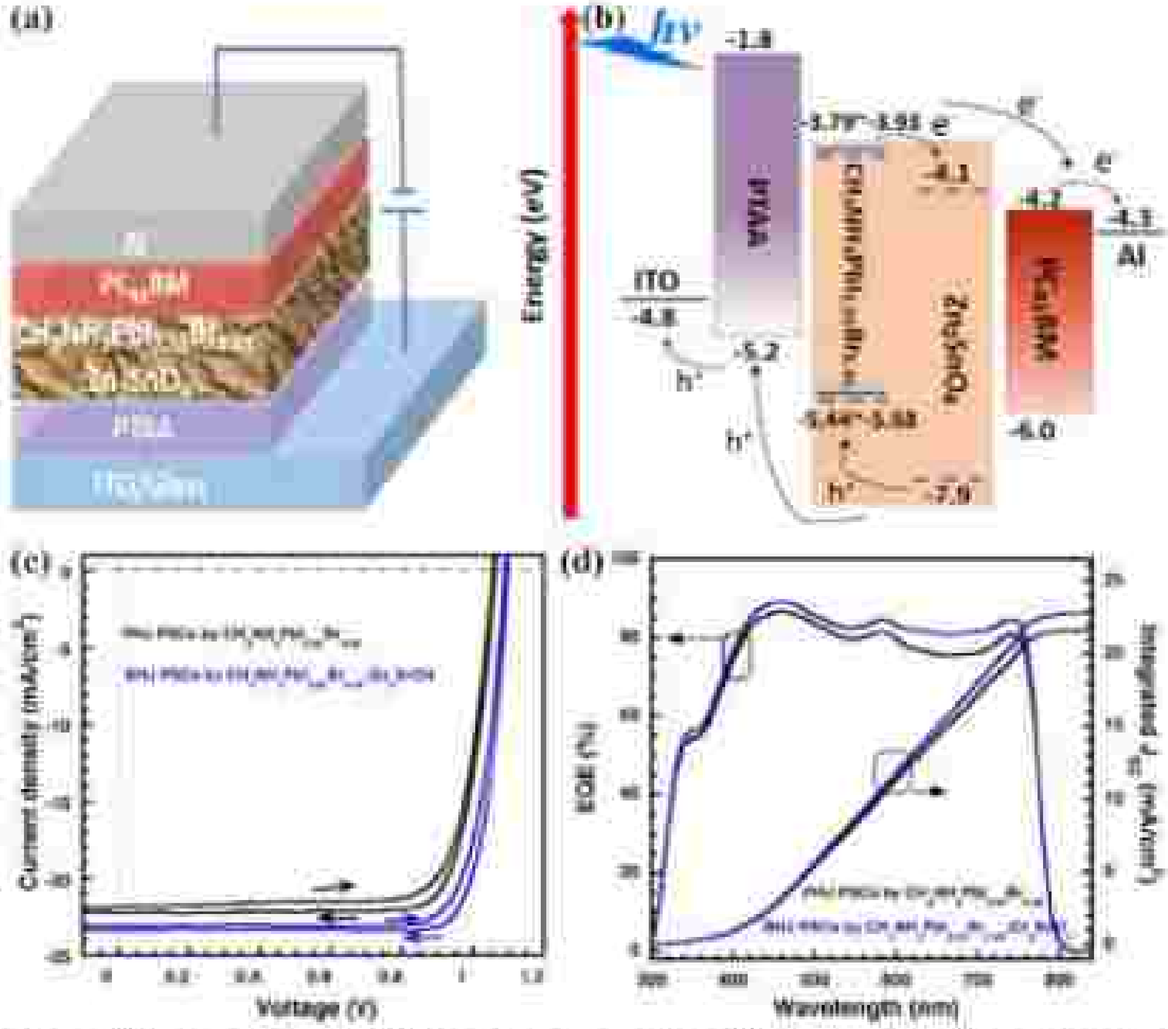

Fig. 18 Schematic of (a) device structure and (b) band diagram of bulk heterojunction (BHJ) PSCs. (c) J–V characteristics and (d) EQE spectra (with integrated J_{SC}) of planar heterojunction (PHJ) and BHJ PSCs, respectively.[illegible] Reprinted with permission from ACS Appl. Mater. Interfaces, 2019, 11, 34070–34078. Copyright (2019) the American Chemical Society.

insulating scaffold to enhance the light absorption and photon management. The assembly of perovskite absorbers over the mesostructured scaffolds forced the electrons to reside in and be transported through the perovskite, thereby being effective in providing a better PCE. The balance between series and shunt resistances was obtained by a thicker capping layer of less conductive spiro-OMeTAD (i.e., $\sim 10^{-5}$ S cm^{-1}). The self-connected percolating network of scaffolds with a larger surface area infiltrated the perovskite and allowed better charge transport. In these scaffolds, the photo-generated electrons flow through the perovskite absorbers to the front electrodes rather than injecting into the oxide layer, and the holes inject into the organic hole conductor to flow through the back contact.

Bell et al.[illegible] systematically explored the effect of inorganic scaffolds on the performance of PSCs, which efficiently absorb light, generate charges, and transport electrons/holes with little recombination losses. This approach eliminates the use of discrete hole and electron transport media in interpenetrating composites by introducing an ambipolar material for the conversion of absorbed photons into collected charges and transport of both electrons and holes. A porous Al_2O_3 scaffold placed between TiO_2 and the perovskite absorber supported the charge separation and transport to deliver a PCE of 12.3%. Moreover, the ultraviolet light instability of TiO_2, due to the surface oxygen vacancies promoting the degradation of perovskite absorbers, was countered by introducing a mesostructured inert Al_2O_3 scaffold in an organometal tri-halide PSC to form a p–i–n heterojunction with spiro-OMeTAD HTL.[illegible]

For the efficient transfer of photogenerated electrons by the inorganic scaffolds, the infiltration of perovskites deep inside the scaffold is an important issue to be investigated. Hwang et al.[illegible] controlled the size of monodispersed SiO_2 nanoparticles and observed an excellent performance at the diameter of 50 nm due to the optimized domain size of the perovskites and stronger optical absorption. The fragmentary infiltration of perovskites in the scaffold with a particle diameter <50 nm restricted the transport of electrons, whereas the needle-like growth of the perovskite grains over the particles with a size of >50 nm decreased the absorption of light due to the complex scattering behaviour, thereby impeding the performance of PSCs. However, the inclusion of SiO_2 nanoparticles in the matrix of TiO_2 formed a mesoporous composite scaffold, which led to an increase in photocurrent by affecting the optical properties of the mesoporous scaffold and altering the ion migration at the perovskite interface, providing a beneficial effect to render a PCE of 16.77%.[illegible] *Zhao et al.*[illegible] replaced the Al_2O_3 scaffold with a hygroscopic polyethylene glycol (PEG) scaffold to control the PSC performance in a highly humid environment. Even though the hygroscopic PEG absorbs H_2O and prevents the evolution of PbI_2 (*i.e.*, degradation of perovskite) by forming a compact moisture barrier in the vicinity of the perovskite grains, the PCE did not exceed 15.4% for unknown reasons. Further, scaffold and mesoporous transport layer combinations have been made to enhance the charge transport synergistically and suppress the charge recombination at the perovskite/transport layer interface. In these combinations of scaffolds, the ratio of scaffold to transport layer nanoparticles is controlled to optimize the transport processes.[illegible] The TiO_2 ETL quickly transfers the electrons through a wide interface with the perovskite, but the insulating Al_2O_3 scaffold directs the electrons to transport entirely through the perovskite. Nevertheless, the heterogeneous combination of Al_2O_3 and TiO_2 directs the electrons to take easy pathways either through the ETL or the perovskite (Fig. 17) and renders a good PCE by engineering the difference in charge carrier balance and ion migration. Moreover, a bilayer mesoporous scaffold of TiO_2 and Al_2O_3 was shown to enhance the air-stability of ambient-processed PSCs with a PCE of 16.84%.[illegible] The inclusion of the Al_2O_3 scaffold not only protected the infiltrated perovskite from degradation due to moisture attack but also offered stable light transmission, ensuring an adequate yield of photo-generated charge carriers, and mitigated the charge transportation property deterioration.

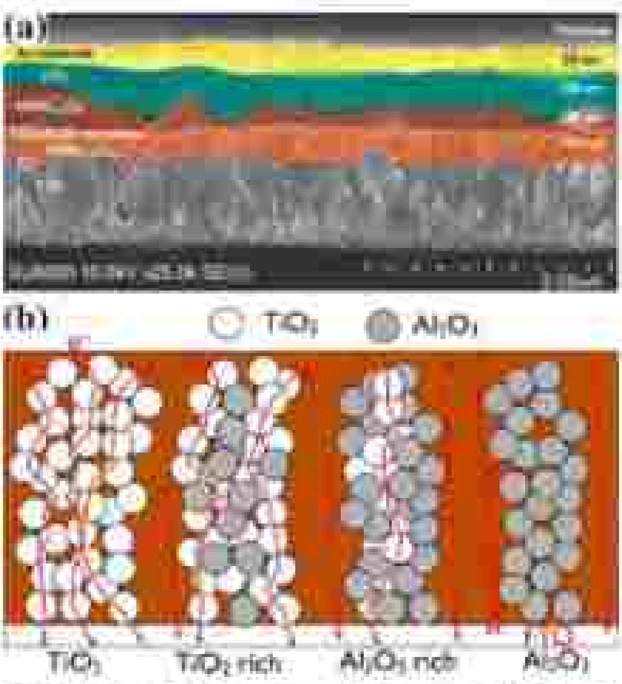

Fig. 17 (a) Device structure composed of mesoscopic Al_2O_3 scaffold, TiO_2 ETL and $FAPbI_3$ perovskite. (b) Scaffold (i.e., TiO_2/Al_2O_3) constitution variation-dependent electron transport mechanism.[illegible] Reproduced with permission from *ACS Appl. Mater. Interfaces*, 2016, **8**, 4608–4615. Copyright (2016), the American Chemical Society.

Kwon *et al.*[illegible] introduced parallelized nanopillar PSCs using anodized alumina oxide (AAO) as a scaffold. The AAO scaffold provided control over spatial distribution, relative volume fraction, and visible range transparency of the perovskite absorber. The vertically aligned perovskite pillars terminated the shunt currents and modulated the visible transmittance due to the vertical electronic transport and modulated the parasitic scattering because of the uneven deposition of the perovskite. The incorporation of an MoO_3 buffer layer and TiO_2 ETL together with the AAO scaffold controlled the ion migration at the perovskite interface and delivered a PCE of 9.6%.

Recently, Xu *et al.*[illegible] introduced slot-die coating for the mass production of PSCs consisting of a TiO_2 ETL and ZrO_2 scaffolds. Even though the infiltration mechanism in the scaffold was discussed based on the Lucas-Washburn model, further understanding of the coating parameters and their effect on the charge transport at the interface is recommended for the mass production of the PSCs. Qiulang *et al.*[illegible] explored an Al_2O_3 scaffold with Li-doped SnO_2 ETL to achieve an enhanced PCE. The Li-doped ETL and scaffold inhibited the charge recombination and prolonged the electron lifetime, but the PCE was restricted to 10.1% due to the unfavourable participation of the grain boundaries and bulk of the materials in the charge transfer process.

Overall, SiO_2,[illegible] Al_2O_3,[illegible] AAO and ZrO_2[illegible] scaffolds have been explored for the better infiltration of perovskites to gain high PCEs, but most of them delivered efficiencies in the range of 10% to 16%. Furthermore, they do not eliminate the need for a compact hole-blocking layer or ETL to fabricate efficient PSCs. The thickness, roughness, and porosity of the scaffolds need to be considered for controlling the charge transport, diffusion coefficient, and collection efficiency of PSCs.

4.1.6. Other inorganic ETLs. In addition to the well studied binary metal oxides such as TiO_2, ZnO, and SnO_2, many other metal oxides such as WO_x,[illegible] CeO_x,[illegible] In_2O_3,[illegible] Nb_2O_5,[illegible] and Fe_2O_3[illegible] have been explored as ETLs for PSCs. Cerium oxide (CeO_x) offers several benefits including wide bandgap (*i.e.*, 3.5 eV), high dielectric constant (ε = 26),[illegible] sufficient optical transparency (refractive index of 2.1–2.7),[illegible] good ionic conductivity (σ = 120 S cm^{-1} K^{-1}),[illegible] high thermal and chemical stability, ease of processing, low cost, and earth abundance, thereby qualifying as a highly promising ETL material.[illegible] The low-temperature processing of CeO_x (x = 1.81 °C at 100 °C) with an inverted architecture and CeO_x (x = 1.87 °C at 150 °C) with a planar device architecture resulted in PCEs of 16.1% and 17.4%, respectively.[illegible] Recently, lower temperature processed CeO_x (at 80 °C) as an ETL was shown to help realize a PCE of 14.6%.[illegible] The dense CeO_x layers not only protect the perovskite absorber from moisture but also act as a diffusion barrier to prevent corrosion.[illegible] Additionally, CeO_x nanocrystals were utilized as a double ETL with PCBM[illegible] and ZnO[illegible] to achieve the best efficiency values of 17.3% and 19.5%, respectively. The improvement in PCE with double ETLs was possible due to the decreased series resistance for charge extraction.[illegible] CeO_x, when introduced with regular ETLs (ZnO), reduces the work function of the electron transport material (*i.e.*, ETM) and eliminates the interfacial barrier. The rich discrete energy levels of CeO_x also prevent the UV-induced degradation of the perovskite absorber.[illegible]

Tungsten oxide (WO_x) is another crucial ETM possessing excellent chemical stability, wide bandgaps (2 to 3 eV),[illegible] and high electron mobility (10 to 20 $cm^2 V^{-1} s^{-1}$).[illegible] Mahmood *et al.*[illegible] explored 0D, 1D, and 2D nanostructures of WO_3 as ETLs for PCSs. The 2D WO_3 nanosheets offered good perovskite infiltration and fast carrier charge dynamics, thereby performing well compared to the nanoparticle and nanorod morphologies. However, they suffered from recombination losses at the WO_3/perovskite interface, which had to be controlled by forming WO_3–TiO_2 core–shell structures. Amorphous WO_x offered control over the conductivity and short circuit current, leading to an improved PCE (∼11%) at the cost of lower transmittance (80% of TiO_2) and V_{OC} due to the inherent charge recombination.[illegible] Conversely, a WO_x film introduced with TiO_2 as a bilayer ETL served as an antireflection coating, rendering an enhanced J_{SC}[illegible] and improved non-wettability, which led to better crystallization of the $CH_3NH_3PbI_3$ perovskite and resulted in a PCE of ∼20%.[illegible] The high-temperature processing of amorphous WO_x incorporates defects, and subsequently deteriorates the performance of PSCs. On the contrary, ultra-low temperature (<50 °C) processing scales down the trap densities and offers high electron mobility, thereby yielding an efficiency of ∼20%.[illegible]

The higher built-in potential achieved by the α-Fe_2O_3 ETL/perovskite interface led to more efficient charge extraction/transport, reduced charge accumulation, and less charge recombination than TiO_2 ETLs.[illegible] The solution-processed Ni-doped (4%) α-Fe_2O_3 yielded an efficiency of ∼15% with the $CH_3NH_3PbI_3$ perovskite owing to its enhanced electrical conductivity and lowered conduction band minimum, and also exhibited good stability upon exposure to ambient air and high-level UV irradiation.[illegible] The effective approach of doping non-equilibrium Ti^{4+} in the lattice of Fe_2O_3 via the quenching process reduced the surficial oxygen vacancies and structural defects, which act as deep trap states. These states are responsible for the sluggish electron charge transfer and accumulation of charges at the ETL/perovskite interface, delivering a PCE of 17.8%.[illegible] The quenching approach assisted with a uniform doping distribution and increased doping density in the bulk lattice of Fe_2O_3 by suppressing the segregation of TiO_2 on the surface (Fig. 18(a)). Likewise, 1D core–shell nanostructures serve to reduce the absorber instability and increase the mobility and recombination resistance. The core–shell structures of ZnO/SnO_2,[illegible] Al_2O_3/ZnO,[illegible] WO_3/TiO_2,[illegible] TiO_2/MgO,[illegible] *etc.* have been explored to gain efficient electron injection and enhancing the recombination resistance at the ETL/perovskite interface. A thin MgO layer (large bandgap of ∼8 eV) coating over

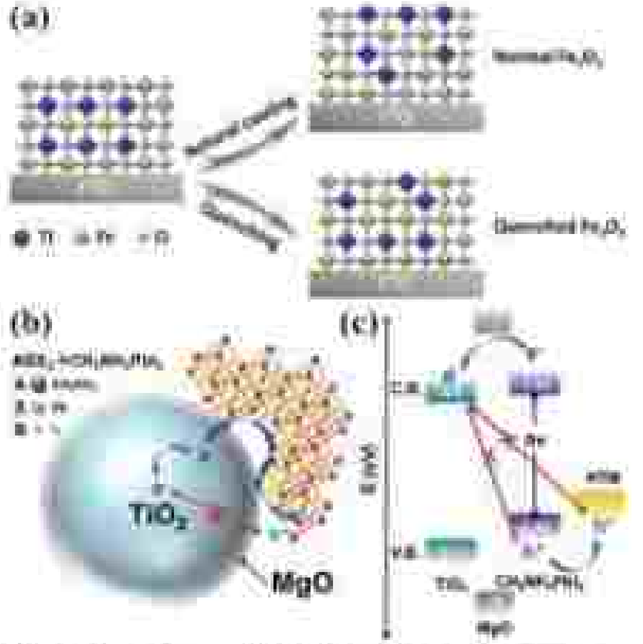

Fig. 18 Schematic representation of (a) mechanism for increased doping density in the bulk and suppressed segregation on the surface of Ti: Fe_2O_3,[illegible] (b) charge transfer mechanism, and (c) band energy diagram of the MgO/TiO_2 core–shell nanoparticle based PSC.[illegible]

mesoporous TiO_2 particles increased the recombination resistance through an effective charge transfer mechanism (Fig. 18(b) and (c)), leading to a better V_{OC} and FF (*i.e.*, 0.89 V and 67.1%) than that of the pristine TiO_2 (*i.e.*, 0.85 V and 71.2%), respectively.

Moreover, the well-optimized In_2O_3, which satisfies the properties required for excellent ETLs such as wide bandgap (*i.e.*, 3.8 eV), high electron mobility (μ = 10 $cm^2 V^{-1} s^{-1}$),[illegible] high transparency, antireflection property, and thermal stability, offer efficient electron extraction and charge transfer, producing a stable efficiency of ∼14% for 31 days when In^{3+} was stabilized by inhibiting hydrolysis using acetylacetone.[illegible] The PCE was further improved (*i.e.*, up to 18.12%) by modifying the In_2O_3/perovskite interface with a PCBM interlayer.[illegible] The doping with Ce,[illegible] Zr,[illegible] and Sn[illegible] resulted in higher electron mobility and lower parasitic absorption in the NIR range than that of pristine In_2O_3 and resulted in a PCE of above 20%. Alternatively, Nb_2O_5 is a visibly transparent, air-stable, and water-insoluble material with extensive polymorphism, and its bandgap can be tuned by controlling the stoichiometry and crystallinity.[illegible] Kogo *et al.*[illegible] first introduced Nb_2O_5 as an effective ETL with mesoporous Al_2O_3 perovskite-based PSCs and observed a higher V_{OC} (1.13 V) than that with TiO_2. However, the room-temperature processed amorphous Nb_2O_5 rendered a PCE of 17% and replaced the crystalline Nb_2O_5 as an ETL in flexible PSCs.[illegible] However, the direct e-beam-evaporated[illegible] and spin-coated[illegible] pristine Nb_2O_5 were shown to offer smooth charge transfer by reducing the charge resistance and recombination at the interface, producing an efficiency of ∼19%. Moreover, 5% Zn doping further assisted in faster charge extraction and reduced charge recombination at the Nb_2O_5 ETL/perovskite interface.[257] The Nb_2O_5 passivation over TiO_2 and ZnO was shown to improve the crystallinity of the perovskite overlayer, and thereby the stability of PSCs.[182,232] Low-temperature processed CdSe,[233] CdS,[234] and Bi_2S_3 nanocrystals are also appealing in the foregoing context due to their corresponding smaller interfacial barrier with suppressed charge trapping and smooth charge transfer without accumulation at the interface.[235] Besides the above-mentioned developments to enhance the capabilities of inorganic ETLs, plasmonic nanoparticles (such as Au and Ag cores) have also been incorporated in inorganic ETLs to enhance their light absorption even further and reduce the exciton binding energy.[illegible]

Even though several inorganic materials have been demonstrated as alternatives to the most common inorganic ETLs (i.e., TiO_2, ZnO, and SnO_2), various combinations of earth-abundant constituent elements in terms of doping, composites, core-shell structures, etc. need to be explored for controlled interfacial reactions, delivering a higher PCE. Additionally, theoretical work on new inorganic ETL materials is essential to understand the electronic and structural properties of the interface, leading the way for a targeted experimental approach.

4.2. Organic ETLs

Organic n-type semiconductors are promising alternatives to metal-oxide-based ETLs due to their good thermal/chemical stability, low-temperature processability, LUMO level matching with the conduction band of the perovskite, etc.[illegible] Additionally, organic ETLs can mend the surface defects by coordination with lead ions and reduce the charge-trap related recombination at the ETL/perovskite interface.[illegible] In contrast, low-temperature processed inorganic ETLs either require high-cost techniques or provide non-uniform film coverage.[illegible] Therefore, various researchers have replaced inorganic ETLs with organic counterparts to address these problems. Particularly, fullerene and its derivatives, with excellent electron mobility and ability to passivate the trap state on the surface of the perovskite layer, have shown the promising possibility of utilization as ETMs.[illegible]

A [6,6]-phenyl-C_{61}-butyric acid methyl ester (PCBM) derivative of fullerene, a well-studied compound in organic solar cells, has been used in low temperature-processed PSCs as an ETL, which efficiently blocks the holes at the perovskite/PCBM interface because of the higher VB of the perovskite than the HOMO level for PCBM, resulting in a PCE of ~12%.[illegible] Furthermore, graphene quantum dot/PCBM nano-composite[illegible] was shown to improve the electrical conductivity compared to pristine PCBM. A blend of polystyrene/PCBM[illegible] was shown to yield smooth films together with a uniform layer of organic ETL, which helped to enhance the charge collection. Moreover, a blend of organic and inorganic ETLs was also explored to govern the morphology and control the stability of the perovskite absorber and improve the device performance. Zeng et al.[illegible] achieved a PCE of ~13% from a composite of CdSe quantum dots with PCBM as the ETL, increasing the built-in potential at the perovskite/ETL interface, which facilitated efficient electron-hole pair separation and enhancement of the photocurrent.

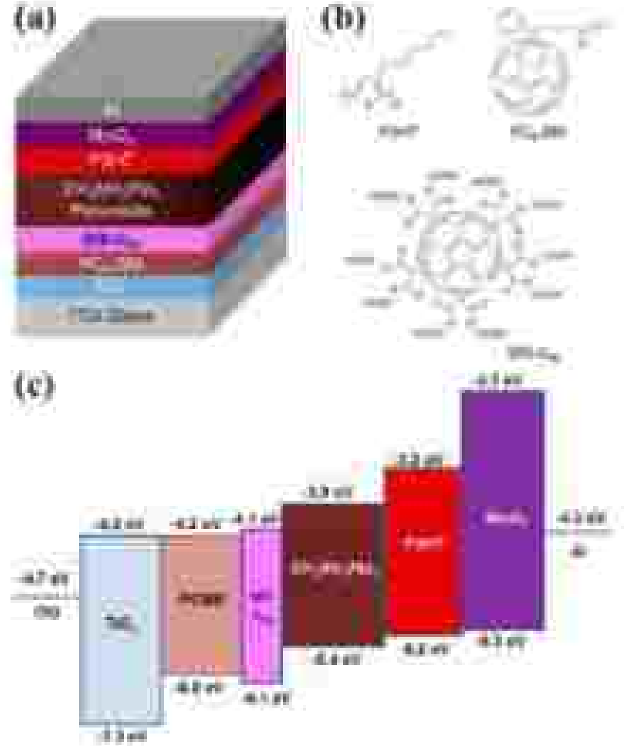

Fig. 19 (a) The device assembly of perovskite hybrid solar cells incorporated with $PC_{61}BM$ the electron extraction layer. (b) Molecular structures of $PC_{61}BM$, water soluble fullerene derivative C_{60} ... and P3HT. (c) LUMO and HOMO energy levels of the materials used in the perovskite hybrid solar cells.[illegible] Reprinted with permission from ACS Appl. Mater. Interfaces, 2015, 7, 1153–1159. Copyright (2015) American Chemical Society.

Liu et al.[illegible] explored thin films of organic $PC_{61}BM$ over inorganic TiO_2 coupled with C_{60} as the ETL and observed efficient charge extraction at the ETL/perovskite interface (Fig. 19).

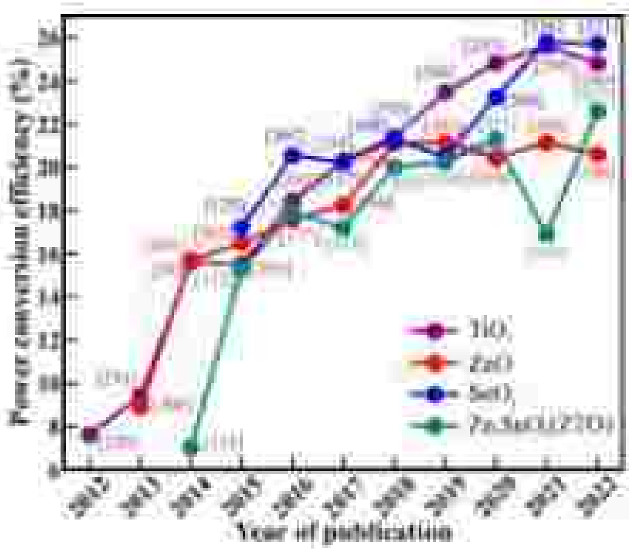

Fig. 20 Comparative study of the influential ETLs developed by year to gain the best maximum efficiency in the last decade (collected from the Web of Knowledge up to 15th August 2022).[illegible]

Table 1 A brief summary of inorganic ETLs processed with various synthesis methods and their corresponding device performance parameters

S. no.	Device configuration	Method^a	V_{oc} [V]	J_{sc} [mA cm^{-2}]	FF	PCE [%]	Year	Ref.
Titanium dioxide (TiO_2)								
1.	FTO/LD TiO_2/$FA_xMA_{1-x}PbI_{3-y}Cl_y$/spiro-OMeTAD:Li-TFSI:TBP/Au	CBD	1.174	25.42	0.831	24.81	2022	299
2.	FTO/KSCl/TiO_2/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	DC	1.11	23.14	0.807	20.75	2022	318
3.	FTO/Ta:TiO_2/Cs(FAMA)Pb(IBr$)_3$/spiro-OMeTAD/Au	DPM	1.094	23.94	0.781	20.45	2022	319
4.	FTO/c-TiO_2/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	SC/MW	1.07	22.18	0.75	17.87	2022	320
5.	FTO/c-TiO_2/mp-TiO_2/α-$FAPbI_3$/OAI/spiro-OMeTAD/Au	SP	1.189	26.21	0.817	25.6	2021	298
6.	FTO/c-TiO_2/Li/Cl-TiO_2/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	SC	1.171	26.17	0.825	25.28	2021	118
7.	FTO/TiO_2/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	ALD	1.06	22.92	0.71	18.05	2021	98
8.	FTO/TiO_2/$FAPbI_3$/spiro-OMeTAD/Au	HT/E	1.16	24.56	0.808	22.99	2020	321
9.	FTO/Nb-TiO_2/(FAMACsPb(IBr$)_3$)/spiro-OMeTAD/Au)	SC	1.11	24.7	0.78	21.1	2020	322
10.	FTO/c-TiO_2/mp-TiO_2/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	HT	1.11	23.42	0.74	19.29	2020	323
11.	ITO/NH_4-TiO_2 NPs/Cs(FAMA)Pb(IBr$)_3$/spiro-OMeTAD/Au	SGS	1.10	23.15	0.767	19.33	2019	324
12.	FTO/TiO_2-B/($FAPbI_3$)($MAPbBr_3$)/spiro-OMeTAD/Au	SC	1.05	24.94	0.72	18.83	2019	325
13.	FTO/Y-TiO_2/$CH_3NH_3PbI_{3-x}Br_x$/spiro-OMeTAD/Au	HP	1.04	23.55	0.75	18.22	2019	108
14.	FTO/c-TiO_2/m-TiO_2 NC-NR/Cs(MAFA)Pb(IBr$)_3$/spiro-OMeTAD/Au	HT	1.015	22.91	0.74	17.2	2019	326
15.	FTO/c-TiO_2/a-SnO_2/Cs(MAFA)Pb(IBr$)_3$/spiro-OMeTAD/Au	SC	1.105	23.91	0.765	21.4	2018	295
16.	FTO/Nb-TiO_2/TiO_2 NR/$CH_3NH_3PbI_{3-x}Br_x$/spiro-OMeTAD/Au	HP	1.01	23.95	0.77	18.08	2018	116
17.	ITO/TiO_2-TOPO/$PC_{61}BM$/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	SC	1.10	23.11	0.802	20.2	2017	294
18.	FTO/TiO_2/FAMAPb(IBr$)_3$/spiro-OMeTAD/Au	SC	1.075	22.58	0.769	18.62	2016	293
19.	FTO/c-TiO_2/TiO_2 NF/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	CBD	0.985	22.0	0.72	15.71	2016	327
20.	FTO/TiO_2/mp-TiO_2 NT/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	ES	0.98	20.0	0.74	15.3	2015	293
21.	FTO/c-TiO_2/$CH_3NH_3PbI_{3-x}Cl_x$/P3HT/Ag	ALD	0.979	18.3	0.573	13.00	2015	328
22.	FTO/graphene/TiO_2/$CH_3NH_3PbI_{3-x}Cl_x$/spiro-OMeTAD/Au	SC	1.05	21.9	0.73	15.6	2014	29
23.	FTO/c-TiO_2/m-TiO_2/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	TO	1.03	21.57	0.63	13.07	2014	84
24.	FTO/c-TiO_2 NR/$MAPbI_3$/spiro-OMeTAD/Au	SC	0.955	15.6	0.63	9.4	2013	291
25.	FTO/c-TiO_2/$CH_3NH_3PbI_2Cl$/spiro-OMeTAD/Ag	SC	0.80	17.8	0.53	7.6	2013	210
Zinc oxide (ZnO)								
26.	FTO/ZnO/TA/Cs(FAMA)Pb(IBr$)_3$/spiro-OMeTAD/Au	SC	1.10	23.9	0.775	20.6	2022	306
27.	FTO/AZO/$CH_3NH_3PbI_3$/spiro-OMeTAD:Li-TFSI:TBP/Au	ALD	1.05	23.16	0.74	18.09	2022	329
28.	FTO/Mg:ZnO/$CH_3NH_3PbI_3$/spiro-OMeTAD:Li-TFSI:TBP/Au	RS	0.83	25.00	0.65	13.52	2022	330
29.	ITO/ZnO/ZnO-Cl/FACsPb(IBr$)_3$/spiro-OMeTAD/Ag	SC	1.16	22.86	0.797	21.37	2021	305
30.	FTO/ZnO/$ZnTiO_3$/spiro-OMeTAD/Au	HT	1.13	24.07	0.77	20.6	2021	331
31.	FTO/ZnO NR/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	SC	1.11	23.91	0.75	18.84	2020	332
32.	FTO/MLG/ZnO/FAMAPb(IBr$)_3$/spiro-OMeTAD/Au	SC/LPCVD	1.15	23.42	0.791	21.01	2019	303
33.	FTO/ZnO-MgO-EA$^+$/TiO_2/(Cs/FAMA)Pb(IBr$)_3$/spiro-OMeTAD/Au/graphene	SC	1.12	23.80	0.789	21.08	2018	60
34.	FTO/ZnO-K/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	SGS	1.12	23.0	0.771	19.90	2018	333
35.	ITO/c-ZnO/ZnO-UC/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	HT	1.11	22.42	0.719	18.28	2017	186
36.	ITO/AZO/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	RFS	1.07	21.5	0.733	17.6	2016	177
37.	ITO/Mg-ZnO/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	SC	1.07	20.1	0.742	16.3	2016	175
39.	PEN/ITO/ZnO/$CH_3NH_3PbI_3$/PTAA/Au	SP	1.10	18.7	0.75	15.6	2016	334
40.	ITO/PEDOT:PSS/$CH_3NH_3PbI_3$/ZnO/Ag/Al_2O_3-PET	ALD	1.02	20.73	0.764	16.2	2015	302
41.	FTO/c-ZnO/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	SC	1.01	20.4	0.749	15.7	2014	301
42.	FTO/c-ZnO/ZnO NR/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	HT	0.991	20.08	0.56	11.13	2014	167
43.	FTO/ZnO/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	CBD	1.03	16.98	0.511	8.9	2013	300
Tin oxide (SnO_2)								
44.	FTO/c-TiO_2/Pax QD SnO_2/$FA_xMA_{1-x}PbI_{3-y}Cl_y$/OAI/spiro-OMeTAD/Au	SC	1.176	26.09	0.838	25.72	2022	311
45.	FTO/SnO_2/SA + PEAI/Cs(FAMA)Pb(IBr$)_3$/spiro-OMeTAD/MoO_3/Ag	SC	1.148	23.16	0.831	22.15	2022	335
46.	FTO/SnO_2-LiOH/FAMAPb(IBr$)_3$/spiro-OMeTAD:Li-TFSI:TBP/Ag	SC	1.15	24.20	0.763	21.21	2022	336
47.	FTO/Cl-SnO_2/FAMAPb(IBr$)_3$/spiro-OMeTAD:Li-TFSI:TBP/Au	SC/DC	1.07	24.25	0.73	18.94	2022	337
48.	FTO/SnO_2/$FAPbI_3$:BDMDACl_2/spiro-OMeTAD/Au	SC	1.189	25.74	0.832	25.8	2021	210
49.	FTO/SnO_2/MAFAPb(IClBr$)_3$/spiro-OMeTAD/Au	CBD	1.181	25.14	0.848	25.2	2021	109
50.	FTO/SnO_2-K_2SO_4/Cs(FAMA)Pb(IBr$)_3$/spiro-OMeTAD:Li-TFSI:TBP/Ag	SC	1.2	23.89	0.771	21.18	2021	338
51.	FTO/SnO_2-CdS QD/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	HT/SC	1.11	23.41	0.78	20.78	2021	153
52.	FTO/SnO_2/$CH_3NH_3PbI_3$/spiro-OMeTAD/Ag	SC	1.14	22.58	0.76	20.34	2021	339
53.	ITO/SnO_2/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	SC	1.12	23.53	0.76	20.25	2021	152
54.	FTO/SnO_2/SnO_2-$TiCl_4$/$CH_3NH_3PbI_3$/spiro-OMeTAD/MoO_3/Ag	SC	1.08	22.56	0.75	18.33	2021	148
55.	ITO/SnO_2/SnO_2:KF/$CsPbI_2Br$/spiro-OMeTAD/MoO_3/Ag	SC	1.31	14.79	0.79	15.29	2021	340
56.	FTO/SnO_2-Au/$CH_3NH_3PbI_3$/spiro-OMeTAD/Au	CBD	1.13	22.61	0.79	20.14	2021	341
57.	FTO/SnO_2 NR/Cs(MAFA)Pb(IBr$)_3$/spiro-OMeTAD/Au	ET	1.15	23.45	0.78	21.05	2020	340
58.	FTO/SnO_2/SA/Cs(FAMA)Pb(IBr$)_3$/spiro-OMeTAD/Au	SC	1.15	22.80	0.78	20.41	2020	154

Table 1 (continued)

S. no.	Device configuration	Method[a]	V_{oc} [V]	J_{sc} [mA cm^{-2}]	FF	PCE [%]	Year	Ref.
59.	FTO/SnO$_2$-CNT/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.12	23.26	0.782	20.33	2020	338
60.	FTO/SnO$_2$/MgO/CsPbIBr$_2$/spiro-OMeTAD/Ag	SC	1.26	11.70	0.693	11.04	2020	341
61.	ITO/SnO$_2$/TPPO/Cs$_{0.05}$(MA$_{0.17}$FA$_{0.83}$)$_{0.95}$Pb(I$_{0.83}$Br$_{0.17}$)$_3$/spiro-OMeTAD/Au	SC	1.11	24.3	0.77	20.69	2019	156
62.	FTO/SnO$_2$/TiO$_2$/FA$_x$MA$_{1-x}$PbI$_{3-y}$Br$_y$/spiro-OMeTAD/Au	SC	1.10	24.2	0.77	20.5	2019	342
63.	FTO/SnO$_2$-NH$_4$Cl/Cs$_{0.05}$(FA$_{0.83}$MA$_{0.17}$)$_{0.95}$Pb(I$_{0.83}$Br$_{0.17}$)$_3$/spiro-OMeTAD/Au	SC	1.19	22.3	0.75	20	2019	343
64.	ITO/SnO$_2$/NGT/Cs$_{0.05}$(FA$_{0.83}$MA$_{0.17}$)$_{0.95}$Pb(I$_{0.83}$Br$_{0.17}$)$_3$/spiro-OMeTAD/Au	SC	1.17	18.67	0.75	16.34	2019	152
65.	ITO/SnO$_2$/C$_{60}$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.12	23.6	0.789	21.2	2018	308
66.	FTO/Mg:SnO$_2$ NR/SnO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	RGS	1.112	23.80	0.758	19.21	2018	343
67.	ITO/SnO$_2$-GQDs/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.13	23.05	0.776	20.23	2017	137
68.	FTO/SnO$_2$/MSC$_{60}$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	HT	1.039	23.62	0.75	18.21	2017	344
69.	FTO/SnO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Ag	ED	1.08	19.75	0.65	13.88	2017	138
70.	ITO/SnO$_2$/(FAPbI$_3$)$_{0.97}$(MAPbCl$_3$)$_{0.03}$/spiro-OMeTAD/Au	SC	1.10	23.28	0.731	20.38	2016	307
71.	FTO/SnO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.11	23.27	0.67	17.21	2015	135
Ternary metal oxides								
72.	FTO/LBSO/Cs$_{0.05}$FA$_{0.81}$MA$_{0.14}$PbI$_{2.55}$Br$_{0.45}$/spiro-OMeTAD-Li-TFSI:TBP/Au	Sono	1.159	24.10	0.86	23.74	2022	345
73.	FTO/ZSO/FA$_x$MA$_{1-x}$PbI$_{3-y}$Br$_y$/spiro-OMeTAD-Li-TFSI:TBP/Au	CBD	1.168	24.24	0.785	22.59	2021	317
74.	FTO/c-TiO$_2$/NO-BSO/ZrO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SP	0.94	23.01	0.68	14.77	2021	346
75.	FTO/ZSO/CsMAFA/spiro-OMeTAD/Au	CBD	1.14	23.59	0.79	21.3	2020	315
76.	FTO/La:BaSnO$_3$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.12	22.3	0.718	18.7	2020	313
77.	FTO/c-ZSO/mp-ZSO/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	HT	1.05	20.79	0.784	16.22	2020	347
78.	FTO/La:BaSnO$_3$/TiO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	HT	0.96	21.5	0.69	14.2	2020	348
79.	FTO/c-ZSO/mp-ZSO/Cs$_{0.05}$(MA$_{0.17}$FA$_{0.83}$)$_{0.95}$Pb(I$_{0.83}$Br$_{0.17}$)$_3$/spiro-OMeTAD/Au	SC	1.06	24.50	0.79	20.1	2019	349
80.	FTO/am-ZSO/SnO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	PLD	1.12	22.40	0.796	20.04	2019	350
81.	FTO/Y:SrSnO$_3$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.14	22.7	0.74	19.0	2019	311
82.	ITO/SrTiO$_3$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.145	23.02	0.721	19.0	2019	305
83.	FTO/ZSO/FAMAPbI$_3$/spiro-OMeTAD/Au	SC	1.036	24.72	0.783	20.02	2018	61
84.	FTO/LBSO/CH$_3$NH$_3$PbI$_3$/PTAA/Au	PP/SC	1.12	23.4	0.81	21.2	2017	308
85.	FTO/c-TiO$_2$/ZSO/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	HT	1.048	22.71	0.692	17.21	2017	312
86.	FTO/ZnSO/ZSO/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SP	1.025	19.71	0.59	12.03	2017	314
87.	FTO/BSO/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	PP	0.968	17.46	0.657	10.96	2017	307
88.	FTO/c-ZSO/mp-ZSO/(FAPbI$_3$)$_{0.85}$(MAPbBr$_3$)$_{0.15}$/PTAA/Au	ES	1.046	22.50	0.76	17.89	2016	317
89.	FTO/TiO$_2$/SBSO/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.01	16.8	0.71	12.1	2016	196
90.	FTO/TiO$_2$/SrTiO$_3$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Ag	SC	0.962	19.2	0.67	12.4	2016	210
91.	FTO/ZSO/CH$_3$NH$_3$PbI$_3$/PTAA/Au	SC	1.05	21.6	0.67	15.2	2015	212
92.	FTO/ZSO/CH$_3$NH$_3$PbI$_3$/spiro-MeOTAD/Au	SC	0.84	15.01	0.62	7.81	2014	218
Scaffolds								
93.	FTO/Nb:SrTiO$_3$/ZrO$_2$/(MAPbI$_3$)$_x$(CsFAMA)$_{1-x}$/spiro-OMeTAD/Au	ST	1.11	23.9	0.76	20.2	2020	306
94.	FTO/c-SiO$_2$-SnO$_2$/CH$_3$NH$_3$PbI$_{3-x}$Cl$_x$/spiro-OMeTAD/Ag	SC/UVT	1.068	22.22	0.782	19.48	2020	351
95.	FTO/Nb$_2$O$_5$/Al$_2$O$_3$/CH$_3$NH$_3$PbI$_{3-x}$Cl$_x$/spiro-OMeTAD/Au	SC	1.13	12.80	0.72	10.2	2015	360
96.	FTO/TiO$_2$/SiO$_2$/CH$_3$NH$_3$PbI$_{3-x}$Cl$_x$/spiro-OMeTAD/Au	SG	1.05	16.4	0.66	11.45	2014	224
97.	FTO/c-TiO$_2$/mp-ZrO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.07	17.3	0.59	10.8	2013	217
98.	FTO/TiO$_2$/Al$_2$O$_3$/Au@SiO$_2$/CH$_3$NH$_3$PbI$_{3-x}$Cl$_x$/spiro-OMeTAD/Ag	SC	1.02	16.94	0.64	11.4	2013	21
99.	FTO/c-TiO$_2$/Al$_2$O$_3$/CH$_3$NH$_3$PbI$_2$Cl/spiro-OMeTAD/Ag	SC	0.98	17.8	0.63	10.9	2012	220
Other inorganic ETLs								
100.	FTO/c-TiO$_2$/CdSe/ZnS QDs/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.08	22.9	0.73	18.1	2020	352
101.	ITO/a-WO$_x$/SnO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Ag	TE	1.11	23.01	0.802	20.52	2019	353
102.	FTO/In$_2$S$_3$/CsPbIBr$_2$/spiro-OMeTAD-Li-TFSI-TBP/Au	CBD	1.09	7.76	0.659	5.59	2019	354
103.	FTO/TiO$_2$ NCs/Nb$_2$O$_5$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SC	1.04	20.49	0.716	15.25	2018	355
104.	FTO/mp-TiO$_2$ ZnS/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	SILAR	1.02	19.05	0.754	14.9	2018	356
105.	FTO/NMT CdS/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	CBD	1.13	19.7	0.74	16.5	2018	357
106.	FTO/CdS/MAPbI$_3$/spiro-OMeTAD/Ag	P-CVD	1.04	20.76	0.68	14.68	2017	358
107.	FTO/WO$_3$/SAM/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Ag	SC	1.02	21.9	0.665	14.9	2015	359

[a] SC – spin coating, PCVD – plasma enhanced chemical vapor deposition, CBD – chemical bath deposition, SILAR – successive ionic layer adsorption and reaction, TE – thermal evaporation, ALD – atomic layer deposition, SP – spray pyrolysis, RC – reflux condensation, ED – electrochemical deposition, ET – emulsion technique, LPCVD – low pressure chemical vapor deposition, TO – thermal oxidation, HP – hydrolysis pyrolysis, SGS – sol–gel synthesis, HT – hydrothermal, ES – electro spinning, ST – solvothermal, PP – peroxide precipitate, UVT – UV treatment, S – spray, and RFS – RF sputtering.

which was stimulated by the higher electrical conductivity of PC$_{61}$BM. Furthermore, an interlayer of organic molecules between the ETL/metal contact interface was introduced to passivate the defects, reducing the band bending and acting as a permeation barrier for moisture to enhance the stability.[199]

The inclusion of additives in PCBM decreases the film roughness and influences the morphology, which increases the recombination resistance at the perovskite/PCBM interface. Also, these additives ease the exciton dissociation and promote fast charge transport.[illegible] Recently, Xiong et al.[illegible] used poly(3-hexylthiophene) (P3HT) as an additive to dope PCBM to avoid aggregation, thereby enhancing the moisture and water resistance. This was shown to result in a retention of 85% of the initial PCE at 30% for 720 h. Similarly, after the modification of the PCBM/perovskite interface with poly(9-vinyl-carbazole) (PVK) doping in PCBM, it showed better anti-UV, moisture, and thermal stability.[illegible] The other non-fullerene-based organic ETLs include naphthalene diimide derivatives, perylene diimide derivatives, azaacene derivatives, indacenodithiophene derivatives, and n-type conjugated polymers, which can be new alternatives to gain a better performance than various modifications of PCBM.[illegible] Non-fullerene-based ETLs have unique advantages such as molecular structure diversity and adjustable frontier molecular orbitals.[illegible] However, a detailed review of organic ETMs is beyond the scope of this review, which can be found in the literature.[illegible]

Despite the promising properties of organic ETLs, they have only appeared in a small number of reports compared with inorganic ETLs. However, assuming that the superior electrical and optical properties can be harnessed from organic ETMs, a roadmap for higher efficiency in PSCs can be visualized. Overall, matching the only energy levels at the ETL/perovskite interface is not sufficient, where matching the electron mobility is a prerequisite to avoid charge accumulation. A detailed study of the interface is required considering the defects on the perovskite surface, chemical reactions, and effect on perovskite morphology due to the presence of the ETL, charge trapping, and charge recombination.

Despite the differences in the electrical properties, synthesis process, and interface effects in the various above-cited materials used as ETLs, numerous ETL systems have delivered high PCEs. ETLs continue to exert a significant influence on the device performance and efficiency even after selecting distinguished perovskite materials as overlayers in PSCs. In the initial stage of research, only ~7% efficiency was observed with the PSCs utilizing oxides of Ti, Zn, Sn, etc. to form ETL/perovskite heterostructures. The higher efficiency reported each year for a decade from a variety of ETLs in the most prominent recent reports is shown in Fig. 20. Recently, the efficiency reached ~25% with the advancement of ETLs in interface engineering due to the doping, co-doping, compositing, decoration, etc. of ETLs. A brief summary of the inorganic ETLs processed using various synthetic methods and their corresponding device performance parameters are tabulated in Table 1. Thus, future developments of novel ETLs should not only focus on enhancing the power conversion efficiency but must be rationalized based on cost and sustainability.

5. Hole transport layer (HTL)

The HTL is equally essential to transport the acceptors or holes generated in the photoactive perovskite layer to the cathode. The HOMO of the hole transport material (HTM) under consideration for PSCs is required to be located at a higher level than the valence band edge of the perovskite absorber (Fig. 21). The minimized energy barrier at the perovskite/HTL interface allows easy collection of the photogenerated holes. Moreover, the conductivity of the HTM, which plays a vital role in charge transfer and charge recombination at the perovskite/HTL interface, can be revamped by governing interface energetics and defect densities. Besides, the thermal and chemical stability of HTMs continue to be a concern for the long-term and efficient photovoltaic performance. Thus far, various nanostructured, doped, and passivated HTLs have been explored in PSCs depending on the selected device architecture. In this section, we critically discuss the involvement of various inorganic HTLs in delivering a higher PCE.

5.1. Inorganic HTLs

Inorganic HTLs have gained importance in PSCs due to their ability to be downsized to nanostructures, increasing the junction interface. Given that PSCs are the resultant evolution of sensitized solar cells, though with conceptually newer foundations, redox electrolytes have been replaced with solid-state electrolytes or HTLs in PSCs. However, the expensive solid-state organic spiro-OMeTAD when introduced in PSCs degrades the perovskite absorbers due to the use of hygroscopic dopants. Therefore, the low-cost inorganic HTLs with high chemical/thermal stability and scalability have attracted considerable attention from the scientific and industrial community as a replacement for spiro-OMeTAD. Various inorganic materials based on binary oxides, cyanates, and delafossite such as NiO, VO_x, CoO_x, CuO_x, CuI, CuSCN, and $CuGaO_2$ have been investigated for their performance as HTLs in PSCs.[illegible] The band structure positions of selected inorganic HTLs with reference to the perovskite absorber are summarized in Fig. 22. These HTMs are sensibly engineered to alter the charge transfer dynamics and to efficiently extract holes. The significance and optoelectronic properties of these important inorganic HTLs employed in PSCs are discussed in this section.

5.1.1. Nickel oxide (NiO). NiO is one of the most widely studied HTLs for PSCs due to its chemical inertness, low processing cost, and earth-abundant nature. Nickel oxides with molecular formulas of NiO, NiO_x, and Ni_2O_3 can be engineered to obtain cubic, monoclinic, rhombohedral, and hexagonal crystalline phases.[illegible] Mainly, p-type semiconducting stoichiometric NiO with a wide bandgap of 3.6–4 eV[illegible] and deep valence band edge (i.e., −5.2 to −5.4 eV) provides excellent band alignment with the perovskite light absorber. The higher conduction band positioning of NiO than perovskite materials become advantageous to conduct holes very efficiently and serves as an excellent electron blocking layer.

Docampo et al.[illegible] introduced NiO as an HTL in PSCs and gained an efficiency of <1% when utilized with a mixed halide perovskite absorber as the photoactive material. The low efficiency was attributed to the inadequate surface coverage and large number of pinholes in the perovskite films coated over the NiO HTL in the inverted device architecture. The possibility of improving the PCE after controlling the doping density

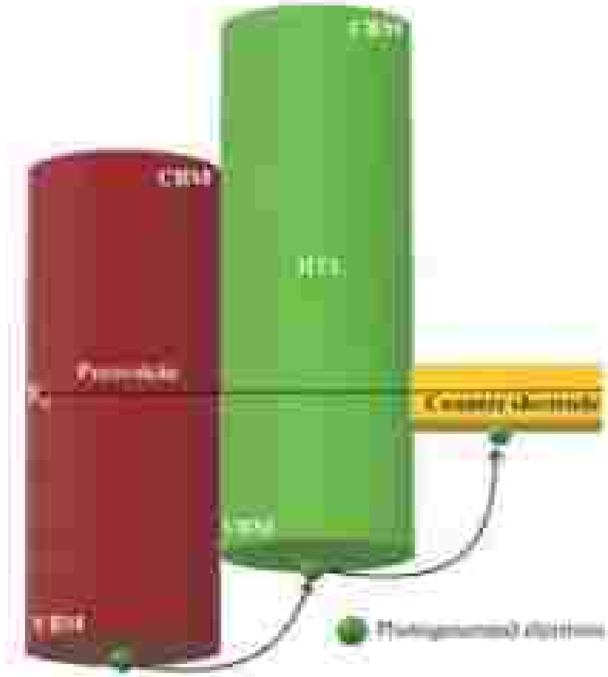

Fig. 21 Schematic displaying the path of the photogenerated hole from the perovskite light absorber to the external circuit. (CBM: conduction band minimum and VBM: valence band maximum.)

Fig. 22 Schematic of band alignment of various inorganic HTLs with perovskite absorber.

projected NiO as one of the forthcoming worthwhile HTL candidates. Therefore, various growth mechanisms and thin-film technologies have been explored for its synthesis or/and coating of NiO films in the ambient atmosphere, such as sputtering,[illegible] atomic layer deposition (ALD),[illegible] solvothermal growth,[illegible] sol-gel,[illegible] e-beam evaporation,[illegible] reactive e-beam evaporation,[illegible] atmospheric pressure spatial atomic layer deposition (AP-SALD),[illegible] and thermal evaporation followed by oxidation.[illegible] Among them, repeated spin coating has been observed to be a simple and cost-effective method to gain precise control over the thickness and crystallinity of NiO nanostructures, although the residual ligands reduce the coverage of the perovskite absorber, and hence the performance of PSCs. Moreover, the thickness of the faceted and corrugated NiO nanocrystalline films controls the hole extraction and transport competence at the HTL/perovskite interface[illegible] because a lower thickness presents a higher leakage current and a higher thickness offers higher series resistance. A precisely controlled ultra-thin NiO film with negligible absorption loss prepared by ALD showed no residuals and pinholes. The extremely thin NiO film with a thickness of 5–7.5 nm, few times the Debye length (*i.e.*, 1–2 nm for NiO), increased the work function and hole concentration by overlapping of the space charge regions. Moreover, high-temperature treatment improved its interfacial properties by reducing the content of hydroxylate NiOOH and reducing the amount of surface defects related to C–N at the HTL/perovskite interface, achieving a PCE of 16.4%.[illegible] Subsequently, Liu *et al.*[illegible] utilized a solution-combustion based NiO HTL with the two-step processed $MA_{1-y}FA_yPbI_{3-x}Cl_x$ perovskite to achieve a PCE 18.4%. Recently, the controlled island-like growth of NiO offered a lower absorption in the visible region, and also increased the effective interface with the perovskite absorber, while preserving the shunt resistance.[illegible] Knowing the fact that mesoporous structures provide a better interface between the HTL and perovskite, Yin *et al.*[illegible] explored a mesoporous nanoforest of 1D NiO nanotube morphology. The hierarchical tube morphology offered a continuous conducting pathway for rapid hole extraction and less charge leakage due to the substantially passivated interfacial hole-trapping state density (*i.e.*, 1.274×10^{16} cm^{-3}), which yielded a PCE of 18.77% with quenched Shockley–Read–Hall recombination losses (Fig. 23).

The Ni^{2+} and Ni^{3+} variations govern the defect levels in NiO and inversely alter the conductivity and optical transmittance of the HTL. The spatial localization of the HOMO of the perovskite/HTL system on the NiO layer estimated by adopting the relativistic pseudopotentials and pseudo-atomic orbitals predicted the transfer of holes from the perovskite in close proximity of the NiO surface connected by halogen and lead atoms (Fig. 24).[illegible] Therefore, precise control of the Ni^{3+}/Ni^{2+} ratio by the defect density aligns the VB of the HTL with the perovskite and provides faster hole extraction with lower energy losses, offering a PCE close to 18%.[illegible] Nevertheless, the significantly reduced oxygen vacancies in self-doped Ni_2O_3,[illegible] and NiOOH[illegible] yielded a PCE close to 20%, gaining attention as futuristic HTLs to replace NiO. The Ni^{3+} cation sites act as a Lewis electron acceptor and Brønsted proton acceptor by deprotonating cation amines and oxidizing iodide species. Therefore, different amounts of Cu,[illegible] Y,[illegible] La,[illegible] Fe,[illegible] Co,[illegible] Sr,[illegible] Ag,[illegible] Na,[illegible] and Zn[illegible] metals and rare earth elements (*i.e.*, Eu, Yb, Tb, Ce, and Nd)[illegible] were doped to enhance the intrinsic conductivity, charge extraction ability, hole mobility, energy level alignment, and optical transparency of NiO films by reducing the Ni^{2+}/Ni^{3+} vacancy formation energy due to their replacement. Even though the segregation of alkaline cations such as Li,[illegible] Cs,[illegible] and K[illegible] on the NiO surface improve the performance of PSCs due to their favorable interaction with perovskite, their time-dependent disparity

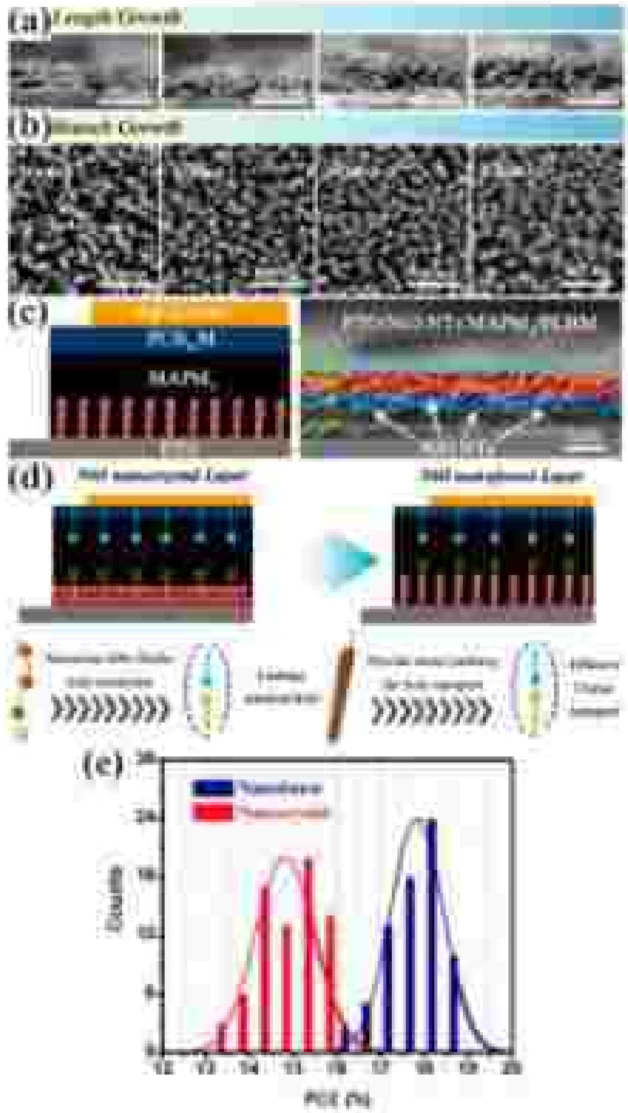

Fig. 23 (a) Cross-sectional and (b) top-view SEM images of the NiO nanotube nanoforests with controlled length and branch growth. Schematic of (c) device architecture and corresponding cross-section SEM image and (d) charge transport in PSCs consisting of NiO nanocrystals and nanotubes HTLs. (e) Comparative PCE distribution of nanocrystal and nanotubes.[illegible] Reprinted with permission from (ACS Appl. Mater. Interfaces, 2019, **11**, 44308–44314). Copyright (2019), the American Chemical Society.

in the spatial distribution modifies their performance and stability.

Al doping in the lattice of NiO_x not only enhances the electrical conductivity of the HTL but also improves the crystalline growth of the perovskite absorber, concurrently aligning its energy levels, which dramatically reduces the energetic non-radiative recombination losses and enables quicker hole transportation at the perovskite/HTL interface to deliver a PCE of 20.84%.[illegible] Mg doping has shown to downshift the VB maximum, matching it well with the perovskite and lowering the energy redundancy for hole injection. The reduced energy band offset benefitted the efficient charge collection/transport and curtailed the hysteresis, yielding a reproducible PCE of 18.5% from an ambient-stable commercial device with an active area of 10 cm × 10 cm.[illegible] Interestingly, embedding Au inside an NiO layer to form Au–NiO_x as both an electrode and electrode interlayer for PSCs was attempted to replace the FTO electrode, but difficulties were encountered in the formation of a compact layer, reducing the film thickness to control the transmittance, and loss of photoexcitation energy due to self-recombination of opposite charges at the electrode. This hampered the PSC device performance (*i.e.*, PCE ~ 10.24%).[illegible] The further addition of Cu on the top of Au–NiO film effectively reduced the resistance, but the device delivered a maximum PCE of 11.1% at a 1 nm Cu layer. This was reduced further with an increase in the thickness of Cu (*i.e.*, >1 nm).[illegible] UV-ozone irradiation reduced the interface barrier between a Cu-doped NiOOH HTL and $MAPbI_3$ perovskite by surface dipole formation and also increased the carrier concentration and charge extraction efficiency.[illegible] Recently, Zhao *et al.*[illegible] improved the electrical conductivity of an NiO_x film by enhancing the Ni^{3+} content after N-doping and achieved a PCE of 17.02%. The reduced Gibbs free energy on the hydrophilic N-doped NiO_x surface led to a higher nucleation density, and thereby larger grain growth of the perovskite absorber with improved interfacial contact and passivation of the trap states in the perovskite layer, thereby suppressing nonradiative recombination.

Cobalt-doping exhibits a synergistic effect and endows the NiO_x film with a further improvement in its performance. As an HTL in PSCs, p-type Co-doping provides low transparency and high conductance, whereas alkali and alkaline co-dopants result in high transparency with low conductivity. It was reported that 10% Li@5% Co co-doping synergistically enhanced the PCE to 20.1% by providing a shorter carrier lifetime of 0.67 μs and a larger recombination lifetime of 3.24 ms, signifying efficient hole/charge transfer/extraction and suppressed charge carrier recombination, respectively.[illegible] The synergy between Ag and Li co-dopants with the +1 oxidation states was shown to tailor the optoelectronic properties of NiO. The smallest formation energy of Li and Ag among the related defects created shallower acceptor levels in NiO and enhanced the hole concentration, which effectively optimized the charge extraction/transport and reduced the charge accumulation at the interface, therefore boosting the PCE to 19.24%.[illegible] Mg^{2+} doping compensates the undesirable positive shift caused in the VB of NiO_x due to the incorporation of Li and promotes the formation of an ohmic contact at the perovskite interface by reducing the barrier height via staircase energy level alignment with the $MAPbI_3$ perovskite.[illegible] However, the inclusion of Co^{2+} in Mg–Li reduced the device performance severely (*i.e.*, PCE ~ 13.22%) for unknown reasons.[illegible] Besides, polymeric PTAA, DEA, PFBT, and PEAI coatings[illegible] introduced as an overlayer for the NiO_x HTL effectively modified the interfacial contact and boosted the interfacial charge transfer through gradient band alignment and reduced trap state density. The lone-paired functional groups on the polymer coordination with Ni and Pb ions form a quasi-2D polymeric-perovskite grain, which blocks the electron transport in the HTL and limits the carrier recombination at the interface.

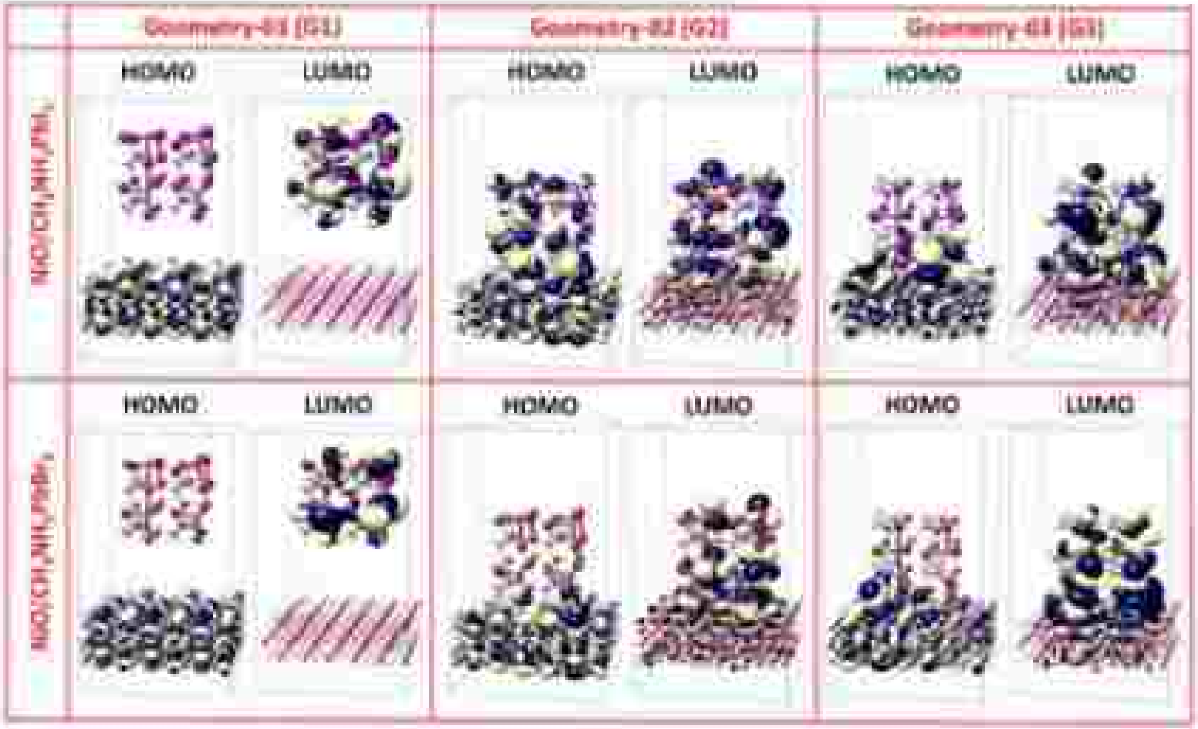

Fig. 24 Optimized structures showing the HOMO (left) and LUMO (right) orbitals for three mutual orientations of an NiO (lower) and perovskite (upper) interfacial region. The geometries G1 refer to the surface separation of ~1 nm between the perovskite and NiO, and G2 and G3 indicate the close proximity of <0.3 nm between the perovskite and NiO, but perovskite contact NiO(100) surface via the classical halogen atom and MA ion and halogen atom and lead atoms, respectively. The upper row shows the $MAPbI_3$, and the lower row represents the $MAPbBr_3$ perovskite nanoparticles. In the NiO structure, the Ni and O atoms are represented by green and red spheres, respectively. In the perovskite structure, the Br, I and Pb atoms are identified in brown.[illegible] Reprinted with permission from ACS Appl. Mater. Interfaces, 2020, **12**, 11467–11478. Copyright (2020), the American Chemical Society.

5.1.2. **Vanadium oxide (VO_x).** Vanadium oxides composed of VO_5 square pyramids or distorted VO_6 octahedra with shared oxygen atoms appear in various chemical forms such as VO_2, V_2O_3, V_2O_5, V_3O_7, V_4O_9, V_6O_{13}, V_4O_7, V_6O_{11} and V_8O_{15} of orthorhombic, cubic, triclinic, tetragonal, monoclinic, and rhombohedral crystalline phases.[illegible] The existence of valence band levels and conduction band levels at −5.36 eV and −2.94 eV, respectively, and the bandgap of ~2.4 eV have projected VO_x as another interesting HTL candidate material for PSCs. The low-temperature synthesis protocols have been shown to incorporate hydroxyl groups in vanadium oxides (i.e., VO_x), and the post-synthesis heat treatment results in oxygen vacancies by establishing V^{5+} (i.e., ~65% to 75%) and V^{4+} (i.e., ~35–25%) cations,[illegible] which are prominent trap sites, restricting their use as HTL. Basically, the air-oxidation of VO_x films during their synthesis naturally results in the formation of V_2O_5 on the top surface at the interface between the perovskite absorber and VO_x HTL and controls the device performance by monitoring the band-offset.[illegible] The large variation between the V^{5+} and V^{4+} cations results in the assembly of V_2O_5 films with higher roughness and sizable thickness, which typically yield a larger barrier to allow the tunnelling of charges in PSCs.[illegible] Therefore, a thin layer of hydrated V_2O_5 (i.e., VO_x) has been explored as an alternative HTL to overcome the catastrophic electrical and structural inhomogeneities in the frequently explored PEDOT:PSS hole extraction layer, which adversely affect the device lifetime. Moreover, a compact layer of thermally stable VO_x nanoparticles not only enhanced the light-harvesting but also delivered extremely high transmittance (i.e., 95–98%), higher quenching efficiency, and reduced internal resistance, which facilitated efficient charge transportation, offering a PCE close to 14%.[illegible] Likewise, it also assisted in improving the stability of gradient hetero-junction based PSCs exposed to solar radiation in N_2 (i.e., 15.8% PCE for 750 h) and ambient (14.1% PCE for 175 h) environments.[illegible]

The V_2O_5 additive, as an interface modification layer, is a good hole extraction layer, and thus has been utilized to improve the quality of perovskite light absorbers (i.e., $CH_3NH_3PbI_{3-x}Cl_x$).[illegible] The hydrogen bonds and dangling bonds in the hydrated V_2O_5 additive produce larger perovskite grains. The optimized amount of additive produces a dense perovskite film of larger grains, which play a crucial role in reducing the trap charge density to improve the current injection, thereby concurrently limiting the leakage current. Although these modifications are performed to overcome the high recombination rate at the V_2O_5/perovskite interface, they also mitigate the migration of iodide ions into the crystal boundaries and retain a stable device performance beyond 1000 h. Besides, an ambient atmosphere-processed VO_x interlayer in an unencapsulated n–i–p device showed excellent PCE retention (i.e., 71% of initial value) after illumination at the high temperature of 70 °C for 1100 h,[413] but the slow ingress of oxygen and water in the unencapsulated device degraded the perovskite layer, despite a barrier layer being imposed to reduce the rate of vanadium ion diffusion. Therefore, the VO_x thin film was further passivated with an aminopropanoic acid (APPA) interfacial layer to control the effect of oxygen vacancies on the charge recombination at the perovskite/VO_x HTL interface, which also enriched the perovskite crystallinity, reducing the content of charge-trapping pinholes.[414]

A copper phthalocyanine (CuPc)[415] and thermally crosslinked triarylamine-based X-DVTPD[416] buffer layer was introduced in the VO_x matrix to resist the incorporation of moisture and realize excellent interfacial energy level alignment. The synergistic bilayer HTL was shown to reduce the charge carrier recombination, enhancing the charge extraction at the interface. Furthermore, VO_x was also introduced over poly(triarylamine) to induce hydrophilicity to grow a high-quality perovskite absorber layer, thereby improving the PCE (i.e., 18.9%).[417] A thin overlayer of VO_x was shown to suppress the trap-assisted recombination, significantly improving the charge extraction and transport at the interface. However, owing to the limited improvement in PCE to 19%, subsequent efforts were focused on increasing the conductivity of pristine VO_x by doping rather than via additives or complex bilayer formation.

