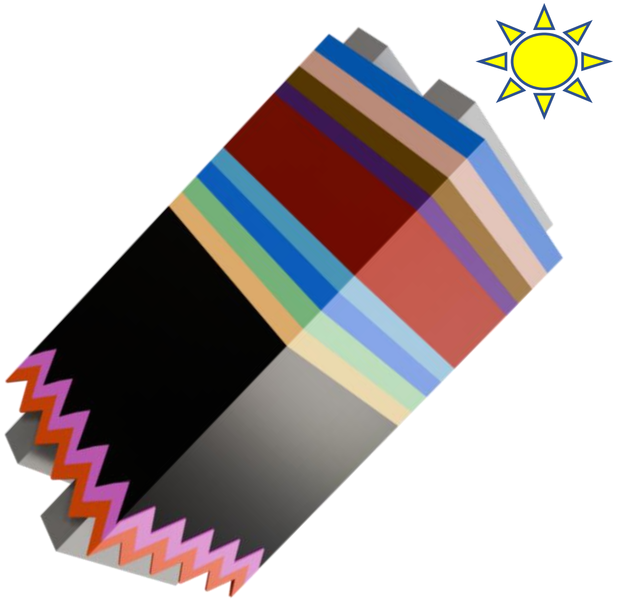
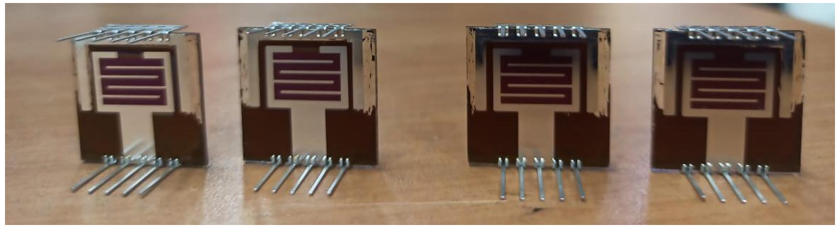
ICOPP -2026





Scale-up of Perovskite Tandem Solar Cells

Highlights → Optoelectronics

Device Engineering

India Semiconductor Mission

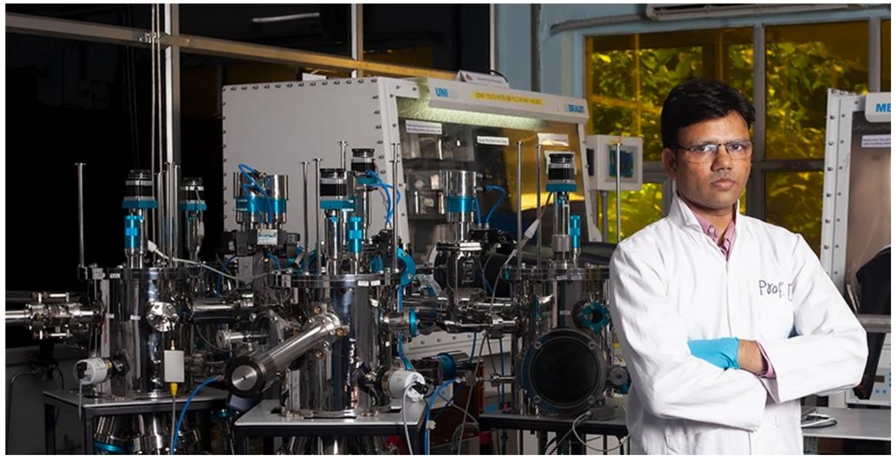
JNNSM for PVs

Unconventional materials that do more with light

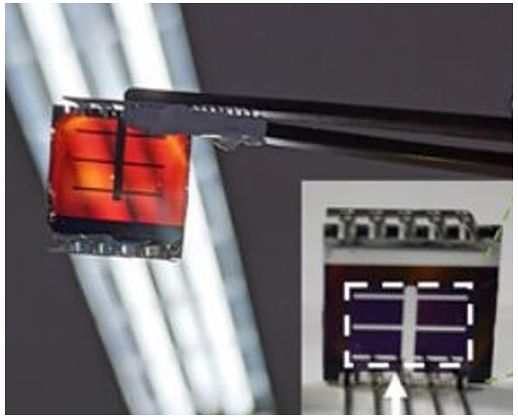
Dinesh Kabra is working with the next generation of optoelectronic materials for solar cells and display technologies.

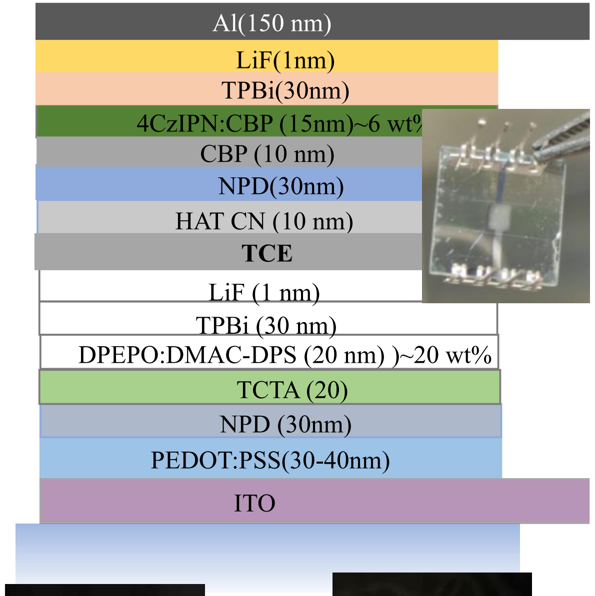
James Mitchell Crow

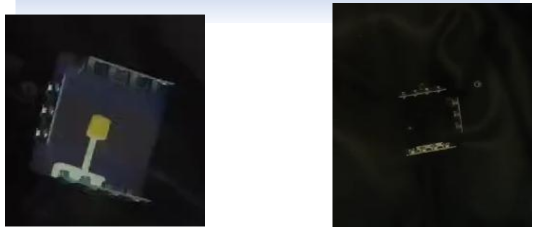
Nature team profile coverage



PV Global magazine Coverage!





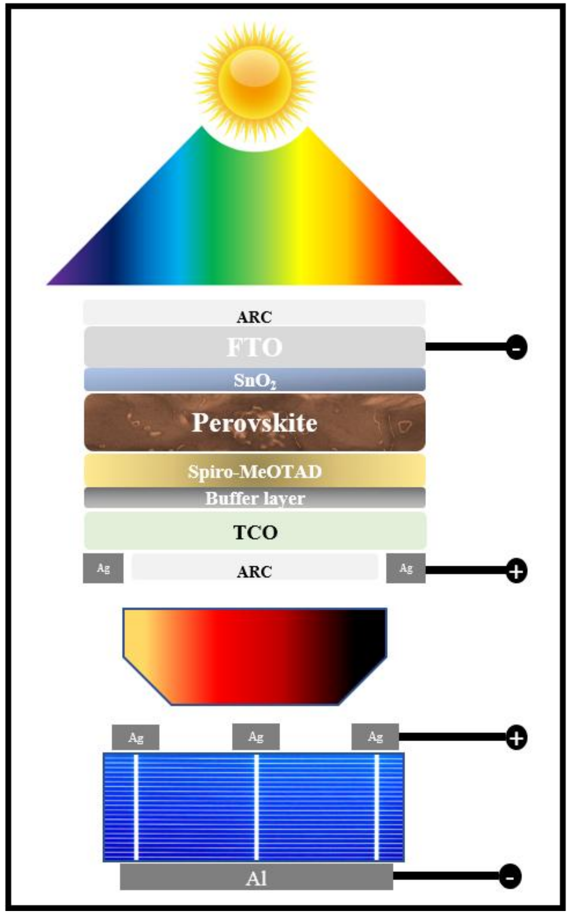


Vertically stacked RGB Tandem OLEDs:

Lighting

High resolution Displays

AOM 2024, Small 2024, ACS EL 2024



Silicon/perovskite Tandem Solar Cell: PCE> 27%

Efficiency gain per unit area!

Industry Partners

CORNING

PILKINGTON
NSG Group Flat Glass Business

Reliance

EXCEL INSTRUMENTS

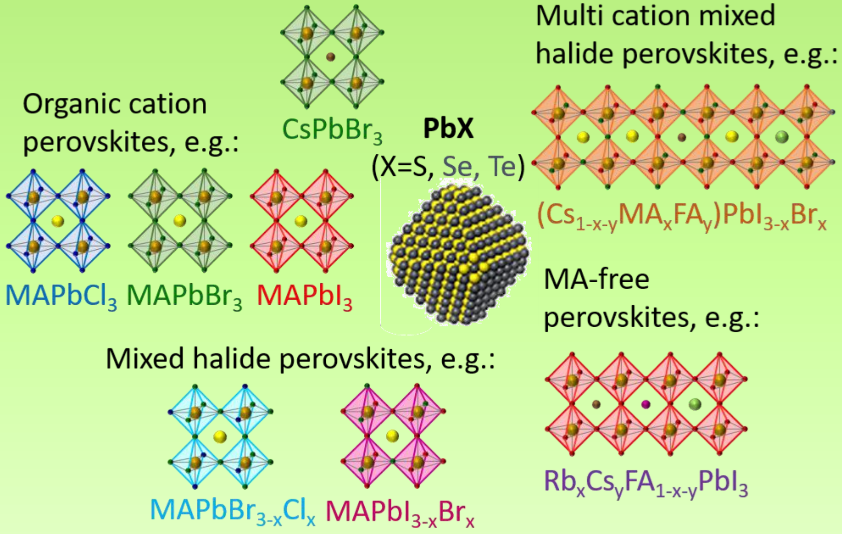
C|D|T

APPLIED MATERIALS
make possible

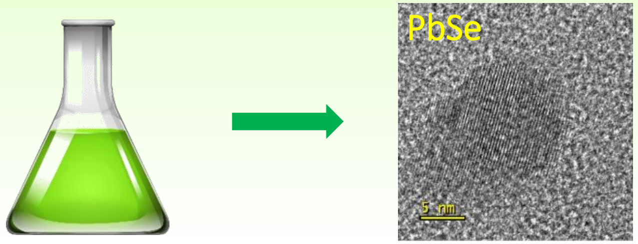
Research Interest: Thinfilm Optoelectronics

CHEMISTRY

Synthesis of novel nanomaterials

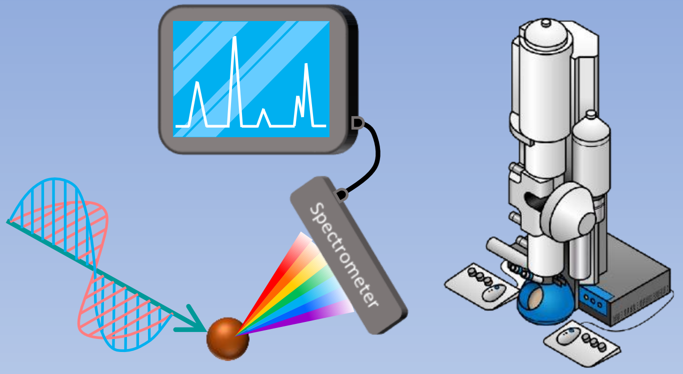


	PbS	PbSe	PbTe	$MAPbI_3$
a (Å)	5.936	6.124	6.462	6.26
Eg (eV), bulk	0.37	0.27	0.23	1.55



