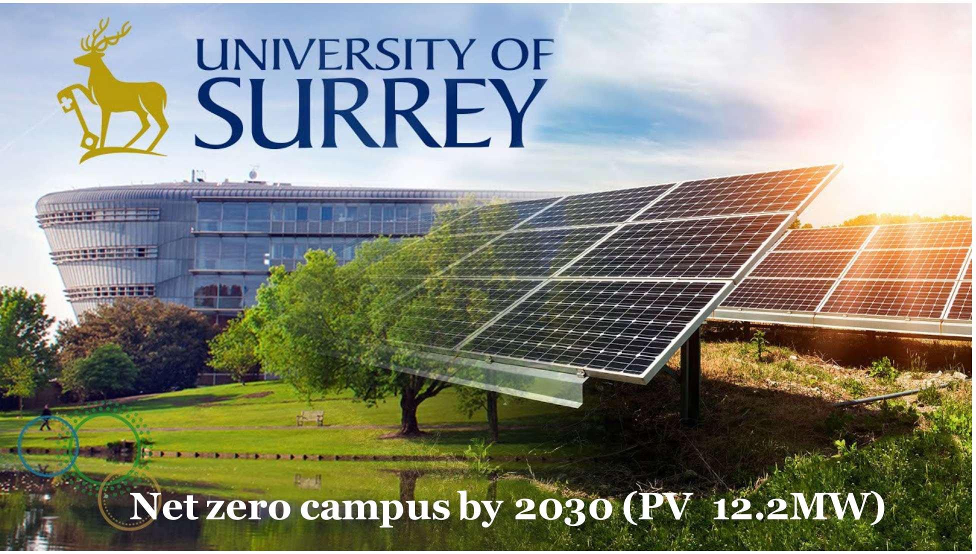
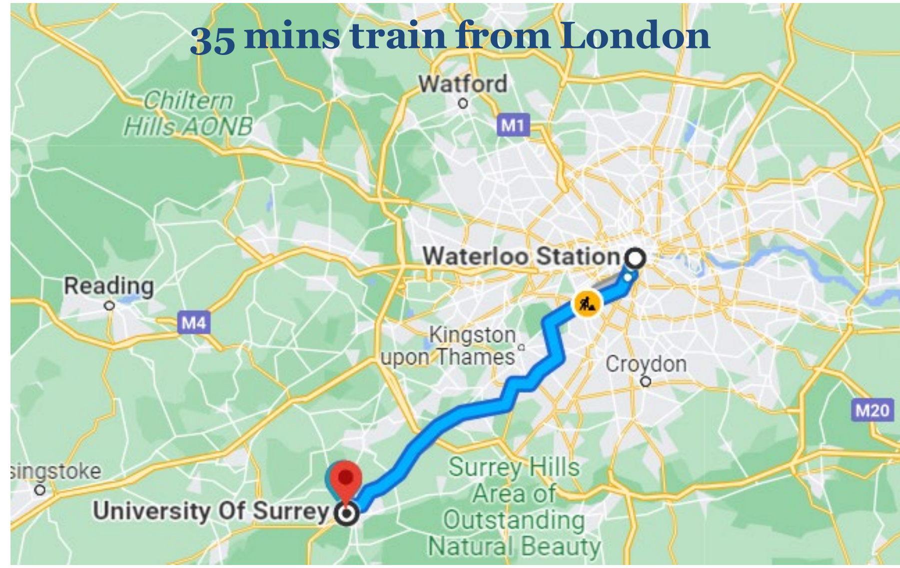
Progress in Thin Film Photovoltaics: From Nanoscale Innovations to Device Efficiency

Jae Sung Yun





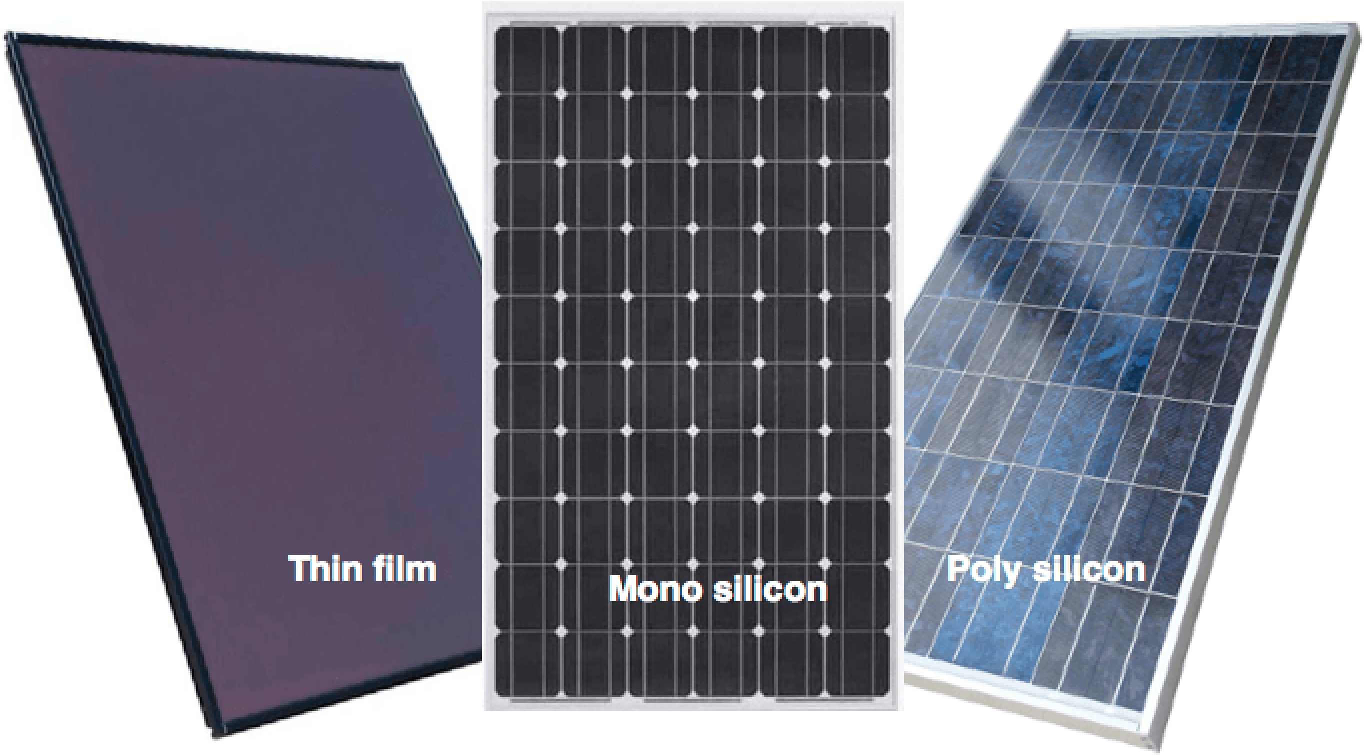
- Located in Guildford
- ~17K students
- 2021 UK REF Ranking 33/135
- Electrical and Electronic Engineering 6th in the UK

1. **Structural Defects in solar cells**

2. **Perovskite solar cells**

3. **Widebandgap Perovskites**

Part I: Thin Film PV



Silicon vs Thin Film

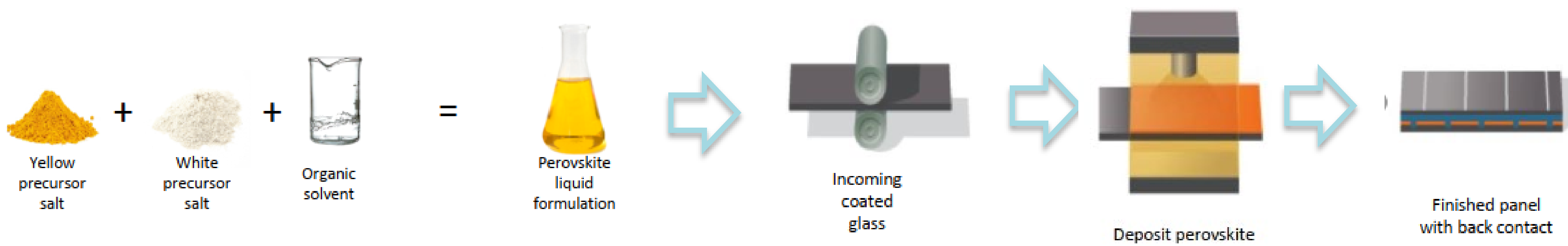
CLEAN ENERGY REVIEWS

Silicon solar cell fabrication process

www.cleanenergyreviews.info

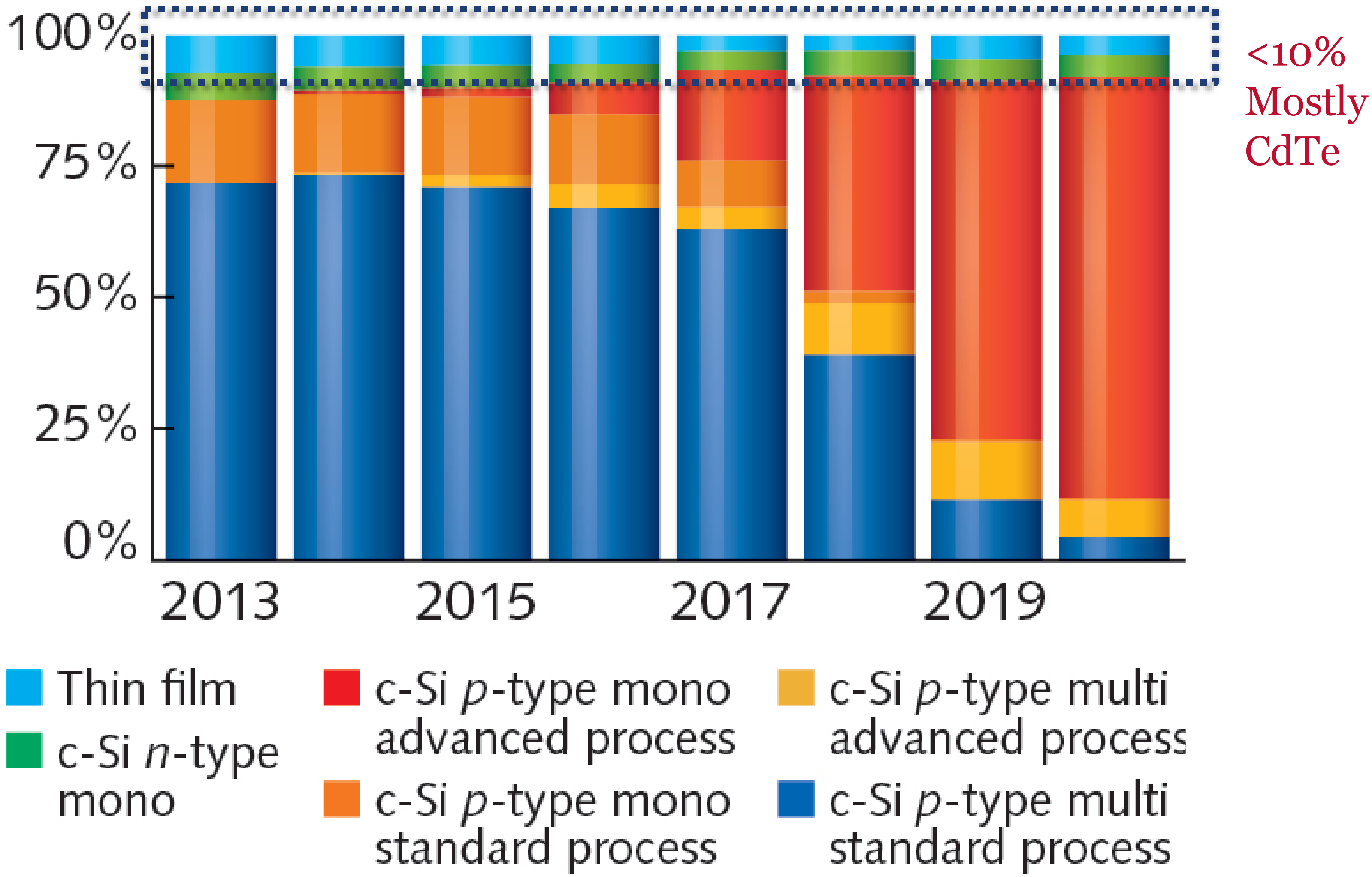
Long processing time- Energy intensive process

Thin film solar cell fabrication process



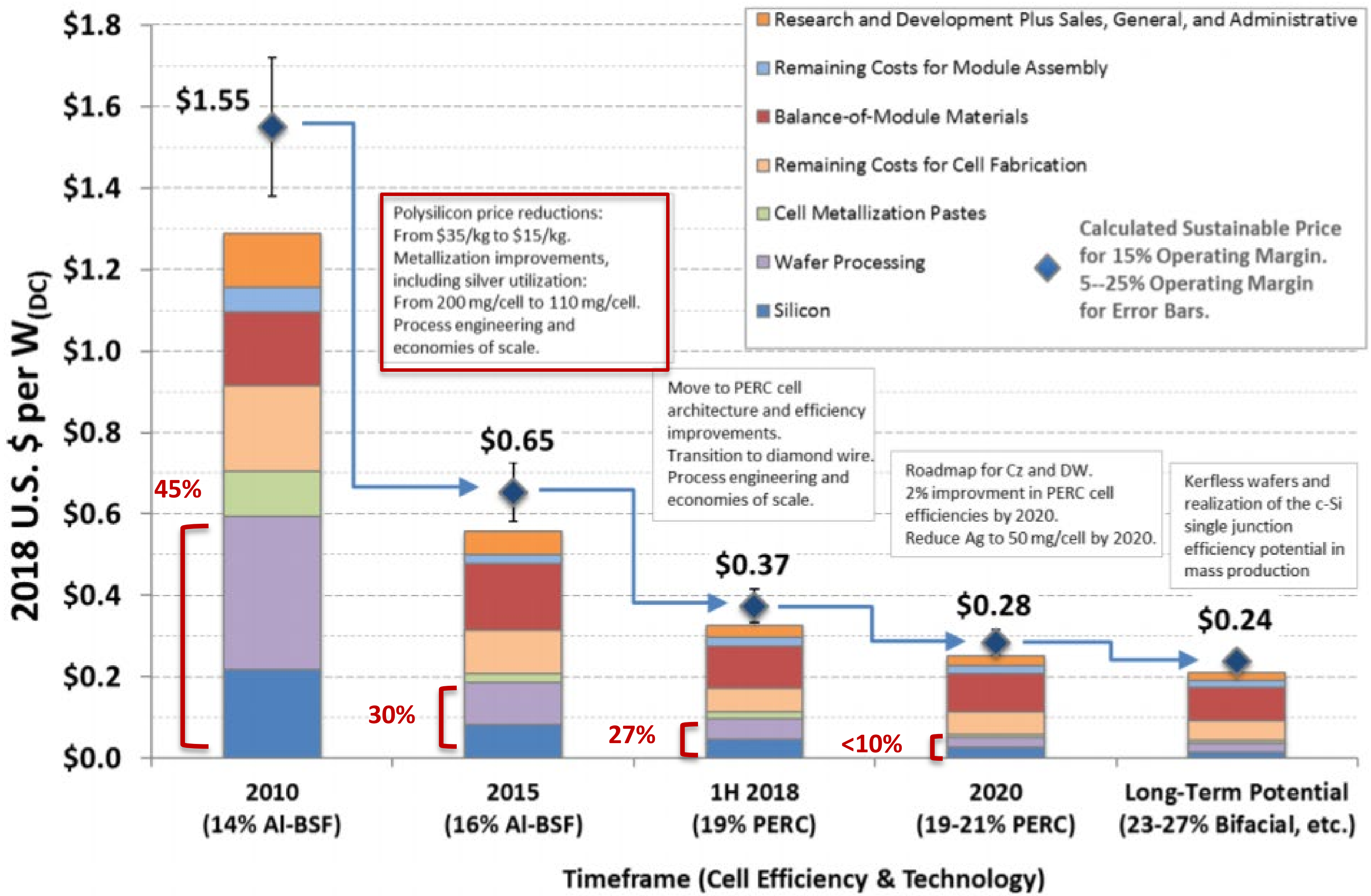
Low material consumption, suitability for flexible substrates, low temperature processability, and monolithic integration