The improved conductivity of VO_x (i.e., 1.05×10^{-4} S m^{-1}) and interfacial adhesion with the $MAPbI_3$ perovskite layer after Cs doping resulted in a 30% enhancement in the device efficiency.[418] On the contrary, when dispersed in carbon, VO_x facilitates the charge transfer at the perovskite/carbon interface due to the high work function without compromising the conductivity of carbon.[419] Recently, PSCs with a top hybrid HTL comprised of VO_x incorporated p-type polytriarylamine (PTAA) polymer reached an efficiency of 20.1% and exhibited negligible degradation after 4500 h of light soaking due to the higher tolerance of VO_x towards the perovskite absorber (Fig. 25).[420] The donor–acceptor interactions between the electron-deficient VO_x and electron-rich amine centers of polymer enable the impeccable fusion of VO_x and PTAA layers, which provide improved charge transport, possibly similar to doping effects. The post-treatment strategy of vanadium oxides offers great flexibility to tailor the cation distribution, and hence the energy level alignment. The UV post-treatment of a few-atomic layer thick (~1 nm) pristine VO_x HTL film was shown to increase the

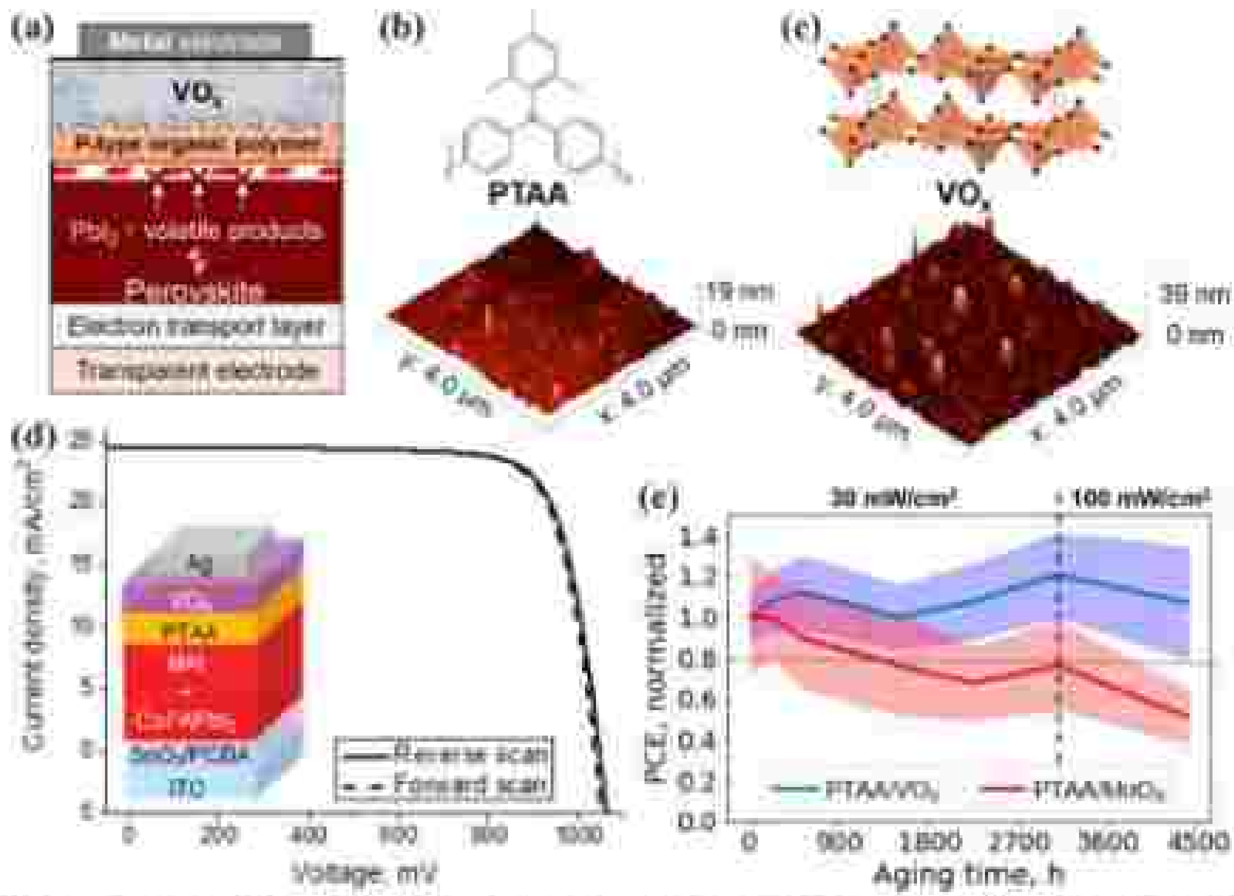

Fig. 25 (a) Schematic of n–i–p PSCs consisting of a hybrid HTL of PTAA and VO_x with lower gas permeability and better barrier properties than the volatile perovskite decomposition products. Molecular structure, tinted pyramid based structure and topography of (b) spin coated p-type PTAA thin film and (c) evaporated 30 nm thick VO_x film on glass. (d) J–V characteristics of PSC consisting of VO_x in bilayer hybrid HTL. (e) Stability of PSCs with bilayer hybrid HTLs under illumination.[420] Reprinted with permission from (J. Phys. Chem. Lett., 2020, **11**, 5563–5568). Copyright (2020), the American Chemical Society.

oxidation states from V^{5+} to V^{4+}, drawing the Fermi level close to the valence band, thereby enabling the hole quenching pathway for the transportation of holes to improve the device efficiency.[437] Even though VO_x has shown promise towards efficient and stable PSCs, further investigation of morphology controlled VO_x nanostructures, doped VO_x, and composites with other promising materials are required to explore as it as an HTL for reaching a milestone efficiency and the cost-effective mass production of PSCs.

The use of an ALD V_2O_5 buffer layer a barrier layer was shown to improve the long-term thermal stability of PSCs.[437] Indeed, a precisely controlled stoichiometric V_2O_5 HTL enhanced the PCE from 13.26% to 18.03% when interfaced with PEDOT:PSS under ambient conditions.[433–435] V_2O_5 curbs the formation of oxygen defects and also ensures hole transfer from the perovskite absorber ($CH_3NH_3PbI_3$) to V_2O_5 HTL by forming an excellent ohmic contact.[436] Moreover, filling the pinholes of PEDOT:PSS by incorporating V_2O_5 nanoparticles improved the carrier mobility and increased the surface energy by exposing more PEDOT chains to the interface with the perovskite absorber.[437] Further, V_2O_5 combined with nickel phthalocyanine (NiPc) effectively extracted holes from the perovskite by mediating the VB of both and rendered a 53% enhancement in the PCE (i.e., 18.9%).[438] Basically, the VB of pristine V_2O_5 forms an electronically barrier-free cascading contact for hole transportation and extraction across the interface.

3.1.3. **Cobalt oxide (CoO_x).** Cobalt oxide is another HTM attracting attention due to its hole-quenching capability and low processing cost. Cobalt oxides with the molecular formulas CoO, Co_3O_4, and Co_2O_3 can be obtained in cubic and hexagonal spinel crystalline phases with a wide bandgap in the range of 1.3 to 2.4 eV.[439] The much shorter hole extraction time of CoO_x (2.8 ns) relative to NiO_x (22.8 ns) and CuO_x (208.5 ns) has projected Co-oxides as possible competitor materials to other inorganic HTLs.[440] In 2016, Shalan *et al.*[441] introduced ultrathin CoO_x films as an HTL in inverted PSCs, which was obtained via a simple spin-coating technique followed by high-temperature processing (400 °C). Besides the excellent light harvesting capability, it was mainly the phenomenal charge separation ability of the highly transparent CoO_x (i.e., 15 nm thick) achieved a PCE of 14.5% even with a single-cation single-halide perovskite. Despite the fact that an ultrathin HTL minimizes the incident photon loss induced by Co ion absorption and curtails the carrier losses by shortening the transport path, the introduction of a metal ion in the CoO_x lattice changes the conductivity of CoO_x and energy-level mismatch with the perovskite. The deeper VB position of CoO_x (~5.36 eV) than the HOMO of $CH_3NH_3PbI_3$ (~5.4 eV) hinders the hole transport and causes severe recombination. However, the incorporation of Cu in CoO_x uplifts the VB (~5.24 eV), without altering the CB edge (~2.2 eV), which is maintained much higher than that of $CH_3NH_3PbI_3$ (~3.9 eV). This severely reduces the carrier transfer loss at the interface and energetically favours the electron injection.[441]

Spinel Co_3O_4 with octahedral Co^{3+} is significantly tolerant to structural distortion or disorder, and hence excellent hole transport materials for PSCs. Co_3O_4 assists with the issues of carrier transport and recombination process at the carbon/perovskite interface in carbon-based PSCs by reducing the charge transfer resistance from perovskite and suppressing interfacial recombination. Moreover, the interfacial layer of Co_3O_4 significantly promotes the separation and extraction of photo-generated carriers, as well as the hydration of perovskites, thereby providing a steady performance under ambient and light soaking conditions.[442,443] Low-valency doping reduces the density of defect states and enhances the hole mobility of Co_3O_4 by introducing acceptor energy levels on both the Co^{2+} and Co^{3+} sites of Co_3O_4. Therefore, Li^+ doping in the lattice of Co_3O_4 improves the light absorption and boosts the hole mobility by forming an Li-enriched $LiCoO_2$ overlayer, which facilitates efficient hole transportation at the Li-Co_3O_4/perovskite interface, delivering a PCE of ~14%.[444] However, the super hydrophilicity induced in $LiCoO_2$ after UV/ozone treatment led to the formation of a highly dense $MAPbI_3$ film with an excellent interface, which was shown to enhance the PCE to 19%.[445]

Recently, the co-doping of Zn^{2+} in $LiCoO_2$ improved its conductivity and enormously enhanced its hole mobility, which caused a 4-fold enhancement in the PCE compared to that of the pristine Co-oxide HTL.[446] The rock-salt CoO with octahedral high-spin Co^{2+} is another HTM from the CoO_x family that has the potential to improve the PCE. Recently, a CoO film was treated with pyridine to control the adverse effect of oleylamine molecules present on the CoO film on the growth of the perovskite film, and thereby the performance of PSCs. The ligand exchange process by pyridine not only improved the conductivity by influencing the defect states in CoO but also altered the HTL/perovskite interface for excellent charge extraction, showing a 3-fold improvement in the PCE.[447] Recently, the decoration of CoO nanoplates in a discontinuous manner to fill the boundaries of crystalline perovskite grains yielded the highest PCE of 20.72% by improving the charge-transfer kinetics and hole extraction ability (Fig. 26).[448] The uncovered perovskite grains assured uninterrupted hole transport from the perovskite to spiro-OMeTAD HTL; moreover, the CoO nanoplates residing at the perovskite grain boundaries (where defect sites exist) reduced the trap state density (3.772×10^{15} cm^{-3}), suppressing the charge recombination. Overall, the best PCE is still to be realized from PSCs utilizing Co-oxide HTLs. In the future, the choice of precursor and reaction kinetics should be considered to obtain the best-quality nanostructures of Co-oxide HTLs to ensure maximum hole quenching and improved efficiency. Therefore, the research direction should be focused on improving the conductivity and mobility of CoO by proper choice of doping and the film quality by tuning the processing method to boost the interface between CoO-perovskite to reduce the recombination loss.

3.1.4. **Copper oxide (CuO_x).** The earth abundance oxides of copper with molecular formulas of CuO (cupric oxide), Cu_2O (cuprous oxide), and Cu_4O_3 (paramelaconite, thermodynamically unstable) can be realized in cubic, monoclinic, and tetragonal structures, respectively.[449,450] Cu-oxides are primarily

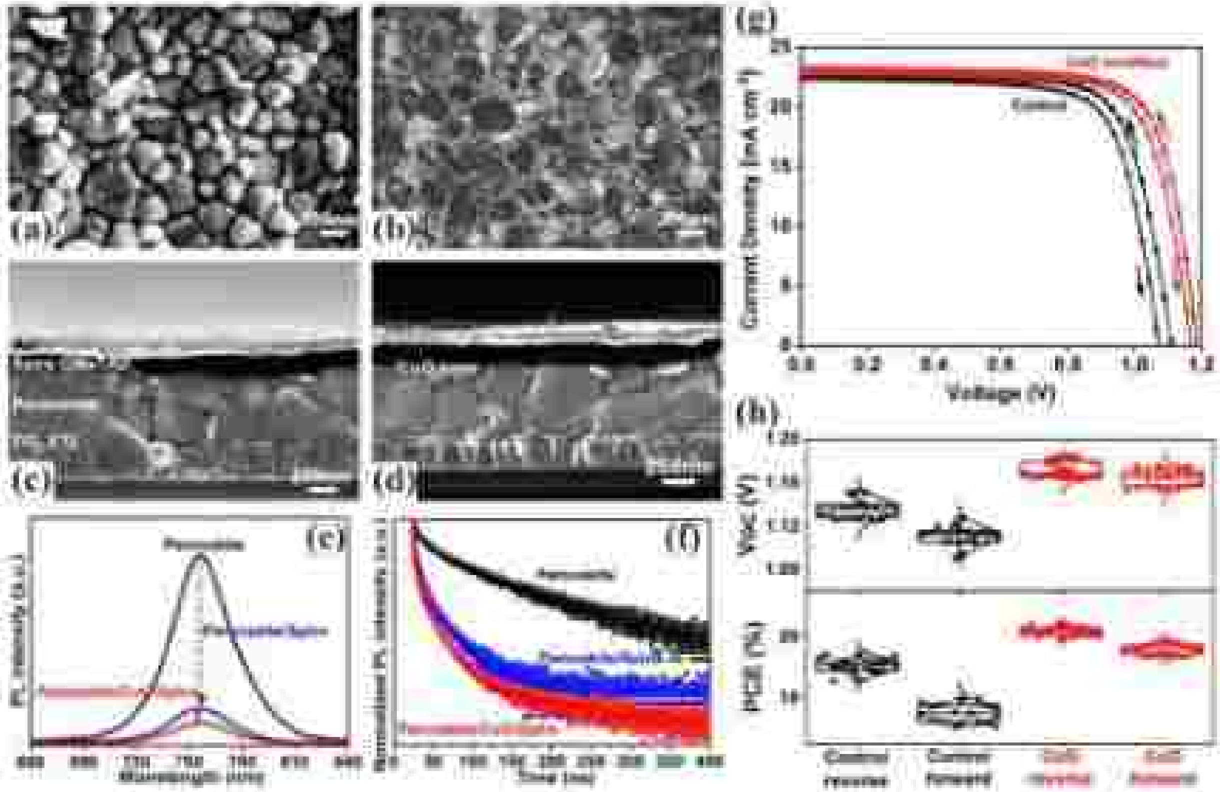

Fig. 26 Top view SEM images of the perovskite layer (a) without and (b) with CuO nanoplate HTL, and their respective cross-sectional views (c) without and (d) with CuO nanoplate HTL. (e) PL and (f) TRPL spectra of the CuO nanoplate HTL. (g) J–V curves of the PSCs with and without CuO nanoplate HTL and (h) V_{OC} and PCE obtained by forward and reverse scan of 20 of these PSCs. The control was a PSC without CuO nanoplates.[446] Reprinted with permission from (ACS Appl. Mater. Interfaces, 2019, 11, 32159–32168). Copyright (2019), the American Chemical Society.

utilized as buffer layers for the stable encapsulation of PSCs to maintain efficiency in adverse environmental conditions.[447] The two-orders of magnitude higher mobility of pristine and modified Cu-oxides (i.e., ~256 cm^2 V^{-1} s^{-1}) than NiO (i.e., 2.8 cm^2 V^{-1} s^{-1}) makes them an excellent choice as HTLs. Most importantly, the best-performing PSCs using copper oxide are prepared with ultrathin films of CuO_x, but the ultra-thin nature of the film restricted the analysis of its crystallographic data for tailoring its interfacial properties. Therefore, X-ray photoelectron spectroscopy (XPS) studies have been given importance to understand the properties of the surface facing the interface. The existence of a Cu^+ content in the range of 63–69% (i.e., 17–22% of Cu^{2+}) confirmed the presence of both Cu_2O and CuO phases in CuO_x.[[illegible]] Nevertheless, the Cu^+/Cu^{2+} ratio was controlled via the self-oxidation of independently prepared Cu_2O and CuO thin layers to govern the channels for charge carrier transport by lattice matching, and thereby the solar device efficiency.[[illegible]] The equal existence of Cu^+ and Cu^{2+} delivered a Cu_4O_3 phase with a bandgap of ~1.6 eV,[[illegible]] which is lower for blocking the conduction electrons, and hence not explored much. However, the Cu_2O and CuO forms exhibit bandgaps (E_g) in the range of ~2.1 to 1.6 eV, with an approximately similar VB level of −5.4 eV, satisfying the primary requirement as HTLs in PSCs.

The conversion of spin-coated CuI into Cu_2O and CuO under controlled thermal treatment delivered a PCE close to 13% and created excitement among the scientific community exploring solar materials.[[illegible]] The mixture of Cu^{2+}/Cu^+ with a ratio of 1:1 produced a PCE of 17.4% by improving the hole extraction and charge dissociation at the CuO_x/$MAPbI_3$ interface in the presence of a buffer layer.[[illegible]] Further, in search of improved efficiency, Chen et al.[[illegible]] transformed complex CuO–Cu_2O uneven morphologies into stable CuO nanoparticles of uniform dimension, but this complex CuO–Cu_2O structure delivered a maximum PCE of only ~8% for unknown reasons. Therefore, various synthesis techniques such as electrostatic spray deposition,[[illegible]] magnetron sputtering,[[illegible]] solvothermal method,[[illegible]] SILAR,[[illegible]] ion beam sputtering,[[illegible]] thermal oxidation,[[illegible]] spin-coating,[[illegible]] chemical vapor deposition,[[illegible]] and electrospinning[[illegible]] have been examined to control the Cu-oxide film thickness and its interface with the perovskite absorber layer, influencing the efficiency of PSCs. The CuO_x employed in place of PEDOT:PSS HTL exhibited a stable and higher PCE (17.1%) than that of the pure Cu_2O and CuO HTLs.[[illegible]] Recently, it has been shown that a highly crystalline perovskite overlayer on CuO_x quantum dots reduced the charge trap state density, leading to a higher carrier transfer efficiency and reduced charge recombination, delivering a PCE of 19.91%.[[illegible]] However, CuO_x suffers from a low transmittance in the visible range, and its further improvement by reducing thickness compromises the optical losses.

The nanoparticle-based interface modification concept provides a series of benefits in PSCs. Monodispersed CuO nanoparticles (3–10 nm) improve the light manipulation, suppress parasitic interfacial resistance, and induce higher hole extraction ability, resulting in a V_{OC} of 1.09 V and an efficiency of 15.3%.[illegible] However, CuO nanowires introduced as an anode buffer layer in the inverted planar device structure yielded a PCE of 16.22%, which originated from the higher hole mobility (or improved conductivity) of the HTL and its larger interfacial area with perovskite. Even though the diameter of nanowires plays a central role in improving the charge extraction ability, unoptimized overlapping of the nanowires increases the hole transport distance and declines the crystallinity of the perovskite layer, thereby reducing the performance of PSCs.[illegible] Further, Ag nanoparticle doping in CuO nanowires increases the light trapping and suppresses the charge recombination rate, but their high cavity mobility reduces the PCE (*i.e.*, ~11%).[illegible] Besides, a reactively sputtered CuO thin film barely accompanied with Cu_2O, under controlled annealing conditions, had shown the highest efficiency of 12.56% due to the increased exciton-assisted band-to-band recombination.[illegible]

The incorporation of Cu_2O in PSCs has been shown to reduce the recombination losses at the interface. Cu_2O forms type II band alignment at both the p–i and i–n interfaces, enabling charge separation and uninterrupted carrier transport from $MAPbI_3$.[illegible] The synergistic effect of Cu_2O nanocubes as the top HTL on the perovskite light absorber ($CH_3NH_3PbI_3$) in a planar n–i–p PSC demonstrated a highly stable PCE of ~17.23% at room temperature without encapsulation.[illegible] Further, the heterojunction of Cu_2O with BiO_x enhanced the PCE to 18.6% by effectively preventing defects and pinholes, and also tailoring the recombination and recollection of charge carriers at the interface with the perovskite absorber.[illegible] To further enhance the device performance, surface modification strategies using nonpolar solvents have been explored. Surface modification of Cu_2O quantum dots using silane molecules has been seen to increase the recombination resistance, offering faster and more efficient charge carrier extraction to deliver a PCE of 18.9%.[illegible] Moreover, a Cu/Cu_2O composite layer introduced as a p-type modified layer between low-mobility hole transport materials and the metal electrode acted as an electron blocking buffer layer and effectively improved the PCE.[illegible] Cu_2O was also blended with CuBCN to avoid the formation of defects and impurities at the interface due to the reaction of halides migrated from organohalide perovskites into CuBCN.[illegible] The existence of Cu_2O nanoparticles resulted in the faster extraction of charges generated in organohalide perovskites by their interaction with CuBCN, thereby rendering a PCE of 19.2% by minimizing the detrimental interfacial degradation.

Device simulations have predicted that Cu_2O has the ability to improve the PCE to over to 23% by tuning the bandgap[illegible] due to its high mobility despite the complications in its synthesis. However, control over the interface properties has become a key obstacle in this development. Due to the presence of Cu vacancies at the surface or termination in the oxygen planes, the reactive oxygen becomes the recombination centres to trap the conduction electrons. Therefore, the atomistic model developed by Castellanos-Aguila *et al.*[illegible] for the Cu_2O(001) and $MAPbI_3$ interface showed that the formation of vacancies in the Cu_2O-terminating planes eliminates the dangling bonds and deep trap states, enabling the PSCs to exhibit excellent photoconversion efficiency (Fig. 27). However, the diverse nanostructure morphologies and doping or co-doping of Cu_2O with promising elements are yet to be fully explored in-depth to understand their effect on the device performance.

5.1.3. **Copper iodide (CuI).** CuI crystallises in zinc blende (<390 °C), wurtzite (>390 °C and <440 °C) and rock salt (>440 °C) structures,[illegible] which is another promising HTL with a wide bandgap (*i.e.*, ~3.1 eV), high hole mobility (*i.e.*, 0.5–2 $cm^2 V^{-1} s^{-1}$), high transparency, good chemical stability, and low production cost. Various solution-based and solid–gas reaction processes have been endorsed as facile methods to synthesise CuI.[illegible] Systematic modelling based on a combination of DFT-based computational and group-theory methods has illustrated that among the intrinsic point defects, copper vacancies are the most prominent to govern the electronic and transport properties of CuI, resulting in an improvement in the PCE.[illegible] Initially, CuI was explored in conventional n–i–p PSCs, and then utilized in inverted planar PSCs to improve the PCE by avoiding iodide formation at the interface. The incorporation of an iodine atom expands the Cu (with lattice constant of 5.99 Å) structure of the film and results in the formation of a compact CuI crystal, removing the pinhole defects. Simultaneously, new species are formed at the interface of perovskite/CuI by binding Cu in the perovskite, resulting in stronger charge-extraction and noticeable short circuit current density.[illegible] Nevertheless, the redundant iodine acts as an interfacial recombination centre.

Christians *et al.*[illegible] introduced CuI as a competitor to spiro-OMeTAD in PSCs, providing 2-orders of magnitude larger electrical conductivity; nevertheless, the high recombination in the CuI-based device restricted the PCE to 6% at a lower V_{OC}, suggesting a strong possibility for the advancement of its performance. Moreover, benefiting from the high transmittance of CuI, with deep valence band, it showed a higher PCE than the acidic and hygroscopic PEDOT:PSS-based PSCs.[illegible] The smaller magnitude of charge separation at the perovskite/CuI interface leads to the generation of a smaller local electric field; thereupon, the faster polarization relaxation down-sizes the hysteresis in *J–V* measurement of CuI-based PSCs.[illegible] The larger roughness of a powder-pressed CuI HTL reduced the device performance by severely trapping the charge carriers at the numerous air voids generated deep inside the HTL layer.[illegible] The thermally evaporated ~40 nm-thick compact CuI HTL decreased the charge carrier recombination losses at the interface and exhibited an air-stable PCE of 14.7%.[illegible] Later, an air-stable PCE of 16.8% was obtained by optimizing the morphology of the perovskite film coated on the CuI HTL to effectively reduce the energy loss at the interface.[illegible] Recently, the use of CuI-decorated Cu nanowires as a hybrid Cu@CuI nanostructure enabled a PCE of 10.8% by efficient charge extraction from the outer CuI layer and rapid charge transfer from the inner Cu wires.[illegible] However, the synergistic effect of Na-doped TiO_2 ETL

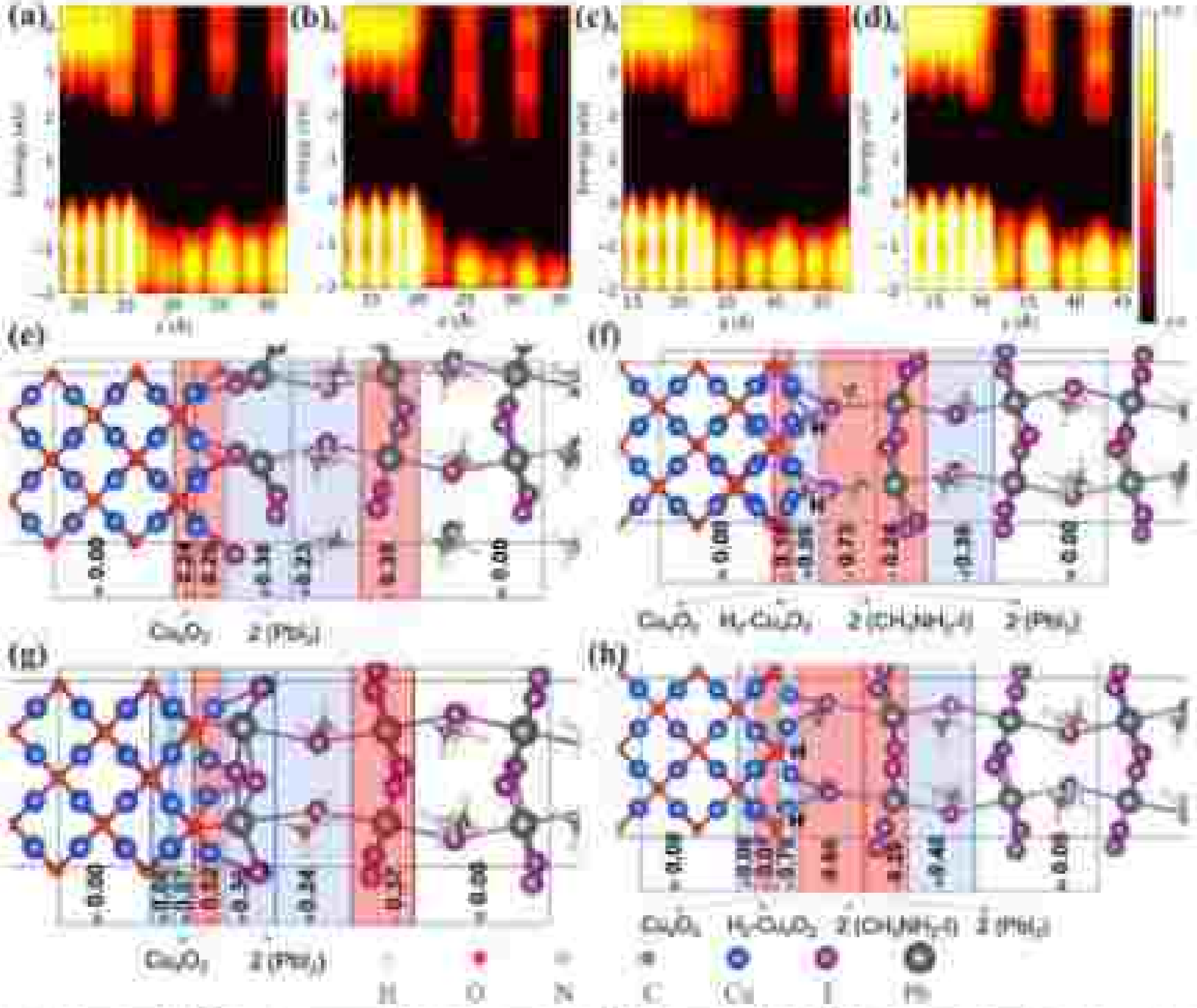

Fig. 27 (a–d) Logarithm of LDOS × N_{sp} averaged in the xy planes calculated between the MAPI and Cu_2O interface and (e–h) their Bader charges summed by layers for the four interface models: (a and e) OrPbI, (b and f) OrMAI, (c and g) CuPbI, and (d and h) CuMAI. The interface states are higher in energy than the MAPI CB, allowing electrons to return to MAPI. Therefore, holes can be transferred from MAPI to Cu_2O without being trapped, although they can be attracted and recombine with electrons trapped at the OrPbI and CuPbI interfaces.[illegible] Reprinted with permission from ACS Appl. Mater. Interfaces, 2020, **12**, 44648–44655. Copyright (2020), the American Chemical Society.

and CuI HTL, where Na-doped TiO_2 enhanced the electron conductivity/mobility and CuI induced a higher recombination resistance, improved charge transport at both interfaces (i.e. HTL/perovskite and ETL/perovskite interface) and delivered an efficiency of 17.6%.[illegible]

Despite its high mobility, the CuI HTL alone forms leakage paths, leading to carrier recombination at the CuI/perovskite interface. Therefore, PEDOT:PSS was introduced as a middle layer for efficient carrier extraction through adequate energy level alignment, making the architecture more efficient with a thicker CuI overlayer.[illegible] The further addition of CuI as a middle layer between PTAA and perovskite enhanced the charge extraction on both the sides and yielded a PCE of 20.34% by creating enhanced upward band bending (0.13 eV) at the CuI/perovskite interface with a large built-in potential (~1.28 V) all over the active layer.[illegible] Moreover, CuI is beneficial to reduce the trap-state concentration and parasitic charge accumulation, limiting the flow of charges through the passivation of other HTLs. Sarasin *et al.*[illegible] observed that the passivation layer of CuI fills the pinholes and severely reduces the trap states of metal oxide, protecting the perovskite/HTL interface from degradation and providing faster injection and relaxation processes in devices, yielding an impressive PCE of 15.2%.

Ayrtamond *et al.*[illegible] introduced CuI islands on a TiO_2 ETL to pull the electrons at the perovskite/TiO_2 interface and extract them via the dipole moments formed. The higher conduction band energy level of CuI (*i.e.*, −2.2 eV) than the perovskite prevents the formation of PbI_2 at the interface, facilitating superior electron extraction with a lower trap density, and the smaller Cu^+ and larger I^- ions mimicking PbI_2 (*i.e.*, Pb^{2+} and I^-) inhibit the back-recombination (Fig. 28(a and b)). Although a moderate number of CuI islands improved the PCE (*i.e.*, 19%), a large number of CuI islands reduced it by blocking the electron pathways (Fig. 28(c)). Apparently, the

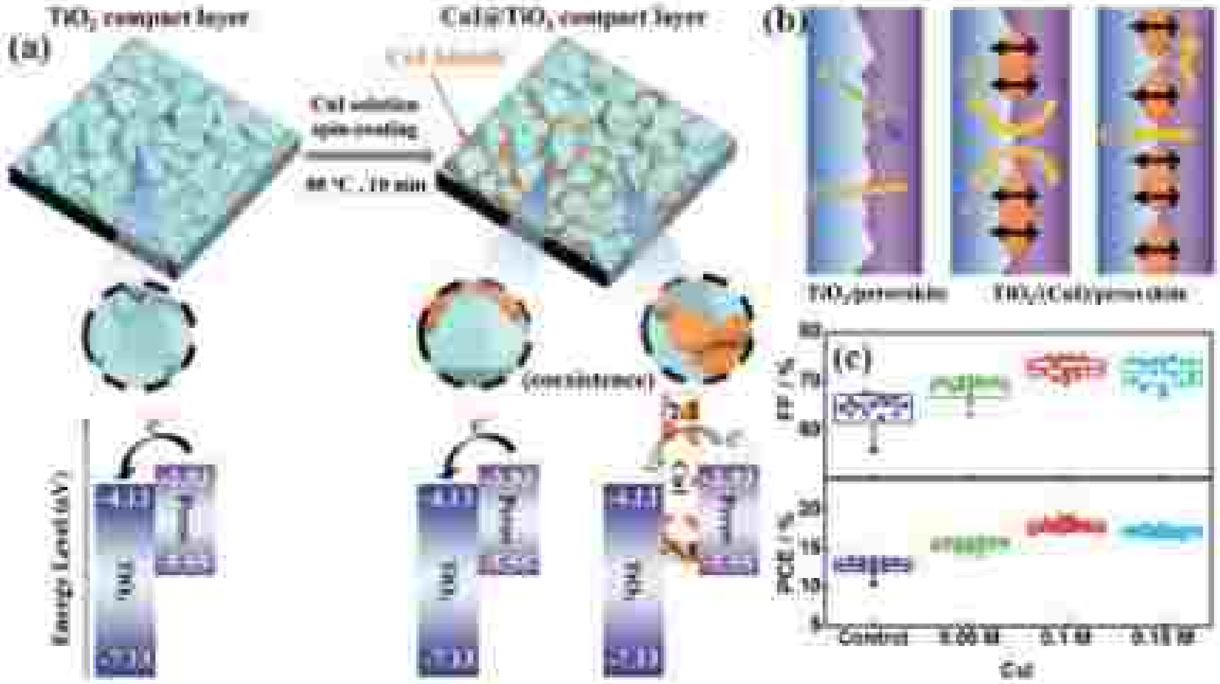

Fig. 28 (a) Schematic of CuI islands formed on TiO_2 compact layer and subsequent deposition of perovskite layer. In CuI modified TiO_2 (CuI@TiO_2) based PSCs, electrons move from the perovskites to the exposed TiO_2 surface instead of CuI islands because of its high conduction band energy level. (b) Interfaces with various amounts of CuI islands. (c) FF and PCE of devices with various concentrations of CuI.[illegible] Reprinted with permission from *Adv. Energy Mater.*, 2017, **8**, 1701722. Copyright (2018), John Wiley & Sons.

incorporation of thiourea in CuI [i.e., Cu(Tu)I] operates by accelerating the hole transport and reducing the charge carrier recombination due to the increased depletion width (from 1[illegible] to 3[illegible] nm) as compared to the traditional CuI. Thus, Cu(Tu)I exhibited a PCE of 19.9% by lowering the trap state energy level and eliminating the potential wells for hole transport at the interface.[illegible] This is why the doping or passivation strategies for further the modification of CuI endow it with potential to serve as magnificent HTLs for efficient PSCs.

Overall, CuI is one of the best HTMs to produce PCEs in the range of 10% to 20% after combining with TiO_2, CdS, ZnSe, ZnO, ZnOS, etc.,[illegible] but a well-optimized thickness ratio of the ETL, perovskite, and HTL is highly demanded. The interplay of Pb and CuI recovers the (Pb-based) perovskite by the Cu–I chemical drain in the system and increases the CuI contact, and hence the charge carrier transport. CuI-based devices show suppressed hysteresis with a significant light soaking effect. The chemical potential gradient redistributes the I^- ions from CuI to the perovskite by diffusive movement during aging, which can be tuned by controlling the distribution and morphology of CuI. The ageing instability can be seen in any PSC that undergoes diffusive ion migration towards the interface, but it is relatively less for HTLs like CuI barely accumulating I^- ions.

5.1.4. **Copper thiocyanate (CuSCN).** CuSCN is one of the cost-effective hole selective contacts for the emerging organo-metal halide PSCs. The hole mobility of 0.01–0.1 $cm^2\ V^{-1}\ s^{-1}$, HOMO level of −5.3 eV (& E_{CB} = −1.8 eV), and high thermal and chemical stability of CuSCN have gained attention as inorganic HTLs in PSCs.[illegible] CuSCN with an inherently wide bandgap (E_g = ∼3.8 eV) transmits in the complete visible spectrum, facilitates photoactive materials to absorb more light, and generates higher photocurrents in solar cells. Ito *et al.*[illegible] proposed the use of CuSCN as an HTL in PSCs for the first time to control the degradation of the $CH_3NH_3PbI_3$ perovskite layer during the light exposure test without encapsulation. Later, various synthesis protocols such as drop-casting,[illegible] electrodeposition,[illegible] spin coating,[illegible] and spraying[illegible] were developed to obtain CuSCN in an ambient atmosphere with minimum damage to the underlying perovskite absorber, followed by annealing strategies to achieve a higher efficiency. Nevertheless, the textured grain growth of CuSCN after recrystallization produces poor interaction with the perovskite absorber, thus inducing non-contacting sites as charge recombination centres, thereby reducing the device efficiency. The high-temperature treatment causes the SCN^- ions to diffuse near the perovskite/HTL interface, resulting in the degradation of the device performance, which can be impeded either by vacuum-assisted thermal treatment[illegible] or KSCN post-treatment.[illegible]

PSCs employing a CuSCN HTL exhibited a PCE of 12.3%, which degraded faster under elevated temperatures in ambient atmosphere. Therefore, the critical instability caused by the interfacial degradation of the heterojunction of CuSCN and perovskite in a dry N_2 environment was resolved with rudimentary on-cell encapsulation using an additional coating of insulating poly-methyl-methacrylate (PMMA).[illegible] The mesoporous and rough surface of a 600–700 nm-thick CuSCN layer utilized in conventional and mesostructured PSCs attained a maximum of PCE of 12%.[201,202] However, a very thin (40 nm) uniform and compact CuSCN film furnished a higher degree of transparency, rendering a PCE of 16%, given that it efficiently generates a higher photocurrent and mitigates the recombination losses at the interface.[204] The well-aligned junction geometries of the nanostructured arrays substantially increase the light trapping by reducing reflection losses, and also improve the carrier extraction by increasing the interfacial area at the perovskite/HTL interface. However, the hexagonal 1D prism, 1D pyramid, and 1D nanowire-like structures of the CuSCN HTL produced uncontrolled defect density and oversized growth of perovskite, restricting the PCE to <12%.[205] Importantly, the incorporation of CuSCN in the mesoporous perovskite absorber layer resulted in the formation of a bulk heterojunction, which facilitated faster hole extraction with a resulting PCE of >15%.[206]

The deposition of the CuSCN HTL overlayer causes damage to the perovskite absorber. Therefore, a protective buffer solvent layer of chlorobenzene[207] and PDMS[208] was placed over the perovskite before the deposition of CuSCN, which not only hampered the formation and migration of defects but also promoted the crystallization of CuSCN to benefit the charge extraction at the interface (Fig. 29). However, the use of NH_3 (aq) as a substitute to the commonly used diethyl sulfide solvent is seen to reduce the shunting pathways and interfacial current losses, resulting in a PCE of 17.5%.[209] Further, a fast solvent removal process facilitates the formation of a compact and conformal CuSCN layer, which serves towards rapid charge extraction and collection. The potential-induced degradation of the CuSCN/Au contact provoked the operational instability of the PSCs with a PCE exceeding 20%. Accordingly, the inclusion of a conductive rGO spacer between CuSCN and Au avoids the electrical potential-induced reaction at their interface, forming an undesirable barrier and exceptionally improving the stability (*i.e.*, >95% of the initial PCE at 60 °C for 1000 h aging).[209] However, rGO has been seen to fail in improving the hole extraction and electron blocking, which cannot further enhance the PCE. Therefore, the introduction of ultrathin polymeric layers of PTB[210] and PTAA[211] over CuSCN has gained attention. These innovative alterations have enhanced the hole extraction efficiency by cascading energy levels and providing environmentally stable PCEs of above 20% for over >1000 h of light illumination. Considering the dissimilarity around the defects structures, multi-component systems have been found to be helpful for the passivation of defects. The interfacial treatment of functional molecules such as Pr-DTC and Pb-DTC has been found to be effective in controlling the perovskite/CuSCN interface, resulting in a PCE of 19.17% PCE with an enhanced V_{OC}.[212]

Recently, Kim *et al.*[213] introduced CuSCN/P3HT composites to address the instability of PSCs towards high-moisture conditions. The hole-extractive CuSCN, when combined with a *p*-type conductive polymer, initiated oxidative activities and triggered *in situ p*-doping of polymers, thereby improving the interfacial charge transportation and device performance. Alternatively, the coordination strategy, where the coordination bond between CuSCN and ligands (*e.g.*, pyridine derivative) forms a stable intermediate phase, has been found to be exceptionally good for realizing a compact CuSCN HTL by reducing the formation of intermediate adducts and enabling faster recrystallization. Consequently, it facilitated hole extraction and suppressed charge recombination at the interface, resulting in a PCE of 18.2%.[214] Besides, CuSCN is either doped or combined with organic HTLs such as F4TCNQ,[215] PEDOT:PSS,[216] and spiro-OMeTAD[217] to reduce the energy barrier and improve the charge extraction at the interface.

Overall, the theoretically predicted PCE of 25%[218] for the device utilizing CuSCN HTL, where Cu–I and Pb–N bonds form at the interface, inducing more significant electrostatic potential and electron–hole pair excitation, is highly encouraging. However, one should always consider that the molecular (atomic) adsorbates such as iodide and lead present in the perovskite absorber interact with CuSCN at the interface and form the PbI_2 moiety, leading to additional empty states in the bandgap of CuSCN and tailoring the corresponding optoelectronic properties. Therefore, theoretical studies on the passivation of CuSCN and interaction of solvent molecules (DMSO or DMF) with CuSCN need to be thoroughly devoted to the molecular interfacial engineering of CuSCN HTLs for realizing excellent PCEs.

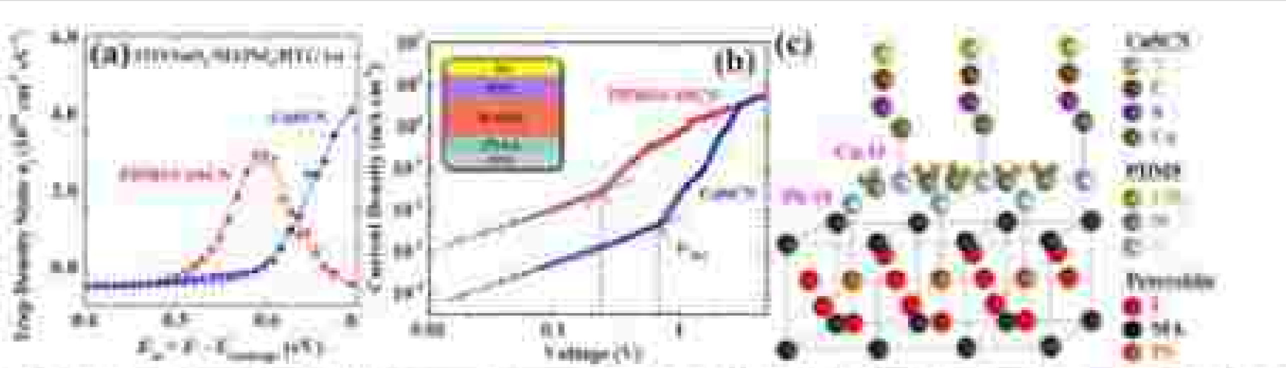

Fig. 29 (a) Trap distribution spectra and (b) J–V characteristics measured in the dark for the $MAPbI_3$/CuSCN based PSCs with and without the PDMS interlayer. (c) Schematic of the cross-linking PDMS interlayer. The mobilities and defection features of the PSCs are estimated from the curves in (a) fitted with dot lines. The arrows in (b) indicate the trap-filled limit voltages (V_{TFL}).[208] Reprinted with permission from (*ACS Appl. Mater. Interfaces*, 2019, **11**, 46818–46824). Copyright (2019), the American Chemical Society.

3.3.7. **Other inorganic HTLs.** Delafossite materials with the general chemical formula of ABO_2, where A (= Cu), B (= Al, Ga, Cr), and O bear +1, +3, and −2 states, respectively, have also attracted scientific attention to understand their photoactivity. These layers are composed of edge-sharing BO_6 octahedrons linked by triangular sheets of monovalent A^+ ions in the ABO_2 materials and possess high mobility, wide bandgap, and excellent stability. However, limited delafossite materials have been explored as HTLs for PSCs. $CuAlO_2$ (CAO) exhibiting a bandgap of ~3.75 eV and hole mobility of ~3.6 $cm^2\ V^{-1}\ s^{-1}$[illegible] is one of them. However, CAO, possessing decent optical transparency and thermal/chemical stability, has processing issues due to the need for high-temperature processing to gain pure polycrystalline delafossite form, and the complex Al chemistry prohibits the efficient synthesis of nanostructures. However, its amorphous phase, which provides a band gap of ~1.86 eV, has attracted attention due to its nonreactive behaviour with ITO or other HTL materials during deposition. Therefore, Igbari et al.[illegible] introduced magnetron-sputtered CAO thin films below a PEDOT:PSS HTL in planar PSCs. The variation in the thickness of the CAO film tailored the energy level alignment and reduced the charge transfer resistance at the HTL/perovskite interface, which yielded an optimized PCE of ~14.52% and stable performance with efficiency retention of 90% over 250 h in the ambient atmosphere without encapsulation. Further, the incorporation of 15% CuO in the uniformly distributed CAO nanoparticles enhanced the electrical conductivity, which further reduced the interfacial charge recombination and induced faster charge collection to render a higher PCE of 16.2%. Recently, PANI introduced during the electro-spray process to form a CAO/polyaniline (PANI) composite film delivered an ~7% larger efficiency for the optimized wt% of CAO (*i.e.*, 0.1%) than pure PANI film.[illegible] The addition of PANI improved the interconnectivity between the CAO nanoparticles, enabling the conformal film coating of a CAO HTL, and enhanced the hole conduction into the organic polymer. Nevertheless, the excessive aggregation of CAO induced high surface roughness and increased the series resistance by segregating the CAO and polymer.

$CuCrO_2$ (*i.e.*, CCO) is another delafossite material with a hole mobility of 0.1–1 $cm^2\ V^{-1}\ s^{-1}$, valence band maximum of −5.3 eV w.r.t. the vacuum level, and a bandgap of 3.1 eV,[illegible] which can offer the tuning of the energy levels by altering the phase composition. Low-temperature solution-processed CCO nanocrystals demonstrated a PCE of ~19% as HTLs in PSCs and acted as an excellent UV inhibitor, protecting the perovskite absorber from UV-induced degradation.[illegible] Although DFT analysis proposed the formation of distinct hexagonal 2H (space group $P6_3/mmc$) and rhombohedral 3R (space group $R\bar{3}m$) polytypes of CCO, both are stable and deliver identical optoelectronic properties.[illegible] Besides the inverted device structure, CCO nanoparticles were utilized with a triple cation perovskite light absorber to form a highly stable n–i–p structure, exhibiting an efficiency of 16%.[illegible] A bigger VB offset does not favour hole transfer, whereas a lower electron affinity favours electron-blocking. Therefore, Qin et al.[illegible] employed different Cu/Cr ratios to modulate the energy levels and phase composition of a CCO film to improve the hole-collection and electron-blocking ability. These Cr-terminated polar CCO films achieved a respectable PCE of 17.19% (Fig. 38).

Yang et al.[illegible] introduced an azeotropic-promoted doping approach for CCO to explore cost-effective commercialization aspects. The d–d excitation of the Cr^{3+} cations at the oxygen octahedrons of the delafossite structure causes the low transparency of CCO. The replacement of Cr^{3+} by In^{3+} (*i.e.*, doping) decreases the absorption of d–d and improves the conductivity (*i.e.*, carrier mobility) and transmittance of CCO, which are beneficial for solar-light harvesting and hole transport, and consequently an impressive PCE of 20.54% was achieved. Furthermore, considering the bond alteration due to the doping of metallic elements, Mg has also been introduced in CCO. The smaller ionic radius of Mg than Cr overlaps the Cu d-orbitals by reducing the Cu–Cu bond distance, resulting in improved charge mobility and conductivity, which produces an efficiency close to 13%.[illegible]

$CuGaO_2$ (*i.e.*, CGO) is also a prominent HTL material with high carrier mobility (~10^{-1} $cm^2\ V^{-1}\ s^{-1}$) and a bandgap of ~3.58 eV, furnishing a well-matched energy level with perovskite absorbers.[illegible] However, the aggregation of CGO results in a larger particle size, which is incapable of enabling the formation of a compact pinhole-free film, hindering its use as an HTL. Therefore, a surfactant such as Pluronic 123 was utilized to synthesize CGO nanoparticles with a diameter of <10 nm.[illegible] Moreover, the use of CGO with CuSCN improved the PCE to 16% by reducing the trap density of cells.[illegible] Besides the increased efficiency, a bilayer HTL was shown to offer high thermal stability, retaining 80% of the initial efficiency after exposure to a temperature of 85 °C and 85% relative humidity (RH) condition (encapsulated) for 400 h. Furthermore, Zn^{2+} doping (*i.e.*, 5%) enhanced the hole mobility of pristine CGO (*i.e.*, from 1.81 × 10^{-4} to 1.39 × 10^{-3} $cm^2\ V^{-1}\ s^{-1}$), which yielded an efficiency of ~20% and high inertness to humidity and temperature.[illegible] Chen et al.[illegible] reported the development of mesoscopic inverted device structures utilizing compact NiO_x and CGO mesoporous layers. The graded band alignment formed at the HTL with compact NiO_x and mesoporous CGO was shown to enable higher hole extraction, leading to an efficiency of ~19%. Further, solution-processed CGO nanoplates were coated on the perovskite absorber to form an n–i–p device structure, effectively lowering the nonradiative Shockley–Read–Hall (SRH) recombination and providing a PCE of ~18%.[illegible] Recently, a 3D hybrid HTL consisting of Cr-doped CGO nanoplates and NiO nanoparticles yielded a PCE of ~20%. The nanoplates acted as expressways for hole extraction, whereas the ultrafine NiO nanoparticles modified the surface properties.[illegible]

Besides delafossite materials, various inorganic materials such as CuS, FeS_2, CuZnS, and CZTS have been investigated for their application as HTLs in PSCs. The use of CuS nanoparticles uniformly deposited on ITO without compromising the roughness and transmittance of the ITO substrate resulted in an

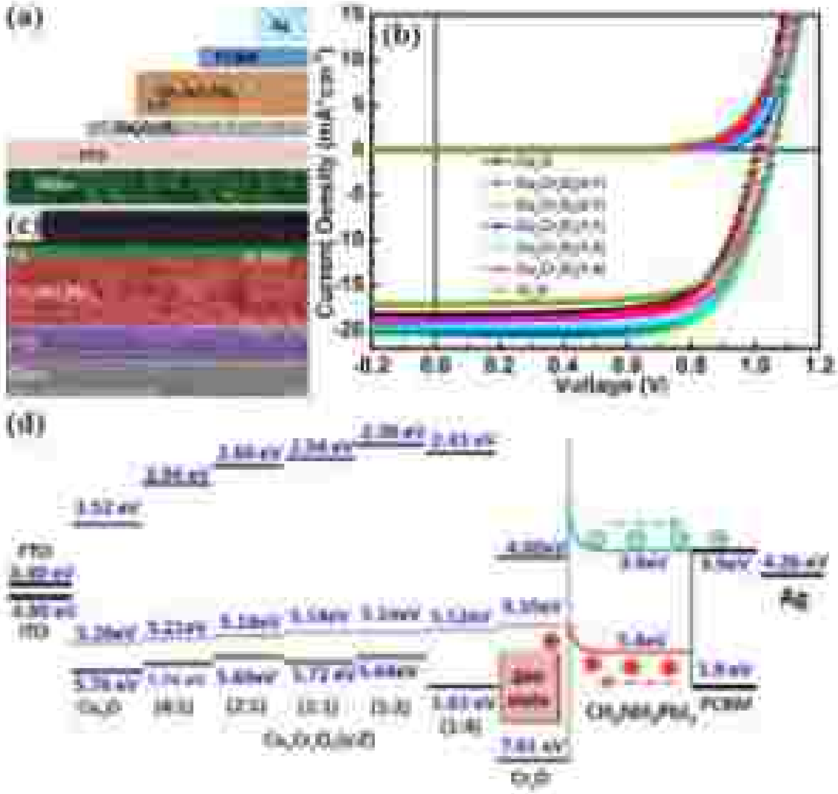

Fig. 30 (a) Schematic, (b) J–V characteristics under illumination, and (c) a cross-sectional SEM image of PSCs consisting of $Cu_yCr_zO_2$ HTL. (d) Band energy level diagram of PSCs comprised of $Cu_yCr_zO_2$ HTL in various volume ratios of $y : z$ = 1 : 0, 4 : 1, 2 : 1, 1 : 1, 1 : 2, 1 : 4, and 0 : 1.[illegible] Reprinted with permission from (Solar RRL, 2017, 1, 1700058). Copyright (2017), John Wiley & Sons.

efficiency of ~16% with $CH_3NH_3PbI_3$ as the light absorber, although its V_{OC} was limited to ~0.8 V due to the considerable offsets in valence band levels at the CuS/perovskite interface.[illegible] High hole mobility CuS nanoparticles have been incorporated in carbon to form a CuS/C composite HTL and improved the hole mobility.[illegible] Moreover, digenite CuZnS nanocrystals were formed by partially replacing Cu with Zn in the covellite CuS structure and tested as HTLs in PSCs. The ternary CuZnS material showcased its potential as an HTL by yielding an efficiency of ~18%.[illegible] High-purity kesterite Cu_2ZnSnS_4 (CZTS) nanocrystals as an inorganic HTM with $CH_3NH_3PbI_3$ perovskite achieved an efficiency of ~13% and remarkable FF of 81%.[illegible] Further, quantum dots of CZTS as HTLs were tested with all-inorganic $CsPbBr_3$ perovskite absorbers, showing a promising efficiency of ~5%.[illegible] The thickness of the light-absorbing CZTS HTLs in inverted PSCs plays a prominent role in controlling the irradiation over the perovskite light absorber.[illegible] Interestingly, numerical simulations have identified the plausible tailorability of the $Cu_2ZnSn_{1-x}Ge_xS_4$ bandgap and band offsets at the perovskite/HTL interface through the partial replacement of Sn with Ge (*i.e.*, x = 0.4) and predicted a theoretical efficiency of ~20% in combination with $CH_3NH_3PbI_3$ as a light absorber.[illegible] Kim *et al.*[illegible] observed an efficiency of ~13% with octadecylamine-capped FeS_2 nanoparticles, preventing moisture attack in the perovskite light absorber, thereby retaining stability for 1000 h. Further, the hole quenching capacity of iron pyrite FeS_2 is comparable to that of the benchmark spiro-OMeTAD, but its efficiency is not higher to the defect-mediated recombination at the FeS_2/perovskite interface, where low-energy photons are left largely unutilized with non-productive recombination events taking place.[illegible] Although FeS_2 is 300 times cheaper than spiro-OMeTAD, its inefficient hole collection needs to be improved by using a capping ligand. Moreover, a wide bandgap p-type quaternary chalcogenide Cu_2BaSnS_4 semiconductor having favourable band alignment with a $CH_3NH_3PbI_3$ perovskite light absorber and high carrier mobility (~10 cm^2 V^{-1} s^{-1}) was shown to exhibit an efficiency of 10% in inverted PSCs.[illegible] Similarly, spinel oxides of Ni, Co, Cu, *etc.* (such as $CuCo_2O_4$ and $NiCo_2O_4$) have been explored as HTLs in PSCs due to their high electrical conductivity, high optical transparency in the UV-Vis-NIR region, and well-matched energy levels to the perovskite absorber.[illegible] The low-temperature solution-processable monodispersed spinel $NiCo_2O_4$ oxide nanoparticles synthesized via a combustion method show high electrical conductivity (~4 S cm^{-1}) and low roughness (0.56 nm), delivering an efficiency of ~15% for the optimized film thickness of 15 nm with higher transmittance and better charge collection.[illegible] Likewise, various doping strategies[illegible] have been explored to investigate the practicality of spinel $NiCo_2O_4$ as HTLs in PSCs. Thus, besides the traditional inorganic HTLs used in PSCs, various combinations of pristine novel p-type materials need to be tested for their hole quenching capabilities.

5.2. Organic HTLs

Several organic HTMs previously used in DSSCs and organic bulk heterojunction solar cells, which satisfy the requirements of PSCs, have been tested as HTLs to improve the performance. 2,2',7,7'-Tetrakis-(N,N-di-4-methoxyphenylamino)-9,9'-spirobifluorene (spiro-OMeTAD) is one of the widely used organic small molecule p-type semiconductors and dominant solid-state HTLs in PSCs. The large bandgap (about 3 eV) with a deep HOMO level of spiro-OMeTAD located at −5.2 eV eases the acceptor transport from most of the perovskite absorbers to the external contact.[illegible] Although spiro-OMeTAD has been proven to be the best HTM with good thermal stability owing to its high melting temperature, it suffers from poor conductivity (8 × 10^{-5} mS cm^{-1}) and hole mobility (2 × 10^{-4} cm^2 V^{-1} s^{-1}).[illegible] Thus, different strategies have been employed to deal with these issues, as follows: (a) doping to improve the conductivity together with hole mobility and to expedite the oxidation process; (b) designing novel synthesis processes to improve the film quality, coverage, and avoid pinholes; and (c) controlling the defects and hydrophobic nature at the interface. Butyl pyridine (TBP) and lithium salt (LiTFSI) are the most common dopants that increase the hole mobility of spiro-OMeTAD,[illegible] but PSCs suffer from low stability with the introduction of the hygroscopic lithium. The doping of CuSCN and CuI in spiro-OMeTAD reduced the amount of pinholes and improved its crystallinity, which protected the perovskite absorber from humidity and exhibited an efficiency of ~18%.[illegible] However, spiro-OMeTAD suffers from complicated synthesis and is ~20 times more expensive than gold.[illegible] Recently, a mixture of PbS/spiro-OMeTAD and potassium persulfate (KPS)-doped spiro-OMeTAD HTLs exhibited a PCE of above 20%.[illegible]

Likewise, poly(3,4-ethylene dioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) is a typical choice as an HTL for inverted PSCs (p–i–n type), which shows high optical transparency in the visible region and exhibits the HOMO level of −5.3 eV, matching well with the perovskite. Unfortunately, PEDOT:PSS in its pristine form suffers from low conductivity (10^{-3} S cm^{-1}), poor hole mobility, and hygroscopic and acidic nature.[illegible] Thus, to overcome these issues, PEDOT:PSS is either treated with a dimethylformamide (DMF)/methanol mixture or annealed with non-polar vapours of toluene, which improves its conductivity, reduces its trap state density, and facilitates smooth charge transfer at the PEDOT:PSS/perovskite interface, resulting in an improved PCE than the pristine HTL.[illegible] Separately, the development of a PEDOT:PSS toluene-based ink coated over the perovskite absorber in the conventional planar (n–i–p type) device architecture has attracted attention from the scientific and industrial community.[illegible] The absorbance of PEDOT films is very low in the UV-visible region, causing less parasitic losses during the second pass through the perovskite layer and resulting in an increased photocurrent with a PCE of 13.5% (Fig. 31). Further, the addition of island-like GeO_2 particles in PEDOT:PSS film served well as growth sites for perovskite absorbers with better crystallinity,[illegible] resulting in a PCE of ~13%.

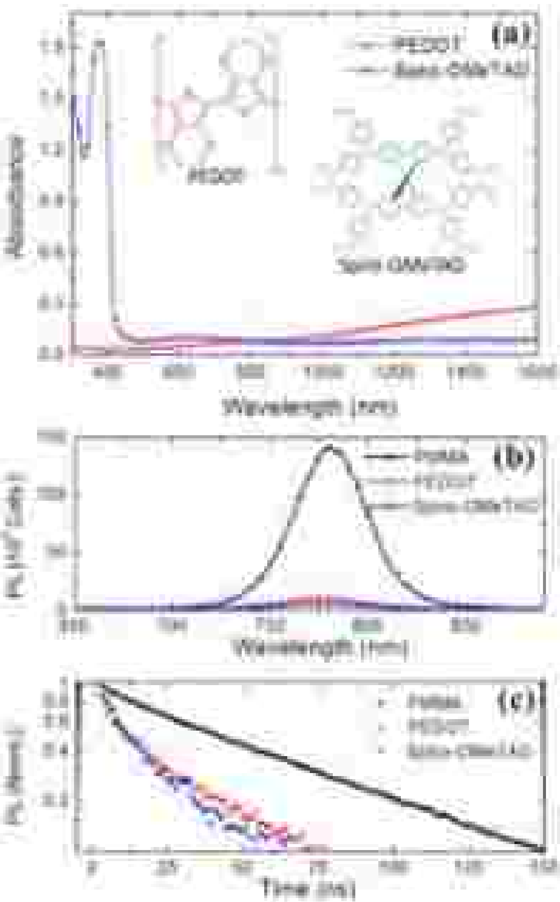

Fig. 31 (a) Absorbance spectra of ~330 nm thick PEDOT films (red circles) and ~280 nm thick spiro-OMeTAD films doped with Li-TFSI (blue triangles) deposited on glass. (b) Steady state PL spectra and (c) time-resolved PL decay curves at 557 nm of perovskite films coated with PMMA (black squares), PEDOT (red circles), and spiro-OMeTAD (blue triangles), respectively.[illegible] Reprinted with permission from (J. Phys. Chem. Lett., 2015, 6, 1666–1673). Copyright (2015) the American Chemical Society.