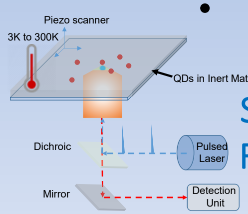
PHYSICS

Spectroscopy and Microscopy



- Absorption
- PL
- TCSPC
- FTIR
- PDS
- XPS/UPS
- Pump-probe single dot

- SEM
- HR TEM



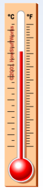
Spatially Resolved

Time resolved
~ 10^{-10} s

Frequency resolved

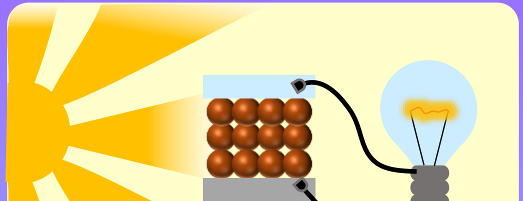
Spectrally resolved
200 -1700nm

Temperature resolved
3K – 300 K

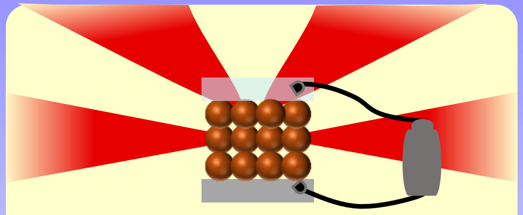


APPLICATION

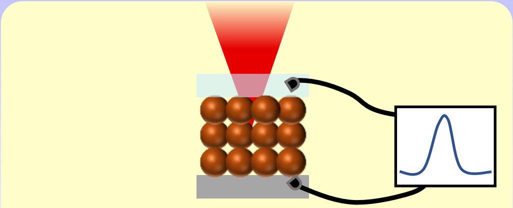
Advanced NIR Optoelectronics



Solar cells



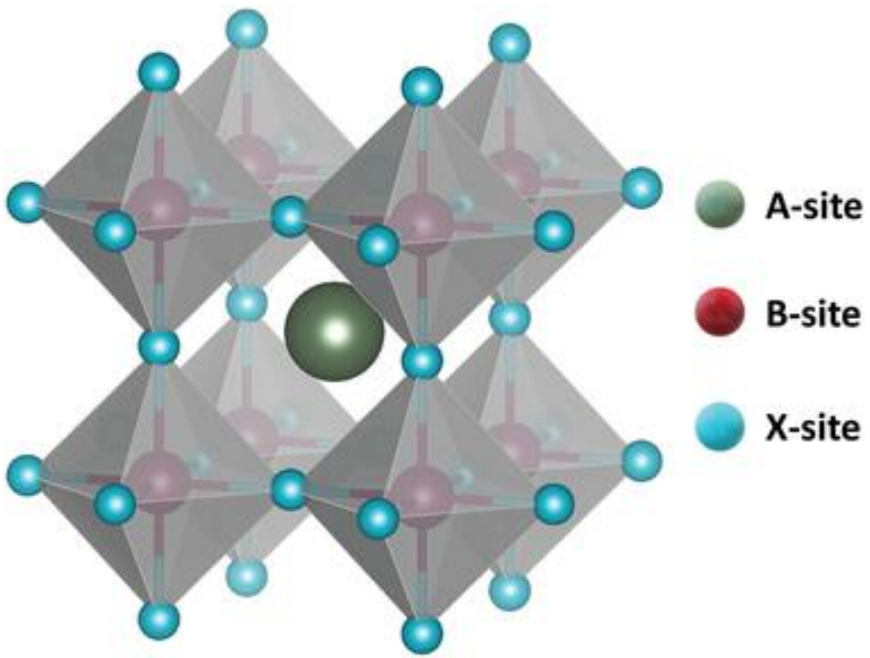
Light-emitting diodes

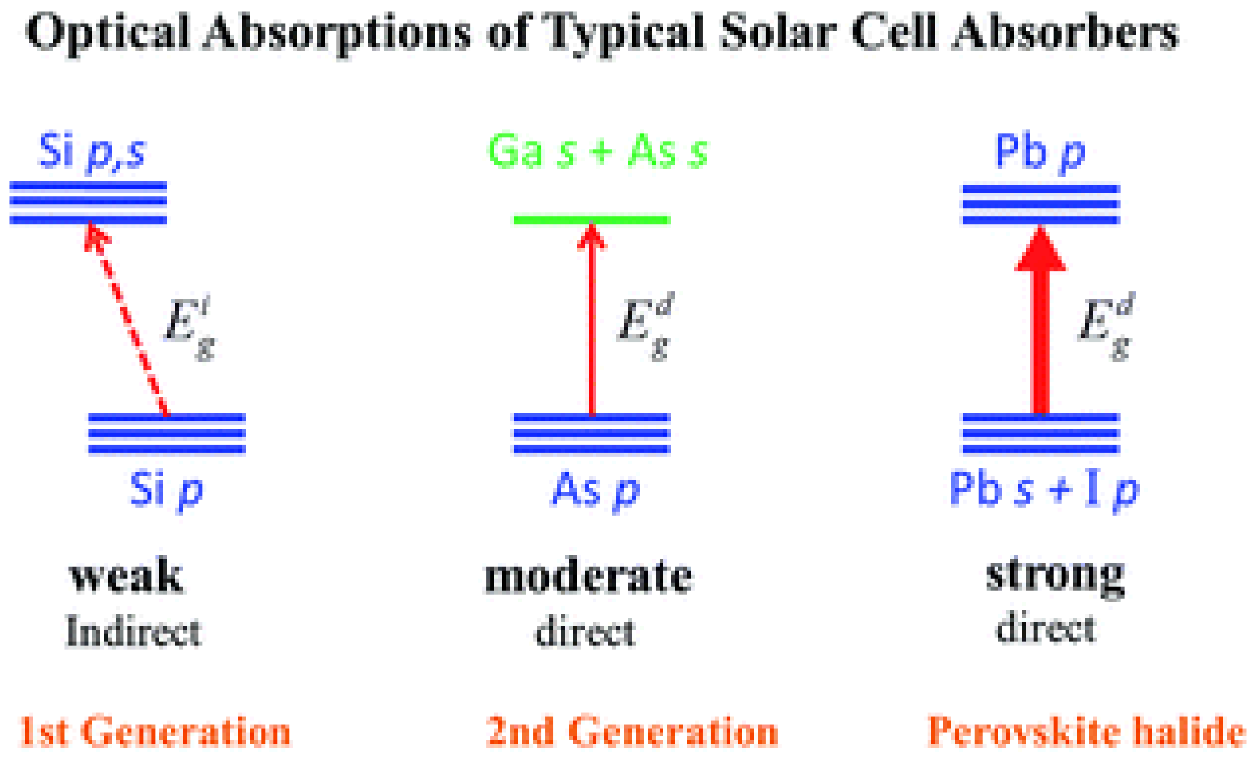


Photodetectors

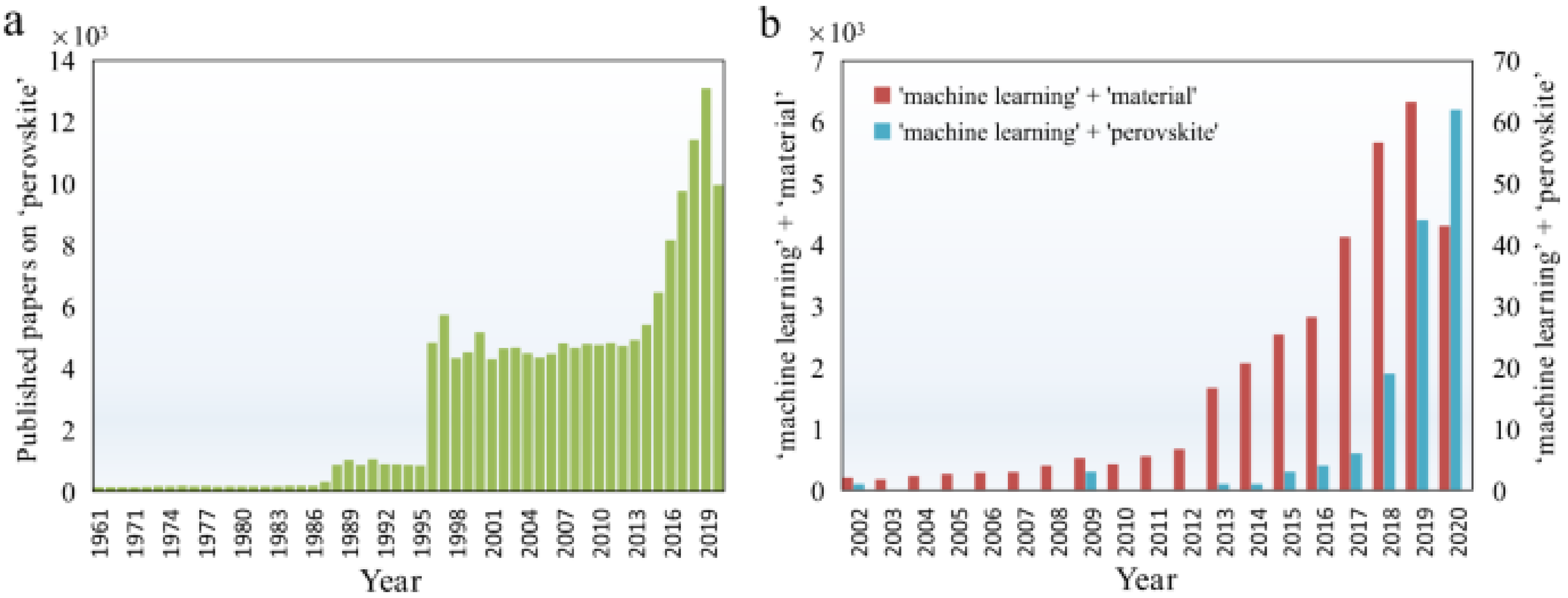
EN04.09 30th Nov. at 2:15 to 2:45 pm

Halide perovskite: New Wonder material

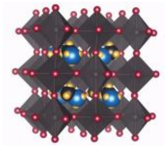




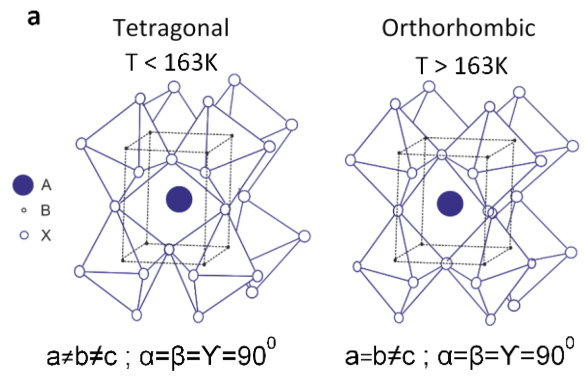
Keeping busy whole spectrum of experts!

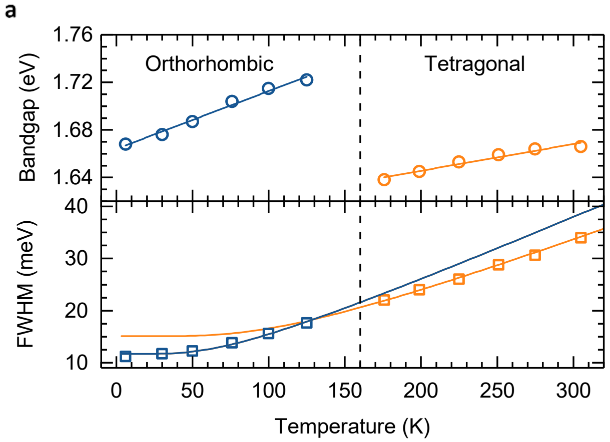


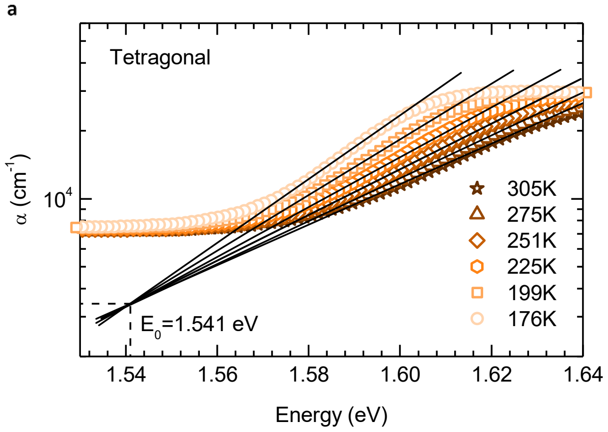
Temperature coefficient of bandgap : +ive or –ive?

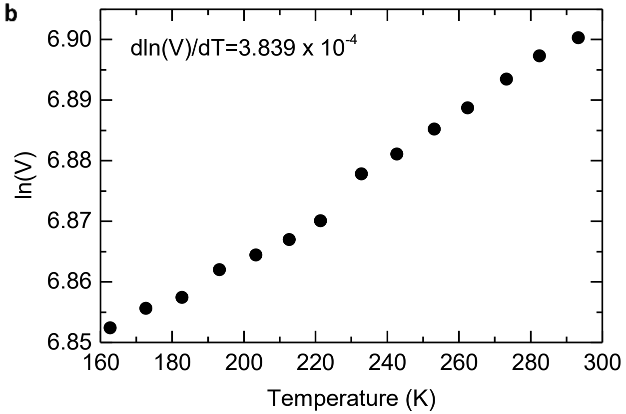


$$\left(\frac{dE_g}{dT}\right)_P = \left(\frac{dE_g}{dT}\right)_V + \left(\frac{dE_g}{d\ln(V)}\right)_T \times \left(\frac{d\ln(V)}{dT}\right)_P$$









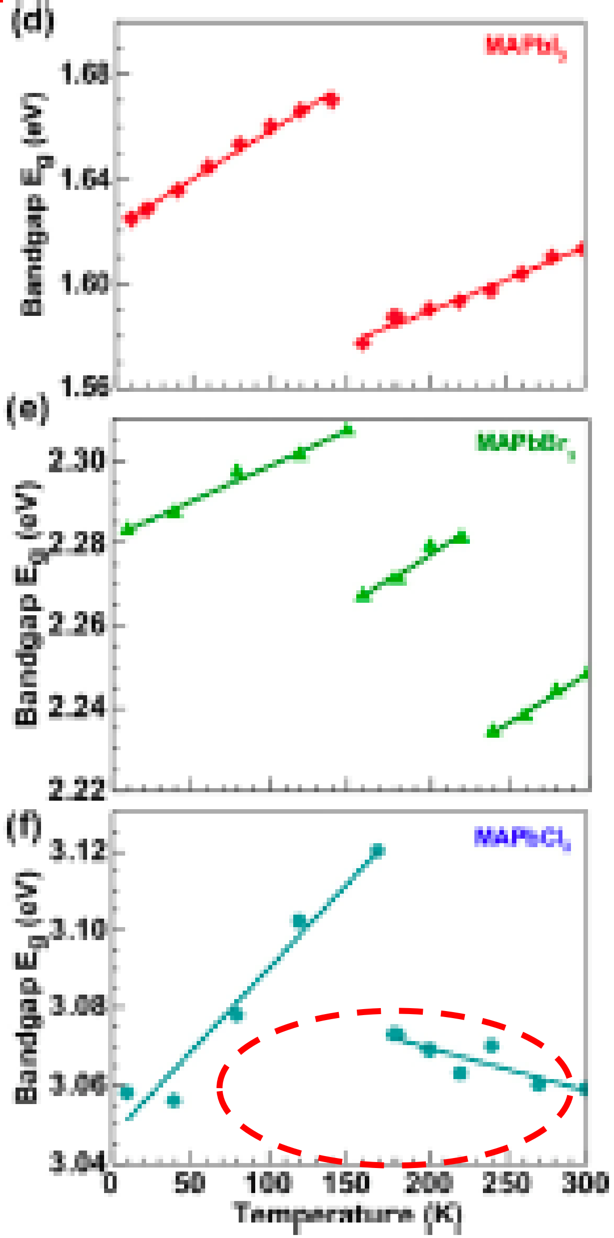
Fröhlich interaction

$\alpha_{Cl} > \alpha_{Br} > \alpha_I$

Lattice dilation is almost same

Rishabh Saxena et al PRB (R) 2020

A. Mahajan



- Lattice Dilation dominated **dynamic semiconductors**
- Urbach Focus in contrast to conventional inorganic crystalline semiconductors

Singh et al JPCL 2016

Static vs Dynamic disorder in semiconductors!

PHYSICAL REVIEW VOLUME 80, NUMBER 1 OCTOBER 1, 195

Deformation Potentials and Mobilities in Non-Polar Crystals

J. Bardeen and W. Shockley
Bell Telephone Laboratories, Murray Hill, New Jersey
(Received May 31, 1950)

The method of effective mass, extended to apply to gradual shifts in energy bands resulting from deformations of the crystal lattice, is used to estimate the interaction between electrons of thermal energy and the acoustical modes of vibration. The mobilities of electrons and holes are thus related to the shifts of the conduction and valence-bond (filled) bands, respectively, associated with dilations of longitudinal waves. The theory is checked by comparison of the sum of the shifts of the conduction and valence-bond bands, as derived from the mobilities, with the shift of the energy gap with dilation. The latter is obtained independently for silicon, germanium and tellurium from one or more of the following: (1) the change in intrinsic conductivity with pressure, (2) the change in resistance of an $n-p$ junction with pressure, and (3) the variation of intrinsic concentration with temperature and the thermal expansion coefficient. Higher mobilities of electrons and holes in germanium as compared with silicon are correlated with a smaller shift of energy gap with dilation.

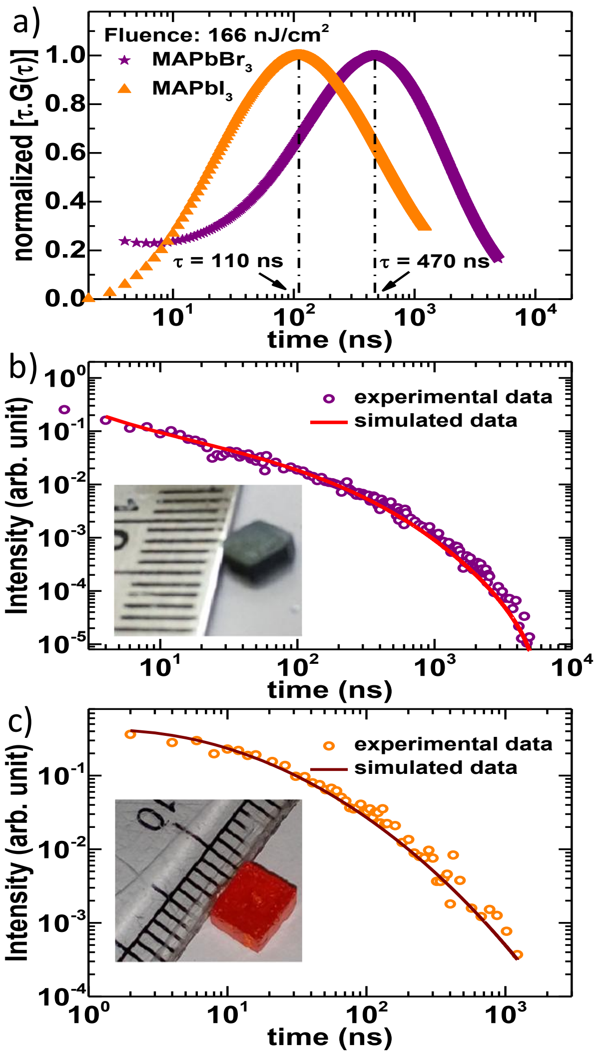
Table III. Derivation of shift of energy bands with dilation from mobility data and comparison with shift of energy gap with dilation.

