Shaping Interfaces and Colloids:
A Nanoscale Journey to Efficient Perovskite Solar Cells

Jincheol Kim (Ph.D.)

Macquarie University

School of Engineering

I. Introduction

II. Research (Solution, Film, Cell/Module)

- Solution Chemistry — Controlling Colloids and Interfaces
- Film Characterisation — Nanoscale Insights with KPFM
- Device and Module — Interface Engineering and Green Solvent for Performance

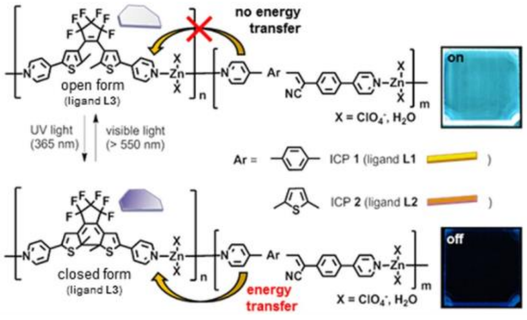
III. Conclusion

I. Introduction

Who Am I?

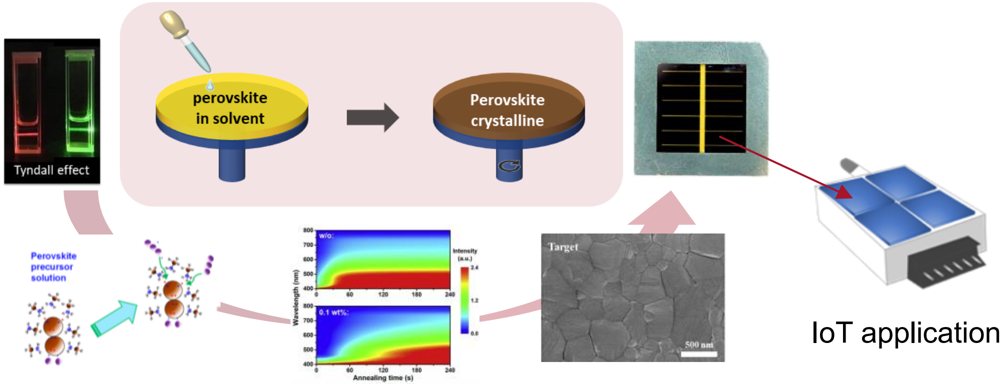
- Jincheol Kim (PhD)
- Education
  - Undergraduate & Master degree at Seoul National University
  - PhD degree at University of New South Wales
- Senior Researcher at Korea Electronics Technology Institute (2019.03~2022.05)
- Research Fellow at Macquarie University (2022.06~)