PV Market



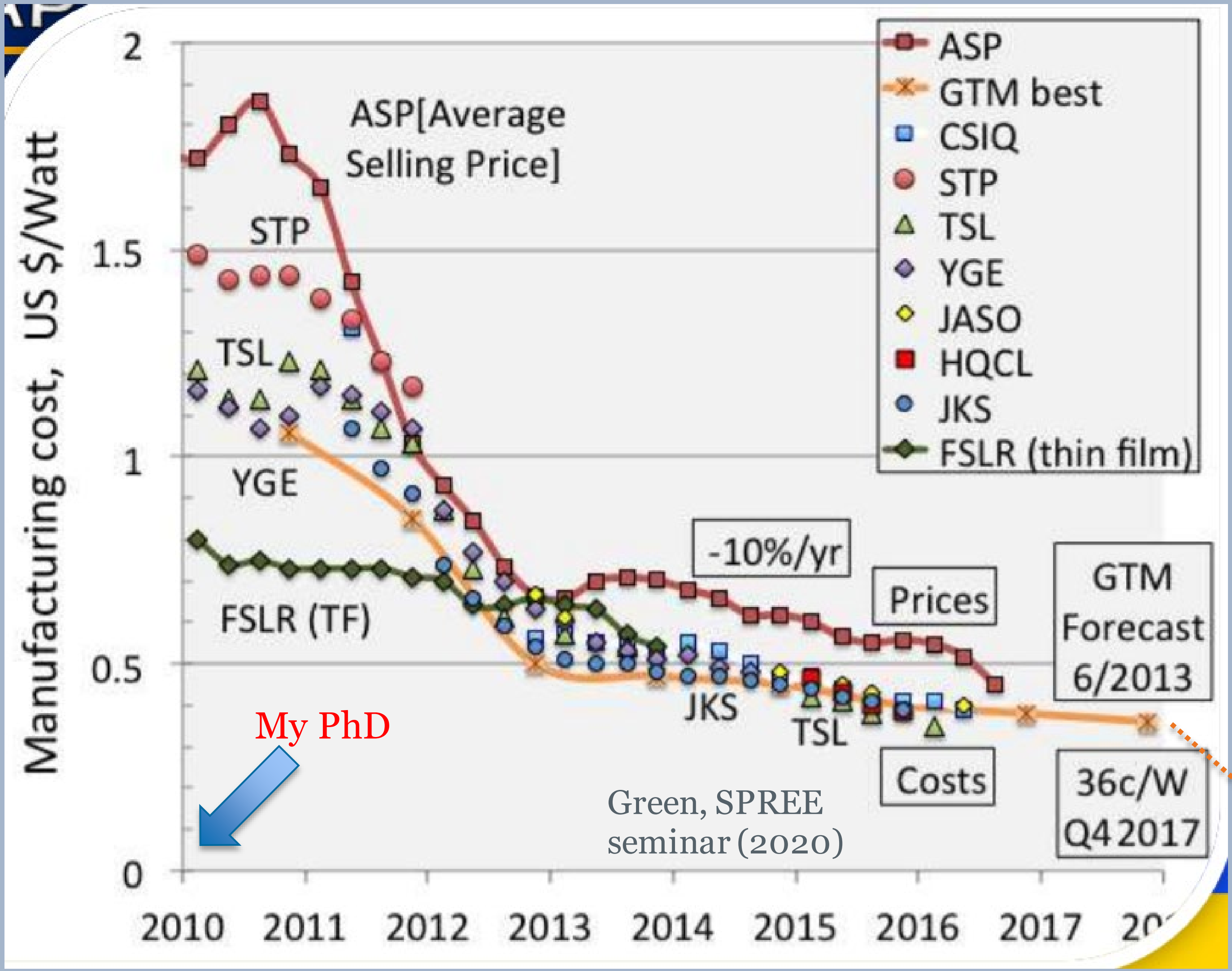
Laser focus world 2020

PV Cost



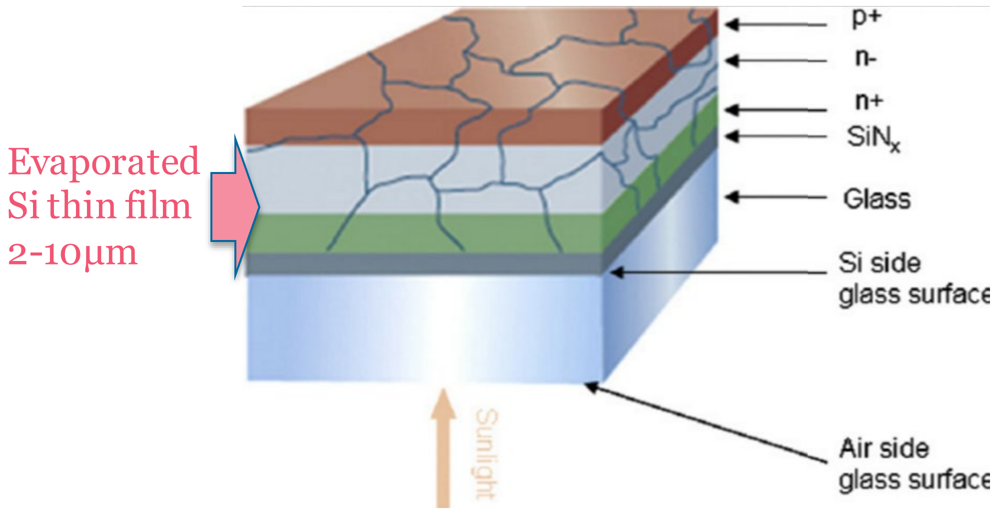
Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing: NREL, 2018

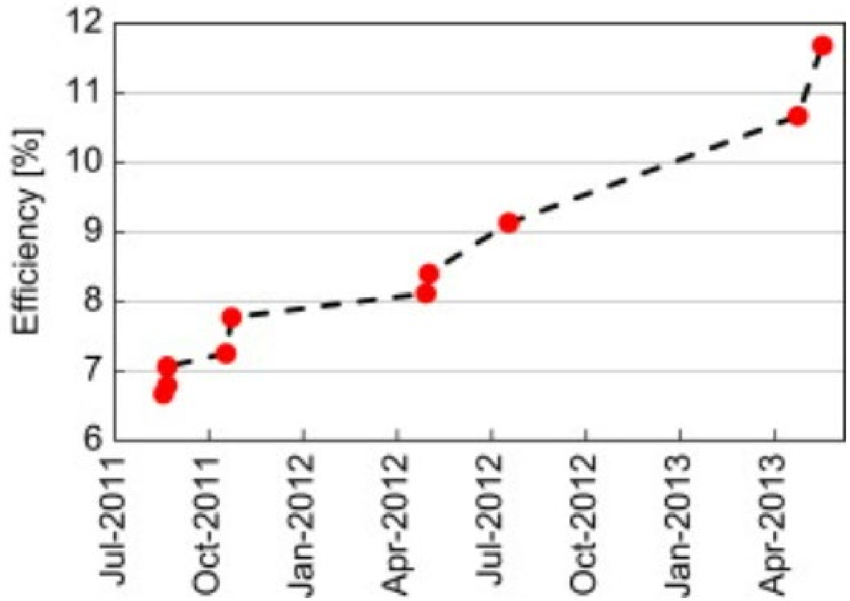
PV Cost History



~10c/W

Crystalline Si thin film on Glass (CSG) Technology

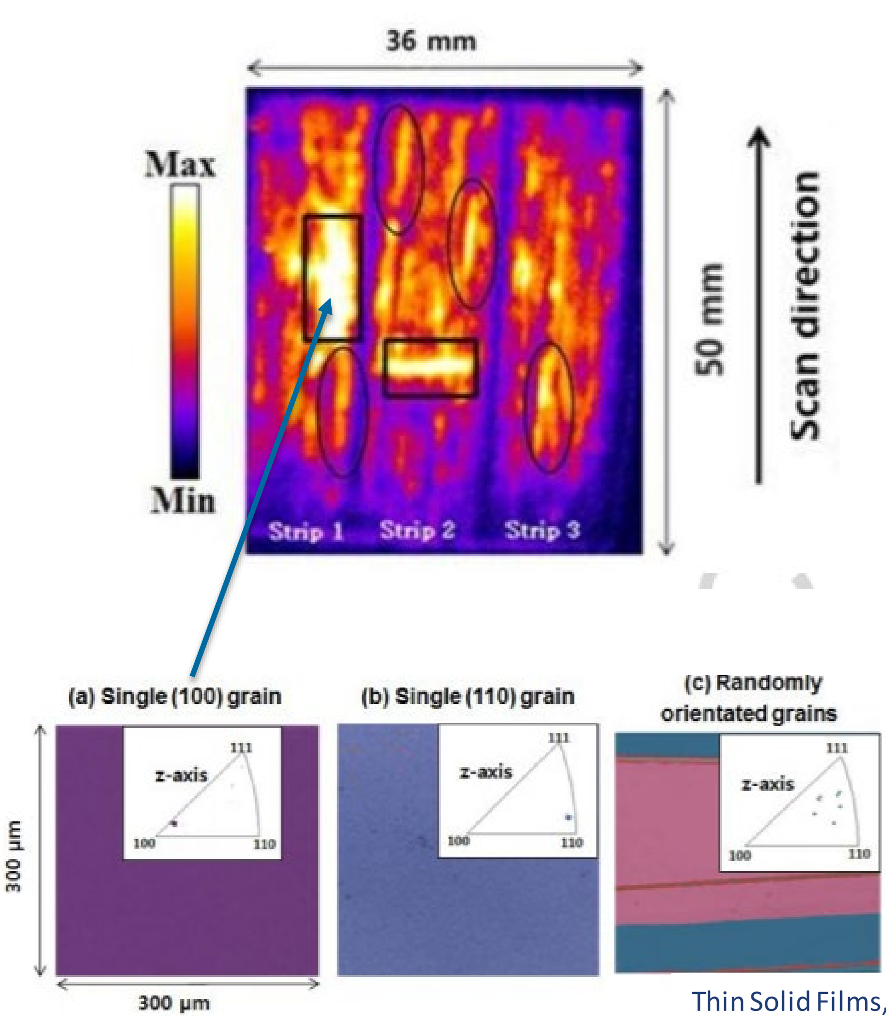




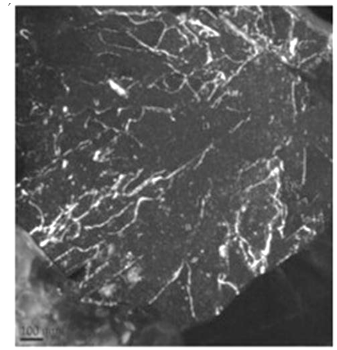
Solar Energy Materials and Solar Cells 119, 246-255

Closing ceremony, last day in Suntech 2013

Crystalline Si thin film on Glass (CSG) Technology

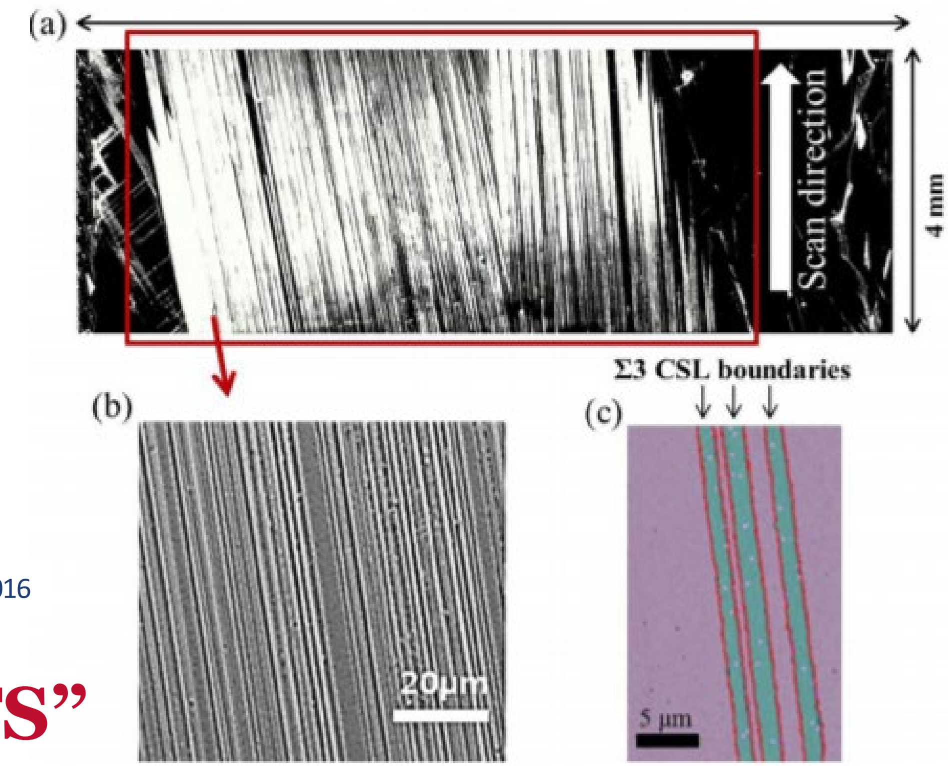


Thin Solid Films, 2016



(━ 200 nm)

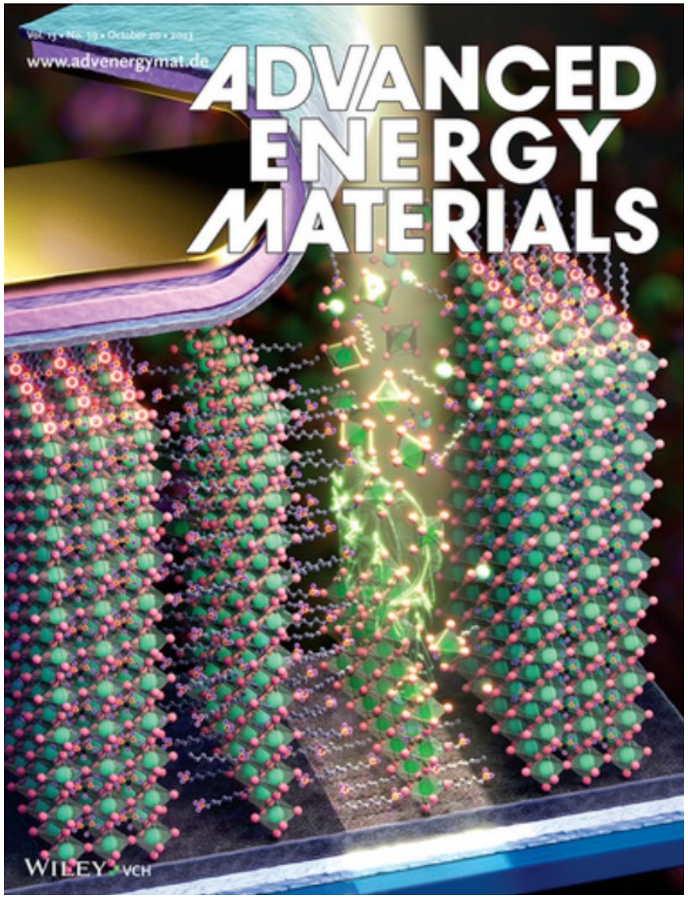
Solar Energy Materials and Solar Cells 132, 282-288



Appl. Phys. Lett. 2014

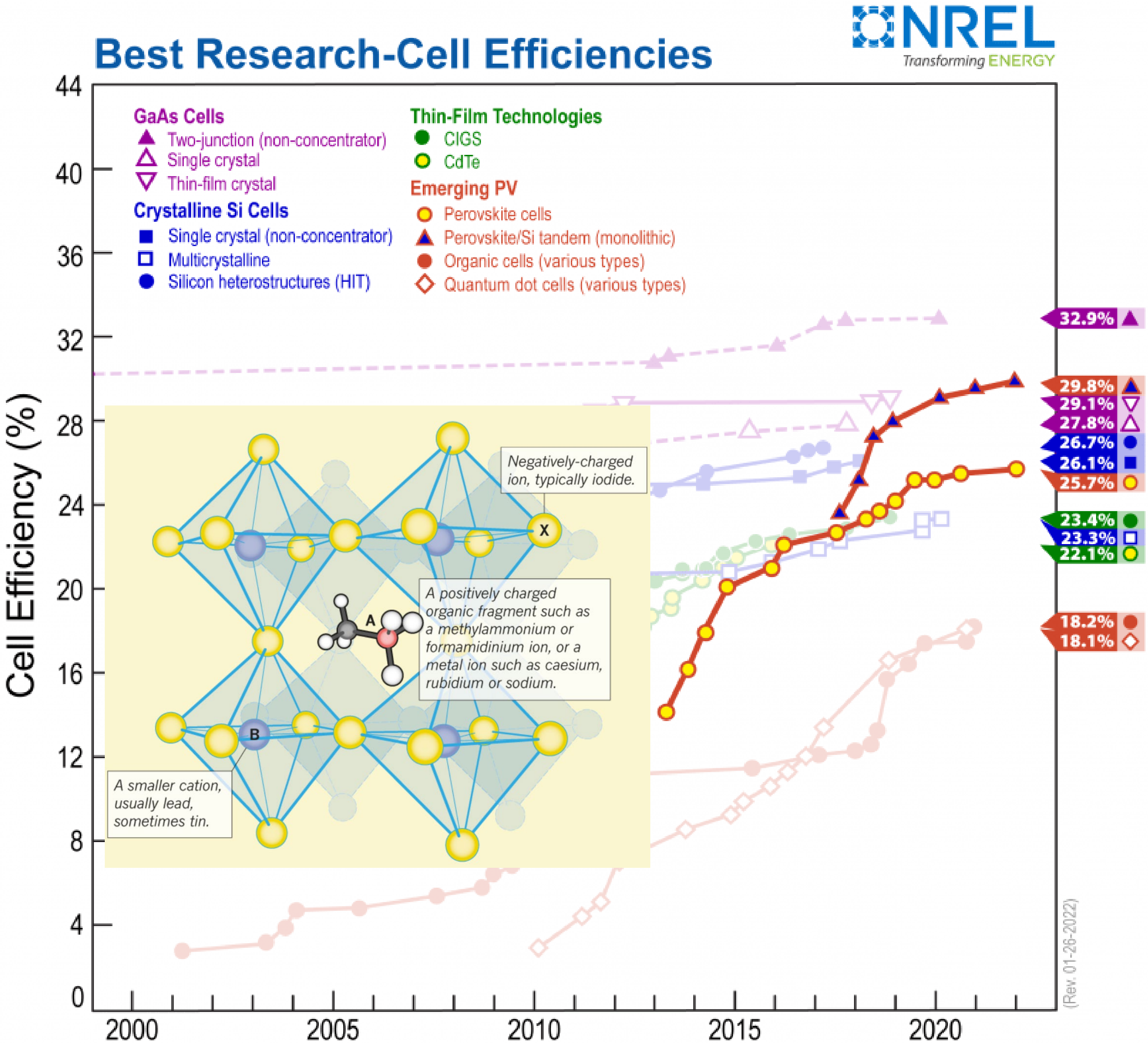
"NANOSCALE DEFECTS"