	Diamond	Silicon	Germanium	Tellurium
(1) $c_{ii}\times10^{-12}$ c.g.s., (110)	10.8	2.0	1.55	0.50
(2) μ_n (electrons) (295°K)	900	300	3500	530
(3) μ_p (holes) (295°K)	>200	100	1700	530
(4) $\mu_n T^{\frac{3}{2}}$	45×10^5	15×10^5	180×10^5	27×10^5
(5) $\mu_p T^{\frac{3}{2}}$	$>10\times10^5$	5×10^5	86×10^5	27×10^5
(6) $\lvert E_{1c}\rvert$ (ev)	8.8	6.5	1.7	2.4
(7) $\lvert E_{1v}\rvert$ (ev)	<30	11.3	2.4	2.4
(8) $\lvert E_{1c}\rvert+\lvert E_{1v}\rvert$ (ev)	<39	17.8	4.1	4.8
(9) E_{1G} (ev)	?	∼−30	∼−5	+4.0

W. Shockley & J. Bardeen Phys Rev. Vol. 80, p-72 (1950)

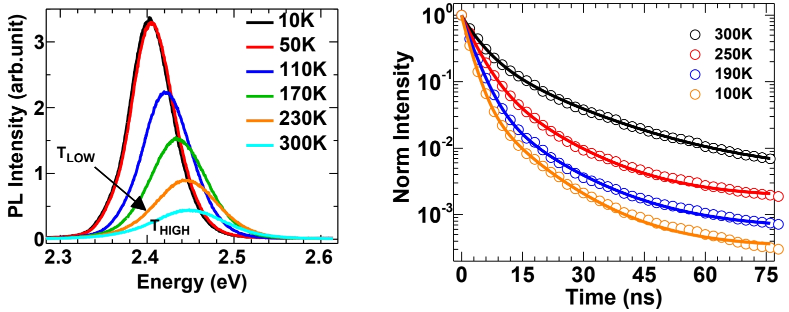
Photo-physics of Perovskites Semiconductors

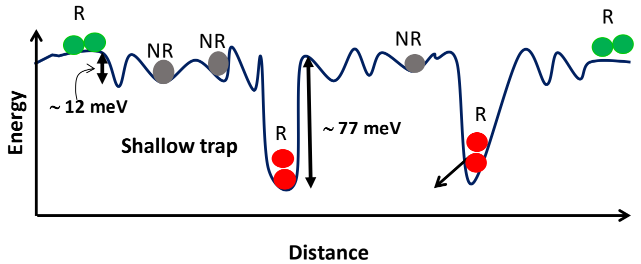
Anomalously large PL decay in HOIP Single Crystal

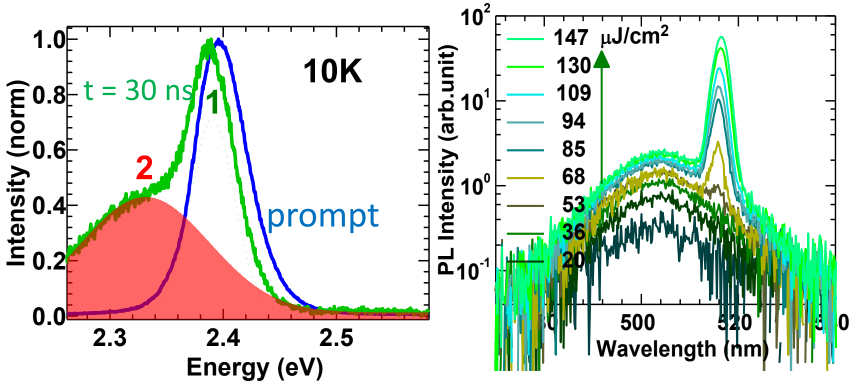


R. Saxena et al *JPC C* 2018

Direct observation of Free vs. Localized excitonic state in Controlling the Photoluminescence Dynamics of High Optical Gain $CsPbBr_3$ Nanocrystals

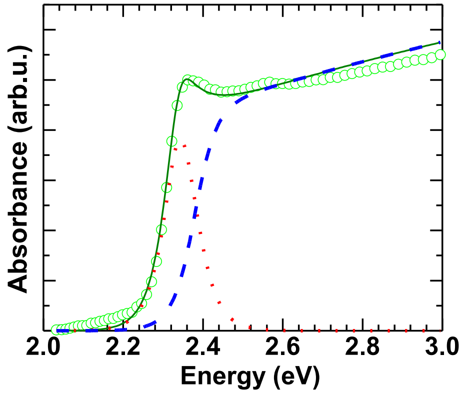


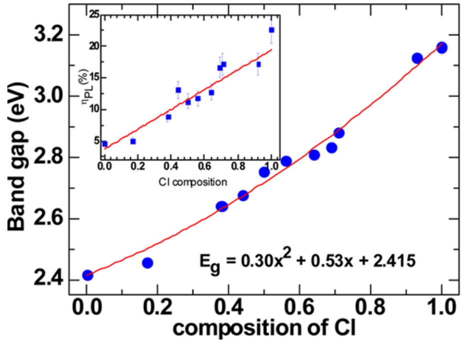


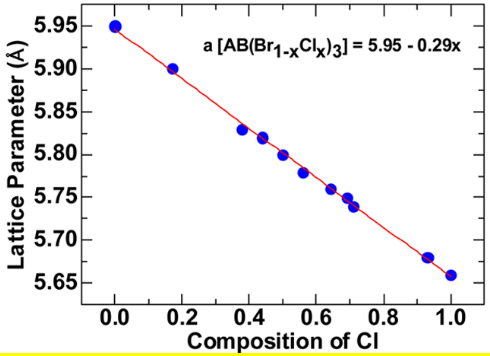


Dey et al Adv. Opt. Mater 2018, JPC C 2018

Sommerfied Correction to determine electronic bandgap : First Blue EL



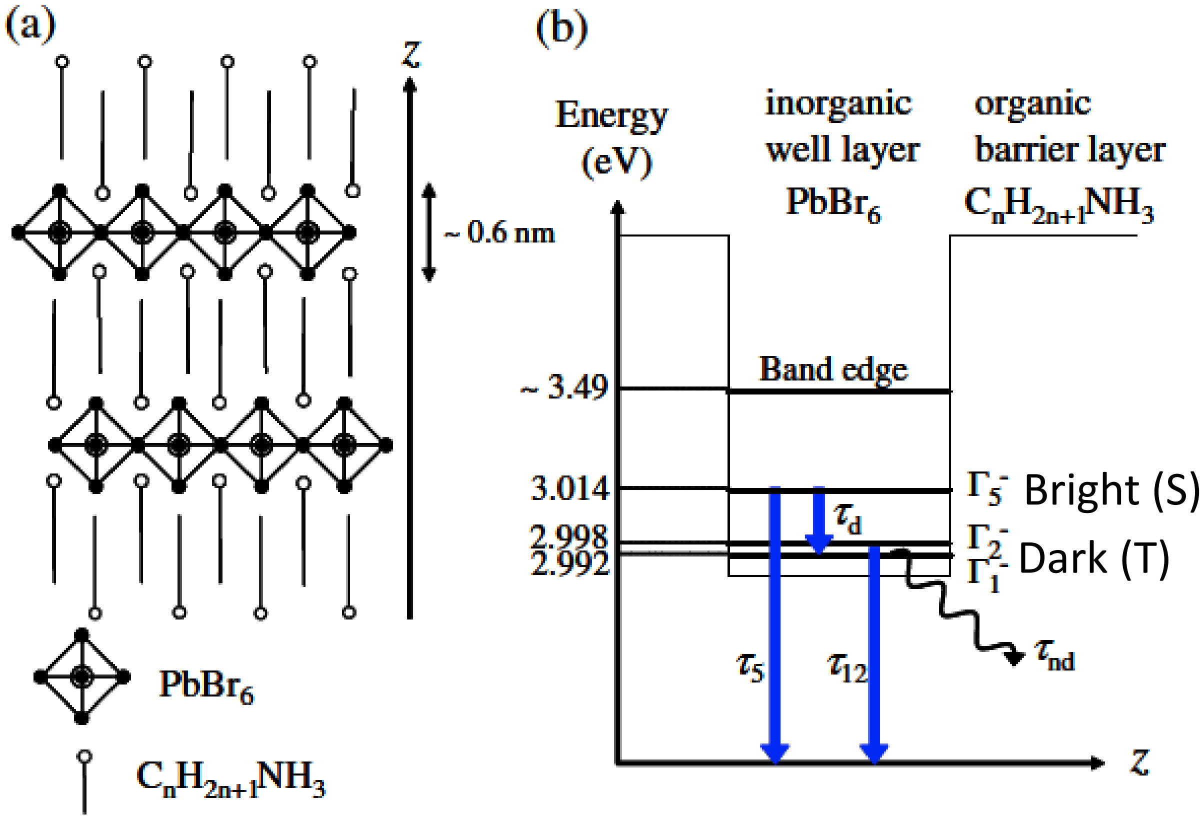


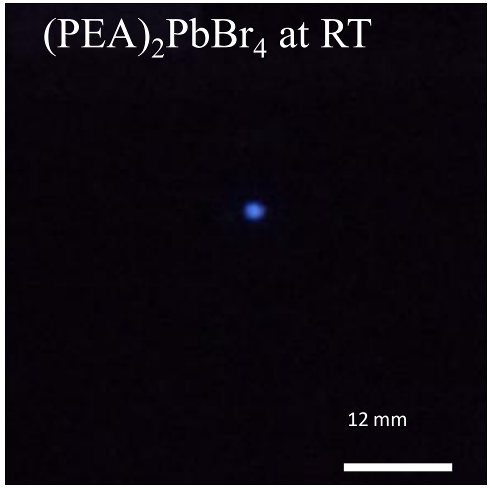


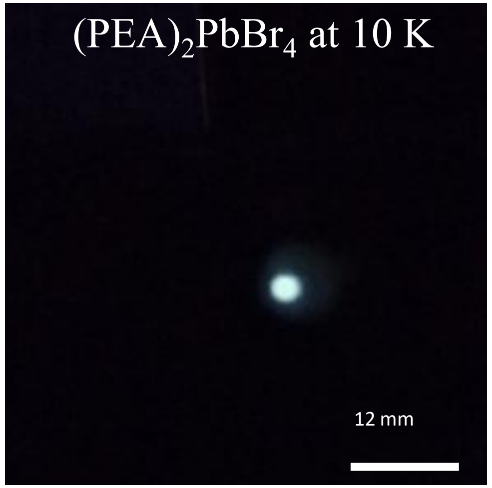
Kumawat el al ACS Appl. Energy Mat. & Inter. 2015

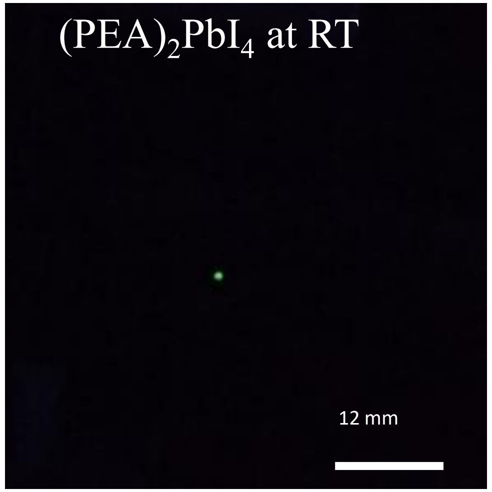
2D Layered Perovskite Emission Spectrum!

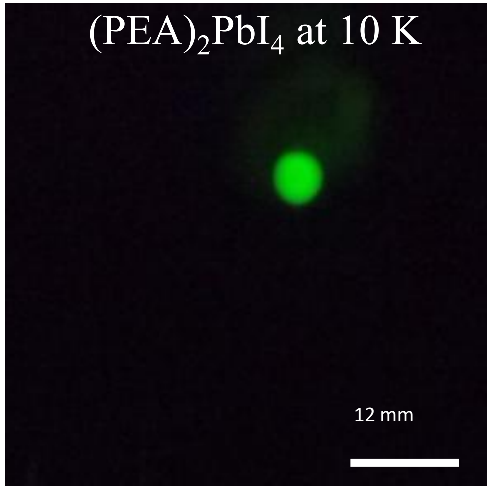
- 2D perovskites improve the moisture stability
- Perfect charge transport layer for PVs
- High exciton binding energy → Efficient quasi-2D PeLEDs









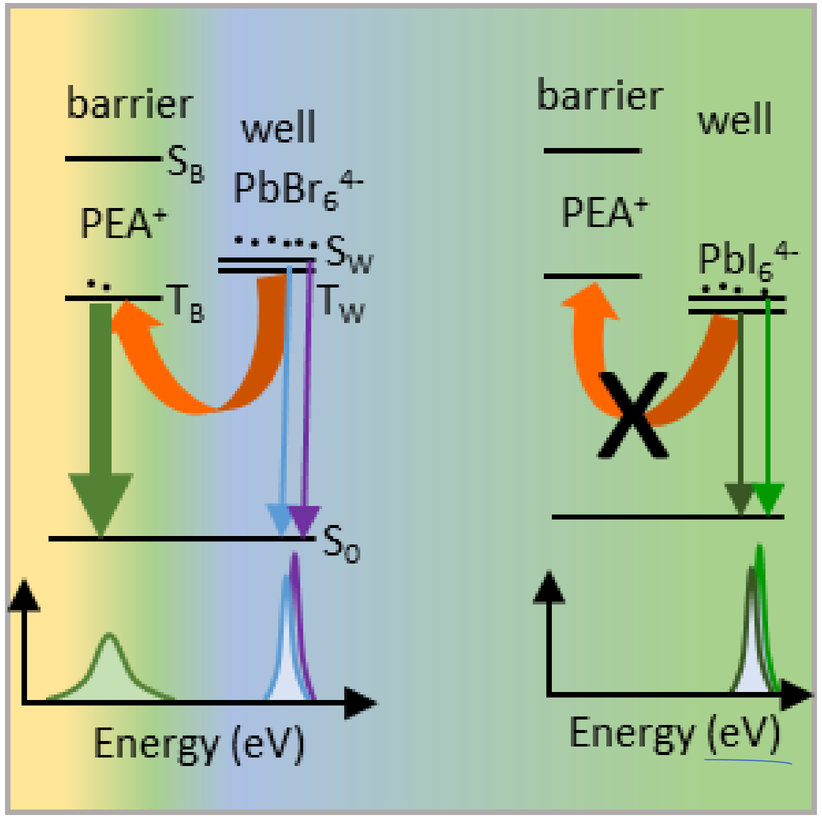


Laxmi

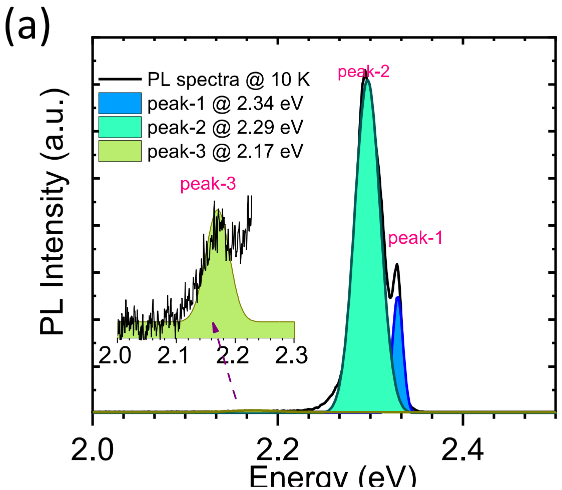
Laxmi et al JPCL. 2022 Mar 21;13:2737-43
K. Ema et al Phys. Rev. B 73, 241310(R) (2006)

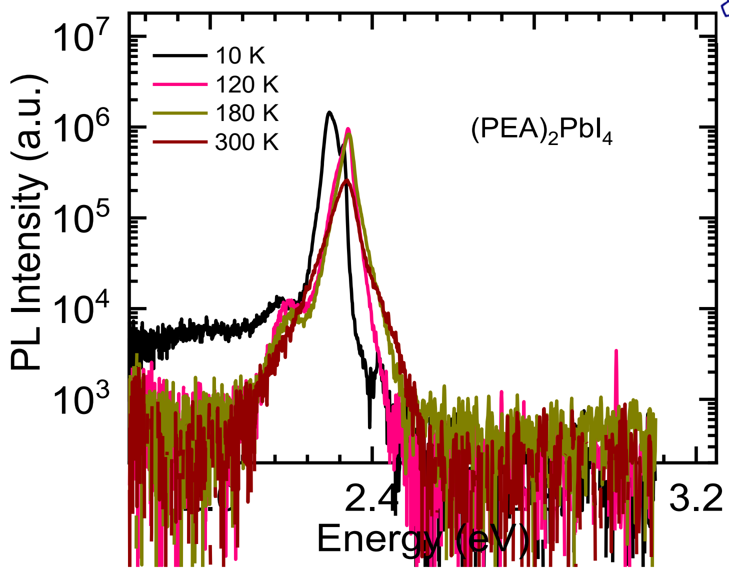
K. Ema et al Phys. Rev. Lett. Vol. 100, p-257401 (2008)
Adachi et al NAT. Photonics Vol. 14 p-70 (2020)