Organic-inorganic Chemical Engineer



Photochromic Fluorescent

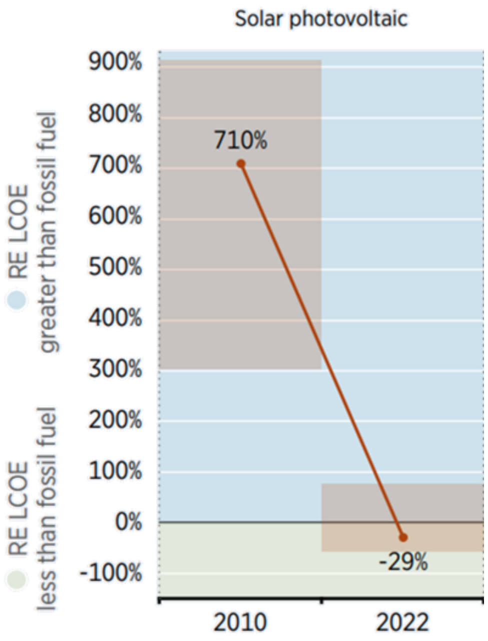
Photovoltaic Engineer

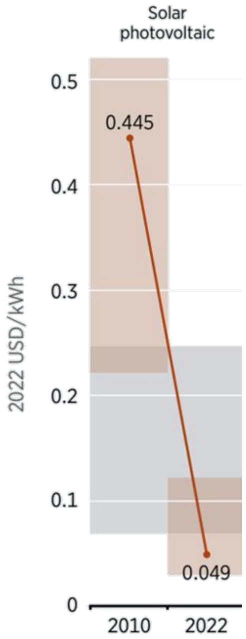


I. Introduction

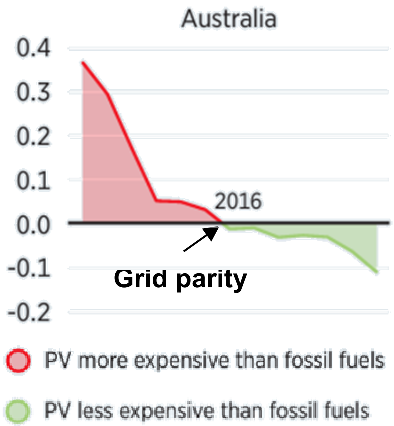
Solar Cells

IRENA
International Renewable Energy Agency





Levelised cost of electricity (LCOE) compared with fossil fuel LCOE 2010-2022

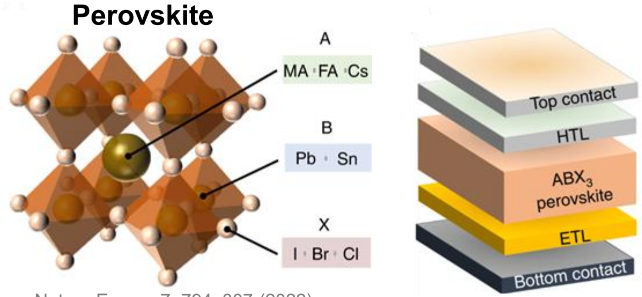


https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022

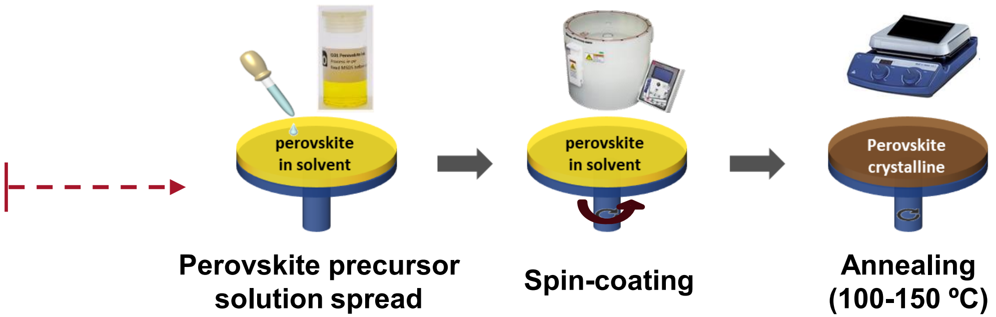
I. Introduction

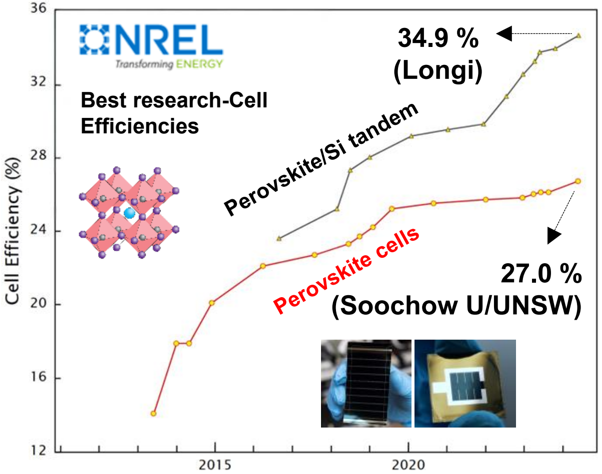
MACQUARIE University SYDNEY·AUSTRALIA

Perovskite Solar Cells



Nature Energy 7, 794–807 (2022)





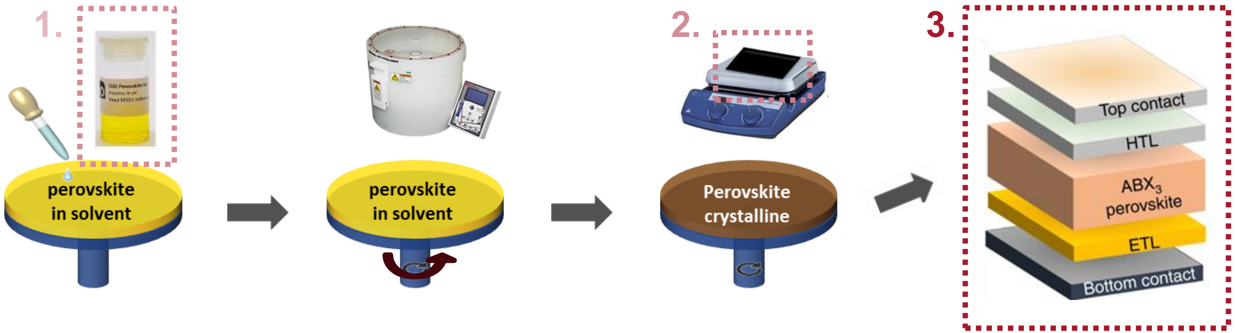
LONGi, JinKO Solar, HZB, OXFORD PHOTOVOL Solar Power Glazin, ENECOAT, SwiftSolar, First Solar, Fraunhofer ISE, MICROQUANTA SEMICONDUCTOR, CSIRO, Hanwha Q CELLS, SAULE TECHNOLOGIES