Part II: Halide Perovskites

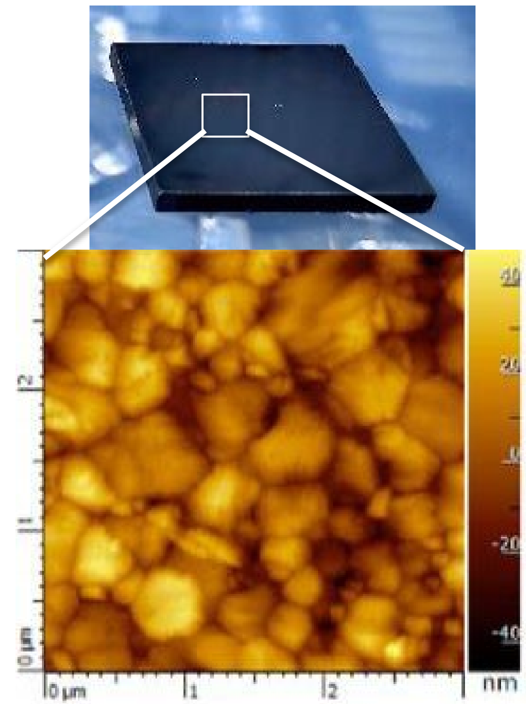


Adv. Energy Mater.2023,13, 2301717

Rise of Halide Polycrystalline Perovskites



$MAPbI_3$, $MAPbBr_3$, $MAPbI_xBr_{1-x}$ $FAPbI_3$, $CsPbI_3$…

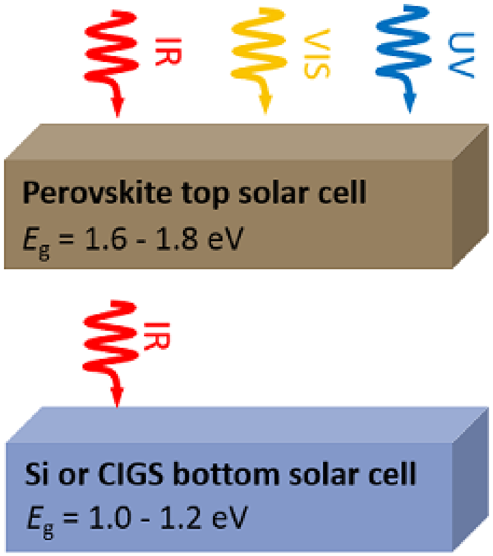


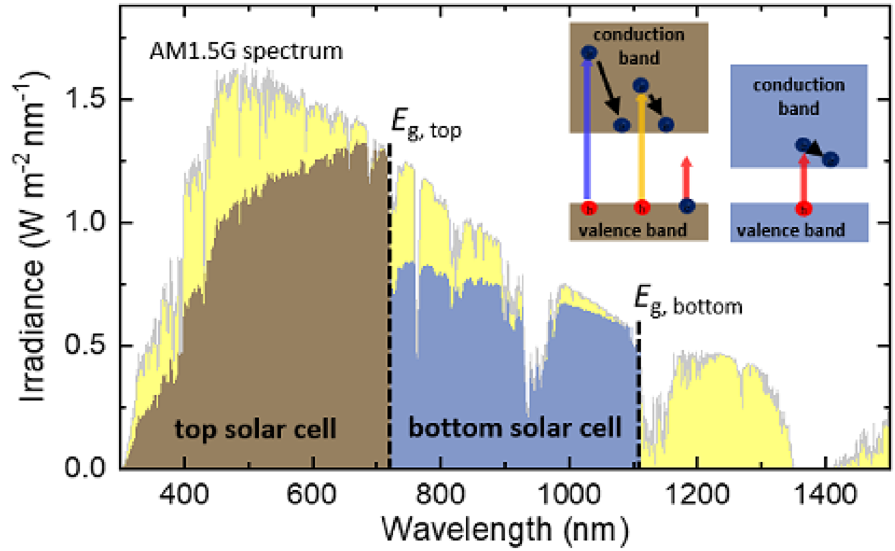
High absorption, carrier lifetime, direct bandgap,

"defect tolerant" (10^{15}-$10^{16}cm^{-3}$)

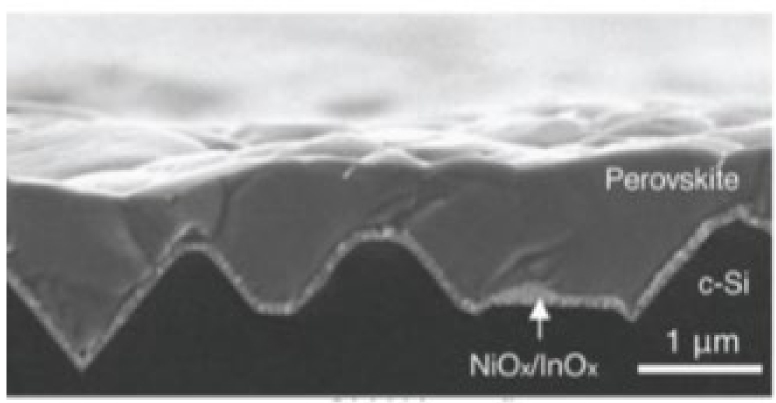
Silicon/Perovskite Tandem Solar Cells

Si/perovskite tandem solar cells >34% (Theoretical efficiency up to 45%)





Advanced Energy Materials 7.15 (2017) 1602807

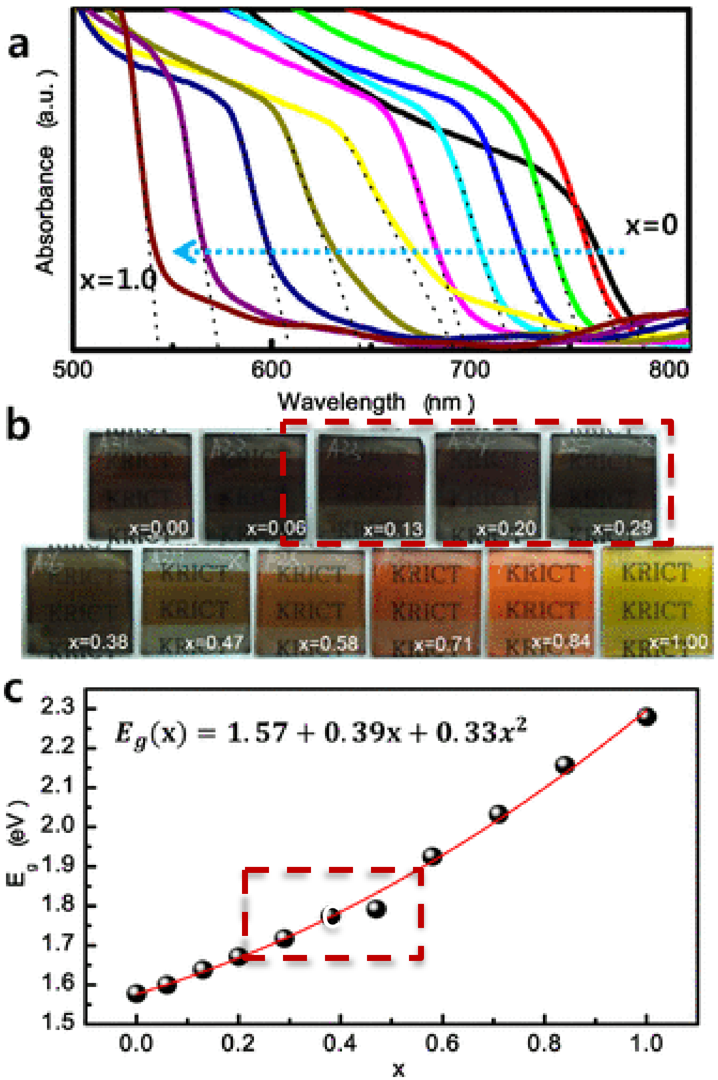


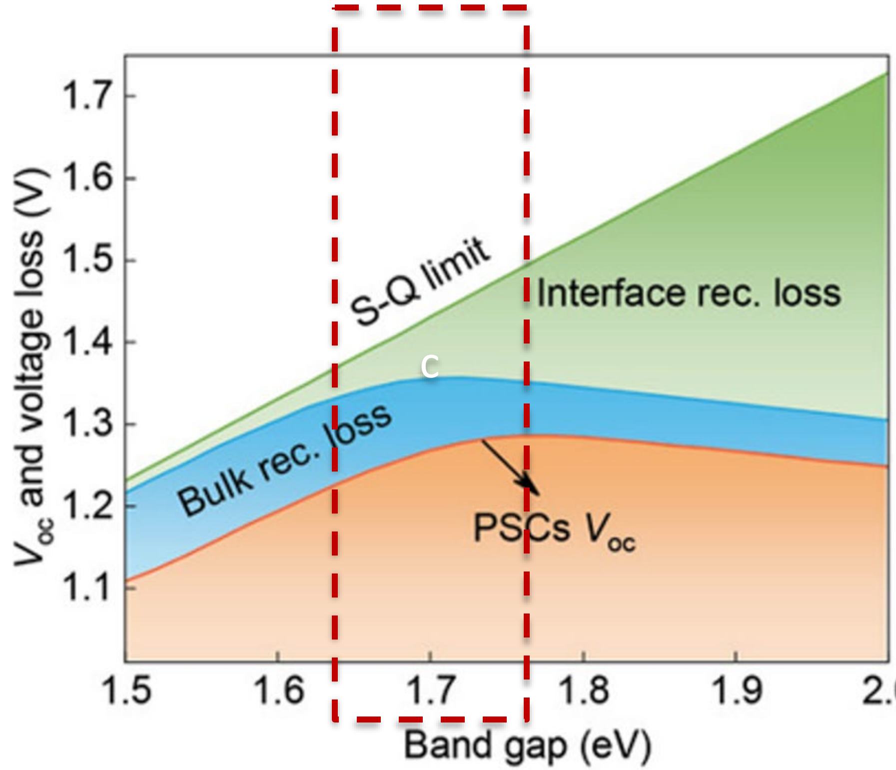
Science 2020, 367, 1135.

13

Wide bandgap phase segregation

$MAPb(I_{1-x}Br_x)_3$



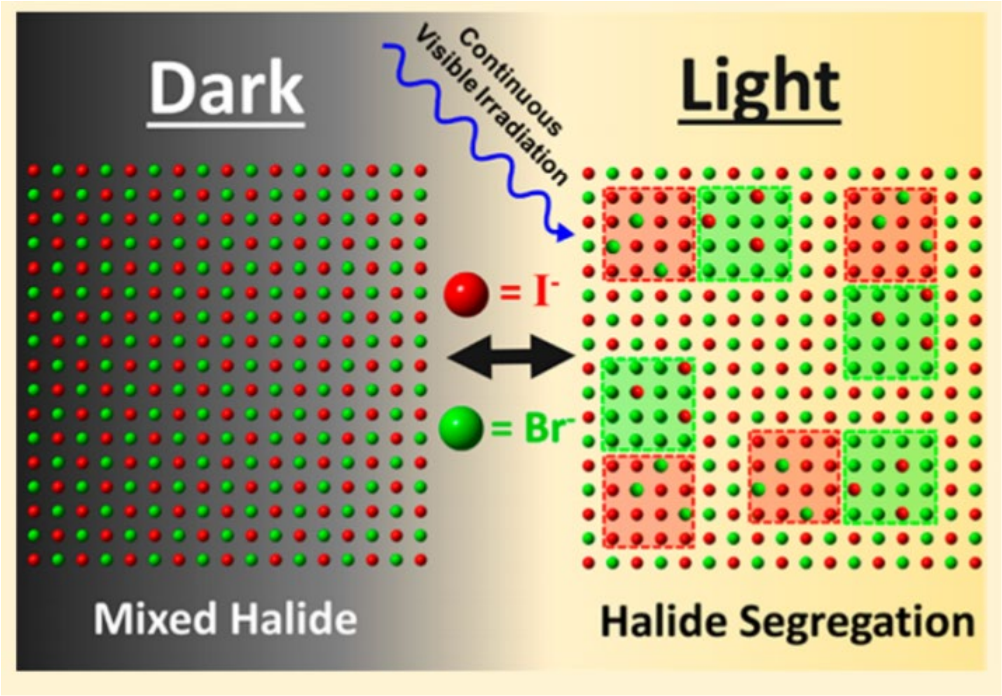


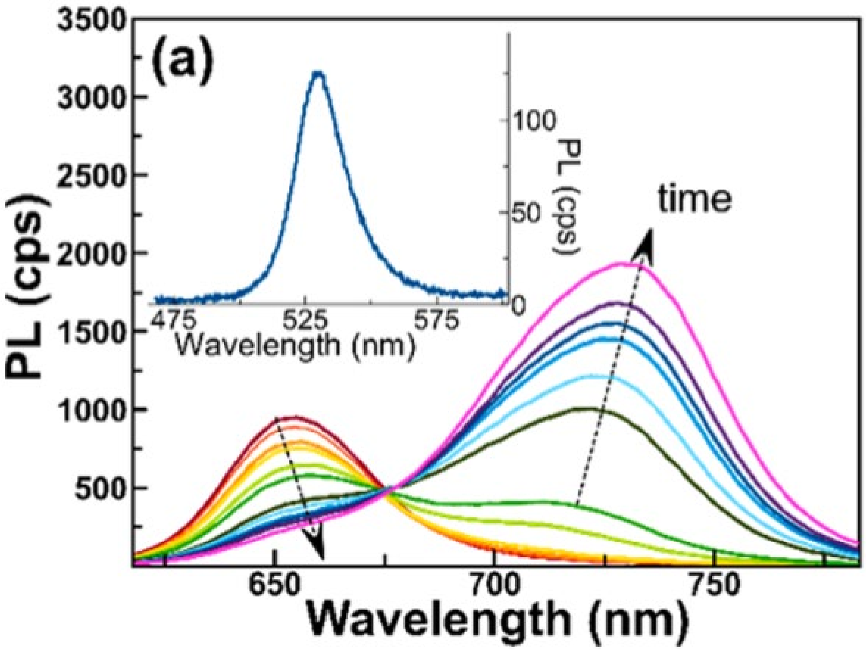
Phase segregation, band alignment mismatch, poor perovskite quality etc.