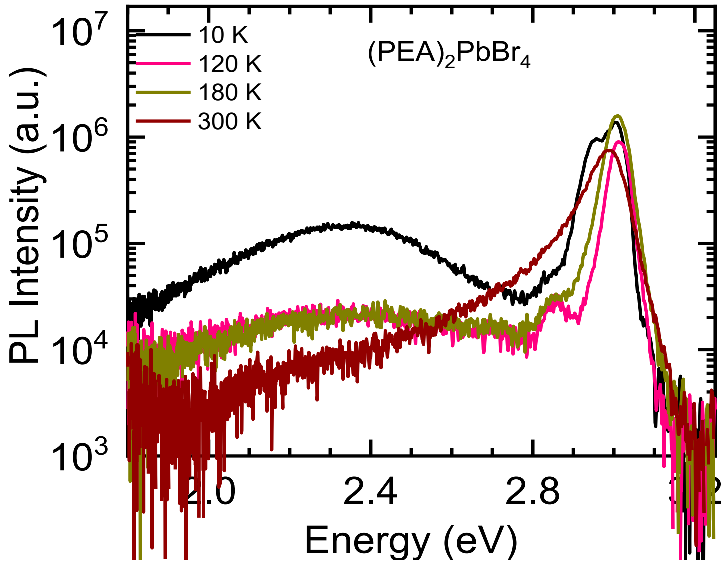
Steady State Photoluminescence (PL)

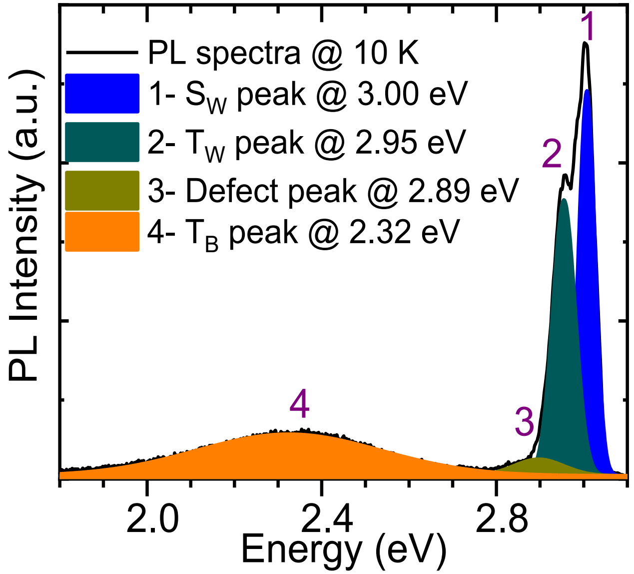


S- Singlet
T-Triplet
B-Barrier
W-Well



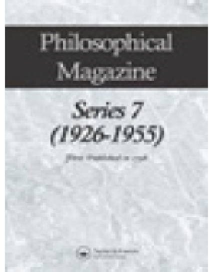






- Multipeaks emission in both perovskites
- White emission in Br based perovskite → mixing of narrow and broad emission colours
- Iodine case 4th peak is missing or significantly small!

No self-trapping of electrons in polar materials with ions!



Taylor & Francis

The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science

Series 7

ISSN: 1941-5982 (Print) 1941-5990 (Online) Journal homepage: https://www.tandfonline.com/loi/tphm18

XX. Properties of slow electrons in polar materials

H. Fröhlich , H. Pelzer & S. Zienau

To cite this article: H. Fröhlich , H. Pelzer & S. Zienau (1950) XX. Properties of slow electrons in polar materials, The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 41:314, 221-242, DOI: 10.1080/14786445008521794

To link to this article: https://doi.org/10.1080/14786445008521794

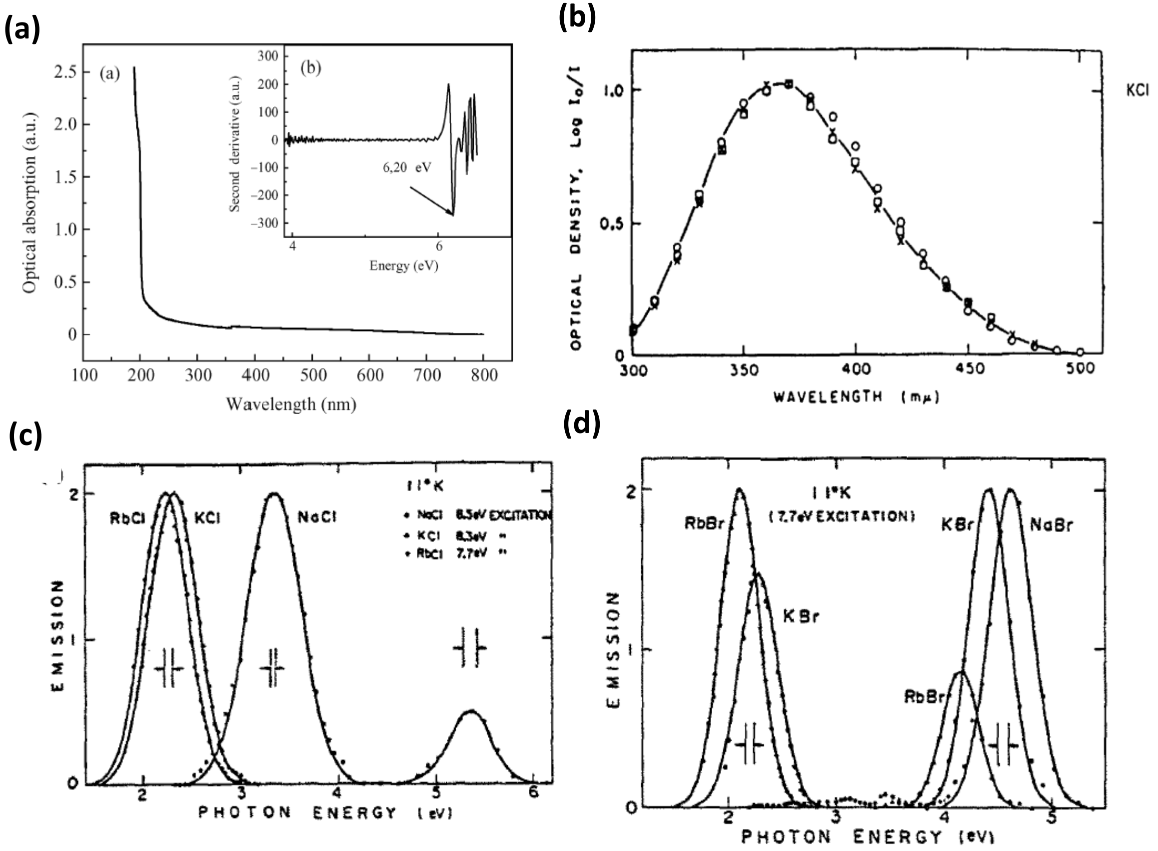
Summary.

Using a variational method we have investigated the properties of the lowest energy levels in a range $\hbar\omega$ above the ground level of the system consisting of an electron and a continuous dielectric medium. The latter is supposed to have a single vibrational frequency $\omega/2\pi$ for long longitudinal polarization waves. The interaction between the electron and the medium then depends on three parameters, the static dielectric constant ϵ, the optical refractive index $\epsilon_\infty^{\frac{1}{2}}$, and ω. The replacement of a crystalline lattice by a continuum is a good approximation if the length $b=(\hbar/2m\omega)^{\frac{1}{2}}$ is large compared with the lattice distance, a condition which is usually fulfilled.

We find that the energy of the ground level may be considerably (compared with $\hbar\omega$) below the energy which the system would have in the absence of interaction. The electron can be found with equal probability at any point in the medium. The average polarization of the medium therefore vanishes at any point. This does not hold, however, for the average polarization at a given distance from the electron. This quantity varies at large distances as the polarization of a point charge, but shows deviations below distances of the order b. The energy of interaction depends very little on the average velocity of the electron. Slow electrons, therefore, behave very similarly to free electrons (§ 4). It follows then that self trapping in the lattice—a suggestion which has often been discussed—does not exist (§ 5).

Modified forms of previous formulæ of the mean free path of electrons are given in § 6. It is shown, however, that the validity of the whole method used at present to calculate mean free paths requires further investigation.

Absorption and Emission features of STE in Alkali Halides



For KCl crystals

- STEs Absorption peak at 3.44 eV
- STEs Emission at 2.5 eV, excitation with 8.3 eV x-rays

For Figure a, Bouhdjer L, Addala S, Chala A, Halimi O, Boudine B, Sebais M. Elaboration and characterization of a KCl single crystal doped with nanocrystals of a Sb2O3 semiconductor. Journal of Semiconductors. 2013 Apr 1;34(4):043001

For Figure b. Delbecq CJ, Smaller B, Yuster P. Optical Absorption of Cl 2− Molecule-Ions in Irradiated Potassium Chloride. Physical Review. 1958 Sep 1;111(5):1235

Figure c and d M, Ikezawa Kojima T. Luminescencs of Alkali Halide Crystals Induced by UV-Light at Low Temperature. Journal of the Physical Society of Japan. 1969 Dec 5;27(6):1551-63

FWHM of Organic Phosphorescence

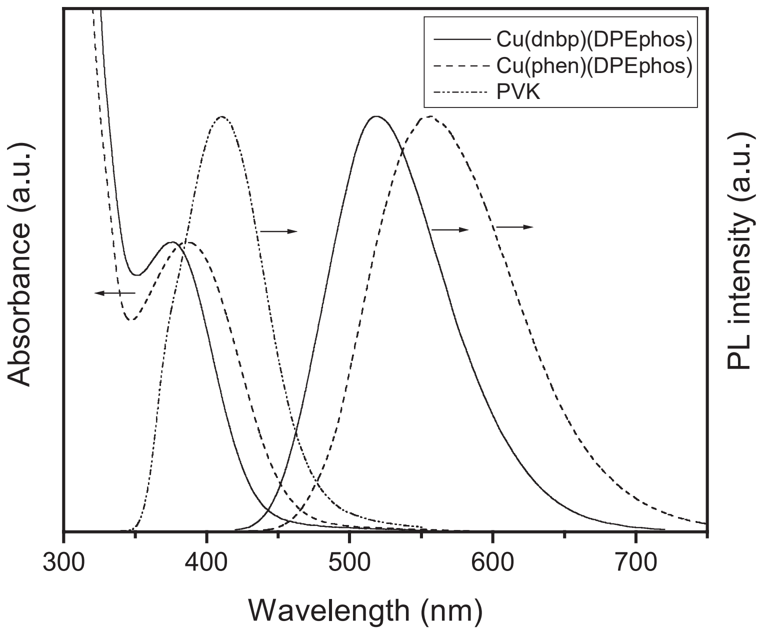
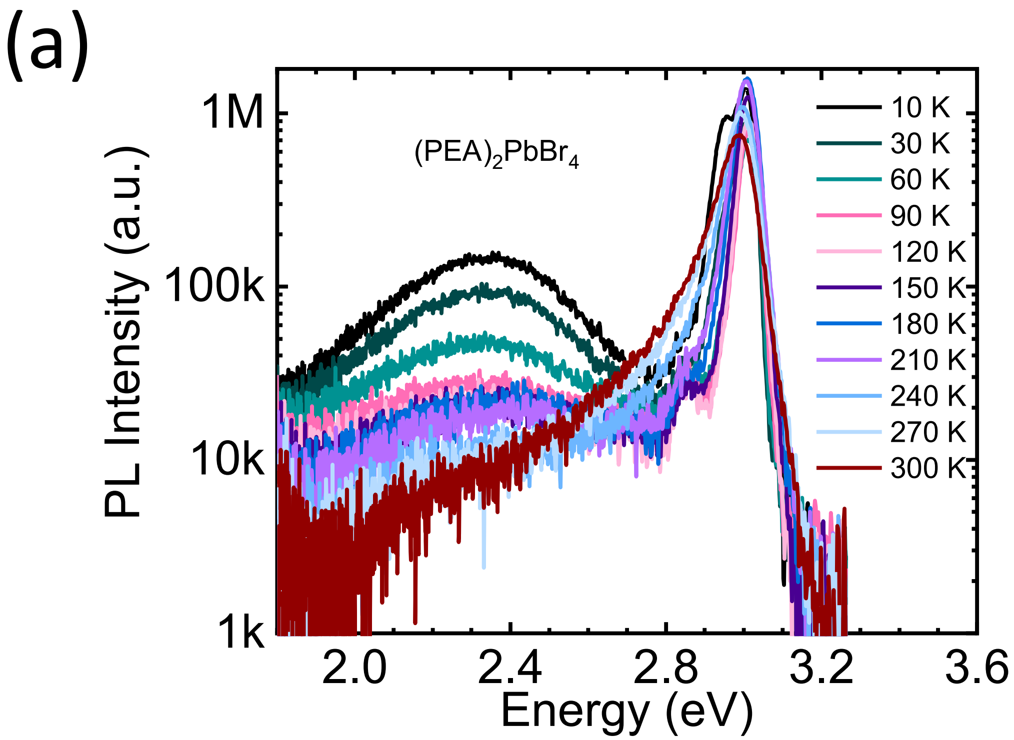


Figure 2. Absorption and photoluminescence spectra of 20 wt.-% [Cu(dnbp)(DPEphos)]BF_4 (3b) and 20 wt.-% [Cu(phen)(DPEphos)]BF_4 (1b) in PMMA, and photoluminescence spectrum of PVK (neat film).