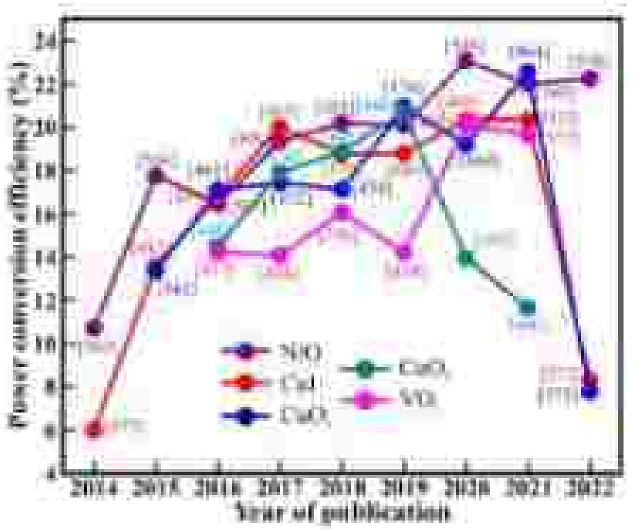

Fig. 32 Comparative study of the influential HTLs developed by year to gain the best maximum efficiency in the last decade (collected from ISI Web of Knowledge up to 31st December 2022).[illegible]

Table 2 A brief summary of inorganic HTLs processed with various synthesis methods and their corresponding device performance parameters

S. no.	Device configuration	Method[a]	V_{oc} (V)	J_{sc} (mA cm^{-2})	FF	PCE (%)	Year	Ref.
Nickel oxide (NiO)								
1.	FTO/NiO$_x$/TPA-BA/PC$_{61}$BM/BCP/Au	SC	1.15	23.26	0.829	22.25	2022	570
2.	FTO/S-NiO/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/BCP/Au	SC	1.13	22.56	0.78	19.93	2022	578
3.	FTO/NiO$_x$/Cs$_{0.05}$(MA$_{0.17}$FA$_{0.83}$)$_{0.95}$Pb(I$_{0.83}$Br$_{0.17}$)$_3$/PF-FAN/PCBM/C$_{60}$/BCP/Cr/Au	SC	1.12	23.53	0.836	22.03	2021	569
4.	FTO/NiO$_x$/ST-MAPb(I$_{1-x}$Cl$_x$)$_3$/PCBM/BCP/Ag	SC	1.16	23.53	0.817	21.07	2020	568
5.	FTO/Al:NiO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/nm-TiO$_2$/Ag	SC	1.26	24.24	0.813	20.84	2020	403
6.	FTO/c-TiO$_2$/Al$_2$O$_3$/FA$_{0.85}$MA$_{0.15}$PbI$_{3-x}$Cl$_x$/Cs:NiO/spiro-OMeTAD/Au	CP/SC	1.03	24.33	0.805	20.67	2020	388
7.	FTO/Ni$_2$O$_3$/MA$_{0.85}$FA$_{0.15}$PbI$_{3-x}$Cl$_x$/PCBM/BCP/Ag	SC	1.06	19.86	0.826	17.89	2020	385
8.	FTO/LiCO-NiO/MA$_{1-x}$FA$_x$PbI$_{3-x}$Cl$_x$/PC$_{61}$BM/BCP/Ag	SC	1.09	23.8	0.78	20.1	2019	409
9.	FTO/NiO-NCs/np-NiO/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/BCP/Au	TT	1.11	22.20	0.741	18.17	2019	579
10.	FTO/NiO/MA$_{1-x}$FA$_x$PbI$_{3-x}$Cl$_x$/PCBM/BCP/Ag	C	1.12	22.7	0.76	20.2	2018	381
11.	FTO/Ag:NiO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/BCP/Ag	SC	1.08	19.35	0.783	16.86	2018	394
12.	FTO/NiO/CH$_3$NH$_3$PbI$_3$/PCBM/BCP/Ag	SPS	1.05	20.57	0.752	16.29	2016	580
13.	FTO/Cu:NiO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/ZrAcac/Ag	SC	1.13	21.77	0.760	19.25	2017	408
14.	FTO/c-TiO$_2$/NiO-NTs + CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Au	ES	1.12	22.7	0.752	19.3	2017	581
15.	FTO/NiMgO/CH$_3$NH$_3$PbI$_3$/PCBM/ZnMgO/Al	DCS	1.08	21.2	0.79	18.2	2017	404
16.	FTO/NiO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/Ag	SC	1.07	20.38	0.769	16.47	2016	567
17.	FTO/Cu:NiO$_x$/CH$_3$NH$_3$PbI$_3$/bis-C$_{60}$/Ag	C	1.05	22.23	0.76	17.74	2015	566
18.	FTO/Cu:NiO$_x$/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/C$_{60}$/Ag	CP	1.12	19.17	0.73	15.4	2015	582
19.	FTO/NiO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/BCP/Al	RFS	1.06	17.4	0.81	16.7	2014	562
Cobalt oxide (CoO$_x$)								
20.	FTO/Zn,Li'-CoO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/BCP/Ag	SC	0.93	19.7	0.635	11.64	2021	583
21.	FTO/Li-Co$_3$O$_4$/CH$_3$NH$_3$PbI$_3$/PCBM/ZnO/Ag	SC	1.01	20.46	0.66	13.56	2020	444
22.	FTO/CoO$_x$/Cs$_{0.05}$(MA$_{0.17}$FA$_{0.83}$)$_{0.95}$Pb(I$_{0.83}$Br$_{0.17}$)$_3$/PCBM/Ag	LBP	0.96	18.9	0.572	10.1	2020	447
23.	FTO/TiO$_2$/Cs$_{0.05}$(MA$_{0.17}$FA$_{0.83}$)$_{0.95}$Pb(I$_{0.83}$Br$_{0.17}$)$_3$/CoO/spiro-OMeTAD/Au	TT	1.14	22.15	0.757	20.76	2019	448
24.	FTO/TiO$_2$/CH$_3$NH$_3$PbI$_3$/ZrO$_2$/Co$_3$O$_4$/C	CP	0.88	23.43	0.64	13.27	2018	442
25.	FTO/Co$_{1-x}$Cu$_x$O$_y$/CH$_3$NH$_3$PbI$_3$/PCBM/Ag	DCS	0.92	17.96	0.599	9.98	2017	441
26.	FTO/Ni:CoO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/Ag	DCS	0.79	15.96	0.660	9.63	2017	584
27.	FTO/CoO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/Ag	SC	0.93	20.08	0.755	14.5	2016	440
Copper oxide (CuO$_x$)								
28.	FTO/c-TiO$_2$/mp-TiO$_2$/CH$_3$NH$_3$PbI$_3$/CuO/C	SC	0.83	16.58	0.57	7.72	2022	575
29.	FTO/CuO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/Ag	RFS	1.06	27.14	0.786	22.56	2021	464
30.	FTO/NiO$_x$/CuO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/Au	SC	1.12	22.29	0.782	19.55	2021	463
31.	FTO/SnO$_2$/CsFAMA/Cu$_2$O-CuSCN/Au	SC	1.05	23.23	0.784	19.2	2020	469
32.	FTO/Cu$_2$O/CH$_3$NH$_3$PbI$_3$/SnO$_2$/ZrO/Ag	RFS	1.12	20.90	0.786	18.4	2020	466
33.	FTO/c-TiO$_2$/mp-TiO$_2$/Cs$_{0.05}$MA$_{0.15}$FA$_{0.80}$PbI$_{2.55}$Br$_{0.45}$/Cu$_2$O/Au	SC	1.10	22.2	0.742	18.9	2019	467
34.	FTO/TiO$_2$/CH$_3$NH$_3$PbI$_3$/Cu$_2$O/Au	SC	1.12	22.53	0.673	17.22	2019	465
35.	FTO/TiO$_2$/CH$_3$NH$_3$PbI$_3$/spiro-OMeTAD/Cu$_2$O/Ag	DIB	1.03	22.46	0.741	17.11	2018	459
36.	FTO/CuO$_x$/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/ZnO/Al	SC	1.03	22.42	0.76	17.43	2017	452
37.	FTO/CuO$_x$/CH$_3$NH$_3$PbI$_3$/C$_{60}$/BCP/Ag	SC	0.99	23.2	0.744	17.1	2016	461
38.	FTO/Cu$_2$O/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/Ag	RFS	0.93	17.5	0.662	11.03	2016	453
39.	FTO/Cu$_2$O/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/Al	Dip[c]	1.07	16.33	0.755	13.35	2015	361
	FTO/CuO/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/Al		1.06	15.82	0.725	12.16		
Vanadium oxide (VO$_x$)								
40.	FTO/Cs-VO$_x$/PTAA/CH$_3$NH$_3$PbI$_3$/PCBM/BCP/Ag	SC	1.08	22.47	0.75	19.64	2023	577
41.	FTO/PTAA/VO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/C$_{60}$/LiF/Al	SC	1.12	22.60	0.75	18.9	2021	427
42.	FTO/VO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/ZnO/Al	RFS	1.00	20.7	0.66	13.66	2021	423
43.	FTO/SnO$_2$/PCBA/CsFAPbI$_3$/MAI/PTAA/VO$_x$/Ag	TE	1.044	24.6	0.78	20.1	2020	430
44.	FTO/PEDOT:PSS/PEDOT:PSS-VO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/C$_{60}$/LiF/Al	SC	1.02	22.98	0.77	18.0	2020	416
45.	FTO/V$_2$O$_5$/PEDOT:PSS/PDI-Th/PC$_{61}$BM/PDINO/Al	SC	0.80	16.83	0.703	9.44	2020	437
46.	FTO/PEDOT:PSS/VO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/C$_{60}$/BCP/Al	SC	0.969	20.3	0.722	14.22	2019	418
47.	FTO/VO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/Al	SC	0.95	20.90	0.765	16.06	2018	576
48.	FTO/TiO$_2$/(FAPbI$_3$)$_{0.85}$(MAPbBr$_3$)$_{0.15}$/NiPc-(OBu)$_8$/V$_2$O$_5$/Au	SC	1.07	23.0	0.729	17.9	2017	438
49.	FTO/VO$_x$/APPA/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/BCP/Ag	SC	0.96	19.42	0.752	14.07	2017	434
50.	FTO/VO$_x$/CH$_3$NH$_3$PbI$_3$/PCBM/Al	SC	0.96	22.29	0.71	14.23	2016	417
Copper iodide (CuI)								
51.	FTO/SnO$_2$/FA$_x$MA$_{1-x}$PbI$_{3-x}$Cl$_x$/CuI/PDMS/Au	SP	0.765	19.3	0.528	8.3	2022	573
52.	FTO/CuI/CuSCN/CH$_3$NH$_3$PbI$_3$/PCBM/carbon	ED	1.16	20.26	0.78	20.25	2021	572
53.	FTO/PEDOT:PSS/CuI/CH$_3$NH$_3$PbI$_3$/PCBM/BCP/Al	SC	0.977	22.13	0.737	16.65	2021	487
54.	FTO/CuSCN@CuI/CH$_3$NH$_3$PbI$_3$/PC$_{61}$BM/carbon	ED	1.08	18.24	0.75	15.58	2021	585
55.	FTO/CuI/FA$_{0.83}$MA$_{0.17}$PbI$_3$/PCBM/C$_{60}$-N/Ag	SC	1.017	24.8	0.77	20.14	2020	488
56.	FTO/CuI/PEDOT:PSS/(FAPbI$_3$)$_{0.85}$(MAPbBr$_3$)$_{0.15}$/C$_{60}$/BCP/Cu	SC	0.75	28.5	0.737	15.75	2020	479
57.	FTO/CuI/MaPI/PCBM/Al/ZnO/Ag	SC	0.99	19.39	0.74	14.21	2020	480

Table 2 (continued)

S. no.	Device configuration	Method^a	V_{oc} (V)	J_{sc} (mA cm^{-2})	FF	PCE (%)	Year	Ref.
58.	FTO/Cu@CuI/PCBM/ZnO/Ag	SC	1.06	22.21	0.761	18.00	2019	496
59.	FTO/NiO/CuI/$CH_3NH_3PbI_3$/PCBM/BCP/Ag	SC	1.07	20.60	0.69	15.26	2019	493
60.	FTO/c-TiO_2/mp-TiO_2/$CH_3NH_3PbI_3$/CuI/Pt-FTO	PPT	0.67	24.25	0.50	8.1	2019	476
61.	ITO/CuI/$CH_3NH_3PbI_{3-x}Cl_x$/$PC_{61}BM$/PEI/Ag	SC	1.05	20.05	0.69	14.53	2018	571
	ITO/CuI/CuSCN/$CH_3NH_3PbI_{3-x}Cl_x$/$PC_{61}BM$/PEI/Ag		1.14	22.22	0.76	18.76		
62.	FTO/Cu(Tu)I–$CH_3NH_3PbI_{3-x}Cl_x$/C_{60}/BCP/Ag	SC	1.12	22.3	0.798	20.0	2017	491
63.	FTO/Na-TiO_2/$CH_3NH_3PbI_3$/CuI/	E	1.01	22.78	0.75	17.6	2017	478
64.	FTO/CuI/$CH_3NH_3PbI_3$/PCBM/PEI/Ag	VI	1.04	20.5	0.66	14.7	2017	484
65.	ITO/CuI/$CH_3NH_3PbI_3$/C_{60}/BCP/Ag	SC	1.01	22.5	0.739	16.8	2016	485
66.	ITO/TiO_2/$CH_3NH_3PbI_{3-x}Cl_x$/CuI/spiro-OMeTAD/Ag	SC	1.06	21.55	0.73	16.67	2016	540
67.	FTO/TiO_2/$CH_3NH_3PbI_3$/CuI/Au	TE	0.72	22.25	0.31	7.40	2016	481
68.	FTO/CuI/$CH_3NH_3PbI_3$/PCBM/Al	SC	1.04	21.06	0.62	13.58	2015	482
69.	FTO/c-TiO_2/mp-TiO_2/$CH_3NH_3PbI_3$/CuI/Au	DC	0.55	17.8	0.62	6.0	2014	477
Copper thiocyanate (CuSCN)								
70.	FTO/c-TiO_2/$CH_3NH_3PbI_3$/CuSCN/Au	SC	0.981	23.77	0.724	16.89	2022	586
71.	FTO/c-TiO_2/$CH_3NH_3PbI_3$/CuSCN/Au	SC	0.93	17.2	0.63	10.1	2022	587
72.	FTO/TiO_2/$CsPbI_2Br$/CuIn/CuSCN/Au	SC	1.05	12.2	0.76	9.96	2022	588
73.	ITO/SnO_2/$FA_{1-x}MA_xPb(I_{1-y}Br_y)_3$/CuSCN/PTB/Au	SC	1.15	20.31	0.786	21.7	2020	510
74.	FTO/c-TiO_2/mp-TiO_2/$CH_3NH_3PbI_3$/CuSCN/Au	SC	0.83	22.15	0.60	11.02	2020	589
75.	FTO/TiO_2/$Cs_{0.05}FA_{0.81}MA_{0.14}PbI_{2.55}Br_{0.45}$/CuSCN/Au	SBND	1.074	22.37	0.756	18.74	2019	590
76.	FTO/TiO_2/$CH_3NH_3PbI_3$/TSC-CuSCN/Au	SC	1.068	22.65	0.763	18.57	2019	512
77.	FTO/c-TiO_2/mp-TiO_2/$Cs_{0.05}(MA_{0.17}FA_{0.83})_{0.95}Pb(I_{0.83}Br_{0.17})_3$/CuSCN/ITO	SC	0.978	20.2	0.721	14.2	2019	591
78.	ITO/GO/CuSCN/$CH_3NH_3PbI_3$/PCBM/BCP/Ag	SC	1.011	18.21	0.761	18.28	2018	592
79.	FTO/TiO_2/$CH_3NH_3PbI_3$/CuSCN/Au	E	1.013	22.10	0.751	17.10	2017	508
80.	ITO/3D-CuSCN/$CH_3NH_3PbI_3$/C_{60}/Bphen/Ag	ED	0.93	19.43	0.66	11.89	2017	503
	ITO/2D-CuSCN/$CH_3NH_3PbI_3$/C_{60}/Bphen/Ag		0.83	18.56	0.61	9.19		
Other inorganic HTLs								
81.	ITO/CuBr/$CH_3NH_3PbI_3$/PCBM/C_{60}-N/Ag	SC	1.02	22.15	0.726	17.65	2022	593
82.	FTO/TiO_2/$Cs_{0.05}(MA_{0.17}FA_{0.83})_{0.95}Pb(I_{0.83}Br_{0.17})_3$/$CuIn_{0.75}Ga_{0.25}S_2$/C	SC	1.08	23.06	0.62	15.51	2020	594
83.	FTO/TiO_2/$CH_3NH_3PbI_3$/Fe-Cr_2/Au	SC	1.13	19.29	0.71	15.42	2020	595
84.	FTO/$NiCo_2O_4$/$CH_3NH_3PbI_3$/PCBM/BCP/Ag	SC	1.08	22.37	0.833	20.03	2019	596
85.	FTO/c-$CuCrO_2$/$CH_3NH_3PbI_3$/PCBM/BCP/Ag	HT	1.07	21.58	0.81	19.0	2018	522
86.	ITO/$LiCoO_2$/$CH_3NH_3PbI_3$/C_{60}/BCP/Ag	RFS	1.06	23.5	0.8	18.88	2018	445
87.	FTO/c-TiO_2/$CH_3NH_3PbI_{3-x}Cl_x$/$CuGaO_2$/Au	HT	1.11	21.66	0.77	18.51	2017	363
88.	ITO/$CuAlO_2$/PEDOT:PSS/$CH_3NH_3PbI_{3-x}Cl_x$/PCBM/Ag	DCS	0.88	21.98	0.75	14.52	2016	520

^{a} SC – spin coating, CP – chemical or co-precipitation method, RFS – RF sputtering, DCS – DC sputtering, SP – screen printing, ST – solvothermal, HT – hydrothermal, ED – electrochemical deposition, IBS – ion beam sputtering, ES – electro spinning, LEP – ligand exchange process, TE – thermal evaporation, SBND – smart bottle neck deposition, DC – drop casting, VI – vapour iodination, PPT – powder press technique, DipC – dip coating, S – spray, and C – combustion.

Furthermore, different doping materials such as WO_3, EMIC (1-ethyl-3-methylimidazolium chloride), CuSCN, and 3-(cyclohexylamino)-2-hydroxy-1-propane sulfonic acid (CAPSO) have been employed to achieve the required electronic and optical properties at the PEDOT:PSS HTL/perovskite interface.

Poly(3-hexylthiophene) (P3HT) has been recommended as a promising organic HTL due to its larger-area solution processability, excellent optoelectronic properties, good hole mobility (0.1 cm^2 V^{-1} s^{-1}) and hydrophobic surface (contact angle > 100°) compared to other organic HTLs. Recently, Jung et al. employed P3HT as the HTL in PSCs and achieved a PCE of 22.7%, which retained 16% over a large area (25 cm^2). The surface treatment of P3HT using a gallium-based ligand, i.e., gallium(III) acetylacetonate (Ga(acac)$_3$), interacted with the defects on the perovskite layer and modified the P3HT/perovskite interface, resulting in PCE of 24%. Moreover, the comparative performance of spiro-OMeTAD, P3HT and 4-(diethylamino)-benzaldehyde diphenylhydrazone (DEH) as the HTL in PSCs showed a better light absorption for P3HT in the visible region compared to spiro-OMeTAD and DEH; besides, a negligible change in photon conversion efficiency. In addition, other organic HTLs such as poly[bis(4-phenyl)(2,4,6-trimethylphenyl)amine] (PTAA), polyaniline doped with camphor sulfonic acid (PANI-CSA), and tetraphenyl benzidine and MeO-triphenylamine (TPB-4-MOTPA) have been employed in PSCs as alternative organic HTLs.

Although the overall efficiency of PSCs generally increases with the use of organic HTLs, their high cost, requirement of very high purity, complicated synthetic process in an inert atmosphere, hydrophilic nature of the surface, requirement of surface treatment, and long-term instability continue to be prime concerns. The stability of the devices is reduced drastically due to the use of hygroscopic dopants, which triggers the degradation of the perovskite layer. In the future, these drawbacks need to be targeted to develop effective strategies for easy processing in the ambient atmosphere.

Similar to ETLs, numerous HTLs have delivered high PCEs despite their distinct electrical, optical, and interfacial properties. HTLs have tailored the device performance and efficiency when utilized with different perovskite coating layers in PSCs. The highest efficiencies proclaimed in the most prominent recent reports from a variety of HTLs are shown in Fig. 27. The initial ~6% efficiency reported for PSCs utilizing oxides of Ni, Cu, Co, and V as HTLs to form an HTL/perovskite heterojunction has recently been boosted to ~23% (Fig. 32) with their advancement in terms of doping, co-doping, composite formation, decoration, etc. A brief summary of the inorganic HTLs processed with various synthesis methods and their corresponding device performance parameters are provided in Table 5. Therefore, the future development of novel HTLs should be explored, focusing on enhanced PCE and sustainable and cost-effective device designs. Finally, the easy, quick, low cost and low-temperature processing of each of the layers of PSCs is an extremely important and decisive consideration for the commercialization of this technology. Therefore, alternative methods are desirable to explore for the cost-effective processing of various HTLs in the ambient atmosphere. Besides, a significant variation in the device performance can be observed when the devices are tested for a small area and scaled to large-area devices. The uniform interface over a larger area is a major concern, which affects the performance and stability of the device under testing. In this scenario, there is plenty space for investigation and finding new materials and processing methods for HTLs, to bring the commercialization of this technology one step closer.

6. Summary and outlook

The past few years have witnessed the significant role of the transport layers on the performance of PSCs and a notable upshot among the PSC devices. Some of the important features attracting researchers in this area are the cost-effective synthesis procedures, use of solar energy, engineering compatibility of ETLs and HTLs, altering the carrier mobility, band edge alignment, carrier concentration, conductivity, optical transparency, and other optoelectronic properties of the transport layers, effects of trap states, dopant and defects on the device performance, charge transport and recombination at the ETL/perovskite interface, etc. Nevertheless, the most essential is the development of ideal transport layers.

Both organic and inorganic PSCs have shown promise to meet future energy demands. Unlike 3D perovskites predominantly suffering from instability, low-dimensional well-oriented perovskites may exhibit enhanced long-term stability. However, other supporting layers utilized with bulk and low dimensional perovskites can alter the performance and stability of PSCs. Among the layers, the transport layers play a crucial role in maintaining and efficiently separating the photogenerated charge carriers and further boosting the solar efficiency and long-term stability. Engineering compatible transport layers with the perovskite light absorbers is essential given that the ETLs and HTLs perform peculiar functionalities depending on the adopted device architecture. Therefore, understanding the intrinsic properties of the transport layers, namely, the electronic band edge alignment, optical transparency, charge conductivity, and charge mobility, is fundamental for developing efficient PSCs. Among the plethora of material systems that can be used as transport layers in PSCs, the ideal transport layers should also be cost-effective with easy processing. Consequently, the research trend reveals that self-organised approaches to develop distinct transport layers will complement the improvement in overall solar cell efficiency, but the search for ideal transport layers is a never-ending process.

In this review, we summarized the evolution of the transport layers analogous to the progress of PSCs based on the observations and discussions in the literature. Although the perovskite light absorbers have shown superior optoelectronic properties, the importance of the transport layers in PSCs was explained parallel to the photoanodes and electrolytes used in DSSCs. Additionally, the transport layers are distinguished based on the filled states as n-type (ETL) and p-type (HTL) to gain deeper insight. In the regular n–i–p device structures, besides the band edge and bandgap alignment with the perovskite light absorbers, the ETLs provide a template for perovskite deposition and blocking UV irradiation, which deteriorates the perovskite light absorber. The compatible electron mobilities of the ETL with perovskite absorbers and conductivity of electrons in ETLs have become the detrimental factor in avoiding charge accumulation and charge recombination at the ETL/perovskite interface. The techniques such as nanostructuring, doping, and faceting used to tackle the charge accumulation and recombination were explained w.r.t. the majorly reported inorganic ETLs. The role of cost-effective synthetic procedures used for developing efficient inorganic ETLs and their feasibility in large-scale production were correlated with the PCEs. Furthermore, different inorganic materials reported as ETLs for PSCs were scrutinised depending on their functionalities, synthetic procedures, and electrical and optical properties. The inorganic ETLs initially delivered an efficiency of 3–9%, but reached the milestone of ~26%. Among the ETLs, employing doped TiO_2 ETLs has shown efficiencies of ~22% and created excitement among researchers. However, their application on plastic substrates is limited by their high processing temperature. Furthermore, the ZnO ETLs contribute to the deprotonation of the perovskite light absorbers. Although SnO_2 ETLs have shown chemical stability and high efficiency with low-temperature processing, understanding their trap states will be beneficial to further tailor the properties towards ideal ETLs. Furthermore, ternary metal oxides need to be engineered as ETLs with better controllability over their optoelectronic properties. The scaffolding technique has been used to prevent shunting paths in PSCs, and thereby increase the V_{OC}. The diverse materials and their composites or combinations that can be used as ETLs in PSCs were discussed. Also, the extensively used organic ETLs in PSCs were compared for a comprehensive understanding. Overall, the ETLs have a direct influence on the efficiency of PSCs.

Conversely, there is an urgent need to replace the expensive hygroscopic organic HTLs employed in high-efficiency PSCs to increase their long-term stability and reduce their cost. Therefore, the importance of the HTL depending on the PSC device architecture was discussed in depth. Analogous to ETLs, HTLs perform similar functionalities *w.r.t.* the transport of photogenerated holes. Thus, the various techniques such as nanostructuring, doping, and forming composites used in PSCs were summarized. Inorganic HTLs such as NiO have achieved efficiency close to 22% in PSCs due to their well-aligned band edges and bandgap with perovskite light absorbers. Similarly, CoO_x as an HTL has shown promise due to its high hole conductivity. The synthetic protocols, nanostructuring, and hole-quenching capabilities of multiple combinations of Cu-based HTLs such as CuO, Cu_2O, CuSCN, and CuI are yet to be explored for a deep understanding. Although there are several reports based on VO_x as an HTL in PSCs, doped and nanostructured VO_x are yet to be explored. Further, the class of materials known as delafossites was briefly presented for their controllability over hole conductivity and ease of processability. Finally, the most commonly used organic HTLs and their influence on the efficiency and long-term stability of PSCs were compared.

Overall, all the materials reported as transport layers were scrutinized based on their optoelectronic properties, stability, durability, and charge separation at the perovskite interface with the transport layer. Furthermore, in this review, the efficiency of PSCs was comparatively evaluated based on only their transport layers. The ETLs and corresponding HTLs play a significant role in the overall performance of PSCs and vice versa. However, to gain better efficiency, the quality of the perovskite light absorber films used and the active device area should be considered during further studies. The systematic investigation of different transport layers and involved material systems interpret that an ideal ETL in the n–i–p device structure should have a band-edged and bandgap alignment with the perovskite light absorbers, should possess compatible electron mobilities and conductivities with the perovskite light absorbers, and should be easily processible at low temperatures with no toxicity at a low-cost. Moreover, the increased effective interface at nanostructured ETL/perovskite (mesoporous structure) can relatively enhance the free-electron transport. Further, the synthesized films should have no pinholes and be easily scaled up with high reproducibility. Conversely, ideal HTLs should perform similar functions as ETLs for hole transport depending on the device architecture.

The outlook for ideal transport layers is presented here.

(a) Tailoring the carrier mobility, band edge levels, and diffusion lengths is a promising approach to achieve ideal ETLs/HTLs.

(b) The physical vapor deposition techniques such as ALD, sputtering, and PLD are feasible for the industrial production of the transport layers. However, one should look for industrially scalable low-temperature processing techniques for the easy and reasonable deposition of ETL/HTL encompassing non-toxic and naturally abundant materials in the ambient atmosphere. Novel low-temperature processing or synthesis can bring out uniform coating, leading to firm interfaces between different materials, which is necessary to avoid unfavourable effects at interfaces, defect state, and interfacial losses such as light sucking effect and charge recombination.

(c) Precise engineering of the transport layer with minimum lattice mismatch, better chemical stability, excellent light management, and non-hygroscopic nature is mandatory to reduce defects and alterations in the intrinsic property of the perovskite active layer.

(d) The quest should be continued to explore new inorganic transport layers with higher p- and n-type conductivity and compatibility with the perovskite solution process deposition method. Moreover, the decoration, doping, faceting, and composites of promising materials identified as ETL/HTL will assist in electron/hole mobility matching, enhancing the light absorption, and improving the recombination resistance, and therefore, enhance the charge extraction. Hence, various combinations of 3d transition metals, graphene, noble metal nanoparticles, organic molecules, *etc.* should be explored in line with further advancement.

(e) Numerical simulation and first-principles calculations can help to understand the density of states, charge accumulation, flow of charge carriers, defect density, optical transparency, optimized thickness, band edge, and photo/thermal stability of the transport layers, which will open up a new window for efficient charge separation, overcoming the issues of photo-reactivity and interface defects, and improving the sensitivity in the visible spectrum. The additional direction of theoretical work should focus on the intrinsic modification and electronic alterations at the transport layer-perovskite interface where experiments are complicated and require simulation-assisted experiments. Furthermore, theoretical methods such as first-principles calculations, DFT, and *ab initio* calculations are necessary to give directions towards less known families of materials that can be applied as transport layers of PSCs.

(f) The industrial focus is on the preparation of planar ETLs and HTLs using physical/chemical vapor deposition methods due to ease of reproducibility and commercial viabilities. However, mesoporous 3D nanostructures provide a larger surface area and better interface with the perovskite absorber layer, have secured a place in the best efficiency chart, and need to be explored for their utilization in the cost-effective mass production of PSCs.

(g) Among the explored nanostructures such as 0D, 1D, and 2D, 1D ETLs and HTLs provide a larger aspect ratio and deliver excellent light trapping deep inside the perovskite absorber and ensure relatively enhanced charge conduction, and hence enhanced efficiency. However, the large-area production of well-defined 1D nanostructures and their better interface with the perovskite absorber needs to be explored for pilot production.

Overall, the paths for the finest optimization of the device structure and successful commercialization of PSCs entail the complete understanding of the transport layers and the charge extraction mechanism.

Author contributions

All authors contributed to conceptualization and writing of this review article.

Conflicts of interest

There are no conflicts to declare.

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References

1 N. Kannan and D. Vakeesan, *Renewable Sustainable Energy Rev.*, 2016, **62**, 1092–1105.

2 E. Kabir, P. Kumar, S. Kumar, A. A. Adelodun and K.-H. Kim, *Renewable Sustainable Energy Rev.*, 2018, **82**, 894–900.

3 J. Zheng, C. F. J. Lau, H. Mehrvarz, F.-J. Ma, Y. Jiang, X. Deng, A. Soeriyadi, J. Kim, M. Zhang, L. Hu, X. Cui, D. S. Lee, J. Bing, Y. Cho, C. Chen, M. A. Green, S. Huang and A. W. Y. Ho-Baillie, *Energy Environ. Sci.*, 2018, **11**, 2432–2443.

4 C. Battaglia, A. Cuevas and S. De Wolf, *Energy Environ. Sci.*, 2016, **9**, 1552–1576.

5 M. A. Green, *Joule*, 2019, **3**, 631–633.

6 S. S. Mali, H. M. Patil, C. A. Betty, P. N. Bhosale, Y. W. Oh, S. R. Jadkar, R. S. Devan, Y. R. Ma and P. S. Patil, *Electrochim. Acta*, 2012, **66**, 216–221.

7 S. R. Bandiya, Y. A. Jadhav, A. Zivkovic, S. B. Jathar, G. K. Rahane, R. W. Cross, A. V. Rokade, R. S. Devan, S. Kolekar, R. L. Z. Hoye, H. N. Ghosh, N. H. de Leeuw, S. R. Jadkar and N. Y. Dzade, *J. Alloys Compd.*, 2022, **898**, 163275.

8 T. S. Bhat, A. V. Shinde, R. S. Devan, A. M. Teli, Y. R. Ma, J. H. Kim and P. S. Patil, *Appl. Phys. A: Mater. Sci. Process.*, 2018, **124**, 34.

9 S. B. Pawar, J. S. Shaikh, R. S. Devan, Y. R. Ma, D. Haranath, P. N. Bhosale and P. S. Patil, *Appl. Surf. Sci.*, 2011, **258**, 1869–1875.

10 S. A. Pawar, R. S. Devan, D. S. Patil, A. V. Moholkar, M. G. Gang, Y. R. Ma, J. H. Kim and P. S. Patil, *Electrochim. Acta*, 2013, **98**, 244–254.

11 S. A. Pawar, D. S. Patil, S. K. Patil, D. V. Awale, R. S. Devan, Y. R. Ma, S. S. Kolekar, J. H. Kim and P. S. Patil, *Electrochim. Acta*, 2014, **148**, 310–316.

12 D. M. Bagnall and M. Boreland, *Energy Policy*, 2008, **36**, 4390–4396.

13 H. W. Hillhouse and M. C. Beard, *Curr. Opin. Colloid Interface Sci.*, 2009, **14**, 245–259.

14 F. C. Krebs, *Sol. Energy Mater. Sol. Cells*, 2009, **93**, 394–412.

15 S. Shalini, R. Balasundara Prabhu, S. Prasanna, T. K. Mallick and S. Senthilarasu, *Renewable Sustainable Energy Rev.*, 2015, **51**, 1306–1325.

16 J.-P. Correa-Baena, A. Abate, M. Saliba, W. Tress, T. Jesper Jacobsson, M. Grätzel and A. Hagfeldt, *Energy Environ. Sci.*, 2017, **10**, 710–727.

17 G. Kim, H. Min, K. S. Lee, D. Y. Lee, S. M. Yoon and S. I. Seok, *Science*, 2020, **370**, 108–112.

18 M. A. Green, A. Ho-Baillie and H. J. Snaith, *Nat. Photonics*, 2014, **8**, 506–514.

19 H. S. Jung and N. G. Park, *Small*, 2015, **11**, 10–25.

20 S. Sun, N. T. P. Hartono, Z. D. Ren, F. Oviedo, A. M. Buscemi, M. Layurova, D. X. Chen, T. Ogunfunmi, J. Thapa, S. Ramasamy, C. Settens, B. L. DeCost, A. G. Kusne, Z. Liu, S. I. P. Tian, I. M. Peters, J.-P. Correa-Baena and T. Buonassisi, *Joule*, 2019, **3**, 1437–1451.

21 Y. Bai, X. Meng and S. Yang, *Adv. Energy Mater.*, 2018, **8**, 1701883.

22 J. Sun, D. K. Zhong and D. R. Gamelin, *Energy Environ. Sci.*, 2010, **3**, 1252–1261.

23 S. S. Mali and C. K. Hong, *Nanoscale*, 2016, **8**, 10528–10540.

24 A. B. Pascoe, M. J. Yang, N. Kopidakis, K. Zhu, M. O. Reese, G. Rumbles, M. Fekete, N. W. Duffy and Y. B. Cheng, *Nano Energy*, 2016, **22**, 439–452.

25 T. Leijtens, G. E. Eperon, S. Pathak, A. Abate, M. M. Lee and H. J. Snaith, *Nat. Commun.*, 2013, **4**, 2885.

26 J. Kim, K. S. Kim and C. W. Myung, *npj Comput. Mater.*, 2020, **6**, 100.

27 Q. Hu, J. Wu, C. Jiang, T. H. Liu, X. L. Que, R. Zhu and Q. H. Gong, *ACS Nano*, 2014, **8**, 10161–10167.

28 A. Yella, L. P. Heiniger, P. Gao, M. K. Nazeeruddin and M. Grätzel, *Nano Lett.*, 2014, **14**, 2591–2596.

29 J. T. W. Wang, J. M. Ball, E. M. Barea, A. Abate, J. A. Alexander-Webber, J. Huang, M. Saliba, I. Mora-Sero, J. Bisquert, H. J. Snaith and R. J. Nicholas, *Nano Lett.*, 2014, **14**, 724–730.

30 V. Karthikeyan, S. Maniarasu, V. Manjunath, E. Ramasamy and G. Veerappan, *Sol. Energy*, 2017, **147**, 202–208.

31 W. Zhang, M. Saliba, S. D. Stranks, Y. Sun, X. Shi, U. Wiesner and H. J. Snaith, *Nano Lett.*, 2013, **13**, 4505–4510.

32 A. Fakharuddin, L. Schmidt-Mende, G. Garcia-Belmonte, R. Jose and I. Mora-Sero, *Adv. Energy Mater.*, 2017, **7**, 1700623.

33 K.-C. Wang, J.-Y. Jeng, P.-S. Shen, Y.-C. Chang, E. W.-G. Diau, C.-H. Tsai, T.-Y. Chao, H.-C. Hsu, P.-Y. Lin, P. Chen, T.-F. Guo and T.-C. Wen, *Sci. Rep.*, 2014, **4**, 4756.

34 V. Manjunath, P. K. Mishra, R. Dobhal, S. Bimli, P. M. Shirage, S. Sen, P. A. Shaikh and R. S. Devan, *ACS Appl. Electron. Mater.*, 2021, **3**, 4548–4557.

35 H. Chen, M. Yang, S. Priya and K. Zhu, *J. Phys. Chem. Lett.*, 2016, **7**, 905–917.

36 C. Eames, J. M. Frost, P. R. F. Barnes, B. C. O'Regan, A. Walsh and M. S. Islam, *Nat. Commun.*, 2015, **6**, 7497.

37 Z. Zhou, S. Pang, Z. Liu, H. Xu and G. Cui, *J. Mater. Chem. A*, 2015, **3**, 19205–19217.

38 V. M. Le Corre, M. Stolterfoht, L. Perdigón Toro, M. Feuerstein, C. Wolff, L. Gil-Escrig, H. J. Bolink, D. Neher and L. J. A. Koster, *ACS Appl. Energy Mater.*, 2019, **2**, 6280–6287.

39 G.-S. Chen, Y.-C. Chen, C.-T. Lee and H.-Y. Lee, *Sol. Energy*, 2018, **174**, 897–900.

40 J. Byeon, J. Kim, J.-Y. Kim, G. Lee, K. Bang, N. Ahn and M. Choi, *ACS Energy Lett.*, 2020, **5**, 2580–2589.

41 W. J. Nimens, J. Ogle, A. Caruso, M. Jonely, C. Simon, D. Smilgies, R. Noriega, M. Scarpulla and L. Whittaker-Brooks, *ACS Appl. Energy Mater.*, 2018, **1**, 602–615.

42 J. Shi, X. Xu, D. Li and Q. Meng, *Small*, 2015, **11**, 2472–2486.

43 J. Shi, Y. Li, Y. Li, D. Li, Y. Luo, H. Wu and Q. Meng, *Joule*, 2018, **2**, 879–901.

44 Z. Yang, B. H. Babu, S. Wu, T. Liu, S. Fang, Z. Xiong, L. Han and W. Chen, *Solar RRL*, 2020, **4**, 1900257.

45 H.-S. Kim, J. S. Park, H. K. Jeong, K. S. Son, T. S. Kim, J.-B. Seon, E. Lee, J. G. Chung, D. H. Kim, M. Ryu and S. Y. Lee, *ACS Appl. Mater. Interfaces*, 2012, **4**, 5416–5421.

46 N. K. Elumalai and A. Uddin, *Energy Environ. Sci.*, 2016, **9**, 391–410.

47 M. F. N. Taufique, R. Khanal, S. Choudhury and S. Banerjee, *J. Chem. Phys.*, 2018, **149**, 164704.

48 M. H. Gharahcheshmeh and K. K. Gleason, *Mater. Today Adv.*, 2020, **8**, 100086.

49 G. Horowitz, *J. Appl. Phys.*, 2015, **118**, 115502.

50 S. Jung, C.-H. Kim, Y. Bonnassieux and G. Horowitz, *J. Phys. D: Appl. Phys.*, 2015, **48**, 395103.

51 H. F. Haneef, A. M. Zeidell and O. D. Jurchescu, *J. Mater. Chem. C*, 2020, **8**, 759–787.

52 J.-P. Yang, L.-T. Shang, F. Bussolotti, L.-W. Cheng, W.-Q. Wang, X.-H. Zeng, S. Kera, Y.-Q. Li, J.-X. Tang and N. Ueno, *Org. Electron.*, 2017, **48**, 172–178.

53 A. D. Scaccabarozzi, A. Basu, F. Aniés, J. Liu, O. Zapata-Arteaga, R. Warren, Y. Firdaus, M. I. Nugraha, Y. Lin, M. Campoy-Quiles, N. Koch, C. Müller, L. Tsetseris, M. Heeney and T. D. Anthopoulos, *Chem. Rev.*, 2022, **122**, 4420–4492.

54 S. Chatterjee and A. J. Pal, *J. Phys. Chem. C*, 2016, **120**, 1428–1437.

55 R. Chakraborty, H. Bhunia, S. Chatterjee and A. J. Pal, *J. Solid State Chem.*, 2020, **283**, 121011.

56 S. Teo, Z. Guo, Z. Xu, C. Zhang, Y. Kamata, S. Hayase and T. Ma, *ChemSusChem*, 2019, **12**, 518–526.

57 W. Hu, J. An, F. Si, H. Xue, F. Tang and W. Li, *J. Electron. Mater.*, 2021, **50**, 2129–2136.

58 V. Zardetto, B. L. Williams, A. Perrotta, F. Di Giacomo, M. A. Verheijen, R. Andriessen, W. M. M. Kessels and M. Creatore, *Sustainable Energy Fuels*, 2017, **1**, 30–55.

59 F. Fu, T. Feurer, T. P. Weiss, S. Pisoni, E. Avancini, C. Andres, S. Buecheler and A. N. Tiwari, *Nat. Energy*, 2016, **2**, 16190.

60 P. Qin, M. Paulose, M. I. Dar, T. Moehl, N. Arora, P. Gao, O. K. Varghese, M. Grätzel and M. K. Nazeeruddin, *Small*, 2015, **11**, 5533–5539.

61 M. Park, J.-Y. Kim, H. J. Son, C.-H. Lee, S. S. Jang and M. J. Ko, *Nano Energy*, 2016, **26**, 208–215.

62 J. Cao, B. Wu, R. Chen, Y. Wu, Y. Hui, B.-W. Mao and N. Zheng, *Adv. Mater.*, 2018, **30**, 1705596.

63 K. Jung, J. Lee, C. Im, J. Do, J. Kim, W.-S. Chae and M.-J. Lee, *ACS Energy Lett.*, 2018, **3**, 2410–2417.

64 C. Chen, Y. Jiang, Y. Wu, J. Guo, X. Kong, X. Wu, Y. Li, D. Zheng, S. Wu, X. Gao, Z. Hou, G. Zhou, Y. Chen, J.-M. Liu, K. Kempa and J. Gao, *Solar RRL*, 2020, **4**, 1900499.

65 R. S. Devan, R. A. Patil, J.-H. Lin and Y.-R. Ma, *Adv. Funct. Mater.*, 2012, **22**, 3326–3370.

66 S. S. Mali, C. A. Betty, P. N. Bhosale, R. S. Devan, Y. R. Ma, S. S. Kolekar and P. S. Patil, *CrystEngComm*, 2012, **14**, 1920–1924.

67 S. S. Mali, S. K. Desai, S. S. Kalagi, C. A. Betty, P. N. Bhosale, R. S. Devan, Y.-R. R. Ma and P. S. Patil, *Dalton Trans.*, 2012, **41**, 6130–6136.

68 R. S. Devan, Y.-R. Ma, R. A. Patil and S.-M. Lukas, *RSC Adv.*, 2016, **6**, 62218–62225.

69 P. N. Didwal, P. R. Chikate, P. K. Bankar, M. A. More and R. S. Devan, *J. Mater. Sci.: Mater. Electron.*, 2019, **30**, 2935–2941.

70 N. Kitchamsetti, R. S. Kalubarme, P. R. Chikate, C. J. Park, Y. R. Ma, P. M. Shirage and R. S. Devan, *ChemistrySelect*, 2019, **4**, 6620–6626.

71 P. N. Didwal, K. S. Pawar, P. R. Chikate, A. C. Abhyankar, H. M. Pathan and R. S. Devan, *J. Mater. Sci.: Mater. Electron.*, 2016, **27**, 12446–12451.

72 S. A. Pawar, R. S. Devan, D. S. Patil, V. V. Burungale, T. S. Bhat, S. S. Mali, S. W. Shin, J. E. Ae, C. K. Hong, Y. R. Ma, J. H. Kim and P. S. Patil, *Electrochim. Acta*, 2014, **117**, 470–479.

73 R. S. Devan, Y.-R. Ma, M. A. More, R. T. Khare, V. V. Antad, R. A. Patil, V. P. Thakare, R. S. Dhayal and L. Schmidt-Mende, *RSC Adv.*, 2016, **6**, 98722–98729.

74 R. A. Patil, R. S. Devan, Y. Liou and Y.-R. Ma, *Sol. Energy Mater. Sol. Cells*, 2016, **147**, 240–245.

75 R. S. Devan, V. P. Thakare, V. V. Antad, P. R. Chikate, R. T. Khare, M. A. More, R. S. Dhayal, S. I. Patil, Y.-R. Ma and L. Schmidt-Mende, *ACS Omega*, 2017, **2**, 2925–2934.

76 N. G. Park, J. van de Lagemaat and A. J. Frank, *J. Phys. Chem. B*, 2000, **104**, 8989–8994.

77 S. S. Mali, R. S. Devan, Y. R. Ma, C. A. Betty, P. N. Bhosale, R. P. Panmand, B. B. Kale, S. R. Jadkar, P. S. Patil, J. H. Kim and C. K. Hong, *Electrochim. Acta*, 2013, **90**, 666–672.

78 S. A. Pawar, D. S. Patil, U. T. Pawar, R. S. Devan, M. M. Karanjkar, Y. R. Ma, S. W. Shin, J. H. Kim and P. S. Patil, *J. Mater. Sci.: Mater. Electron.*, 2015, **26**, 2595–2604.

79 A. Kojima, K. Teshima, Y. Shirai and T. Miyasaka, *J. Am. Chem. Soc.*, 2009, **131**, 6050–6051.

80 N. Jain, A. Mary, V. Manjunath, R. Sahu, R. S. Devan, D. A. Jose and A. R. Nasiruddin, *Eur. J. Inorg. Chem.*, 2021, 3014–3023.

81 H. S. Kim, C. R. Lee, J. H. Im, K. B. Lee, T. Moehl, A. Marchioro, S. J. Moon, R. Humphry-Baker, J. H. Yum,

J. E. Moser, M. Gratzel and N. G. Park, *Sci. Rep.*, 2012, **2**, 591.

82 G. K. Pinheiro, R. B. Serpa, L. V. de Souza, M. L. Sartorelli, F. T. Reis and C. R. Rambo, *Colloids Surf., A*, 2017, **527**, 89–94.

83 L. Qiu, Z. Zhuang, S. Yang, W. Chen, L. Song, M. Ding, G. Xia, P. Du and J. Xiong, *Mater. Res. Bull.*, 2018, **106**, 439–443.

84 W. J. Ke, G. J. Fang, J. Wang, P. L. Qin, H. Tao, H. W. Lei, Q. Liu, X. Dai and X. Z. Zhao, *ACS Appl. Mater. Interfaces*, 2014, **6**, 15959–15965.

85 A. K. Shalan, S. Narra, T. Oshikiri, K. Ueno, X. Shi, H. P. Wu, M. M. Elshanawany, E. W. G. Diau and H. Misawa, *Sustainable Energy Fuels*, 2017, **1**, 1533–1540.

86 J. F. Li, Z. L. Zhang, H. P. Gao, Y. Zhang and Y. L. Mao, *J. Mater. Chem. A*, 2015, **3**, 19476–19482.

87 Y. S. Bhat, K. S. Devan, S. S. Mali, A. S. Kamble, S. A. Pawar, J. Y. Kim, Y. R. Ma, C. K. Hong, J. H. Kim and P. S. Patil, *J. Mater. Sci.: Mater. Electron.*, 2014, **25**, 4501–4511.

88 H.-C. Hsieh, J. Yu, S.-P. Rwei, K.-F. Lin, Y.-C. Shih and L. Wang, *Thin Solid Films*, 2018, **659**, 41–47.

89 S. H. Lin, Y. H. Su, H. W. Chu, P. Y. Kung, W. P. Liao and J. J. Wu, *J. Mater. Chem. A*, 2016, **4**, 1119–1125.

90 S. S. Mali, C. S. Shim, H. K. Park, J. Heo, P. S. Patil and C. K. Hong, *Chem. Mater.*, 2015, **27**, 1541–1551.

91 I. S. Kim, R. T. Haasch, D. H. Cao, O. K. Farha, J. T. Hupp, M. G. Kanatzidis and A. B. F. Martinson, *ACS Appl. Mater. Interfaces*, 2016, **8**, 24310–24314.

92 L. Cojocaru, S. Uchida, Y. Sanehira, J. Nakazaki, T. Kubo and H. Segawa, *Chem. Lett.*, 2015, **44**, 674–676.

93 Q. Q. Gao, S. W. Yang, L. Lei, S. D. Zhang, Q. P. Cao, J. J. Xie, J. Q. Li and Y. Liu, *Chem. Lett.*, 2015, **44**, 624–626.

94 S. Dharani, H. K. Mulmudi, N. Yantara, P. T. T. Trang, N. G. Park, M. Graetzel, S. Mhaisalkar, N. Mathews and P. P. Boix, *Nanoscale*, 2014, **6**, 1675–1679.

95 P. Zhou, W. N. Li, T. H. Li, T. L. Bu, X. P. Liu, J. Li, J. He, R. Chen, K. P. Li, J. Zhao and F. Z. Huang, *Micromachines*, 2017, **8**, 55.

96 D. Zhang, B. Cai, X. L. Wang, Z. Yang, Y. D. Xing, S. Miao, W. H. Zhang and C. Li, *Nano Energy*, 2015, **11**, 409–418.

97 Y. Xiao, C. Wang, K. K. Kondamareddy, N. Cheng, P. Liu, Y. Qiu, F. Qi, S. Kong, W. Liu and X.-Z. Zhao, *ACS Appl. Energy Mater.*, 2018, **1**, 5453–5462.

98 H. Lu, B. Gu and S. Fang, *Sustainable Energy Fuels*, 2021, **5**, 880–885.

99 M. Thambidurai, H. A. Dewi, F. C. Harikesh, S. Foo, K. M. Muhammed Salim, N. Mathews and C. Dang, *ACS Appl. Energy Mater.*, 2018, **1**, 5847–5852.

100 W. Okada, T. Suga, K. Oyaizu, H. Segawa and H. Nishide, *ACS Appl. Energy Mater.*, 2019, **2**, 2848–2853.

101 G. Ren, W. Han, Z. Li, C. Liu, L. Shen and W. Guo, *Sol. Energy*, 2019, **193**, 220–226.

102 K. Wang, Z. Zhang, L. Wang, K. Chen, L. Tao, Y. Zhang and X. Zhou, *ACS Appl. Energy Mater.*, 2021, **4**, 3255–3264.

103 H. Wang, M. Zhang, X. Cui, Z. Wang, M. Kager, Y. Yang, Z. Zou, Z. L. Wang and Z. Lin, *Angew. Chem., Int. Ed.*, 2020, **59**, 1611–1618.

104 H. Wang, J. Yang, L. Lu, W. Xiao, H. Wu, S. Xiong, J. Tang, C. Duan and Q. Bao, *Adv. Mater. Interfaces*, 2020, **7**, 1901964.

105 M. Batmunkh, T. J. Macdonald, C. J. Shearer, M. Bat-Erdene, Y. Wang, M. J. Biggs, I. P. Parkin, T. Nann and J. G. Shapter, *Adv. Sci.*, 2017, **4**, 1600504.

106 C. Huang, C. Liu, Y. Di, W. Li, F. Liu, L. Jiang, J. Li, X. Hao and H. Huang, *ACS Appl. Mater. Interfaces*, 2016, **8**, 8520–8526.

107 A. Apostolopoulou, D. Sygkridou, A. Rapsomanikis, A. N. Kalarakis and E. Stathatos, *Sol. Energy Mater. Sol. Cells*, 2017, **166**, 100–107.

108 X. Deng, Y. Wang, Y. Chen, Z. Cui and C. Shi, *J. Solid State Chem.*, 2019, **275**, 206–209.

109 M. Thambidurai, F. Shini, J. Y. Kim, C. Lee and C. Dang, *Mater. Lett.*, 2020, **274**, 128003.

110 H. Nagaoka, F. Ma, D. W. deQuilettes, S. M. Vorpahl, M. S. Glaz, A. E. Colbert, M. E. Ziffer and D. S. Ginger, *J. Phys. Chem. Lett.*, 2015, **6**, 669–675.

111 S. Wang, B. Liu, Y. Zhu, Z. Ma, B. Liu, X. Miao, R. Ma and C. Wang, *Sol. Energy*, 2018, **169**, 335–342.

112 Z. L. Zhang, J. F. Li, X. L. Wang, J. Q. Qin, W. J. Shi, Y. F. Liu, H. P. Gao and Y. L. Mao, *RSC Adv.*, 2017, **7**, 13123–13130.

113 X. L. Wang, Z. L. Zhang, J. Q. Qin, W. J. Shi, Y. F. Liu, H. P. Gao and Y. L. Mao, *Electrochim. Acta*, 2017, **245**, 839–845.

114 X. Yan, J. H. Liang, Y. L. Li, J. X. Luo, B. Shi, C. C. Wei, D. K. Zhang, B. Z. Li, Y. Ding, Y. Zhao and X. D. Zhang, *Adv. Sci.*, 2017, **4**, 1700008.

115 Y. M. Li, Y. Guo, Y. H. Li and X. F. Zhou, *Electrochim. Acta*, 2016, **200**, 29–36.

116 G. Xiao, C. Shi, K. Lv, C. Ying and Y. Wang, *ACS Appl. Energy Mater.*, 2018, **1**, 2576–2581.

117 H. Sun, D. Xie, Z. Song, C. Liang, L. Xu, X. Qu, Y. Yao, D. Li, H. Zhai, K. Zheng, C. Cui and Y. Zhao, *ACS Appl. Mater. Interfaces*, 2020, **12**, 22853–22861.

118 M. Kim, I.-W. Choi, S. J. Choi, J. W. Song, S.-I. Mo, J.-H. An, Y. Jo, S. Ahn, S. K. Ahn, G.-H. Kim and D. S. Kim, *Joule*, 2021, **5**, 659–672.

119 B. J. Kim, D. H. Kim, Y. Y. Lee, H. W. Shin, G. S. Han, J. S. Hong, K. Mahmood, T. K. Ahn, Y. C. Joo, K. S. Hong, N. G. Park, S. Lee and H. S. Jung, *Energy Environ. Sci.*, 2015, **8**, 916–921.

120 W. M. Qiu, U. W. Paetzold, R. Gehlhaar, V. Smirnov, H. G. Boyen, J. G. Tait, B. Conings, W. M. Zhang, C. B. Nielsen, I. McCulloch, L. Froyen, P. Heremans and D. Cheyns, *J. Mater. Chem. A*, 2015, **3**, 22824–22829.

121 D. Yang, R. X. Yang, J. Zhang, Z. Yang, S. Z. Liu and C. Li, *Energy Environ. Sci.*, 2015, **8**, 3208–3214.

122 Y. H. Chu, H. K. Cai, L. K. Huang, Z. X. Xing, Y. Y. Du, J. Ni, J. Li and J. J. Zhang, *Phys. Status Solidi A*, 2019, **216**, 1800669.

123 B. Conings, L. Baeten, T. Jacobs, R. Dera, J. D'Haen, J. Manca and H. G. Boyen, *Appl. Mater.*, 2014, **2**, 081505.

124 Q. Jiang, X. Zhang and J. You, *Small*, 2018, **14**, 1801154.

125 W. Ke, G. Fang, Q. Liu, L. Xiong, P. Qin, H. Tao, J. Wang, H. Lei, B. Li, J. Wan, G. Yang and Y. Yan, *J. Am. Chem. Soc.*, 2015, **137**, 6730–6733.

126 L. Kavan, L. Steier and M. Grätzel, *J. Phys. Chem. C*, 2017, **121**, 342–350.

127 E. H. Anaraki, A. Kermanpur, L. Steier, K. Domanski, T. Matsui, W. Tress, M. Saliba, A. Abate, M. Grätzel, A. Hagfeldt and J.-P. Correa-Baena, *Energy Environ. Sci.*, 2016, **9**, 3128–3134.

128 J.-Y. Chen, C.-C. Chueh, Z. Zhu, W.-C. Chen and A. K.-Y. Jen, *Sol. Energy Mater. Sol. Cells*, 2017, **164**, 47–55.

129 Z. Chen, G. Yang, X. Zheng, H. Lei, C. Chen, J. Ma, H. Wang and G. Fang, *J. Power Sources*, 2017, **351**, 123–129.

130 J. Ma, X. Zheng, H. Lei, W. Ke, C. Chen, Z. Chen, G. Yang and G. Fang, *Solar RRL*, 2017, **1**, 1700118.

131 X. Pan, Y. Bai, X. Han, J. Yang, Y. Wang and Q. Zhang, *J. Power Sources*, 2020, **448**, 227405.

132 B. Taheri, E. Calabrò, F. Matteocci, D. Di Girolamo, G. Cardone, A. Liscio, A. Di Carlo and F. Brunetti, *Energy Technol.*, 2020, **8**, 1901284.

133 Q. Jiang, X. Chu, P. Wang, X. Yang, H. Liu, Y. Wang, Z. Yin, J. Wu, X. Zhang and J. You, *Adv. Mater.*, 2017, **29**, 1703852.

134 C. M. Gao, S. Yuan, B. Q. Cao and J. H. Yu, *Chem. Eng. J.*, 2017, **325**, 378–385.

135 X. Liu, K. W. Tsai, Z. Zhu, Y. Sun, C. C. Chueh and A. K. Y. Jen, *Adv. Mater. Interfaces*, 2016, **3**, 1600122.

136 Y. Li, J. Zhu, Y. Huang, F. Liu, M. Lv, S. Chen, L. Hu, J. Tang, J. Yao and S. Dai, *RSC Adv.*, 2015, **5**, 28424–28429.

137 J. Xie, K. Huang, X. Yu, Z. Yang, K. Xiao, Y. Qiang, X. Zhu, L. Xu, P. Wang, C. Cui and D. Yang, *ACS Nano*, 2017, **11**, 9176–9182.

138 H. Tang, Q. Cao, Z. He, S. Wang, J. Han, T. Li, B. Gao, J. Yang, D. Deng and X. Li, *Solar RRL*, 2020, **4**, 1900415.

139 J. J. Yoo, G. Seo, M. R. Chua, T. G. Park, Y. Lu, F. Rotermund, Y.-K. Kim, C. S. Moon, N. J. Jeon, J.-P. Correa-Baena, V. Bulović, S. S. Shin, M. G. Bawendi and J. Seo, *Nature*, 2021, **590**, 587–593.

140 R. Ramanujam, M. Kovendhan, K. Thangaraju, D. P. Joseph and K. R. Babu, *Appl. Surf. Sci.*, 2019, **487**, 1385–1393.

141 J. Bahadur, A. H. Ghahremani, B. Martin, T. Druffel, M. K. Sunkara and K. Pal, *Org. Electron.*, 2019, **67**, 159–167.

142 L. Xiong, M. Qin, G. Yang, Y. Guo, H. Lei, Q. Liu, W. Ke, H. Tao, P. Qin, S. Li, H. Yu and G. Fang, *J. Mater. Chem. A*, 2016, **4**, 8374–8383.

143 J. Liang, Z. Chen, G. Yang, H. Wang, F. Ye, C. Tao and G. Fang, *ACS Appl. Mater. Interfaces*, 2019, **11**, 23152–23159.

144 Y. Chen, X. Zuo, Y. He, F. Qian, S. Zuo, Y. Zhang, L. Liang, Z. Chen, K. Zhao, Z. Liu, J. Gou and S. Liu, *Adv. Sci.*, 2021, **8**, 2001466.

145 S. Zhang, H. Gu, S.-C. Chen and Q. Zheng, *J. Mater. Chem. C*, 2021, **9**, 4240–4247.

146 J.-J. Cao, K.-L. Wang, C. Dong, X.-M. Li, W.-F. Yang and Z.-K. Wang, *Org. Electron.*, 2021, **88**, 105972.

147 J. Tian, J. Zhang, X. Li, B. Cheng, J. Yu and W. Ho, *Solar RRL*, 2020, **4**, 2000090.

148 J. Ye, Y. Li, A. A. Medjahed, S. Pouget, D. Aldakov, Y. Liu and P. Reiss, *Small*, 2021, **17**, 2005671.

149 G. Yang, H. Lei, H. Tao, X. Zheng, J. Ma, Q. Liu, W. Ke, Z. Chen, L. Xiong, P. Qin, Z. Chen, M. Qin, X. Lu, Y. Yan and G. Fang, *Small*, 2017, **13**, 1601769.

150 E. Halvani Anaraki, A. Kermanpur, M. T. Mayer, L. Steier, T. Ahmed, S.-H. Turren-Cruz, J. Seo, J. Luo, S. M. Zakeeruddin, W. R. Tress, T. Edvinsson, M. Grätzel, A. Hagfeldt and J.-P. Correa-Baena, *ACS Energy Lett.*, 2018, **3**, 773–778.

151 W. Gong, H. Guo, H. Zhang, J. Yang, H. Chen, L. Wang, F. Hao and X. Niu, *J. Mater. Chem. C*, 2020, **8**, 11638–11646.

152 J. A. Hong, E. D. Jung, J. C. Yu, D. W. Kim, Y. S. Nam, I. Oh, E. Lee, J.-W. Yoo, S. Cho and M. H. Song, *ACS Appl. Mater. Interfaces*, 2020, **12**, 2417–2423.

153 Z. Lv, L. He, H. Jiang, X. Ma, F. Wang, L. Fan, M. Wei, J. Yang, L. Yang and N. Yang, *ACS Appl. Mater. Interfaces*, 2021, **13**, 16326–16335.

154 H. Xiu, X. Li, J. Zhou, B. Wang, Y. Chu, Y. Li, G. Wu, D. Zhang, R. Xue, X. Zhang, Y. Hu, H. Zhou and Y. Zhang, *ACS Appl. Energy Mater.*, 2020, **3**, 3186–3192.

155 B. Gao, Q. Cao, X. Pu, J. Yang, J. Han, S. Wang, T. Li, Z. He and X. Li, *Appl. Surf. Sci.*, 2021, **546**, 148711.

156 B. Tu, Y. Shao, W. Chen, Y. Wu, X. Li, Y. He, J. Li, F. Liu, Z. Zhang, Y. Lin, X. Lan, L. Xu, X. Shi, A. M. C. Ng, H. Li, L. W. Chung, A. B. Djurišić and Z. He, *Adv. Mater.*, 2019, **31**, 1805944.

157 S. Zhang, H. Si, W. Fan, M. Shi, M. Li, C. Xu, Z. Zhang, Q. Liao, A. Sattar, Z. Kang and Y. Zhang, *Angew. Chem., Int. Ed.*, 2020, **59**, 11573–11582.

158 Y. Yang, H. Lu, S. Feng, L. Yang, H. Dong, J. Wang, C. Tian, L. Li, H. Lu, J. Jeong, S. M. Zakeeruddin, Y. Liu, M. Grätzel and A. Hagfeldt, *Energy Environ. Sci.*, 2021, **14**, 3447–3454.

159 J. Luo, Y. Wang and Q. Zhang, *Sol. Energy*, 2018, **163**, 289–306.

160 P. R. Chikate, P. K. Bankar, R. J. Choudhary, Y. R. Ma, S. I. Patil, M. A. More, D. M. Phase, P. M. Shirage and R. S. Devan, *RSC Adv.*, 2018, **8**, 21664–21670.

161 P. R. Chikate, K. D. Daware, D. S. Gavhane, Y. R. Ma, R. J. Choudhary, S. I. Patil, M. A. More, D. M. Phase, S. W. Gosavi, P. M. Shirage and R. S. Devan, *ChemistrySelect*, 2018, **3**, 7891–7899.

162 P. R. Chikate, A. Sharma, S. R. Rondiya, R. W. Cross, N. Y. Dzade, P. M. Shirage and R. S. Devan, *New J. Chem.*, 2021, **45**, 1404–1414.

163 J. H. Lin, R. A. Patil, R. S. Devan, Z. A. Liu, Y. P. Wang, C. H. Ho, Y. Liou and Y. R. Ma, *Sci. Rep.*, 2014, **4**, 6967.

164 N. L. Tarwal, A. V. Rajgure, A. I. Inamdar, R. S. Devan, I. Y. Kim, S. S. Suryavanshi, Y. R. Ma, J. H. Kim and P. S. Patil, *Sens. Actuators, A*, 2013, **199**, 67–73.

165 P. R. Chikate, K. D. Daware, S. S. Patil, P. N. Didwal, G. S. Lole, R. J. Choudhary, S. W. Gosavi and R. S. Devan, *New J. Chem.*, 2020, **44**, 5535–5544.

166 N. L. Tarwal, R. S. Devan, Y. R. Ma, R. S. Patil, M. M. Karanjkar and P. S. Patil, *Electrochim. Acta*, 2012, **72**, 32–39.

167 D. Y. Son, J. H. Im, H. S. Kim and N. G. Park, *J. Phys. Chem. C*, 2014, **118**, 16567–16573.

168 F. Wang, J. Zhao, J. Liu, L. Wei, Z. Liu, L. Guan and G. Cao, *J. Power Sources*, 2017, **339**, 51–60.
169 Z.-L. Tseng, C.-H. Chiang and C.-G. Wu, *Sci. Rep.*, 2015, **5**, 13211.
170 K.-M. Lee, S. H. Chang, K.-H. Wang, C.-M. Chang, H.-M. Cheng, C.-C. Kei, Z.-L. Tseng and C.-G. Wu, *Sol. Energy*, 2015, **120**, 117–122.
171 K. Mahmood, B. S. Swain and H. S. Jung, *Nanoscale*, 2014, **6**, 9127–9138.
172 J. Yang, B. D. Siempelkamp, E. Mosconi, F. De Angelis and T. L. Kelly, *Chem. Mater.*, 2015, **27**, 4229–4236.
173 X. Dong, H. Hu, B. Lin, J. Ding and N. Yuan, *Chem. Commun.*, 2014, **50**, 14405–14408.
174 J. Dong, J. Shi, D. Li, Y. Luo and Q. Meng, *Appl. Phys. Lett.*, 2015, **107**, 073507.
175 J. Song, E. Zheng, L. Liu, X.-F. Wang, G. Chen, W. Tian and T. Miyasaka, *ChemSusChem*, 2016, **9**, 2640–2647.
176 L. K. Zhenyun Zhang and J. Qi, *Chin. Phys. B*, 2021, **30**, 038801.
177 Z.-L. Tseng, C.-H. Chiang, S.-H. Chang and C.-G. Wu, *Nano Energy*, 2016, **28**, 311–318.
178 J. Dong, Y. Zhao, J. Shi, H. Wei, J. Xiao, X. Xu, J. Luo, J. Xu, D. Li, Y. Luo and Q. Meng, *Chem. Commun.*, 2014, **50**, 13381–13384.
179 R. Zhao, H. Shen, Y. Zhang, X. Li, X. Zhao, M. Tai, J. Li, J. Li, X. Li and H. Lin, *ACS Appl. Mater. Interfaces*, 2016, **8**, 7826–7833.
180 Y.-Z. Zheng, E.-F. Zhao, F.-L. Meng, X.-S. Lai, X.-M. Dong, J.-J. Wu and X. Tao, *J. Mater. Chem. A*, 2017, **5**, 12416–12425.
181 T. Y. Xu, Y. H. Zheng, Z. W. Ma, L. Cheng, X. L. Xu, P. P. Zhang, G. Yu and Z. G. Sheng, *ChemistrySelect*, 2018, **3**, 363–367.
182 C. Liu, W. Wu, D. Zhang, Z. Li, G. Ren, W. Han and W. Guo, *J. Mater. Chem. A*, 2021, **9**, 12161–12168.
183 M. K. A. Mohammed and M. Shekargoftar, *Sustainable Energy Fuels*, 2021, **5**, 540–548.
184 Z. Wang, X. Zhu, J. Feng, C. Wang, C. Zhang, X. Ren, S. Priya, S. Liu and D. Yang, *Adv. Sci.*, 2021, **8**, 2002860.
185 Q. Z. An, P. Fassl, Y. J. Hofstetter, D. Becker-Koch, A. Bausch, P. E. Hopkinson and Y. Vaynzof, *Nano Energy*, 2017, **39**, 400–408.
186 P. Chen, X. Yin, M. Que, Y. Yang and W. Que, *RSC Adv.*, 2016, **6**, 57996–58002.
187 P. Zhang, F. Yang, G. Kapil, Q. Shen, T. Toyoda, K. Yoshino, T. Minemoto, S. S. Pandey, T. Ma and S. Hayase, *Org. Electron.*, 2018, **62**, 615–620.
188 M. Tai, X. Zhao, H. Shen, Y. Guo, M. Zhang, Y. Zhou, X. Li, Z. Yao, X. Yin, J. Han, X. Li and H. Lin, *Chem. Eng. J.*, 2019, **361**, 60–66.
189 X. Yin, W. Que, D. Fei, H. Xie and Z. He, *Electrochim. Acta*, 2013, **99**, 204–210.
190 V. Manjunath, Y. K. Reddy, S. Bimli, R. J. Choudhary and R. S. Devan, *Mater. Today Commun.*, 2022, **32**, 104061.
191 N. Kitchamsetti, M. Samtham, P. N. Didwal, D. Kumar, D. Singh, S. Bimli, P. R. Chikate, D. A. Basha, S. Kumar, C. J. Park, S. Chakraborty and R. S. Devan, *J. Power Sources*, 2022, **538**, 231525.
192 N. Kitchamsetti, Y. R. Ma, P. M. Shirage and R. S. Devan, *J. Alloys Compd.*, 2020, **833**, 155134.
193 N. Kitchamsetti, P. N. Didwal, S. R. Mulani, M. S. Patil and R. S. Devan, *Heliyon*, 2021, **7**, e07297.
194 N. Kitchamsetti, R. J. Choudhary, D. M. Phase and R. S. Devan, *RSC Adv.*, 2020, **10**, 23446–23456.
195 M. S. Patil, N. Kitchamsetti, S. R. Mulani, S. R. Rondiya, N. G. Deshpande, R. A. Patil, R. W. Cross, N. Y. Dzade, K. K. Sharma, P. S. Patil, Y. R. Ma, H. K. Cho and R. S. Devan, *J. Taiwan Inst. Chem. Eng.*, 2021, **122**, 201–209.
196 L. Z. Zhu, Z. P. Shao, J. J. Ye, X. H. Zhang, X. Pan and S. Y. Dai, *Chem. Commun.*, 2016, **52**, 970–973.
197 C. Y. Sun, L. Guan, Y. P. Guo, B. J. Fang, J. M. Yang, H. A. Duan, Y. J. Chen, H. Li and H. Z. Liu, *J. Alloys Compd.*, 2017, **722**, 196–206.
198 A. Roy, P. Selvaraj, P. Sujatha Devi and S. Sundaram, *Mater. Lett.*, 2018, **219**, 166–169.
199 Y. Guo, Y. Xue, C. Geng, C. Li, X. Li and Y. Niu, *J. Phys. Chem. C*, 2019, **123**, 16075–16082.
200 S. S. Shin, E. J. Yeom, W. S. Yang, S. Hur, M. G. Kim, J. Im, J. Seo, J. H. Noh and S. I. Seok, *Science*, 2017, **356**, 167–171.
201 S. S. Shin, J. H. Suk, B. J. Kang, W. Yin, S. J. Lee, J. H. Noh, T. K. Ahn, F. Rotermund, I. S. Cho and S. I. Seok, *Energy Environ. Sci.*, 2019, **12**, 958–964.
202 R. Dileep K, M. R. Rajbhar, A. Ashina, E. Ramasamy, S. Mallick, T. N. Rao and G. Veerappan, *Mater. Chem. Phys.*, 2021, **258**, 123919.
203 Y. J. Hu, C. Wang, Y. Tang, L. Huang, J. S. Fu, W. M. Shi, L. J. Wang and W. G. Yang, *J. Alloys Compd.*, 2016, **679**, 32–38.
204 A. Bera, K. W. Wu, A. Sheikh, E. Alarousu, O. F. Mohammed and T. Wu, *J. Phys. Chem. C*, 2014, **118**, 28494–28501.
205 M. Neophytou, M. De Bastiani, N. Gasparini, E. Aydin, E. Ugur, A. Seitkhan, F. Moruzzi, Y. Chaibi, A. J. Ramadan, J. R. Troughton, R. Hallani, A. Savva, L. Tsetseris, S. Inal, D. Baran, F. Laquai, T. D. Anthopoulos, H. J. Snaith, S. De Wolf and I. McCulloch, *ACS Appl. Energy Mater.*, 2019, **2**, 8090–8097.
206 N. Tsvetkov, B. C. Moon, J. Lee and J. K. Kang, *ACS Appl. Energy Mater.*, 2020, **3**, 344–351.
207 C. Wang, Y. Tang, Y. Hu, L. Huang, J. Fu, J. Jin, W. Shi, L. Wang and W. Yang, *RSC Adv.*, 2015, **5**, 52041–52047.
208 T. Mahmoudi, Y. Wang and Y.-B. Hahn, *Adv. Energy Mater.*, 2020, **10**, 1903369.
209 X. Luo, J. Ding, J. Wang and J. Zhang, *J. Mater. Res.*, 2020, **35**, 2158–2165.
210 Y. Okamoto and Y. Suzuki, *J. Phys. Chem. C*, 2016, **120**, 13995–14000.
211 J. Qin, Z. Zhang, W. Shi, Y. Liu, H. Gao and Y. Mao, *ACS Appl. Mater. Interfaces*, 2018, **10**, 36067–36074.
212 H. Guo, H. Chen, H. Zhang, X. Huang, J. Yang, B. Wang, Y. Li, L. Wang, X. Niu and Z. Wang, *Nano Energy*, 2019, **59**, 1–9.