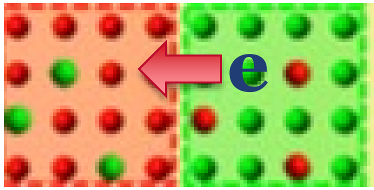
Adv Func. Mater. 2022;32(12):2110698

Nano Lett. (2013), 13, 4

Phase Segregation-Hoke Effect

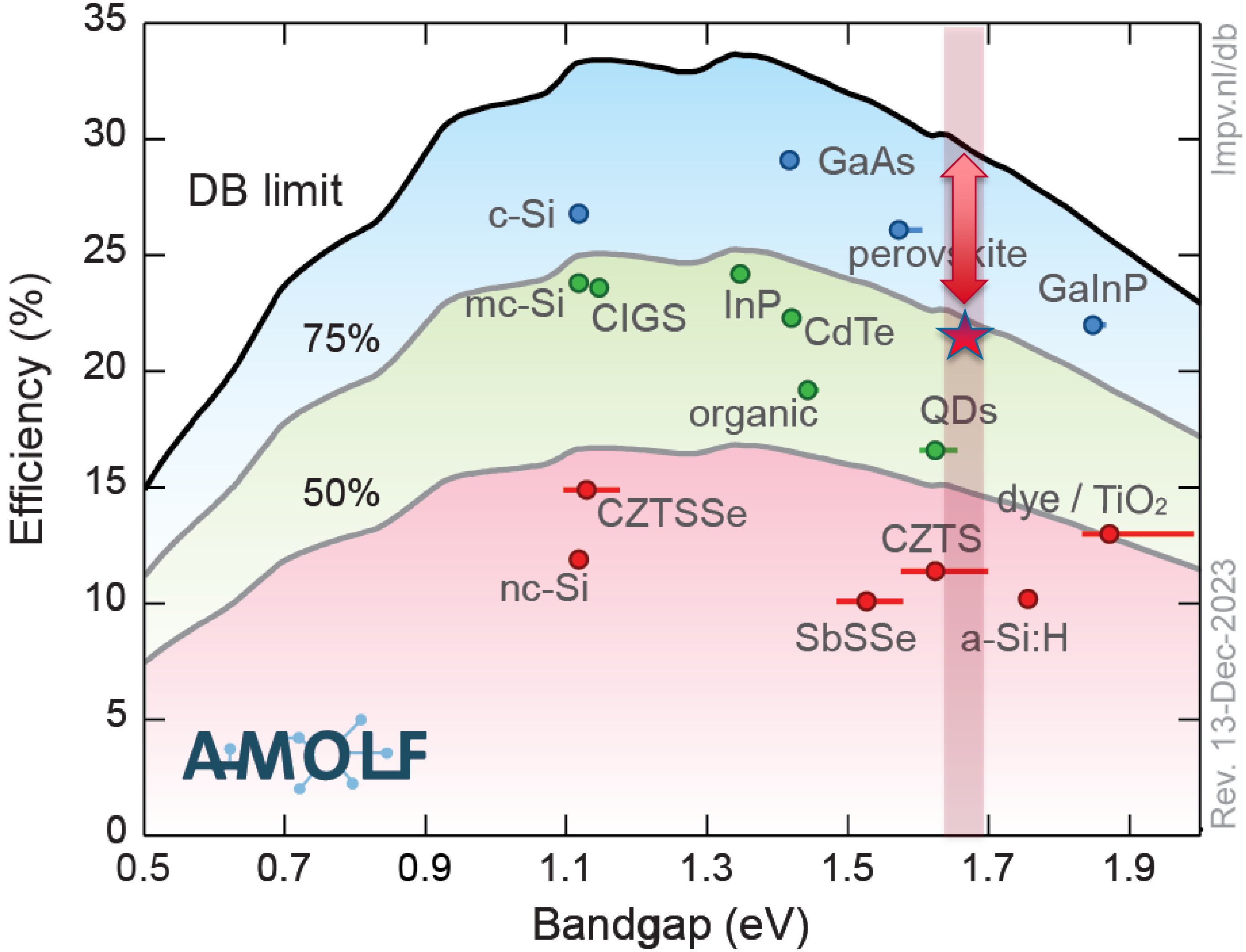




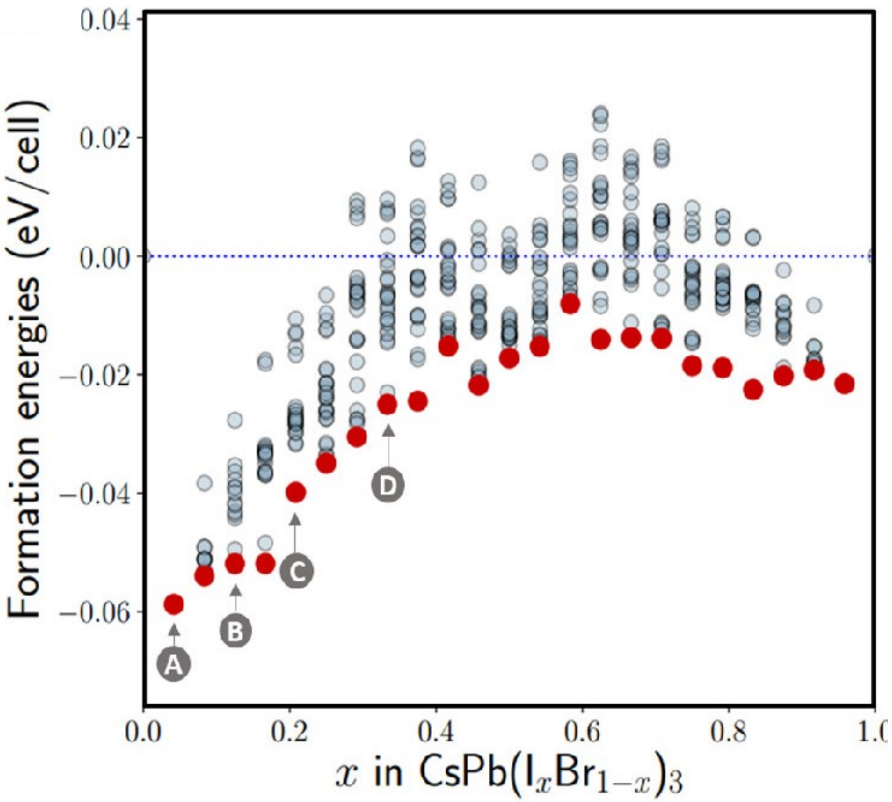


Chem. Sci., 2015,**6**, 613

Widebandap Perovskite



I vs Br



ACS Appl. Mater. Interfaces 2020, 12, 34, 38376

Solubility difference between MAI and MABr

→ **precipitation**

Chem. Commun., 2015, 51, 17658

Ionic radius difference

→ **lattice distortion**

RSC Adv., 2019, 9, 11151

Widebandgap Perovskites

UNIVERSITY OF SURREY

ACS NANO | UNSW SYDNEY | KOREA UNIVERSITY

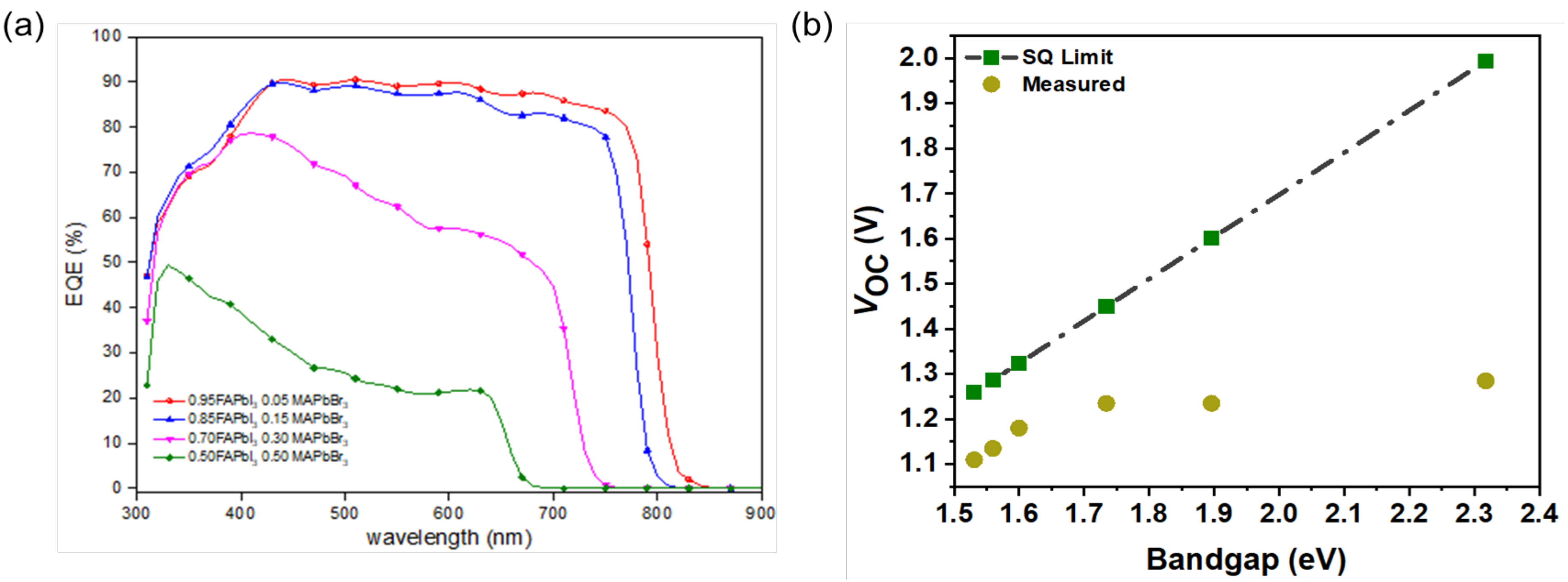
www.acsnano.org

Microstructural Evaluation of Phase Instability in Large Bandgap Metal Halide Perovskites

Dohyung Kim,¶ Jihoo Lim,¶ Seungmin Lee,¶ Arman Mahboubi Soufiani,* Eunyoung Choi, Anton V. Ievlev, Nikolay Borodinov, Yongtao Liu, Olga S. Ovchinnikova, Mahshid Ahmadi, Sean Lim, Pankaj Sharma, Jan Seidel, Jun Hong Noh,* and Jae Sung Yun*