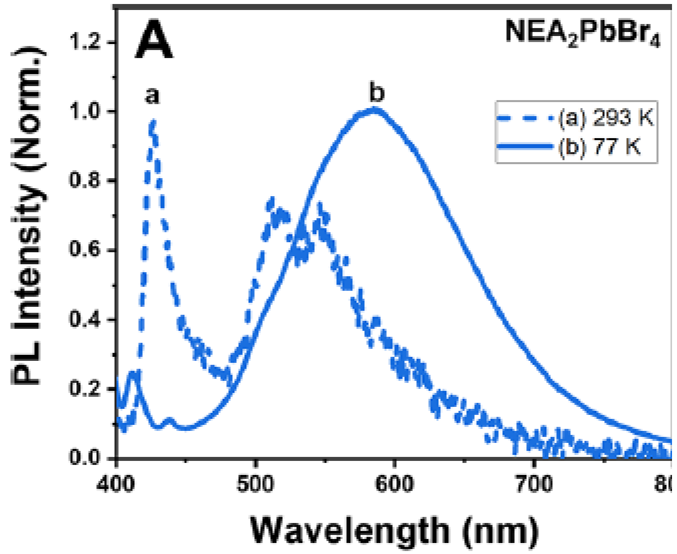


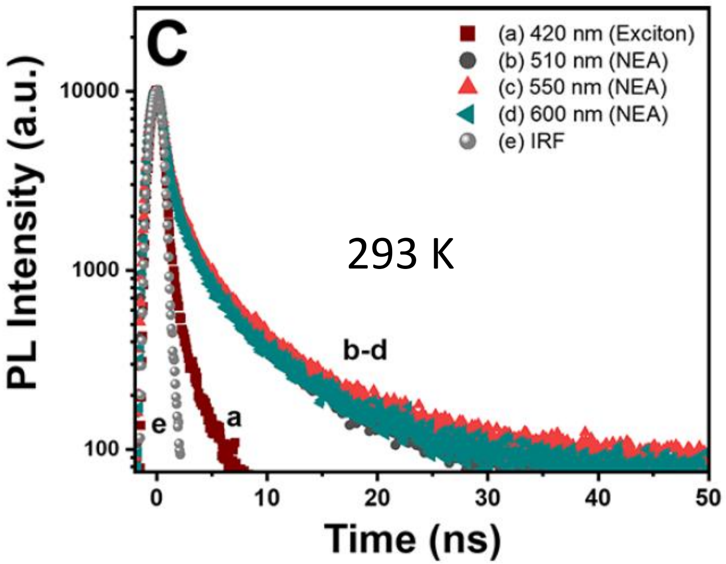
1.8 eV → 688 nm

2.8 eV → 442 nm

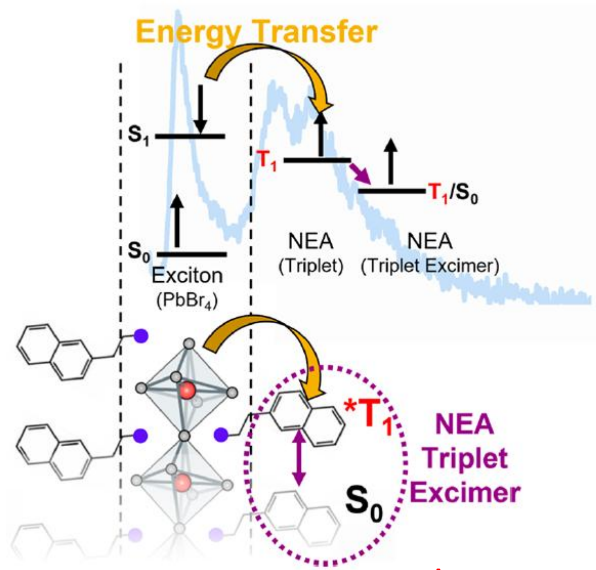
https://onlinelibrary.wiley.com/doi/epdf/10.1002/adma.200306414

Literature Data

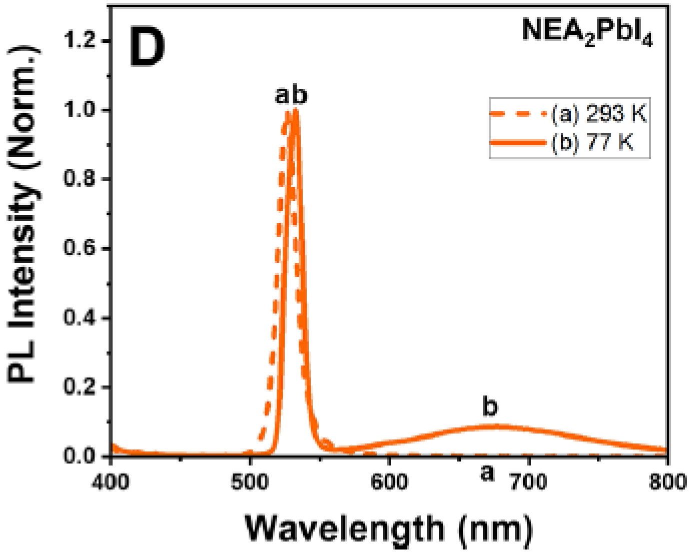


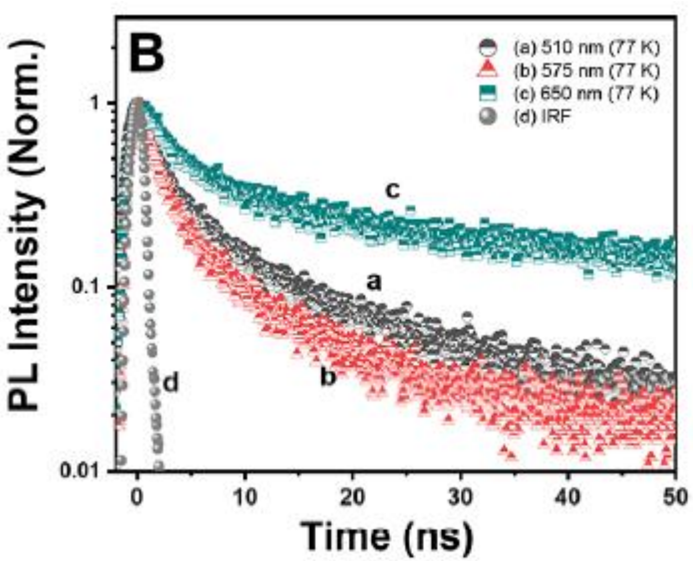


Scheme 1. Origin of Broad Emission from NEA_2PbBr_4 and $NEA_2Pb(Br_{0.7}I_{0.3})_4$[a]



Broad emission in 2D perovskites



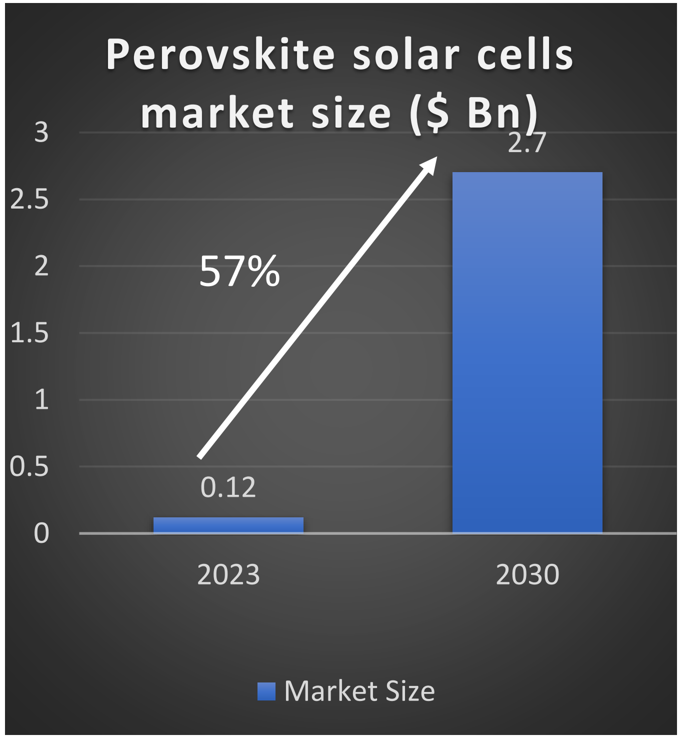


- ❖ An emission from triplet of molecular cation (NEA – naphthyl ethyl ammonium) -phosphorescence
- ❖ Emission strength depends upon energy level alignment in inorganic layer and organic cation
- ❖ Temperature decrease further boost the emission
- ❖ Wavelength dependent PL kinetic shows the contributing emissive states

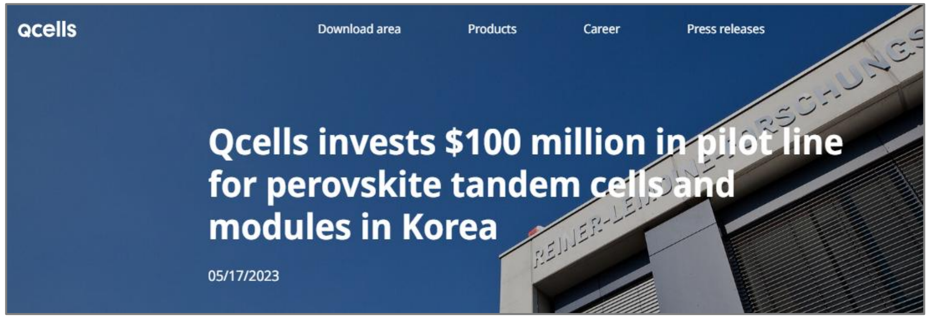
PV Kamat et al ACS Nano **2023, 17, 19052–19062**

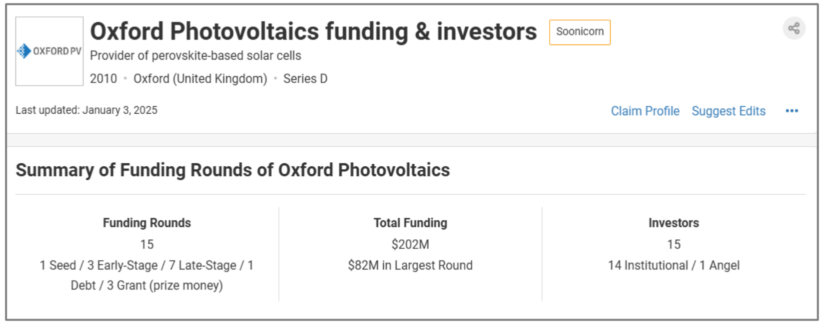
…. there is huge growth projected for perovskite cells with 57% CAGR between 2024-31 with all global giants investing significantly in perovskite technology

Projected Perovskite cell market size



Major investments in Perovskite technology


Qcells
Download area
Products
Career
Press releases
Qcells invests $100 million in pilot line for perovskite tandem cells and modules in Korea
05/17/2023


Oxford Photovoltaics funding & investors
Soonicorn
Provider of perovskite-based solar cells
2010 · Oxford (United Kingdom) · Series D
Last updated: January 3, 2025
Claim Profile Suggest Edits

Summary of Funding Rounds of Oxford Photovoltaics

Funding Rounds	Total Funding	Investors
15	$202M	15
1 Seed / 3 Early-Stage / 7 Late-Stage / 1 Debt / 3 Grant (prize money)	$82M in Largest Round	14 Institutional / 1 Angel


THE STRAITS TIMES SINGAPORE

$77 million solar research lab launched to improve efficiency, cost-effectiveness of solar panels

The uppermost layer will be made of perovskite, a family of crystalline compounds known for its low production cost and high energy conversion efficiency, with silicon as the bottom cell.


Perovskite-info
The Perovskite-Info Perovskites for the Solar Industry Market Report
Home | About us | Introduction | The Perovskite Handbook | Perovskite Solar | Displays | Compa
Perovskite Connect | Perovskite LEDs | Perovskite QDs | Perovskite lasers | Perovskite and Graphene | Perovskite fuel ce
Home » China's GCL to invest USD$98 million in tandem silicon/perovskite PV

China's GCL to invest USD$98 million in tandem silicon/perovskite PV

GCL Technology, one of China's largest solar panel materials producers, will reportedly invest 700 million yuan (almost USD$98 million) to transition to a more lucrative next-generation technology, as the industry grapples with losses and oversupply.

Trina: 841W panels.
Longi: 34.58% efficiency.
These aren't incremental improvements. We're watching solar's next chapter unfold.

Source: Fortune Business Insights (link)

IIT Bombay SINE Business Incubator

Best R&D Team

Prof. D. Kabra
Department of Physics

Prof. B. Kavaipatti
ESE Department

Prof. P. Nair
EE Department

Subash Pai, **EXCEL INNOVATORS AND INTEGRATORS PVT LTD**

Prof. P. Bhargava
MEMS Department

Prof. N. Shiradkar
EE Department

K. L. Narasimhan
Electrical Engineering

B. M. Arora
Electrical Engineering

Public Funds:
- IOE, MoE-India
- DST-India
- MNRE-India
- MEITY-India

IIT Bombay SINE Business Incubator

ART-PV india

WAAREE One with the Sun

First Solar

indus TOWERS

CORNING

E I&I

PILKINGTON
NSG Group Flat Glass Business

C|D|T

Perovskite cells offer higher efficiency, lower cost, flexibility, and better low-light performance and ease of manufacturing!

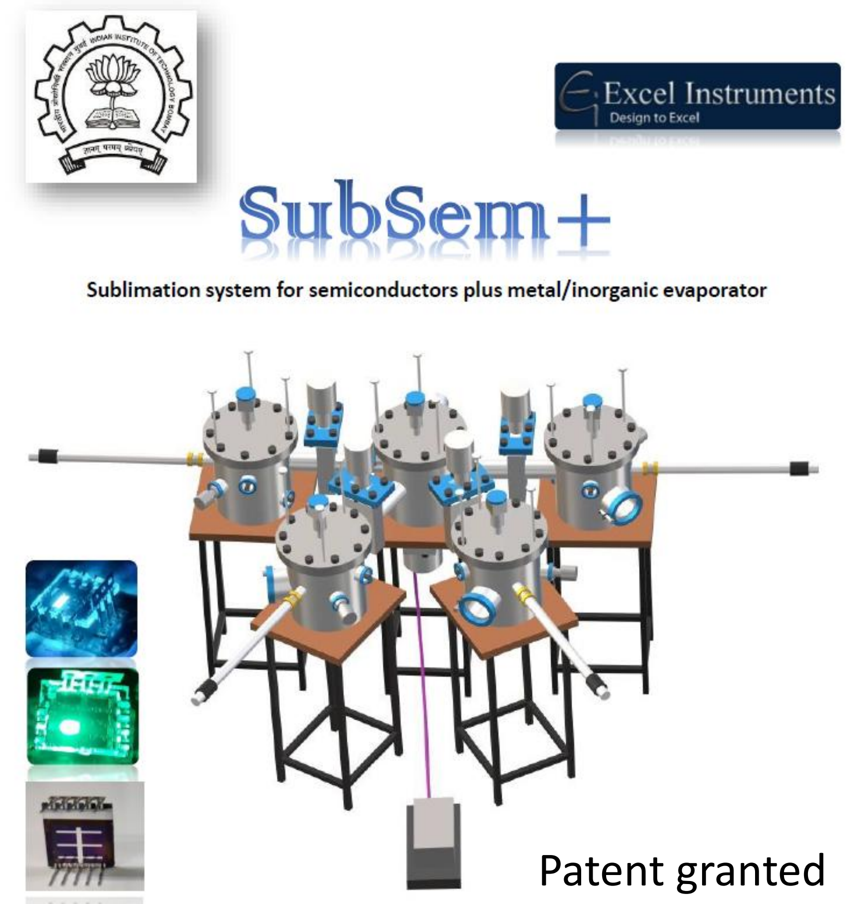
	Parameters	Silicon based cells	Perovskite cells
1	**Theoretical maximum and commercial efficiency**	29-33% (1) (Shockley-Queisser limit) Commercially available: 25.09 % (3)	Theoretical: **45.3%** (2) Demonstrated: 28% module efficiency (4)
2	**Light absorption**	Can absorb photons with a **wavelength greater than 800 nm** as the bandgap width of silicon is 1.1 eV (6)	Can absorb photons with a **wavelength less than 800 nm** as the bandgap width of perovskite is 1.55 eV (6)
3	**Raw Material availability**	China controls ~80% of the global supply chain from raw poly-silicon to finished modules (5)	Lead halide and tin halide are widely available, less energy-intensive to process
4	**Raw material Cost**	Lower cost due to abundance and simplicity in processing	Lower cost due to abundance and simplicity in processing
5	**Manufacturing ease**	Established manufacturing with complex and energy intensive processes for monocrystalline silicon and casting for polycrystalline silicon	Utilizes techniques like printing & coating, which are less energy-intensive & more scalable
6	**Durability and lifespan**	25-30 years	Shorter lifespan compared to silicon cells, recent advances in encapsulation and stabilization techniques are extending their operational life