213 H. Guo, H. Zhang, J. Yang, W. Geng, H. Chen, H. Wang, X. Liu, F. Han, R. Niu and Y. Zhao, *ACS Appl. Energy Mater.*, 2020, **3**, 6889–6896.
214 L. S. Oh, D. H. Kim, J. A. Lee, S. S. Shin, J. W. Lee, I. J. Park, M. J. Ko, N. G. Park, S. G. Pyo, K. S. Hong and J. Y. Kim, *J. Phys. Chem. C*, 2014, **118**, 22991–22994.
215 A. Bera, A. D. Sheikh, M. A. Haque, R. Bose, E. Alarousu, O. F. Mohammed and T. Wu, *ACS Appl. Mater. Interfaces*, 2015, **7**, 28404–28411.
216 W. X. Li, Q. H. Jiang, J. Y. Yang, Y. B. Luo, X. Li, Y. R. Hou and S. Q. Zhou, *Sol. Energy Mater. Sol. Cells*, 2017, **159**, 143–150.
217 S. S. Mali, C. S. Shim, H. Kim and C. K. Hong, *J. Mater. Chem. A*, 2016, **4**, 12158–12169.
218 W. Xu, L. Zheng, T. Zhu, L. Liu and X. Gong, *ACS Appl. Mater. Interfaces*, 2019, **11**, 34020–34029.
219 A. Fang, D. Shen, M. Wei and Z.-N. Chen, *ChemSusChem*, 2018, **11**, 424–431.
220 M. M. Lee, J. Teuscher, T. Miyasaka, T. N. Murakami and H. J. Snaith, *Science*, 2012, **338**, 643–647.
221 E. Edri, S. Kirmayer, D. Cahen and G. Hodes, *J. Phys. Chem. Lett.*, 2013, **4**, 897–902.
222 S. D. Stranks, G. E. Eperon, G. Grancini, C. Menelaou, M. J. P. Alcocer, T. Leijtens, L. M. Herz, A. Petrozza and H. J. Snaith, *Science*, 2013, **342**, 341–344.
223 J. M. Ball, M. M. Lee, A. Hey and H. J. Snaith, *Energy Environ. Sci.*, 2013, **6**, 1739–1743.
224 S. H. Hwang, J. Roh, J. Lee, J. Ryu, J. Yun and J. Jang, *J. Mater. Chem. A*, 2014, **2**, 16429–16433.
225 N. Aeineh, A.-F. Castro-Méndez, P. J. Rodriguez-Cantó, R. Abargues, E. Hassanabadi, I. Suarez, A. Behjat, P. Ortiz, J. P. Martínez-Pastor and I. Mora-Seró, *ACS Omega*, 2018, **3**, 9798–9804.
226 Y. Zhao, J. Wei, H. Li, Y. Yan, W. Zhou, D. Yu and Q. Zhao, *Nat. Commun.*, 2016, **7**, 10228.
227 Y. Numata, Y. Sanehira and T. Miyasaka, *ACS Appl. Mater. Interfaces*, 2016, **8**, 4608–4615.
228 D. Wang, Q. Chen, H. Mo, J. Jacobs, A. Thomas and Z. Liu, *Mater. Adv.*, 2020, **1**, 2057–2067.
229 H.-C. Kwon, A. Kim, H. Lee, D. Lee, S. Jeong and J. Moon, *Adv. Energy Mater.*, 2016, **6**, 1601055.
230 M. Xu, W. Ji, Y. Sheng, Y. Wu, H. Cheng, J. Meng, Z. Yan, J. Xu, A. Mei, Y. Hu, Y. Rong and H. Han, *Nano Energy*, 2020, **74**, 104842.
231 Y. Qiang, Y. Xie, Y. Qi, P. Wei, H. Shi, C. Geng and H. Liu, *Sol. Energy*, 2020, **201**, 523–529.
232 X. Dong, X. Fang, M. H. Lv, B. C. Lin, S. Zhang, J. N. Ding and N. Y. Yuan, *J. Mater. Chem. A*, 2015, **3**, 5360–5367.
233 D. Q. Bi, S. J. Moon, L. Haggman, G. Boschloo, L. Yang, E. M. J. Johansson, M. K. Nazeeruddin, M. Gratzel and A. Hagfeldt, *RSC Adv.*, 2013, **3**, 18762–18766.
234 K. Wang, Y. T. Shi, Q. S. Dong, Y. Li, S. F. Wang, X. F. Yu, M. Y. Wu and T. L. Ma, *J. Phys. Chem. Lett.*, 2015, **6**, 755–759.
235 X. Wang, L.-L. Deng, L.-Y. Wang, S.-M. Dai, Z. Xing, X.-X. Zhan, X.-Z. Lu, S.-Y. Xie, R.-B. Huang and L.-S. Zheng, *J. Mater. Chem. A*, 2017, **5**, 1706–1712.
236 M. Qin, J. Ma, W. Ke, P. Qin, H. Lei, H. Tao, X. Zheng, L. Xiong, Q. Liu, Z. Chen, J. Lu, G. Yang and G. Fang, *ACS Appl. Mater. Interfaces*, 2016, **8**, 8460–8466.
237 X. Ling, J. Yuan, D. Liu, Y. Wang, Y. Zhang, S. Chen, H. Wu, F. Jin, F. Wu, G. Shi, X. Tang, J. Zheng, S. Liu, Z. Liu and W. Ma, *ACS Appl. Mater. Interfaces*, 2017, **9**, 23181–23188.
238 W. Hu, T. Liu, X. Yin, H. Liu, X. Zhao, S. Luo, Y. Guo, Z. Yao, J. Wang, N. Wang, H. Lin and Z. Guo, *J. Mater. Chem. A*, 2017, **5**, 1434–1441.
239 M. F. García-Sánchez, A. Ortiz, G. Santana, M. Bizarro, J. Peña, F. Cruz-Gandarilla, M. A. Aguilar-Frutis and J. C. Alonso, *J. Am. Ceram. Soc.*, 2010, **93**, 155–160.
240 T. Inoue, M. Osonoe, H. Tohda, M. Hiramatsu, Y. Yamamoto, A. Yamanaka and T. Nakayama, *J. Appl. Phys.*, 1991, **69**, 8313–8315.
241 T. Suzuki, I. Kosacki, H. U. Anderson and P. Colomban, *J. Am. Ceram. Soc.*, 2001, **84**, 2007–2014.
242 R. Fang, S. Wu, W. Chen, Z. Liu, S. Zhang, R. Chen, Y. Yue, L. Deng, Y. B. Cheng, L. Han and W. Chen, *ACS Nano*, 2018, **12**, 2403–2414.
243 A. Fang, J. Li, X.-F. Wei, Z.-W. Yuan, M. Yang and Z.-N. Chen, *Nanoscale Adv.*, 2020, **2**, 4062–4069.
244 J. Yang, J. Xu, Q. Zhang, Z. Xue, H. Liu, R. Qin, H. Zhai and M. Yuan, *RSC Adv.*, 2020, **10**, 18608–18613.
245 Z. Xing, S.-H. Li, B.-S. Wu, X. Wang, L.-Y. Wang, T. Wang, H.-R. Liu, M.-L. Zhang, D.-Q. Yun, L.-L. Deng, S.-Y. Xie, R.-B. Huang and L.-S. Zheng, *J. Power Sources*, 2018, **389**, 13–19.
246 R. Meng, X. Feng, Y. Yang, X. Lv, J. Cao and Y. Tang, *ACS Appl. Mater. Interfaces*, 2019, **11**, 13273–13278.
247 Z. Guo, L. Guo, C. Zhang, Z. Xu and T. Ma, *J. Mater. Chem. A*, 2018, **6**, 4572–4589.
248 T. Hu, X. Xiao, H. Yang, L. Chen and Y. Chen, *Chem. Commun.*, 2018, **54**, 471–474.
249 L. Ottaviano, L. Lozzi, M. Passacantando and S. Santucci, *Surf. Sci.*, 2001, **475**, 73–82.
250 L. Weinhardt, M. Blum, M. Bär, C. Heske, B. Cole, B. Marsen and E. L. Miller, *J. Phys. Chem. C*, 2008, **112**, 3078–3082.
251 D. S. Dalavi, R. S. Devan, R. A. Patil, R. S. Patil, Y. R. Ma, S. B. Sadale, I. Kim, J. H. Kim and P. S. Patil, *J. Mater. Chem. C*, 2013, **1**, 3722–3728.
252 M. Gillet, K. Aguir, C. Lemire, E. Gillet and K. Schierbaum, *Thin Solid Films*, 2004, **467**, 239–246.
253 K. Mahmood, B. S. Swain, A. R. Kirmani and A. Amassian, *J. Mater. Chem. A*, 2015, **3**, 9051–9057.
254 F. Wang, Y. Zhang, M. Yang, J. Du, L. Yang, L. Fan, Y. Sui, X. Liu and J. Yang, *J. Power Sources*, 2019, **440**, 227157.
255 X. Li, Y. Liu, V. O. Eze, T. Mori, Z. Huang, K. P. Homewood, Y. Gao and B. Lei, *Sol. Energy Mater. Sol. Cells*, 2019, **196**, 157–166.
256 F. Wang, M. Yang, Y. Zhang, J. Du, D. Han, L. Yang, L. Fan, Y. Sui, Y. Sun, X. Meng and J. Yang, *Chem. Eng. J.*, 2020, **402**, 126303.
257 Y. Guo, T. Liu, N. Wang, Q. Luo, H. Lin, J. Li, Q. Jiang, L. Wu and Z. Guo, *Nano Energy*, 2017, **38**, 193–200.

258 W. Zhu, Q. Zhang, C. Zhang, D. Chen, L. Zhou, Z. Lin, J. Chang, J. Zhang and Y. Hao, *Dalton Trans.*, 2018, **47**, 6404–6411.

259 A. K. Chandiran, M. Abdi-Jalebi, A. Yella, M. I. Dar, C. Y. Yi, S. A. Shivashankar, M. K. Nazeeruddin and M. Grätzel, *Nano Lett.*, 2014, **14**, 1190–1195.

260 G. S. Han, H. S. Chung, B. J. Kim, D. H. Kim, J. W. Lee, B. S. Swain, K. Mahmood, J. S. Yoo, N. G. Park, J. H. Lee and H. S. Jung, *J. Mater. Chem. A*, 2015, **3**, 9160–9164.

261 X. Guo, Z. Lin, J. Ma, Z. Hu, J. Su, C. Zhang, J. Zhang, J. Chang and Y. Hao, *J. Power Sources*, 2019, **438**, 226987.

262 X. Zhang, J. Li, Z. Bi, K. He, X. Xu, X. Xiao, Y. Zhu, Y. Zhan, L. Zhong, G. Xu and H. Yu, *J. Alloys Compd.*, 2020, **836**, 155460.

263 S. An, P. Chen, F. Hao, Q. Wang, H. Pan, X. Chen, X. Lu, Y. Zhao, Q. Huang and X. Zhang, *Sol. Energy*, 2020, **196**, 409–418.

264 E. Aydin, M. De Bastiani, X. Yang, M. Sajjad, F. Aljamaan, Y. Smirnov, M. N. Hedhili, W. Liu, T. G. Allen, L. Xu, E. Van Kerschaver, M. Morales-Masis, U. Schwingenschlögl and S. De Wolf, *Adv. Funct. Mater.*, 2019, **29**, 1901741.

265 J. H. Kim, T. Y. Seong, K. B. Chung, C. S. Moon, J. H. Noh, H.-J. Seok and H.-K. Kim, *J. Power Sources*, 2019, **418**, 152–161.

266 K. A. Rani, A. S. Zoolfakar, A. P. O'Mullane, M. W. Austin and K. Kalantar-Zadeh, *J. Mater. Chem. A*, 2014, **2**, 15683–15703.

267 J. H. Lin, R. A. Patil, M. A. Wu, L. G. Yu, K. D. Liu, W. T. Gao, R. S. Devan, C. H. Ho, Y. Liou and Y. R. Ma, *J. Mater. Chem. C*, 2014, **2**, 8667–8672.

268 A. Kogo, Y. Numata, M. Ikegami and T. Miyasaka, *Chem. Lett.*, 2015, **44**, 829–830.

269 J. Feng, Z. Yang, D. Yang, X. Ren, X. Zhu, Z. Jin, W. Zi, Q. Wei and S. Liu, *Nano Energy*, 2017, **36**, 1–8.

270 D. Shen, W. Zhang, Y. Li, A. Abate and M. Wei, *ACS Appl. Nano Mater.*, 2018, **1**, 4101–4109.

271 X. Ye, H. Ling, R. Zhang, Z. Wen, S. Hu, T. Akasaka, J. Xia and X. Lu, *J. Power Sources*, 2020, **448**, 227419.

272 R. Li, X. Hou, X. Han, Z. Wang, M. Zhang and M. Guo, *Appl. Surf. Sci.*, 2021, **542**, 148728.

273 L. Wang, W. F. Fu, Z. W. Gu, C. C. Fan, X. Yang, H. Y. Li and H. Z. Chen, *J. Mater. Chem. C*, 2014, **2**, 9087–9090.

274 M. Abulikemu, J. Barbe, A. El Labban, J. Eid and S. Del Gobbo, *Thin Solid Films*, 2017, **636**, 512–518.

275 D.-B. Li, L. Hu, Y. Xie, G. Niu, T. Liu, Y. Zhou, L. Gao, B. Yang and J. Tang, *ACS Photonics*, 2016, **3**, 2122–2128.

276 M. D. Que, L. L. Zhu, Y. W. Yang, J. Liu, P. Chen, W. Chen, X. T. Yin and W. X. Que, *J. Power Sources*, 2018, **383**, 42–49.

277 Z. L. Lu, X. J. Pan, Y. Z. Ma, Y. Li, L. L. Zheng, D. F. Zhang, Q. Xu, Z. J. Chen, S. F. Wang, B. Qu, F. Liu, Y. D. Huang, L. X. Xiao and Q. H. Gong, *RSC Adv.*, 2015, **5**, 11175–11179.

278 H. Wang, F. Yang, N. Li, M. A. Kamarudin, J. Qu, J. Song, S. Hayase and C. J. Brabec, *ACS Sustainable Chem. Eng.*, 2020, **8**, 8848–8856.

279 T. Cao, P. Huang, K. Zhang, Z. Sun, K. Zhu, L. Yuan, K. Chen, N. Chen and Y. Li, *J. Mater. Chem. A*, 2018, **6**, 3435–3443.

280 J. Xiong, Y. Qi, Q. Zhang, D. Box, K. Williams, J. Tatum, P. Dan, N. K. Pradhan and Q. Dai, *ACS Appl. Energy Mater.*, 2021, **4**, 1815–1821.

281 O. Malinkiewicz, A. Yella, Y. H. Lee, G. M. Espallargas, M. Graetzel, M. K. Nazeeruddin and H. J. Bolink, *Nat. Photonics*, 2014, **8**, 128–132.

282 Z. B. Yang, J. S. Xie, V. Arivazhagan, K. Xiao, Y. P. Qiang, K. Huang, M. Hu, C. Cui, X. G. Yu and D. R. Yang, *Nano Energy*, 2017, **40**, 345–351.

283 Y. Bai, H. Yu, Z. L. Zhu, K. Jiang, T. Zhang, N. Zhao, S. H. Yang and H. Yan, *J. Mater. Chem. A*, 2015, **3**, 9098–9102.

284 X. F. Zeng, T. W. Zhou, C. Q. Leng, Z. G. Zang, M. Wang, W. Hu, X. S. Tang, S. R. Lu, L. A. Fang and M. Zhou, *J. Mater. Chem. A*, 2017, **5**, 17499–17505.

285 C. Liu, K. Wang, P. C. Du, T. Y. Meng, X. F. Yu, S. Z. D. Cheng and X. Gong, *ACS Appl. Mater. Interfaces*, 2015, **7**, 1153–1159.

286 J. Ciro, S. Mesa, J. I. Uribe, M. A. Mejía-Escobar, D. Ramirez, J. F. Montoya, R. Betancur, H. S. Yoo, N. G. Park and F. Jaramillo, *Nanoscale*, 2017, **9**, 9440–9446.

287 Y. Liu, Z. Xu, S. L. Zhao, B. Qiao, Y. Li, Z. L. Qin and Y. Q. Zhu, *Acta Phys. Sin.*, 2017, **66**, 118801.

288 Y. Lin, R. Long, R. Chen, S. Huang, W. OuYang and X. Chen, *ACS Appl. Energy Mater.*, 2021, **4**, 3812–3821.

289 A. A. Said, J. Xie and Q. Zhang, *Small*, 2019, **15**, 1900854.

290 D. Wang, T. Ye and Y. Zhang, *J. Mater. Chem. A*, 2020, **8**, 20819–20848.

291 H. S. Kim, J. W. Lee, N. Yantara, P. P. Boix, S. A. Kulkarni, S. Mhaisalkar, M. Gratzel and N. G. Park, *Nano Lett.*, 2013, **13**, 2412–2417.

292 K. Mahmood, B. S. Swain and A. Amassian, *Adv. Mater.*, 2015, **27**, 2859–2865.

293 L. F. Zhu, Y. Z. Xu, J. J. Shi, H. Y. Zhang, X. Xu, Y. H. Zhao, Y. H. Luo, Q. B. Meng and D. M. Li, *RSC Adv.*, 2016, **6**, 82282–82288.

294 F. Cai, L. Yang, Y. Yan, J. Zhang, F. Qin, D. Liu, Y.-B. Cheng, Y. Zhou and T. Wang, *J. Mater. Chem. A*, 2017, **5**, 9402–9411.

295 M. M. Tavakoli, P. Yadav, R. Tavakoli and J. Kong, *Adv. Energy Mater.*, 2018, **8**, 1800794.

296 M. Kim, G.-H. Kim, T. K. Lee, I. W. Choi, H. W. Choi, Y. Jo, Y. J. Yoon, J. W. Kim, J. Lee, D. Huh, H. Lee, S. K. Kwak, J. Y. Kim and D. S. Kim, *Joule*, 2019, **3**, 2179–2192.

297 M. Jeong, I. W. Choi, E. M. Go, Y. Cho, M. Kim, B. Lee, S. Jeong, Y. Jo, H. W. Choi, J. Lee, J.-H. Bae, S. K. Kwak, D. S. Kim and C. Yang, *Science*, 2020, **369**, 1615–1620.

298 J. Jeong, M. Kim, J. Seo, H. Lu, P. Ahlawat, A. Mishra, Y. Yang, M. A. Hope, F. T. Eickemeyer, M. Kim, Y. J. Yoon, I. W. Choi, B. P. Darwich, S. J. Choi, Y. Jo, J. H. Lee, B. Walker, S. M. Zakeeruddin, L. Emsley, U. Rothlisberger, A. Hagfeldt, D. S. Kim, M. Grätzel and J. Y. Kim, *Nature*, 2021, **592**, 381–385.

299 H. Huang, P. Cui, Y. Chen, L. Yan, X. Yue, S. Qu, X. Wang, S. Du, B. Liu, Q. Zhang, Z. Lan, Y. Yang, J. Ji, X. Zhao, Y. Li, X. Wang, X. Ding and M. Li, *Joule*, 2022, **6**, 2186–2202.

300 M. H. Kumar, N. Yantara, S. Dharani, M. Graetzel, S. Mhaisalkar, P. P. Boix and N. Mathews, *Chem. Commun.*, 2013, **49**, 11089–11091.

301 D. Liu and T. L. Kelly, *Nat. Photonics*, 2014, **8**, 133–138.

302 C. Y. Chang, K. T. Lee, W. K. Huang, H. Y. Siao and Y. C. Chang, *Chem. Mater.*, 2015, **27**, 5122–5130.

303 M. M. Tavakoli, R. Tavakoli, P. Yadav and J. Kong, *J. Mater. Chem. A*, 2019, **7**, 679–686.

304 Y. W. Noh, I. S. Jin, K. S. Kim, S. H. Park and J. W. Jung, *J. Mater. Chem. A*, 2020, **8**, 17163–17173.

305 S. Leng, L. Wang, X. Wang, Z. Zhang, J. Liang, Y. Zheng, J. Jiang, Z. Zhang, X. Liu, Y. Qiu and C.-C. Chen, *Solar RRL*, 2021, **5**, 2100285.

306 Y. Wu, J. K. Song, X. R. Wu, C. F. Qiu, X. X. Yin, L. Hu, Z. Su, Y. Z. Jin, J. J. Chen and Z. F. Li, *Chem. Commun.*, 2022, **58**, 9266–9269.

307 Q. Jiang, L. Zhang, H. Wang, X. Yang, J. Meng, H. Liu, Z. Yin, J. Wu, X. Zhang and J. You, *Nat. Energy*, 2016, **2**, 16177.

308 K. Liu, S. Chen, J. Wu, H. Zhang, M. Qin, X. Lu, Y. Tu, Q. Meng and X. Zhan, *Energy Environ. Sci.*, 2018, **11**, 3463–3471.

309 C. Ma and N.-G. Park, *ACS Energy Lett.*, 2020, **5**, 3268–3275.

310 H. Min, D. Y. Lee, J. Kim, G. Kim, K. S. Lee, J. Kim, M. J. Paik, Y. K. Kim, K. S. Kim, M. G. Kim, T. J. Shin and S. Il Seok, *Nature*, 2021, **598**, 444–450.

311 M. Kim, J. Jeong, H. Z. Lu, T. K. Lee, F. T. Eickemeyer, Y. H. Liu, I. W. Choi, S. J. Choi, Y. Jo, H. B. Kim, S. I. Mo, Y. K. Kim, H. Lee, N. G. An, S. Cho, W. R. Tress, S. M. Zakeeruddin, A. Hagfeldt, J. Y. Kim, M. Gratzel and D. S. Kim, *Science*, 2022, **375**, 302.

312 S. S. Shin, W. S. Yang, J. H. Noh, J. H. Suk, N. J. Jeon, J. H. Park, J. S. Kim, W. M. Seong and S. I. Seok, *Nat. Commun.*, 2015, **6**, 7410.

313 S. Ran, J. Wu, X. He, Y. Tu, S. Wang, M. Huang and Z. Lan, *Electrochim. Acta*, 2017, **251**, 307–315.

314 J. Duo, Y. Zhang, Q. Wang, A. Abate, Y. Li and M. Wei, *Chem. Commun.*, 2019, **55**, 14673–14676.

315 F. Sadegh, S. Akin, M. Moghadam, V. Mirkhani, M. A. Ruiz-Preciado, Z. Wang, M. M. Tavakoli, M. Graetzel, A. Hagfeldt and W. Tress, *Nano Energy*, 2020, **75**, 105038.

316 Q. Zhang, K. Williams, J. Tatum, F. Han, X. Zhu and Q. Lei, *J. Renewable Sustainable Energy*, 2021, **13**, 063501.

317 X. H. Liu, Y. Zhang, M. Chen, C. X. Xiao, K. G. Brooks, J. X. Xu, X. X. Gao, H. Kanda, S. Kinge, A. M. Asiri, J. M. Luther, Y. Q. Feng, P. J. Dyson and M. K. Nazeeruddin, *ACS Appl. Mater. Interfaces*, 2022, **14**, 22297–22306.

318 Y. Tang, K. Roy, Z. H. Zhang, Y. C. Hu, F. Yang, C. C. Qin, L. L. Jiang and H. R. Liu, *Sol. Energy*, 2022, **231**, 440–446.

319 A. Gulu, I. C. Kaya and S. Sonmezoglu, *ACS Appl. Energy Mater.*, 2022, **5**, 3454–3462.

320 S. Ranjan, R. Ranjan, A. Tyagi, K. S. Rana, A. Soni, H. K. Kodali, V. Dalal, A. Singh, A. Garg, K. S. Nalwa and R. K. Gupta, *ACS Appl. Energy Mater.*, 2022, **5**, 2679–2686.

321 M. J. Paik, Y. Lee, H.-S. Yun, S.-U. Lee, S.-T. Hong and S. I. Seok, *Adv. Energy Mater.*, 2020, **10**, 2001799.

322 Y. Sanehira, N. Shibayama, Y. Numata, M. Ikegami and T. Miyasaka, *ACS Appl. Mater. Interfaces*, 2020, **12**, 15175–15182.

323 K.-M. Lee, W.-J. Lin, S.-H. Chen and M.-C. Wu, *Org. Electron.*, 2020, **77**, 105406.

324 W. Hu, W. Zhou, X. Lei, P. Zhou, M. Zhang, T. Chen, H. Zeng, J. Zhu, S. Dai, S. Yang and S. Yang, *Adv. Mater.*, 2019, **31**, 1806095.

325 F. Xie, J. Zhu, Y. Li, D. Shen, A. Abate and M. Wei, *J. Power Sources*, 2019, **415**, 8–14.

326 A. Khorasani, M. Marandi, A. Irajizad and N. Taghavinia, *Electrochim. Acta*, 2019, **297**, 1071–1078.

327 X. Chen, L. J. Tang, S. Yang, Y. Hou and H. G. Yang, *J. Mater. Chem. A*, 2016, **4**, 6521–6526.

328 H. Lu, Y. Ma, B. Gu, W. Tian and L. Li, *J. Mater. Chem. A*, 2015, **3**, 16445–16452.

329 J. Krzyżynska, J. Ostapko, V. Ozkaya, B. Surucu, O. Szaniecow, K. Nikiforow, M. Holdynski, M. M. Tavakoli, P. Yadav, M. Kot, G. P. Kolodziej, M. Wlodarski, S. Satapathi, S. Akin and D. Prochowicz, *Adv. Mater. Interfaces*, 2022, **9**, 2200575.

330 Z. Arshad, S. Wageh, T. Maiyalagan, M. Ali, U. Arshad, A. Noorul, M. B. Qadir, F. Mateen and A. G. Al-Sehemi, *Ceram. Int.*, 2022, **48**, 34363–34371.

331 K. Chen, W. Tang, Y. Chen, R. Yuan, Y. Lv, W. Shan and W.-H. Zhang, *J. Energy Chem.*, 2021, **61**, 553–560.

332 Z. Yang, Q. Fan, T. Shen, J. Jin, W. Deng, J. Xin, X. Huang, X. Wang and J. Li, *Sol. Energy*, 2020, **208**, 233–238.

333 R. Azmi, S. Hwang, W. Yin, T.-W. Kim, T. K. Ahn and S.-Y. Jang, *ACS Energy Lett.*, 2018, **3**, 1241–1246.

334 J. H. Heo, M. H. Lee, H. J. Han, B. R. Patil, J. S. Yu and S. H. Im, *J. Mater. Chem. A*, 2016, **4**, 1572–1578.

335 C. Zhang, Q. X. Zhuang, H. Y. Li, C. Gong, H. X. Wang, R. Li, H. X. Li, Z. Y. Zhang, H. Yang, J. Z. Chen and Z. G. Zang, *Sol. RRL*, 2022, 2200512.

336 Q. X. Zhuang, H. X. Wang, C. Zhang, C. Gong, H. Y. Li, J. Z. Chen and Z. G. Zang, *Nano Res.*, 2022, **15**, 5114–5122.

337 J. B. Wu, C. Zhen and G. Liu, *Rare Met.*, 2022, **41**, 361–367.

338 C. Zhang, H. X. Wang, H. Y. Li, Q. X. Zhuang, C. Gong, X. F. Hu, W. S. Cai, S. Y. Zhao, J. Z. Chen and Z. G. Zang, *J. Energy Chem.*, 2021, **63**, 452–460.

339 Z. Xu, Y. Jiang, Z. Li, C. Chen, X. Kong, Y. Chen, G. Zhou, J. M. Liu, K. Kempa and J. Gao, *ACS Appl. Energy Mater.*, 2021, **4**, 1887–1893.

340 J. Song, G. Li, D. Wang, W. Sun, J. Wu and Z. Lan, *Solar RRL*, 2020, **4**, 1900558.

341 H. X. Wang, H. Y. Li, S. L. Cao, M. Wang, J. Z. Chen and Z. G. Zang, *Solar RRL*, 2020, **4**, 2000226.

342 M. Hu, L. Zhang, S. She, J. Wu, X. Zhou, X. Li, D. Wang, J. Miao, G. Mi, H. Chen, Y. Tian, B. Xu and C. Cheng, *Solar RRL*, 2020, **4**, 1900331.

343 L. Xiong, M. Qin, C. Chen, J. Wen, G. Yang, Y. Guo, J. Ma, Q. Zhang, P. Qin, S. Li and G. Fang, *Adv. Funct. Mater.*, 2018, **28**, 1706276.

344 W. Q. Wu, D. Chen, Y.-B. Cheng and R. A. Caruso, *Solar RRL*, 2017, **1**, 1700117.

345 X. K. Yang, W. H. Zhao, M. J. Li, L. F. Ye, P. F. Guo, Y. X. Xu, H. Gou, H. W. Yu, Q. Ye, H. Y. Wang, D. Huang,

D. Shchukin, M. J. Feng, T. C. Sum and H. Q. Wang, *Adv. Funct. Mater.*, 2022, **32**, 2112388.

346 J. L. Lin, Y. J. Guan, S. Lin, X. Li, C. X. Gao, J. K. Hu, C. Qiu, D. Y. Li, D. Y. Zhang, X. D. Wang, Y. F. Wang, Y. Hu, Y. G. Rong, A. Y. Mei and H. W. Han, *ACS Appl. Energy Mater.*, 2021, **4**, 11032–11040.

347 M. Zheng, W. Xu, H. Yuan and J. Wu, *J. Alloys Compd.*, 2020, **823**, 153730.

348 X. Lan, Y. Li, K. Liu and J. Zhang, *Solid State Sci.*, 2020, **108**, 106387.

349 J. Dou, D. Shen, Y. Li, A. Abate and M. Wei, *ACS Appl. Mater. Interfaces*, 2019, **11**, 36553–36559.

350 Y. Gao, Y. Wu, Y. Liu, C. Chen, X. Shen, X. Bai, Z. Shi, W. W. Yu, Q. Dai and Y. Zhang, *Solar RRL*, 2019, **3**, 1900314.

351 J. Sun, Y. Li, N. Tang, Y. Zhou, K. Zhang, X. Lu, X. Gao, J. Gao, L. Shui, S. Wu and J.-M. Liu, *ACS Appl. Energy Mater.*, 2020, **3**, 2320–2326.

352 M. M. Tavakoli, D. Prochowicz, P. Yadav and R. Tavakoli, *Phys. Status Solidi RRL*, 2020, **14**, 2000062.

353 F. Wang, Y. Zhang, M. Yang, J. Du, L. Xue, L. Yang, L. Fan, Y. Sui, J. Yang and X. Zhang, *Nano Energy*, 2019, **63**, 103825.

354 B. Yang, M. Wang, X. F. Hu, T. W. Zhou and Z. G. Zang, *Nano Energy*, 2019, **57**, 718–727.

355 J. Jiang, S. Wang, X. Jia, X. Fang, S. Zhang, J. Zhang, W. Liu, J. Ding and N. Yuan, *RSC Adv.*, 2018, **8**, 12823–12831.

356 S. F. Shaikh, H. C. Kwon, W. Yang, R. S. Mane and J. Moon, *J. Alloys Compd.*, 2018, **738**, 405–414.

357 M. Kim, T. N. Murakami, T. W. Kim, S. Kim, H. Tampo, M. Chikamatsu and H. Segawa, *Chem. Lett.*, 2018, **47**, 1330–1333.

358 G. Tong, Z. Song, C. Li, Y. Zhao, L. Yu, J. Xu, Y. Jiang, Y. Sheng, Y. Shi and K. Chen, *RSC Adv.*, 2017, **7**, 19457–19463.

359 T. Hou, C. O. R. Quiroz, S. Schröder, W. Chen, T. Stubhan, A. Hirsch, M. Halik and C. J. Brabec, *Adv. Energy Mater.*, 2015, **5**, 1501056.

360 W. Chen, Y. Wu, Y. Yue, J. Liu, W. Zhang, X. Yang, H. Chen, E. Bi, I. Ashraful, M. Grätzel and L. Han, *Science*, 2015, **350**, 944–948.

361 C. T. Zuo and L. M. Ding, *Small*, 2015, **11**, 5528–5532.

362 N. Wijeyasinghe, A. Regoutz, F. Eisner, T. Du, L. Tsetseris, Y.-H. Lin, H. Faber, P. Pattanasattayavong, J. Li, F. Yan, M. A. McLachlan, D. J. Payne, M. Heeney and T. D. Anthopoulos, *Adv. Funct. Mater.*, 2017, **27**, 1701818.

363 H. Zhang, H. Wang, W. Chen and A. K. Y. Jen, *Adv. Mater.*, 2017, **29**, 1604984.

364 D. S. Dalavi, R. S. Devan, R. S. Patil, Y. R. Ma and P. S. Patil, *Mater. Lett.*, 2013, **90**, 60–63.

365 R. A. Patil, R. S. Devan, J. H. Lin, Y. Liou and Y. R. Ma, *Sci. Rep.*, 2013, **3**, 3070.

366 R. A. Patil, C. P. Chang, R. S. Devan, Y. Liou and Y. R. Ma, *ACS Appl. Mater. Interfaces*, 2016, **8**, 9872–9880.

367 N. Kitchamsetti, P. R. Chikate, R. A. Patil, Y. R. Ma, P. M. Shirage and R. S. Devan, *CrystEngComm*, 2019, **21**, 7130–7140.

368 N. Kitchamsetti, M. S. Ramteke, S. R. Rondiya, S. R. Mulani, M. S. Patil, R. W. Cross, N. Y. Dzade and R. S. Devan, *J. Alloys Compd.*, 2021, **855**, 157337.

369 R. A. Patil, R. S. Devan, J. H. Lin, Y. R. Ma, P. S. Patil and Y. Liou, *Sol. Energy Mater. Sol. Cells*, 2013, **112**, 91–96.

370 D. S. Dalavi, R. S. Devan, R. S. Patil, Y. R. Ma, M. G. Kang, J. H. Kim and P. S. Patil, *J. Mater. Chem. A*, 2013, **1**, 1035–1039.

371 K. H. Parmar, V. Manjunath, S. Bimli, P. R. Chikate, R. A. Patil, Y. R. Ma and R. S. Devan, *Chin. J. Phys.*, 2022, **77**, 143–150.

372 P. Docampo, J. M. Ball, M. Darwich, G. E. Eperon and H. J. Snaith, *Nat. Commun.*, 2013, **4**, 2761.

373 J. Cui, F. Meng, H. Zhang, K. Cao, H. Yuan, Y. Cheng, F. Huang and M. Wang, *ACS Appl. Mater. Interfaces*, 2014, **6**, 22862–22870.

374 S. Seo, I. J. Park, M. Kim, S. Lee, C. Bae, H. S. Jung, N. G. Park, J. Y. Kim and H. Shin, *Nanoscale*, 2016, **8**, 11403–11412.

375 J. Tang, D. Jiao, L. Zhang, X. Zhang, X. Xu, C. Yao, J. Wu and Z. Lan, *Sol. Energy*, 2018, **161**, 100–108.

376 Z. Zhu, Y. Bai, T. Zhang, Z. Liu, X. Long, Z. Wei, Z. Wang, L. Zhang, J. Wang, F. Yan and S. Yang, *Angew. Chem., Int. Ed.*, 2014, **53**, 12571–12575.

377 Y. Abzieher, S. Moghadamzadeh, F. Schackmar, H. Eggers, F. Sutterlüti, A. Farooq, D. Kojda, K. Habicht, R. Schmager, A. Mertens, R. Azmi, L. Klohr, J. A. Schwenzer, M. Hetterich, U. Lemmer, B. S. Richards, M. Powalla and U. W. Paetzold, *Adv. Energy Mater.*, 2019, **9**, 1802995.

378 T. J. Routledge, M. Wong-Stringer, O. S. Game, J. A. Smith, J. E. Bishop, N. Vaenas, B. G. Freestone, D. M. Coles, T. McArdle, A. R. Buckley and D. G. Lidzey, *J. Mater. Chem. A*, 2019, **7**, 2283–2290.

379 B. Zhao, L. C. Lee, L. Yang, A. J. Pearson, H. Lu, X.-J. She, L. Cui, K. H. L. Zhang, R. L. Z. Hoye, A. Karani, P. Xu, A. Sadhanala, N. C. Greenham, R. H. Friend, J. L. MacManus-Driscoll and D. Di, *ACS Appl. Mater. Interfaces*, 2018, **10**, 41849–41854.

380 V. Manjunath, S. Bimli, K. H. Parmar, P. M. Shirage and R. S. Devan, *Sol. Energy*, 2019, **193**, 387–394.

381 Z. Liu, J. Chang, Z. Lin, L. Zhou, Z. Yang, D. Chen, C. Zhang, S. Liu and Y. Hao, *Adv. Energy Mater.*, 2018, **8**, 1703432.

382 X. Yin, J. Zhai, L. Song, P. Du, N. Li, Y. Yang, J. Xiong and F. Ko, *ACS Appl. Mater. Interfaces*, 2019, **11**, 44308–44314.

383 U. K. Thakur, P. Kumar, S. Gusarov, A. E. Kobryn, S. Riddell, A. Goswami, K. M. Alam, S. Savela, P. Kar, T. Thundat, A. Meldrum and K. Shankar, *ACS Appl. Mater. Interfaces*, 2020, **12**, 11467–11478.

384 M. Feng, M. Wang, H. Zhou, W. Li, X. Xie, S. Wang, Z. Zang and S. Chen, *ACS Appl. Energy Mater.*, 2020, **3**, 9732–9741.

385 A. M. Kheman, L. Luo and Q. L. Song, *Dalton Trans.*, 2020, **49**, 14243–14250.

386 C. C. Boyd, R. C. Shallcross, T. Moot, R. Kerner, L. Bertoluzzi, A. Onno, S. Kavadiya, C. Chosy, E. J. Wolf, J. Werner, J. A. Raiford, C. de Paula, A. F. Palmstrom,

Z. J. Yu, J. J. Berry, S. F. Bent, Z. C. Holman, J. M. Luther, E. L. Ratcliff, N. R. Armstrong and M. D. McGehee, *Joule*, 2020, **4**, 1759–1775.

387 F. Khan, B. D. Rezgui and J. H. Kim, *Sol. Energy*, 2020, **209**, 226–234.

388 Y. Wang, T. Mahmoudi and Y.-B. Hahn, *Adv. Energy Mater.*, 2020, **10**, 2000967.

389 Z. Hu, D. Chen, P. Yang, L. Yang, L. Qin, Y. Huang and X. Zhao, *Appl. Surf. Sci.*, 2018, **441**, 258–264.

390 P. S. Chandrasekhar, Y.-H. Seo, Y.-J. Noh and S.-I. Na, *Appl. Surf. Sci.*, 2019, **481**, 588–596.

391 J. H. Lee, Y. W. Noh, I. S. Jin, S. H. Park and J. W. Jung, *J. Power Sources*, 2019, **412**, 425–432.

392 Y. Xie, K. Lu, J. Duan, Y. Jiang, L. Hu, T. Liu, Y. Zhou and B. Hu, *ACS Appl. Mater. Interfaces*, 2018, **10**, 14153–14159.

393 J. Zhang, W. Mao, X. Hou, J. Duan, J. Zhou, S. Huang, W. Ou-Yang, X. Zhang, Z. Sun and X. Chen, *Sol. Energy*, 2018, **174**, 1133–1141.

394 Y. Wei, K. Yao, X. Wang, Y. Jiang, X. Liu, N. Zhou and F. Li, *Appl. Surf. Sci.*, 2018, **427**, 782–790.

395 D. Di Girolamo, N. Phung, M. Jošt, A. Al-Ashouri, G. Chistiakova, J. Li, J. A. Márquez, T. Unold, L. Korte, S. Albrecht, A. Di Carlo, D. Dini and A. Abate, *Adv. Mater. Interfaces*, 2019, **6**, 1900789.

396 J. H. Lee, Y. W. Noh, I. S. Jin and J. W. Jung, *Electrochim. Acta*, 2018, **284**, 253–259.

397 X. Wan, Y. Jiang, Z. Qiu, H. Zhang, X. Zhu, I. Sikandar, X. Liu, X. Chen and B. Cao, *ACS Appl. Energy Mater.*, 2018, **1**, 3947–3954.

398 R. Chen, L. Xu, C. Chen, Y. Wu, W. Bi, Z. Song, X. Zhuang, S. Yang, S. Zhu and H. Song, *J. Power Sources*, 2019, **444**, 227267.

399 M.-A. Park, I. J. Park, S. Park, J. Kim, W. Jo, H. J. Son and J. Y. Kim, *Curr. Appl. Phys.*, 2018, **18**, 553–559.

400 W. Chen, F.-Z. Liu, X.-Y. Feng, A. B. Djurišić, W. K. Chan and Z.-B. He, *Adv. Energy Mater.*, 2017, **7**, 1700722.

401 X. Yin, J. Han, Y. Zhou, Y. Gu, M. Tai, H. Nan, Y. Zhou, J. Li and H. Lin, *J. Mater. Chem. A*, 2019, **7**, 5666–5676.

402 P.-C. Chen and S.-H. Yang, *ACS Appl. Energy Mater.*, 2019, **2**, 6705–6713.

403 R. Parida, S. Yoon, J. Ryu, S. Hayase, S. M. Jeong and D.-W. Kang, *ACS Appl. Mater. Interfaces*, 2020, **12**, 22958–22970.

404 G. Li, Y. Jiang, S. Deng, A. Tam, P. Xu, M. Wong and H.-S. Kwok, *Adv. Sci.*, 2017, **4**, 1700463.

405 W.-C. Lai, K.-W. Lin, Y.-T. Wang, T.-Y. Chiang, P. Chen and T.-F. Guo, *Adv. Mater.*, 2016, **28**, 3290–3297.

406 W.-C. Lai, K.-W. Lin, T.-F. Guo, P. Chen and Y.-Y. Liao, *Appl. Phys. Lett.*, 2018, **112**, 071103.

407 J. Kim, H. R. Lee, H. P. Kim, T. Lin, A. Kanwat, A. R. B. Mohd Yusoff and J. Jang, *Nanoscale*, 2016, **8**, 9284–9292.

408 P. Zhou, R. Li, Z. Fang, W. Zhou, M. Zhang, W. Hu, T. Chen, Z. Xiao and S. Yang, *Solar RRL*, 2019, **3**, 1900164.

409 S. Wang, B. Zhang, D. Feng, Z. Lin, J. Zhang, Y. Hao, X. Fan and J. Chang, *J. Mater. Chem. C*, 2019, **7**, 9270–9277.

410 X. Xiu, Y. Jiang, Q. Wan, X. Wang, L. Wang and F. Li, *ACS Appl. Mater. Interfaces*, 2018, **10**, 44501–44510.

411 E. P. Gokdemir Choi, H. Mosini Alishah, S. Bozar, C. Kahveci, M. Cantürk Rodop and S. Gunes, *Sol. Energy*, 2021, **215**, 434–442.

412 Y. Du, C. Xin, W. Huang, B. Shi, Y. Ding, C. Wei, Y. Zhao, Y. Li and X. Zhang, *ACS Sustainable Chem. Eng.*, 2018, **6**, 16806–16812.

413 Y. Liu, J. Duan, J. Zhang, S. Huang, W. Ou-Yang, Q. Bao, Z. Sun and X. Chen, *ACS Appl. Mater. Interfaces*, 2020, **12**, 771–779.

414 X. Yin, J. Zhai, P. Du, N. Li, L. Song, J. Xiong and F. Ko, *ChemSusChem*, 2020, **13**, 1006–1012.

415 W. Mao, G. Ren, Z. Li, M. Dong, C. Liu and W. Guo, *J. Energy Chem.*, 2020, **46**, 202–207.

416 L. Xu, M. Qian, C. Zhang, W. Lv, J. Jin, J. Zhang, C. Zheng, M. Li, R. Chen and W. Huang, *Nano Energy*, 2020, **67**, 104244.

417 H. Sun, X. Hou, Q. Wei, H. Liu, K. Yang, W. Wang, Q. An and Y. Rong, *Chem. Commun.*, 2016, **52**, 8099–8102.

418 L. Xu, M. Qian, Q. Lu, H. Zhang and W. Huang, *Mater. Lett.*, 2019, **236**, 16–18.

419 Z. Liu, T. He, K. Liu, Q. Zhi and M. Yuan, *RSC Adv.*, 2017, **7**, 26202–26210.

420 H. T. Peng, W. H. Sun, Y. L. Li, S. Y. Ye, H. X. Rao, W. B. Yan, H. P. Zhou, Z. Q. Bian and C. H. Huang, *Nano Res.*, 2016, **9**, 2960–2971.

421 K. Hom, I. H. Yoo, Q. A. Sial and H. Seo, *Curr. Appl. Phys.*, 2021, **23**, 62–67.

422 Z. Liu, T. He, K. Liu, J. Wang, Y. Zhou, J. Yang, H. Liu, Y. Jiang, H. Ma and M. Yuan, *J. Mater. Chem. A*, 2017, **5**, 24282–24291.

423 T. H. Schloemer, J. A. Raiford, T. S. Gehan, T. Moot, S. Nanayakkara, S. P. Harvey, R. C. Bramante, S. Dunfield, A. E. Louks, A. E. Maughan, L. Bliss, M. D. McGehee, M. F. A. M. van Hest, M. O. Reese, S. F. Bent, J. J. Berry, J. M. Luther and A. Sellinger, *ACS Energy Lett.*, 2020, **5**, 2349–2360.

424 X. Yao, W. Xu, X. Huang, J. Qi, Q. Yin, X. Jiang, F. Huang, X. Gong and Y. Cao, *Org. Electron.*, 2017, **47**, 85–93.

425 T. Lei, H. Dong, J. Xi, Y. Niu, J. Xu, F. Yuan, B. Jiao, W. Zhang, X. Hou and Z. Wu, *Chem. Commun.*, 2018, **54**, 6177–6180.

426 C.-C. Chang, J.-H. Tao, C.-E. Tsai, Y.-J. Cheng and C.-S. Hsu, *ACS Appl. Mater. Interfaces*, 2018, **10**, 21466–21471.

427 L. Xu, H. Wang, X. Feng, Y. Zhou, Y. Chen, R. Chen and W. Huang, *Adv. Photonics Res.*, 2021, 2000132.

428 X. Yao, J. Qi, W. Xu, X. Jiang, X. Gong and Y. Cao, *ACS Omega*, 2018, **3**, 1117–1125.

429 D. Li, C. Tong, W. Ji, Z. Fu, Z. Wan, Q. Huang, Y. Ming, A. Mei, Y. Hu, Y. Rong and H. Han, *ACS Sustainable Chem. Eng.*, 2019, **7**, 2619–2625.

430 M. M. Tepliakova, A. N. Mikheeva, L. A. Frolova, A. G. Boldyreva, A. Elakshar, A. V. Novikov, S. A. Tsarev, M. I. Ustinova, O. R. Yamilova, A. G. Nasibulin, S. M. Aldoshin, K. J. Stevenson and P. A. Troshin, *J. Phys. Chem. Lett.*, 2020, **11**, 5563–5568.

431 S. Chu, R. Zhao, R. Liu, Y. Gao, X. Wang, C. Liu, J. Chen and H. Zhou, *Semicond. Sci. Technol.*, 2018, **33**, 115016.

432 J. A. Raiford, R. A. Belisle, K. A. Bush, R. Prasanna, A. F. Palmstrom, M. D. McGehee and S. F. Bent, *Sustainable Energy Fuels*, 2019, **3**, 1517–1525.

433 Y.-H. Lou and Z.-K. Wang, *Nanoscale*, 2017, **9**, 13506–13514.

434 Z. Liu, T. He, H. Wang, X. Song, H. Liu, J. Yang, K. Liu and H. Ma, *RSC Adv.*, 2017, **7**, 18456–18465.

435 D. Wang, N. K. Elumalai, M. A. Mahmud, M. Wright, M. B. Upama, K. H. Chan, C. Xu, F. Haque, G. Conibeer and A. Uddin, *Org. Electron.*, 2018, **53**, 66–73.

436 T.-H. Yeh, H.-Y. Lee and C.-T. Lee, *J. Alloys Compd.*, 2020, **822**, 153620.

437 J. Li, J. Qin, X. Liu, M. Ren, J. Tong, N. Zheng, W. Chen and Y. Xia, *Sol. Energy*, 2020, **211**, 1102–1109.

438 M. Cheng, Y. Li, M. Safdari, C. Chen, P. Liu, L. Kloo and L. Sun, *Adv. Energy Mater.*, 2017, **7**, 1602556.

439 S. S. Kanakkillam, B. Shaji, B. Krishnan, S. Vazquez-Rodriguez, J. A. A. Martinez, M. I. M. Palma and D. A. Avellaneda, *Appl. Surf. Sci.*, 2020, **501**, 144223.

440 A. E. Shalan, T. Oshikiri, S. Narra, M. M. Elshanawany, K. Ueno, H.-P. Wu, K. Nakamura, X. Shi, E. W.-G. Diau and H. Misawa, *ACS Appl. Mater. Interfaces*, 2016, **8**, 33592–33600.

441 A. Huang, L. Lei, J. Zhu, Y. Yu, Y. Liu, S. Yang, S. Bao, X. Cao and P. Jin, *Langmuir*, 2017, **33**, 3624–3634.

442 A. Bashir, S. Shukla, J. H. Lew, S. Shukla, A. Bruno, D. Gupta, T. Baikie, R. Patidar, Z. Akhter, A. Priyadarshi, N. Mathews and S. G. Mhaisalkar, *Nanoscale*, 2018, **10**, 2341–2350.

443 Y. Zhou, X. Zhang, X. Lu, X. Gao, J. Gao, L. Shui, S. Wu and J.-M. Liu, *Solar RRL*, 2019, **3**, 1800315.

444 Y. Zhang, J. Ge, B. Mahmoudi, S. Förster, F. Syrowatka, A. W. Maijenburg and R. Scheer, *ACS Appl. Energy Mater.*, 2020, **3**, 3755–3769.

445 C.-H. Chiang, C.-C. Chen, M. K. Nazeeruddin and C.-G. Wu, *J. Mater. Chem. A*, 2018, **6**, 13751–13760.

446 F. P. Gokdemir Choi, *J. Mater. Sci.: Mater. Electron.*, 2021, **32**, 4136–4148.

447 R. Li, Y. Rui, J. Xu, Y. Wang, J. Yang, Q. Zhang and P. Müller-Buschbaum, *J. Colloid Interface Sci.*, 2020, **573**, 78–86.

448 Y. Dou, D. Wang, G. Li, Y. Liao, W. Sun, J. Wu and Z. Lan, *ACS Appl. Mater. Interfaces*, 2019, **11**, 32159–32168.

449 M. Heinemann, B. Eifert and C. Heiliger, *Phys. Rev. B: Condens. Matter Mater. Phys.*, 2013, **87**, 115111.

450 J. S. Shaikh, R. C. Pawar, R. S. Devan, Y. R. Ma, P. P. Salvi, S. S. Kolekar and P. S. Patil, *Electrochim. Acta*, 2011, **56**, 2127–2134.

451 T. Kim, S. Kim, K. E. Agbenyeke, H. Jung, S. M. Shin, Y. K. Lee, C. G. Kim, T.-M. Chung, N. J. Jeon, H. H. Park and J. Seo, *Adv. Mater. Interfaces*, 2021, **8**, 2170000.

452 Z.-K. Tu, W.-F. Fu, W.-Q. Liu, Z.-Q. Zhang, Y.-J. Liu, J.-L. Yun, T. Ye, W.-T. Yang, H.-Y. Li and H.-Z. Chen, *Chin. Chem. Lett.*, 2017, **28**, 13–18.

453 W. L. Yu, F. Li, H. Wang, E. Alarousu, Y. Chen, B. Lin, L. F. Wang, M. N. Hedhili, Y. Y. Li, K. W. Wu, X. B. Wang, O. F. Mohammed and T. Wu, *Nanoscale*, 2016, **8**, 6173–6179.

454 Q. Yu, J. Pan, J. Min, Z. Chen, P. Wang, P. Wang, J. Wang, C. Song, Y. Zhong and C. Li, *J. Mater. Sci.*, 2021, **56**, 5730–5747.

455 Y. Guo, H. Lei, L. Xiong, B. Li and G. Fang, *J. Mater. Chem. C*, 2017, **5**, 8033–8040.

456 L.-C. Chen, C.-C. Chen, K.-C. Liang, S. H. Chang, Z.-L. Tseng, S.-C. Yeh, C.-T. Chen, W.-T. Wu and C.-G. Wu, *Nanoscale Res. Lett.*, 2016, **11**, 402.

457 L. Y. Y. Hu, Y. X. Fu, J. F. Li and Y.-F. Guo, *RSC Adv.*, 2017, **7**, 46651–46656.

458 A. Sarra, I. T. Papadas, D. Tsikritzis, G. S. Armatas, S. Kennou and S. A. Choulis, *J. Mater. Chem. A*, 2017, **5**, 20303–20309.

459 Y. J. Chen, M. H. Li, J. C. A. Huang and P. Chen, *Sci. Rep.*, 2018, **8**, 7646.

460 Q. Sun, S. Zhou, X. Shi, X. Wang, L. Gao, Z. Li and Y. Hao, *ACS Appl. Mater. Interfaces*, 2018, **10**, 11289–11296.

461 W. Sun, Y. Li, S. Ye, H. Rao, W. Yan, H. Peng, Y. Li, Z. Liu, S. Wang, Z. Chen, L. Xiao, Z. Bian and C. Huang, *Nanoscale*, 2016, **8**, 10806–10813.

462 Y. Ma, Y. Zhang, H. Zhang, H. Lv, R. Hu, W. Liu, S. Wang, M. Jiang, L. Chu, J. Zhang, X. A. Li, R. Xia and W. Huang, *Appl. Surf. Sci.*, 2021, **547**, 149117.

463 Z. Zhuang, L. Qiu, L. Dong, Y. Chen, Z. Chu, X. Ma, P. Du and J. Xiong, *Polym. Compos.*, 2020, **41**, 3145–3153.

464 M. A. Islam, Y. A. Wahab, M. U. Khandaker, A. Alsubaie, A. S. A. Almalki, D. A. Bradley and N. Amin, *Crystals*, 2021, **11**, 389.

465 A. M. Elseman, M. S. Selim, L. Luo, C. Y. Xu, G. Wang, Y. Jiang, D. B. Liu, L. P. Liao, Z. Hao and Q. L. Song, *ChemSusChem*, 2019, **12**, 3808–3816.

466 C.-C. Tseng, L.-C. Chen, L.-B. Chang, G.-M. Wu, W.-S. Feng, M.-J. Jeng, D. W. Chen and K.-L. Lee, *Sol. Energy*, 2020, **204**, 270–279.

467 C. Liu, X. Zhou, S. Chen, X. Zhao, S. Dai and B. Xu, *Adv. Sci.*, 2019, **6**, 1801169.

468 Y.-J. Chen, M.-H. Li, J.-C.-A. Huang and P. Chen, *J. Mater. Chem. C*, 2018, **6**, 6280–6286.

469 J. Kim, Y. Lee, B. Gil, A. J. Yun, J. Kim, H. Woo, K. Park and B. Park, *ACS Appl. Energy Mater.*, 2020, **3**, 7572–7579.

470 K. Deepthi Jayan and V. Sebastian, *Int. J. Energy Res.*, 2021, **45**, 16618–16632.

471 A. Kumar and S. Singh, *Mod. Phys. Lett. B*, 2020, **34**, 2050258.

472 M. I. Hossain, F. H. Alharbi and N. Tabet, *Sol. Energy*, 2015, **120**, 370–380.

473 J. F. Castellanos-Águila, L. Lodeiro, E. Menéndez-Proupin, A. L. Montero-Alejo, P. Palacios, J. C. Conesa and P. Wahnón, *ACS Appl. Mater. Interfaces*, 2020, **12**, 44648–44657.

474 J. S. M. Zheng-Johansson, I. Ebbsjö and R. L. McGreevy, *Solid State Ionics*, 1995, **82**, 115–122.

475 A. Pishtshev and S. Z. Karazhanov, *J. Chem. Phys.*, 2017, **146**, 064706.

476 S. Uthayaraj, D. G. B. C. Karunarathne, G. R. A. Kumara, T. Murugathas, S. Rasalingam, R. M. G. Rajapakse,

P. Ravirajan and D. Velauthapillai, *Materials*, 2019, **12**, 2037.

477 J. A. Christians, R. C. M. Fung and P. V. Kamat, *J. Am. Chem. Soc.*, 2014, **136**, 758–764.

478 X. Li, J. Yang, Q. Jiang, W. Chu, D. Zhang, Z. Zhou and J. Xin, *ACS Appl. Mater. Interfaces*, 2017, **9**, 41354–41362.

479 J. Song, W. Hu, Z. Li, X.-F. Wang and W. Tian, *Sol. Energy Mater. Sol. Cells*, 2020, **207**, 110351.

480 D. B. Khadka, Y. Shirai, M. Yanagida and K. Miyano, *Sol. Energy Mater. Sol. Cells*, 2020, **210**, 110486.

481 S. Gharibzadeh, B. A. Nejand, A. Moshaii, N. Mohammadian, A. H. Alizadeh, R. Mohammadpour, V. Ahmadi and A. Alizadeh, *ChemSusChem*, 2016, **9**, 1929–1937.

482 W. Y. Chen, L. L. Deng, S. M. Dai, X. Wang, C. B. Tian, X. X. Zhan, S. Y. Xie, R. B. Huang and L. S. Zheng, *J. Mater. Chem. A*, 2015, **3**, 19353–19359.

483 G. A. Sepalage, S. Meyer, A. Pascoe, A. D. Scully, F. Huang, U. Bach, Y.-B. Cheng and L. Spiccia, *Adv. Funct. Mater.*, 2015, **25**, 5650–5661.

484 H. Wang, Z. Yu, X. Jiang, J. Li, B. Cai, X. Yang and L. Sun, *Energy Technol.*, 2017, **5**, 1836–1843.

485 W. Sun, S. Ye, H. Rao, Y. Li, Z. Liu, L. Xiao, Z. Chen, Z. Bian and C. Huang, *Nanoscale*, 2016, **8**, 15954–15960.

486 J. Cao, B. Wu, J. Peng, X. Feng, C. Li and Y. Tang, *Sci. China: Chem.*, 2019, **62**, 363–369.

487 Y. Chen, J. Chu, C. Li, A. S. Yerramilli, Y. He, D. Yang, Y. Shen and T. L. Alford, *J. Mater. Sci.: Mater. Electron.*, 2021, **32**, 12929–12938.

488 H. Javaid, V. V. Duzhko and D. Venkataraman, *ACS Appl. Energy Mater.*, 2021, **4**, 72–80.

489 D. Saranin, P. Gostischev, D. Tatarinov, I. Ermanova, V. Mazov, D. Muratov, A. Tameev, D. Kuznetsov, S. Didenko and A. Di Carlo, *Materials*, 2019, **12**, 1406.

490 M. M. Byranvand, T. Kim, S. Song, G. Kang, S. U. Ryu and T. Park, *Adv. Energy Mater.*, 2018, **8**, 1702235.

491 S. Ye, H. Rao, Z. Zhao, L. Zhang, H. Bao, W. Sun, Y. Li, F. Gu, J. Wang, Z. Liu, Z. Bian and C. Huang, *J. Am. Chem. Soc.*, 2017, **139**, 7504–7512.

492 M. M. Salah, K. M. Hassan, M. Abouelatta and A. Shaker, *Optik*, 2019, **178**, 958–963.

493 S. Z. Haider, H. Anwar, Y. Manzoor, A. G. Ismail and M. Wang, *Curr. Appl. Phys.*, 2020, **20**, 1080–1089.

494 P. Pattanasattayavong, G. O. N. Ndjawa, K. Zhao, K. W. Chou, N. Yaacobi-Gross, B. C. O'Regan, A. Amassian and T. D. Anthopoulos, *Chem. Commun.*, 2013, **49**, 4154–4156.

495 S. Ito, S. Tanaka, H. Vahlman, H. Nishino, K. Manabe and P. Lund, *ChemPhysChem*, 2014, **15**, 1194–1200.

496 S. Chavhan, O. Miguel, H.-J. Grande, V. Gonzalez-Pedro, R. S. Sánchez, E. M. Barea, I. Mora-Seró and R. Tena-Zaera, *J. Mater. Chem. A*, 2014, **2**, 12754–12760.

497 A. S. Subbiah, A. Halder, S. Ghosh, N. Mahuli, G. Hodes and S. K. Sarkar, *J. Phys. Chem. Lett.*, 2014, **5**, 1748–1753.

498 S. Y. Ye, W. H. Sun, Y. L. Li, W. B. Yan, H. T. Peng, Z. Q. Bian, Z. W. Liu and C. H. Huang, *Nano Lett.*, 2015, **15**, 3723–3728.

499 J. W. Jung, C.-C. Chueh and A. K. Y. Jen, *Adv. Energy Mater.*, 2015, **5**, 1500486.

500 I. S. Yang, M. R. Sohn, S. D. Sung, Y. J. Kim, Y. J. Yoo, J. Kim and W. I. Lee, *Nano Energy*, 2017, **32**, 414–421.

501 J. Wang, S. Gong, Z. Chen and S. Yang, *ACS Appl. Mater. Interfaces*, 2021, **13**, 22684–22693.

502 M. Lyu, J. Chen and N.-G. Park, *J. Solid State Chem.*, 2019, **269**, 367–374.

503 J. Liu, S. K. Pathak, N. Sakai, R. Sheng, S. Bai, Z. Wang and H. J. Snaith, *Adv. Mater. Interfaces*, 2016, **3**, 1600571.

504 P. Qin, S. Tanaka, S. Ito, N. Tetreault, K. Manabe, H. Nishino, M. K. Nazeeruddin and M. Grätzel, *Nat. Commun.*, 2014, **5**, 3834.

505 Q. Xi, G. Gao, H. Zhou, Y. Zhao, C. Wu, L. Wang, P. Guo and J. Xu, *Nanoscale*, 2017, **9**, 6136–6144.

506 I. Zimmermann, P. Gratia, D. Martineau, G. Grancini, J.-N. Audinot, T. Wirtz and M. K. Nazeeruddin, *J. Mater. Chem. A*, 2019, **7**, 8073–8077.

507 G. A. Sepalage, S. Meyer, A. R. Pascoe, A. D. Scully, U. Bach, Y.-B. Cheng and L. Spiccia, *Nano Energy*, 2017, **32**, 310–319.

508 J. Kim, Y. Lee, A. J. Yun, B. Gil and B. Park, *ACS Appl. Mater. Interfaces*, 2019, **11**, 46818–46824.

509 N. Arora, M. I. Dar, A. Hinderhofer, N. Pellet, F. Schreiber, S. M. Zakeeruddin and M. Grätzel, *Science*, 2017, **358**, 768–771.

510 C. Liu, L. Zhang, Y. Li, X. Zhou, S. She, X. Wang, Y. Tian, A. K. Y. Jen and B. Xu, *Adv. Funct. Mater.*, 2020, **30**, 1908462.

511 Y. Xu, Y. Tian, M. Hou, Y. Wu, Y. Ding, Y. Zhao, X. Zhang and G. Hou, *J. Phys. Chem. C*, 2020, **124**, 27977–27984.

512 I. S. Yang, S. Lee, J. Choi, M. T. Jung, J. Kim and W. I. Lee, *J. Mater. Chem. A*, 2019, **7**, 6028–6037.

513 M. Kim, A. Alfano, G. Perotto, M. Serri, N. Dengo, A. Mezzetti, S. Gross, M. Prato, M. Salerno, A. Rizzo, R. Sorrentino, E. Cescon, G. Meneghesso, F. Di Fonzo, A. Petrozza, T. Gatti and F. Lamberti, *Commun. Mater.*, 2021, **2**, 6.

514 P. Xu, J. Liu, J. Huang, F. Yu, X. Zhang, C.-H. Li, Y.-X. Zheng and J.-L. Zuo, *Solar RRL*, 2021, **5**, 2000777.

515 I. S. Jin, J. H. Lee, Y. W. Noh, S. H. Park and J. W. Jung, *Inorg. Chem. Front.*, 2019, **6**, 2158–2166.

516 L. Xu, Y. Li, C. Zhang, Y. Liu, C. Zheng, W. Lv, M. Li, Y. Chen, W. Huang and R. Chen, *Sol. Energy Mater. Sol. Cells*, 2020, **206**, 110316.

517 I. S. Jin, S. H. Park, K. S. Kim and J. W. Jung, *J. Alloys Compd.*, 2020, **847**, 156572.

518 S. Z. Haider, H. Anwar and M. Wang, *Phys. Status Solidi A*, 2019, **216**, 1900102.

519 B. Gil, A. J. Yun, Y. Lee, J. Kim, B. Lee and B. Park, *Electron. Mater. Lett.*, 2019, **15**, 505–524.

520 F. Igbari, M. Li, Y. Hu, Z.-K. Wang and L.-S. Liao, *J. Mater. Chem. A*, 2016, **4**, 1326–1335.

521 L. Y.-T. Bu, Y.-C. Lu, Y.-S. Fu and C.-T. Hung, *Optik*, 2020, **210**, 164505.

522 H. Zhang, H. Wang, H. Zhu, C.-C. Chueh, W. Chen, S. Yang and A. K. Y. Jen, *Adv. Energy Mater.*, 2018, **8**, 1702762.

523 W. A. Dunlap-Shohl, T. B. Daunis, X. Wang, J. Wang, B. Zhang, D. Barrera, Y. Yan, J. W. P. Hsu and D. B. Mitzi, *J. Mater. Chem. A*, 2018, **6**, 469–477.

324 S. Akin, Y. Liu, M. I. Dar, S. M. Zakeeruddin, M. Grätzel, S. Turan and S. Sonmezoglu, *J. Mater. Chem. A*, 2018, **6**, 20327–20337.
325 P.-L. Qin, Q. He, C. Chen, X.-L. Zheng, G. Yang, H. Tao, L.-B. Xiong, L. Xiong, G. Li and G.-J. Fang, *Solar RRL*, 2017, **1**, 1700058.
326 B. Yang, D. Ouyang, Z. Huang, X. Ren, H. Zhang and W. C. H. Choy, *Adv. Funct. Mater.*, 2019, **29**, 1902600.
327 S. Jeong, S. Seo and H. Shin, *RSC Adv.*, 2018, **8**, 27956–27962.
328 I. T. Papadas, A. Savva, A. Ioakeimidis, P. Eleftheriou, G. S. Armatas and S. A. Choulis, *Mater. Today Energy*, 2018, **8**, 57–64.
329 B. Lee, A. J. Yun, J. Kim, B. Gil, B. Shin and B. Park, *Adv. Mater. Interfaces*, 2019, **6**, 1901372.
330 Y. Chen, Z. Yang, X. Jia, Y. Wu, N. Yuan, J. Ding, W.-H. Zhang and S. Liu, *Nano Energy*, 2019, **61**, 148–157.
331 Y. Chen, W. Tang, Y. Wu, R. Yuan, J. Yang, W. Shan, S. Zhang and W.-H. Zhang, *Solar RRL*, 2020, **4**, 2000344.
332 D. Ouyang, C. Chen, Z. Huang, L. Zhu, T. Yan and W. C. H. Choy, *ACS Appl. Mater. Interfaces*, 2021, **13**, 16651–16659.
333 J. Tirado, C. Roldán-Carmona, F. A. Muñoz-Guerrero, G. Bonilla-Arboleda, M. Ralaiarisoa, G. Grancini, V. I. E. Queloz, N. Koch, M. K. Nazeeruddin and F. Jaramillo, *Appl. Surf. Sci.*, 2019, **478**, 607–614.
334 R. Hu, R. Zhang, Y. Ma, W. Liu, L. Chu, W. Mao, J. Zhang, J. Yang, Y. Pu and X. A. Li, *Appl. Surf. Sci.*, 2018, **462**, 840–846.
335 J. Li, C. Kuang, M. Zhao, C. Zhao, L. Liu, F. Lu, N. Wang, C. Huang, C. Duan, H. Jian, L. Yao and T. Jiu, *Inorg. Chem.*, 2018, **57**, 8375–8381.
336 L. S. Khanzada, I. Levchuk, Y. Hou, H. Azimi, A. Osvet, R. Ahmad, M. Brandl, P. Herre, M. Distaso, R. Hock, W. Peukert, M. Batentschuk and C. J. Brabec, *Adv. Funct. Mater.*, 2016, **26**, 8300–8306.
337 Z.-J. Zhou, Y.-Q. Deng, P.-P. Zhang, D.-X. Kou, W.-H. Zhou, Y.-N. Meng, S.-J. Yuan and S.-X. Wu, *Solar RRL*, 2019, **3**, 1800354.
338 G. Y. Ashebir, C. Dong, Z. Wan, J. Qi, J. Chen, Q. Zhao, W. Chen and M. Wang, *J. Phys. Chem. Solids*, 2019, **129**, 204–208.
339 M. Jamil, A. Ali, K. Mahmood, M. I. Arshad, S. Tahir, M. Ajmal Nabi, S. Ikram, N. Amin and S. Hussain, *J. Alloys Compd.*, 2020, **821**, 153221.
340 B. Koo, H. Jung, M. Park, J. Y. Kim, H. J. Son, J. Cho and M. J. Ko, *Adv. Funct. Mater.*, 2016, **26**, 5400–5407.
341 A. J. Huckaba, P. Sanghyun, G. Grancini, E. Bastola, C. K. Taek, L. Younghui, K. P. Bhandari, C. Ballif, R. J. Ellingson and M. K. Nazeeruddin, *ChemistrySelect*, 2016, **1**, 5316–5319.
342 J. Ge, C. R. Grice and Y. F. Yan, *J. Mater. Chem. A*, 2017, **5**, 2920–2928.
343 A. Ioakeimidis, I. T. Papadas, D. Tsikritzis, G. S. Armatas, S. Kennou and S. A. Choulis, *APL Mater.*, 2019, **7**, 021101.
344 J. H. Lee, I. S. Jin, Y. W. Noh, S. H. Park and J. W. Jung, *ACS Sustainable Chem. Eng.*, 2019, **7**, 17661–17670.
345 I. T. Papadas, A. Ioakeimidis, G. S. Armatas and S. A. Choulis, *Adv. Sci.*, 2018, **5**, 1701029.
346 R. Huang, Y. Cheng, H. Lei, L. Hu, Z. Li, X. Huang, L. Chen and Y. Chen, *Chem. Commun.*, 2021, **57**, 4015–4018.
347 B. Tan, S. R. Raga, A. S. R. Chesman, S. O. Fürer, F. Zheng, D. P. McMeekin, L. Jiang, W. Mao, X. Lin, X. Wen, J. Lu, Y.-B. Cheng and U. Bach, *Adv. Energy Mater.*, 2019, **9**, 1901519.
348 M. Li, Z. K. Wang, Y. G. Yang, Y. Hu, S. L. Feng, J. M. Wang, X. Y. Gao and L. S. Liao, *Adv. Energy Mater.*, 2016, **6**, 1601156.
349 S. N. Habisreutinger, T. Leijtens, G. E. Eperon, S. D. Stranks, R. J. Nicholas and H. J. Snaith, *Nano Lett.*, 2014, **14**, 5561–5568.
350 G. Li, J. Song, D. Wang, W. Sun, J. Wu and Z. Lan, *J. Power Sources*, 2021, **481**, 229149.
351 W. Sun, P. Yuan, S. Wang, Y. Du, J. Zen, F. Cao, Z. Lan and J. Wu, *Electrochim. Acta*, 2021, **380**, 138233.
352 Z. Zhao, L. Yuan, J. Huang, J. Shi, Y. Gao, W. Zi and W. Zhang, *Org. Electron.*, 2020, **78**, 105557.
353 P. Li, M. I. Omer Mohamed, C. Xu, X. Wang and X. Tang, *Org. Electron.*, 2020, **78**, 105582.
354 Z. Niu, K. Zheng, H. Dong, G. A. Tosado and Q. Yu, *ACS Appl. Energy Mater.*, 2020, **3**, 9656–9666.
355 J. W. Liu, S. Pathak, T. Stergiopoulos, T. Leijtens, K. Wojciechowski, S. Schumann, N. Kausch-Busies and H. J. Snaith, *J. Phys. Chem. Lett.*, 2015, **6**, 1666–1673.
356 Z. K. Wang, M. Li, D. X. Yuan, X. B. Shi, H. Ma and L. S. Liao, *ACS Appl. Mater. Interfaces*, 2015, **7**, 9645–9651.
357 X. Zhou, M. Hu, C. Liu, L. Zhang, X. Zhong, X. Li, Y. Tian, C. Cheng and B. Xu, *Nano Energy*, 2019, **63**, 103866.
358 H. Yi, D. Wang, L. Duan, F. Haque, C. Xu, Y. Zhang, G. Conibeer and A. Uddin, *Electrochim. Acta*, 2019, **319**, 349–358.
359 E. H. Jung, N. J. Jeon, E. Y. Park, C. S. Moon, T. J. Shin, T.-Y. Yang, J. H. Noh and J. Seo, *Nature*, 2019, **567**, 511–515.
360 X. Wang, T. Ederth and O. Inganäs, *Langmuir*, 2006, **22**, 9287–9294.
361 M. J. Jeong, K. M. Yeom, S. J. Kim, E. H. Jung and J. H. Noh, *Energy Environ. Sci.*, 2021, **14**, 2419–2428.
362 D. Bi, L. Yang, G. Boschloo, A. Hagfeldt and E. M. Johansson, *J. Phys. Chem. Lett.*, 2013, **4**, 1532–1536.
363 S. Valero, S. Collavini, S. F. Völker, M. Saliba, W. R. Tress, S. M. Zakeeruddin, M. Grätzel and J. L. Delgado, *Macromolecules*, 2019, **52**, 2243–2254.
364 K. Lee, H. Yu, J. W. Lee, J. Oh, S. Bae, S. K. Kim and J. Jang, *J. Mater. Chem. C*, 2018, **6**, 6250–6256.
365 K.-C. Wang, P.-S. Shen, M.-H. Li, S. Chen, M.-W. Lin, P. Chen and T.-F. Guo, *ACS Appl. Mater. Interfaces*, 2014, **6**, 11851–11858.
366 J. W. Jung, C.-C. Chueh and A. K.-Y. Jen, *Adv. Mater.*, 2015, **27**, 7874–7880.
367 X. Yin, P. Chen, M. Que, Y. Xing, W. Que, C. Niu and J. Shao, *ACS Nano*, 2016, **10**, 3630–3636.
368 K. Wang, C. Wu, Y. Hou, D. Yang, T. Ye, J. Yoon, M. Sanghadasa and S. Priya, *Energy Environ. Sci.*, 2020, **13**, 3412–3422.