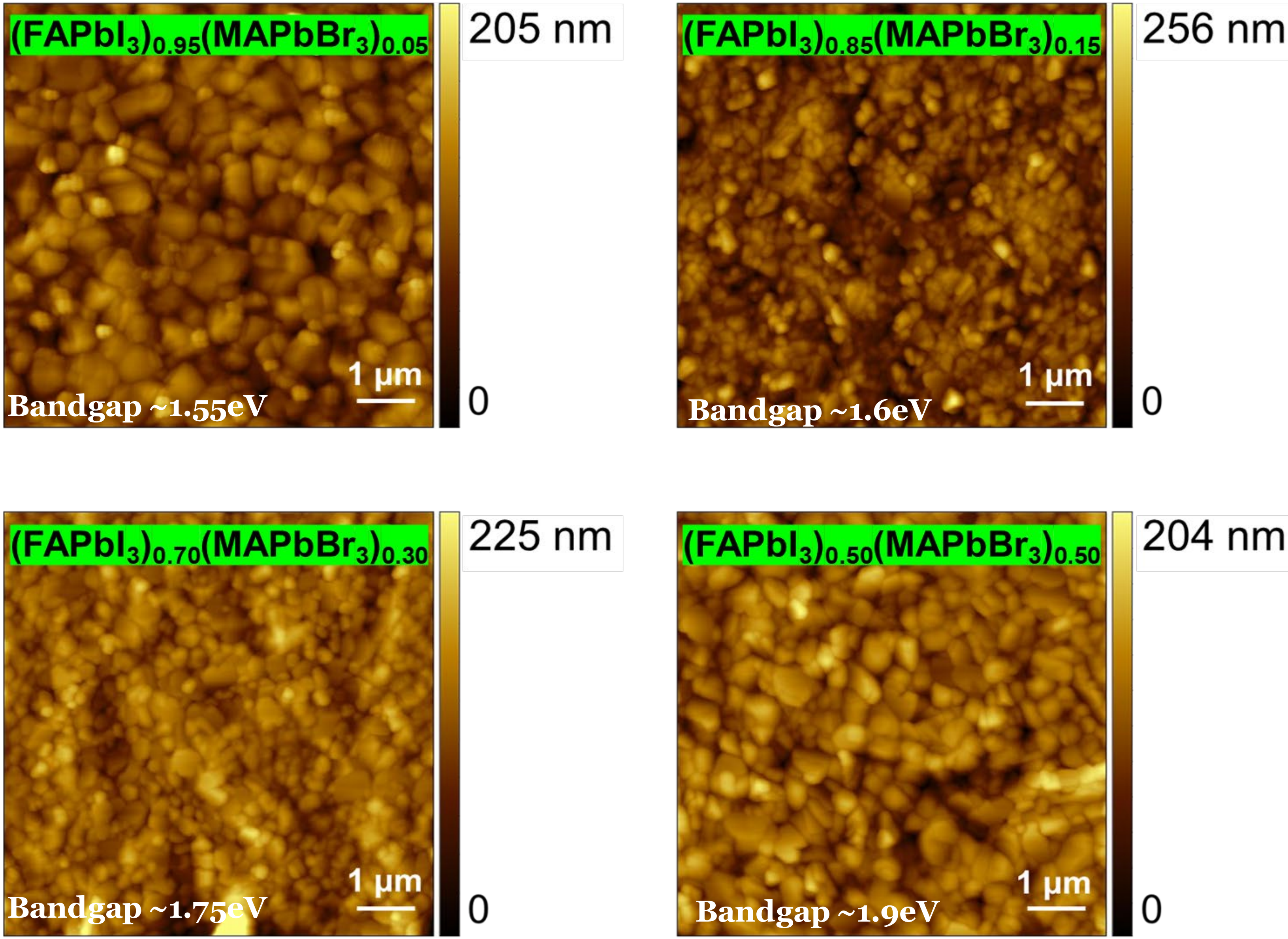
D. Kim

J. Lim



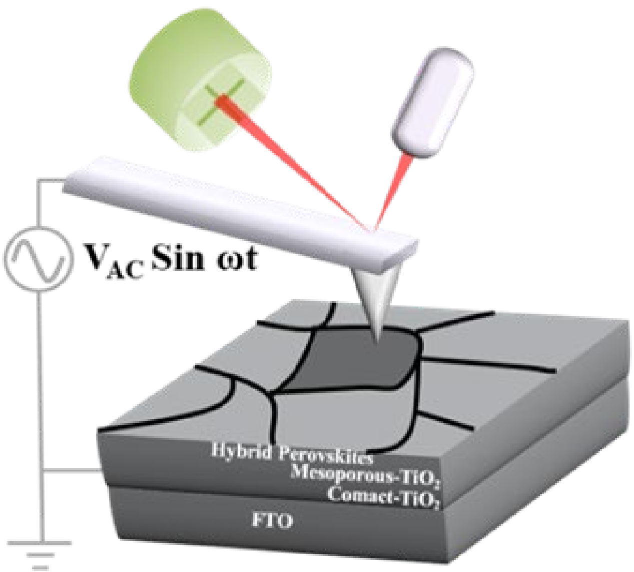
ACS nano 15.12 (2021): 20391

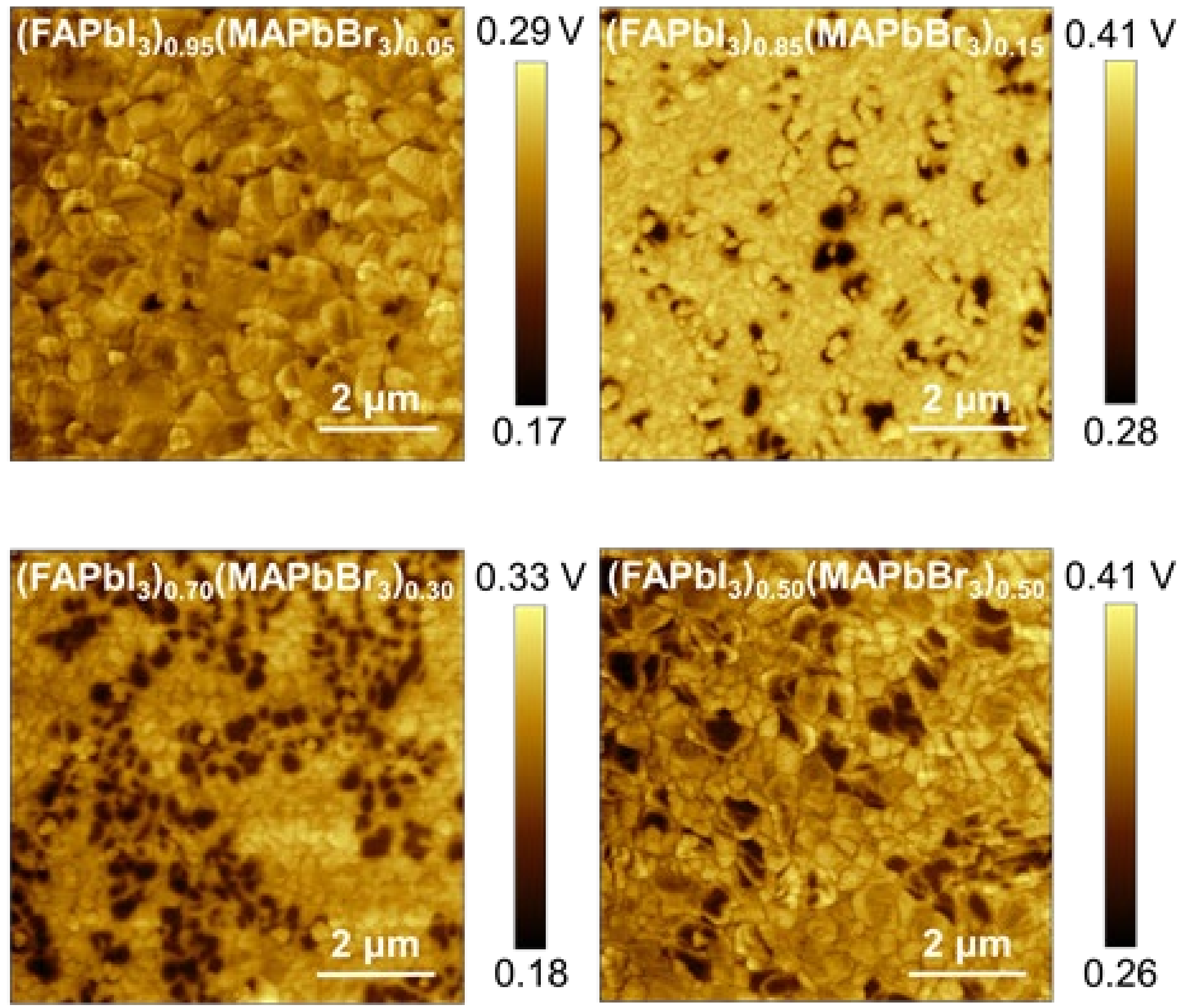
Effect of MABr incorporation



ACS nano 15.12 (2021): 20391

Kelvin probe force microscopy



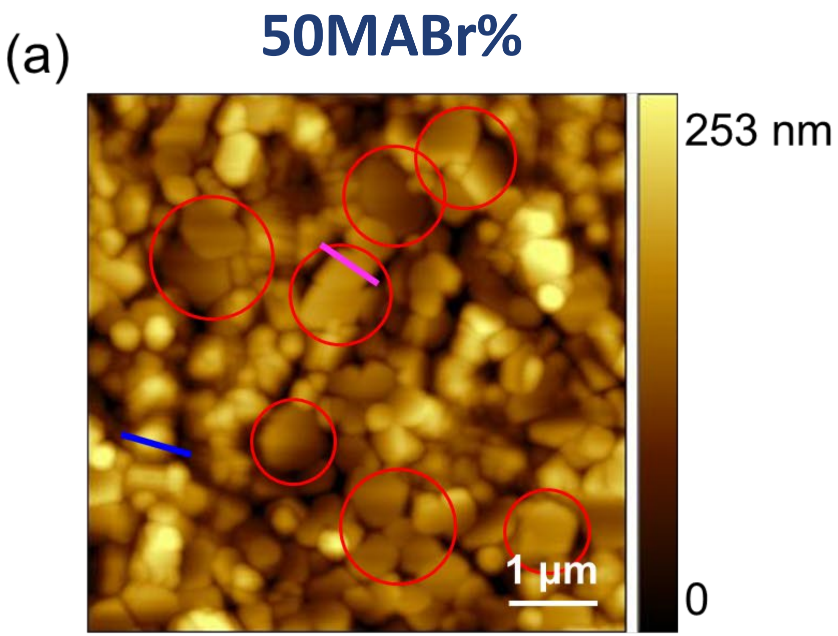


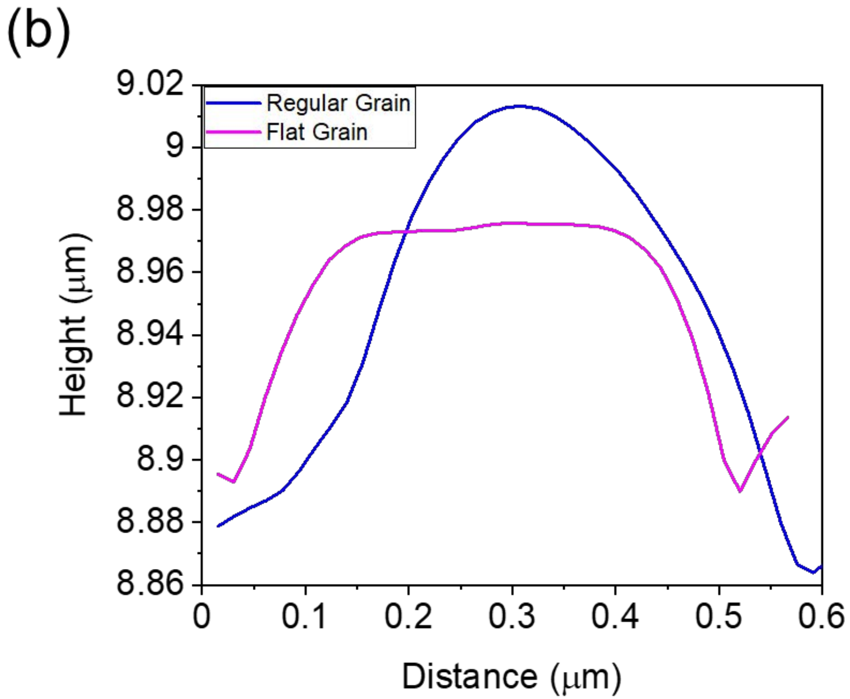
MABr%

Flat dark grain

ACS nano 15.12 (2021): 20391

Flat grains



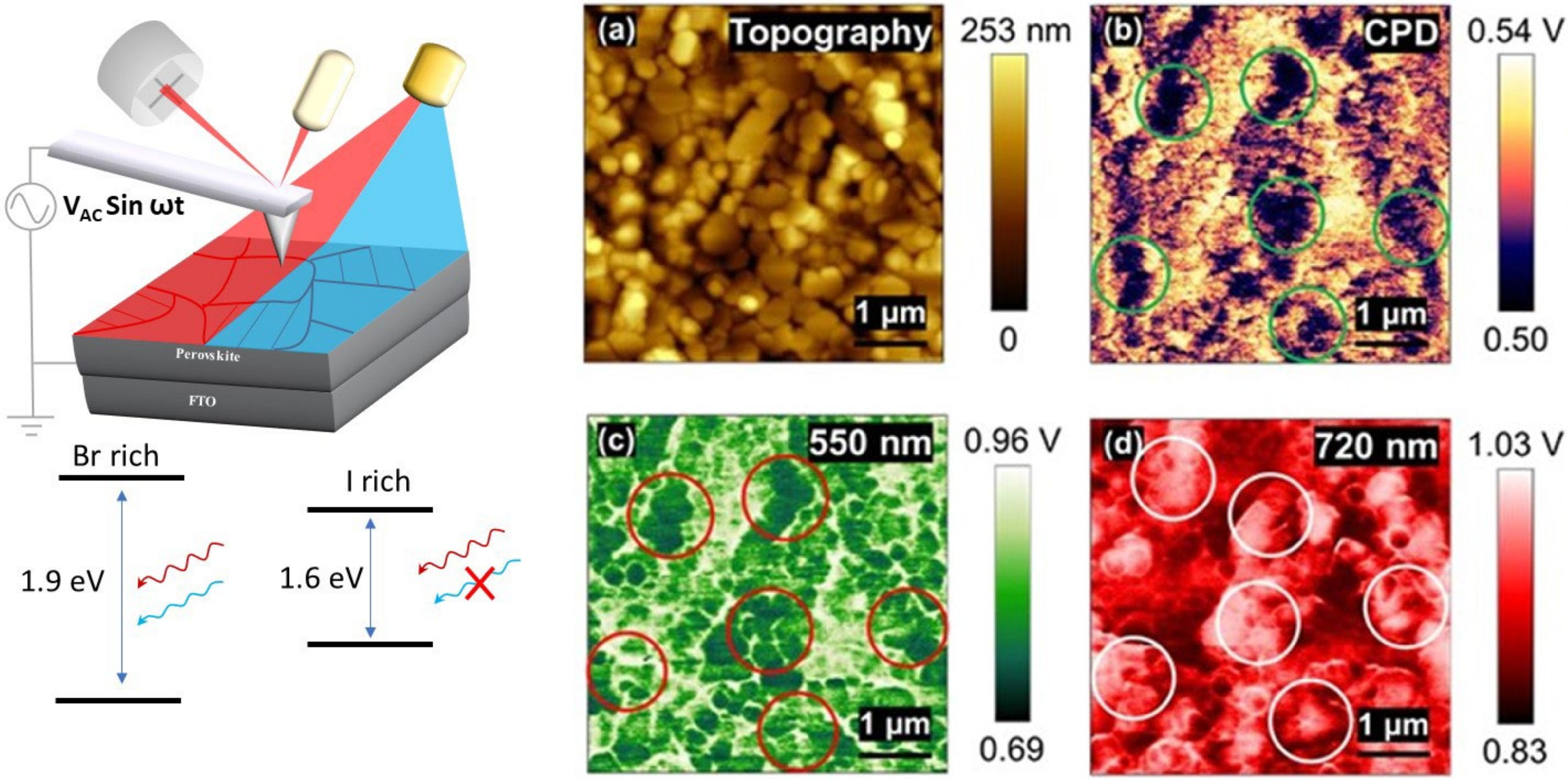


Formation of embedded and flat grain with <u>higher work function</u>

J. Noh, J.Yun*, ACS Nano* (2021)

The speaker has redacted this page

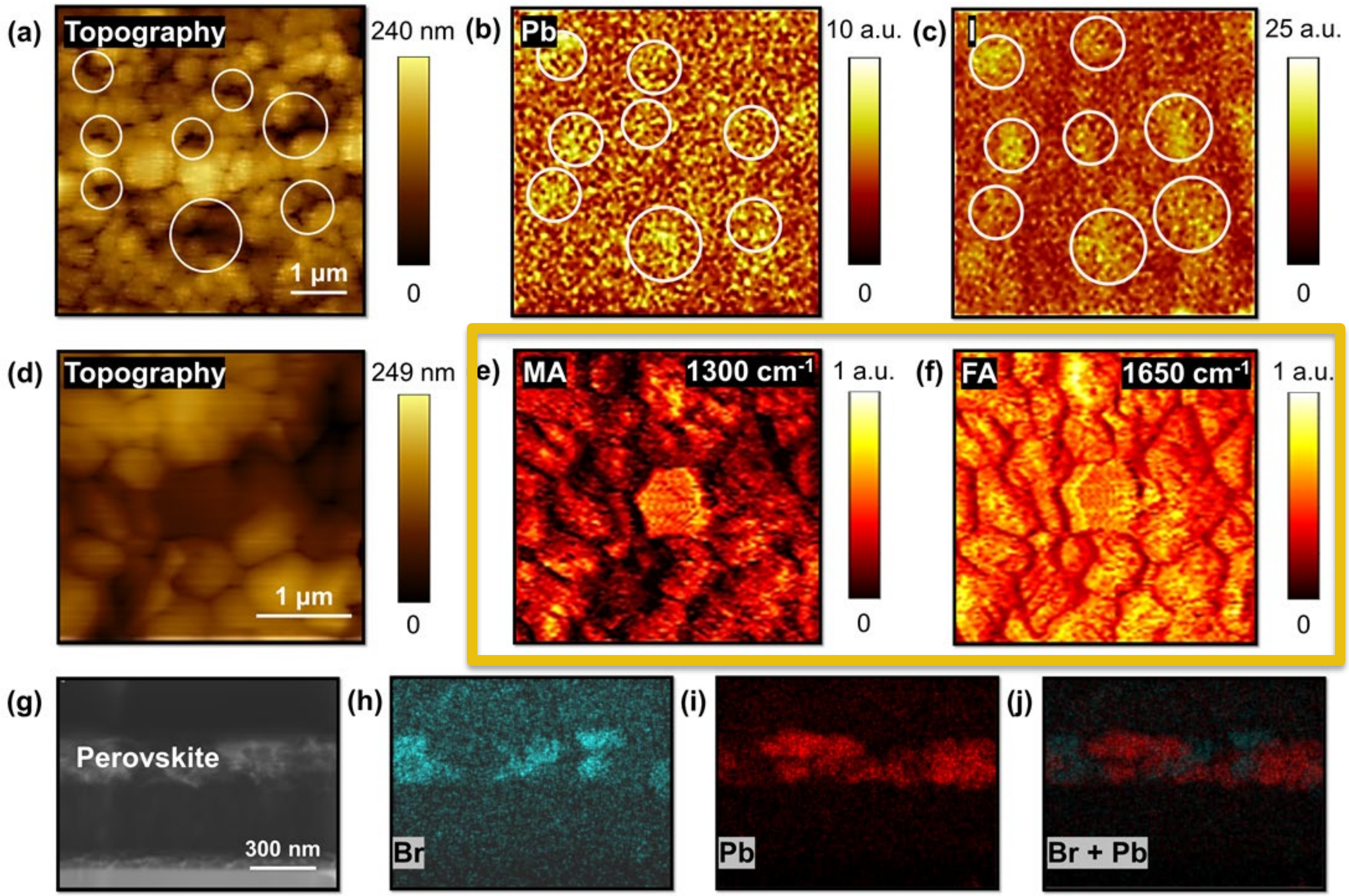
KPFM under illumination



Flat grains-> only responses to 720nm -> likely I rich domain

ACS nano 15.12 (2021): 20391

Nano-IR and HIMS-SIMS

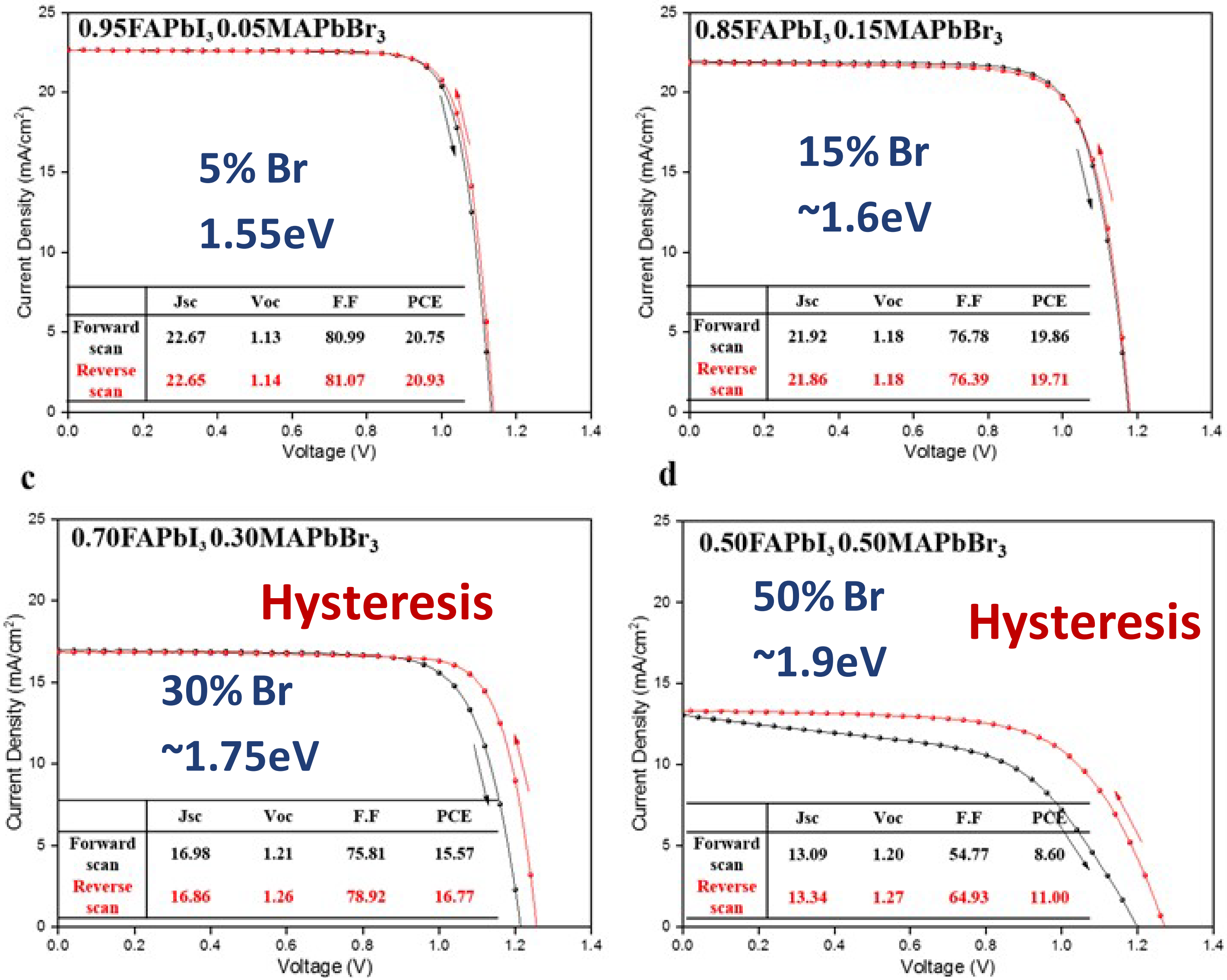


Contacts:
Minwoo Lee
Moonyong Kim

Pb, I, MA rich

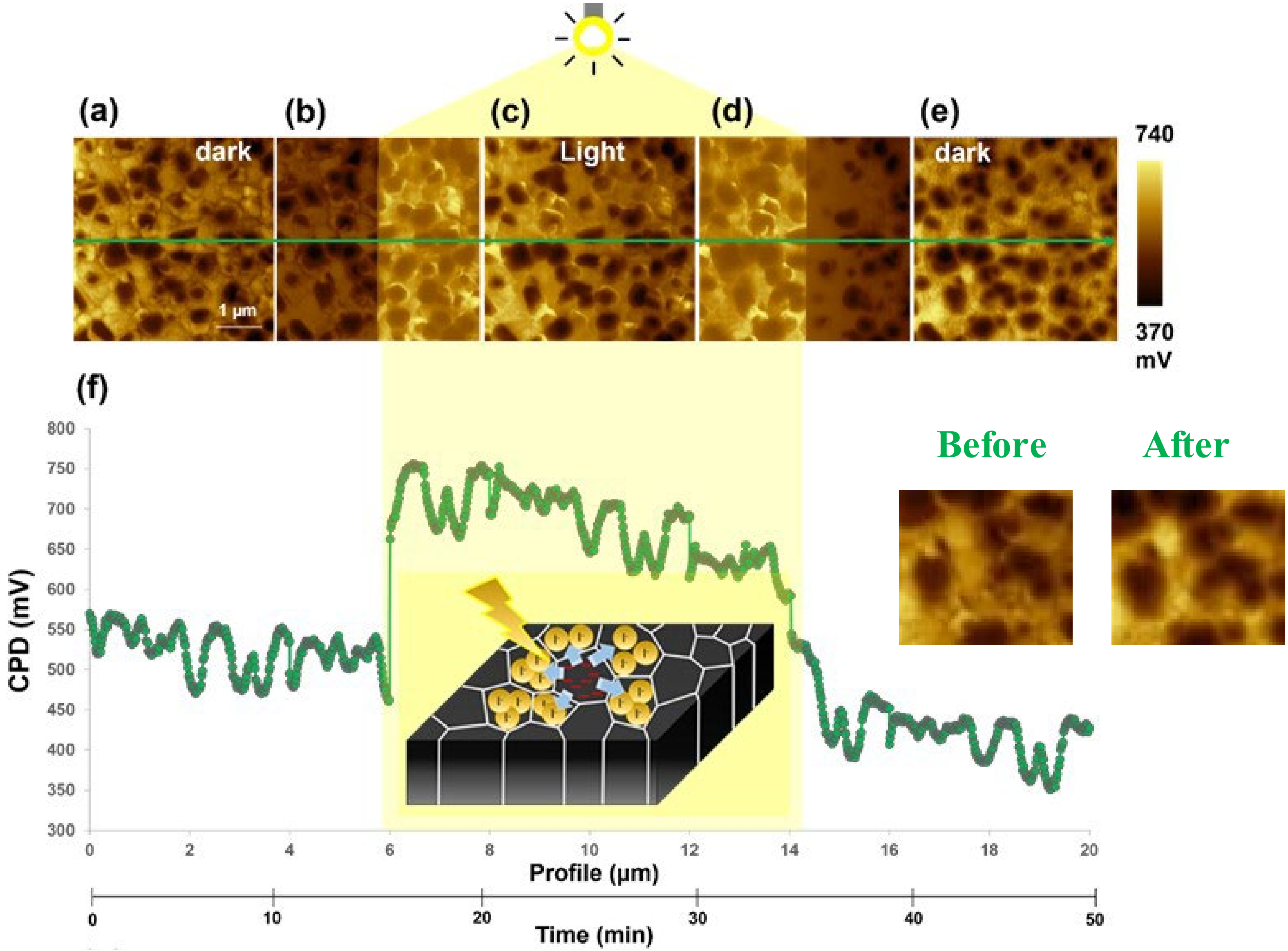
ACS nano 15.12 (2021): 20391

IV curve



ACS nano 15.12 (2021): 20391

Phase Segregation



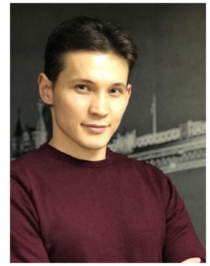
UNIVERSITY OF SURREY

RESEARCH ARTICLE

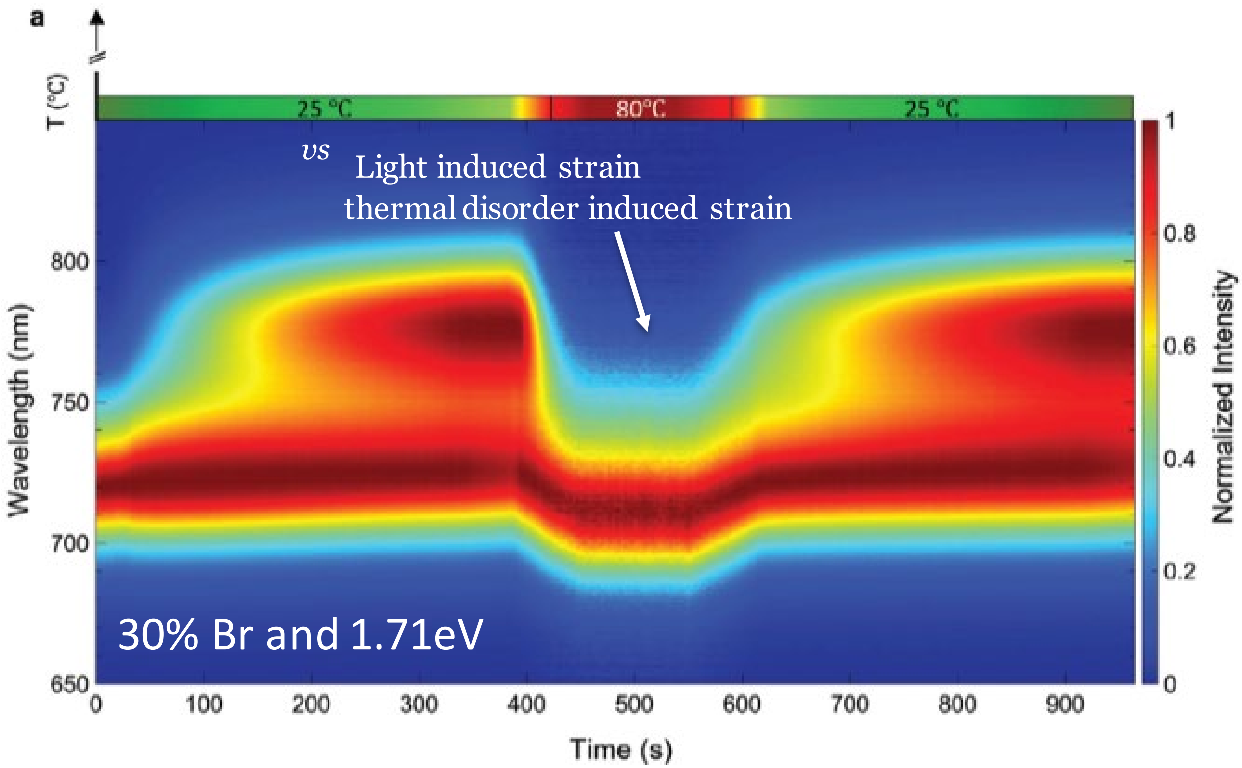
ADVANCED MATERIALS
www.advmat.de

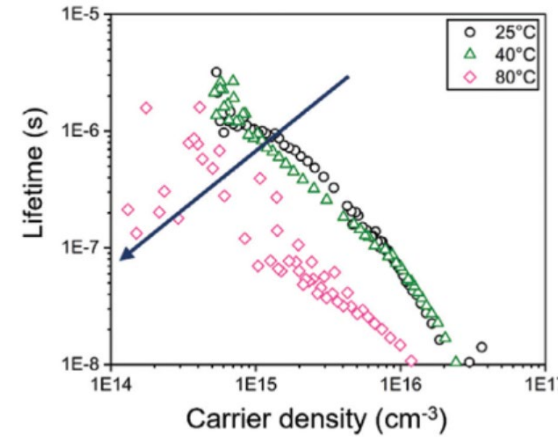
Thermal Disorder-Induced Strain and Carrier Localization Activate Reverse Halide Segregation