IIT Bombay SINE Business Incubator

Micro-quanta Perovskite Solar plant 1.1 MW

Technology Transfer and licensing of IPs

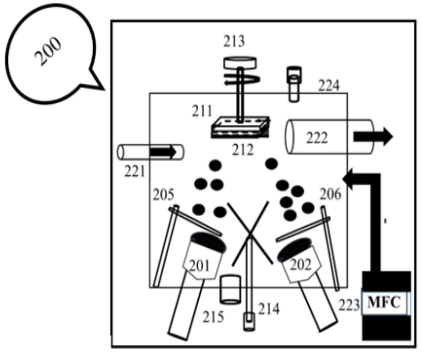
Optoelectronic device fabrication tool

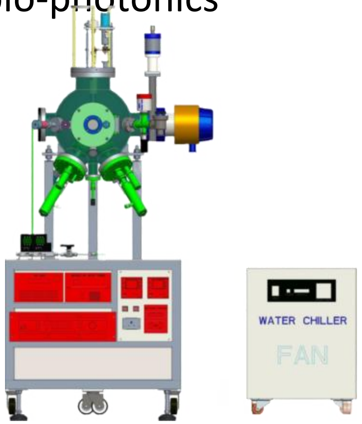


Patent granted

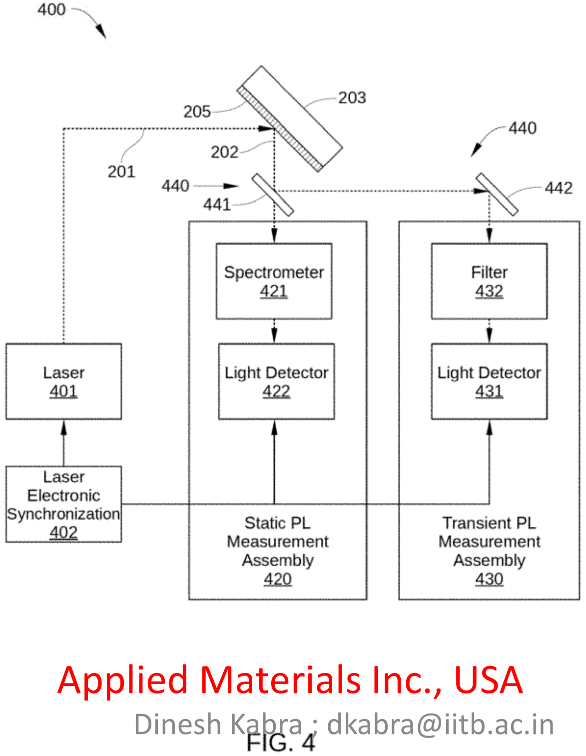
Patents filed
Countries includes: India, US, China, Japan, Taiwan, South Korea, Europe

TCE on soft materials fabrication tool
→ Optoelectronics and bio-photonics





OLED manufacturing meteorology tool



Applied Materials Inc., USA

Research Highlights

Nature – where I work
IOP – Physics world
AIP- SCIlight
Global PV Magazine

Method of forming perovskite film via vacuum approach

US 20220325398A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2022/0325398 A1**
Sharma et al. (43) **Pub. Date: Oct. 13, 2022**

(54) METHOD OF FORMING A HALIDE-CONTAINING PEROVSKITE FILM

(71) Applicant: **Applied Materials, Inc.**, Santa Clara, CA (US)

(72) Inventors: **Vijay Bhan Sharma**, Rajasthan (IN); **Abhijeet Laxman Sangle**, Maharashtra (IN); **Ankur Anant Kadam**, Thane (IN); **Suresh Chand Seth**, Mumbai (IN); **Richa Pandey**, Kanpur (IN); **Dinesh Kabra**, Mumbai (IN); **Valipe Ramgopal Rao**, New Delhi (IN)

(73) Assignee: **Applied Materials, Inc.**, Santa Clara, CA (US)

(21) Appl. No.: **17/229,492**

(22) Filed: **Apr. 13, 2021**

C23C 14/58 (2006.01)
B05D 1/00 (2006.01)
B05D 3/00 (2006.01)

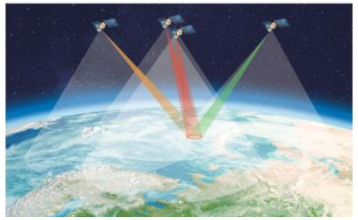
(52) U.S. Cl.
CPC *C23C 14/0694* (2013.01); *C23C 14/024* (2013.01); *C23C 14/24* (2013.01); *C23C 14/54* (2013.01); *C23C 14/5806* (2013.01); *B05D 1/005* (2013.01); *B05D 3/007* (2013.01); *B05D 2401/10* (2013.01); *B05D 2425/02* (2013.01)

(57) ABSTRACT

A hybrid halide perovskite film and methods of forming a hybrid halide perovskite film on a substrate are described. The film is formed on the substrate by depositing an organic solution on a substrate, heating the substrate and the organic solution to form an organic layer on the substrate, depositing an inorganic layer on the organic layer, and heating the substrate having the inorganic layer thereon to form a hybrid halide perovskite film. In some embodiments, the hybrid

Applied Materials Inc., USA

Space grade PV solutions



Why Space grade PV:

- For strategic reasons
- Rise in privatization of space industries
- 6G communication: 0.1 M satellite by 2030!
- Only 3 companies makes these cells
- (AZUR, CESI and Spectrolab)

III-V group is widely used

- Gallium (Ga) : 90 % of it is in China
- Ga is announced as critical element by DOE-USA

Halide perovskite PV :

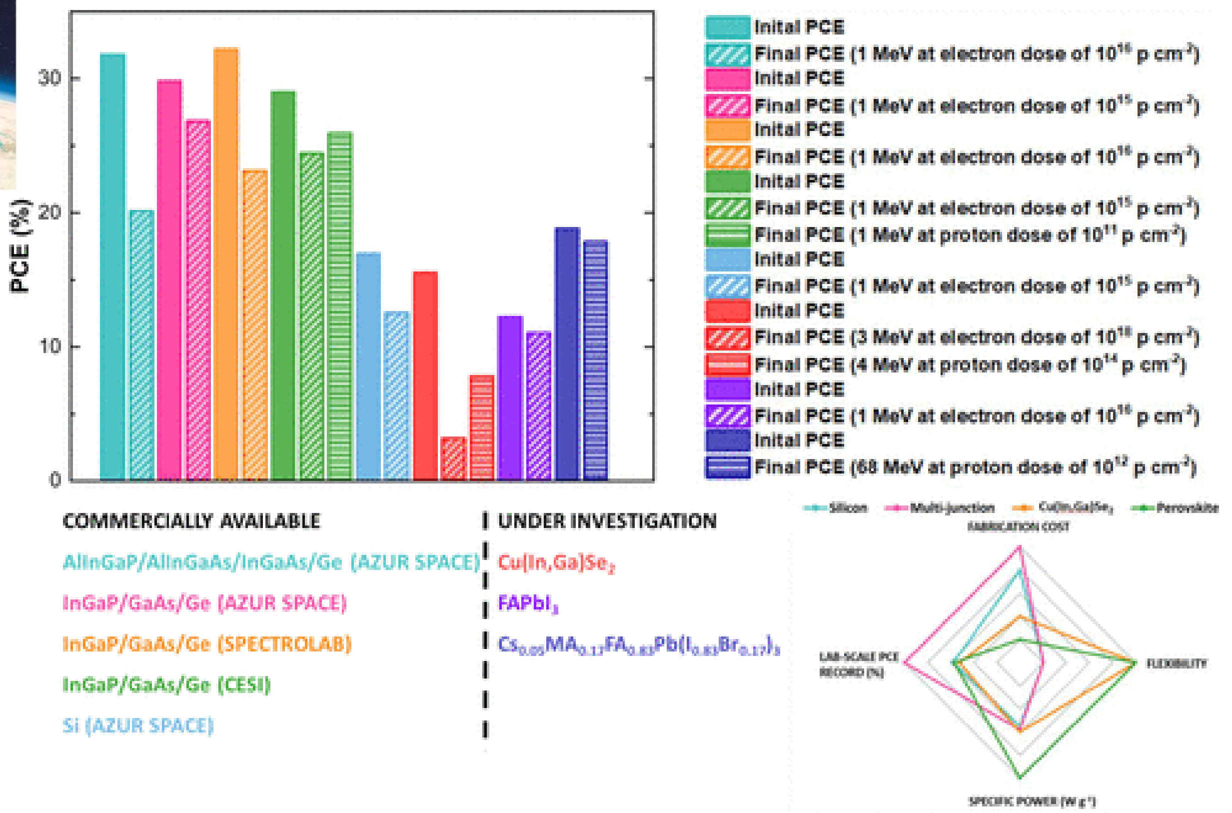
- Proven to work
- Moisture free environment
- Atomic number and bond strength!

Threshold are lower:

- Cell Size (8 cm x 8cm)
- life-span 3-5 years

Customers:

ISRO/DRDO , NASA, European Space Agency
Australian Space agency, Many private companies



Material	Atomic Number(Z)	Bond Strength (KJ/mole)	Specific Power (W/Kg)	Ref
Si	14	200-300	10-30	[15]
CdTe	48(Cd) 52(Te)	~200	40-80	[16]
GaAs	31(Ga) 33(As)	~200	200-1000	[17]
Perovskite	Pb(82) I(53)	~150-200	100-2300	[18]

SUBSem+

Glass or Si/ TCO substrate to complete device stack!

Excel Instruments, Vasai, Mumbai

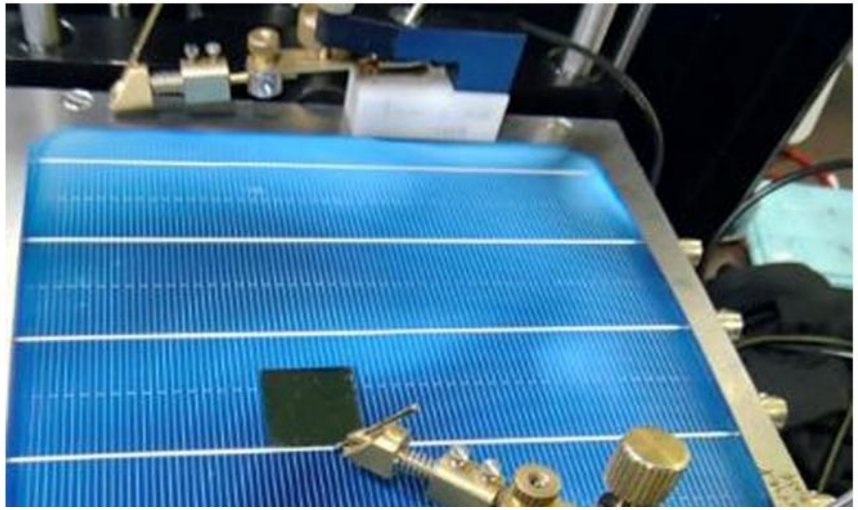
4T Silicon perovskite Tandem PCE ~ 30.18%

Indian scientists build 29.14%-efficient tandem solar cell with inverted top perovskite device

The researchers said they optimized the low-bandgap inverted perovskite cells through a passivating aluminum oxide (Al2O3) interlayer deposited via atomic layer deposition (ALD), which significantly helped improve device efficiency.

JUNE 4, 2025 EMILIANO BELLINI

MODULES & UPSTREAM MANUFACTURING | TECHNOLOGY AND R&D | INDIA

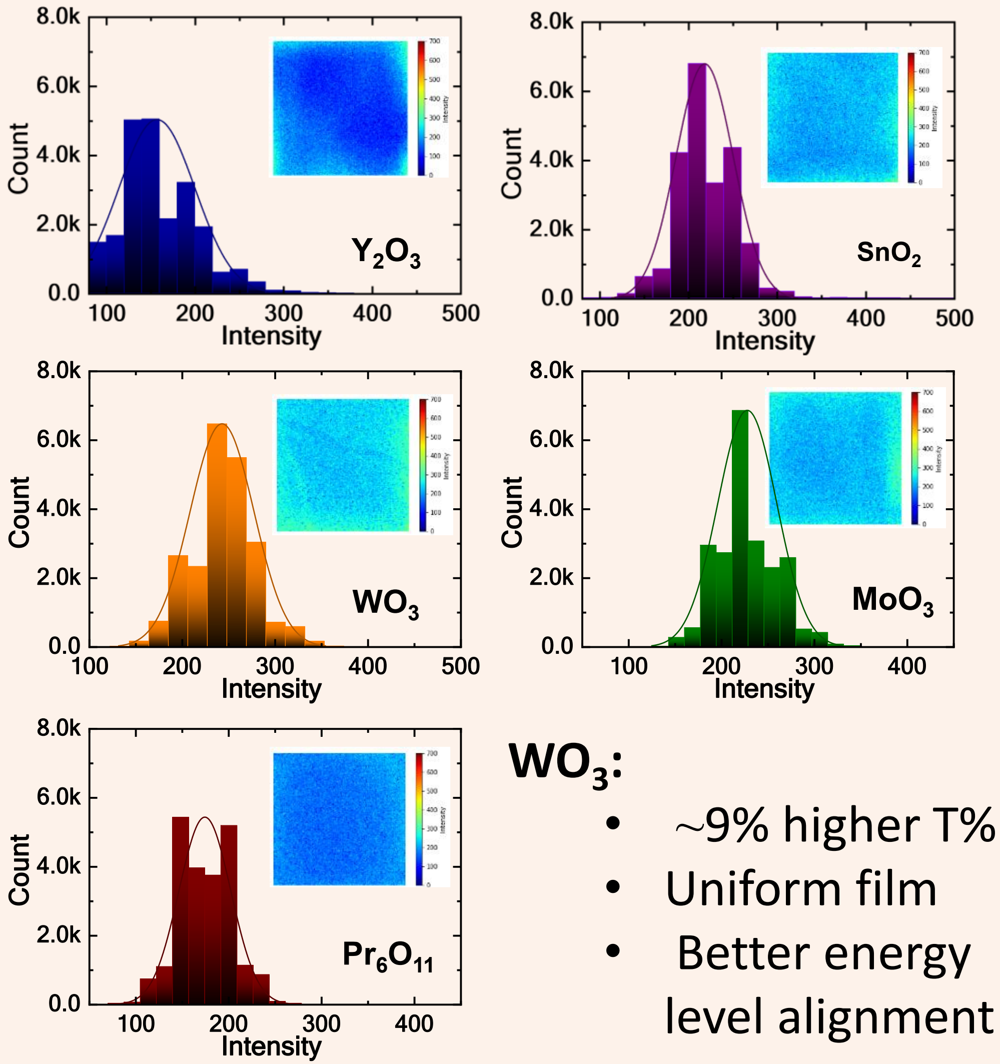


Cell parameters	Top PSC	Individual silicon solar cell	Filtered bottom silicon solar cell	**4-T PCE tandem solar cell (perovskite cell + silicon cell)**
(perovskite cell active area = 0.175 cm^2)				
V_{oc} (V)	1.195	0.720	0.720	29.14%
J_{sc} (mA/cm^2)	20.40	42.09	17.11	
FF (%)	76.99	84.15	84.15	
PCE (%)	18.77	25.5	10.37	
(perovskite cell active area = 1.08 cm^2)				
V_{oc} (V)	1.205	0.720	0.720	26.86%
J_{sc} (mA/cm^2)	20.46	42.09	16.41	
FF (%)	68.61	84.15	84.15	
PCE (%)	16.92	25.5	9.94	

4T silicon perovskite tandem cell efficiency > 30% achieved at 17.5 mm^2 and 29.14% published in public domain!