569 J. Yang, Q. Cao, Z. He, X. Pu, T. Li, B. Gao and X. Li, *Nano Energy*, 2021, **82**, 105731.

570 L. Li, X. R. Zhang, H. F. Zeng, S. Zheng, Y. Zhao, L. Luo, F. X. Liu and X. Li, *Chem. Eng. J.*, 2022, **443**, 136405.

571 H. Wang, Z. Yu, J. Lai, X. Song, X. Yang, A. Hagfeldt and L. Sun, *J. Mater. Chem. A*, 2018, **6**, 21435–21444.

572 K. Ramachandran, C. Jeganathan and S. Karuppuchamy, *J. Alloys Compd.*, 2021, **881**, 160530.

573 R. P. Srivastava, H. S. Jung and D. Y. Khang, *Nanomaterials*, 2022, **12**, 1467.

574 L. Lin, L. Jiang, P. Li, B. Fan and Y. Qiu, *J. Phys. Chem. Solids*, 2019, **124**, 205–211.

575 V. Arjun, K. P. Muthukumaran, K. Ramachandran, A. Nithya and S. Karuppuchamy, *J. Alloys Compd.*, 2022, **923**, 166285.

576 Q. Guo, C. Wang, J. Li, Y. Bai, F. Wang, L. Liu, B. Zhang, T. Hayat, A. Alsaedi and Z. A. Tan, *Phys. Chem. Chem. Phys.*, 2018, **20**, 21746–21754.

577 X. Yao, H. Geng, Y. Gu, H. Cui, G. Guan and M. Han, *J. Phys. Chem. C*, 2021, **125**, 21474–23482.

578 S. Park, D. W. Kim and S. Y. Park, *Adv. Funct. Mater.*, 2022, **32**, 2200437.

579 G. D. Li, K. M. Deng, Y. F. Dou, Y. S. Liao, D. Wang, J. H. Wu and Z. Lan, *Sol. Energy*, 2019, **193**, 111–117.

580 X. Yan, J. H. Zheng, L. L. Zheng, G. H. Lin, H. D. Lin, G. Chen, B. B. Du and F. Y. Zhang, *Mater. Res. Bull.*, 2018, **103**, 150–157.

581 J. Yun, J. Jun, H. Yu, K. Lee, J. Ryu, J. Lee and J. Jang, *J. Mater. Chem. A*, 2017, **5**, 21750–21756.

582 J. H. Kim, P. W. Liang, S. T. Williams, N. Cho, C. C. Chueh, M. S. Glaz, D. S. Ginger and A. K. Y. Jen, *Adv. Mater.*, 2015, **27**, 695–701.

583 E. P. G. Choi, *J. Mater. Sci.: Mater. Electron.*, 2011, **22**, 8136–8148.

584 A. B. Huang, L. Lei, Y. Yu, Y. Liu, S. W. Yang, S. H. Bao, X. Cao and P. Jin, *Nanotechnology*, 2017, **28**, 201702.

585 K. Ramachandran, C. Jeganathan, G. P. Kalaignan and S. Karuppuchamy, *Ceram. Int.*, 2021, **47**, 17883–17894.

586 G. Kim, N. Kwon, D. Lee, M. Kim, M. Kim, Y. Lee, W. Kim, D. Hyeon, B. Kim, M. S. Jeong, J. Hong and J. Yang, *ACS Appl. Mater. Interfaces*, 2022, **14**, 5203–5210.

587 R. R. Krishna, G. Veerappan, P. Bhyrappa, C. Sudakar and E. Ramasamy, *Mater. Adv.*, 2022, **3**, 3000–3010.

588 Y. P. Liao, N. Tian, J. L. Wang, D. S. Yao, G. Y. Zheng, B. Zhou, Y. H. Yang and F. Long, *ACS Appl. Energy Mater.*, 2022, **5**, 9542–9548.

589 U. Er, K. C. Icli and M. Ozenbas, *J. Solid State Electrochem.*, 2020, **24**, 293–304.

590 S. S. Mali, J. V. Patil and C. K. Hong, *J. Mater. Chem. A*, 2019, **7**, 10246–10255.

591 H. Wang, H. A. Dewi, T. M. Koh, A. Bruno, S. Mhaisalkar and N. Mathews, *ACS Appl. Mater. Interfaces*, 2019, **12**, 484–493.

592 T. H. Chowdhury, M. Akhtaruzzaman, M. E. Kayesh, R. Kaneko, T. Noda, J.-J. Lee and A. Islam, *Sol. Energy*, 2018, **171**, 652–657.

593 H. Javaid, N. Heller, V. V. Duzhko, N. Hight-Huf, M. D. Barnes and D. Venkataraman, *ACS Appl. Energy Mater.*, 2022, **5**, 8075–8083.

594 F. Behrouznejad, M. Forouzandeh, R. Khosroshahi, K. Meraji, M. N. Badrabadi, M. Dehghani, X. G. Li, Y. Q. Zhan, Y. Liao, Z. J. Ning and N. Taghavinia, *Solar RRL*, 2020, **4**, 564.

595 F. Ansari, M. Salavati-Niasari, O. Amiri, N. Mir, B. A. Hejazil and V. Ahmadi, *Ind. Eng. Chem. Res.*, 2020, **59**, 743–750.

596 Y. Hou, L. J. Yang, H. W. Qiao, Z. R. Zhou, Y. L. Zhang, L. R. Zheng, M. J. Chen, S. Yang and H. G. Yang, *J. Mater. Chem. A*, 2019, **7**, 20905–20910.

सावित्रीबाई फुले पुणे विद्यापीठ
(पूर्वीचे पुणे विद्यापीठ)
पदार्थविज्ञान विभाग
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Date: 08/03/2018

TO WHOMSOEVER IT MAY CONCERN

Dr. Faiz Mohammed [illegible], Assistant Professor, Department of Physics of AKI'S Poona College, Camp, Pune-01 is having a collaboration with me for carrying out research work in the Department of Physics, Savitribai Phule Pune University, Pune-07, since 12.12.2008. Moreover, he is allowed to use the research facilities such as 14 MeV Neutron Generator, Microtron, 8 MeV electron accelerator, Low energy neutron facility, Radiation spectrometer system, Gamma ray spectroscopy, etc. of Department of Physics, Savitribai Phule Pune University for carrying out his research work. He is also contributed to develop the 14 MeV Neutron Generator and some codes such as TALYS, EMPIRE, etc. for the nuclear reaction studies.

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Activation cross section measurements and estimation of photon and neutron induced nuclear reactions for ytterbium isotopes with covariance analysis

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ABSTRACT

The cross sections of the [illegible] nuclear reactions at 14.77 MeV neutron energy and the flux weighted average cross sections of the [illegible] nuclear reactions at 12 and 15 MeV bremsstrahlung endpoint energies are measured using offline gamma spectroscopy. The bremsstrahlung photon-induced reactions are reported for the first time at these energies. The results are compared with the evaluated nuclear data from the ENDF/B-VIII.0, JEFF-3.3 and TENDL-2019 libraries. The theoretical model calculations are performed with the TALYS-1.96 nuclear code with parameters tuned to reproduce the measured data. The measured cross sections are in good agreement with the literature and evaluated data. The results are significant for the experimental nuclear database and reactor technology development.

1. Introduction

The cross sections of nuclear reactions are significant for nuclear technology and nuclear theory. Especially the cross sections of the neutron and photon-induced nuclear reactions are important for the development of fission and fusion reactor technology for structural, shielding, first wall and blanket materials (Chang, [illegible]; [illegible] et al., 200[illegible]). The cross sections are also useful for dosimetric work in the radiation environment ([illegible] et al., 20[illegible]). They are also used to probe into the nuclear structure studies, predictions of nuclear reactions and confirming the nuclear theory. Cross sections of specific reactions like (n,p), (n,2n) and (n,α) are required to estimate the nuclear heating and gas formation in the reactors. The photon-induced nuclear reactions via (γ,n), (γ,p) and (γ,α) are of astrophysical importance for studying the nucleosynthesis in stellar environments. Similar nucleosynthesis studies can be performed in laboratories with high flux gamma sources having energy >8 MeV. Unlike the strongly interacting particles, photons weakly interact with the nucleons. The photon-induced reactions are also used for the study of correlations of the nucleons inside heavy (A>[illegible]) nucleus.

Ytterbium occurs naturally as 7 stable isotopes having mass numbers 168, 170-174 and 176 and abundances 0.123%, 2.982%, 14.086%, 21.686%, 16.103%, 32.025% and 12.995% respectively (National Nuclear Data Center, [illegible]). It has several practical applications such as doping in stainless steel, lasers, industrial catalyst and memory devices. The isotopes ^{169}Yb and ^{175}Yb can be used as portable X-ray sources for medical imaging due to their relatively long half-lives of 32.018 and 4.185 days respectively ([illegible] et al., 20[illegible]; [illegible] et al., 2017). These isotopes are generally obtained from the nuclear reactors. The ^{169}Yb isotope is also known for its medical use as a high dose rate γ source for brachytherapy. The medical isotope ^{167}Tm is used for targeted tumor therapy ([illegible] et al., 20[illegible]). The ^{167}Tm isotope is produced by the β+ decay of ^{167}Yb isotope. The production yields of these important medical radio-isotopes through a neutron generator and an electron accelerator can be estimated from the present work.

The cross sections of the neutron-induced nuclear reactions on ytterbium isotopes have been previously reported on the EXFOR database (Otuka et al., 2014) by few authors ([illegible] et al., [illegible]; [illegible] et al., [illegible]; [illegible], 1971; [illegible] et al., [illegible]; [illegible] et al., [illegible]; [illegible] et al., [illegible]; [illegible] and [illegible], 1987; [illegible] and [illegible], [illegible]; [illegible]

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et al., 1980; KUMABE et al., 1977; Lan et al., 2008; Luo et al., 2015; Pandey et al., 2016; Qaim, 1974; Sakane et al., 1987; SATO et al., 1975; Sprague, 1964; Wright et al., 1978; Wille and Fink, 1960). Out of which, only four authors have reported measured cross sections in the last two decades. The reported cross sections have discrepancies due to the detection techniques used for measurement of gamma ray activity of the radioisotopes produced. While the (γ,n) cross sections for ^{168}Yb and ^{170}Yb have been reported only by the authors (Tsoneva and Bhatia, 2018) and (γ,n) cross sections for ^{176}Yb have been reported by only two authors (Tsoneva and Bhatia, 2018) and (Naik et al., 2014). In addition, a detailed covariance analysis is missing for these authors. The uncertainties along with the contributions of various experimental parameters are required by the data evaluators which is often missing in the existing literature. Therefore, it is necessary to measure the cross sections of these nuclear reactions more accurately with a detailed error analysis.

In the present work, we have reported the cross sections of nine nuclear reactions on the ytterbium isotopes which comprises of (i) six nuclear reactions at 14.77 ± 0.17 MeV neutron energy and (ii) three nuclear reactions at 10 and 15 MeV bremsstrahlung endpoint energies. The neutron-induced nuclear reactions are ^{168}Yb(n,2n)^{167}Yb, ^{174}Yb(n,p)^{174}Tm, ^{176}Yb(n,p)^{176}Tm, ^{174}Yb(n,α)^{171}Er, ^{170}Yb(n,2n)^{169}Yb and ^{176}Yb(n,2n)^{175}Yb, while the photon-induced nuclear reactions are ^{168}Yb(γ,n)^{167}Yb, ^{170}Yb(γ,n)^{169}Yb and ^{176}Yb(γ,n)^{175}Yb. A detailed covariance analysis has been performed for each reaction and the corresponding correlation matrix has been stated. The theoretical model calculations for these nuclear reactions are performed with the TALYS-1.95 code (Koning et al., 2007a). The results are compared with the literature data from the EXFOR database and with the evaluated nuclear data libraries ENDF/B-VIII.0 (Brown et al., 2018), JEFF-3.3 (Plompen et al., 2020) and TENDL-2019 (Koning et al., 2019). The measured cross sections are in good agreement with the theoretical, evaluated and literature data.

2. Experimental details

2.1. Sample preparation

The samples of natural isotopic abundance of 99.9% pure Yb_2O_3 in powdered form were used. A single sample consisted of 1 g of powder weighed by a microbalance and wrapped in a polyethylene sheet. The size of each sample was 1 × 1 cm by sides. Aluminium was used as a neutron flux monitor, so, the samples used for neutron irradiation were covered in 99.99% pure aluminium foil of 0.3 g. Whereas, the samples used for photon-induced reactions were irradiated simultaneously with gold foils of 0.3 g each.

2.2. Neutron irradiation and measurement of γ-ray activity

The neutron irradiation of the Yb sample covered in Al foil was performed at the 14 MeV Neutron Generator at Department of Physics, Savitribai Phule Pune University, Pune, India (Bhoraskar, 1989). The neutrons are generated by bombarding a 175 keV deuterium ion beam on an 8 Ci tritium target. A typical 100 μA current of the deuterium ion beam was maintained during the irradiations. The neutron generator has a typical neutron flux of ~10^8 n/cm^2 sec. The sample was kept at 0° with respect to the incident deuterium ion beam, where the energy of the neutrons corresponds to 14.77 ± 0.17 MeV (Handbook on Nuclear Activation Data, 1987). The gamma spectroscopy was performed with a calibrated HPGe detector, having 1.8 keV energy resolution at 1.33 MeV gamma peak. The detector has a p-type Ge crystal of radius 5.18 cm and length 4.85 cm. The output of the detector was connected to an 8k multichannel analyzer operated through a PC. The detector was shielded by lead blocks to reduce the background noise. The low-energy neutrons flux having E_n < 10 MeV produced in the D-T reaction is about two orders of magnitude lower than the 14 MeV neutrons (Kerasala et al., 2021). So, the contribution to the error is less than 2%. Similarly, the effects of multiple scattering of neutrons and neutron flux fluctuations were neglected as the errors contributed are negligibly small. The irradiation and counting was performed in following steps: (i) The first sample was irradiated for a period 1200 s and then transferred within ~30 s to the counting room for gamma spectroscopy and counted for 1200 s. (ii) The second sample was irradiated for a period 3600 s, then transferred to the counting room for gamma spectroscopy, cooled for ~9000 s and counted for 3600 s. The experimental details are summarized in Table 1 and the spectra of the neutron irradiated samples are shown in Fig. 1(a) and (b).

2.3. Bremsstrahlung irradiation and measurement of γ-ray activity

The bremsstrahlung irradiation of the Yb samples along with Au foil was performed with the medical linear accelerator at Dr. Vikhe Patil Memorial Hospital, Ahmednagar, India. The Medical LINAC is generally used for medical applications, having a monochromatic electron beam of current 8 μA and energy spread of less than 3.5%. A field area of 8 × 8 cm was set up the patient table situated 100 cm from the bremsstrahlung target. The samples were irradiated one by one for a period of 1800 s by the bremsstrahlung beams of 10 MeV and 15 MeV endpoint energies. A constant dose rate of 560 ± 10 cGy/min for 10 MeV and 670 ± 10 cGy/min for 15 MeV was maintained during the irradiation. After the irradiation, the samples were brought to the control room for gamma spectroscopy with the HPGe detector. The thermal neutrons are generated around the LINAC due to photonuclear reactions. The thermal neutrons flux is lower by about four orders of magnitude than the photon flux (Vyrskh et al., 2020). Therefore the activity induced by the thermal neutrons due to the parasitic (n,γ) reaction was calculated and corresponding error was found to be less than 2%. The details of the irradiation, cooling and counting time are given in Table 1, the spectra of 10 MeV photon irradiated Yb samples are shown in Fig. 2(a) and (b) and the spectra of 15 MeV photon irradiated Yb samples are shown in Fig. 3(a) and (b).

The nuclear spectroscopic data for the different radioisotopes produced during the neutron and bremsstrahlung irradiations, is given in Table 2 which is adopted from the ENSDF data library (Baglin, 2008, 2003; BASU, 2002; Basunia, 2004; Browne, 1984; Firestone, 2007; Shamsuzzoha Basunia, 2021; Singh, 1995; Kinsey, 2007). The gamma ray peaks used for data analysis are highlighted. The gamma ray lines used for analysis have the least coincidences due to the other radioisotopes produced and are completely resolved.

3. Data analysis

3.1. Efficiency calibration and covariance analysis for HPGe detector

The HPGe detector was calibrated with a standard ^{152}Eu gamma source, before the gamma spectroscopy of the irradiated samples. The ^{152}Eu γ source has a half-life of 13.517 years (Martin, 2013) and an initial activity A_0 = 4336.98 Bq on 1 Oct 1999. The detection efficiency of the HPGe detector was calculated by the eq. (1)

$$\varepsilon = K_c \frac{C}{A_0 I_\gamma e^{-\lambda T} \Delta t} \tag{1}$$

where, ε is the geometry dependent efficiency, C is the area under curve for a γ peak, A_0 is the initial activity, I_γ is the intensity of the gamma peak, λ is the decay constant, T is the time elapsed from the manufacturing of the source to the start of the counting time, Δt is the counting time 3600 s and K_c is the correction factor for coincidence summing effect calculated with the EFFTRAN code (Vidmar, 2005). The distance between the source and detector surface was 45 mm, which was incorporated in the EFFTRAN code along with other detector specifications given by the manufacturer. As the γ source has a finite geometry, the efficiency was transferred from point source geometry (ε_p) to the

Table 1
Experimental details of the irradiation, cooling and counting time for the reactions along with the threshold energy.

Reaction	Projectile Radiation	Irradiation Time (seconds)	Cooling Time (seconds)	Counting Time (seconds)	Threshold Energy E_{th} (MeV)
$^{168}Yb(n,2n)^{167}Yb$	14.77 MeV Neutrons	1200	28	1200	8.11
$^{172}Yb(n,p)^{172}Tm$		1200	28	1200	2.31
$^{173}Yb(n,p)^{173}Tm$		3600	5010	3600	1.61
$^{176}Yb(n,\alpha)^{173}Er$		3600	5010	3600	0
$^{170}Yb(n,2n)^{169}Yb$		3600	5010	3600	8.50
$^{176}Yb(n,2n)^{175}Yb$		3600	5010	3600	5.86
$^{168}Yb(\gamma,n)^{167}Yb$	Bremsstrahlung 10 MeV	1000	78	222	9.38
$^{170}Yb(\gamma,n)^{169}Yb$		1000	35021	3600	8.48
$^{176}Yb(\gamma,n)^{175}Yb$		1000	35021	3600	5.83
$^{197}Au(\gamma,n)^{196}Au$		1000	88850	3600	8.07
$^{168}Yb(\gamma,n)^{167}Yb$	Bremsstrahlung 18 MeV	1000	222	387	9.38
$^{170}Yb(\gamma,n)^{169}Yb$		1000	120481	3600	8.48
$^{176}Yb(\gamma,n)^{175}Yb$		1000	120481	3600	5.83
$^{197}Au(\gamma,n)^{196}Au$		1000	138000	3600	8.07

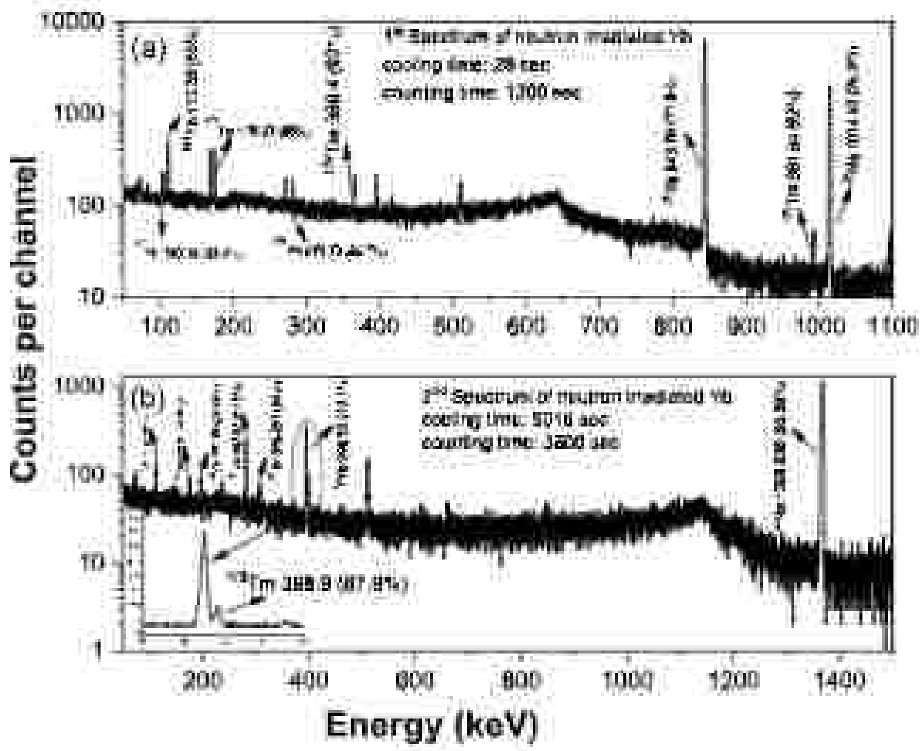

Fig. 3. (a) First gamma-ray spectrum of 14 MeV neutron irradiated Yb sample irradiated for 1200 s. (b) Second gamma-ray spectrum of 14 MeV neutron irradiated Yb sample irradiated for 3600 s.

finite geometry (Ω) with the EFFTRAN code, which reduces the efficiencies approximately by 3%. The measured efficiencies at the corresponding γ energies are given in Table 3 and the calibration curve is shown in Fig. 4.

A detailed covariance analysis for the calibration efficiencies of the HPGe detector was performed to determine the uncertainty in the detection efficiency, to understand the correlation between the different γ peaks, to fit a polynomial curve for the efficiencies and to determine the detection efficiency required for other energies of the produced radioisotopes. The covariance analysis was performed following the standard procedure (Mannhart, 2011; Otuka et al., 2017). The polynomial fit was obtained with the covariance matrix. The polynomial of the order m = 5 was found to be the best fit for the efficiency curve, and given is by eq. (2).

$$\ln(\varepsilon_i) = \sum_m p_m (\ln E_i)^{m-1} \quad (2)$$

where, ε_i are efficiencies, p_m are the fitting parameters for the order m and E_i are the corresponding gamma energies in MeV. The fitting parameters for m = 5 are p_m = (−3.0691, −1.4275, −0.2412, −0.3791, −0.1604). The goodness of fit of the parameters was checked by the χ^2 test with the value of $\chi^2/(n-m) = 0.61 \approx 1$, for m = 5 and n = 8 (number of gamma lines used). The efficiencies for the characteristic γ energies of the radio isotopes produced were calculated, with the polynomial curve equation. The uncertainties were determined by the same technique of covariance analysis.

2.3. Calculations of correction factors for induced activity

The area under the gamma peak of the radio isotopes produced was corrected for (i) the self-absorption of the gamma rays and (ii) the coincidence summing effect due to the cascade gammas. The coincidence summing factor k_c was calculated by the TrueCoinc code (Sudár, 2002). The self-absorption coefficient k_s was calculated by eq. (3).

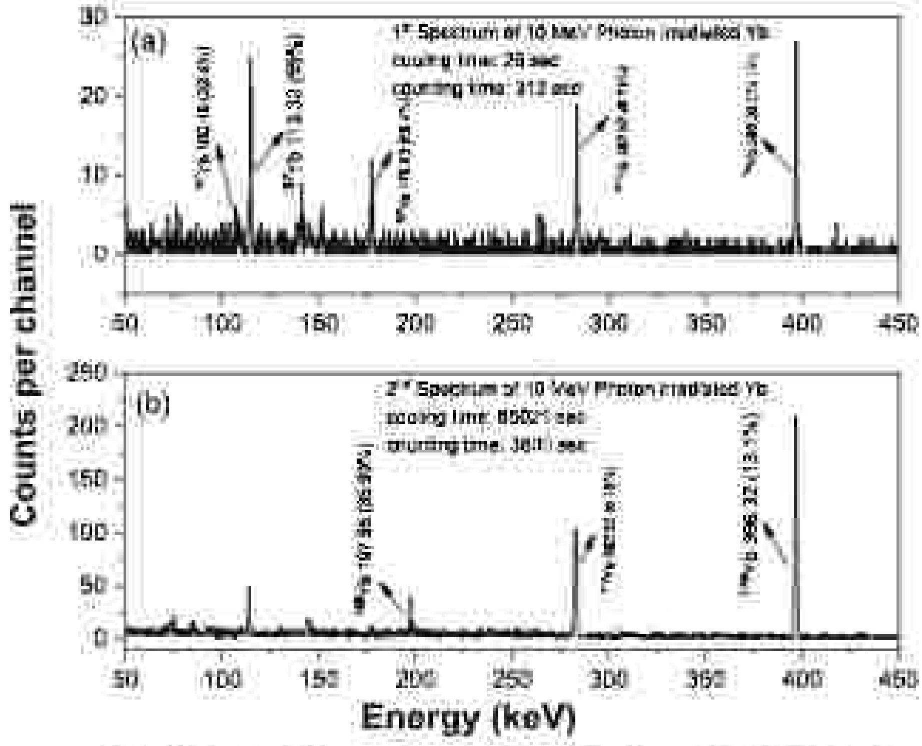

Fig. 2. (a) First gamma-ray spectrum of 10 MeV photon irradiated Yb sample irradiated for 1800 s and counted for 313 s (b) Second gamma-ray spectrum of 10 MeV photon irradiated Yb sample irradiated for 1800 s and counted for 3600 s.

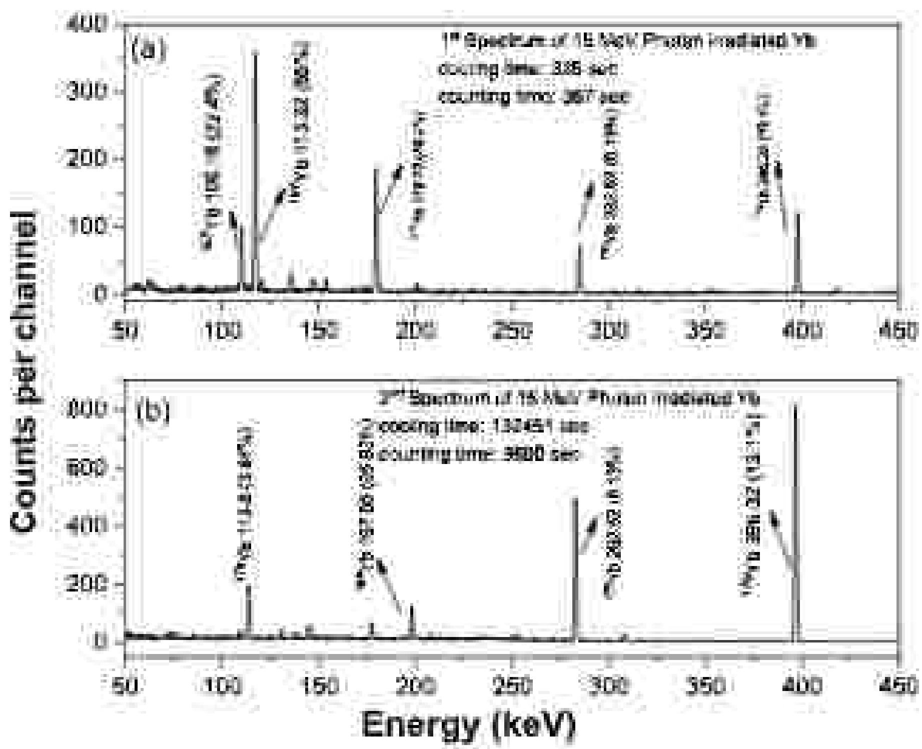

Fig. 3. (a) First gamma-ray spectrum of 15 MeV photon irradiated Yb sample irradiated for 1800 s and counted for 367 s (b) Second gamma-ray spectrum of 15 MeV photon irradiated Yb sample irradiated for 1800 s and counted for 3600 s.

$$f_s = \frac{\mu l}{1-\exp(-\mu l)} \quad (2)$$

where μ is the linear attenuation coefficient in cm^{-1} for the sample and l is the thickness of the sample in cm. The mass attenuation coefficient μ/ρ for the constituent elements were obtained by interpolating the data from the NIST Standard Reference Database (Hubbell and Seltzer, 2004). The mass attenuation coefficient μ/ρ of a compound can be calculated by scaling with the atomic weight of the constituent elements. The total correction factor is denoted as F_c which is the product of

Table 2
The nuclear spectroscopic data for the different radioisotopes produced in the present work.

Nuclide	Half-life	Decay Mode	Eγ (keV)	Iγ (%)
^{167}Yb	17.5 ± 0.2 m	ε+β+ (100%)	113.30	55 ± 3
			106.16	23.4 ± 1.2
			176.22	20.4 ± 0.9
^{174}Tm	5.4 ± 0.1 m	β− (100%)	366.4	93 ± 4
			991.84	87 ± 4
			273.12	85.7 ± 0.3
			176.82	55 ± 3
			494.12	11.4 ± 0.7
^{173}Tm	8.4 ± 0.2 h	β− (100%)	398.9	87.9 ± 2.6
			461.4	6.9 ± 0.2
^{171}Er	7.516 ± 0.0020 h	β− (100%)	308.291	64 ± 3
			295.901	28.9 ± 1.2
			111.621	20.5 ± 1
			124.017	9.1 ± 0.4
			116.658	2.2 ± 0.09
^{169}Yb	32.018 ± 0.005 d	ε (100%)	197.95674	35.93 ± 0.12
			177.213	22.28 ± 0.11
			109.779	17.36 ± 0.09
			130.523	11.38 ± 0.05
^{175}Yb	4.185 ± 0.001 d	β− (100%)	396.329	13.2 ± 0.3
			282.522	6.13 ± 0.08
			113.805	3.87 ± 0.05
			144.865	0.672 ± 0.01
Flux Monitors				
^{27}Mg	9.458 ± 0.012 m	β− (100%)	843.76	71.8 ± 0.02
			1014.52	28.2 ± 0.02
			170.68	0.98 ± 0.02
^{24}Na	14.997 ± 0.012 h	β− (100%)	1368.626	99.9936 ± 0.0015
			2754.007	99.855 ± 0.005
^{196}Au	6.1669 ± 0.0006 d	ε β+ (93%) β− (7%)	355.73	87 ± 3
			333.03	22.9 ± 0.9
			426.1	6.6 ± 0.2

Table 3
Measured detector efficiency at the corresponding gamma energies and intensities from the ^{152}Eu γ source and the coincidence summing correction factors.

E_γ (keV)	I_γ (%)	ΔI_γ (%)	K_c	ε (%)
121.78	28.53	0.16	1.05	5.92 ± 0.12
244.70	7.55	0.04	1.05	3.73 ± 0.09
411.12	2.24	0.013	1.05	2.32 ± 0.05
778.90	12.93	0.06	1.05	0.97 ± 0.02
964.08	14.51	0.07	1.04	0.65 ± 0.02
1112.08	13.67	0.06	1.02	0.53 ± 0.02
1299.14	1.63	0.011	1.05	0.42 ± 0.04
1408.01	20.87	0.09	1.03	0.38 ± 0.01

self-absorption coefficient f_s and coincidence summing factor f_c. The self-absorption coefficient f_s and coincidence summing factor f_c for the produced radio isotopes are given in Table 4.

2.2. Cross section measurements and data analysis

2.2.1. Measurements of the neutron-induced reaction cross sections and covariance analysis

In the present work, we have measured the cross sections of six nuclear reactions at 14.77 ± 0.17 MeV neutron energy. The cross sections of the nuclear reactions ^{168}Yb(n,2n)^{167}Yb and ^{174}Yb(n,p)^{174}Tm were measured relative to the ^{27}Al(n,p)^{27}Mg monitor reaction. The 843.76 keV (71.800) peak of ^{27}Mg was used for the analysis. The cross sections of the ^{173}Yb(n,p)^{173}Tm, ^{174}Yb(n,α)^{171}Er, ^{170}Yb(n,2n)^{169}Yb and ^{176}Yb (n,2n)^{175}Yb nuclear reactions were measured relative to the ^{27}Al (n,α)^{24}Na monitor reaction. The 1368.626 keV (99.9936%) peak of ^{24}Na was used for the analysis. The cross section data for the monitor reactions was adopted from the IRDFF-II library (Trkov et al., 2020). The nuclear spectroscopic data of the reaction products is given in Table 2.

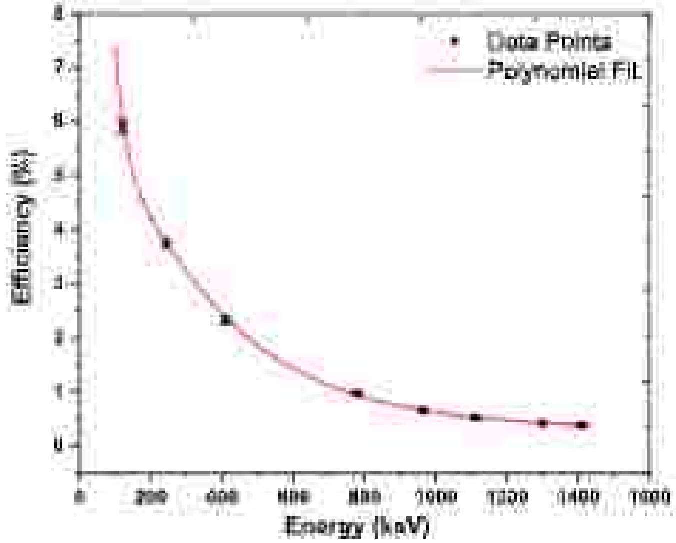

Fig. 4. The efficiency-energy calibration curve for the HPGe detector.

Table 4
Calculated values of the self-absorption coefficient f_s and coincidence summing factor f_c for gamma energies corresponding to the produced radio isotopes.

Nuclide	Eγ (keV)	f_s	f_c	$F = f_s \times f_c$
^{167}Yb	113.30	1.0794	1.0011	1.0790
^{174}Tm	366.4	1.0908	1.0202	1.0963
^{173}Tm	398.9	1.0760	0.9803	1.0581
^{171}Er	308.291	1.1223	1.0014	1.1238
^{169}Yb	197.95674	1.0152	1	1.0152
^{175}Yb	396.329	1.0799	0.998	1.0787
Flux Monitors				
^{27}Mg	843.76	1.0089	1.0015	1.0104
^{24}Na	1368.626	1.0071	1	1.0071
^{196}Au	355.73	1.1487	1.0242	1.1654

The cross sections were estimated with the activation eq. (4).

$$\sigma_{Yb} = \sigma_m \frac{F_{Yb} C_{Yb} M_m a_m A_{Yb} \varepsilon_m I_m f_m}{F_m C_m M_{Yb} a_{Yb} A_m \varepsilon_{Yb} I_{Yb} f_{Yb}} \tag{4}$$

where, the subscripts Yb and m correspond to the parameters belonging to ytterbium and monitor aluminium respectively. σ is the reaction cross section, F is the activity correction factor mentioned in Table 4, C is the area under gamma peak, M is the mass of the samples, a is the isotopic abundance, A is the atomic mass, ε is the detector efficiency at corresponding gamma energy, I_γ is the gamma peak intensity and f_i is the timing factor given in eq. (3).

$$f_i = \frac{\lambda}{(1 - e^{-\lambda t_1}) e^{-\lambda t_2} (1 - e^{-\lambda t_3})} \tag{3}$$

where, λ is the decay constant and t_1, t_2 and t_3 are the irradiation, cooling and counting time respectively.

The total uncertainty in the measured cross sections is the root of sum of squares of the partial uncertainties due to each attribute in the equation (4). The partial uncertainty in the cross sections can be calculated by differentiating the eq. (4) with respect to each attribute. The partial uncertainties due to the t_1, t_2 and t_3 are negligible, so the uncertainty in f_i can be calculated by differentiating eq. (3) with λ. The partial uncertainties due to each attribute in the eq. (4) are given in Table 5, where $\eta = \varepsilon_m/\varepsilon_{Yb}$ i.e., the ratio of the efficiencies. The correlation between every attribute is also given in the same table. This correlation (0 or 1) is used to calculate the micro-correlation matrix for calculating the correlation coefficients of the measured cross sections of

Table 5
The fractional uncertainties (%) due to the various parameters used to obtain the neutron-induced reaction cross sections.

	Reaction	$\langle\sigma_{M}\rangle$	C_{Yb}	C_M	I_{Yb}	I_M	M_{Yb}	M_M	ε_{Yb}	ε_M	η	λ_{Yb}	λ_M	Total
1	$^{168}Yb(n,2n)^{167}Yb$	1.48	3.67	0.74	5.46	0.03	0.62	0.01	2.44	0.01	1.16	0.33	0.01	7.42
2	$^{174}Yb(n,p)^{174}Tm$	1.48	9.00	0.74	4.38	0.03	0.62	0.01	0.33	0.01	0.38	1.16	0.02	10.22
3	$^{176}Yb(n,p)^{176}Tm$	0.29	12.09	1.43	1.02	0.00	0.58	0.01	0.29	0.01	0.46	0.59	0.07	12.54
4	$^{174}Yb(n,\alpha)^{171}Er$	0.29	14.88	1.43	4.68	0.00	0.58	0.01	0.23	0.01	0.88	0.05	0.07	15.69
5	$^{168}Yb(n,2n)^{167}Yb$	0.29	8.26	1.43	0.33	0.00	0.58	0.01	1.40	0.01	1.31	0.05	0.07	8.81
6	$^{176}Yb(n,2n)^{175}Yb$	0.28	3.85	1.43	0.27	0.00	0.58	0.01	0.04	0.01	0.46	0.02	0.07	4.88
	Corr(1,2)	1	0	1	0	1	1	1	0	1	1	1	1	
	Corr(1,3)	0	0	0	0	1	0	1	0	1	1	0	0	
	Corr(1,4)	0	0	0	0	1	0	1	0	1	1	0	0	
	Corr(1,5)	0	0	0	0	1	0	1	0	1	1	0	0	
	Corr(1,6)	0	0	0	0	1	0	1	0	1	1	0	0	
	Corr(2,3)	0	0	0	0	1	0	1	0	1	1	0	0	
	Corr(2,4)	0	0	0	0	1	0	1	1	1	1	0	0	
	Corr(2,5)	0	0	0	0	1	0	1	0	1	1	0	0	
	Corr(2,6)	0	0	0	0	1	0	1	0	1	1	0	0	
	Corr(3,4)	1	0	1	0	1	1	1	0	1	1	1	1	
	Corr(3,5)	1	0	1	0	1	1	1	0	1	1	1	1	
	Corr(3,6)	1	0	1	0	1	1	1	0	1	1	1	1	
	Corr(4,5)	1	0	1	0	1	1	1	0	1	1	1	1	
	Corr(4,6)	1	0	1	0	1	1	1	0	1	1	1	1	
	Corr(5,6)	1	0	1	0	1	1	1	0	1	1	1	1	

the reactions. The uncertainty contribution due to the isotopic abundance of the monitor a_M is negligible.

2.3.2. Measurements of the bremsstrahlung photon-induced reaction cross sections and covariance analysis

We have measured the flux weighted average cross sections of the $^{168}Yb(\gamma,n)^{167}Yb$, $^{176}Yb(\gamma,n)^{175}Yb$ and $^{174}Yb(\gamma,n)^{173}Yb$ nuclear reactions at 10 MeV and 15 MeV bremsstrahlung endpoint energies relative to the $^{197}Au(\gamma,n)^{196}Au$ nuclear reaction. The 355.73 keV (87%) peak of ^{196}Au was used for the analysis. The excitation function curve for the $^{197}Au(\gamma,n)^{196}Au$ monitor reaction was calculated with the TALYS-1.95 Code (Koning et al., 2007b) and the bremsstrahlung spectra of the medical LINAC was simulated with the Geant4 code (Agostinelli et al., 2003; Allison et al., 2006) for 10 MeV and 15 MeV electron energies. A similar approach was made in our earlier work for photon flux calculations (Badwar et al., 2021). The simulated bremsstrahlung spectra are shown in Fig. 3. The average cross section of the monitor reaction $^{197}Au(\gamma,n)^{196}Au$ was calculated by the eq. (6).

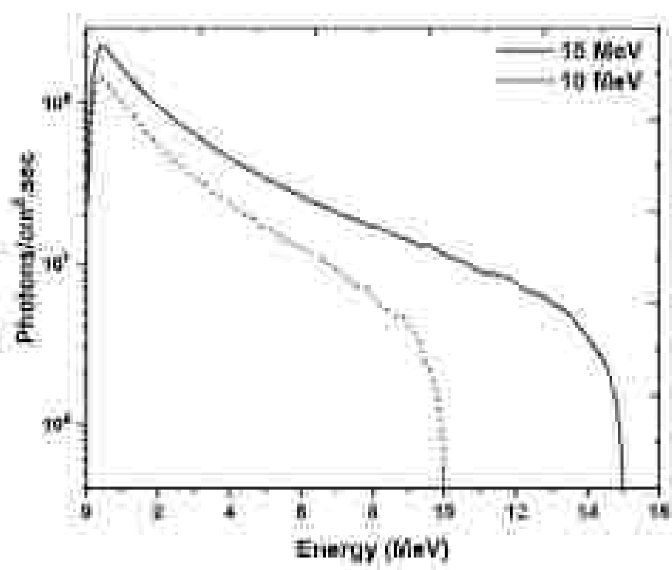

Fig. 3. Geant4 simulated bremsstrahlung spectra for 10 MeV and 15 MeV endpoint energies.

$$\langle\sigma_{Au}\rangle = \frac{\sum_i^{E} \sigma\varphi}{\sum_i \varphi} \tag{6}$$

where φ is the Geant4 simulated bremsstrahlung flux and σ is the cross section of the monitor reaction at the corresponding photon energies calculated using TALYS-1.95. The flux correction factor CF is calculated with eq. (7) to account the difference between the threshold energies of the monitor and sample reactions.

$$CF = \frac{\int_{E_{th,Yb}}^{E_e} \varphi(E)dE}{\int_{E_{th,Au}}^{E_e} \varphi(E)dE} \tag{7}$$

where, $E_{th,Yb}$ is the threshold energy for the nuclear reactions of the ytterbium isotopes and $E_{th,Au}$ = 8.07 MeV is the threshold energy for the monitor reaction. The cross section for the samples can be estimated by the modified eq. (4).

$$\sigma_{Yb} = \frac{\langle\sigma_{Au}\rangle}{CF} \times \frac{F_{Yb}C_{Yb}M_{Au}a_{Au}\lambda_{Yb}I_{Au}\varepsilon_{Au}f_{Au}}{F_{Au}C_{Au}M_{Yb}a_{Yb}\lambda_{Au}I_{Yb}\varepsilon_{Yb}f_{Yb}} \tag{8}$$

where, all the parameters have the same meaning as in eq. (4) and except $\langle\sigma_{Au}\rangle$ is the average cross section of the monitor reaction calculated by eq. (6).

The covariance analysis was performed similarly to determine the uncertainty in the measured cross sections. The Table 6 gives the partial and total uncertainties due to each attribute for the photon-induced reactions at 10 MeV and 15 MeV bremsstrahlung endpoint energies. The correlation between each attribute is also mentioned.

2.4. Nuclear model calculations with the TALYS-1.95 code

The excitation functions for the $^{168}Yb(n,2n)^{167}Yb$, $^{174}Yb(n,p)^{174}Tm$, $^{176}Yb(n,p)^{176}Tm$, $^{174}Yb(n,\alpha)^{171}Er$, $^{176}Yb(n,2n)^{175}Yb$ and $^{176}Yb(n,2n)^{175}Yb$ nuclear reactions were calculated from the reaction threshold to 20 MeV with the TALYS-1.95 nuclear reaction code (Koning et al., 2007a). The TALYS-1.95 code can be used for calculations of nuclear reaction cross sections with projectiles gamma, neutrons, protons, deuterons and α-particles in the energy range from 1 keV to 200 MeV. The default set of parameters in the TALYS-1.95 incorporates the Hauser-Feshbach mechanism (Hauser and Feshbach, 1952) for the compound nucleus reactions, the phenomenological constant temperature model and the Fermi gas model (CTM + FGM) for nuclear level densities, the nucleon-nucleus optical model potentials are given by the

Table 6
The fractional uncertainties (%) due to various the parameters used to calculate flux-weighted average cross sections for photon-induced reactions.

	Reaction	Eγ	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Total
1	$^{168}Yb(\gamma,n)^{167}Yb$	15 MeV	0.99	11.24	0.32	0.48	0.48	0.10	0.01	2.44	0.01	0.22	0.04	0.01	14.72
2	$^{170}Yb(\gamma,n)^{169}Yb$		0.99	14.20	1.86	0.22	0.45	0.10	0.01	2.31	0.01	0.18	0.02	0.01	18.09
3	$^{176}Yb(\gamma,n)^{175}Yb$		0.46	4.02	1.86	2.37	0.45	0.13	0.01	2.64	0.01	0.01	0.02	0.01	7.26
4	$^{168}Yb(\gamma,n)^{167}Yb$	18 MeV	0.88	3.69	0.13	0.48	0.48	0.12	0.01	2.44	0.01	0.22	0.26	0.01	8.88
5	$^{170}Yb(\gamma,n)^{169}Yb$		0.88	6.89	0.85	0.22	0.45	0.12	0.01	1.31	0.01	0.18	0.02	0.01	6.97
6	$^{176}Yb(\gamma,n)^{175}Yb$		0.88	3.48	0.85	2.37	0.45	0.12	0.01	2.64	0.01	0.01	0.02	0.01	6.07
	Corr(1,2)		1	0	0	0	1	1	1	0	1	1	0	0	
	Corr(1,3)		1	0	0	0	1	1	1	0	1	1	0	0	
	Corr(1,4)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(1,5)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(1,6)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(2,3)		1	0	1	0	1	1	1	0	1	1	1	1	
	Corr(2,4)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(2,5)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(2,6)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(3,4)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(3,5)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(3,6)		0	0	0	0	0	0	0	0	1	1	0	0	
	Corr(4,5)		1	0	0	0	1	1	1	0	1	1	0	0	
	Corr(4,6)		1	0	0	0	1	1	1	0	1	1	0	0	
	Corr(5,6)		1	0	1	0	1	1	1	0	1	1	1	1	

nucleus specific local optical model (KD localOMP) (Koning and Delaroche, 2003), the two-component exciton model (Koning and Duijvestijn, 2004) for calculating pre-equilibrium contribution and the γ-ray transmission coefficients for E1 transition are given by the Kopecky-Uhl generalized Lorentzian (Kopecky and Uhl, 1990). Whereas, TENDL-2019 calculations incorporate the Back-shifted Fermi Gas model (Dilg et al., 1973) for nuclear level densities and other default parameters.

In this work, we have performed the calculations for all the 384 possible combinations for 6 nuclear level density models, 2 nucleon-nucleus optical model potentials, 4 pre-equilibrium models and 8 gamma-ray strength functions. The input parameters were optimized for the theoretical calculations to closely fit with the current measured cross sections. The various parameters used in present work for the calculations of the neutron-induced reactions are given in Table 7. The different parameters given in Table 7 refer to the following models.

- ldmodel 2: Back-shifted Fermi Gas model (Dilg et al., 1973)
- localomp n: Global optical model of Koning and Delaroche (2003)
- localomp y: Local optical model of Koning and Delaroche (2003)
- preeqmode 1: Exciton Model: Analytical Transition rates (Koning and Duijvestijn, 2004)
- preeqmode 2: Exciton Model: Numerical Transition rates (Koning and Duijvestijn, 2004)
- preeqmode 3: Exciton Model + optical model (Koning and Duijvestijn, 2004)

The following eight gamma strength functions are available in the TALYS-1.96 code.

- GSF 1: Generalized Lorentzian of Kopecky and Uhl (1990)
- GSF 2: Generalized Lorentzian of Brink and Axel (Axel, 1962; Brink, 1957)
- GSF 3: Hartree-Fock-BCS-quasiparticle random-phase Approximation (Goriely et al., 2002)
- GSF 4: Hartree-Fock-Bogolyubov quasiparticle random-phase approximation (Khan et al., 2008)
- GSF 5: Hybrid model of Goriely (1998)
- GSF 6: Goriely T-dependent HFB (Goriely, 1998)
- GSF 7: T-dependent RMF (Goriely, 1998)
- GSF 8: Gogny D1M HFB + QRPA (Goriely, 1998)

The excitation functions for the $^{168}Yb(\gamma,n)^{167}Yb$, $^{170}Yb(\gamma,n)^{169}Yb$ and $^{176}Yb(\gamma,n)^{175}Yb$ nuclear reactions induced by photons from threshold to 23 MeV are calculated by the TALYS-1.96 code. In addition, the cross section data for the $^{197}Au(\gamma,n)^{196}Au$ monitor reaction was calculated with the default set of parameters in TALYS-1.96. The cross section calculations for the photon-induced reactions were performed with the default constant temperature model and the Fermi gas model for nuclear level densities, the Hauser-Feshbach mechanism for compound nucleus reactions, local optical model for the nucleon-nucleus optical potentials and eight gamma strength functions (GSF) available in the TALYS-1.96 code. There is negligible variance in the cross sections due to the choice of the parameters other than GSFs. The results of the calculations with eight GSFs are compared with the TENDL-2019 data.

4. Results and discussion

We have measured the cross sections of six nuclear reactions for the Yb isotopes induced by 14.77 MeV neutrons. The measured cross sections of neutron-induced reactions are compared with the experimental data from the EXFOR database (Otuka et al., 2014) and the evaluated

Table 7
Input parameters of the TALYS-1.96 code used for neutron-induced reactions.

Reaction	TALYS-1.96 Model Parameters used			
	Nuclear Level Density	Nucleon-nucleus OMP	Pre-equilibrium	Gamma-Ray Strength Function
$^{168}Yb(n,2n)^{167}Yb$	ldmodel 2	localomp n	preeqmode 1	GSF 7
$^{174}Yb(n,p)^{174}Tm$		localomp y	preeqmode 2	GSF 2
$^{176}Yb(n,p)^{176}Tm$		localomp n	preeqmode 2	GSF 1
$^{174}Yb(n,\alpha)^{171}Er$		localomp y	preeqmode 2	GSF 2
$^{170}Yb(n,2n)^{169}Yb$		localomp n	preeqmode 2	GSF 2
$^{176}Yb(n,2n)^{175}Yb$		localomp n	preeqmode 2	GSF 1

nuclear data libraries ENDF/B-VIII.0 (Brown et al., 2018), JEFF-3.3 (Plompen et al., 2020) and TENDL-2019 (Koning et al., 2019). We have normalized the earlier reported cross sections from EXFOR, with the data from IRDFF-II library. The normalization was performed to avoid unreasonable comparison of the data points. Due to normalization, the cross sections vary from 1 to 10%. The details about the normalizations of every author are discussed in the following sub-sections. For the authors where monitor information is not available, no normalization was performed.

We have measured the cross sections of three nuclear reactions for the Yb isotopes induced by 10 MeV and 15 MeV bremsstrahlung photons, relative to the $^{197}Au(\gamma,n)^{196}Au$ reaction. The measured average cross sections of bremsstrahlung photon-induced reactions on ytterbium isotopes are compared with the cross sections calculated with TALYS-1.95 code. The TALYS-1.95 calculations were performed for eight gamma strength functions. Theoretical flux weighted average cross section was calculated for all the gamma strength functions. The theoretical flux weighted average cross sections are compared with the evaluated data available only from the TENDL 2019 library. The experimental data reported on the EXFOR database for $^{168}Yb(\gamma,n)^{167}Yb$, $^{170}Yb(\gamma,n)^{169}Yb$ and $^{176}Yb(\gamma,n)^{175}Yb$ reactions is available only from two authors (Kamman, 2014; Tagma and Naidu, 2018), at 14 MeV and 23 MeV bremsstrahlung endpoint energies.

The measured cross sections of the neutron and bremsstrahlung photon-induced reactions for the ytterbium isotopes are given in the Table 8 and Table 9 respectively. The cross sections in these tables are presented along with their uncertainties and correlation coefficients. The correlation matrix describes the degree to which the different cross sections are correlated. There exists a correlation in the measured cross sections, due to the models and parameters used to estimate the efficiencies, photon flux and monitor reactions used. The cross sections are fully correlated through the efficiencies as the same detector was used for the measurements. The correlation between the first two and the rest four neutron induced reactions and first three and the rest three photon induced reactions is very less as they correlated through very few parameters. The correlation between the different neutron induced reactions varies from 1% to 7 %. Whereas, the correlation between the different photon induced reactions varies from 11% to 50 %, because of more uncertainty contribution due to correlated parameters.

In the following subsections we have discussed each neutron and bremsstrahlung photon-induced reaction in detail.

4.1. Neutron-induced reactions

4.1.1. The $^{168}Yb(n,2n)^{167}Yb$ reaction

In Fig. 6 we have shown the measured cross section for the $^{168}Yb(n,2n)^{167}Yb$ reaction relative to the $^{27}Al(n,p)^{27}Mg$ monitor reaction, at 14.77 MeV neutron energy. The data is given along with the literature data from the EXFOR database, the evaluated cross sections from the ENDF/B-VIII.0, JEFF-3.3, TENDL-2019 libraries and optimized TALYS-1.95 data.

The reported cross section agrees with the evaluated data at 14.77 MeV energy within the given uncertainty. It also agrees with the cross sections of the authors (Bari, 1971), (Qaim, 1974), (Kong et al., 1998), (Dzysiuk et al., 2013) and (Luo et al., 2015). Whereas, the data for the authors (Das et al., 1991) disagrees with our work and the evaluated cross sections.

The cross sections of the authors (Bari, 1971), (Das et al., 1991) and (Qaim, 1974) have been normalized with monitor reaction cross section data from the IRDFF-II data for the $^{27}Al(n,\alpha)^{24}Na$ reaction and for the authors (Dzysiuk et al., 2013) the cross section is normalized for the $^{93}Nb(n,2n)^{92m}Nb$ reaction. For the authors (Luo et al., 2015) cross section is normalized for both $^{27}Al(n,\alpha)^{24}Na$ and $^{93}Nb(n,2n)^{92m}Nb$ reactions. After normalization the values vary from 4 to 7 % for (Bari, 1971), (Qaim, 1974) and (Dzysiuk et al., 2013), for others it varies less than 1%. No normalization is performed for authors (Kong et al., 1998) as no monitor details are available.

We have reported the cross section of 1908.41 ± 141.79 mb for this reaction. Where, the total uncertainty is 7.43%, major uncertainty contribution is from the monitor reaction cross section 1.43%, counting statistics 3.87%, gamma peak intensity 5.43%, 2.43% due to less abundant isotope ^{168}Yb and detector efficiency 3.38% as it is a low energy 113.32 keV gamma peak.

4.1.2. The $^{174}Yb(n,p)^{174}Tm$ reaction

In Fig. 7 we have shown the measured cross section for the $^{174}Yb(n,p)^{174}Tm$ nuclear reaction relative to the $^{27}Al(n,p)^{27}Mg$ reaction, at 14.77 MeV energy, along with the literature data and evaluated data from the ENDF/B-VIII.0, JEFF-3.3 and TENDL-2019 libraries.

The cross-section data does not agree with the evaluated data from the ENDF/B-VIII.0, JEFF-3.3 and TENDL-2019 data libraries for most of the authors along with us. The TALYS-1.95 calculations with the modified parameter agree with the literature and our data. The cross sections of the authors (Coleman and Mukherjee, 1967), (Ikeda et al., 1987), (Luo et al., 2008), (Dzysiuk et al., 2013) and (Luo et al., 2015) agree with our work. Whereas, the authors Bari (1971), Andrus et al. (1982), (Amemiya et al., 1982), (Kong et al., 1998) and (Kondo et al., 2014) slightly disagree with the current work.

The authors (Bari, 1971), (Ikeda et al., 1987) and (Kong et al., 1998) have used the $^{27}Al(n,\alpha)^{24}Na$ monitor reaction, which has been normalized with the IRDFF-II data. Other authors (Coleman and Mukherjee, 1967) have used the $^{63}Cu(n,2n)^{62}Cu$ reaction, the authors (Andrus et al., 1982) have used the $^{51}V(n,p)^{51}Ti$ reaction, the authors (Amemiya et al., 1982) have used the $^{56}Fe(n,p)^{56}Mn$ reaction, the authors (Dzysiuk et al., 2013) have used the $^{93}Nb(n,2n)^{92m}Nb$ reaction, which have been normalized. The data of the authors (Luo et al., 2015) have been normalized with respect to both reactions $^{27}Al(n,\alpha)^{24}Na$ and $^{93}Nb(n,2n)^{92m}Nb$. Normalization is not performed for (Kondo et al., 2014) as they have used long counters for flux monitoring and no monitor details are available for (Kong et al., 1998) and (Luo et al., 2008).

We have reported 2.78 ± 0.28 mb cross section for this reaction. The major contributions to uncertainty are the monitor cross section 1.43%, counting statistics 3.90%, gamma peak intensity 4.54% and f_c factor of sample 1.20% due to short half-life of product. The total uncertainty is 10.21%.

4.1.3. The $^{176}Yb(n,p)^{176}Tm$ reaction

In Fig. 8 we have shown the measured cross section for the $^{176}Yb(n,p)^{176}Tm$ reaction relative to the $^{27}Al(n,\alpha)^{24}Na$ reaction, at 14.77 MeV energy, along with the literature data and the evaluated data from the ENDF/B-VIII.0, JEFF-3.3 and TENDL-2019 libraries.

The measured cross sections do not agree with any of the evaluated data and agree only with the TALYS-1.95 calculations performed with the modified input parameters. Data of the authors (SATO et al., 1975) agrees with the JEFF-3.3 and TENDL-2019 evaluations. Other authors

Table 8
Measured cross sections of the neutron-induced reactions for ytterbium isotopes along with uncertainties and correlation coefficients.

Reaction	Cross section (mb)	Correlation Coefficients					
$^{168}Yb(n,2n)^{167}Yb$	1908.41 ± 141.79	1					
$^{174}Yb(n,p)^{174}Tm$	2.78 ± 0.28	0.04	1				
$^{176}Yb(n,p)^{176}Tm$	4.83 ± 0.62	0.008	0.0007	1			
$^{176}Yb(n,\alpha)^{173}Er$	1.18 ± 0.28	0.008	0.005	0.01	1		
$^{170}Yb(n,2n)^{169}Yb$	2092.81 ± 188.54	0.22	0.003	0.02	0.02	1	
$^{176}Yb(n,2n)^{175}Yb$	2243.24 ± 128.88	0.03	0.020	0.04	0.04	0.07	1

Table 9
Measured cross sections of the bremsstrahlung photon-induced reactions for ytterbium isotopes along with uncertainties and correlation coefficients.

Reaction	Energy (MeV)	Measured Cross section (mb)	Correlation Coefficients					
$^{168}Yb(\gamma,n)^{167}Yb$	9.20 to 30	40.98 ± 3.40	1					
$^{170}Yb(\gamma,n)^{169}Yb$	6.40 to 30	28.38 ± 2.88	0.11	1				
$^{176}Yb(\gamma,n)^{175}Yb$	6.80 to 30	40.82 ± 2.21	0.12	0.20	1			
$^{168}Yb(\gamma,n)^{167}Yb$	9.20 to 35	124.72 ± 11.87	0.0008	0.0002	1.2E-05	1		
$^{170}Yb(\gamma,n)^{169}Yb$	6.40 to 35	182.89 ± 19.28	0.0002	0.0001	1.6E-07	0.31	1	
$^{176}Yb(\gamma,n)^{175}Yb$	6.80 to 35	182.52 ± 8.83	1.6E-06	1.20E-05	1.20E-06	0.83	0.44	1

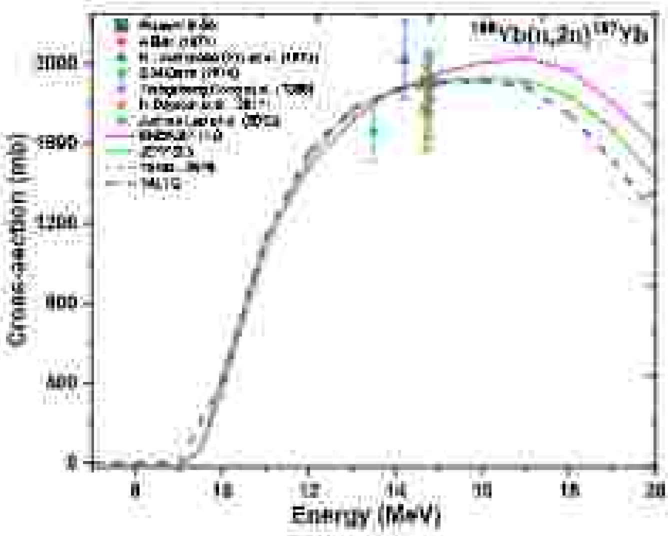

Fig. 6. Comparison of present experimental $^{168}Yb(n,2n)^{167}Yb$ reaction cross section with literature data, evaluated data and TALYS-1.95 calculations.

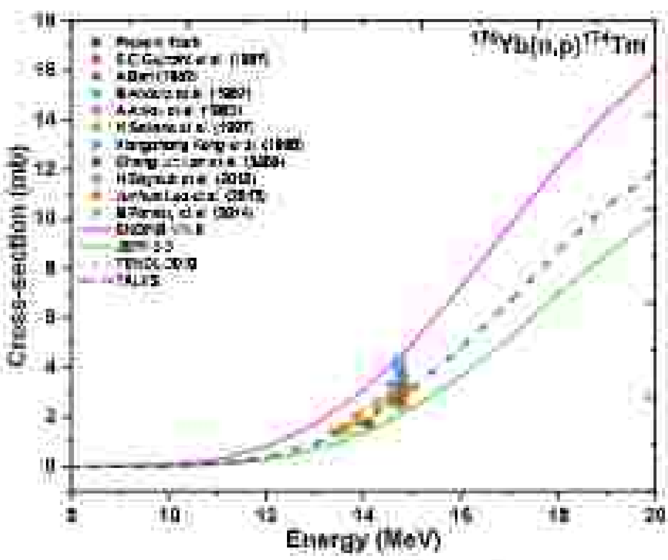

Fig. 7. Comparison of present experimental $^{174}Yb(n,p)^{174}Tm$ reaction cross section with literature data, evaluated data and TALYS-1.95 calculations.

(Kong et al., 1998), (Dzysiuk et al., 2012) and (Luo et al., 2015) agree with the present data point and the TALYS-1.95 calculated curve. Normalization information is similar for all the authors as mentioned in the 4.1.1 and 4.1.2 sections except for the authors (SATO et al., 1975) have used $^{27}Al(n,\alpha)^{24}Na$ monitor reaction and we have normalized it with the IRDFF-II data.

Our cross section for this reaction is 4.55 ± 0.62, with 13.80% total uncertainty. The major uncertainty is contributed due to the counting

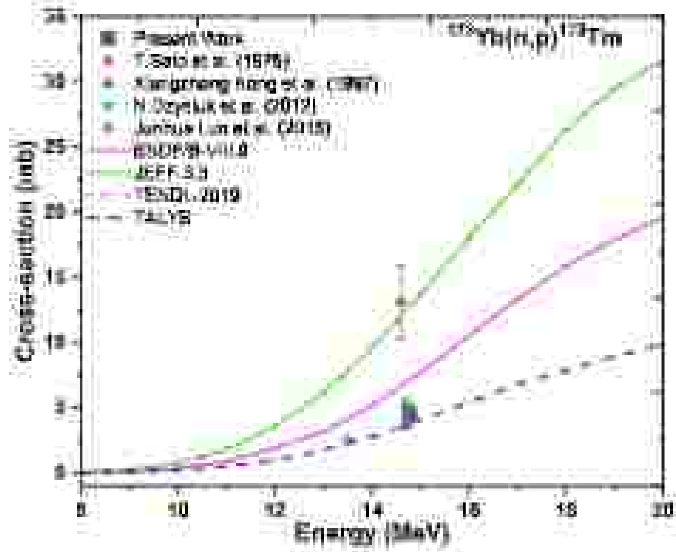

Fig. 8. Comparison of present experimental $^{173}Yb(n,p)^{173}Tm$ reaction cross section with literature data, evaluated data and TALYS-1.95 calculations.

statistics (13.87%), as the gamma peak of product ^{173}Tm (398.9 keV) is very close to gamma peak of ^{175}Yb (396.329 keV) produced in (n,2n) reaction with ^{176}Yb isotope.

4.1.4. The $^{174}Yb(n,\alpha)^{171}Er$ reaction

The Fig. 9 shows the cross section of the $^{174}Yb(n,\alpha)^{171}Er$ reaction along with the literature data from the EXFOR database and the evaluated data from the ENDF/B-VIII.0, JEFF-3.3 and TENDL-2019 libraries.

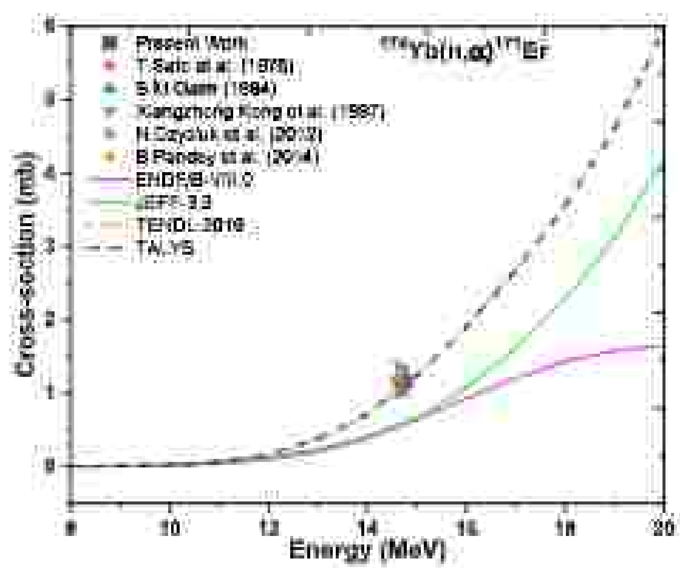

Fig. 9. Comparison of present experimental $^{174}Yb(n,\alpha)^{171}Er$ reaction cross section with literature data, evaluated data and TALYS-1.95 calculations.