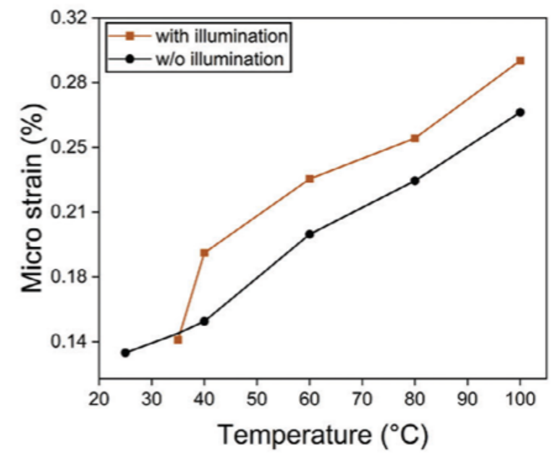
Nursultan Mussakhanuly, Arman Mahboubi Soufiani, Stefano Bernardi, Jianing Gan, Saroj Kumar Bhattacharyya, Robert Lee Chin, Hanif Muhammad, Milos Dubajic, Angus Gentle, Weijian Chen, Meng Zhang, Michael P. Nielsen, Shujuan Huang, John Asbury,* Asaph Widmer-Cooper,* Jae Sung Yun,* and Xiaojing Hao**



Nursultan Mussakhanuly







Wide bandgap Perovskites

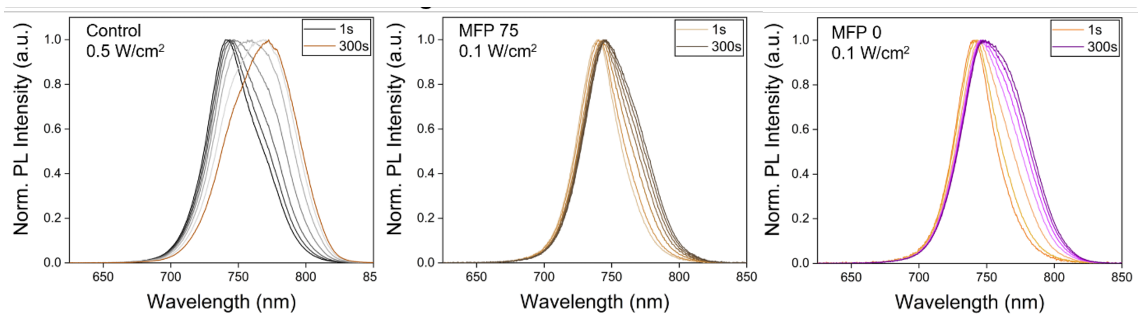
UNIVERSITY OF SURREY

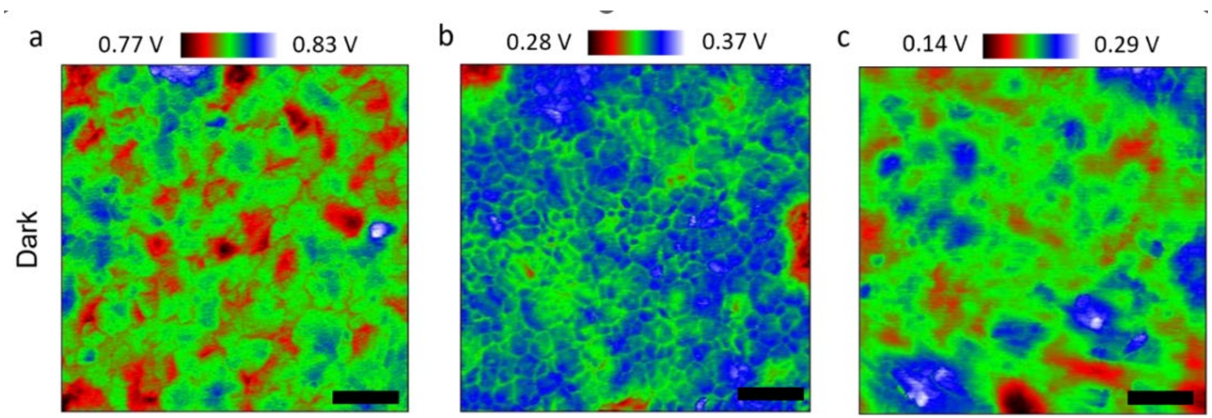
Multi-functional Surface Treatment against Imperfections and Halide Segregation in Wide-bandgap Perovskite Solar Cells

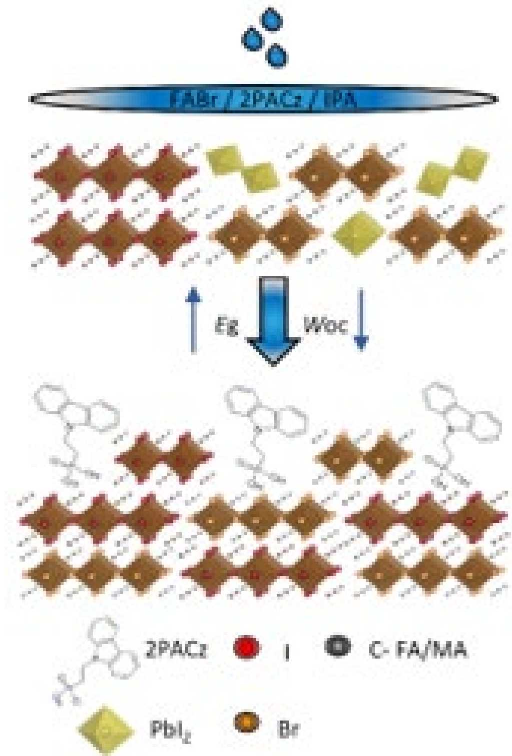
ACS APPLIED MATERIALS & INTERFACES

Nursultan Mussakhanuly[†], Eunyoung Choi[†,‡,¶], Robert L. Chin[†], Yihao Wang[†], Jan Seidel[†], Martin A. Green[†], Arman M. Soufiani[†*], Xiaojing Hao[†*], Jae S. Yun[†,x*]

15% Br and 1.67eV





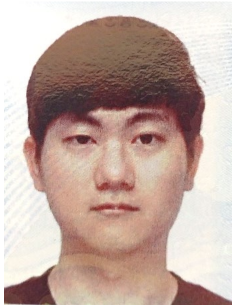


Favourable band bending and **uniform W$_f$** at the interface prevents the funnelling of carriers, thereby, phase segregation

FULL PAPER
ADVANCED FUNCTIONAL MATERIALS
www.afm-journal.de

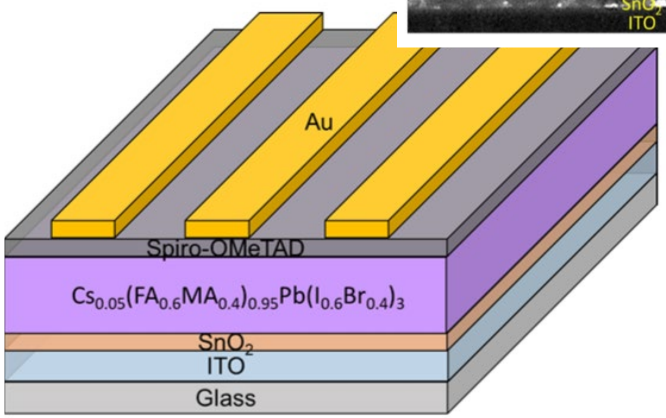
Enhanced Hole-Carrier Selectivity in Wide Bandgap Halide Perovskite Photovoltaic Devices for Indoor Internet of Things Applications

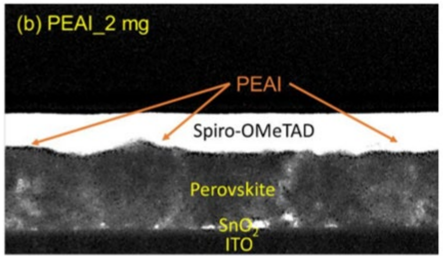
Minwoo Lee, Eunyoung Choi, Arman Mahboubi Soufiani, Jihoo Lim, Moonyong Kim, Daniel Chen, Martin Andrew Green, Jan Seidel, Sean Lim, Jincheol Kim, Xinchen Dai, Robert Lee-Chin, Bolin Zheng, Ziv Hameiri, Jongsung Park, Xiaojing Hao,* and Jae Sung Yun**

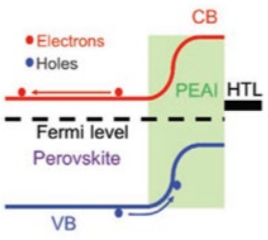


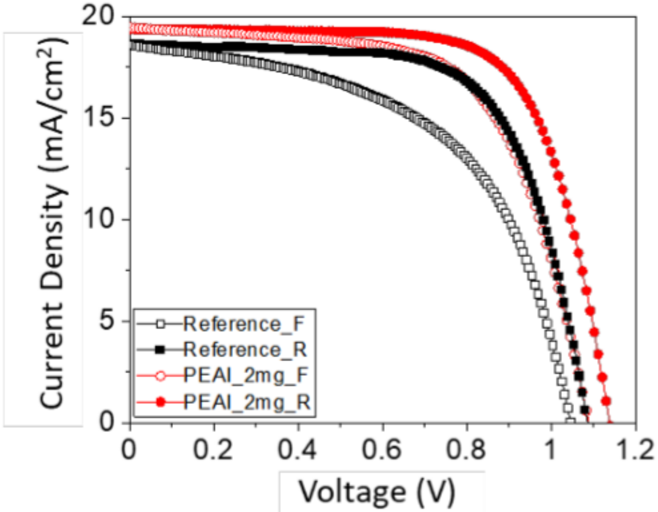
Minwoo Lee

40% Br 1.75 eV





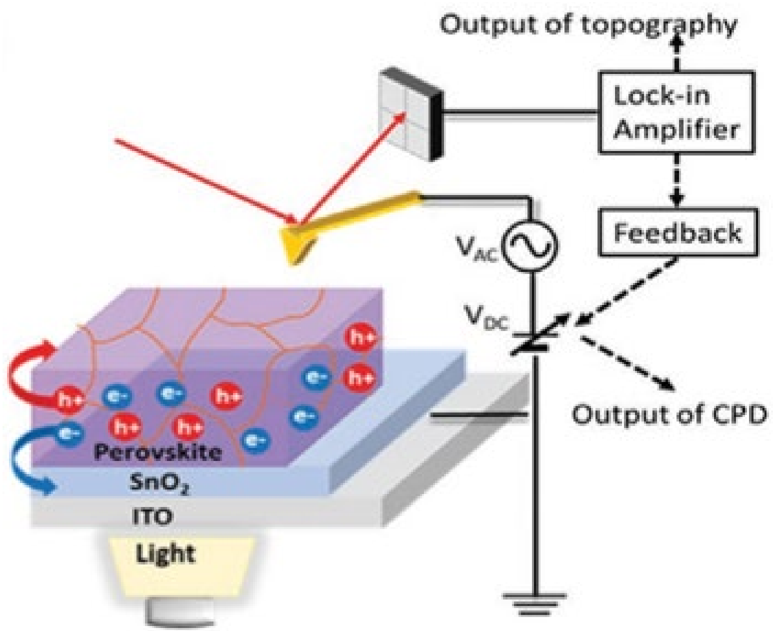


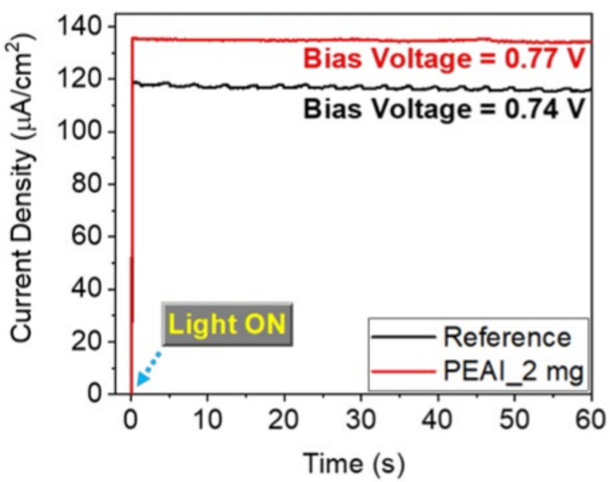


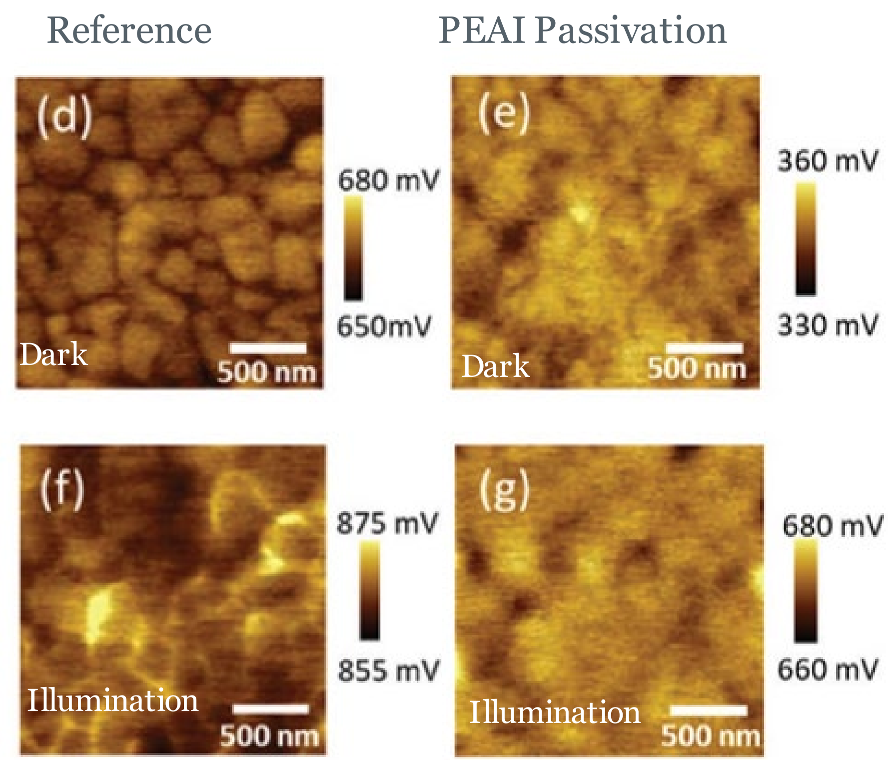
	Scan direction	V_{OC} (V)	J_{sc} (mA/cm^2)	FF (%)	PCE (%)
Reference	Forward	1.05 ± 0.02	18.86 ± 0.03	53.30 ± 0.59	10.52 ± 0.15
Reference	Reverse	1.09 ± 0.01	18.61 ± 0.03	66.95 ± 0.18	13.55 ± 0.04
PEAI_2mg	Forward	1.09 ± 0.03	19.46 ± 0.02	62.99 ± 1.59	13.31 ± 0.36
PEAI_2mg	Reverse	1.14 ± 0.02	19.37 ± 0.01	69.59 ± 2.21	15.32 ± 0.49

Adv. Funct. Mater. 2021, 2008908

Widebandgap Perovskite







Adv. Funct. Mater. 2021, 2008908

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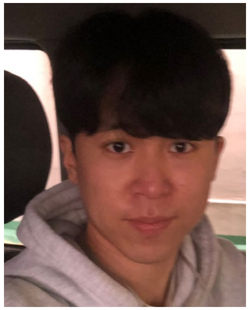
Wide Bandgap Perovskite