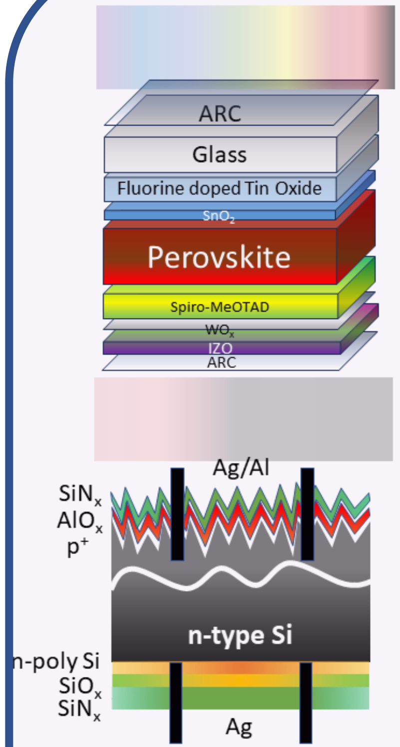
https://doi.org/10.1002/solr.202500163

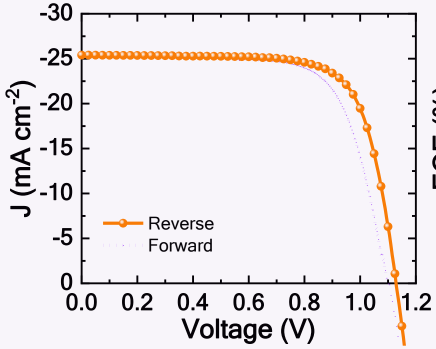
Role of Buffer Layer for Tandem

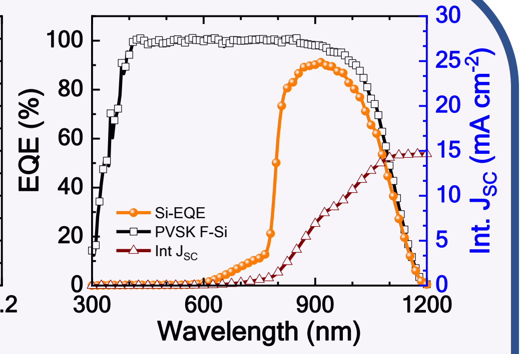


WO_3:

- ~9% higher T%
- Uniform film
- Better energy level alignment







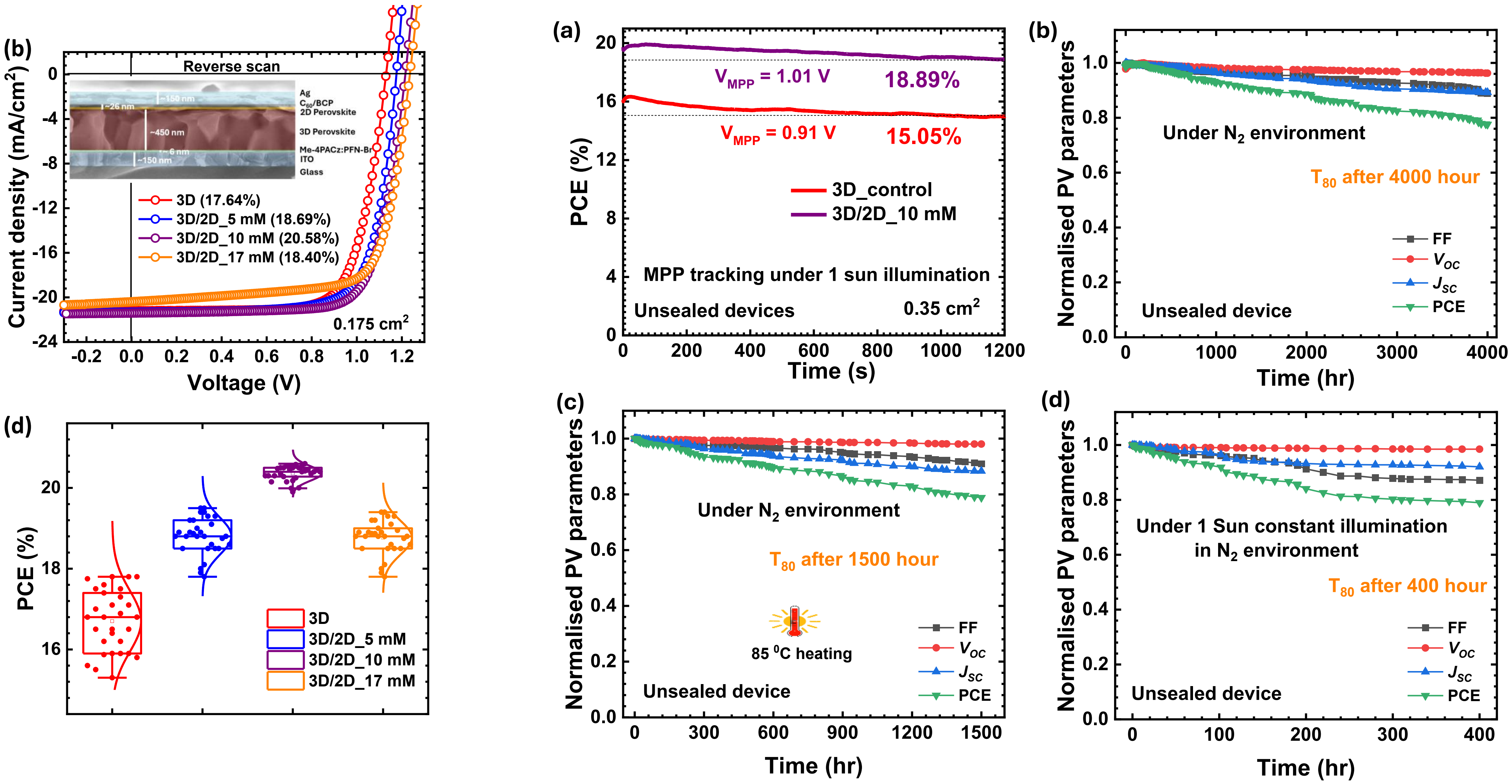
Device	J_{SC} (mA cm^{-2})	V_{OC} (V)	FF	η (%)
Perovskite	25.41	1.13	73.7	21.3
	25.31	1.10	70.7	19.7
n-TOPCON	42.09	0.72	84.2	25.5
Perovskite-F n-TOPCON	14.67	0.72	84.2	8.9
Si/perovskite 4T	**-**	**-**	**-**	**30.2**

- 30.2% efficient Si/perovskite 4T tandem
- ETL/perovskite and HTL/perovskite interface passivation
- Energy level tuning

Adv. Mater. (Under communication)

EES Solar, 2025 (In press)

Interfacial engineering for stable PSCs



Under Review with Adv. Energy Mater 2025

Halide perovskite is stable under DAMP HEAT beyond IEC Requirement!

Edge Sealed Modules for Improved Perovskite Stability in 1000 Hours of Damp Heat Testing

R. Ruhle*[1], D. Durney[1], D. McDougal[1], L. Laxmi[2], V, Chityala[2], D. Kabra[2], and W. Sampath[1]

[1] Colorado State University (CSU), Fort Collins, Colorado 80523, US

[2] Indian Institute of Technology, Bombay,

SPF2050 SOLAR POWERED FUTURE

Colorado State University

Abstract

Perovskite and perovskite tandem devices offer

Edge Sealed Module History

CSU/Abound Solar

CSU
Explores the use of internal nanostructures hot-embossed ... module

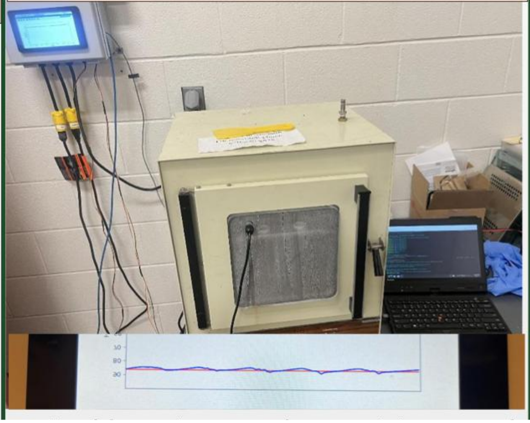
CSU
Tests encapsulation technology on Perovskite samples in 1000 hours of damp heat (85°C, 85% RH), with continued testing underway.

2024

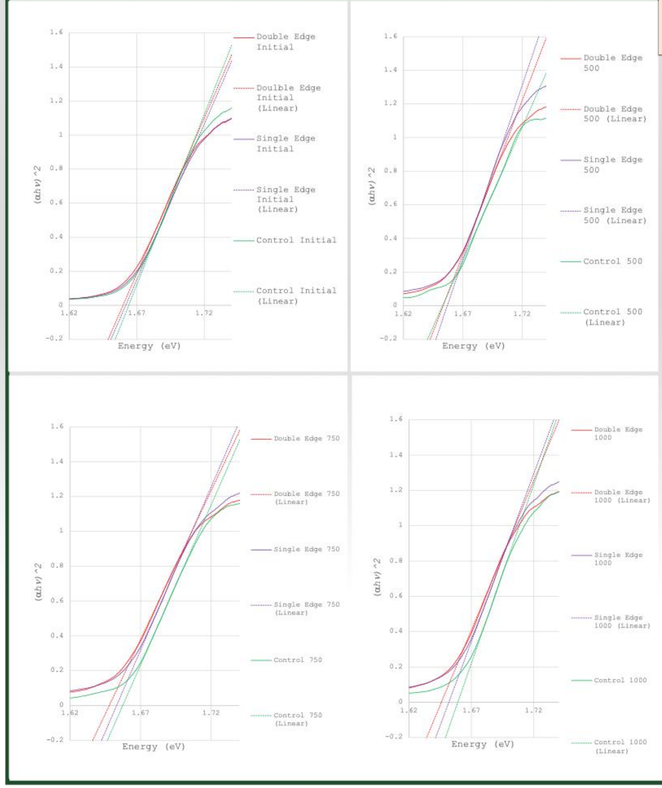
2024

...ops in-situ monitoring station for small cells, ...ssfully assembling and deploying prototypes.

CSU's Environmental Test Chamber



1,000 Hours Results



- Tracking is useful for perovskites since a change in material composition can be detected by a significantly shifted bandgap.
- One effective way to accomplish this is to utilize Tauc plots. This can be done with transmission measuremetns.
- Perovskite samples encapsulated in argon environment for greater stability.
- Samples have undergone DH testing in an environmental chamber manufactured at CSU.
- Samples are removed every 100 hours for the first 500 hours, since no change is detected in the bandgap, the time is increased to 250 hours between measurements.
- After 1,000 hours, none of the bandgaps are measured outside of the margin of error, indicating strong stability in 1,000 hours of DH testing.

Experimental Section

Perovskite film is stable at 85 ^{0}C and 85% RH

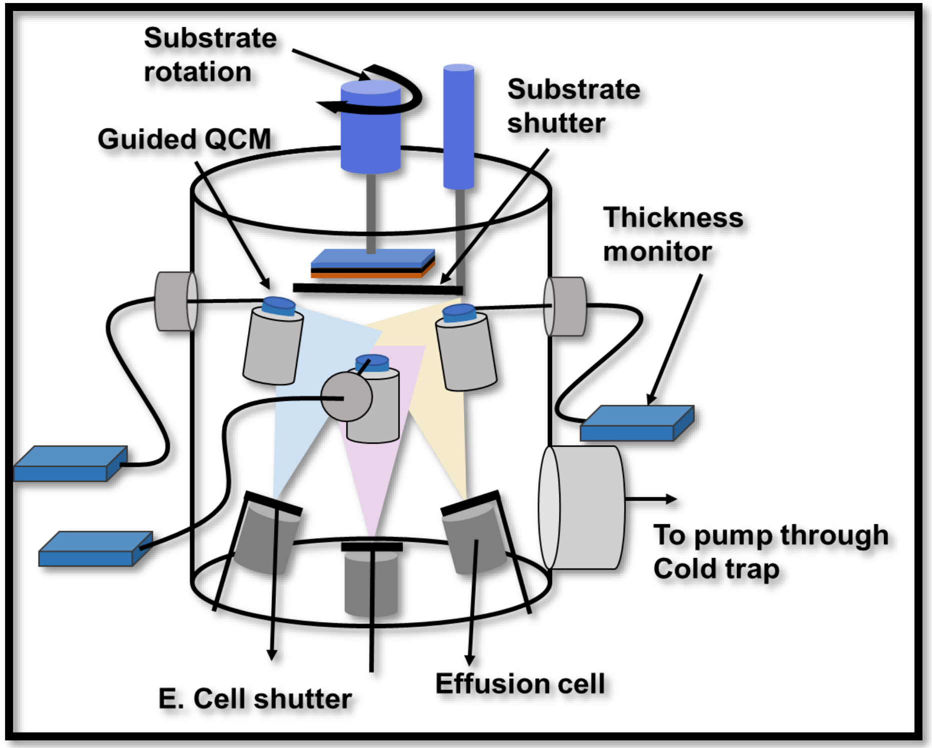
Device level testing underway

Light + heat : Crucial!

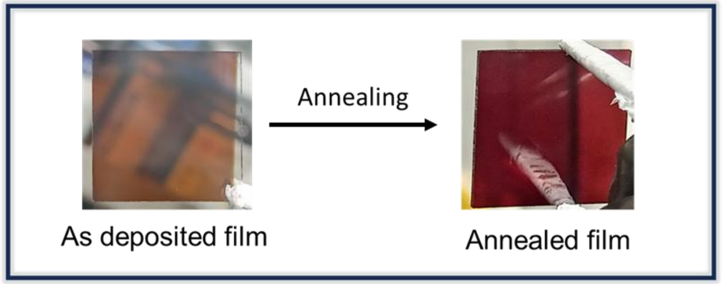
...al Science foundation under the Industry/University Cooperative Research Center (I/UCRC) for Solar Powered Future SPF 2050 (Award Numbers – 1821526 and 2052735), and ... being measured. Support under the NSF INTERN program is also acknowledged.

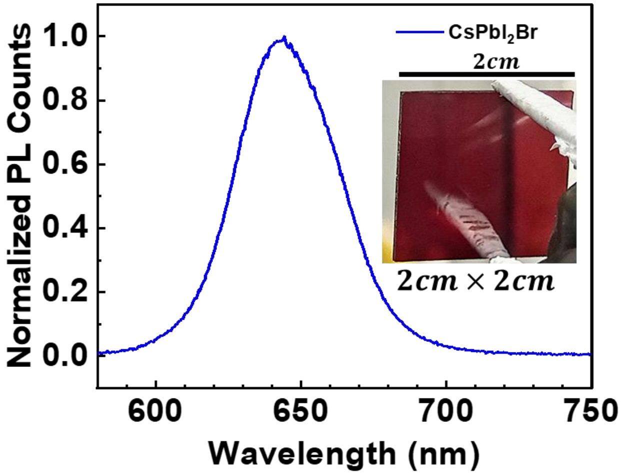
Evaporated Perovskite solar cells

- **High Reproducible**
- **Scalable**
- **Solvent Free Process**
- **Highly Uniform**

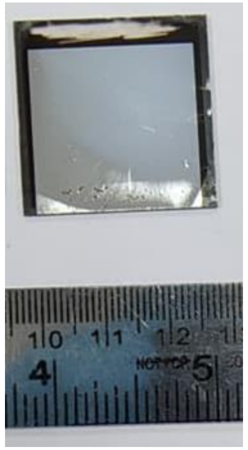


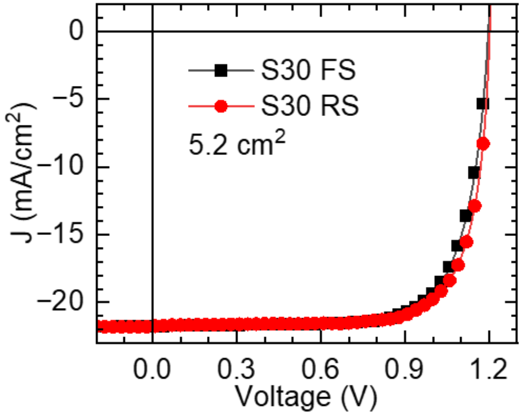
Schematic of the perovskite evaporation chamber with capability of evaporating three sources simultaneously.