The literature data and our data do not agree with the ENDF/B-VIII.0 and JEFF-3.3 evaluations. The literature data along with our data agree with the TENDL-2019 and TALYS-1.95 calculations. The cross sections of the authors (SATO et al., 1970), (Qaim, 1974), (Kong et al., 1998), (Dzysiuk et al., 2012) and (Bandey et al., 2014) agree with our data within the uncertainties. The normalization information is similar to the 4.1.1 and 4.1.2 sections for all the authors.

We have reported cross section value of 1.18 ± 0.18 mb for this reaction with 15.49% uncertainty. The major part of uncertainty comes from counting statistics 14.88% as the reaction is less probable and gamma peak intensity of product 4.83%.

4.1.5. The ^{170}Yb(n,2n)^{169}Yb reaction

Fig. 10 shows the cross section of the ^{170}Yb(n,2n)^{169}Yb reaction along with the literature data from the EXFOR and the evaluated data from the ENDF/B-VIII.0, JEFF-3.3 and TENDL-2019 libraries.

Our cross section matches with the ENDF/B-VIII.0 data and TALYS-1.95 data with modified input parameters and disagrees with the JEFF-3.3 and TENDL-2019 evaluations. The data also agrees with the cross sections of authors (Dilg et al., 1968), (Bao, 1971), (Kong et al., 1998) and (Luo et al., 2008), slightly disagrees with the authors (Qaim, 1974) and (Dzysiuk et al., 2012) and strongly disagrees with cross sections of the authors (Weigel et al., 1975). The normalization information is similar for all the authors as mentioned in 4.1.1 and 4.1.2 sections except for the authors (Dilg et al., 1968) have used the ^{27}Al(n,α)^{24}Na monitor reaction and (Weigel et al., 1975) have used the ^{63}Cu(n,γ)^{64}Cu reaction which has been normalized with the IRDFF-II data.

We have reported cross section value of 2163.81 ± 188.84 mb of this reaction with 8.6% total uncertainty. The major contributions to uncertainty are counting statistics 8.2% and detector efficiency 6.83% due to the 197.95 keV peak.

4.1.6. The ^{176}Yb(n,2n)^{175}Yb reaction

In Fig. 11 we have shown the cross section of the ^{176}Yb(n,2n)^{175}Yb reaction with the experimental cross sections from the EXFOR database and the evaluated data from the ENDF/B-VIII.0, JEFF-3.3 and TENDL-2019 libraries.

Our reported cross section along with most of the literature data does not match with the evaluated data from the ENDF/B-VIII.0, JEFF-3.3 or TENDL-2019 evaluations. Moreover, the measured cross section and the literature data does not match with any of the model calculations for TALYS-1.95 code. We have plotted the measured cross section data with the closest fitting curve.

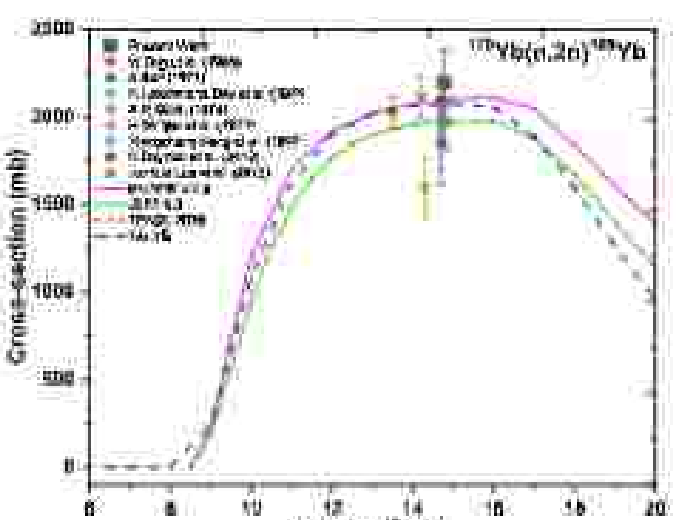

Fig. 10. Comparison of present experimental ^{170}Yb(n,2n)^{169}Yb reaction cross section with literature data, evaluated data and TALYS-1.95 calculations.

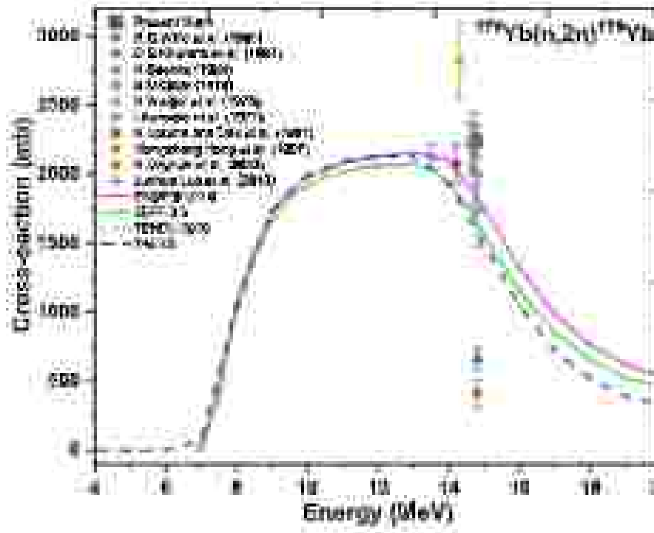

Fig. 11. Comparison of present experimental ^{176}Yb(n,2n)^{175}Yb reaction cross section with literature data, evaluated data and TALYS-1.95 calculations.

The cross section data of the authors (Qaim, 1974), (KUMABE et al., 1977), (Kong et al., 1998), (Dzysiuk et al., 2012) and (Luo et al., 2013) agree with our value. The cross sections of (Wille and Fink, 1960), (Khurana and Hans, 1961), (Sposito, 1964) and (Weigel et al., 1975) strongly disagree with our value. The experimental cross section data reported in last 20-30 years for all the authors disagree with the evaluated cross sections from all the data libraries and nuclear model calculations with the TALYS-1.95 code. This calls for some refinement in the nuclear model calculation of cross sections for this reaction.

The normalization data is same as 4.1.1 and 4.1.2 sections for all the authors except for the authors (Wille and Fink, 1960) have used the ^{63}Cu(n,2n)^{62}Cu reaction (Khurana and Hans, 1961), have used the ^{56}Fe(n,p)^{56}Mn reaction (Sposito, 1964), and (KUMABE et al., 1977) have used the ^{27}Al(n,α)^{24}Na reaction. The cross sections for all the authors have been normalized with the IRDFF-II data library.

We have reported the cross section value of 2243.54 ± 109.88 mb for this reaction with 4.88% total uncertainty, where the major contribution is coming from only counting statistics 3.93%.

4.2. Bremsstrahlung photon-induced reactions at 10 and 15 MeV bremsstrahlung endpoint energy

The Figs. 12–14 show the cross section data for the ^{168}Yb(γ,n)^{167}Yb, ^{170}Yb(γ,n)^{169}Yb and ^{176}Yb(γ,n)^{175}Yb nuclear reaction for mono-energetic photons from reaction threshold 20 MeV energy calculated with the TALYS-1.95 code and the evaluated data from the TENDL-2019 library. The TALYS-1.95 calculations are performed for eight Gamma Strength Functions (GSF) available in the code, named as GSF1 to GSF8. The effective cross section is calculated for all the eight gamma strength functions and is given in Table 10. No literature data is available for these reactions at 10 and 15 MeV bremsstrahlung endpoint energies to compare. The calculated effective cross sections cannot be graphically compared with the TALYS-1.95 curves because TALYS-1.95 evaluates the cross sections for monoenergetic photons, while, we have calculated the flux weighted average cross sections.

4.2.1. The ^{168}Yb(γ,n)^{167}Yb reaction

Fig. 12 shows the cross section for the ^{168}Yb(γ,n)^{167}Yb reaction for GSF1 to GSF8 along with the TENDL 2019 data. Only the authors (Tagirov and Zimalev, 2015) have reported the cross section for this reaction at 14 MeV bremsstrahlung endpoint energy. They have reported 128 ± 21 mb cross section at 14 MeV bremsstrahlung endpoint energy.

We have reported the average cross section value of 43.90 ± 8.48 mb

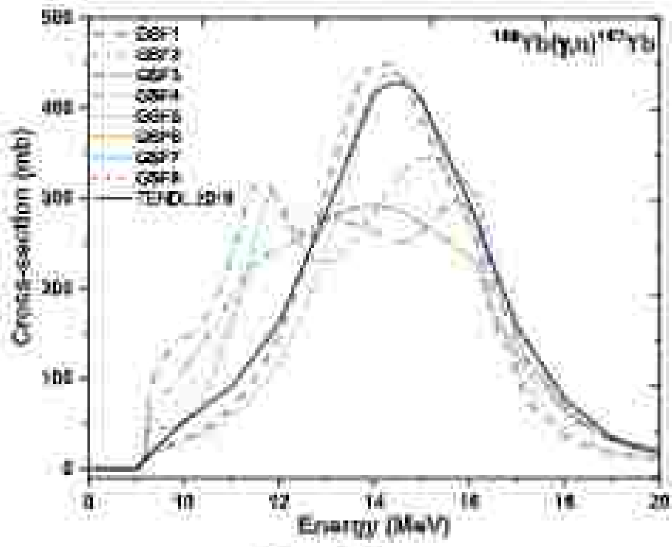

Fig. 12. Comparison of the ^{168}Yb(γ,n)^{167}Yb reaction cross section with the TENDL 2019 data and TALYS-1.95 calculations for eight gamma strength functions.

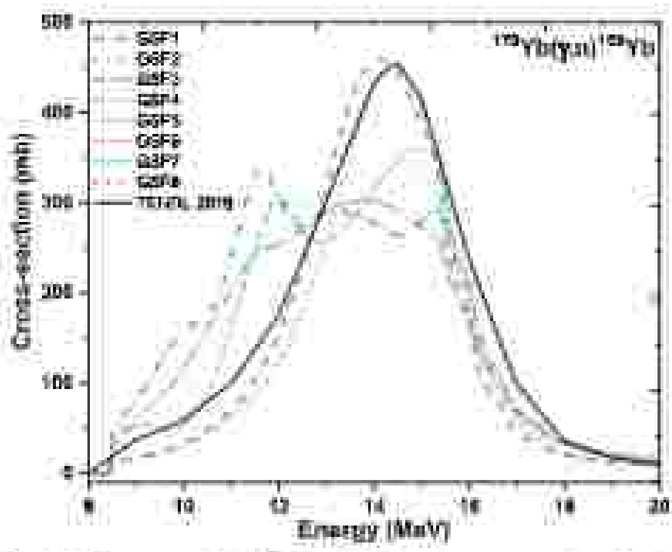

Fig. 13. Comparison of the ^{170}Yb(γ,n)^{169}Yb reaction cross section with the TENDL 2019 data and TALYS-1.95 calculations for eight gamma strength functions.

and 134.73 ± 11.27 mb for 10 and 15 MeV bremsstrahlung endpoint energies respectively. The major contribution to the uncertainty is due to the counting statistics 11.22% and 2.5% of sample, counting of monitor 5.37% and 2.59% respectively for 10 and 15 MeV energies and due to the gamma peak intensity 3.42% and abundance of the sample 2.43%. The theoretical effective cross section calculated from TALYS-1.95 curves varies from 17.23 to 81.05 mb for 10 MeV and 113.16 to 206.87 mb for 15 MeV energy.

4.2.2. The ^{170}Yb(γ,n)^{169}Yb reaction

Fig. 13 shows the cross section for the ^{170}Yb(γ,n)^{169}Yb reaction for GSF1 to GSF8 along with the TENDL 2019 data. Only the authors (Varlamov and Stepanov, 2022) have reported the cross section of 117 ± 31 mb for this reaction at 14 MeV bremsstrahlung endpoint energy.

We have reported the average cross section of 25.38 ± 3.86 mb and 150.55 ± 13.25 mb at 10 and 15 MeV bremsstrahlung endpoint energies respectively. The major contribution to the uncertainty is due to the counting statistics 14.28% and 8.26% of sample for 10 and 15 MeV energies respectively. The theoretical effective cross section calculated from the TALYS-1.95 curves varies from 16.57 to 84.22 mb for 10 MeV and 101.83 to 205.69 mb for 15 MeV energy.

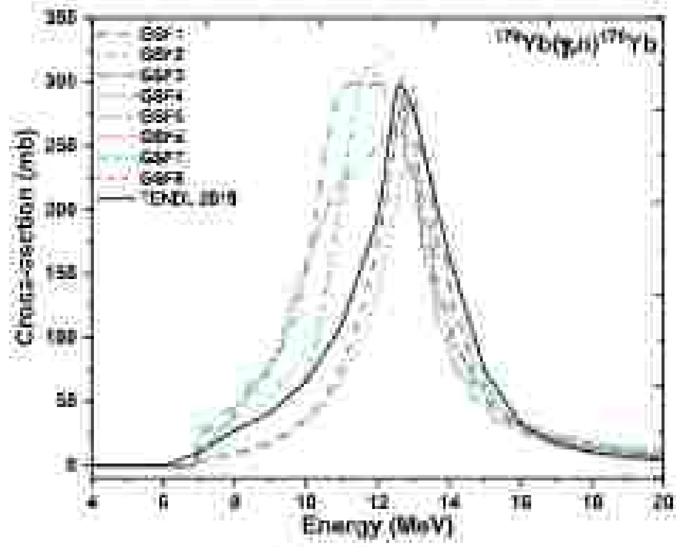

Fig. 14. Comparison of the ^{172}Yb(γ,n)^{171}Yb reaction cross section with the TENDL 2019 data and the TALYS-1.95 calculations for eight gamma strength functions.

4.2.3. The ^{172}Yb(γ,n)^{171}Yb reaction

Figure 14 shows the cross section for the ^{172}Yb(γ,n)^{171}Yb reaction for GSF1 to GSF8 along with TENDL 2019 data. Only the authors (Varlamov and Stepanov, 2022) have reported the cross section of 125 ± 36 mb for this reaction at 14 MeV bremsstrahlung endpoint energy and the author (Kharamov, 2014) has given the (γ,n) yield ratios for 22 MeV bremsstrahlung endpoint energy.

We have reported the average cross section of 45.81 ± 3.22 mb and 132.83 ± 8.92 mb at 10 and 15 MeV bremsstrahlung endpoint energies respectively. The major contribution to the uncertainty is due to the counting statistics 4.03% and 2.48% of sample for 10 and 15 MeV energies respectively. The theoretical effective cross section calculated from the TALYS-1.95 curves varies from 11.48 to 48.66 mb for 10 MeV and 54.02 to 131.75 mb for 15 MeV energy.

5. Conclusions

We have reported the cross sections of six neutron-induced reactions and the flux weighted average cross sections of six bremsstrahlung photon-induced reactions in the present work. The uncertainties in the measured data have been determined by a detailed covariance analysis. The uncertainties for the data vary from 4 to 16% depending on various factors for each reaction. We have discussed in detail the partial uncertainties due to various attributes and reported them separately, which is recommended by the data evaluators. We have also reported the cross section of the less probable (n,p) and (n,d) reactions, with good accuracy. The isotopes ^{167}Tm, ^{169}Yb and ^{175}Yb are medically important. The current study of production cross sections of these isotopes, points out the alternative ways of producing these isotopes with compact systems such as Neutron Generators and Medical LINAC. We have normalized the cross sections from the literature with respect to the IRDFF-II data in order to avoid unfair comparison. The reported cross sections are compared with the evaluated data from the ENDF/B-VIII.0, JEFF-3.3 and TENDL-2019 libraries. Except for the ^{176}Yb(n,2n)^{175}Yb reaction, the cross sections for all the reactions agree with the evaluated data. All of our measured cross sections agree with the recent literature data. The bremsstrahlung photon-induced reaction cross sections are the first and

Table 10
The Theoretical flux-weighted average cross sections for 8 gamma strength functions (GSF) compared with measured cross-sections.

Reaction	Energy (MeV)	Measured Cross-section (mb)	GSF1	GSF2	GSF3	GSF4	GSF5	GSF6	GSF7	GSF8
[illegible](γ,n)[illegible]	9.36 ± 10	49.38 ± 5.46	17.32	25.20	81.12	55.28	15.46	55.26	33.59	42.28
[illegible](γ,n)[illegible]	8.46 ± 10	25.26 ± 3.96	16.88	26.22	84.22	61.28	17.82	61.28	44.58	50.28
[illegible](γ,n)[illegible]	8.88 ± 10	45.81 ± 2.22	10.46	27.16	49.66	48.61	11.99	48.81	41.72	29.72
[illegible](γ,n)[illegible]	9.36 ± 15	194.73 ± 13.87	132.13	139.78	205.98	179.49	112.17	179.49	160.18	172.49
[illegible](γ,n)[illegible]	8.46 ± 15	152.99 ± 15.28	116.84	132.89	185.75	168.99	101.89	168.99	148.24	161.72
[illegible](γ,n)[illegible]	8.88 ± 15	132.66 ± 9.92	81.87	82.87	131.78	115.61	94.98	115.54	137.87	124.88

very important addition to the nuclear database at 10 and 15 MeV endpoint energies.

CRediT author statement

G.T. Bholane: Methodology, Data curation, Writing - original draft, Software, Investigation, Formal analysis, Validation. T.S. Ganesapandy: Data curation, Software, Validation, Formal analysis. A.B. Phatangare: Visualization, Validation. F. M. D. Attar: Formal analysis. S.S. Dahiwale: Resources, Funding acquisition. S.V. Suryanarayana: Conceptualization, Funding acquisition. V.N. Bhoraskar: Conceptualization, Project administration, Supervision, Investigation. S.D. Dhole: Funding acquisition, Project administration, Resources, Writing - review & editing, Supervision, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Agostinelli, S., et al., 2003. Geant4 - a simulation toolkit. Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. 506, 250–303. https://doi.org/10.1016/S0168-9002(03)01368-8.

Allison, J., et al., 2006. Geant4 developments and applications. IEEE Trans. Nucl. Sci. 53, 270–278. https://doi.org/10.1109/TNS.2006.869826.

[illegible]

Axel, P., 1962. Electric dipole ground-state transition width strength function and 7-mev photon interactions. Phys. Rev. 126, 671–683. https://doi.org/10.1103/PhysRev.126.671.

Baglin, C.M., 2008. Nuclear data sheets for A = 166. Nucl. Data Sheets 109, 2033–2256. https://doi.org/10.1016/j.nds.2008.08.001.

Baglin, C.M., 2000. Nuclear data sheets for A = 167. Nucl. Data Sheets 90, 431–644. https://doi.org/10.1006/ndsh.2000.0012.

Baglin, C.M., 2002. Nuclear data sheets for A = 171. Nucl. Data Sheets 96, 399–610. https://doi.org/10.1006/ndsh.2002.0014.

[illegible]

Basunia, M.S., 2004. Nuclear data sheets for A = 170. Nucl. Data Sheets 101, 713–903. https://doi.org/10.1016/j.nds.2004.01.001.

Bholane, G.T., et al., 2022. Measurements and estimation of cross sections of neutron and bremsstrahlung induced nuclear reactions for molybdenum isotopes with covariance analysis. Nucl. Phys. A 1020, 122[illegible]. https://doi.org/10.1016/j.nuclphysa.2022.122[illegible].

Bhoraskar, V.N., 1989. A facility for 14-MeV neutron irradiation and activation analysis. Indian J. Pure Appl. Phys. 27, 648–653.

[illegible]

Brown, D.A., et al., 2018. ENDF/B-VIII.0: the 8th major release of the nuclear reaction data library with CIELO-project cross sections, new standards and thermal scattering data. Nucl. Data Sheets 148, 1–142. https://doi.org/10.1016/j.nds.2018.02.001.

Browne, E., 1986. Nuclear data sheets for A = 174. Nucl. Data Sheets 47, 813–838. https://doi.org/10.1016/S0090-3752(86)80068-4.

[illegible]

Das, N.L., Srinivasa Rao, C.V., Thirumala Rao, B.V., Rama Rao, J., 1981. Pre-equilibrium effects in (n, 2n) reactions at 14.2 MeV. Pramana 17, 99–104. https://doi.org/10.1007/BF02872041.

[illegible]

Dilg, W., Schantl, W., Vonach, H., Uhl, M., 1973. Level density parameters for the back-shifted fermi gas model in the mass range 40 < A < 250. Nucl. Phys. A 217, 269–298. https://doi.org/10.1016/0375-9474(73)90196-6.

Dilg, W., Vonach, H., Winkler, G., Hille, P., 1968. [illegible] (n, 2n) [illegible]. Nucl. Phys. A 118, 9–16. https://doi.org/10.1016/0375-9474(68)90713-6.

Filatenkov, A.A., [illegible], 2011. Measurement and systematic study of (n,x) cross sections for dysprosium (Dy), erbium (Er), and ytterbium (Yb) isotopes at 14.7 MeV neutron energy. Phys. Rev. C 83, 04[illegible]. https://doi.org/10.1103/PhysRevC.83.04[illegible].

[illegible], 2021. Future candidates for targeted alpha therapy: production and radiochemical considerations. Nucl. Med. Biol. [illegible]. https://doi.org/10.1016/j.nucmedbio.2020.11.001, 24–38.

Firestone, R.B., 2007. Nuclear data sheets for A = 24. Nucl. Data Sheets 108, 2319–2392. https://doi.org/10.1016/j.nds.2007.10.001.

Forrest, R., [illegible], Chang, K., Forrest, R.A., [illegible], 2005. Nuclear data for fusion energy technologies: requests, status and development needs. AIP Conf. Proc. 769, 1478–1483. https://doi.org/10.1063/1.1945284.

Goriely, S., 1998. Radiative neutron captures by neutron-rich nuclei and the r-process nucleosynthesis. Phys. Lett. B 436, 10–18. https://doi.org/10.1016/S0370-2693(98)00907-1.

[illegible]

Handbook on Nuclear Activation Data, 1987. Technical Reports Series. [illegible], Vienna.

Hauser, W., Feshbach, H., 1952. The inelastic scattering of neutrons. Phys. Rev. 87, 366–373. https://doi.org/10.1103/PhysRev.87.366.

Hubbell, J.H., Seltzer, S.M., 2004. Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients 1 keV to 20 MeV for Elements Z = 1 to 92 and 48 Additional Substances of Dosimetric Interest.

[illegible]

[illegible], 2002. Measurement method of activation cross-sections of reactions producing short-lived nuclei with 14 MeV neutrons. Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. 480, 183–187. https://doi.org/10.1016/S0168-9002(01)01[illegible].

Khan, S., Derrick, S., [illegible], Koning, A.J., Mihaila, S., Hayhoe, M.B., 2015. Photodisintegration of ultra-high-energy cosmic rays revisited. Astropart. Phys. 62, 182–[illegible]. https://doi.org/10.1016/j.astropartphys.2014.11.007.

Khurana, C.S., Hans, H.S., 1961. Cross-sections for (n, 2n) reactions at 14.8 MeV. Nucl. Phys. 28, 560–569. https://doi.org/10.1016/0029-5582(61)91077-X.

Kong, X., Wang, Y., Yang, J., 1998. Cross sections for (n, 2n), (n, p) and (n, α) reactions on rare-earth isotopes at 14.1 MeV. Appl. Radiat. Isot. 49, 1529–1532. https://doi.org/10.1016/S0969-8043(97)10011-9.

Koning, A.J., Delaroche, J.P., 2003. Local and global nucleon optical models from 1 keV to 200 MeV. Nucl. Phys. A 713, 231–310. https://doi.org/10.1016/S0375-9474(02)01321-0.

Koning, A.J., Duijvestijn, M.C., 2004. A global pre-equilibrium analysis from 7 to 200 MeV based on the optical model potential. Nucl. Phys. A 744, 15–76. https://doi.org/10.1016/j.nuclphysa.2004.08.013.

Koning, A.J., Hilaire, S., Duijvestijn, M.C., 2007a. TALYS-1.0. EDP Sciences, Les Ulis, France. https://doi.org/10.1051/ndata:07767, 058087.

Koning, A.J., Hilaire, S., Duijvestijn, M.C., 2007b. TALYS-1.0. EDP Sciences, Les Ulis, France. https://doi.org/10.1051/ndata:07767, 058087.

Koning, A.J., et al., 2019. TENDL: complete nuclear data library for innovative nuclear science and technology. Nucl. Data Sheets 155, 1–55. https://doi.org/10.1016/j.nds.2019.01.002.

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Measurements of neutron and photon induced cross sections for the production of medical isotopes of strontium

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Abstract

The cross sections of the ^{88}Sr(n,2n)^{87}Sr^{m}, ^{88}Sr(n,p)^{88}Rb, ^{88}Sr(n,α)^{85}Kr, ^{86}Sr(n,2n)^{85}Sr^{m}, ^{86}Sr(n,2n)^{85}Sr^{g} and ^{84}Sr(n,2n)^{83}Sr nuclear reactions at 14.77 ± 0.15 MeV neutron energy and the average cross sections of the ^{88}Sr(γ,n)^{87}Sr^{m} and ^{84}Sr(γ,n)^{83}Sr^{m} nuclear reactions at bremsstrahlung of 15 MeV endpoint energy were measured with the activation method and offline gamma-ray spectroscopy. The measured cross sections were reported with a detailed covariance analysis for uncertainty and correlation coefficients. The experimental results were compared with the previously reported experimental data from the EXFOR database and the evaluated data from the TENDL-2019 library. Statistical model calculations were performed with the latest TALYS-1.95 code with optimized input parameters to better reproduce reported experimental data. The measured cross sections were found to be in good agreement with the literature and theoretical calculations. These results highlight the alternate production routes for the medical radioisotopes of ^{87}Sr^{m} and ^{85}Sr^{g}.

Keywords: Strontium; Medical radioisotopes; Neutron activation; Photon activation; TALYS-1.95

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1. Introduction

The radioisotopes of strontium (^{85}Sr, $^{87}Sr^m$, ^{83}Sr and ^{89}Sr) are used in nuclear medicine for diagnostic imaging [1–3] and treatment. The radioisotope ^{89}Sr is shown to lessen the pain in bones for patients having metastatic carcinoma [4]. $^{87}Sr^m$ having a short half-life 2.815 h [5] decays by internal transition emitting 388.531 keV gamma-ray without any beta particles and this makes it ideal for imaging malignant metastatic bone lesions [6]. $^{85}Sr^g$ is used to study calcium intake in bones [7] due to its similar chemistry. ^{82}Sr is used to generate ^{82}Rb, an important positron emitter tomography isotope.

$^{87}Sr^m$ is indirectly produced from $^{87}Y^m$ which has a half-life of 13.37 h [5] by bombarding rubidium targets with alpha particles [8]. $^{87}Sr^m$ can also be directly produced by protons [9] or deuterium ions [1] induced reactions on natural rubidium (^{nat}Rb) target or by bombarding natural krypton (^{nat}Kr) targets with alpha particles [10]. $^{85}Sr^g$ can be indirectly produced from ^{85}Y by the $^{86}Sr(p,2n)^{85}Y$ reaction [11]. Direct production routes for $^{85}Sr^g$ are i) $^{nat}Rb(p,xn)^{85}Sr$ [12] ii) $^{nat}Rb(d,xn)^{85}Sr$ [1] and $^{nat}Kr(\alpha,n)^{85}Sr$ [13]. Alternatively $^{87}Sr^m$, $^{85}Sr^g$ can be directly produced by bombarding natural strontium targets with 14 MeV neutrons through $^{88}Sr(n,2n)^{87}Sr^m$, $^{86}Sr(n,2n)^{85}Sr^m$ reactions [14] or 15 MeV photons [15].

Neutron-induced reaction cross sections on natural strontium target have been studied by a few authors [14,16–19] in the neutron energy range 12.6-15 MeV. The uncertainties reported by Gonzalez et al. [14] is 6%, by Rao et al. [16] is 10%, by Husain et al. [17] is 10%, by Bormann et al. [18] is 8% and Strohal et al. [19] is 7%. The cross sections reported by the authors at 13.5–14.9 MeV have uncertainties from 3% to 19%. Photo-nuclear cross sections on strontium by 65 MeV bremsstrahlung reported by [20] do not include $^{88}Sr(\gamma,n)^{87}Sr^m$ results. There are discrepancies in reported literature in neutron-induced reactions on strontium and there is scarce availability of literature on photo-neutron data at 15 MeV. Therefore, there is a need for experimental measurements in both the above cases.

In the present work the cross sections for $^{88}Sr(n,2n)^{87}Sr^m$, $^{88}Sr(n,p)^{88}Rb$, $^{88}Sr(n,\alpha)^{85}Kr$, $^{86}Sr(n,2n)^{85}Sr^m$, $^{86}Sr(n,2n)^{85}Sr^g$ and $^{84}Sr(n,2n)^{83}Sr$ reactions are measured at 14.77 ± 0.17 [21] MeV neutron energy with $^{27}Al(n,p)^{27}Mg$ and $^{27}Al(n,\alpha)^{24}Na$ as monitor reactions, and the average cross sections for $^{88}Sr(\gamma,n)^{87}Sr^m$ and $^{86}Sr(\gamma,n)^{85}Sr^m$ reactions are measured with 15 MeV bremsstrahlung photons with $^{197}Au(\gamma,n)^{196}Au$ as a monitor reaction using the activation technique and off-line gamma-ray spectroscopy. Statistical model calculations for neutron-induced reactions on strontium from reaction threshold to 20 MeV with the TALYS-1.95 [22] nuclear code is compared with the evaluated cross section data files of the TENDL-2019 [23] library and experimental data from the EXFOR database [24].

2. Experimental details

2.1. Measurement of 14.77 MeV neutron-induced reaction cross sections on strontium

Samples of pure SrO_2 (99.99%) powder of natural isotopic abundance were prepared and wrapped in pure aluminium foil as a monitor element. A known weight of the sample was packed in a polythene bag and sandwiched between two aluminium foils and the sample size was made to be 10 mm × 10 mm. Neutron irradiation of the samples was carried out at the 14 MeV neutron generator facility [25], Department of Physics, Savitribai Phule Pune University, Pune, India. The 14 MeV neutron generator is a 250 kV DC electrostatic accelerator. Deuterium ions are produced by an RF ion source [26]. The 14 MeV neutron beam was produced by bombarding ∼150 keV

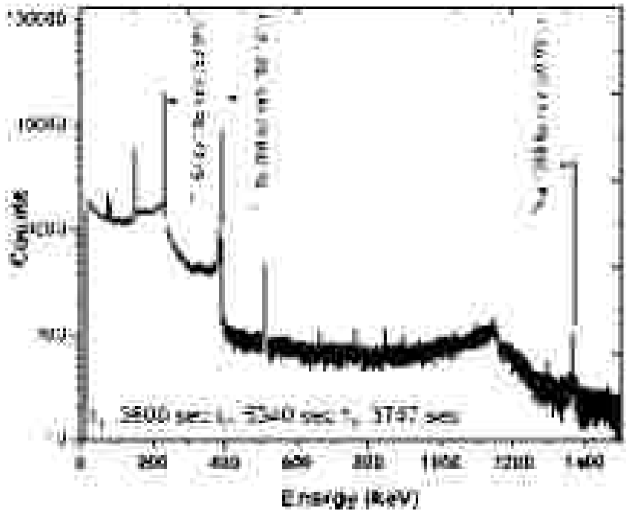

Fig. 1. The typically recorded gamma-ray spectrum for the Sr sample and Al monitor element irradiated by 14.77 MeV neutrons.

deuteron beam on an 8 Ci tritium target. The neutron flux was determined with the $^{27}Al(n,\alpha)^{24}Na$ reference monitor reaction [27]. The calculated neutron flux was ~ 10^{8} n/cm^2 sec. The strontium sample was mounted at 0° with respect to the incident deuterium beam where the neutron energy corresponds to 14.77 ± 0.15 MeV [28]. The deuterium ion beam current on the tritium target was ~60 μA at 175 kV accelerating voltage. The sample was irradiated with neutrons for an hour and then immediately transferred to the counting room where it was cooled.

The gamma-ray activity of the irradiated samples were measured with a coaxial HPGe (30%) detector cooled by a liquid nitrogen cryostat. The energy resolution of the detector was measured as 1.49 keV at the 1332.5 keV peak of ^{60}Co gamma source. The detector was connected to an Ortec EASY-MCA-8K Multichannel Analyser through an amplifier. The Ortec-make Maestro software was used for the data acquisition and the dead time was maintained below 2%. Eu-152 standard source was used for energy calibration of the HPGe detector. The calibration source was kept at 50 mm from the central area of the detector surface. The gamma-ray activity of the neutron irradiated samples was measured by mounting the sample at the marked position in front of the pre-calibrated HPGe detector. Typical recorded gamma-ray spectrum for Sr and Al samples irradiated by 14.77 MeV neutrons are shown in Fig. 1, along with the timing details where t_i is the irradiation time, t_c is the cooling time and t_c is the counting time. The details of the irradiation time, cooling time and counting time are given in Table 1. The nuclear data used for the reactions are given in Table 2.

2.2. Measurement of 15 MeV bremsstrahlung induced nuclear reaction cross sections for Strontium

Samples of pure SrO_2 (99.99%) powder of known weight and natural isotopic abundance were prepared. Au foil (0.5 gm), of the same size as the samples was placed along with the samples for monitoring the bremsstrahlung flux. The bremsstrahlung irradiation experiment of the samples was carried out with the medical linear electron accelerator at Dr. Vikhe Patil Memorial Hospital, Ahmednagar, India. The Medical LINAC is capable of delivering a monochromatic electron

Table 1
Timing details of the samples irradiated with 14.77 MeV neutrons.

Reaction	Irradiation time (secs)	Cooling time (secs)	Counting time (secs)
$^{88}Sr(n,2n)^{87}Sr^{m}$	3600	1549	1747
$^{88}Sr(n,p)^{88}Rb$	3600	50	1502
$^{88}Sr(n,\alpha)^{85}Kr$	3600	77640	7232
$^{86}Sr(n,2n)^{85}Sr^{m}$	3600	1469	1897
$^{86}Sr(n,2n)^{85}Sr^{g}$	3600	77640	7232
$^{84}Sr(n,2n)^{83}Sr$	3600	77640	7232

Table 2
Decay data adopted in the present work [1,25–27] along with threshold energy.

Reaction	Threshold (MeV)	$T_{1/2}$	Decay mode	E_{γ} (keV)	I_{γ} (%)
$^{88}Sr(n,2n)^{87}Sr^{m}$	11.632	2.815 ± 0.012 h	IT (99.7%)	388.531	82.19 ± 0.22
$^{88}Sr(n,p)^{88}Rb$	4.562	17.773 ± 0.011 min	β^- (100%)	898.03	14.4 ± 0.24
$^{88}Sr(n,\alpha)^{85}Kr$	0.664	4.480 ± 0.008 h	β^- (78.8%)	151.195	75.2 ± 0.5
$^{86}Sr(n,2n)^{85}Sr^{m}$	11.839	67.63 ± 0.04 min	IT (86.6%)	231.86	83.9 ± 0.4
$^{86}Sr(n,2n)^{85}Sr^{g}$	11.821	64.849 ± 0.007 d	ε (100%)	514.0048	96 ± 4
$^{84}Sr(n,2n)^{83}Sr$	12.060	32.41 ± 0.03 h	ε β^+ (100%)	762.65	26.7 ± 2.2

Table 3
Timing details of the samples irradiated with bremsstrahlung of 15 MeV end point energy.

Reaction	Irradiation time (secs)	Cooling time (secs)	Counting time (secs)
$^{88}Sr(\gamma,n)^{87}Sr^{m}$	1500	186	600
$^{86}Sr(\gamma,n)^{85}Sr^{m}$	1500	1465	600

beam of current 5 μA with an energy spread of less than 0.5%. The bremsstrahlung radiation was generated by bombarding the high energy electron beam on a tungsten target. A field size of 5 cm × 5 cm was setup by the operators at the patient table 100 cm from the source. The samples were placed in this field on the patient table. Both the Sr sample and Au monitor were irradiated simultaneously with bremsstrahlung of 15 MeV endpoint energies of dose rate 670 ± 10 cGy/min for 1500 seconds. Samples were taken to the control room after irradiation for counting. The gamma-ray activity of the irradiated samples was measured with a pre-calibrated HPGe (30%) detector one after the other. Typical recorded gamma-ray spectrum for Sr sample irradiated with bremsstrahlung of 15 MeV end point energy is shown in Fig. 2, along with the timing details. The timing details of the present experiment are given in Table 3. The nuclear data used for the reactions are given in Table 2.

3. Data analysis

3.1. Calibration and estimation of the efficiency of the HPGe detector

The calibration of the HPGe detector was carried out with a standard ^{152}Eu source of known activity (A_0 = 4336.96 ± 86.74 Bq as on 1 Oct. 1999). The absolute efficiency ε for the point

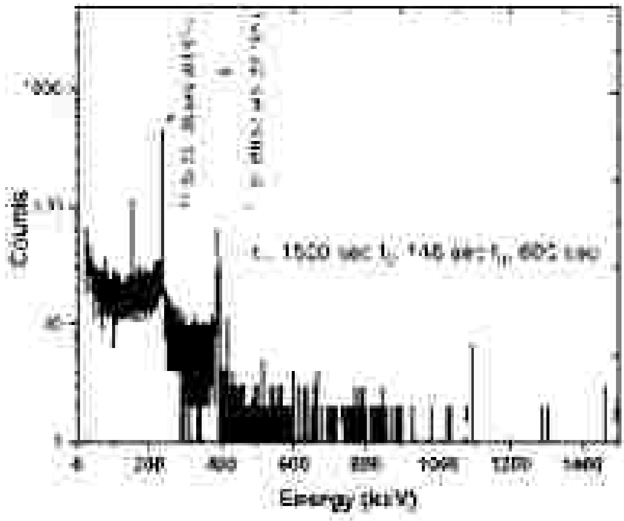

Fig. 2. The typically recorded spectrum for the Te sample irradiated by bremsstrahlung of 15 MeV end-point energy.

Table 4
HPGe detector efficiency calibration with ^{152}Eu standard source.

E_γ (keV)	I_γ (%)	C	K_C	$\epsilon(E_\gamma)$
121.78	28.53 ± 0.016	73877 ± 256	1.0468	5.859 ± 0.168
344.28	26.59 ± 0.20	36611 ± 209	1.0297	2.941 ± 0.079
778.9	12.93 ± 0.08	8768 ± 116	1.0711	1.318 ± 0.012
964.08	14.51 ± 0.07	8183 ± 103	1.0418	1.097 ± 0.027
1112.076	13.67 ± 0.08	6968 ± 107	1.0346	0.998 ± 0.026
1408.01	20.87 ± 0.09	6655 ± 97	1.0266	0.804 ± 0.019

source placed at a distance of 55 mm from the end-cap of the detector is given by the expression

$$\epsilon = \frac{C K_C}{A_0 e^{-\lambda T} I_\gamma \Delta t} \tag{1}$$

where C is the count obtained for a counting time (Δt = 3600 seconds) for a particular gamma-line of ^{152}Eu having a decay intensity I_γ. A_0 is the activity of ^{152}Eu source at the time of manufacture, T is the time between date of manufacture to the beginning of counting and K_C is the correction factor for the coincidence summing effect. Absolute efficiency was obtained from EFFTRAN code [32]. Efficiency $\epsilon(E_\gamma)$ at each of the six identified γ-rays of Eu-152 are presented in Table 4. The uncertainty in efficiency was calculated with the Taylor series expansion of detector efficiency (equation (1)) from Ref. [33]. The interpolated detector efficiency fitting curve and measured detector efficiency is plotted in Fig. 3.

The efficiencies of the detector at required points of energies were generated with a linear parametric function [34]

$$\ln \epsilon_i = \sum_m p_m (\ln E_i)^{m-1}, \quad 1 \le m \le 6 \tag{2}$$

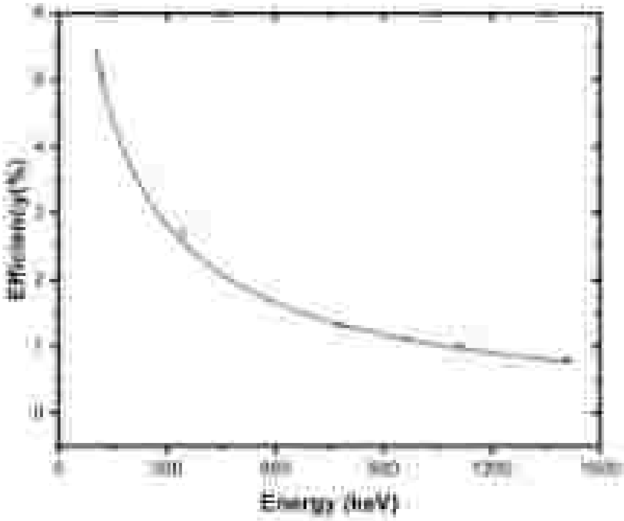

Fig. 7 Measured detector efficiency with interpolated detector efficiency curve

Table 5
Interpolated sample efficiencies with uncertainty and correlation matrix for the sample and the monitor reaction.

E_γ (keV)	Efficiency	Correlation matrix							
151.195	4.611 ± 0.059	1.000							
231.86	3.469 ± 0.044	0.977	1.000						
388.53	2.433 ± 0.035	0.932	0.956	1.000					
514.0048	1.921 ± 0.047	0.847	0.920	0.967	1.000				
762.65	1.36 ± 0.01	0.746	0.880	0.946	0.971	1.000			
843.76	1.244 ± 0.026	0.739	0.862	0.873	0.962	0.998	1.000		
898.05	1.173 ± 0.025	0.731	0.857	0.872	0.956	0.997	0.999	1.000	
1368.626	0.823 ± 0.019	0.575	0.689	0.757	0.763	0.761	0.756	0.880	1.000

The best quality of fit was achieved for m = 4, with $\chi^2_{\nu} = 1.06 \approx 1$. In order to estimate the efficiencies corresponding to γ-rays emitted from the decay of the reaction products $^{85}Sr^{m}$, ^{88}Rb, ^{85}Kr, $^{85}Sr^{g}$, $^{87}Sr^{m}$, ^{83}Sr, ^{24}Na and ^{27}Mg, the following linear parametric model was used

$$\ln \varepsilon = -4.534403 - 0.836434 \ln E + 0.067139 \ln E^2 + 0.039392 \ln E^3 \tag{3}$$

The interpolated efficiencies and the corresponding correlation matrix for characteristic γ lines for the sample and the monitor reaction are given in Table 5.

3.2. Measurement of (n,2n), (n,p) and (n,α) reaction cross sections on natural strontium target

The cross sections of $^{86}Sr(n,2n)^{85}Sr^{m}$, $^{88}Sr(n,p)^{88}Rb$, $^{88}Sr(n,\alpha)^{85}Kr$, $^{86}Sr(n,2n)^{85}Sr^{g}$, $^{88}Sr(n,2n)^{87}Sr^{m}$ and $^{84}Sr(n,2n)^{83}Sr$ reactions were measured at 14.77 ± 0.17 MeV neutron energy relative to $^{27}Al(n,\alpha)^{24}Na$ monitor reaction. The cross section was determined with the neutron activation equation [35]

$$\sigma_s = \sigma_m \frac{\varepsilon_m C_s a_m \lambda_s I_{\gamma m} M_m f_m CF_s}{\varepsilon_s C_m a_s \lambda_m I_{\gamma s} M_s f_s CF_m} \tag{4}$$

Table 6
Correction factors (CF) for self-attenuation and coincidence summing for sample and monitor.

Product nuclide	E_γ (keV)	Sample	CF
$^{87}Sr^m$	388.53	SrO_2	1.023
^{88}Rb	898.04	SrO_2	1.017
^{85}Kr	151	SrO_2	1.013
$^{85}Sr^m$	231.86	SrO_2	1.041
^{85}Sr	514.0048	SrO_2	1.017
^{83}Sr	762.65	SrO_2	1.027
^{24}Na	1368.626	Al foil	1.001
^{27}Mg	843.76	Al foil	1.003
^{196}Au	355.73	Au foil	1.053

where, the subscript s denotes sample reaction parameters and subscript m denotes the monitor reaction parameters. Here $\sigma_m = 111.5 \pm 0.42$ mb is taken from the IRDFF-II evaluated data file at 14.77 MeV. ϵ is the detector efficiency, C is the photo peak counts, a is the isotopic abundance, A atomic mass, I_γ is the branching ratio of γ-ray taken from [36], M is the mass, f is the timing factor and CF is the correction factor due to coincidence summing effects and gamma ray self-attenuation. The timing factor f is given by

$$f = \frac{(1 - e^{-\lambda t_i})(e^{-\lambda t_c})(1 - e^{-\lambda t_a})}{\lambda} \tag{5}$$

where, λ is the decay constant, t_i is the irradiation time, t_c is the cooling time and t_a is the counting time. The Coincidence summing correction factor f_c was calculated by the TrueCoinc code [37]. The total efficiency curve for the HPGe detector was obtained from the TrueCoinc code. The self-attenuation coefficients f_s due to interactions of gamma rays within the sample thickness is given by

$$f_s = \frac{\mu t}{1 - e^{-\mu t}} \tag{6}$$

where μ is the linear attenuation coefficient in cm^{-1} for the irradiated sample and t is the thickness of the sample in cm. The mass attenuation coefficient μ/ρ for individual elements (Strontium, Oxygen, Aluminium and Gold) was obtained by interpolating the curves from the NIST Standard Reference Database [38]. The μ/ρ for the compound SrO_2 was calculated using

$$(\mu/\rho)_{SrO_2} = \sum_i W_i (\mu/\rho)_i \tag{7}$$

where W_i is fraction of the ith element by weight in the compound SrO_2 and $(\mu/\rho)_i$ is the mass attenuation coefficient of the ith element. CF for induced activity in sample is given by

$$CF = f_c \times f_s \tag{8}$$

The calculated self-attenuation coefficients f_s and coincidence summing correction factor f_c are given in Table 6 for SrO_2 sample, Al and Au monitor.

The measured cross section calculated with equation (4) contains uncertainty [35] contributed by parameters observed with uncertainty. The partial uncertainties for each parameter of equation (4) and their correlations are given in Table 7 following Sec. 4.1.4 of Ref. [35]. The fractional uncertainties in atomic mass for sample and monitor are negligible.

Table 7
[illegible]

	Reaction	C_x	C_m	$I_{\gamma x}$	$I_{\gamma m}$	$\eta_{m,x}$	f_x	f_m	M_x	M_m	a_x	a_m
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(1,2)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(1,3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(1,4)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(1,5)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(1,6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(2,3)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(2,4)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(2,5)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(2,6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(3,4)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(3,5)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(3,6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(4,5)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(4,6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Cor(5,6)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 8
Correction factor (CT_φ) and the threshold energy for monitor and sample reactions

Reaction	Threshold energy (MeV)	CT_φ
$^{197}Au(\gamma,n)^{196}Au$	8.072	
$^{88}Sr(\gamma,n)^{87m}Sr$	11.113	0.34
$^{86}Sr(\gamma,n)^{85m}Sr$	11.492	0.29

3.5. Measurement of (γ,n) reaction cross sections for natural strontium target

The average cross sections of $^{88}Sr(\gamma,n)^{87m}Sr$ and $^{86}Sr(\gamma,n)^{85m}Sr$ reactions were measured using the ratio method [39] at bremsstrahlung of 15 MeV end-point energy with $^{197}Au(\gamma,n)^{196}Au$ as the monitor reaction. Here, the cross section was determined with the equation

$$\sigma_x = \langle\sigma_m\rangle \frac{CF_x \varepsilon_m C_x a_m \lambda_x I_{\gamma m} M_m f_m}{CF_m \varepsilon_x C_m a_x \lambda_m I_{\gamma x} M_x f_x CT_\varphi} \tag{9}$$

where the parameters have the same meaning as in equation (4) and I_γ is the branching ratio of γ-ray taken from Refs. [5,39,40]. CT_φ is the flux ratio used to normalise the cross sections due to the monitor and targets having different threshold energies and is given in Table 8.

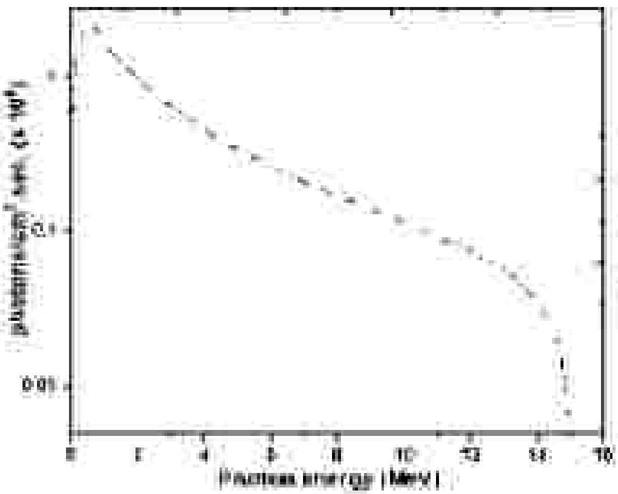

Fig. 4. GEANT4 simulated bremsstrahlung spectrum of 15 MeV end point energy.

The flux ratio is given as

$$CF_{\varphi}=\frac{\int_{E_{s}}^{E_{max}}\varphi(E)dE}{\int_{E_{m}}^{E_{max}}\varphi(E)dE} \tag{10}$$

where $E_{max}=15$ MeV, E_s is the threshold energy for the sample and E_m is the threshold energy for the sample. $\varphi(E)$ was taken from the bremsstrahlung spectrum Fig. 4 simulated using Monte Carlo based GEANT4 code [41]. The Geant4 simulations were performed by default physics models with EMStandardPhysics physics list. The bremsstrahlung photons incident on the sample surface was estimated by adopting the LINAC geometry of the experiment. The dose deposited on the patient table was correlated with the simulated dose deposit to obtain the photon flux as in Refs. [42,43].

$$\langle\sigma_{m}\rangle=\frac{\int_{E_{m}}^{E_{max}}\varphi(E)\sigma(E)dE}{\int_{E_{m}}^{E_{max}}\varphi(E)dE} \tag{11}$$

$\langle\sigma_{m}\rangle$ in equation (9) is the average value of the cross section for the monitor reaction from threshold energy to 15 MeV and $\varphi(E)$ is taken from the simulated bremsstrahlung spectrum Fig. 4 and $\sigma(E)$ is taken from interpolated cross section of ^{197}Au$(\gamma,n)^{196}$Au reaction in Ref. [44] from threshold energy for the monitor reaction to 15 MeV bremsstrahlung end point energy.

Here $\langle\sigma_{m}\rangle=159.93\pm4.76$ mb is calculated from equation (11). The partial uncertainties for each parameter of equation (9) and their correlations are given in Table 9. The fractional uncertainties in atomic mass for sample and timing factor for monitor are negligible. The fractional uncertainties of the measured cross sections were calculated as the quadratic sum of the fractional uncertainties.

4. Nuclear model calculations

The excitation functions for ^{84}Sr$(n,2n)^{83}$Sr^{m}, ^{88}Sr$(n,p)^{88}$Rb, ^{88}Sr$(n,\alpha)^{85}$Kr, ^{86}Sr$(n,2n)^{85}$Sr^{m}, ^{88}Sr$(n,2n)^{87}$Sr^{m} and ^{84}Sr$(n,2n)^{83}$Sr reactions were calculated from reaction threshold to 20 MeV

Table 9
Fractional uncertainties (%) in various parameters used to obtain cross sections.

	Reaction	C_r	C_m	f_{pr}	f_{pm}	$\varepsilon_{\gamma r}$	$I_{\gamma r}$	M_r	M_m	a_r	a_m	c_m
1	$^{88}Sr(\gamma,n)^{87m}Sr$	0.9052	2.4799	0.2477	1.4405	0.0621	0.5941	0.00	0.1	0.1614	0.0000	1
2	$^{86}Sr(\gamma,n)^{85m}Sr$	2.5866	2.4799	0.4744	1.4405	0.5549	0.4401	0.00	0.1	0.6121	0.0001	1
	Used (…)	3	1	4	1	1	1	1	1	4	1	10

with the TALYS-1.95 statistical model code [22]. The TALYS-1.95 code can be used for nuclear reactions that involve incident projectiles such as gammas, neutrons, protons, deuterons and α-particles in the incident energy range from 1 keV to 200 MeV. The TALYS-1.95 calculations of the present work are based on the contributions of the compound nucleus theory, direct reactions, optical model potentials and pre-equilibrium processes. An elaborate description of the TALYS-1.95 code can be found in Ref. [22]. Inelastic scattering for 14 MeV neutrons has both compound and direct-like components. The latter is described by the Distorted Wave Born Approximation (DWBA). At energies above the threshold of the (n,2n) channel, the direct-like components' contribution to the inelastic scattering dominates the former. There are 384 model combinations in TALYS-1.95 code. These correspond to the combinations of six level density models [45–50], two nucleon-nucleus optical model potentials [51], four pre-equilibrium models [52] and eight γ-ray strength functions [53–59]. Chi-squared validation of calculated cross sections with experimental data from the EXFOR database was done to determine a consistent parameter set [60]. The uncertainty band in the optimised parameter set was studied based on Refs. [61,62]. Here, parameters of the level density model and optical model potential were assigned an uncertainty based on the above. 1000 calculations were performed to determine the uncertainty in the excitation functions by randomly varying the value of the aforementioned parameters within the optimised parameter set between ± X% of its central value. The neutron energies were binned at intervals of 1 MeV. The statistical mean corresponding to 1000 values of cross section and the standard deviation (SD) for each energy bin was calculated. The uncertainty in theoretical calculations was expressed as the percentage SD per unit calculated cross-section per bin multiplied by 1.96 to determine the 95% confidence interval. The direct-like component was accounted for by DWBA calculations. The pre-equilibrium contributions were accounted for by the two-component exciton model [52]. The default local optical model parameters in the present work are the parameterisation of Koning and Delaroche [51]. The level densities are described by the generalised superfluid model [48]. The gamma-ray transmission coefficients are calculated through the energy-dependent gamma-ray strength function given by Brink–Axel [54,55].

The excitation functions for $^{88}Sr(\gamma,n)^{87m}Sr$ and $^{86}Sr(\gamma,n)^{85m}Sr$ were calculated for photon energies from reaction threshold to 30 MeV using TALYS-1.95 code with the default constant temperature model for calculating nuclear level densities, with the eight available gamma-ray strength functions as given below:

(1) GSF-1: Generalised Lorentzian of Kopecky and Uhl [53]
(2) GSF-2: Generalised Lorentzian of Brink and Axel [54,55]
(3) GSF-3: Hartee-Fock-BCS tables [57]
(4) GSF-4: Hartee-Fock-Bogolyubov tables [57]
(5) GSF-5: Hybrid model of Goriely [58]
(6) GSF-6: Goriely TDHFB [59]

Table 10
Measured cross-sections with the covariance matrix and correlation matrix.

Reaction	Cross-section (barns)	Covariance matrix ($\times 10^{-5}$)						Correlation matrix					
$^{88}Sr(n,2n)^{87}Sr^m$	0.2172 ± 0.0198	1.08						1					
$^{88}Sr(n,p)^{88}Rb$	0.0146 ± 0.0004	0.47	0.46					0.1	1				
$^{88}Sr(n,\alpha)^{85}Kr$	0.00127 ± 0.00012	0.61	0.4	0.06				0.07	0.01	1			
$^{86}Sr(n,2n)^{85}Sr^m$	0.2841 ± 0.0051	0.69	0.47	4.75	7.14			0.27	0.69	0.08	1		
$^{86}Sr(n,2n)^{85}Sr^g$	0.7427 ± 0.0274	0.3	0.33	0.22	9.6	13.45		0.1	0.04	0.01	0.09	1	
$^{84}Sr(n,2n)^{83}Sr$	0.6572 ± 0.0749	0.3	0.72	0.41	0.58	0.47	156.06	0.05	0.01	0.01	0.03	0.01	1

Table 11
Measured cross-sections at 14.77 ± 0.17 MeV neutron energy compared with the evaluated data of the TENDL-2019 library [27] and TALYS-1.95 calculations.

Reaction	Present work (barns)	TALYS-1.95 (barns)	TENDL-2019 (barns)
$^{88}Sr(n,2n)^{87}Sr^m$	0.2172 ± 0.0058	0.2167 ± 0.0238	0.2464
$^{88}Sr(n,p)^{88}Rb$	0.0146 ± 0.0004	0.0152 ± 0.0014	0.0145
$^{88}Sr(n,\alpha)^{85}Kr$	0.00127 ± 0.00012	0.00117 ± 0.00016	0.00127
$^{86}Sr(n,2n)^{85}Sr^m$	0.2841 ± 0.0051	0.2541 ± 0.0309	0.2857
$^{86}Sr(n,2n)^{85}Sr^g$	0.7427 ± 0.0274	0.7546 ± 0.0623	0.7741
$^{84}Sr(n,2n)^{83}Sr$	0.6572 ± 0.0749	0.5558 ± 0.0651	0.5244

(7) GSF-7: T-dependent relativistic mean field [58].
(8) GSF-8: Gogny D1M HFB + quasi-random-phase approximation [58].

5. Results and discussion

The covariance matrix and the correlation matrix of the measured neutron-induced reaction cross sections for strontium are presented in Table 10. Normalisation is carried out for earlier reported experimental data with respect to the recent evaluated cross section data for monitor cross section from the IRDFF-II [27] database. The measured cross sections for $^{88}Sr(n,2n)^{87}Sr^m$, $^{88}Sr(n,p)^{88}Rb$, $^{88}Sr(n,\alpha)^{85}Kr$, $^{86}Sr(n,2n)^{85}Sr^m$, $^{86}Sr(n,2n)^{85}Sr^g$ and $^{84}Sr(n,2n)^{83}Sr$ reactions are compared with the normalised experimental data from the EXFOR database. The measured data is also compared with the cross section reported by evaluated cross section data from the TENDL-2019 [25] library and statistical model calculations with the TALYS-1.95 nuclear code in Table 11. For all the reactions in the present study, the TALYS-1.95 calculations were done with generalised the superfluid model for level densities (ldmodel 3), the exciton model for pre-equilibrium contributions (preeqmode 2), the generalised lorentzian of Brink and Axel (strength 2) and the local nucleon nucleus potential of Koning and Delaroche (localomp y). The optimised TALYS-1.95, the cross sections from the TENDL-2019 evaluation are represented by a thin black solid line, ENDF/B-VIII.0 evaluation by a black dotted line, TALYS-1.95 95% upper confidence level by a red dotted, TALYS-1.95 95% lower confidence level by a black dashed line and the region between the above two dashed lines is filled in Fig. 3 to Fig. 8. For experimental data where monitor cross section is not available on the EXFOR database, normalisation is not performed and compared with the present work.

The covariance matrix and the correlation matrix for measured photon-induced reaction cross sections on strontium are presented in Table 12. The TENDL-2019 evaluated data is compared

Table 12
Covariance matrix and correlation matrix for measured cross sections.

Reaction	Cross section (barn)	Covariance matrix ($\times 10^{-8}$)		Correlation matrix	
^{88}Sr(γ,n)^{87}Sr^{m}	0.01166 ± 0.00093	28.274		1	
^{86}Sr(γ,n)^{85}Sr^{m}	0.01146 ± 0.00066	27.075	33.676	0.875	1

Table 13
Measured average cross section $\langle\sigma\rangle$ for ^{88}Sr(γ,n)^{87}Sr^{m} and ^{86}Sr(γ,n)^{85}Sr^{m} reactions at [illegible] MeV bremsstrahlung end-point energy.

Reaction	Present work (barn)	TALYS-1.95 calculations (barn)							
		GSF-1	GSF-2	GSF-3	GSF-4	GSF-5	GSF-6	GSF-7	GSF-8
^{88}Sr(γ,n)^{87}Sr^{m}	0.01166 ± 0.00093	0.02480	0.03141	0.04457	0.03336	0.02217	0.03136	0.02480	0.04697
^{86}Sr(γ,n)^{85}Sr^{m}	0.01146 ± 0.00066	0.02588	0.03379	0.03664	0.03775	0.02210	0.03175	0.03168	0.04744

with TALYS-1.95 calculations for eight different gamma strength functions (GSF-1 to GSF-8) and the present work is presented in Table 13.

5.1. The ^{88}Sr(n,2n)^{87}Sr^{m} reaction

In Fig. 5 the measured cross section for ^{88}Sr(n,2n)^{87}Sr^{m} reaction at 14.77 ± 0.17 MeV neutron energy is plotted along with reported experimental data from the EXFOR database and evaluated data from the TENDL-2019 library. For this reaction, Filatenkov et al. [63], Murao et al. [64], Molla et al. [65], Dabek et al. [66], Rao et al. [67], Holub et al. [68], Husain et al. [17] and Strohal et al. [19] adopted ^{27}Al(n,α)^{24}Na reaction as monitor reaction. He et al. [14] and Konno et al. [69] adopted ^{93}Nb(n,2n)^{92}Nb^{m} reaction as a monitor reaction, while Minetti et al. [70] adopted ^{63}Cu(n,2n)^{62}Cu reaction as a monitor reaction. Rao et al. [16] adopted ^{56}Fe(n,p)^{56}Mn reaction as monitor reaction. Reported cross section data are normalised at respective neutron energies with respect to IRDFF-II data for respective monitor reactions.

As shown in the Fig. 5, cross sections reported by Dabek et al. [66], Molla et al. [65], Konno et al. [69], Guozhu et al. [14] and Filatenkov et al. [71] whose neutron energies overlap with the present value are in good agreement with the present result within reported experimental uncertainty. Our measured cross section does not correspond with those reported by Zhou et al. [64], Husain et al. [17] and Minetti et al. [70]. The measured cross section is in good agreement with TALYS-1.95 calculations and the TENDL-2019 evaluation within the error bar.

5.2. The ^{88}Sr(n,p)^{88}Rb reaction

Fig. 6 shows the measured cross section for ^{88}Sr(n,p)^{88}Rb reaction at 14.77 ± 0.17 MeV neutron energy along with reported experimental data from the EXFOR database and evaluated data from the TENDL-2019 library. For this reaction, Kasugai et al. [72], Dabek et al. [66], Molla et al. [65], Tiaku et al. [73], Husain et al. [17] and Strohal et al. [19] adopted ^{27}Al(n,α)^{24}Na reaction as a monitor reaction. Guozhu-He et al. [14] adopted ^{93}Nb(n,2n)^{92}Nb^{m} reaction as monitor reaction, whereas Levkovskii et al. [74,75] adopted ^{65}Cu(n,2n)^{64}Cu reaction as monitor reaction. Gupta et al. [76], Dresler et al. [77], Rao et al. [16] and Prasad et al. [78] adopted ^{56}Fe(n,p)^{56}Mn

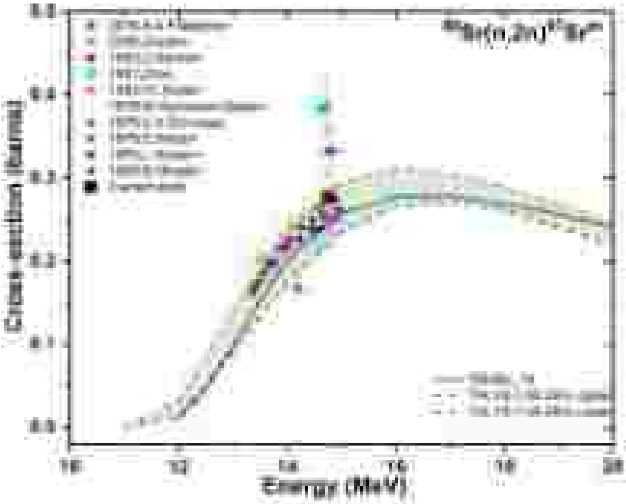

Fig. 5. Comparison of the experimental ^{88}Sr(n,2n)^{87}Sr^{m} reaction cross sections with the evaluated TENDL-2019 data and theoretical values calculated with TALYS-1.95. (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

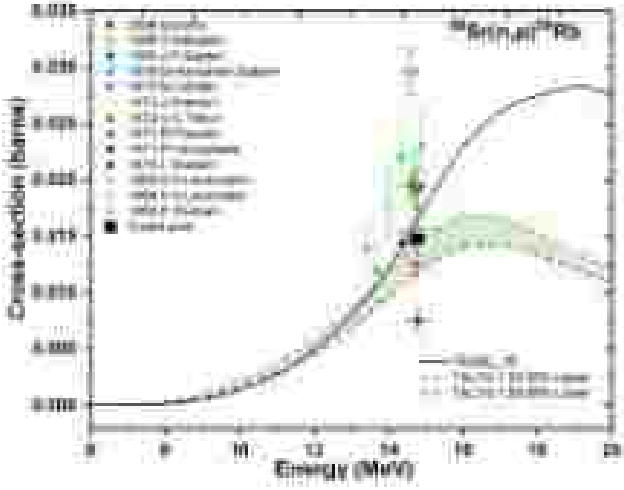

Fig. 6. Comparison of ^{88}Sr(n,p)^{88}Rb reaction experimental cross sections with the evaluated TENDL-2019 data and theoretical values using TALYS-1.95.

reaction as a monitor reaction. Reported cross section data are normalized at respective neutron energies with respect to IRDFF-II data for respective monitor reactions.

As shown in the Fig. 6, cross sections for ^{88}Sr(n,p)^{88}Rb reaction reported by Gupta et al. [76] and Levkovskii et al. [33], whose neutron energies overlap with the present value are in good agreement with the present result. The measured cross section shows a large deviation with those reported by Ghanim-Ha et al. [14], Kasugai et al. [71], Dubak et al. [66], Molla et al. [61], Dresler et al. [77], Tikku et al. [73], Prasad et al. [78], Hussain et al. [17] and Strohal et al. [19]. However,

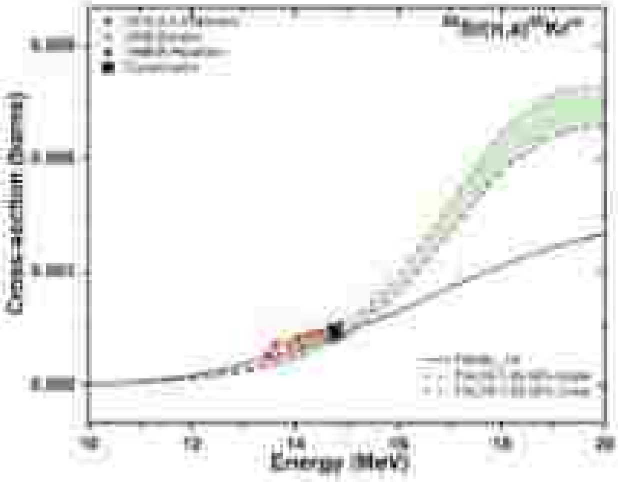

Fig. 7. Comparison of experimental $^{86}Sr(n,\alpha)^{83}Kr^m$ reaction cross sections with the evaluated TENDL-2019 data and theoretical values using TALYS-1.95.

the measured cross section is in good agreement with TALYS-1.95 calculations and the TENDL-2019 evaluation within the error bar.

3.3. The $^{86}Sr(n,\alpha)^{83}Kr^m$ reaction

In Fig. 7 the measured cross section for $^{86}Sr(n,\alpha)^{83}Kr^m$ reaction at 14.77 ± 0.17 MeV neutron energy is plotted along with reported experimental data from the EXFOR database and evaluated data from the TENDL-2019 library. For this reaction, Filatenkov et al. [63], Pepelnik et al. [76] and Strohal et al. [19] adopted $^{27}Al(n,\alpha)^{24}Na$ reaction as a monitor reaction. He et al. [14] adopted $^{93}Nb(n,2n)^{92}Nb^m$ reaction as a monitor reaction. Reported cross section data are normalised at respective neutron energies with respect to IRDFF-II data for respective monitor reactions.

The present results for $^{86}Sr(n,\alpha)^{83}Kr^m$ reaction are in good agreement with the reported experimental cross sections of Filatenkov et al. [71], Guozhu-He et al. [14] and Pepelnik et al. [76]. Moreover, the measured cross section matches with TALYS-1.95 calculations and the TENDL-2019 evaluation within the error bar.

3.4. The $^{86}Sr(n,2n)^{85}Sr^m$ reaction

Fig. 8 shows our measured cross section for $^{86}Sr(n,2n)^{85}Sr^m$ reaction at 14.77 ± 0.17 MeV neutron energy along with reported experimental data from the EXFOR database and evaluated data from the TENDL-2019 library. For this reaction, Ma Hui-Fang et al. [80], Dabek et al. [66], Rao et al. [81], Holub et al. [68], Hussain et al. [17], Frieder et al. [82] and Strohal et al. [19] adopted $^{27}Al(n,\alpha)^{24}Na$ reaction as a monitor reaction. Luo et al. [83], Guozhu-He et al. [14] and Konno et al. [69] adopted $^{93}Nb(n,2n)^{92}Nb^m$ reaction as a monitor reaction. Rao et al. [16] adopted $^{56}Fe(n,p)^{56}Mn$ reaction as monitor reaction. Reported cross section data are normalised at respective neutron energies with respect to IRDFF-II data for respective monitor reactions.