ACS APPLIED MATERIALS & INTERFACES

www.acsami.org Research Article

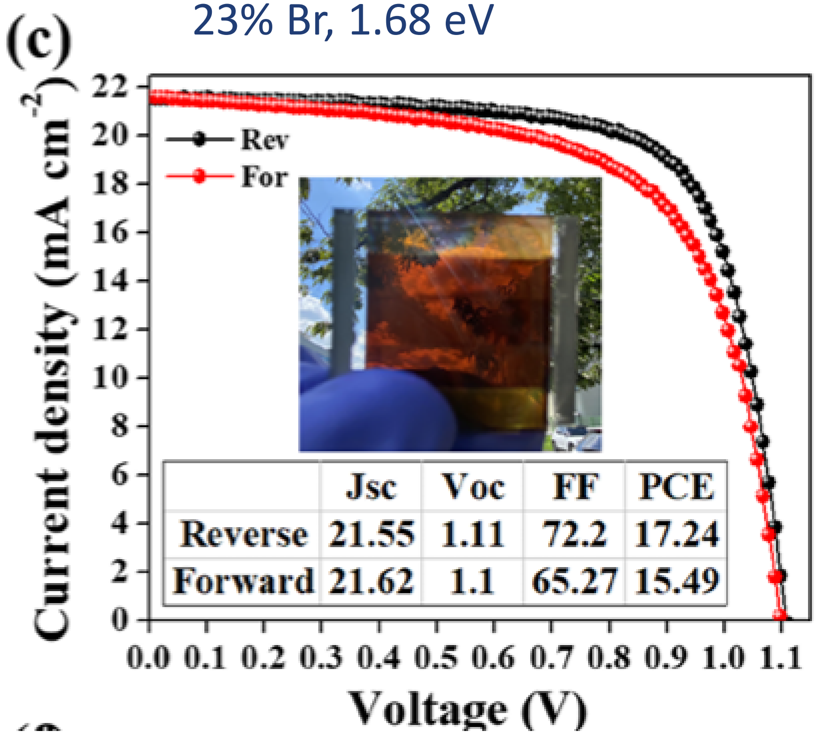
Adjusted Bulk and Interfacial Properties in Highly Stable Semitransparent Perovskite Solar Cells Fabricated by Thermocompression Bonding between Perovskite Layers

Hee-Yun Jung, Eun Sung Oh, Dong Jun Kim, Hongjae Shim, Wonjong Lee, Soon-Gil Yoon, Jongchul Lim, Jae Sung Yun, Taek-Soo Kim, and Tae-Youl Yang*

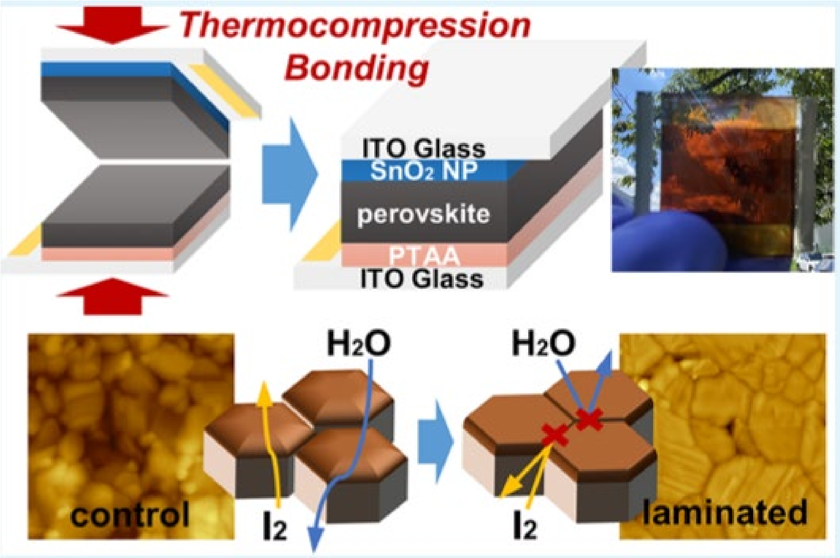


Hongjae Shim

23% Br, 1.68 eV



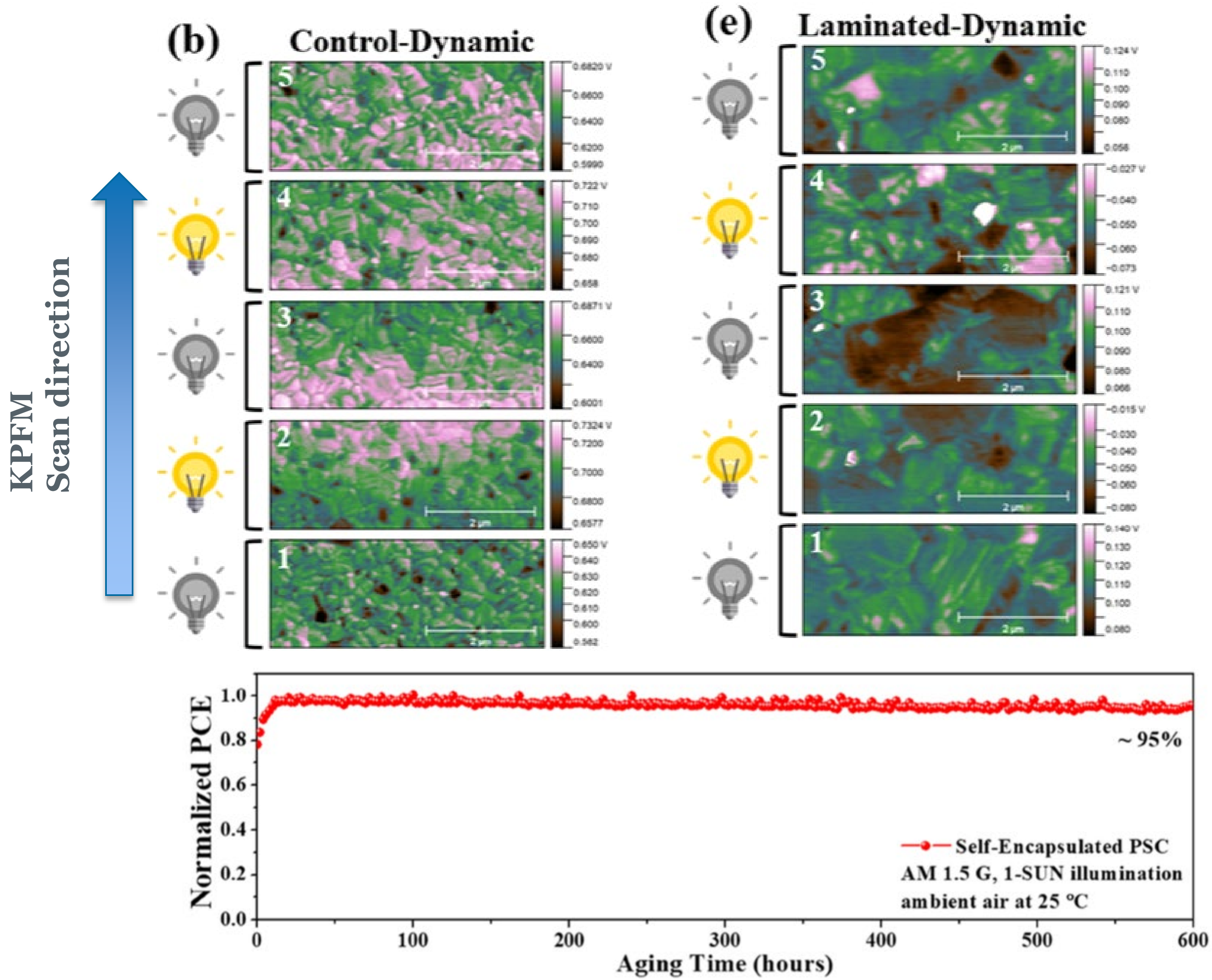
	Jsc	Voc	FF	PCE
Reverse	21.55	1.11	72.2	17.24
Forward	21.62	1.1	65.27	15.49



Large crystal growth, denser interface, reduced trap density

ACS Appl. Mater. Interfaces 2023, 15, 31344

Wide bandgap Perovskite



ACSAppl.Mater. Interfaces2023,15,31344

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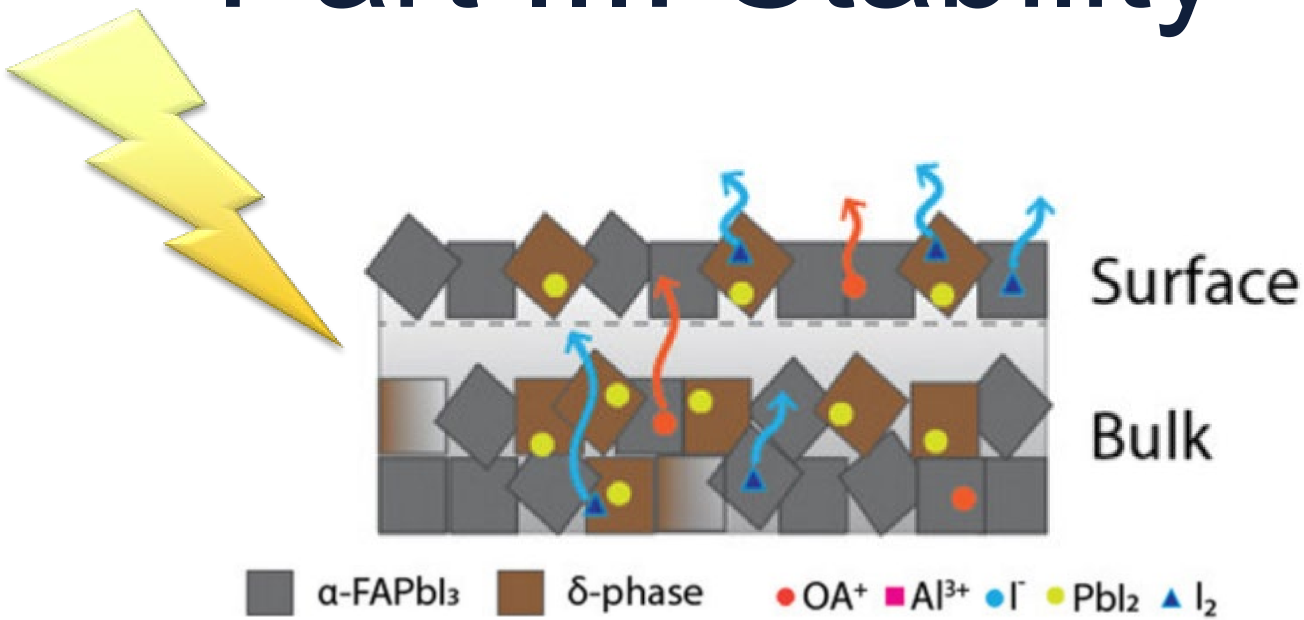
Part III: Stability



$$(2I^- + 2h^+ \rightarrow I_2\uparrow)$$

$$(Pb^{2+} + 2e^- \rightarrow Pb^0)$$

Carriers need to be extracted fast to avoid interfacial recombination!

FAPbI3 Perovskite

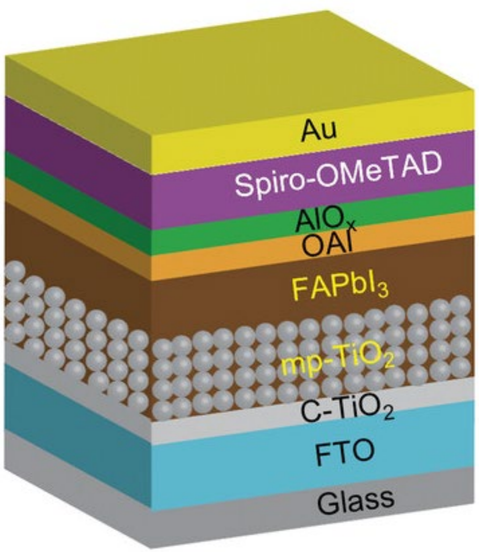
RESEARCH ARTICLE

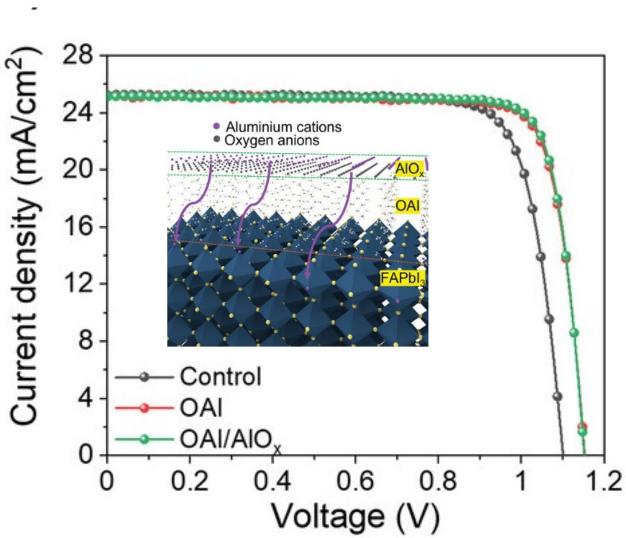
www.advenergymat.de

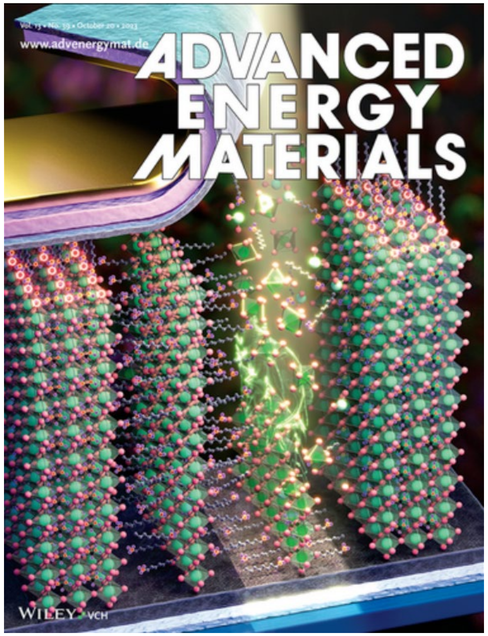
Synergetic Effect of Aluminum Oxide and Organic Halide Salts on Two-Dimensional Perovskite Layer Formation and Stability Enhancement of Perovskite Solar Cells

Eunyoung Choi, Jin-Won Lee, Miguel Anaya, Alessandro Mirabelli, Hongjae Shim, Joseph Strzalka, Jongchul Lim, Siwon Yun, Milos Dubajic, Jihoo Lim, Jan Seidel, Raphael Edem Agbenyeke, Chang Gyoun Kim, Nam Joong Jeon, Arman Mahboubi Soufiani, Helen Hejin Park,* and Jae Sung Yun**

Eunyoung Choi
(now at Diamond Light Source&Cambridge)