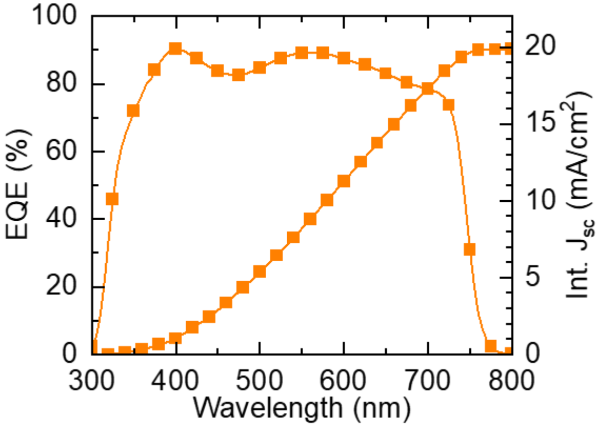




Larger cells, Eg 1.67 eV



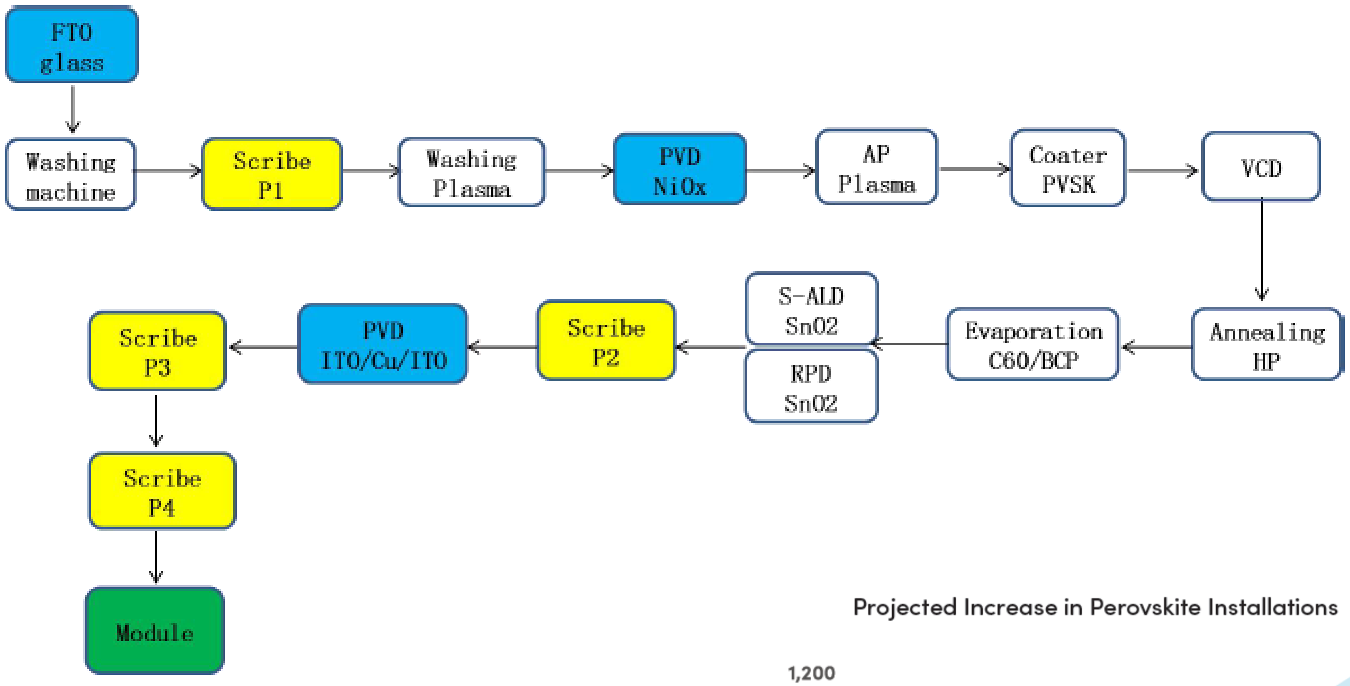




EL image

Device S30	Forward scan				Reverse scan			
	Jsc(mA/cm2)	VOC (V)	FF (%)	PCE (%)	Jsc(mA/cm2)	VOC (V)	FF (%)	PCE (%)
S30	21.79	1.195	74.3	19.3	21.77	1.195	76.1	19.8

For 4T/2T Silicon Perovskite Tandem Solution

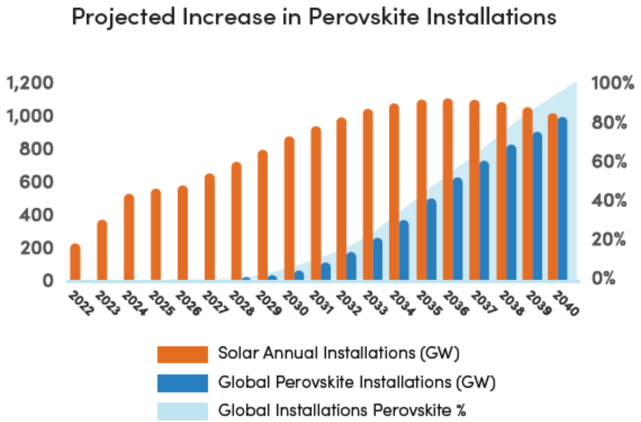


Pre-re **e development**

e

00 m2

arehouse)

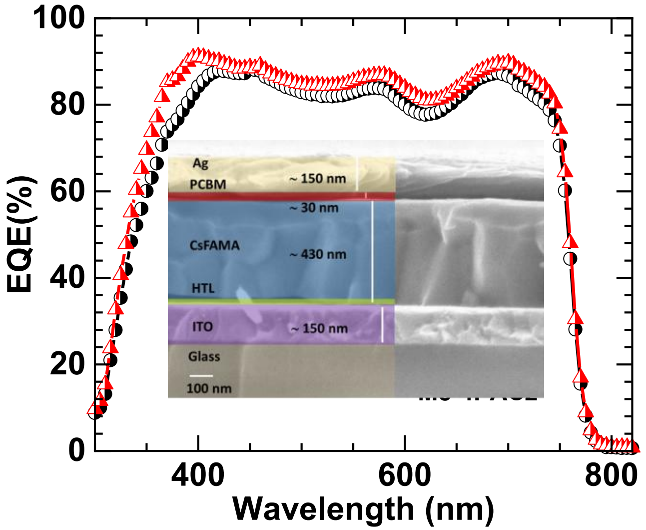


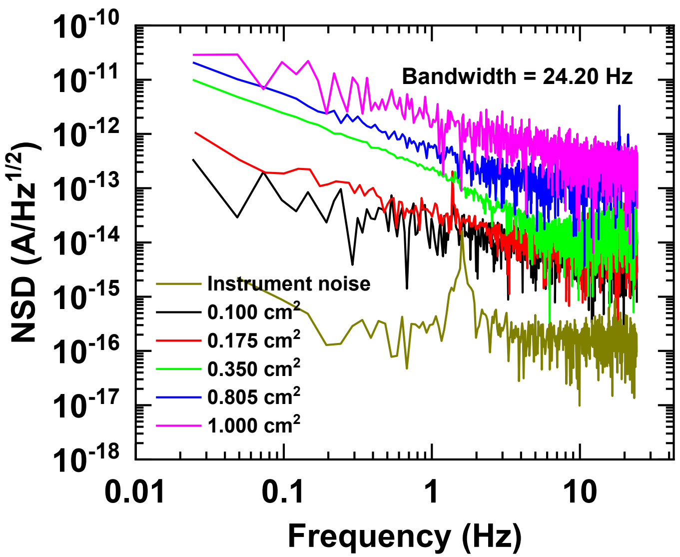
Partners/stackholders discussion:
- Central Government
- State-government
- Large scale Manufacturers

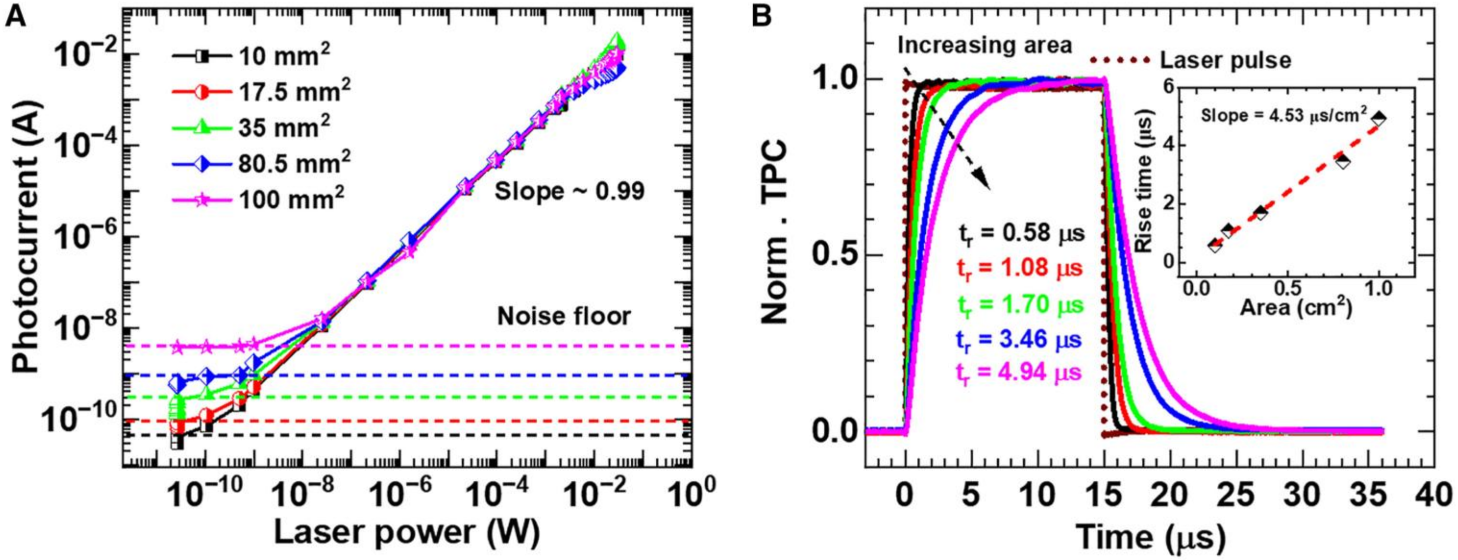
ART-PV india

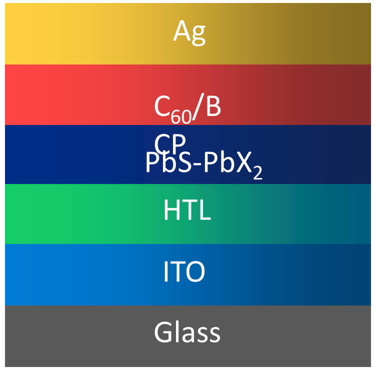
Solar cells → photodetector/optical sensors

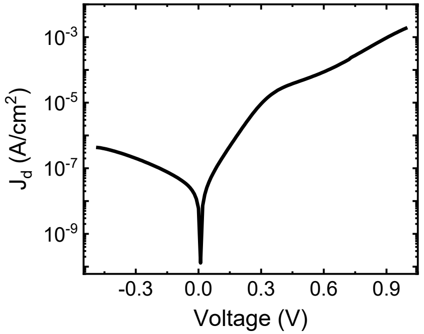
Strategic → beyond Silicon

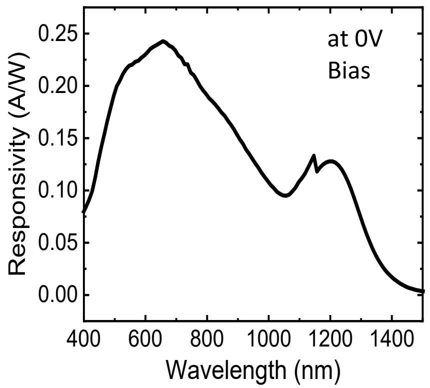


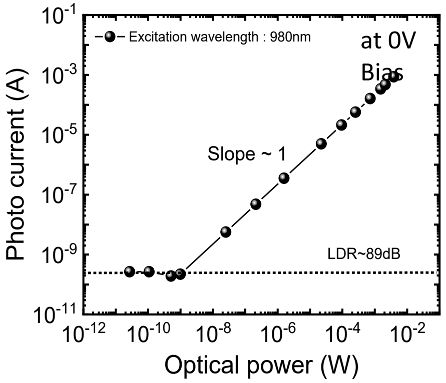


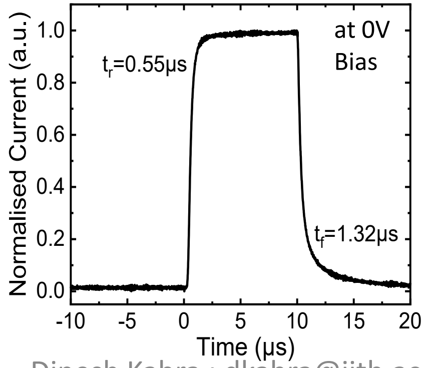












Such a low noise level makes them ideal for Photon-counting detectors

Hossain & Kabra et al Device 2024

Dinesh Kabra ; dkabra@iitb.ac.in

Conclusions

- Static vs Dynamic Disorder
- Self-trapped excitons vs Fine structure of Excitons
- To overcome fundamental single junction limit→ Tandem cell is solution
- Halide perovskite semiconductor engineering promise to provide the solution
- Space PV: free from Ga supply!
- Equipment : indigenous solution
- Silicon-perovskite Tandem solar cells PCE > 30.2%
- Monofacial perovskite single pixel cells with **active area > 5 cm^2** with PCE 19.8% → 4T tandem PCE ~ 30%!
- Photodetector: lowest noise current → photon counting detector!

2. We have secured 4 Indian patent, 2 US patents and 5 patents are under applicatior Patents have be transferred from IIT B to ART PV India(1/2)

Patents to be transferred to ART PV from IIT B

Country	Patent description	Status
India	Photonic devices by organometallic halides based perovkites material and its method of preparation (Inventors: Dinesh Jugal Kabra, Naresh Kumar Kumawat, Amrita Dey)	Granted (Patent No: 405924) PCT application number: **XX**
India	System and Method for Fabrication of Multi-layer Thin Film Optoelectronic Devices (Inventors: Dinesh Jugal Kabra, Laxmi Nrita Gaur, Gangadhar Banappanavar, Aldrin Antony, Subash Pai	Granted (Patent No: 464062)
India	Nir-Transparent Organic And Perovskite Bi-Facial Optoelectronic Devices And System For Preparation Thereof (Inventors: K.R. Balasubramaniam, Sudhanshu Mallick, Dinesh Jugal Kabra, Abhijit Singha, Ananta Paul, Subash Pai, Venkatesh Chityala	Granted (Patent No: 503121)
India	Molecular and Device Engineering for Electroluminescence Using Organic Semiconductors. (Inventors : Dinesh Kabra and Amrita Dey)	Granted (Patent No: XX)
US	Piezoelectric materials and devices and methods for preparing the same. R Pandey, S Boyer, A Kadam, VR Rao, SC Seth, and D Kabra.	Granted Patent Publication Number WO 2019/135911 A1)
US	Metrology for OLED manufacturing using photoluminescence spectroscopy" (2020) A Ghosh, BS Kwak, T Egan, RJ Visser, G Banappanavar, D Kabra	Granted US Patent 10,935,492.

2. We have secured 4 Indian patent, 2 US patents and 5 patents are under application, 5 Patents will be transferred from IIT B to ART PV India(2/2)

Patents to be transferred to ART PV from IIT B

Country	Patent description	Status
	Tailored work function based hole transport layer for optoelectronic devices (Inventors: Dinesh Jugal Kabra, Kashimul Hossain, Nrita Gaur)	Applied Patent Application no: 202321054565
	Ultrathin insulating passivation layer for optoelectronic devices (Inventors: Dinesh Jugal Kabra, Laxmi, Manas Misra, Venkatesh Gangareddy Chityala, Saurabh Gupta	Applied Patent Application no: 202421006885
	Novel Lead-Free Piezoelectric Material". Inventors: Richa PANDEY, Sankesha BHOYAR, Ankur KADAM, Dinesh KABRA, V. Ramgopal RAO and Suresh Chand SETH	Application filed (Docket No.: 25491INL/ATG/ATG/DHWANG)
	Large area thin film deposition technique for hybrid halide perovskite via novel two-step process (thermal evaporation and spin coating) of Lead-free hybrid halide perovskite-based piezoelectric materials.	Application filed US Patent Application No. 44018148)
	Electro-Optic diode devices: This invention relates to electro-optic diode devices, and especially but not exclusively to high efficiency electro-optic diode devices having polymer and metal oxide components. Dinesh Kabra, Myoung Hoon Song, Bernard Wenger, Richard H. Friend and Henry J. Snaith	Application pending

ART-PV india

IIT Bombay SINE Business Incubator

Lab to LIFE

Thanks for your kind attention