As shown in the Fig. 8, cross sections for $^{86}Sr(n,2n)^{85}Sr^m$ reaction reported by Holub et al. [68] and Strohal et al. [19], whose neutron energies overlap with the present value are in good

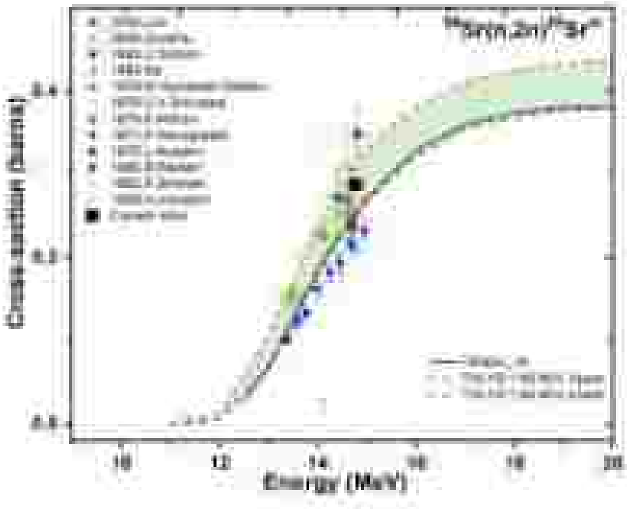

Fig. 8. Comparison of ^{86}Sr(n,2n)^{85}Sr^m reaction experimental cross sections with the evaluated TENDL-2019 data and theoretical values using TALYS-1.96.

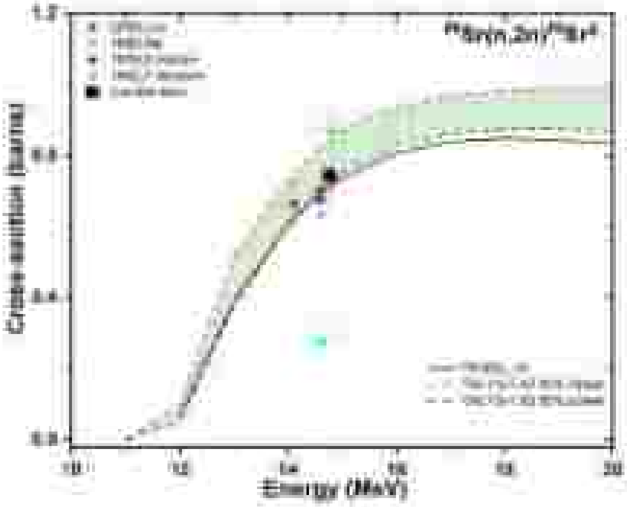

Fig. 9. Comparison of experimental ^{84}Sr(n,2n)^{83}Sr^m reaction cross sections with the evaluated TENDL-2019 data and theoretical values using TALYS-1.96.

agreement with the present result. Our measured cross section shows a large deviation with those reported by Luo et al. [53], Guozhu-He et al. [14], Konno et al. [69], Ma Hui-Fang et al. [80], Dubek et al. [66], Rao et al. [81], Rao et al. [16], Hussain et al. [17] and Rieder et al. [82]. The measured cross section is in good agreement with TALYS-1.96 calculations within the error bar, however they are higher than the evaluated excitation function by the TENDL-2019 library.

3.3. The ^{84}Sr(n,2n)^{83}Sr^m reaction

Fig. 9 shows the measured cross section for ^{84}Sr(n,2n)^{83}Sr^m reaction at 14.77 ± 0.17 MeV neutron energy along with reported experimental data from the EXFOR-database and evaluated

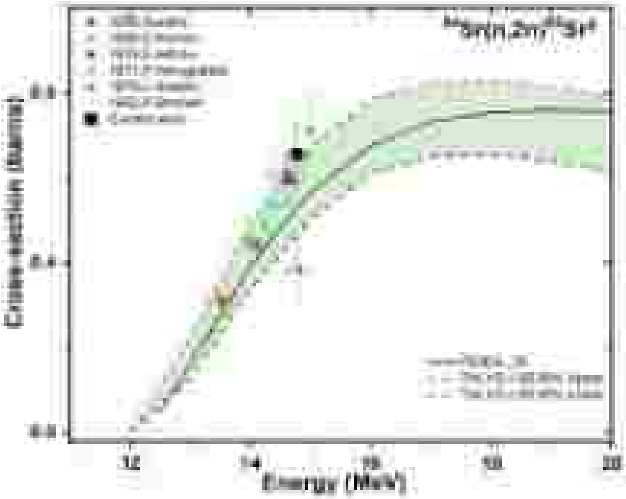

Fig. 9. Comparison of experimental $^{86}Sr(n,2n)^{85}Sr^{g}$ reaction cross sections with the evaluated TENDL-2019 data and theoretical values using TALYS-1.95.

data from the TENDL-2019 library. For this reaction, Hui-Feng et al. [80], Holub et al. [68] and Strohal et al. [19] adopted $^{27}Al(n,\alpha)^{24}Na$ reaction as a monitor reaction. Luo et al. [33], adopted $^{93}Nb(n,2n)^{92}Nb^{m}$ reaction as a monitor reaction. Reported cross section data are normalised at respective neutron energies with respect to IRDFF-II data for respective monitor reactions.

The present results for $^{86}Sr(n,2n)^{85}Sr^{g}$ reaction are in good agreement with the reported experimental cross sections of Luo et al. [33]. However, the experimental results reported by Ma et al. [80], Holub et al. [68] and Strohal et al. [19] show large deviations from our results. TALYS-1.95 calculations agree with the present results within the error bar, while the evaluated excitation function by the TENDL-2019 library predicts a lower cross section for 14.77 MeV neutron energy for the $^{86}Sr(n,2n)^{85}Sr^{g}$ reaction.

5.4. The $^{84}Sr(n,2n)^{83}Sr^{g}$ reaction

Fig. 10 shows our measured cross section for $^{84}Sr(n,2n)^{83}Sr^{g}$ reaction at 14.77 ± 0.17 MeV neutron energy along with reported experimental data from the EXFOR database and evaluated data from the TENDL-2019 library. For this reaction, He et al. [14] and Konno et al. [69] adopted $^{93}Nb(n,2n)^{92}Nb^{m}$ reaction as a monitor reaction. Rao et al. [16] adopted $^{56}Fe(n,p)^{56}Mn$ reaction as a monitor reaction. Holub et al. [68], Husain et al. [17] and Strohal et al. [19] adopted $^{27}Al(n,\alpha)^{24}Na$ reaction as a monitor reaction. Reported cross section data are normalised at respective neutron energies with respect to IRDFF-II data for respective monitor reactions.

For $^{84}Sr(n,2n)^{83}Sr^{g}$ reaction, the present results are in good agreement with Guozhu-He et al. [14], Konno et al. [69] and Holub et al. [68]. However, the present results do not agree the reported data of Husain et al. [17] and Strohal et al. [19]. The above two reported data do not follow the TENDL-2019 evaluation for the same reaction. The present results match with the general trend of the excitation function for the $^{84}Sr(n,2n)^{83}Sr^{g}$ reaction and the TALYS-1.95 calculations. The TENDL-2019 evaluation is lower than most normalised experimental data above 14 MeV neutron energy.

5.7. The $^{86}Sr(\gamma,n)^{85}Sr^{m}$ and $^{88}Sr(\gamma,n)^{87}Sr^{m}$ reactions

The average cross sections of $^{86}Sr(\gamma,n)^{85}Sr^{m}$ and $^{88}Sr(\gamma,n)^{87}Sr^{m}$ reactions have been measured relative to the cross section of $^{197}Au(\gamma,n)^{196}Au^{m}$ monitor reaction at 15 MeV Bremsstrahlung endpoint energy. The total uncertainties in the measured cross sections of $^{86}Sr(\gamma,n)^{85}Sr^{m}$ and $^{88}Sr(\gamma,n)^{87}Sr^{m}$ reactions are 5.37% and 5.81% respectively with a detailed covariance analysis. The energy dependent cross section from the TENDL-2019 library and TALYS-1.95 calculations with eight different gamma-ray strength functions have been converted to the average cross section for bremsstrahlung with end point energy of 15 MeV by using equation (11) and compared with the present result in Table 13. It is observed from the present work that for both $^{86}Sr(\gamma,n)^{85}Sr^{m}$ and $^{88}Sr(\gamma,n)^{87}Sr^{m}$ reactions, the measured average cross section is not in agreement with the TENDL-2019 evaluation and GSF-1 to GSF-8 although they are of the same order of magnitude of the present results.

6. Conclusions

Cross sections for $^{84}Sr(n,2n)^{83}Sr^{m}$, $^{84}Sr(n,p)^{84}Rb$, $^{84}Sr(n,\alpha)^{81}Kr$, $^{86}Sr(n,2n)^{85}Sr^{m}$, $^{86}Sr(n,2n)^{85}Sr^{g}$ and $^{88}Sr(n,2n)^{87}Sr$ reactions have been measured at 14.77 ± 0.17 MeV neutron energy with $^{27}Al(n,\alpha)^{24}Na$ and $^{27}Al(n,p)^{27}Mg$ as monitor reactions. In addition, the average cross sections for $^{86}Sr(\gamma,n)^{85}Sr^{m}$ and $^{88}Sr(\gamma,n)^{87}Sr^{m}$ reactions have been measured using 15 MeV bremsstrahlung photons from a medical LINAC with $^{197}Au(\gamma,n)^{196}Au$ as a monitor reaction with Activation Technique and off-line gamma-ray spectroscopy. Uncertainty in measured cross section is determined with a detailed covariance analysis. The results from the present work were compared with available normalised EXFOR experimental data and evaluated nuclear data from the TENDL-2019 library. The measured cross sections are found to be in good agreement with certain literature and statistical model calculations with the TALYS-1.95 code. The results of the present study validate nuclear model approaches with increased predictive power. The photonuclear reaction cross sections are reported for the first time at 15 MeV bremsstrahlung end point energy. The present results highlight alternative production routes for $^{85}Sr^{m}$ and $^{87}Sr^{m}$.

CRediT authorship contribution statement

T.S. Ganesapandy: Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Writing – original draft. **G.T. Bholane**: Data curation, Formal analysis, Software, Validation. **A.B. Phatangare**: Resources, Visualization. **F.M.D. Attar**: Formal analysis. **S.S. Dahiwale**: Funding acquisition, Resources. **S.V. Suryanarayana**: Conceptualization, Funding acquisition. **V.N. Bhoraskar**: Conceptualization, Project administration, Supervision. **S.D. Dhole**: Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] F. Tárkányi, A. Hermanne, F. Ditrói, S. Takács, [illegible] Eur. Phys. J. A 57 (2021) 21.
[2] [illegible] (1964) [illegible].
[3] [illegible].
[4] [illegible].
[5] [illegible] Nucl. Data Sheets [illegible].
[6] [illegible] Int. J. Appl. Radiat. Isot. [illegible].
[7] [illegible] Radiology [illegible].
[8] [illegible] Appl. Radiat. Isot. [illegible].
[9] [illegible].
[10] F. Tárkányi, [illegible] Int. J. Radiat. Appl. Instrum., Part A, Appl. Radiat. Isot. [illegible].
[11] [illegible] Radiochim. Acta [illegible].
[12] [illegible] Int. J. Appl. Radiat. Isot. [illegible].
[13] F. Tárkányi, [illegible] Int. J. Radiat. Appl. Instrum., Part A, Appl. Radiat. Isot. [illegible].
[14] [illegible] Ann. Nucl. Energy [illegible].
[15] [illegible].
[16] [illegible] Phys. Rev. C [illegible].
[17] [illegible] Phys. Rev. C [illegible].
[18] [illegible] Nucl. Phys. A [illegible].
[19] [illegible] Nucl. Phys. [illegible].
[20] [illegible] Nucl. Chem. [illegible].
[21] [illegible] J. Phys. Soc. Jpn. [illegible].
[22] [illegible] TALYS-1.0, EDP Sciences, France, 2008.
[23] A.J. Koning, [illegible] Nucl. Data Sheets [illegible].
[24] [illegible] Nucl. Data Sheets [illegible] (2014) [illegible].
[25] [illegible] Indian J. Pure Appl. Phys. [illegible].
[26] [illegible] Pramana [illegible].
[27] [illegible] Nucl. Data Sheets [illegible].
[28] Reference Neutron Activation Library, International Atomic Energy Agency, Vienna, [illegible].
[29] [illegible] Nucl. Data Sheets [illegible].
[30] [illegible] Nucl. Data Sheets [illegible].
[31] [illegible] Nucl. Data Sheets [illegible].
[32] [illegible].

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Isomeric cross sections of the *(n, α)* reactions on the ^{90}Zr, ^{93}Nb and ^{92}Mo isotopes measured for 13.73 MeV–14.77 MeV and estimated for 10 MeV–20 MeV neutron energies

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ABSTRACT

Isomeric cross sections for the $^{90}Zr(n, \alpha)^{87}Sr^m$, $^{93}Nb(n, \alpha)^{90}Y^m$ and $^{92}Mo(n, \alpha)^{89}Zr^m$ reactions were measured at five neutron energies over the range 13.73 MeV–14.77 MeV using the activation technique in combination with high resolution gamma spectrometry. In the present work, the cross sections are measured for the $^{90}Zr(n, \alpha)^{87}Sr^m$ and $^{93}Nb(n, \alpha)^{90}Y^m$ reactions are referenced to the $^{27}Al(n, \alpha)^{24}Na$ standard reaction cross section whereas those measured for $^{92}Mo(n, \alpha)^{89}Zr^m$ reaction are referenced to the $^{56}Fe(n, p)^{56}Mn$ standard reaction cross section. The cross sections for these reactions were also theoretically estimated using the EMPIRE-3.2 and TALYS 1.8 codes over the neutron energy range of 10 MeV–20 MeV and matched with the experimental cross sections by making a proper choice of the model parameters. A minimum eight different sets of these statistical model calculations were performed by using the consistent sets of model parameters along with the pre-equilibrium mechanism in addition to the direct-reaction and the statistical Hauser-Feshbach (HF) compound nucleus ones. The measured cross sections for these three reactions increase with the increase in neutron energy from 13.73 MeV to 14.77 MeV. As the proton number increased by one when we go from zirconium to niobium or from niobium to molybdenum, the probability of alpha particle emission also increases at each corresponding neutron energy. The present results indicate that the measured cross section at each neutron energy for the $^{92}Mo(n, \alpha)^{89}Zr^m$ reaction is found to be the highest as compared to the other two reactions whereas, for the $^{90}Zr(n, \alpha)^{87}Sr^m$ reaction, the measured cross section is found to be the lowest as compared to the other two reactions studied. The results obtained from the present measurement are found to be in good agreement with the calculated reaction cross section based on theoretical models and also with the work reported by earlier authors.

1. Introduction

The measurement of isomeric cross sections in the neutron-induced reactions with the use of the activation technique is an effective method for knowing mainly the details of (n, α) reactions. This work is also of importance for both the basic and applied research including nuclear technology, and most of these cross sections are given in the EXFOR database (Otuka et al., 2014). The cross sections for different nuclear reactions such as (n, p), (n, α), (n, 2n), (n, np) have remained a field of interest for the past few decades ([illegible] et al., 2018, 2014; Avrigeanu et al., 2006; [illegible] et al., [illegible]). EXFOR compilation shows that several measurements are done near 14 MeV neutron energy, however the available cross section data in literature within the neutron energy range of 13.73 MeV–14.77 MeV are very much scattered.

Measurements of cross sections for the emission of α particles in reactions induced by fast neutrons for neutron-rich nuclei with $N > 50$ for the mass region around 90 are of considerable interest in testing the nuclear models. At higher neutron energies up to 20 MeV this data is important in several fields of applications such as Accelerator-Driven Systems (ADS) for energy production and transmutation of nuclear waste, for medical therapy and in many other field. Moreover, knowledge of these cross sections for the emission of α-particle is also important for assessing the radiation damage in fusion reactors as zirconium, niobium and molybdenum are used as constituents of structural

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materials in fusion reactors (Zinkle and Busby, 2009). For example, zirconium is used in cladding of uranium fuel elements and also as a hardening agent in alloys required for nuclear reactors. Molybdenum is an excellent structural metal particularly when the operations are to be made at elevated temperatures. Moreover, it is also used for numerous applications, such as controlled nuclear fusion devices. The niobium is used as a first wall and structural material in the experimental fusion reactors. This acts as an effective microalloying element for steel. Similarly, niobium metal can increase the toughness, strength, formability and weldability of the micro alloyed steel. The alloy of niobium-zirconium is also used for fabricating fuel element claddings of the pressurized water reactors. As these elements are used in reactor technology, the cross-sections for neutron induced reactions are important. Neutron induced reaction cross sections provide the data for the evaluation of processes in these materials under irradiation in reactors and is also of particular importance in the hydrogen and helium gas production through (n, p) and (n, α) reactions.

In the present work, the activation technique has been used to measure the cross sections for the $^{90}Zr(n, \alpha)^{87}Sr^m$, $^{93}Nb(n, \alpha)^{90}Y^m$ and $^{92}Mo(n, \alpha)^{89}Zr^m$ reactions at 13.73 MeV, 14.07 MeV, 14.42 MeV, 14.68 MeV and 14.77 MeV neutron energies. All the three reactions studied have positive Q values and zero threshold energies (IAEA Nuclear Data Center). These three target nuclei in the mass region ~ 90 constitute excellent test cases for nuclear models in the neutron energy range from 10 MeV to 20 MeV.

Since many reaction channels are opened in the neutron energy range above 14 MeV, the experimental results are compared with the theoretically calculated cross-sections up to the neutron energy of 20 MeV by using global and local-parameter approaches, which take into account direct reaction, pre-equilibrium emission (PE), and statistical Hauser-Feshbach (HF) models compound nucleus considerations. The parameter databases obtained by global optimization within the computer codes EMPIRE 3.2 (Herman et al., 2007) and TALYS 1.8 (Koning et al., 2008a) and have been used over the neutron energy range from 10 MeV to 20 MeV.

Attempts were also made to use different values of the parameters like nuclear potential namely neutron and alpha particle, level density, level density parameters and nuclear models, etc., to match the theoretically estimated cross sections with the cross sections measured in the present work as well as those reported literature data compiled in EXFOR (Otuka et al., 2014). The comparison of various calculations including their sensitivity to model approaches and parameters will be complemented by an analysis of recent data measurements.

2. Experiment

2.1. Neutron irradiation

The neutron irradiation work was carried out at the 14 MeV neutron generator laboratory (Bhoraskar, 1989), Department of Physics, Savitribai Phule Pune University, Pune, India. The 14 MeV neutrons were produced by bombarding deuterium ions having an energy of 175 keV on an 8 Ci tritium target. On the tritium target, the deuterium beam had a diameter of about 4 mm and current of about 100 μA. For the study of $^{90}Zr(n, \alpha)^{87}Sr^m$, $^{93}Nb(n, \alpha)^{90}Y^m$ and $^{92}Mo(n, \alpha)^{89}Zr^m$ reactions, the samples were made from natural ZrO_2 (99.99%) powder, Nb_2O_5 (99.99%) powder and the molybdenum (14.84%) target was in the form of a metal foil respectively. For the study of all the three reactions, the samples were prepared for neutron irradiation by packing in a polyethylene bag. The polyethylene bag was folded in such a way that the size of the sample was close to 10 mm × 10 mm. Following this procedure three sets of samples were made in which each set had five samples. In each experiment performed for each reaction, the samples were irradiated with neutrons by placing them at 0°, 30°, 60°, 90° and 120° angular positions at a distance of 30 mm from the tritium target (Mandal et al., 2012).

For the measurement of $^{90}Zr(n, \alpha)^{87}Sr^m$ and $^{93}Nb(n, \alpha)^{90}Y^m$ reaction cross-sections, aluminium in the form of a metal foil (99.99%) was used as monitor element and the $^{27}Al(n, \alpha)^{24}Na$ reaction was chosen as a monitor reaction. Each respective sample (ZrO_2 and Nb_2O_5) was made by sandwiching 1 gm of element powder between two aluminium foils with total weight 0.2 gm measured with a microbalance at an accuracy of 110 μg. For the $^{92}Mo(n, \alpha)^{89}Zr^m$ reaction the molybdenum samples in the form of metal foils were used and the $^{56}Fe(n, p)^{56}Mn$ reaction was chosen as a monitor reaction. Each sample was prepared by taking 0.8 gm of molybdenum foil and 0.5 gm of Fe powder in a polyethylene bag. Five such samples for each element were placed at 0°, 30°, 60°, 90° and 120° angular positions relative to deuterium ion beam direction. The energy of neutrons at these positions correspond to 14.77 MeV, 14.68 MeV, 14.42 MeV, 14.07 MeV and 13.73 MeV (IAEA TECDOC, 2002). These samples of Zr, Nb and Mo were irradiated for a period of 3600 s, 3300 s and 600 s respectively. Two more sets of irradiations were carried out for each sample following the same procedure. After the irradiation the samples were immediately transferred to the counting room.

2.2. *Measurement of the γ-ray activity*

The induced γ-ray activities of the irradiated samples were measured with a HPGe detector. The γ-ray detection efficiency and energy calibration of this detector was performed with a Canberra make Multi Gamma Standard MGS-3 γ-ray source. Initially the γ-ray activity of the sample irradiated at 0° was measured. Later on, the γ-ray activities of the samples irradiated at 30°, 60°, 90° and 120° were measured in sequence. A total period of 30 s was kept between the end of counting the γ-ray activity of first sample and the start of counting the γ-ray activity of second sample. Accordingly, the total cooling time for each sample was accounted while estimating the actual induced γ-ray activity. The decay data of the radioisotopes $^{87}Sr^m$, $^{90}Y^m$, $^{89}Zr^m$, ^{24}Na and ^{56}Mn produced via the $^{90}Zr(n, \alpha)^{87}Sr^m$, $^{93}Nb(n, \alpha)^{90}Y^m$, $^{92}Mo(n, \alpha)^{89}Zr^m$, $^{27}Al(n, \alpha)^{24}Na$ and $^{56}Fe(n, p)^{56}Mn$ reactions respectively are given in Table 1 (National Nuclear Data Center, 2008).

The induced photo-peak activity of 0.388 MeV γ-ray from $^{87}Sr^m$ and 1.368 MeV γ-ray from ^{24}Na was measured for a period of 1200 s. The induced photo-peak activity of 0.48 MeV γ-ray from $^{90}Y^m$ and 1.369 MeV γ-ray from ^{24}Na was measured for a period of 1800 s. Similarly, the induced photo-peak activity of 0.588 MeV γ-ray from $^{89}Zr^m$ and 0.847 MeV γ-ray from ^{56}Mn was measured for a period of 60 s.

3. Data analysis

Fig. 1, Fig. 2 and Fig. 3 show the gamma-ray spectra of $^{87}Sr^m$ and ^{24}Na, $^{90}Y^m$ and ^{24}Na and $^{89}Zr^m$ and ^{56}Mn respectively, produced via neutron induced reactions. The spectra shown in these figures are background subtracted and therefore the area under each photo peak is proportional to the respective γ-ray activity induced in the sample. The activation cross sections for the $^{90}Zr(n, \alpha)^{87}Sr^m$, $^{93}Nb(n, \alpha)^{90}Y^m$ and

Table 1
The decay data of the radioisotopes produced in neutron induced reactions (National Nuclear Data Center, 2008).

Nuclear Reaction	Abundance (%)	Half-life	E_γ (MeV)	I_γ (%)
$^{90}Zr(n, \alpha)^{87}Sr^m$	51.45 ± 0.40	2.815 ± 0.012 h	0.388	82.19 ± 0.23
$^{93}Nb(n, \alpha)^{90}Y^m$	100	3.19 ± 0.06 h	0.48	90.7 ± 2.3
$^{92}Mo(n, \alpha)^{89}Zr^m$	14.649 ± 0.035	4.161 ± 0.010 m	0.588	89.62 ± 0.17
$^{27}Al(n, \alpha)^{24}Na$	100	14.997 ± 0.012 h	1.368	99.99
$^{56}Fe(n, p)^{56}Mn$	91.754 ± 0.036	2.5789 ± 0.0001 h	0.847	98.85 ± 0.30

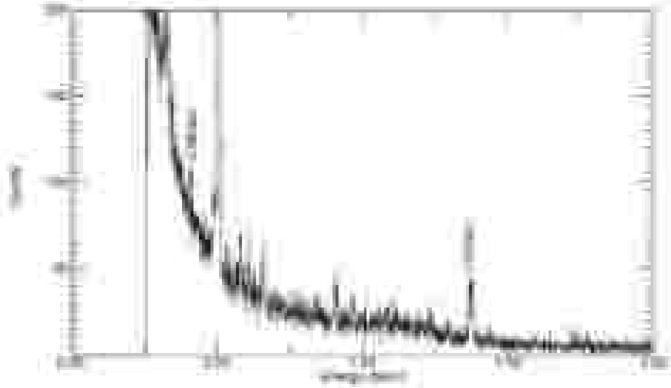

Fig. 1. γ-ray spectra of $^{89}Zr^{m}$ and ^{24}Na radio-nuclei produced by irradiating ^{90}Zr and ^{27}Al respectively with 13.73 MeV neutrons.

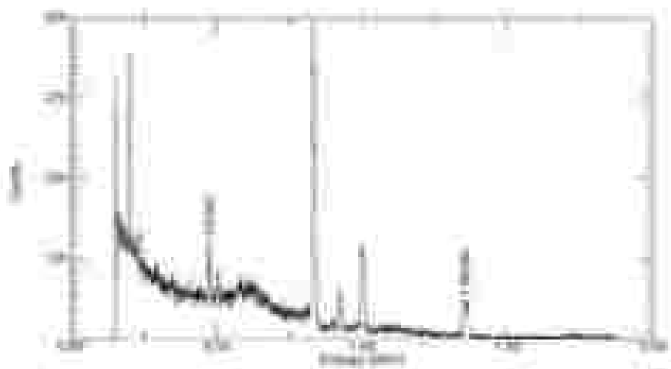

Fig. 2. γ-ray spectra of $^{90}Y^{m}$ and ^{24}Na radio-nuclei produced by irradiating ^{93}Nb and ^{27}Al respectively with 13.73 MeV neutrons.

$^{92}Mo(n, \alpha)^{89}Zr^{m}$ reactions were obtained at 13.73–14.77 MeV neutron energies using the activation formula given by the following activation equation (1).

$$\sigma_R = \sigma_M \frac{A_R \gamma_M \varepsilon_M \lambda_R}{A_M \gamma_R \varepsilon_R \lambda_M} \frac{N_M}{N_R} \left(\frac{1-e^{-\lambda_M t_i}}{1-e^{-\lambda_R t_i}}\right) \frac{e^{-\lambda_M t_c}}{e^{-\lambda_R t_c}} \left(\frac{1-e^{-\lambda_M t_m}}{1-e^{-\lambda_R t_m}}\right) \quad (1)$$

where σ_R is the isomeric reaction cross section, A is the number of counts under the photopeak, γ is the photon disintegration probability, ε is the detector efficiency, σ_M is the cross section for monitor reaction, λ is the decay constant, N is the number of atoms of the isotope of the element, t_i is the irradiation time, t_c is the cooling time, and t_m is the period for which the activity is measured. The quantity with the subscript M stands for the monitor reaction.

By considering the uncertainties involved in the measurements of each parameter, the error analysis was carried out using the quadrature method (Taylor, 1982). The flux of the low energy neutrons (E_n < 10 MeV) in the D-T reaction is about two orders of magnitude lower than that at 14 MeV (Kasugai et al., 2000). In the present work, the contributions of the low energy neutrons in the cross sections of all the three reactions studied are negligible and were therefore not taken into account. Similarly, the effects of the multiple scattering of neutrons and the inhomogeneities were also not taken into account as the errors induced by these processes are negligibly small. For different parameters, the estimated errors are as follows: (i) detector efficiency (~ 1.5%) (ii) self-absorption of gamma-rays (< 2–3%) (Mukhtar and Salam, 2004) (iii) neutron energy distribution (< 3%) (iv) absolute gamma-ray intensity (< 2.1%) and (v) reference reaction cross section of $^{27}Al(n, \alpha)^{24}Na$ (< 1.1%) (Tarasenkov et al., 1996) and reference reaction cross section of $^{56}Fe(n, p)^{56}Mn$ (2–2.7%) (Tarasenkov et al., 1996).

4. Nuclear model based reaction cross section calculations

The theoretical isomeric cross sections for the $^{90}Zr(n, 2n)^{89}Zr^{m}$, $^{93}Nb(n, \alpha)^{90}Y^{m}$ and $^{92}Mo(n, \alpha)^{89}Zr^{m}$ reactions were estimated over 10 MeV–20 MeV neutron energies by using statistical nuclear reaction models using the EMPIRE-3.2 (Herman et al., 2007) and TALYS-1.9 codes (Koning et al., 2008a) to investigate if a consistent description can be obtained by the use of these codes. The calculations were performed in the framework of the direct-reaction, PE and statistical Hauser-Feshbach (HF) models in which a minimum of eight different sets of calculations of cross sections for these three reactions were performed by considering the pre-equilibrium mechanism, namely the exciton

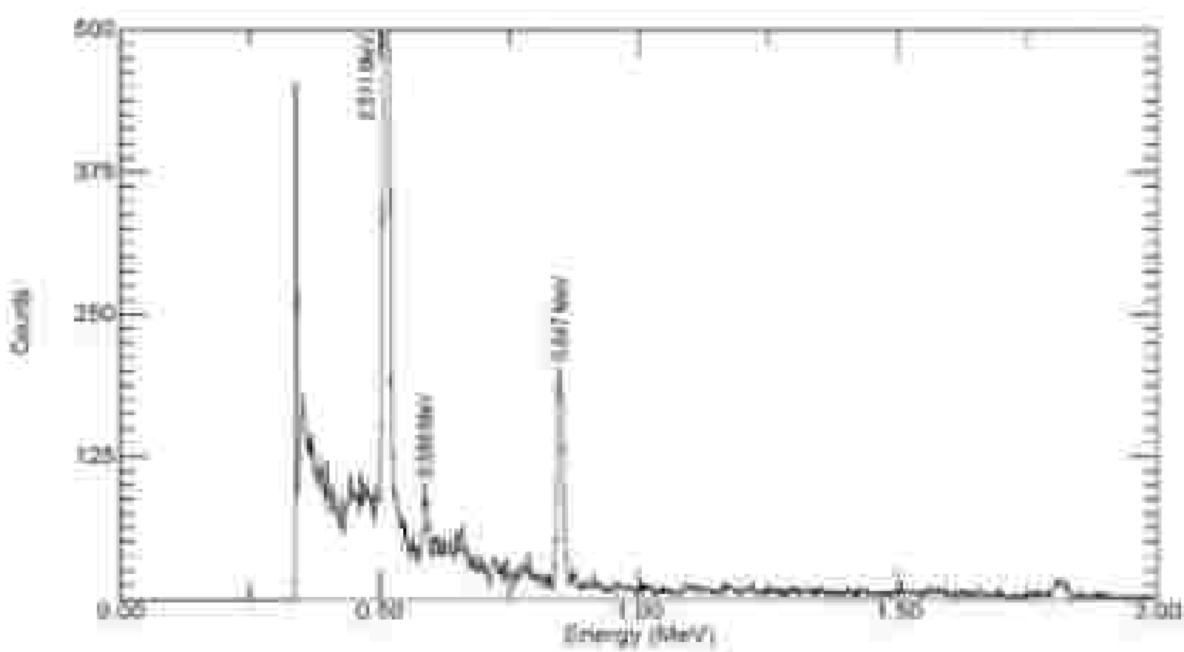

Fig. 3. γ-ray spectra of $^{89}Zr^{m}$ and ^{56}Mn radio-nuclei produced by irradiating ^{92}Mo and ^{56}Fe respectively with 13.73 MeV neutrons.

model PCROSS code (Cserpak and Kunieda, 1982) of EMPIRE-3.2 and the two-component exciton model (Koning and Duijvestijn, 2004) of TALYS-1.8. The first four sets of calculations were performed by means of the computer code EMPIRE-3.2 and the other four sets of calculations were performed by using the TALYS-1.8 code. In these codes, a number of options are available mainly for the nuclear level density, the nuclear potentials etc. Initially the choice of the parameters was made to obtain a good matching between the theoretical cross sections with those measured in the present work for neutron beam energies between 13.73 MeV and 14.77 MeV by considering the possible reaction channels depending on the compound nucleus excitation energy. Using these consistent sets of input parameters options, the theoretical cross sections of these reactions were estimated between 10 MeV and 20 MeV by the EMPIRE-3.2 and TALYS-1.8 codes, as these models make use of structure and model parameters.

4.1. The EMPIRE-3.2 code

The cross sections of the $^{90}Zr(n,\alpha)^{87}Sr^{m}$, $^{93}Nb(n,\alpha)^{90}Y^{m}$ and $^{92}Mo(n,\alpha)^{89}Zr^{m}$ reactions were estimated using the EMPIRE-3.2 code over the neutron energy range of 10 MeV–20 MeV in which all the transmission coefficients for the incident nucleon emission were calculated within the coupled channel approach using ECIS-06 (Raynal, 1994). The calculations of cross sections were carried out using the microscopic combinatorial level density by (Goriely et al., 2007) obtained from the Hartree-Fock-Bogoliubov method and considering the pre-equilibrium mechanism as defined in the exciton model (Griffin, 1966) as implemented in PCROSS code (Cserpak and Kunieda, 1982). While employing the exciton model, the calculations were performed by choosing the values 1.5 (default) and 2 for the mean free path multiplier namely the MFP parameter. Moreover, in these calculations, for each MFP parameter value, the optical potentials for incident neutrons given by Koning (Koning and Delaroche, 2003) and by Strohmaier (1981) were separately used along with the alpha potential given by Avrigeanu (Avrigeanu et al., 1994) for the outgoing alpha particle. Hence there are two sets for each MFP value chosen in PCROSS code and each set of model parameters was used for estimating the cross sections over the neutron energy range of 13.73 MeV–14.77 MeV. Moreover for the $^{93}Nb(n,\alpha)^{90}Y^{m}$ reaction, the calculations were also performed by considering multistep compound model (Nishioka et al., 1986) along with the MFP parameter values 1.5 and 2 in the PCROSS code.

A comparison between the estimated cross sections with those measured in the present work provided important information about the best option of the input parameters available. Using all these best options of the input parameters and their combinations, the cross sections for the $^{90}Zr(n,\alpha)^{87}Sr^{m}$, $^{93}Nb(n,\alpha)^{90}Y^{m}$ and $^{92}Mo(n,\alpha)^{89}Zr^{m}$ reactions were successfully reproduced from 10 MeV to 20 MeV neutron energy using the EMPIRE-3.2 code.

4.2. The TALYS-1.8 code

The TALYS-1.8 code was also used for estimating the cross sections for the $^{90}Zr(n,\alpha)^{87}Sr^{m}$, $^{93}Nb(n,\alpha)^{90}Y^{m}$ and $^{92}Mo(n,\alpha)^{89}Zr^{m}$ reactions over the neutron energy range of 10 MeV–20 MeV in which all the optical model calculations were performed by ECIS-06 (Raynal, 1994). The calculations of the cross sections for these reactions were carried out using the level density model by (Hilaire et al., 2012), which uses temperature dependent combinatorial level densities with the D1M Gogny force given by Hartree-Fock-Bogoliubov calculations. Moreover these calculations were performed implementing the preequilibrium mechanism via the exciton model (Koning and Duijvestijn, 2004) and by using the local, global optical model parameters of neutrons as given by Koning (Koning and Delaroche, 2003) and for the alpha particle as given by Avrigeanu (Avrigeanu et al., 1994). For all three reactions, the calculations were performed using a sensitive parameter for the alpha particle emission namely Cstrip (Kalbach, 2005) with the assigned values of 1.6 and 1.8. For each value of Cstrip, two sets of calculations were performed, one by using the neutron local potential and the other set by using the neutron global potential. Moreover for the $^{93}Nb(n,\alpha)^{90}Y^{m}$ reaction, the calculations were also performed by considering the additional parameters colldamp (Hilaire et al., 2012; Koning et al., 2008a) and complexal (Gilbert and Cameron, 1965) along with a Cstrip value of 2.04.

Initially, the calculations were carried out using all the input parameters mentioned above to find out the consistent best option set. The parameters that produced theoretical cross sections close to those measured over 13.73 MeV–14.77 MeV were used for estimating the cross sections for the $^{90}Zr(n,\alpha)^{87}Sr^{m}$, $^{93}Nb(n,\alpha)^{90}Y^{m}$ and $^{92}Mo(n,\alpha)^{89}Zr^{m}$ reactions from 10 MeV to 20 MeV neutron energy.

5. Results and discussion

The experimental cross sections for the $^{90}Zr(n,\alpha)^{87}Sr^{m}$, $^{93}Nb(n,\alpha)^{90}Y^{m}$ and $^{92}Mo(n,\alpha)^{89}Zr^{m}$ reactions were obtained over the neutron energies of 13.73 MeV–14.77 MeV by substituting the values of all the experimental parameters and constants in the activation expression (1) and the values of the cross sections for each reaction under study are given in Table 2. It is evident from Table 2 that, the cross sections of (i) $^{90}Zr(n,\alpha)^{87}Sr^{m}$ reaction varies from 3 mb to 4.2 mb, (ii) $^{93}Nb(n,\alpha)^{90}Y^{m}$ reaction varies from 5 mb to 7 mb and (iii) $^{92}Mo(n,\alpha)^{89}Zr^{m}$ reaction varies from 5.8 mb to 8 mb.

The theoretical cross sections for the $^{90}Zr(n,\alpha)^{87}Sr^{m}$, $^{93}Nb(n,\alpha)^{90}Y^{m}$ and $^{92}Mo(n,\alpha)^{89}Zr^{m}$ reactions obtained using EMPIRE-3.2 and TALYS-1.8 are given in Table 3, Table 4 (a and b) and Table 5 respectively. In the present work, most of the theoretically estimated cross sections for the three reactions studied are close to the measured cross-sections within the experimental error bar.

On comparing the theoretically estimated isomeric cross sections with the respective measured isomeric cross sections given in Table 2, it is observed that the cross sections estimated by the EMPIRE-3.2 code using the MFP parameter value 2 and that estimated by the TALYS-1.8 code using the Cstrip parameter with a value of 1.8 are in good agreement with the corresponding isomeric cross sections measured in the present work from 13.73 MeV to 14.77 MeV as compared to the other sets of input parameter options used. Using the consistent set of input parameters given in Table 3, the cross sections of the $^{90}Zr(n,\alpha)^{87}Sr^{m}$ reaction were also estimated using EMPIRE-3.2 and TALYS-1.8 codes and the results are given in Fig. 4. In addition, the cross sections measured in the present work and those reported in literature (Bormann and Feddersen, 1965; ...; Zupranska et al., 1978) are also plotted in Fig. 4. The plots in Fig. 4 show that, the theoretical cross sections obtained using almost all the best options of input model parameters of the EMPIRE-3.2 and TALYS-1.8 codes mentioned in Table 3 are in good agreement with the cross sections measured in the

Table 2
Measured cross sections of the $^{90}Zr(n,\alpha)^{87}Sr^{m}$, $^{93}Nb(n,\alpha)^{90}Y^{m}$ and $^{92}Mo(n,\alpha)^{89}Zr^{m}$ reactions over 13.73 MeV–14.77 MeV neutron energies.

Neutron energy (MeV)	Measured isomeric cross section (mb)		
	$^{90}Zr(n,\alpha)^{87}Sr^{m}$	$^{93}Nb(n,\alpha)^{90}Y^{m}$	$^{92}Mo(n,\alpha)^{89}Zr^{m}$
13.73 ± 0.11	3.0 ± 0.2	5.0 ± 0.4	5.8 ± 0.3
14.27 ± 0.11	3.4 ± 0.2	5.2 ± 0.5	6.3 ± 0.3
14.42 ± 0.12	3.7 ± 0.2	5.8 ± 0.5	6.8 ± 0.4
14.68 ± 0.08	4.0 ± 0.3	6.1 ± 0.6	7.0 ± 0.4
14.77 ± 0.08	4.2 ± 0.3	7.0 ± 0.6	8.0 ± 0.4

Table 3
Cross sections for ^{90}Zr(n, α)^{87}Sr^{m} reaction estimated over 13.73 MeV–14.77 MeV neutron energies using EMPIRE-3.2 and TALYS 1.8 codes along with cross sections measured in the present work.

Neutron energy (MeV)	Measured isomeric cross section (mb)	Theoretical isomeric cross section (mb)							
		EMPIRE-3.2				TALYS 1.8			
		LDF 1.8		LDF 2		Ctable a 1.8		Ctable a 1.8	
		neutron potential by Strohmaier	neutron global potential by Koning	neutron potential by Strohmaier	neutron global potential by Koning	neutron local potential by Koning	neutron global potential by Koning	neutron local potential by Koning	neutron global potential by Koning
13.73	2.0 ± 0.2	2.10	2.72	2.26	2.68	2.49	2.57	2.69	2.72
14.07	2.4 ± 0.2	2.26	2.92	2.36	2.84	2.94	3.02	3.13	3.25
14.42	2.7 ± 0.2	2.60	3.14	2.64	3.19	3.26	3.36	3.45	3.56
14.68	4.0 ± 0.2	2.80	3.32	2.89	3.42	3.59	3.83	3.81	4.02
14.77	4.2 ± 0.2	2.88	3.42	2.97	3.51	3.84	3.86	4.07	4.17

Table 4a
Cross sections for ^{93}Nb(n, α)^{90}Y^{m} reaction estimated over 13.73 MeV–14.77 MeV neutron energies using EMPIRE-3.2 code along with cross sections measured in the present work.

Neutron energy (MeV)	Measured isomeric cross section (mb)	Theoretical isomeric cross section (mb) using EMPIRE-3.2 code							
		LDF 1.8				LDF 2			
		LDSC 2		LDSC 1		LDSC 2		LDSC 1	
		neutron potential by Strohmaier	neutron global potential by Koning	neutron potential by Strohmaier	neutron global potential by Koning	neutron potential by Strohmaier	neutron global potential by Koning	neutron potential by Strohmaier	neutron global potential by Koning
13.73	5.0 ± 0.4	4.17	3.59	4.33	3.73	4.17	3.59	5.05	4.48
14.07	5.5 ± 0.5	4.25	3.66	4.43	3.84	4.25	3.66	5.25	4.50
14.42	5.9 ± 0.5	4.21	3.64	4.42	3.81	4.21	3.64	5.28	4.54
14.68	6.1 ± 0.5	4.22	3.63	4.42	3.83	4.22	3.63	5.32	4.59
14.77	7.0 ± 0.6	4.22	3.65	4.43	3.85	4.23	3.62	5.37	4.72

Table 4b
Cross sections for ^{93}Nb(n, α)^{90}Y^{m} reaction estimated over 13.73 MeV–14.77 MeV neutron energies using TALYS 1.8 code along with cross sections measured in the present work.

Neutron energy (MeV)	Measured isomeric cross section (mb)	Theoretical isomeric cross section (mb) using TALYS 1.8 code					
		Ctable a 0.04 + colldamp + omglobal		Ctable a 1.8 + colldamp + omglobal		Ctable a 1.8 + colldamp + omglobal	
		neutron local potential by Koning	neutron global potential by Koning	neutron local potential by Koning	neutron global potential by Koning	neutron local potential by Koning	neutron global potential by Koning
13.73	5.5 ± 2.4	5.88	5.88	25.55	25.50	28.11	26.59
14.07	5.5 ± 2.6	6.11	6.07	27.33	26.99	29.73	29.67
14.42	5.3 ± 2.6	6.74	6.68	28.62	28.34	31.40	31.35
14.68	6.1 ± 2.6	7.13	7.06	29.20	28.13	32.02	31.88
14.77	7.5 ± 2.6	7.09	7.02	29.13	29.01	31.82	32.24

Table 5
Cross sections for ^{92}Mo(n, α)^{89}Zr^{m} reaction estimated over 13.73 MeV–14.77 MeV neutron energies using EMPIRE-3.2 and TALYS 1.8 codes along with cross sections measured in the present work.

Neutron energy (MeV)	Measured isomeric cross section (mb)	Theoretical isomeric cross section (mb)							
		EMPIRE-3.2				TALYS 1.8			
		LDF 1.8		LDF 2		Ctable a 1.8		Ctable a 1.8	
		neutron potential by Strohmaier	neutron global potential by Koning	neutron potential by Strohmaier	neutron global potential by Koning	Koning neutron local potential	neutron global potential by Koning	Koning neutron local potential	neutron global potential by Koning
13.73	5.8 ± 0.3	6.16	5.40	6.28	5.61	5.68	5.60	6.52	6.50
14.07	6.2 ± 0.3	6.53	5.72	6.63	6.04	6.62	6.60	7.12	7.09
14.42	6.8 ± 0.4	6.88	6.05	7.02	6.40	7.22	7.20	7.78	7.72
14.68	7.2 ± 0.4	7.04	6.21	7.18	6.62	7.68	7.63	8.30	8.23
14.77	8.0 ± 0.4	7.13	6.29	7.28	6.75	7.90	7.86	8.48	8.42

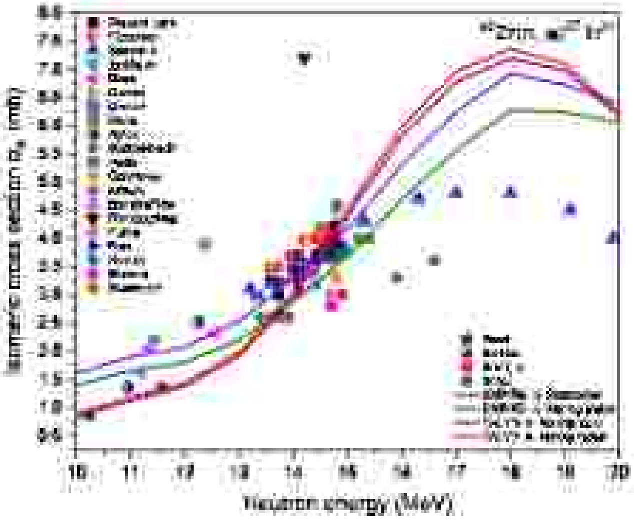

Fig. 4. Cross sections for ^{90}Zr(n, α)^{87}Sr^m reaction at different neutron energies (i) measured in the present work and (ii) estimated over 10 MeV–20 MeV neutron energies using consistent set of input model parameters of EMPIRE-3.2 and TALYS 1.8 codes in the present work. A few literature cross sections are plotted for comparison.

present work as well as with most of those reported in literature ([illegible] et al., 1988; [illegible] and [illegible], 1962; [illegible] et al., 1998; [illegible], 2014; [illegible] et al., 1977; [illegible] et al., 2007; [illegible] et al., 1993; [illegible] et al., 1978; Din Majah et al., 2003; [illegible] et al., 1968; Marcinkowski et al., 1990; [illegible] et al., 1961; [illegible] and [illegible], 1963; [illegible], 1996; [illegible] et al., 1963; [illegible], 1960; [illegible] et al., 1977; [illegible] et al., 2010; [illegible] and [illegible], 1975) between 10 MeV and 16.2 MeV.

The cross sections measured by Semkova (Semkova et al., 2010) above 16.8 MeV are found to be lower than those estimated theoretically using both codes, whereas the cross sections measured by DinMajah (Din Majah et al., 2003) at 13.37 MeV and by Srinivasalu (Srinivasa Rao et al., 1978) at 14.2 MeV are found to higher than the theoretically estimated cross sections. Moreover, the cross sections measured by Marcinkowski (Marcinkowski et al., 1990) at 15.6 MeV and at 16.6 MeV, by Bramlitt (Bramlitt and Fink, 1963) and by Bealley Jr (Bealley et al., 1968) are found to be lower as compared to the theoretically estimated values. The overall picture shows a well determined production cross section of the ^{87}Sr^m isomer for the (n, α) reaction on ^{90}Zr.

The cross sections for the ^{93}Nb(n, α)^{90}Y^m reaction were calculated using some additional parameters available in both codes as compared to the set of input parameters which were used for the other two (n, α) reactions of the present study. This is mainly because the theoretical cross sections for this reaction obtained using EMPIRE-3.2 or TALYS-1.8 are found to be much lower or much higher than the presently measured cross sections respectively.

Table 4-a gives a summary of the cross sections for the ^{93}Nb(n, α)^{90}Y^m reaction measured in the present work and estimated using the EMPIRE-3.2 code. It is observed from Table 4-a that the variation in the obtained isomeric cross sections is very small using all the options of the input parameters used in the theoretical calculations as compared to the variation in the measured isomeric cross sections, which is 2 mb over the whole neutron energy range. In the present work, out of all the input parameter options used in the theoretical calculations, only the option with MFP 2 and MSC 1 renders the theoretical cross-section values close to the measured ones at 13.73 MeV and 14.57 MeV. For the remaining three higher neutron energies, the theoretical cross sections are found to be lower than the corresponding measured ones. Similarly, Table 4-b gives a summary of the cross sections for the ^{93}Nb(n, α)^{90}Y^m reaction measured in the present work and estimated using the TALYS-1.8 code by considering the different values for the Cstrip parameter along with soukhovitskii, strength and the neutron local as well as global potentials by Koning. It is observed from Table 4-b that the cross-sections obtained using the Cstrip parameter value 3.04 are close to the one measured in the present work as compared to any other set of input parameter options which resulted very large values at each neutron energy.

Similarly, using the consistent set of the input parameters given in Table 4-a and Table 4-b, the cross sections of the ^{93}Nb(n, α)^{90}Y^m reaction were estimated using EMPIRE-3.2 and TALYS-1.8 codes and the results are shown in Fig. 5. In addition, the cross sections measured in the present work and those reported in literature ([illegible] et al., 1961; [illegible] et al., 1988; Bramlitt and Fink, 1963; [illegible] et al., 1998; [illegible] et al., 2000; Filatenkov, 2016; [illegible] et al., 1979; [illegible] et al., 2000; Harper and Alford, 1982; [illegible] et al., 1970; [illegible] et al., 1988; [illegible] et al., 1977; Kim et al., 1996; Levkovskii et al., 1970; Lu et al., 1970; [illegible] and Qaim, 1988; [illegible] et al., 1991; [illegible] et al., 2019; [illegible] and [illegible], 1981; [illegible], 1976; Wölfle et al., 1988) are also plotted in Fig. 5. The plots in Fig. 5 show that, the theoretical cross sections obtained using almost all the four options of input model parameters of EMPIRE-3.2 and TALYS-1.8 codes mentioned in Table 4-a and Table 4-b are close to the cross sections measured in the present work within the uncertainties as well as to most of those reported in literature ([illegible] et al., 1961; [illegible] et al., 1988; Bramlitt and Fink, 1963; [illegible] et al., 1998; [illegible] et al., 2000; Filatenkov, 2016; [illegible] et al., 1979; [illegible] et al., 1998; Harper and Alford, 1982; [illegible] et al., 1970; [illegible] et al., 1988; [illegible] et al., 1977; Kim et al., 1996; Lu et al., 1970; [illegible] and Qaim, 1988; [illegible] et al., 1991; [illegible] et al., 2019; [illegible] and [illegible], 1981; [illegible], 1976; Wölfle et al., 1988) between 10 MeV and 19 MeV. The cross sections measured by Wölfle (Wölfle et al., 1988) between 12.55 MeV and 13.33 MeV and above 18.5 MeV are found to be higher than those estimated theoretically using both codes. However, the cross sections measured by Wölfle between 15.8 MeV and 17 MeV lies between the theoretical cross sections estimated using both codes. Moreover, the cross sections measured by Levkovskii (Levkovskii et al., 1970) are found to be lower than the theoretically estimated cross sections. The overall picture shows a well determined production cross section of the ^{90}Y^m isomer for the (n, α) reaction on ^{93}Nb.

Table 5 gives a summary of the cross sections for ^{90}Zr(n, α)^{87}Sr^m reaction measured in the present work and estimated theoretically. On comparing the theoretically estimated cross sections with the respective

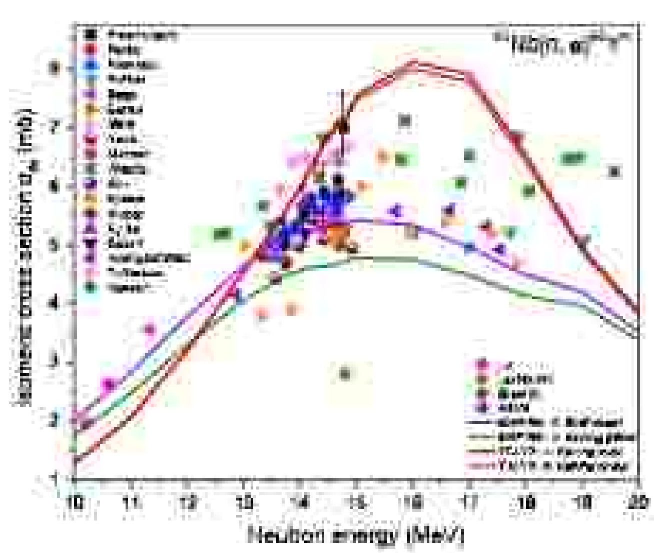

Fig. 5. Cross sections for ^{93}Nb(n, α)^{90}Y^m reaction at different neutron energies (i) measured in the present work and (ii) estimated over 10 MeV–20 MeV neutron energies using consistent set of input model parameters of EMPIRE-3.2 and TALYS 1.8 codes in the present work. A few literature cross sections are plotted for comparison.

measured ones given in Table 5, it is observed that the agreement is quite satisfactory as compared to any other set of input parameter options used.

Using the consistent set of input parameters given in Table 5, the theoretical cross sections of the ^{92}Mo(n, α)^{89}Zr^{m} reaction are shown in Fig. 6. In addition, the cross sections measured in the present work and those reported in literature (Amemiya et al., 1982; Filatenkov, 2016; Fujino et al., 1977; Garlea et al., 1992; Hasan et al., 1972; Ikeda et al., 1988; Kanda, 1972; Lu et al., 1970; Marcinkowski et al., 1986; Qaim et al., 1974; Rao et al., 1981; Reimer et al., 2005; Sigg and Kuroda, 1975) are also plotted in Fig. 6. The plots in Fig. 6 show that, the theoretical cross sections obtained using almost all the best options of input model parameters of EMPIRE-3.2 and TALYS-1.8 codes mentioned in Table 5 are also in good agreement with most of those reported in literature (Amemiya et al., 1982; Filatenkov, 2016; Ikeda et al., 1988; Marcinkowski et al., 1986; Sigg and Kuroda, 1975) between 13 MeV and 15.5 MeV. The cross sections measured by Reimer (Reimer et al., 2005), Garlea (Garlea et al., 1992), Srinivasan (Rao et al., 1981), Fujino (Fujino et al., 1977), most of the measured cross sections by Kanda (1972), Hasan (Hasan et al., 1972) and Qaim (Qaim et al., 1974) are found to be lower than those estimated theoretically using both codes as well as earlier works mainly. In addition, the cross section measured by Lu (Lu et al., 1970) is found to be higher than those estimated theoretically using both codes. The overall picture shows a well determined production cross section of the ^{89}Zr^{m} isomer for the (n, α) reaction on ^{92}Mo.

From the results shown in Figs. 4–6, it can be observed that the theoretical cross sections for all the three reactions studied are found to decrease around and above 17 MeV as other reaction channels are beginning to emerge.

The measured cross sections for these three reactions increase with the increase in neutron energy. Moreover, from the results of Table 2 it is quite interesting to know that, as the proton number increased by one when we go from zirconium to niobium or from niobium to molybdenum, the probability of alpha particle emission also increased with the neutron energy. The present results indicate that the measured cross section at each neutron energy for the ^{92}Mo(n, α)^{89}Zr^{m} reaction is found to be the highest as compared to the other two reactions whereas, for the ^{90}Zr(n, α)^{87}Sr^{m} reaction it is found to be the lowest as compared to the other two reactions studied. This is mainly due to the increase in coulomb repulsion between the protons as we go from zirconium to molybdenum via niobium, because the percentage increase in the proton number is quite large as compared to percentage increase in the number of neutrons in a target nucleus which are responsible for compensating the coulomb repulsion between the protons. Therefore, these cross sections for the emission of α particles in these three reactions induced by fast neutrons for neutron-rich nuclei with $N = 50$ in the mass region ~ 90 are found to be useful in testing the nuclear models. The results obtained from the measurement are compared with new model calculations and also with works by other authors and good agreement was found to exist between the experimental data and the new model calculations.

4. Conclusions

The isomeric cross sections for the ^{90}Zr(n, α)^{87}Sr^{m}, ^{93}Nb(n, α)^{90}Y^{m} and ^{92}Mo(n, α)^{89}Zr^{m} reactions were measured at five neutron energies over the range of 13.73 MeV–14.77 MeV, using the neutron activation technique. The results obtained were compared with new model based calculated values and also with earlier works reported by other authors and were found to be in good agreement. The measured cross sections increase with the neutron energy from 13.73 MeV to 14.77 MeV. From the results of the present study, it can be concluded that as the proton number increases by one, from zirconium to niobium, or from niobium to molybdenum, the probability of alpha particle emission also increases at each corresponding neutron energy. Moreover, the theoretical cross-

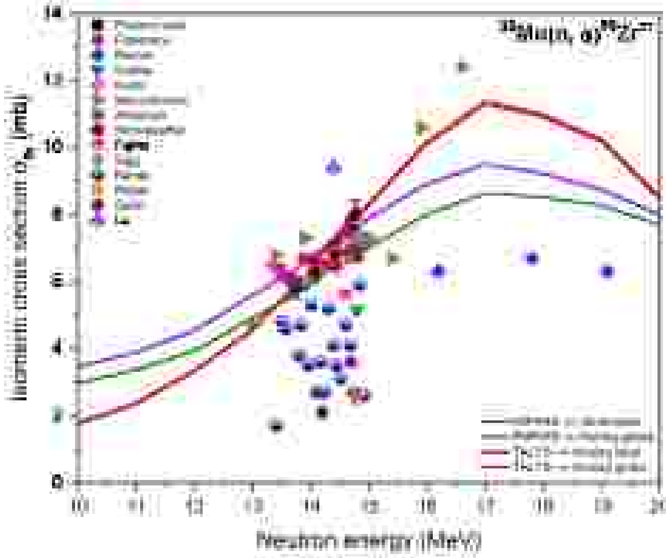

Fig. 6. Cross sections for ^{92}Mo(n, α)^{89}Zr^{m} reaction at different neutron energies (i) measured in the present work and (ii) estimated over 10 MeV–20 MeV neutron energies using consistent set of input model parameters of EMPIRE-3.2 and TALYS-1.8 codes in the present work. A few literature cross sections are plotted for comparison.

sections obtained using the mean free path multiplier namely MFP for EMPIRE-3.2 and those obtained using a sensitive parameter for alpha particle emission, namely Cstrip for TALYS-1.8, plays an important role in getting the cross-section values close to the measured ones in the present work. These experimental results are important for reactor technology applications and constitute an addition to the EXFOR database.

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F. M. D. Attar: Methodology; Data curation; Writing - original draft; Software; Project administration; Funding acquisition.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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NO OBJECTION CERTIFICATE

This is to certify that **Dr. Zakir Mohammed [illegible] Attar** working as an Assistant Professor in Physics at Poona College, Pune is associated with **Research Centre of Physics**, Haribhai V. Desai College, Pune to guide **Ph.D.** students.

We do not have any objection about him for guiding *M.Phil. Ph.D.* students in our research centre.

Hence, eligibility and financial aspects are as per the norms of our institute and Savitribai Phule Pune University (SPPU), Pune.

This letter is provided for your information.

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Effect of low energy argon ion irradiation on work function of AISI 304L stainless steel

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Abstract
The effect of low-energy Ar^+ ion irradiation on the work function of stainless steel AISI 304L (SS-304L) was studied by varying energy and fluence of Ar^+ ion. The irradiation of Ar^+ ions on stainless steel creates several vacancies in the target material which resulted a change in work function. The retarding field diode method was used for the measurement of work function. Results reveal work function decreases with an increase in ion energy (for fixed ion fluence) of irradiated Ar^+ ion. Furthermore, it was observed that at varying ion fluence (for fixed ion energy) the decrease in work function value was more prominently, but at higher fluence, it again increases. In both (energy and fluence) cases of irradiation, the displacement per atom (DPA) in the material has been estimated with the stopping range using the SRIM-2013.00 program and is correlated with the experimental observation. Overall, the maximum work function was observed to be decreased by ~ 7.28% relative to the pristine sample in the case of fluence variation keeping the energy constant at 30 keV. The results indicate that low-energy ion irradiation can be utilized for work function modulation of materials and can be optimized by controlling ion fluence. The results are useful for further understanding of corrosion rate of materials and the data are extremely important for various nuclear reactors, where these materials are used.

Keywords Low energy ion irradiation · DPA · Work function · SS-304L

1 Introduction

Stainless Steel is an important material for many decades due to its good stability, specific material properties, easy fabrication, broad applicability in circuital parts, etc. Due to the long durability and stability of stainless steel, it has a very high demand in metallurgical processes, construction, various engineering applications, etc. [1, 2]. However, Stainless steel is a corrosive metal when it comes in contact with a humid environment. M. Stratmann et al. investigated the kinetics of corrosion rate and corrosion potential of the metals, such as iron and steel, during drying of wetted metal surfaces. They have shown if the surface kept in humid environment the voltage drop across the oxide scale formed on top of the iron surface is small as a result corrosion rate changes [3]. M. Briceno et al. reported ion irradiation on 304 stainless steel which forms defects on the mobility of dislocations, dislocation sources and newly generated dislocations. In this work they have reported that mobility of dislocations is altered due to ion irradiation and in depth analysis is given for the same [4]. The content of Chromium (Cr) and Nickel (Ni) in stainless steel is responsible for its superior corrosion resistance [5]. Austenitic stainless steel used in biomaterials engineering application. Reports are available on the measurements made for the corrosion resistance with electropolishing methods for austenitic stainless steel [6, 7]. To protect from corrosion of austenitic stainless

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steel, electrochemical treatment was also been used [8]. Earlier, Akos Horvath et al. investigated the behaviour of work function for the stainless steel material by H^+ and Ar^+ ions irradiation. It was found that the stability of corrosion depends on the work function of the material as well as on the projectile ion species [9]. Controlling the corrosion rate is of prime importance from the application point of view.

The metal or semiconductors when exposed to high energy radiation leads to the formation of lattice defects, such as vacancies as well as dislocation loops near the interface. As a result of which materials properties may get altered [10–12]. G. D. Tolstolutskaya et al. studied the nano hardness and microstructural changes in SS-316 austenitic stainless steel by influence of different gaseous (hydrogen, helium, argon) ion irradiation. They found that regardless of the type of incident energetic ions; the formation of radiation-induced dislocation structure is responsible for hardening of the steel [13]. They further extended their work for the swelling behavior of 18Cr10NiTi austenitic stainless steel irradiated with energetic Ar^+ ions which shows changing behavior of microstructure and swelling occur after 0.7–1.4 MeV Ar^+ irradiations in the temperature range of 550–700 °C to doses between of 40 and 105 DPA. He revealed that microstructure strongly based on Ar^+ concentration, implantation temperature and level of displacements per atom [14]. The heavy ion irradiation causes a change in the magnetic properties of the soft magnetic alloys as a result of a reduction in coercivity and removal of anisotropy [15]. Stainless steel is an important material for accelerators as well as nuclear reactors. In the accelerators or nuclear reactors, the material gets exposed to various radiation, such as the proton, neutron, or ions. Exposure to such radiation causes activations and deteriorations in the physical and chemical properties of the materials [16]. Very recently 247 MeV Ar ions irradiation on martensitic steel (SIMP) material was reported by Cunfeng Yao et al. They reported that due to ion irradiation thickness of surface oxides increases with modification in microstructure of oxides [17]. Austenitic stainless steel (ASS) was irradiated with 1.1 MeV Nitrogen ions which show a hardening behavior after irradiation reported by Chunliang Xu et al. [18]. Thus, as mentioned above, there is a massive scope of the stainless-steel material in various fields, such as construction, metallurgy, biomedical, nuclear reactors, electronic, etc. However, stainless-steel material has tendency that they easily gets corroded due to various reasons and thus their properties gets degraded. Various physical and chemical approaches are used to reduce the corrosion of this material. In this work also, our aim is to explore the effect of ion irradiation on SS-304L work function, which is related to corrosion property.

A very few reports are available for Ar^+ ions irradiation on stainless steel. In the present work we report the effect of Ar^+ ion irradiation on the SS-304L material. The Paper is divided into two part. In first part, study on Ar^+ ion irradiation on the work function of SS-304L at different ion energy Ar^+ ion (keeping the ion fluence fix) was carried out and in second part of study on Ar^+ ion irradiation on the work function of SS-304L at different ion fluences (keeping ion energy fix at 30 keV) was carried out. For both the cases, we studied the variation in work function along with the calculations of DPA. The observed variation in work function is implied to change the corrosion property.

2 Experimental method

2.1 Sample preparation

In the present work, a piece of SS-304L material of size 10 mm × 10 mm × 0.5 mm was cut and taken directly for experiments. The cleaning of samples was done with soap water, ethanol, and ultra-sonication for 5 min at room temperature. The sample was further sonicated for 60 min in isopropanol at room temperature. After that, the samples were left for drying overnight under ambient conditions.

2.2 Ion irradiation

The indigenously developed low energy (5–100 keV) ion irradiation facility at the Department of Physics, Savitribai Phule Pune University was used for ion irradiation purpose. Figure 1 shows a schematic view of the ion irradiation facility. In this system, the penning ionization gauge (PIG) type gaseous ion source is used to get the ion species.

Gaseous ion sources primarily consist of cylindrical anodes and cathodes. It is a cold cathode discharge type ion source. In the cathode region, the gas to be ionized is injected through a gas needle valve. The cathode is a hollow cylinder made from mild steel (MS). Inside the cathode cylinder, a hollow thin anode cylinder is placed. A Neodymium permanent magnet (NdFeB) is placed at the center of the cathode bottom face. The detailed schematic of the ion source is shown in inset of Fig. 1d.

Potential difference of about 3 kV is applied between the cathode and anode. When gas is fed into the cathode region, the stray electrons gets accelerated and collide with neutral gas atoms while traveling toward the anode, thereby creating electric discharge. Electrons from first ionization further get accelerated and gain enough energy to knock out electrons from other neutrals atoms. This continuous process creates a plasma at the central part of anode. The permanent magnet helps in increasing the density and sustaining the plasma. Finally, the ions are extracted from the plasma by applying suitable potential to extraction electrode.

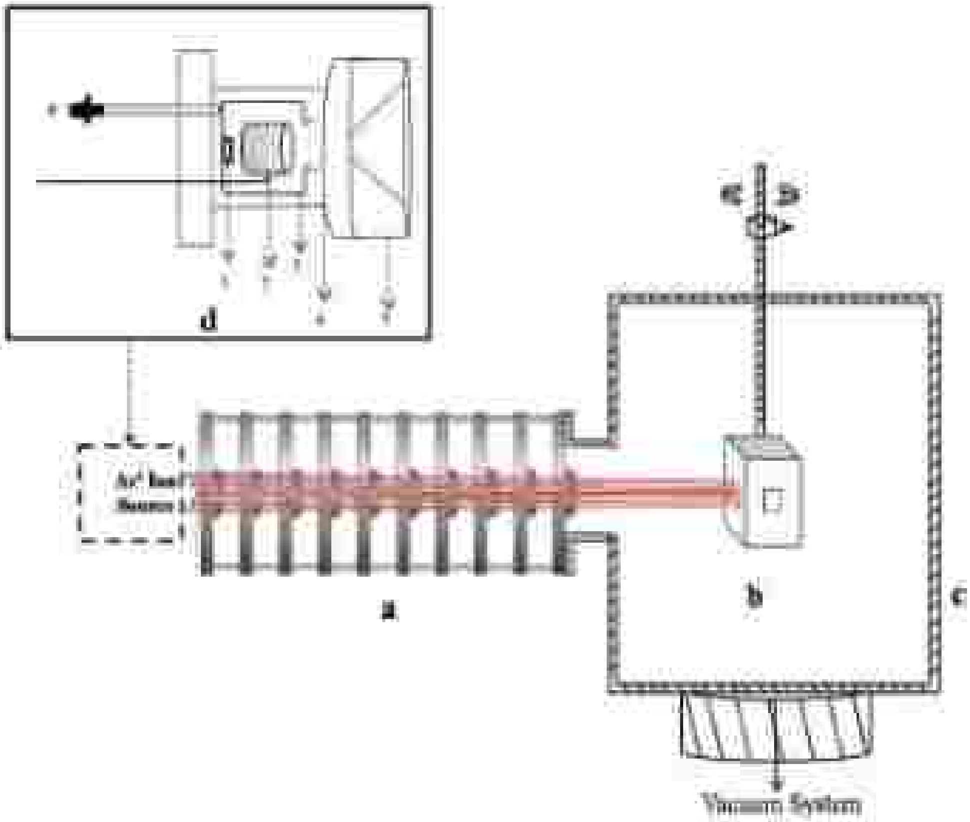


Fig. 1 Schematic view of ion irradiation facility of energy ranging 5–100 keV. **a** Ion accelerator tube with ion source, **b** Sample holder cube, **c** Experimental Chamber placed on the vacuum system, **d** Schematic of the penning ionization gauge (PIG) type gaseous ion source 1—Magnet, 2—Anode, 3—Cathode, 4—Nylon Case, 5—Extractor, 6—Gas Inlet

The total potential drops due to resistor chain across anode and last electrode of accelerator from where ions are extracted and falls on the sample holder results in the total ion energy, which is the kinetic energy of ions. The ion energy can be varied by increasing the high-voltage between anode and last extraction electrode. The ion fluence can be varied by varying ion irradiation time.