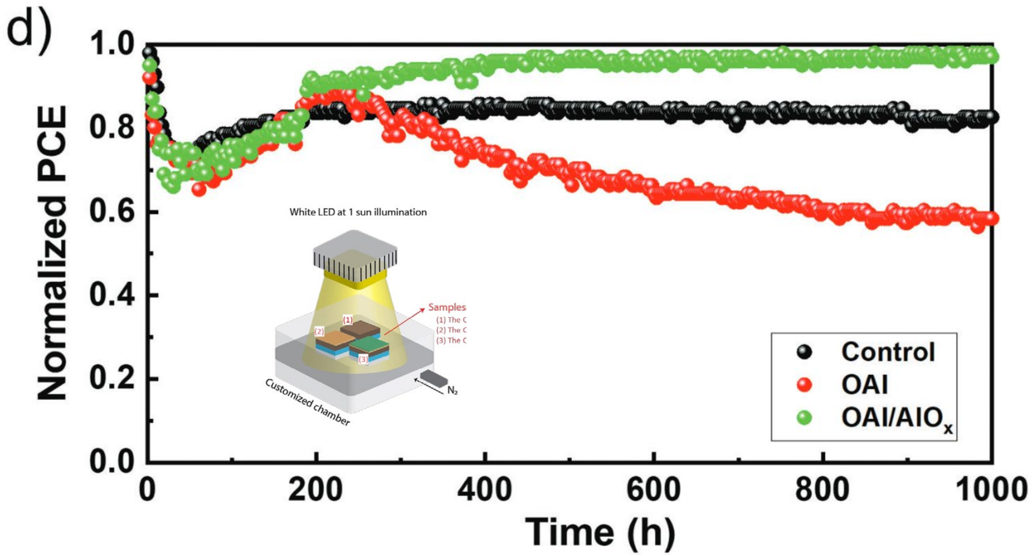


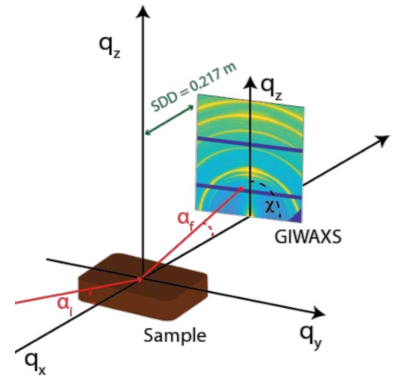


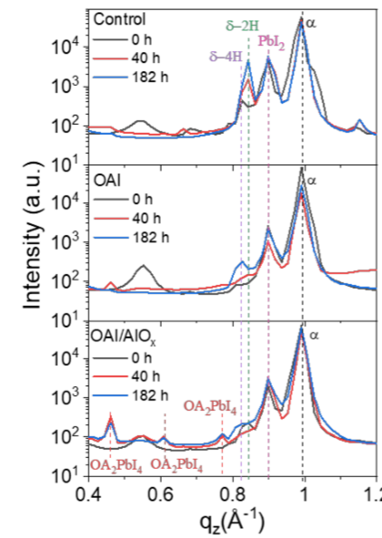


Al diffusion into the bulk

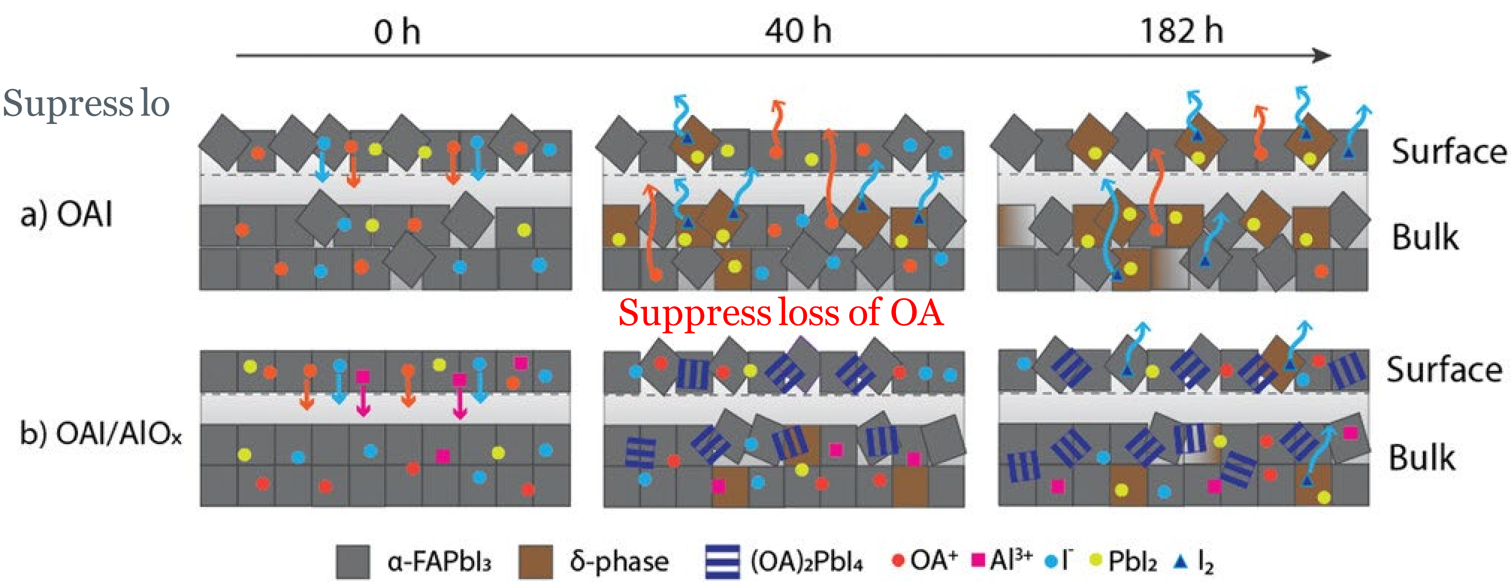
ALD AlOx







Supress lo



Suppress loss of OA

Thermal Stability

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RESEARCH ARTICLE

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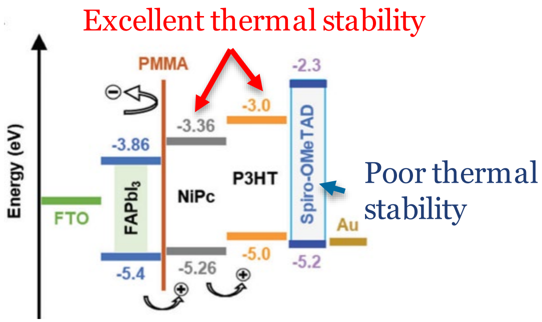
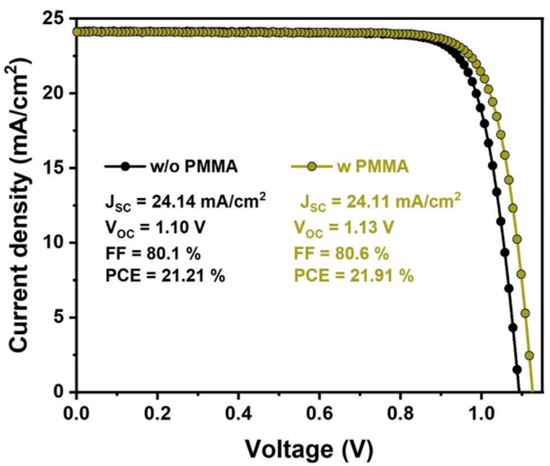
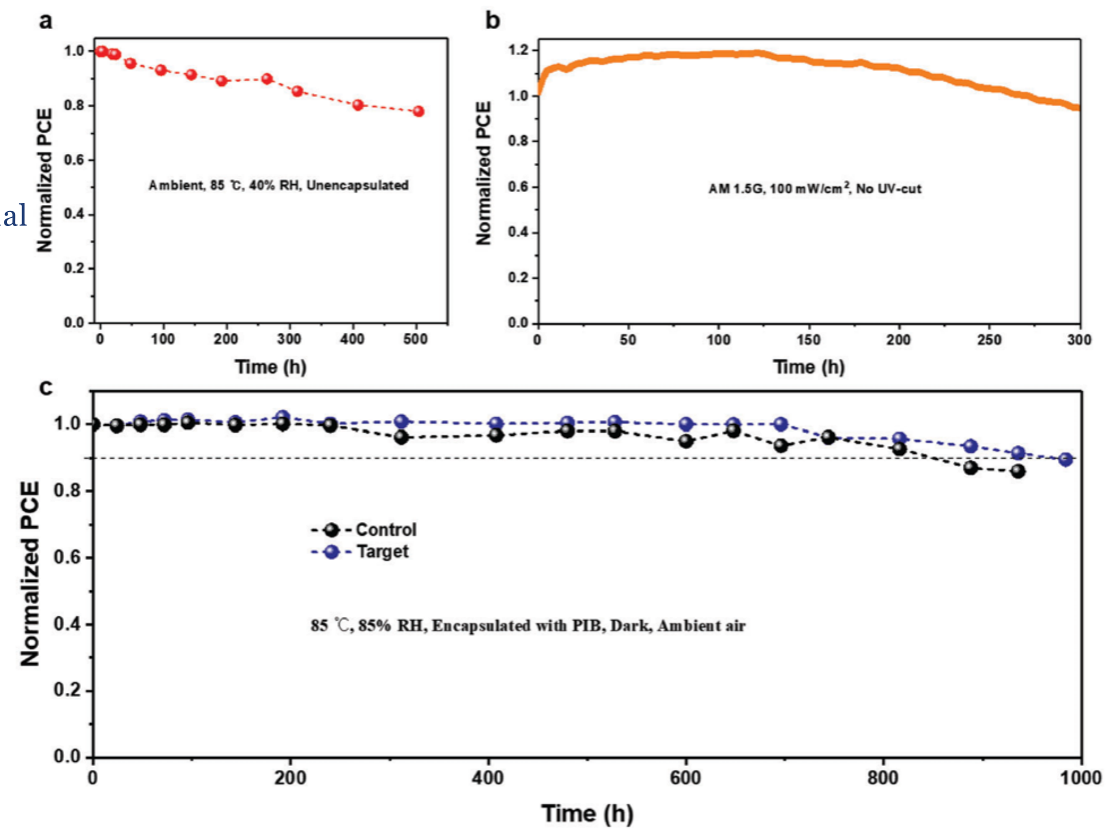
Enhancing Stability and Efficiency of Perovskite Solar Cells with a Bilayer Hole Transporting Layer of Nickel Phthalocyanine and Poly(3-Hexylthiophene)

*Hyeonwoo Kim, Do Yoon Lee, Jihoo Lim, Jongbeom Kim, Jaewang Park, Jan Seidel, Jae Sung Yun, and Sang Il Seok**

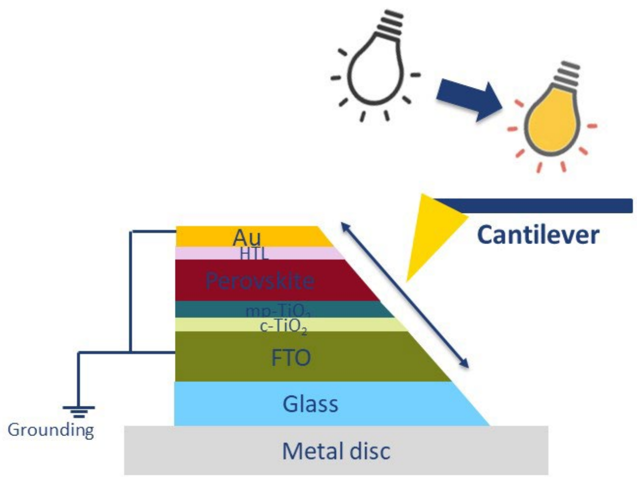
Jihoo Lim

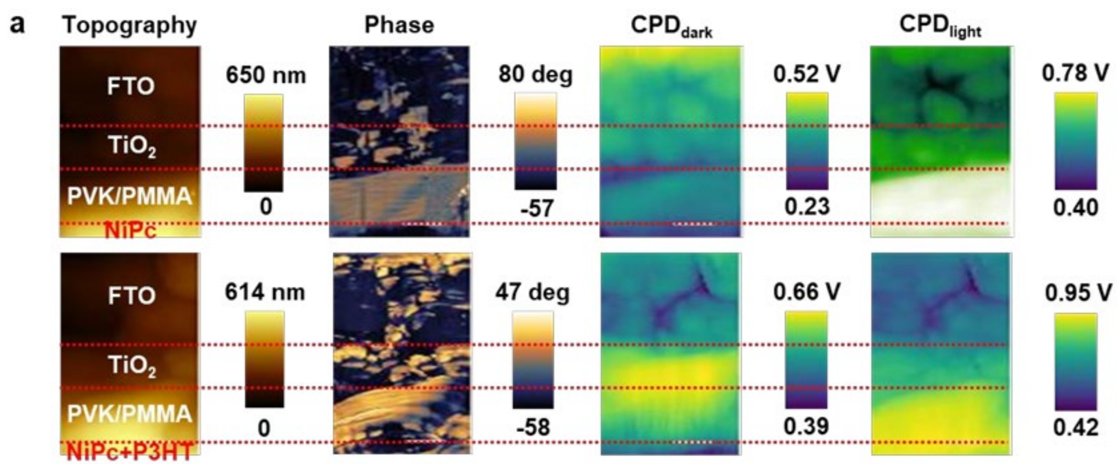




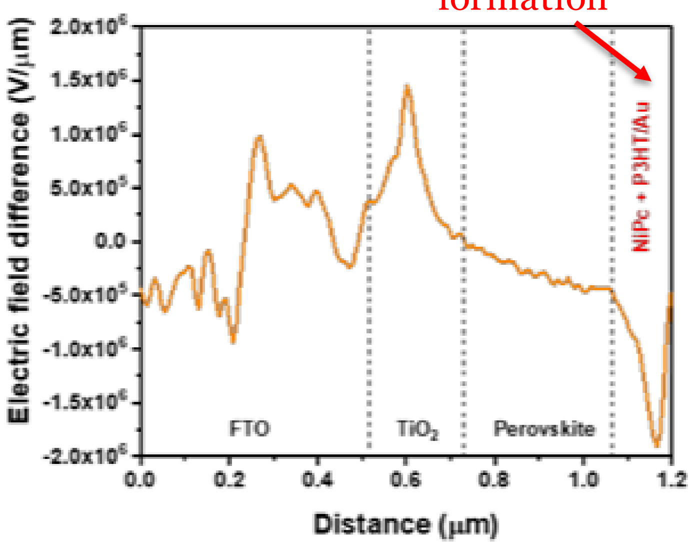


Thermal Stability

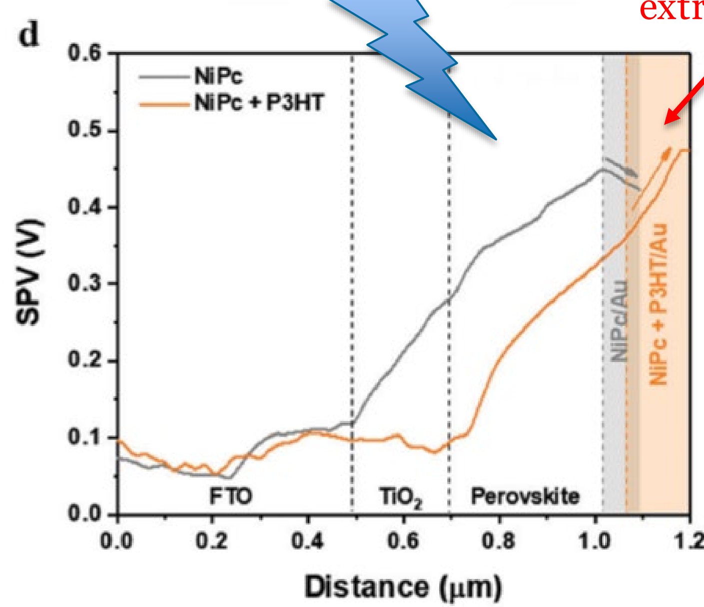




High e-field formation



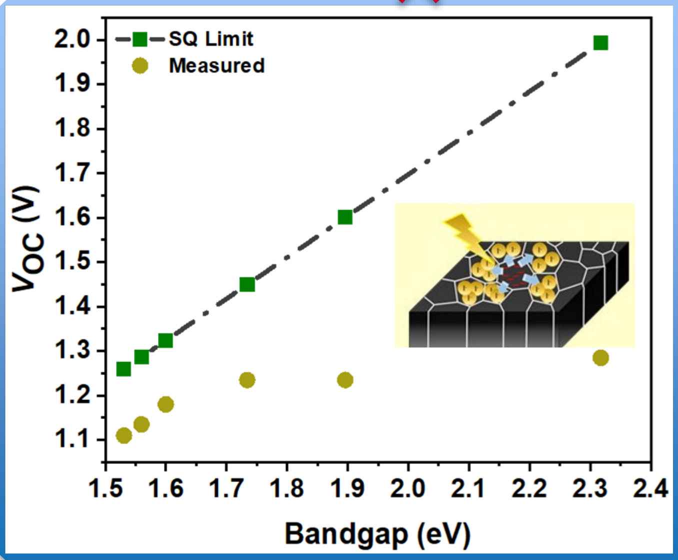
Efficient hole extraction



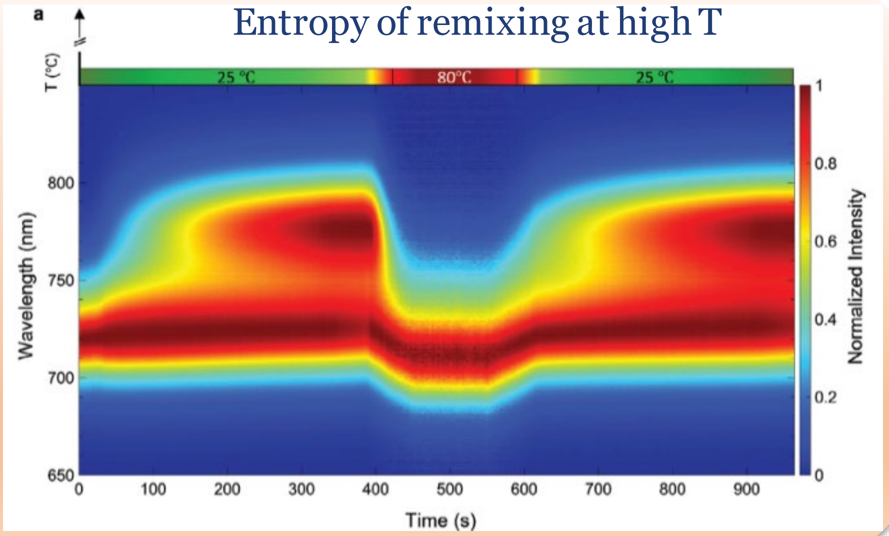
The speaker has redacted this page

Summary

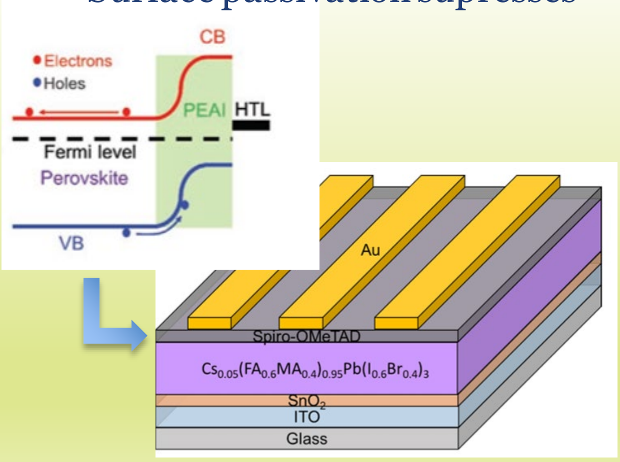
I & Br



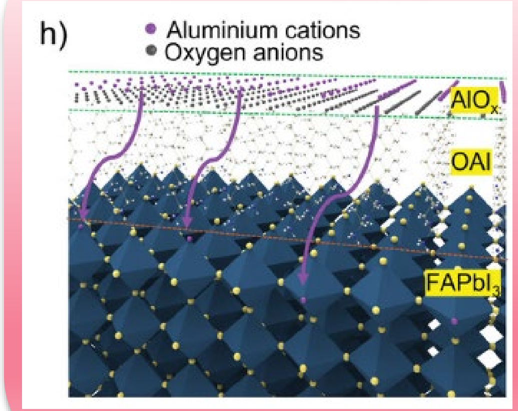
Entropy of remixing at high T



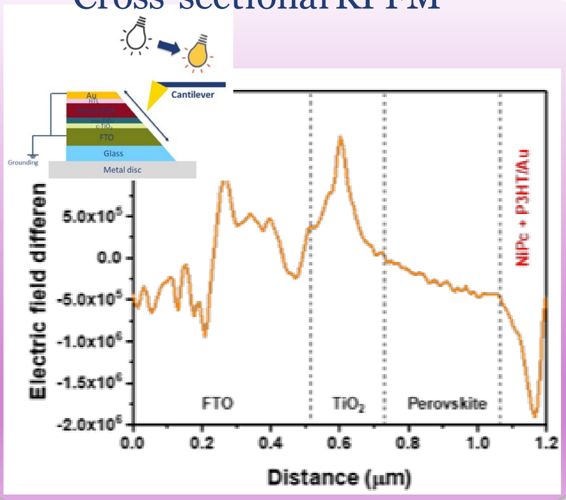
Surface passivation supresses



ALD AlOx Stability



Cross-sectional KPFM



Thank you!!

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National Research Foundation of Korea

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Acknowledgment

MPhil, 2021~
Minwoo Lee

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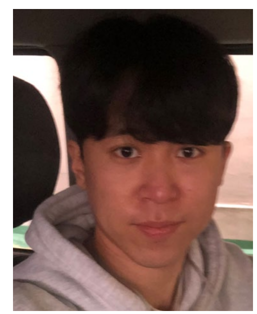
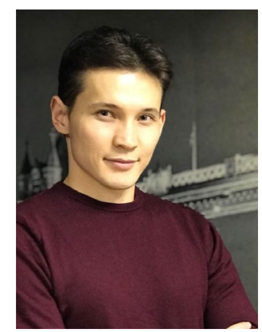
Eunyoung Choi

PhD, 2021~
Jihoo Lim



PhD, 2021~
Hongjae Shim



PhD, 2020-2023
Nursultan Mussakhanuly

Any questions?