The SS-304L sample was placed on the copper sample holder and it was suspended with Wilson port. The desired Ar^+ ion energy was used for the sample irradiation. The ion current density was 3.53 μA cm^{-2} ± 0.015% and it was kept constant throughout the experiment under the vacuum pressure of 4×10^{-4} Pa. Before irradiation, the base pressure in the chamber was maintained at 1×10^{-4} Pa. At a time four samples were placed on a hollow cubical sample holder, one sample placed on each face of the cube (leaving the top and bottom face empty). One by one each sample was exposed to the Ar^+ ion beam by rotating the sample holder by 90° without breaking vacuum pressure. These irradiated samples were then used for further analysis.

2.3 DPA calculations

Estimation of ion distribution in the target material was computed using the Monte Carlo simulation Code with SRIM-13.00 Software. The dislocation of the target atoms in the solid phase of a material by bombarding ions creates vacancies. The vacancies created per ion per unit length give the displacement per ion per unit length. The SRIM-13.00 also estimates stopping energy and projected range of ions in the matter along with vacancies created per ion per unit length [19–22]. The total number of displaced atoms in a unit volume over a total number of atoms in the material gives a DPA [9, 23, 24].

The ion energy, angle of incidence of ions, elemental composition, and atomic density of target material are the required parameters to find out the full cascade of ion distribution in the target material which was used as input for SRIM-13.00. The angle of incidence for ion was kept at 0° and atomic density input for SS-304L was 7.78 g/cm^3. All the results recorded from SRIM-13.00 were the average of 9999 ion trajectories. The required calculation of DPA was done by following Eq. 1 given by Akos Horvath et al [18].

$$\text{Peak Area} = \int_{z_c - z_1}^{z_c + z_2} \mathrm{DPA}(z)\,dz \tag{1}$$

Here, z_c is the projectile depth, where we get a maximum of DPA(z), full-width half maxima (FWHM) have been computed in the region which is denoted by $z_1 + z_2$ for the DPA(z) distribution.

2.4 Measurement of work function

Work function measurement for SS-304L samples was carried out using retarding field diode method with the help of a low energy electron beam. The design of the electron gun is similar to that as discussed by Klauser and Bas [25]. Work function measurement of a variety of samples viz. metals, semiconductors are well-known and reported earlier, and [26, 27] almost similar method applies to insulators too.

In the present work, work function measurement system used consists of an electron gun and sample manipulator assembly enclosed in the Stainless-Steel high vacuum chamber. The polycrystalline gold sample was used as a reference sample which was placed on the sample manipulator along with other samples. The work function of gold ($\phi = 4.9$ eV) was taken as a reference for calculating the work function of the pristine and irradiated SS-304L samples. In the retarding field diode method, the sample was kept at a negative potential relative to cathode, i.e., filament of the electron gun. When the sample and filament are at the same potential, the sample sees the electron above its vacuum level, with a kinetic energy (Eq. 2) equal to

$$K.E. = E_i - \phi_s \tag{2}$$

where E_i is the kinetic energy of electrons (in eV) ejected from the electron gun and ϕ_s is sample's work function.

However, if we apply a retarding potential (V_R) to a sample, the sample current will reduce in magnitude, and approach a zero value when the vacuum level approaches the electron kinetic energy. Prior to this same measurement is done for reference sample. Using the plot of sample current vs retarding potential on a semi-logarithmic scale one obtains the value of the work function by measuring the shift of the linear region of the graph compared to a reference sample. The work function of SS-304L samples were measured before and after Ar^+ ions irradiation for two different conditions, (i) at varying ion energy keeping, ion fluence constant and (ii) at varying ion fluence keeping the ion energy constant. These work function measurements were carried out at vacuum pressure of 3×10^{-4} Pa.

2.5 Electrochemical measurement

The AUTOLAB PGSTAT302N was used for the corrosion J-V test using three-electrode cell measurement. Platinum (Pt) foil was used as a counter electrode, a Silver/Silver Chloride (Ag/AgCl) was used as a reference electrode, and a stainless-steel specimen (surface area of 1×1 cm^2) was used as the working electrode. Potentiodynamic polarization was used to investigate the corrosion stability of AISI 304L stainless steel in the range of − 0.5 to 0.5 V at a scan rate of 1 mV/s vs Ag/AgCl at ambient temperature. Tafel extrapolation method was used for the corrosion rate analysis. The corrosion behavior of AISI 304L stainless steel was studied with polarization experiments in an aqueous solution of 0.05 M NaCl [28–31].

3 Results and discussion

3.1 Work function analysis

To calculate the work function using the retarding field diode method (described in Sect. 2.4), initially sample current (I_s) was measured as a function of retarding potential (V_R). Graph of sample current as a function of retarding potential is shown in Fig. 2A.

As the retarding potential was increased the sample current was decreased for all the samples, as it was expected. However, it was observed that with increase in the ion irradiation energy, the change in sample current increased with respect to pristine sample. Furthermore, no significant difference in sample current within the irradiated samples (for all the irradiated samples) was observed at any energy. To understand the effect more clearly, a log plot of sample current vs retarding potential was plotted and is shown in Fig. 2B.

It can be seen from the graph that there is a change in values of current for pristine sample compared to irradiation samples at any typical value of retarding potential. By taking the linear and parallel part of the low current region, considering gold sample as reference, we estimated the work function values. From the estimated values, variation in work-function (ϕ) was plotted as a function of ion energy and is shown in Fig. 3A.

As evident from the figure, it can be clearly seen that there is substantial change in work function value between pristine and first irradiated sample (i.e., 10 keV); however, no significant change in the work-function values was observed as we increase ion energy (within the irradiated samples). This may be because, the energy and the fluences we are using here are only able to sputter the top surface of the SS-304L and further change in energy does not affect the work-function values. The maximum depth for 40 keV argon ion in SS-304L sample is ~ 19 nm. As fluence is constant for all the energies used for irradiation, the major damage or defects per unit length is not changing substantially. The defects are mainly created by number of ions falling per unit area of the sample. Therefore, even if we change the energy from 10 to 40 keV it is not affecting work function values as a result we observe almost constant work function within irradiated samples. To verify our argument, we made DPA calculations using SRIM 13.00 software. We performed the calculations for displacement damage as a function of depth

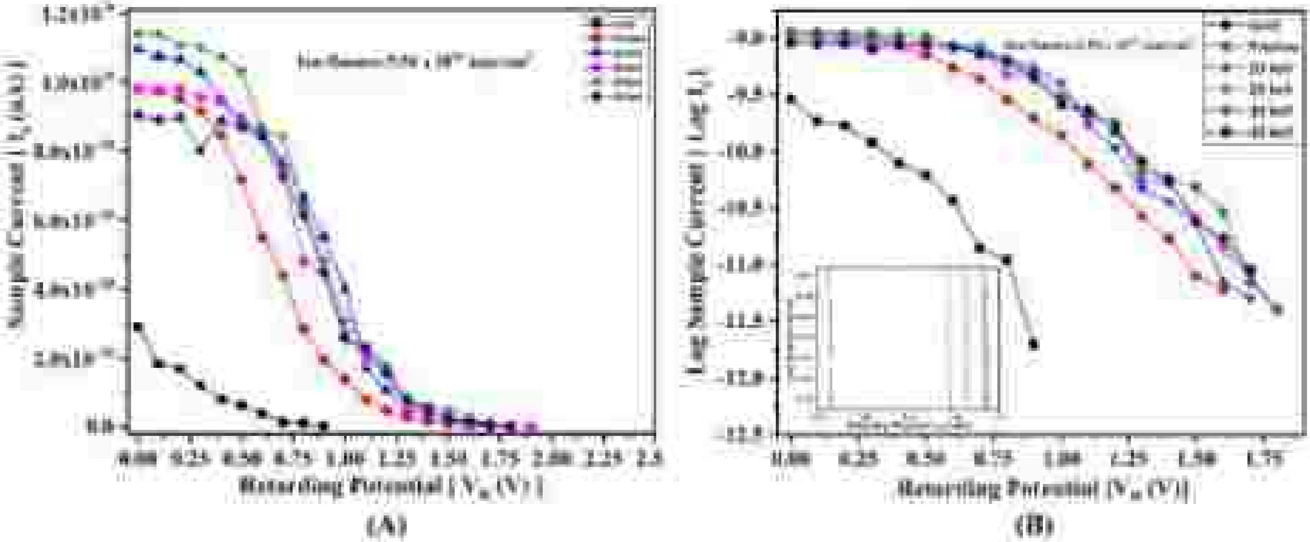
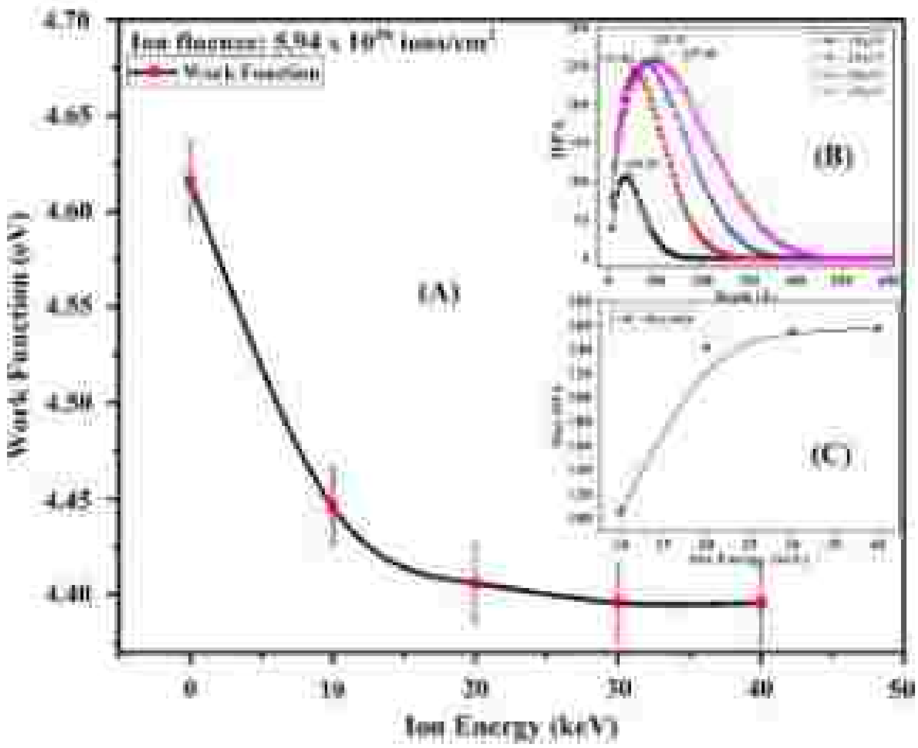


Fig. 2 Graph of **A** sample current I_s (nA) as a function of retarding potential V_R (V), **B** log I_s as a function of retarding potential V_R for pristine and samples irradiated at different ion energies keeping ion fluence constant

Fig. 3 Graph of **A** work function as a function of ion energy, **B** distribution of DPA as a function of depth, and **C** Max DPA as a function of ion energy at constant ion fluence 5.94×10^{16} ions/cm^2



for Ar+ ion in SS-304L samples at varying ion energy (keeping fluence constant).

In this specific case, ion energy was varied and fluence was kept constant (5.94×10^{16} ions/cm^2). With increasing ion energy from 20 to 40 keV, the DPA value has changed from 241.82 to 257.8, i.e., only 6% change has been observed. DPA is correlated with damage in the surface of the material, which in turn changes the Wigner Seitz radius thereby affecting the work function value. Because of the lower damage, the change in the Wigner Seitz radius is smaller, which results in an insignificant change in the work function values, as can be seen in Fig. 3A. The sputtering yield estimated from SRIM for the ion energy 10 keV was obtained to be 5.12 atoms/ion, whereas for ion energy 40 keV it is 4.80 atoms/ion. Change in sputtering yield is also not significant, which may be the other reason behind insignificant change in the work function values.

Figure 3B shows that as the Ar^{+} ion energy is increased the penetration depth increases and the peak of DPA curve also increases. For 40 keV the peak of DPA curve is obtain at 100Å. Furthermore, we checked the max DPA as a function of increasing ion energy, as shown in Fig. 3C. From the graph it is observed that the maximum DPA saturates at higher energies.

Both calculation results agree with our experimentally observed work-function values. It can be correlated as follows, since the displacement damage created by 10 keV and 40 keV ions is almost same, the change in work function which is related to displacement damage also remains constant. Now, the work function (Φ) is also related to electrostatic potential ($\delta\varphi$) of the metal surface and the electron fermi energy (ϵ_f) by the relation given in Eq. 3.

$$\Phi = \delta\varphi - \epsilon_f. \quad (3)$$

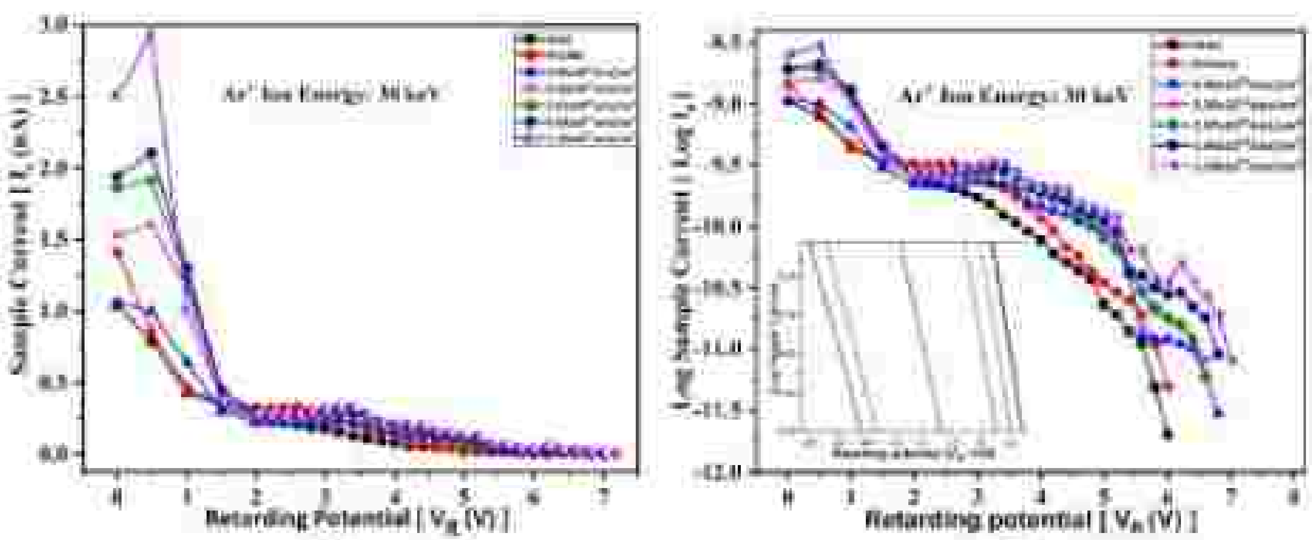
$\delta\varphi$, ϵ_f both are related to Wigner–Seitz radius (r_s) for given metal, as a decreasing exponential function [9, 28–30]. In general, r_s defined as a radius of sphere, whose volume is equal to mean volume per atom in a solid. Now, if r_s increases, $\delta\varphi$, ϵ_f both may decrease and depending upon whether your $\delta\varphi$ or ϵ_f is dominating work function will change. In our experimental observation, among the irradiated sample the work-function (Φ) is not changing. This may be because, as we increase the energy, the damage/displacements are neither affecting $\delta\varphi$ nor ϵ_f (within the irradiated samples) as ion fluence is constant. However, as compare to pristine sample, certainly some defects/displacement has been created on the surface of the SS-304L due to irradiation, which has increased r_s, which resulted in decrease in $\delta\varphi$ and ϵ_f eventually showing reduction in work-function Φ.

To verify our above argument, we further performed second set of experiment in which ion energy was kept constant and ion fluence was varied.

In this set of experiment, ion energy was kept constant at 30 keV and the ion fluence from varied from 9.9×10^{15} ions/cm^2 to 1.18×10^{17} ions/cm^2. Figure 4A shows measured sample current as a function of retarding potential. It was observed that there was a gradual increase and then a decrease in the sample current values to make it close to zero with individual retarding potential values for individual ion fluences. To get more clarity at low current region (close to zero) a log plot was plotted. Figure 4B shows samples Log current as a function of retarding potential. It is observed that irradiated samples current were retarded for higher values as a result the differences in retarding potential were higher.

From both the graphs, it is not very clear how much it has affected the surface, so we estimated the work-function values as a function of fluence, at constant ion energy of 30 keV. The graph is shown in Fig. 5A. We can clearly observe that with increase in ion fluence the work-function value has decreased lowest up to 4.27 eV for the ion fluence of 5.94×10^{16} ions/cm^2 and then gradually increased back up to 4.45 eV for the ion fluence of 1.18×10^{17} ions/cm^2.

These results clearly indicate the definite effect of ion fluence on the surface and subsurface region of the material, which resulted in the work-function change. As it was



(A) (B)

Fig. 4 Graph of A sample current I_s (nA) as a function of retarding potential V_R, B log (I_s) as a function of retarding potential V_R for various ion fluences at constant ion energy 30 keV

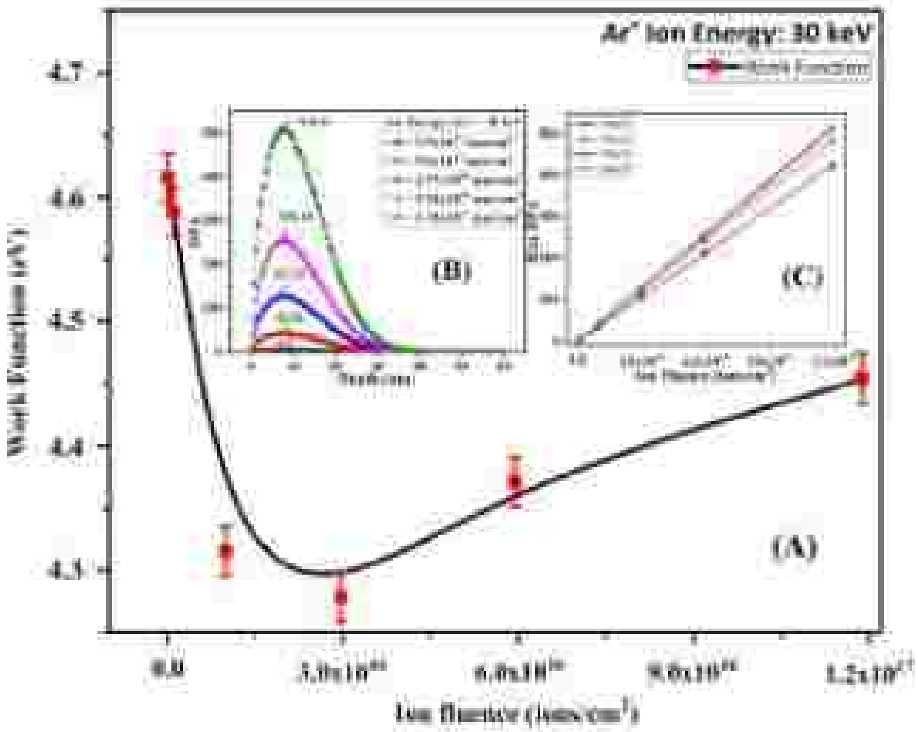


Fig. 5 Graph of A work function as a function of ion fluence B Distribution of DPA determined for 30 keV Ar^+ ion irradiation, and C Max DPA as a function of ion fluence at constant ion energy 30 keV

argument in previous section that the fluence, i.e., number of ions falling per unit area plays a role in creating defects/ displacement which might result in change in work-function values seems to be true. However, it is showing a non-linear behaviour of initial decrease and then increase in the work-function with increase in the ion fluence, which needs to be understood.

For this purpose, we again plotted the DPA values as a function of depth and ion fluence, and is shown in Fig. 5B, C, respectively. Figure 5B shows the area under the curve keeps on increasing with increase in the ion fluence without change in the depth value. In addition, from Fig. 5C, we can see that, as the fluence increases the DPA increases linearly. Thus, both the results indicate that, the number of displacements increases with increase in the ion fluences. This increase in the defects have resulted in decrease in the work-function. However, this is not following, what we have observed experimentally. Experimentally we observe that initially there is decrease in work function up to certain fluence and then it increases with fluence. This decrease and increasing trend of work-function can be again be explained on the basis of Wigner–Seitz radius following the relation given by Eq. 3. As the fluence is increasing at initial stages, i.e., at low fluence, change in r_s is due to both δ_{gi} and ϵ_i (where both are competing). After certain threshold of fluence δ_{gi} dominates as compare to change in ϵ_i, which results in increase in work function (Φ) [32].

In contrast with previous observations for change of work function as function of ion energy, when ion fluence is varied (keeping ion energy constant 30 keV), the DPA change is 91.67%. Which resulted in change in Wigner Seitz radius in a significant way causing change in work function values. These results indicate that ion fluence variations dominate modification of work function. Similar results are also been observed by Ákos Horváth et al. [9] and are in agreements with these experimental findings.

3.2 XRD analysis

Figure 6 shows the XRD pattern for pristine and irradiated AISI 304L SS samples with different ion fluences pristine (a), 9.9×10^{15} ions/cm^2 (b), 2.97×10^{16} ions/cm^2 (c), 5.94×10^{16} ions/cm^2 (d), and 1.18×10^{17} ions/cm^2 (e), respectively. XRD peaks observed at 2θ values 43.7°, 50.7°, 74.8° corresponds to (111), (200), (220) planes indicating austenitic γ-Fe phase accordance with the JCPDS card No: (00-003-0397) [33–38]. It has been observed that with increase in ion fluence, the peak intensities are decreasing. The peak intensity of highest fluence decreased up to 32% compared with pristine sample.

3.3 SEM Analysis

Figure 7 shows SEM (Surface morphology) of pristine and irradiated AISI 304L stainless steel samples for Fig. 7A Pristine (B) 9.9×10^{15} ions/cm^2 (C) 2.97×10^{16} ions/cm^2, (D) 5.94×10^{16} ions/cm^2 and (E) 1.18×10^{17} ions/cm^2, respectively. Figure 7A of pristine and Fig. 7B of 9.9×10^{15} ions/

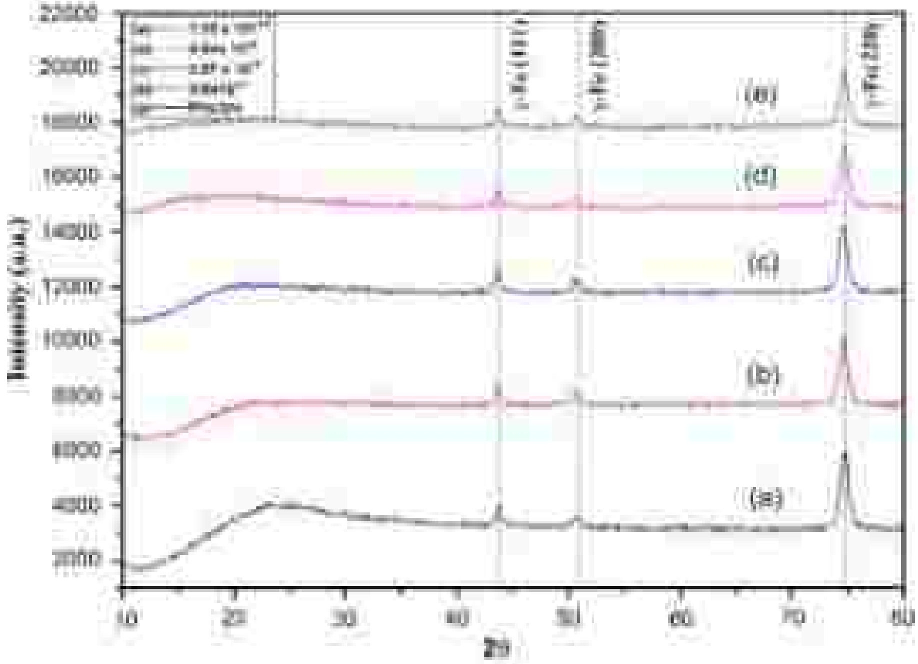


Fig. 6 X-ray diffraction patterns of AISI 304L SS material before and after Ar^{+} ion irradiation at various ion fluences

cm^2 irradiated sample shows a smooth surface. Figure 7C of 2.97×10^{16} ions/cm^2 irradiated sample shows little rough surface with line formation. Further increase in ions fluence, Fig. 7D, shows highest roughness with line formation and the highest fluence sample, Fig. 7E, shows quite smooth surface; however, as we increase the ion fluence the roughness goes on increasing up to the ion fluence of 5.94×10^{16} ions/cm^2 and then at highest ion fluence, the roughness has been decreased.

3.4 Potentiodynamic polarization studies

As work function is related to corrosion rate, we further performed the corrosion test experiments to validate our findings. Figure 8A shows potentiodynamic polarization curve for pristine and irradiated samples. The corrosion potential (E_{corr}) and corrosion current density (I_{corr}) were obtained from the polarization curve and the values are tabulated in Table 1. From the graph it was observed that as the ion fluence increases, corrosion potential values also increased (shifted right) and corrosion current values were decreased. All measured values of I_{corr} and E_{corr} obtained from the Tafel extrapolation method [34, 39, 40] have been tabulated in Table 1. The graph was further utilized for the calculation of corrosion resistance and corrosion rate. Figure 8B shows a corrosion resistance and corrosion rate as a function of ion fluence at constant ion energy. The corrosion resistance increases, whereas corrosion rates decrease with an increase in ion fluence. The obtained results are in corroboration with our work function values as explained in previous section.

The E_{corr} of all irradiated samples was shifted to more positive as compared to pristine (− 0.128 V vs Ag/AgCl), meaning improvement in the corrosion resistance. With an increase in ion fluence from 9.90×10^{15} to 1.18×10^{17} ions/cm^2 E_{corr} value shifted toward positive − 0.106 V vs Ag/AgCl to − 0.093 V vs Ag/AgCl, respectively. The 1.18×10^{17} ions/cm^2 sample exhibits most positive corrosion potential with corresponding lowest corrosion current of 3.42×10^{-7} A/cm^2. This positive shift of corrosion potential and reduction in corrosion current implies reduction in surface oxidation of samples with increase in ion fluence. The corrosion current indicates oxidative dissolution of sample species during interaction of electrolyte with sample surface. Herein, the decrease of corrosion current with ion fluence shows less dissolution of sample preventing conversion of Fe to Fe^{+3}/Fe^{+2}. This might have happened because of damage created by ions on AISI 304L SS surface, resulting in restriction of Fe to Fe^{+3}/Fe^{+2} [29–31].

During the anodic polarization process the following reactions (R) may occur:

$Fe \rightarrow Fe^{+3} + 3e^{-}$ (R1)

$Fe \rightarrow Fe^{+2} + 2e^{-}$ (R2)

$Cr^{+2} \rightarrow Cr^{+3} + e^{-}$ (R3)

Hence from these results, i.e., change in work function due to variation in ion energy (keeping fluence constant) and change in work function due to variation in ion fluence (keeping ion energy constant), we can conclude that ion fluence plays a major role in controlling the work function values. We can either increase or decrease the cofunction by

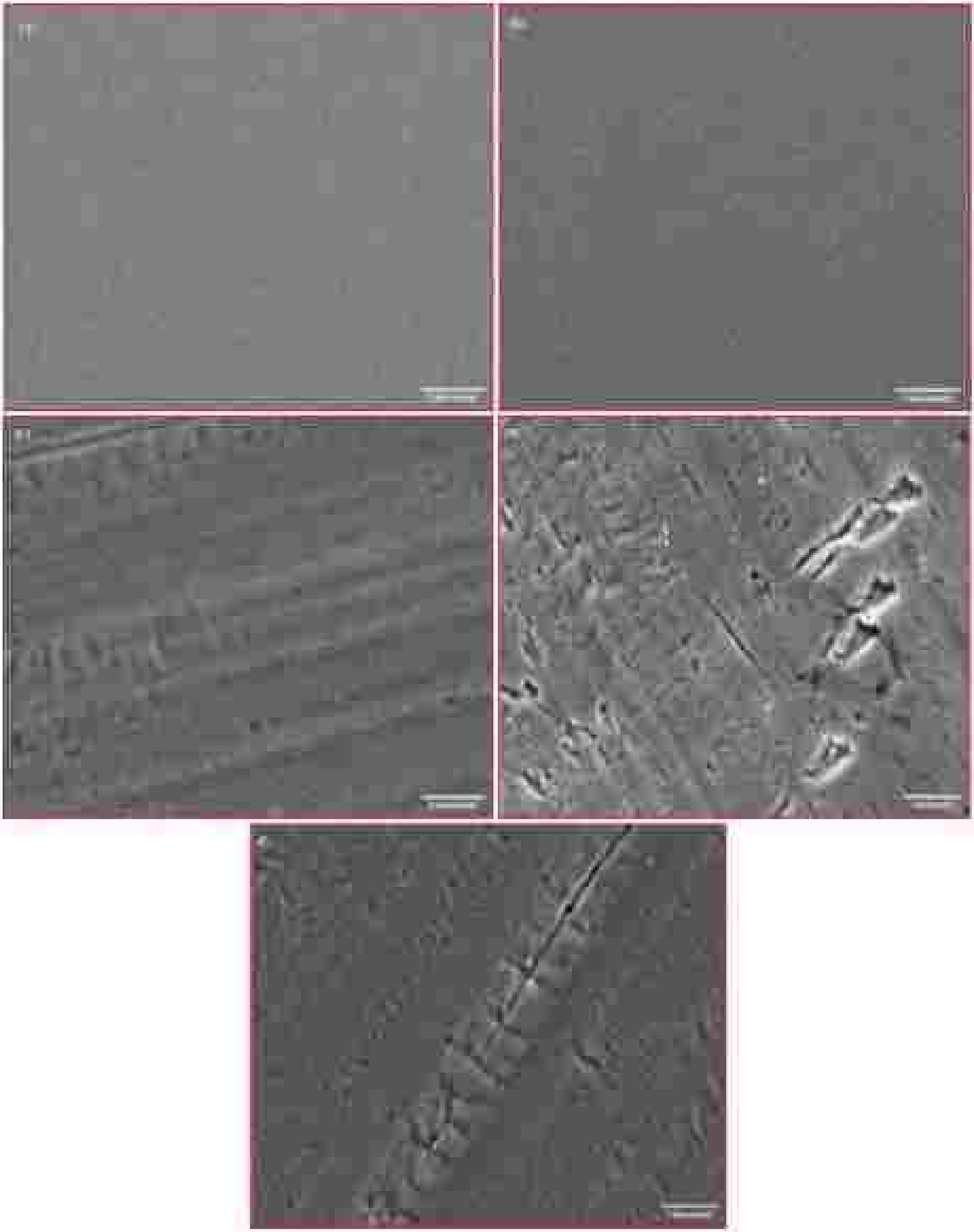


Fig. 7 SEM images of AISI 304L SS samples of A pristine, B 9.9×10^{15} ions/cm^2 C 2.97×10^{16} ions/cm^2; D 5.94×10^{16} ions/cm^2; and E 1.18×10^{17} ions/cm^2 ion fluences

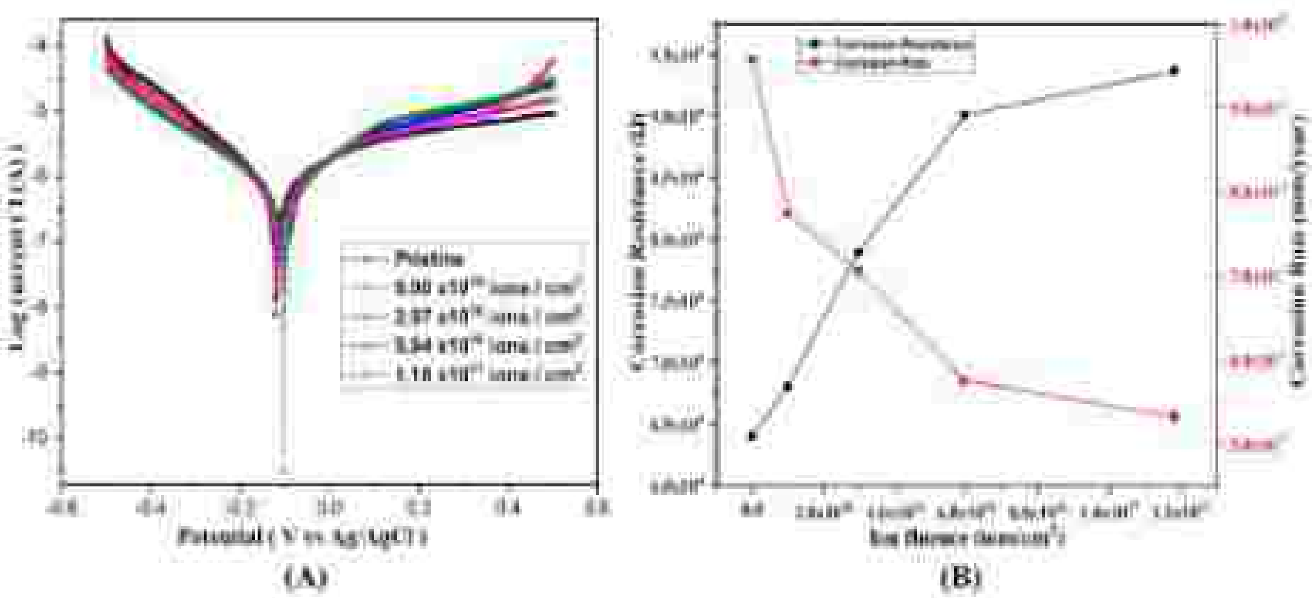


Fig. 8 A Potentiodynamic polarization curve for various ion fluences and B corrosion resistance and Corrosion rate as a function of ion fluence at a constant ion energy 30 keV

choosing the suitable fluence values. We can either increase or decrease the eofunction by choosing the suitable fluence values. As it is known that, work-function is related to corrosion rate too, thus we can also control the corrosion of given sample by properly tuning the ion fluence in the given energy range.

4 Conclusion

The energetic ion induced displacement/damage depends on the energy of incoming ions and its fluence, for a particular material. The irradiation effect due to variation in ion energy and ion fluence on work function of SS-304L samples was explored. Variation in ion irradiation energy up to 40 keV, does not affect the work function of samples. Whereas, if the energy is kept constant and fluence is change it modulates the work-function substantially. This change in work-function are related to displacement/damage created by primary ions, which resulted in increase of Wigner–Seitz radius, which is due to change in electrostatic potential ($\delta\varphi$) and the electron fermi energy (ϵ_F) of the SS-304L. The results are useful to control the corrosion stability of stainless-steel material which is applicable in aged nuclear reactors, construction industry, electrical industry, transportation industry and the places, where corrosion stability is required.

Table 1 Obtained values of E_{corr} and I_{corr} for AISI 304L stainless steel material with various ion fluences

Ion fluence (ions/cm²)	E_{corr} (V vs Ag/AgCl)	I_{corr} (A/cm²)
Pristine	− 0.128	8.24×10^{-7}
9.90×10^{15}	− 0.106	6.38×10^{-7}
2.97×10^{16}	− 0.103	6.07×10^{-7}
3.94×10^{16}	− 0.097	4.95×10^{-7}
1.18×10^{17}	− 0.093	3.42×10^{-7}

Acknowledgements The financial support from the Science and Engineering Research Board, New Delhi, for the development of low energy ion irradiation system under a project (SB/FMEQ-401/2014) is gratefully acknowledged by S. S. Dahiwale. A. B. Thorat acknowledges to Council of Scientific and Industrial Research (CSIR), India for Senior research fellowship award. A. B. Thorat thankful to Dr. Babasaheb Ambedkar National Research Fellowship (BARTI/Fellowship/BANRF-2018/19-20/1036) for financial support (BANRF-2018). S. A. Kamble thankful to SR/WOS-A/PM-11/2019 Women Scientist-A DST, India for financial support. AVR thank SPPU PDF (Grant No. SPPUPDF/ST/PH/2021/0005). One of the authors ABT is thankful to Prof. S.R. Jadkar and Prof. V.L. Mathe, Department of Physics, S. P. Pune University, Pune-411007 for provided access to the electrochemical measurement system and work function measurement system, respectively.

Data availability The authors declare that the data supporting the findings of this study are available within the paper.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

References

1. L. Gardner, Thin-Walled Struct. 141, 208 (2019)

2. N.R. Hakiki, J. Constr. Steel Res. **64**, 1199 (2008)
3. M. Stratmann, H. Streckel, Corros. Sci. **30**, 681 (1990)
4. M. Bricotte, J. Fenske, M. Dadfarnia, P. Sofronis, I.M. Robertson, J. Nucl. Mater. **409**, 18 (2011)
5. J.H. Park, Y. Kang, Steel Res. Int. **88**, 1 (2017)
6. T. Hryniewicz, K. Rokosz, Anti-Corros. Methods Mater. **61**, 57 (2014)
7. R. Rokicki, T. Hryniewicz, C. Pulletikurthi, K. Rokosz, N. Munroe, J. Mater. Eng. Perform. **24**, 1634 (2015)
8. K. Rokosz, T. Hryniewicz, S. Raaen, J. Valíček, Teh. Vjesn. **22**, 125 (2015)
9. A. Horváth, N. Nagy, G. Vértesy, R. Schiller, Mater. Chem. Phys. **217**, 541 (2018)
10. A. Kaleem, S. Bashir, M. Akram, E. Amir, K. Mahmood, M.S. Rafique, S. Naeem, S. Riaz, M. Sarwar, A. Tariq, Appl. Phys. A Mater. Sci. Process. **128**, 1 (2022)
11. A. Thorat, K. Tikote, M. Bhadane, A. Phatangare, V. Bhoraskar, S. Dhole, S. Dahiwale, Opt. Mater. (Amst). **128**, 112349 (2022)
12. L. Bischoff, W. Pilz, B. Schmidt, Appl. Phys. A Mater. Sci. Process. **104**, 1153 (2011)
13. G. D. Tolstolutskaya, S. A. Karpov, G. Y. Rostova, B. S. Sungurov, and G. N. Tolmacheva, J. V.N. Karazin Kharkiv Natl. Univ. Ser. "Physics" 66 (2013).
14. G.D. Tolstolutskaya, S.A. Karpov, A.S. Kalchenko, I.E. Kopanets, A.V. Nikitin, V.N. Voyevodin, Probl. At. Sci. Technol. **126**, 27 (2020)
15. R. Dubey, A. Gupta, P. Sharma, N. Darowski, G. Schumacher, J. Magn. Magn. Mater. **310**, 2491 (2007)
16. E. Mustafin, T. Seidl, A. Plotnikov, I. Strašík, M. Pavlovič, M. Miglierini, S. Stanček, A. Fertman, A. Lančok, Radiat. Eff. Defects Solids **164**, 460 (2009)
17. C. Yao, H. Zhang, H. Chang, Y. Sheng, T. Shen, Y. Zhu, L. Pang, M. Cui, K. Wei, Y. Xu, D. Wang, C. Liu, Z. Ma, L. Zhao, W. Yan, T. Peng, J. Li, C. Qin, Z. Wang, Corros. Sci. **195**, 109953 (2022)
18. C. Xu, X. Liu, Y. Li, W. Guan, W. Jia, Q. Quan, J. Yin, Nucl. Technol. **00**, 1 (2022)
19. J.F. Ziegler, Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms **219–220**, 1027 (2004)
20. J.F. Ziegler, M.D. Ziegler, J.P. Biersack, Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms **268**, 1818 (2010)
21. R.E. Stoller, M.B. Toloczko, G.S. Was, A.G. Certain, S. Dwaraknath, F.A. Garner, Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms **310**, 75 (2013)
22. J. F. Ziegler, M. D. Ziegler, and J. P. Biersack, Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. Mater. Atoms **268**, 1818 (2010).
23. A. Horváth, N. Nagy, G. Vértesy, R. Schiller, Nucl. Instrum. Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms **466**, 12 (2020)
24. S.K. Singh, V.V.S. Kumar, P. Kumar, Appl. Phys. A Mater. Sci. Process. **127**, 1 (2021)
25. S.J. Kramer, F.H. Bas, J. Phys. E. **12**, 841 (1979)
26. T.M. Bhave, S.V. Bhoraskar, J. Vac. Sci. Technol. B Microelectron. Nanom. Struct. **16**, 2073 (1998)
27. N.R. Rajopadhye, S.V. Bhoraskar, J. Mater. Sci. Lett. **5**, 603 (1986)
28. L. Hamadou, A. Kadri, N. Benbrahim, Corros. Sci. **52**, 859 (2010)
29. S. Ningshen, U. Kamachi Mudali, S. Ramya, B. Raj, Corros. Sci. **53**, 64 (2011)
30. P. Dhaiveegan, N. Elangovan, T. Nishimura, N. Rajendran, RSC Adv. **6**, 47314 (2016)
31. Y. Zhang, H. Luo, Q. Zhong, H. Yu, J. Lv, Chinese J. Mech. Eng. (English Ed.) **32**, 27 (2019)
32. N.D. Lang, W. Kohn, Phys. Rev. B **3**, 1215 (1971)
33. L. Wang, J. Sun, P. Li, J. Sun, Y. Lv, B. Jing, S. Li, S. Ji, Z. Wen, Int. J. Hydrogen Energy **37**, 5876 (2012)
34. S. Saboori, H. Rashtchi, A. Erfanni, F. Karimzadeh, M.H. Enayati, K. Raeissi, A.H.W. Ngan, R.F. Imani, Int. J. Mater. Res. **108**, 532 (2017)
35. S.Y. Lee, E.W. Huang, W. Woo, C. Yoon, H. Chae, S.G. Yoon, Metals (Basel). **5**, 2109 (2015)
36. F.J. Baldenebro-Lopez, C.D. Gomez-Esparza, R. Corral-Higuera, S.P. Arredondo-Rea, M.J. Pellegrini-Cervantes, J.E. Ledezma-Sillas, R. Martinez-Sanchez, J.M. Herrera-Ramirez, Materials (Basel). **8**, 451 (2015)
37. F. Mohri, H. Savaloni, J. Theor. Appl. Phys. **14**, 223 (2020)
38. G. Shit, P. Bhaskar, S. Ningshen, A. Dasgupta, U.K. Mudali, A.K. Bhaduri, AIP Conf. Proc. **1832**, 4 (2017)
39. Z. Shi, M. Liu, A. Atrens, Corros. Sci. **52**, 579 (2010)
40. A.R. El-Sayed, H.S. Mohran, H.M. El-Lateef, Metall. Mater. Trans. A Phys. Metall. Mater. Sci. **43**, 619 (2012)

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ACTIVITY REPORT
(2022-23)

I. Basic Details:

Name of The Activity: Educational Visit to District Sericulture Office, Wai, District Satara			
Date	Faculty	Department/ Committee	Coordinator Name & Phone no.
26.11.2022	Science	Zoology	Dr. Kalim Shaikh, Mrs. Anjum Pathan & Ms. Sameen Gazikhan (7972224613, 9890485569, 7276936488)
Time 6:00 am to 10:00 pm	Venue District Sericulture Office, Wai	Activity for class/ group & student number S.Y.B.Sc (Zoology) and M.Sc. (Zoology) (59)	Nature: Co-curricular

II. Brief Information about the Activity (Criterion no -):

Topic/ Subject of the activity	Educational Visit to District Sericulture Office
Objective for conducting the activity	To experience the students about technicalities of sericulture and also help to setup their own business.
Methodology	Live Demonstration
Outcome	Students experienced live demonstration of Sericulture techniques and they got the importance of this Agro based Industry with reference to both Employment and Business.

III. Proofs attached: letters/ student list of participation/ certificate/ document/photos/ any other

1. Permission Letter	2. Student Attendance	3. Photo
4. Detailed Report	5.	6.

Y & M Anjuman Khairul Islam's

POONA COLLEGE
OF ARTS, SCIENCE AND COMMERCE
(Affiliated to Savitribai Phule Pune University: ID No. PU/PN/ASC/023/1970)

DEPARTMENT OF ZOOLOGY

Educational Visit to District Sericulture Office, Wai, District Satara

DETAILED REPORT

Date: 26.11.2022 **No. of Participants: 59**

With the able guidance and support of Principal, Dr. Aftab Anwar Shaikh, Vice Principal, Mr. Iqbal N. Shaikh Department of Zoology has conducted a Visit to Educational Visit to District Sericulture Office, Wai, District Satara on 26th November 2022 for of S.Y.B.Sc (Zoology) and M.Sc I & II (Zoology) students. The Visit was coordinated by Dr. Kalim Shaikh (replacement of Dr. Mujeeb Shaikh), Mrs. Anjum Pathan & Ms. Sameen Garikhan accompanied with Dr. Shoeb Ahmad and Ms. Raniya Shaikh. Total 59 students from S.Y.B.Sc (Zoology) M.Sc I & II (Zoology) visited to District Sericulture Office, Wai. The main aim of this visit to make students sound with the techniques sericulture to setup Sericulture Unit. Technical Assistant of the District Sericulture Office gave live demonstration to handle the silkworms and he also elaborated the life cycle, habit habitat and disease of silkworms. Hence, with this visit students experienced live demonstration of Sericulture techniques and they got the importance of this Agro based Industry with reference to both Employment and Business.

Y & M Anjuman Khairul Islam's

POONA COLLEGE
OF ARTS, SCIENCE AND COMMERCE

(Affiliated to Savitribai Phule Pune University: ID No. PU/PN/ASC/023/1970)

DEPARTMENT OF ZOOLOGY

	
Technical Assistant of District Sericulture Office explaining silkworm rearing techniques (Dated: 26.11.2022)	Students inside rearing house observing cocoon (Dated: 26.11.2022)
	
Obersing Constitution day at District Sericulture Office, Wai (Dated: 26.11.2022)	Students at District Sericulture office, Wai (Dated: 26.11.2022)

Date:- 23/11/2022

To,
The Principal,
Poona College,
Camp, Pune-411001.

Subject:-M.Sc. I, II and S.Y.B.Sc. Zoology Educational Visit at District Sericulture Office, Wai, Satara.

Respected Sir,

As per syllabus of SPPU Pune, M.Sc. I, II and S.Y.B.Sc Zoology Students have compulsory Educational Visitto study Sericulture techniques.The required rules and regulations prescribed by U.G.C and Savitribai Phule Pune University related to organizing educational visit for students will be followed by making all necessary arrangements. The one day visit is scheduled on 26/11/2022.

You are requested to kindly grant the permission.

Thanking you.

Yours Faithfully,

Dr. Mujeeb Shaikh
Head
Department of Zoology

Forwarded

In-Charge Teachers
Dr. Mujeeb Shaikh
Dr. Shoeb Ahmad
Mrs. Anjum Pathan
Ms. Sameen Garikhan
Ms. Raniya Shaikh

Ok
23/11/2022

Anjuman Khairul Islam's

POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

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- Junior College Index No: J-11.15.004
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Professor (Dr.) Aftab Anwar Shaikh
M.Com, Ph.D (Busi. Admin.)
PRINCIPAL

To
The Office In charge
District Sericulture Office
Wai, District – Satara

Date: 23/11/2022

Sir,

As per syllabus of SPPU Pune, M.Sc I, II and S.Y.B.Sc Zoology Students have compulsory Educational Visit to study Sericulture techniques.

We request yourcooperation and guidance to our students about the various aspects related to Sericulture.

Kindly give us suitable date and time as per your convenience.

Thanking you,

Yours Faithfully

Dr. Aftab Anwar Shaikh
Principal

PRINCIPAL
Poona College of Arts, Science & Commerce
Camp, Pune-411001
Principal Office

26/11/2022

AKI's Poona college of Arts, Science & commerce, Pune-01

Date of Activity: 26.11.2022		Time slot: 7.00am to 12.00am	
Activity Name	Educational Visit to District Sericulture Office, [illegible]	Teacher Incharge	Dr. Kabir Shaikh
Organising Dept./Committee: ZOOLOGY		Venue:	N.A.
Total Number of Students Attended:		Report generated by: Dr. Kabir Shaikh	

Sr.No	Name	Roll No.	Class	Mobile No.	Signature
1	AFA ATIQUE RAHMAN KHAN	7501	SYBSc (Zoology)	[illegible]	[illegible]
2	FATIMA ASLAM SHAIKH	7504	SYBSc (Zoology)	[illegible]	[illegible]
3	ALFIYA MUSLIM KHAN	7505	SYBSc (Zoology)	[illegible]	[illegible]
4	ZOYA SHAKIL SAYYED	7506	SYBSc (Zoology)	[illegible]	[illegible]
5	ABIIYA AFZAL SAYYED	7507	SYBSc (Zoology)	[illegible]	[illegible]
6	RUHINA GAUS SHAIKH	7508	SYBSc (Zoology)	[illegible]	[illegible]
7	AMYA WASIM KHAN	7509	SYBSc (Zoology)	[illegible]	[illegible]
8	IIZA NISAR SHAIKH	7511	SYBSc (Zoology)	[illegible]	[illegible]
9	MAHEK SHAFIK SHAIKH	7512	SYBSc (Zoology)	[illegible]	[illegible]
10	LANCHENBI THOUNAOJAM	7514	SYBSc (Zoology)	[illegible]	[illegible]
11	MASEERA BEGUM BASHIR M.	7515	SYBSc (Zoology)	[illegible]	[illegible]
12	TRUPTI SANTOSH CHANDALIYA	7517	SYBSc (Zoology)	[illegible]	[illegible]
13	TASMIYA JAVED SHAIKH	7518	SYBSc (Zoology)		Cancel
14	MADIHA JALIL KHAN	7520	SYBSc (Zoology)	[illegible]	[illegible]
15	PRIYA S. SHAHANE	7522	SYBSc (Zoology)	[illegible]	[illegible]
16	ALIYA AHSAN DESHMUKH	7525	SYBSc (Zoology)	[illegible]	[illegible]
17	AALIYA AYYUB BANGI	7531	SYBSc (Zoology)	[illegible]	[illegible]
18	MUSKAN MUBIN PATHAN	7532	SYBSc (Zoology)	[illegible]	[illegible]
19	MANTASHA PARVEEN M. I. SK.	7534	SYBSc (Zoology)	[illegible]	[illegible]
20	AYESHA ABDUL MATEEN MOMIN	7620	SYBSc (Zoology)	[illegible]	[illegible]
21	MOHD KANAIT SHAIKH	7623	SYBSc (Zoology)	[illegible]	[illegible]
22	MARIYA JAVED KHAN	7681	SYBSc (Zoology)	[illegible]	[illegible]
23	TASHA NASIMUDDIN BOGDI	7682	SYBSc (Zoology)	[illegible]	[illegible]
24	FUZAIL UR RAHMAN	7683	SYBSc (Zoology)	[illegible]	[illegible]
25	AFSANA VAZIR PATHAN	7684	SYBSc (Zoology)	[illegible]	[illegible]
26	AYESHA ABDUL SAYYED	7685	SYBSc (Zoology)	[illegible]	[illegible]
27	HASAN SHAIKH	7686	SYBSc (Zoology)	[illegible]	[illegible]
28	FAIZAN SHAIKH	7688	SYBSc (Zoology)	[illegible]	[illegible]
29	MISBAH AYUB SHAIKH	7689	SYBSc (Zoology)	[illegible]	[illegible]
30	SANIYA AYUB SHAIKH	7690	SYBSc (Zoology)	[illegible]	[illegible]
31	ARSHA QAYYUM SHAIKH	7691	SYBSc (Zoology)	[illegible]	[illegible]
32	NAZRIN AKIL SHAIKH	7694	SYBSc (Zoology)	[illegible]	[illegible]
33	BAZILA SAMEER KHOT	7695	SYBSc (Zoology)	[illegible]	[illegible]
34	MISBAH MOHD AYAAZ ANSARI	7697	SYBSc (Zoology)	[illegible]	[illegible]
35	MANTASHA FAYYAZ ANSARI	7705	SYBSc (Zoology)	[illegible]	[illegible]
36	SANIYA SAMEER SHAIKH	7706	SYBSc (Zoology)	[illegible]	[illegible]
37	SAFA SAQUIB KHOT	7709	SYBSc (Zoology)	[illegible]	[illegible]
38	ZAKIYA ZAKIR SHAIKH	7710	SYBSc (Zoology)	[illegible]	[illegible]
39	Aayan Raja Shaikh	7642	SYBSc (Zoology)	[illegible]	[illegible]

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Signature of Faculty Incharge

AKI's Poona college of Arts, Science & commerce, Pune-01

Date of Activity: 26-11-2022		Time Slot: 7:00 am-11:00 am	
Activity Name	Educational visit to District Sericulture office, Wai	Teacher incharge	Ms.Sameen Gazikhan
Organizing Dept./Committee: Zoology		Venue:	
Total Number of Students Attended:		Report Generated by: Ms Sameen Gazikhan	

Sr.No.	Name	Class	Roll No	Mobile No.	Signature
1	Khan Aayesha Begum Fakhruddin	M.Sc-I	8401	[illegible]	[illegible]
2	Ansari Aatif Irfanul Hasan	M.Sc-I	8402	[illegible]	[illegible]
3	Lokhande Raju Nasir	M.Sc-I	8403	[illegible]	[illegible]
4	Shaikh Muskan Abdul Rafique	M.Sc-I	8404	[illegible]	[illegible]
5	Farid Misba Mehboob	M.Sc-I	8408	[illegible]	[illegible]
6	Shaikh Musfira Kamruddin	M.Sc-I	8410	[illegible]	[illegible]
7	Khan Zoya Javed	M.Sc-I	8411	[illegible]	[illegible]
8	Singure Madiya Nisar	M.Sc-I	8412	[illegible]	[illegible]
9	Nazia Farooqui	M.Sc-I	8417	[illegible]	[illegible]
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Signature of Faculty Incharge

AKI's Poona college of Arts, Science & commerce, Pune-01

Date of Activity : 26.11.2022		Time Slot: 7.00 am-11.00 am	
Activity Name	Educational visit to District Sericulture office, Wai	Teacher Incharge	Mrs Anjum M. Pathan
Organizing Dept/Committee: Zoology		Guest:	
Total Number of Students Attended:		Report Generated by: Mrs Anjum Pathan	

Sr.No	Name	Class	Roll No	Mobile No.	Signature
1	Pathan Tanvir Dastagir	M.Sc-II	8451	9572623535	
2	Dhondkar Fatima Asif	M.Sc-II	8452	[illegible]	
3	Shaikh Muskan Nasarm	M.Sc-II	8454	9309879205	
4	Priyanka Thiruneajam	M.Sc-II	8455	[illegible]	
5	Omery Lalrempuii Chhangte	M.Sc-II	[illegible]	9366133198	
6	Ghawte Sabila Sufiyan	M.Sc-II	8457	[illegible]	
7	Shendge Mahima sanjay	M.Sc-II	8458	9767946724	
8	Quraishi Aafiya Atif	M.Sc-II	8459	9552853000	
9	Chourmal Ashwini Rajendra	M.Sc-II	8463	[illegible]	
10	Thamasha S. Thankachan	M.Sc-II	[illegible]	9016273943	
11	Shaikh Uzma Riyaz	M.Sc-II	8467	[illegible]	
12	Shaikh Maira R.	M.Sc-II	8468	[illegible]	
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Signature of Faculty Incharge

ACTIVITY REPORT
(2022-23)

I. Basic Details:

Name of The Activity: Educational Visit to Directorate of Beekeeping, Mahabaleshwar			
Date	Faculty	Department/ Committee	Coordinator Name & Phone no.
26.11.2022	Science	Zoology	Dr. Shoeb Ahmad (9919509673), Mrs. Anjum Pathan & Ms. Sameen Gazikhan (7972224513, 9890485569, 7276936488)
Time 6:00 am to 10:00 pm	Venue Directorate of Beekeeping, Mahabaleshwar	Activity for class/ group & student number S.Y.B.Sc (Zoology), M.Sc (Zoology) (59)	Nature: Co-curricular

II. Brief Information about the Activity (Criterion no -):

Topic/ Subject of the activity	Educational Visit to Directorate of Beekeeping
Objective for conducting the activity	To exposed student with Beekeeping techniques and handling of bees with beekeeping equipment
Methodology	Live Demonstration
Outcome	Created an end-to-end implementation framework for beekeeping skill development, which will provide empowerment opportunities and income generation to unemployed youth.

III. Proofs attached: letters/ student list of participation/ certificate/ document/photos/ any other

1. Permission Letter	2. Student Attendance	3. Photo
4. Detailed Report	5.	6.

Y & M Anjuman Khairul Islam's
POONA COLLEGE
OF ARTS, SCIENCE AND COMMERCE
(Affiliated to Savitribai Phule Pune University: ID No. PU/PN/ASC/023/1970)

DEPARTMENT OF ZOOLOGY

Educational Visit to Directorate of Beekeeping, Mahabaleshwar

DETAILED REPORT

Date: 26.11.2022 **No. of Participants: 59**

With the able guidance and support of Principal, Dr. Aftab Anwar Shaikh, Vice Principal, Mr. Iqbal N. Shaikh Department of Zoology has conducted a Visit to Educational Visit to Directorate of Beekeeping, Mahabaleshwar on 26th November 2022 for of S.Y.B.Sc (Zoology) and M.Sc I & II (Zoology) students. The Visit was coordinated by Dr. Shoeb Ahmad, Mrs. Anjum Pathan and Ms. Sameen Gazikhan accompanied with Dr. Kalim Shaikh (replacement of Dr. Mujeeb Shaikh), and Ms. Raniya Shaikh. Total 59 students from S.Y.B.Sc (Zoology) M.Sc I & II (Zoology) visited to Directorate of Beekeeping, Mahabaleshwar. The main aim of this visit to exposed student with Beekeeping techniques and handling of bees with beekeeping equipment. Technical Assistant of Directorate of beekeeping gave demo how to handle bees in artificial colony. He also demonstrated the different beekeeping equipment like honey purification unit and bee wax extractor. Hence, this visit created an end-to-end implementation framework for beekeeping skill development, which provides empowerment opportunities and income generation to unemployed youth.

Y & M Anjuman Khairul Islam's

POONA COLLEGE

OF ARTS, SCIENCE AND COMMERCE

(Affiliated to Savitribai Phule Pune University: ID No. PU/PN/ASC/023/1970)

DEPARTMENT OF ZOOLOGY

PHOTOGRAPHS	
	
Technical Assistant of Directorate of Beekeeping demonstrating the Bee Colony (Dated: 26.11.2022)	Technical Assistant of Directorate of Beekeeping demonstrating Honey purification technique (Dated: 26.11.2022)
	
Technical Assistant of Directorate of Beekeeping explaining honey storage and bottling. (Dated: 26.11.2022)	Student group at Directorate of Beekeeping. (Dated: 26.11.2022)

Date:- 23/11/2022

To,
The Principal,
Poona College,
Camp, Pune-411001.

Subject:-M.Sc.I, II and S.Y.B.Sc. Zoology Educational Visit at Directorate of Beekeeping, Mahabaleshwar.

Respected Sir,

As per syllabus of SPPU Pune, M.Sc. I, II and S.Y.B.Sc Zoology Students have compulsory Educational Visitto study Bee Keeping techniques.The required rules and regulations prescribed by U.G.C and Savitribai Phule Pune University related to organizing Educational visit for students will be followed by making all necessary arrangemants. The one day visit is scheduled on 26/11/2022.

You are requested to kindly grant the permission.

Thanking you,

Yours Faithfully,

Dr. Mujeeb Shaikh
Head
Department of Zoology

Forwarded

In-Charge Teachers
Dr. Mujeeb Shaikh
Dr. Shoeb Ahmad
Mrs. Anjum Pathan
Ms. Sameen Gazikhan
Ms. Raniya Shaikh

Ok
23/11/22

Anjuman Khairul Islam's

POONA COLLEGE OF ARTS, SCIENCE & COMMERCE

- Affiliated to Savitribai Phule Pune University, ID No PU/PN/ASC/023/1970
- Junior College Index No: J-11.15.004
- Government of Maharashtra and Savitribai Phule Pune University Recognized Minority College
- UGC - 2(f) & 12 (B) Status • NAAC Reaccredited College • DST - FIST Funded College

K. B. Hidayatullah Road, Camp, Pune - 411001 (MS), India | +91-20-2645 4240 / 2644 8318 | principal@poonacollege.edu.in www.poonacollege.edu.in

Professor (Dr.) Aftab Anwar Shaikh
M.Com, Ph.D (Busi. Admin.)
PRINCIPAL

To
The Office In charge
Directorate of Beekeeping
Mahabaleshwar

Date: 23/11/2022

Sir,

As per syllabus of SPPU Pune, M.Sc I, II and S.Y.B.Sc Zoology Students have compulsory Educational Visit to study beekeeping techniques.

We request your cooperation and guidance to our students about the various aspects related to beekeeping.

Kindly give us suitable date and time as per your convenience.

Thanking you,

Yours Faithfully

Dr. Aftab Anwar Shaikh
Principal

PRINCIPAL
Poona College of Arts, Science & Commerce
Camp, Pune-411001
Principal Office

AKI's Poona college of Arts, Science & commerce, Pune 01

Date of Activity: 26/11/2022		Time Slot: [illegible]	
Activity Name:	Educational visit to Directorate of Beekeeping, Mahabaleshwar	Teacher Incharge:	Dr. Shoeb Ahmad
Organizing Dept./Committee: ZOOLOGY		Units:	NA
Total Number of Students Attended:		Report submitted by:	

Sr. No.	Name	Roll No.	Class	Mobile No.	Signature
1	M A ATIQUR RAHMAN KHAN	7503	SYBSc (Zoology)	[illegible]	
2	FATIMA ASLAM SHAIKH	7504	SYBSc (Zoology)	[illegible]	
3	ALFIYA MUSLIM KHAN	7505	SYBSc (Zoology)	[illegible]	
4	ZOYA SHAKIR SAYYED	7506	SYBSc (Zoology)	[illegible]	
5	ARBIYA AFZAL SAYYED	7507	SYBSc (Zoology)	[illegible]	
6	RESHMA GAUS SHAIKH	7508	SYBSc (Zoology)	[illegible]	
7	ASIYA WASIM KHAN	7509	SYBSc (Zoology)	[illegible]	
8	FIZA NISAR SHAIKH	7511	SYBSc (Zoology)	[illegible]	
9	MAHEK SHAFIK SHAIKH	7512	SYBSc (Zoology)	[illegible]	
10	LANCHENBI THOUNAOJAM	7514	SYBSc (Zoology)	[illegible]	
11	MASLEEA BEGUM BASHIR M.	7515	SYBSc (Zoology)	[illegible]	
12	TRUPTI SANTOSH CHANDALIYA	7517	SYBSc (Zoology)	[illegible]	
13	TASMIYA JAVED SHAIKH	7518	SYBSc (Zoology)		
14	MADIHA JALIL KHAN	7520	SYBSc (Zoology)	[illegible]	
15	PRIYA S. SHEKHAR	7522	SYBSc (Zoology)	[illegible]	
16	ALFIYA AHESAN DESHMUKH	7523	SYBSc (Zoology)	[illegible]	
17	AALIYA AYYUB BANGI	7531	SYBSc (Zoology)	[illegible]	
18	MUSKAN MUBIN PATHAN	7532	SYBSc (Zoology)	[illegible]	
19	MANTASHA PARVEEN M. I. SK	7534	SYBSc (Zoology)	[illegible]	
20	AYESHA ABDULMATEEN MOMIN	[illegible]	SYBSc (Zoology)	[illegible]	
21	MOHD KANATI SHAIKH	[illegible]	SYBSc (Zoology)	[illegible]	
22	MARIYA JAVED KHAN	7581	SYBSc (Zoology)	[illegible]	
23	RASHA NASIMODDIN BOGDI	7582	SYBSc (Zoology)	[illegible]	
24	FUZAIL UR RAHMAN	7583	SYBSc (Zoology)	[illegible]	
25	AFSANA YAZIR PATHAN	7584	SYBSc (Zoology)	[illegible]	
26	AYESHA ABDUL SAYYED	7585	SYBSc (Zoology)	[illegible]	
27	HASAN SHAIKH	7586	SYBSc (Zoology)	[illegible]	
28	FAIZAN SHAIKH	7588	SYBSc (Zoology)	[illegible]	
29	MISBAH AYUB SHAIKH	7589	SYBSc (Zoology)	[illegible]	
30	SANIYA AYUB SHAIKH	7590	SYBSc (Zoology)	[illegible]	
31	AFSHA QAYYUM SHAIKH	7593	SYBSc (Zoology)	[illegible]	
32	NAZKIN AKIL SHAIKH	7594	SYBSc (Zoology)	[illegible]	
33	HAZILA SAMEER KHOT	7595	SYBSc (Zoology)	[illegible]	
34	MISBAH MOHD FAYAAZ ANSARI	7597	SYBSc (Zoology)	[illegible]	
35	MANTASHA FAYYAZ ANSARI	7705	SYBSc (Zoology)	[illegible]	
36	SANIYA SAMEER SHAIKH	7706	SYBSc (Zoology)	[illegible]	
37	SAFA SAQUIB KHOT	7709	SYBSc (Zoology)	[illegible]	
38	ZAKIYA ZAKIR SHAIKH	7710	SYBSc (Zoology)	[illegible]	
39	Anjum Raju Shaikh	7712	SyBSc (Zoology)	[illegible]	

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Signature of Faculty Incharge

AKI's Poona college of Arts, Science & commerce, Pune-01

Date of Activity: 26/11/2022		Time Slot: 12:00 pm-4:00 pm	
Activity Name	Educational visit to Directorate of Beekeeping, Mahabaleshwar	Teacher Incharge:	Ms.Sameen Gazikhan
Organizing Dept/Committee: Zoology		Guest:	
Total Number of Students Attended:		Report Generated by: Ms.Sameen Gazikhan	

Sr.No	Name	Class	Roll No	Mobile No.	Signature
1	Khan Aayesha Begum Fakhruddin	M.Sc-I	8401	[illegible]	Khan
2	Ansari Aasif Irfanul Hasan	M.Sc-I	8402	[illegible]	[illegible]
3	Lokhande Raza Nasir	M.Sc-I	8403	[illegible]	[illegible]
4	Shaikh Muskan Abdul Razique	M.Sc-I	8404	8623591029	[illegible]
5	Farid Misba Mahboob	M.Sc-I	8408	[illegible]	[illegible]
6	Shaikh Musfira Karimuddin	M.Sc-I	8410	72494612[illegible]	[illegible]
7	Khan Zoya Javed	M.Sc-I	8411	[illegible]	[illegible]
8	Sayyed Sadiya Nisar	M.Sc-I	8412	8050237016	Sadiya
9	Nazia Farooqui	M.Sc-I	8417	[illegible]	Nazia
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Signature of Faculty Incharge

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AKI's Poona college of Arts, Science & commerce, Pune-01

Date of Activity: 26/11/2022		Time Slot: 12:00 pm-5:00 pm	
Activity Name	Educational visit to Directorate of Beekeeping, Mahabaleshwar	Teacher In-charge	Mrs Anjum M. Pathan
Organizing Dept Committee: Zoology		Guest:	
Total Number of Students Attended:		Report Generated by: Mrs Anjum Pathan	

Sr.No.	Name	Class	Roll No	Mobile No.	Signature
1	Pathan Tanvir Dastagir	M.Sc-II	8451	[illegible]	[illegible]
2	Dhondkar Fatima Asif	M.Sc-II	8452	[illegible]	[illegible]
3	Shaikh Muskan Naeem	M.Sc-II	8454	9309827008	Shaikh
4	Priyanka Thoonanjam	M.Sc-II	8455	9356091386	Priyanka
5	Omery Lalrempuii Chhangte	M.Sc-II	8456	9366615895	Omery
6	Ghawte Sahila Sufiyan	M.Sc-II	8457	8530674772	[illegible]
7	Shendge Mahima sanjay	M.Sc-II	8458	9767464724	[illegible]
8	Qureshi Aafiya Atif	M.Sc-II	8459	9552833053	Aafiya
9	Choudhari Ashwini Rajendra	M.Sc-II	8463	9822559856	[illegible]
10	Thanusha S. Thankachan	M.Sc-II	8466	9016627861	[illegible]
11	Shaikh Uzma Riyaz	M.Sc-II	8467	9067669769	[illegible]
12	Shaikh Maaira	M.Sc-II	8468	7709121333	[illegible]
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