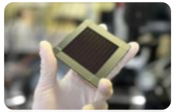
Perovskite Solar Cell/module Industries/Institutes

I. Introduction

MACQUARIE University SYDNEY·AUSTRALIA

Perovskite Activities at MQ





Target

High-performance

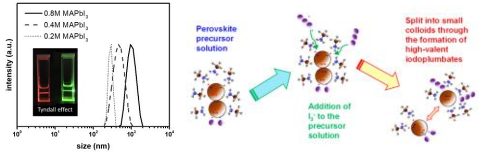
Manufacturability

- Scaling up

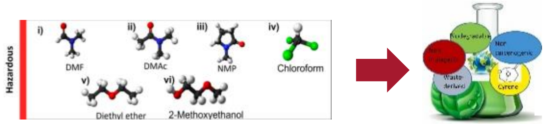
- Green (non-toxic)

1. Solution

- **Precursor Solution Analysis**

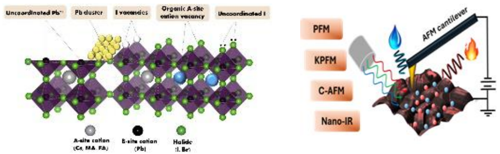


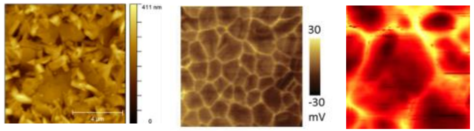
- **Precursor Solution Design (non-toxic)**



2. Film

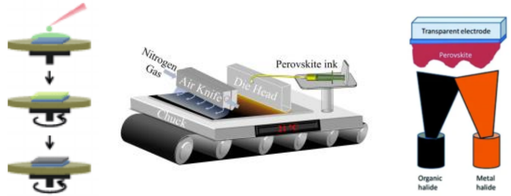
- **Film quality Analysis**





3. Cell/Module Fabrication

- **Device Fabrication Engineering**



I. Introduction

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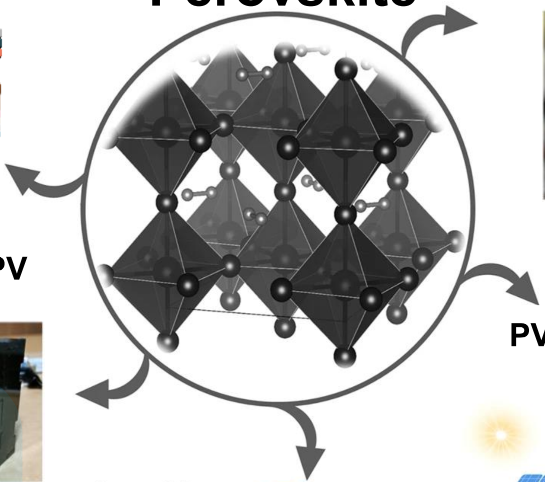
Perovskite Activities at MQ

Tandem Solar Cells

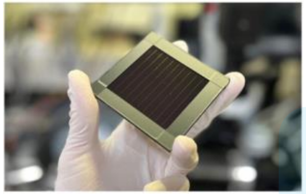
NRF

Starting July 2024

Perovskite



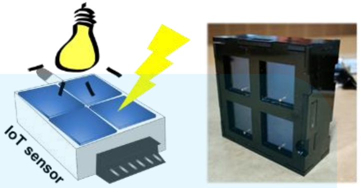
Perovskite module



Australian Government
Department of Education

Starting Oct 2023

Low-light intensity PV



NRF

2020-2023

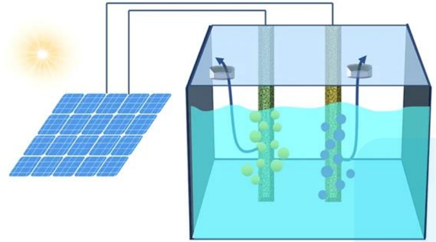
KIAT

2019-2022

Australian Government
Australian Research Council

2021-2024

PV-Integrated Energy Storage Systems



KIAT

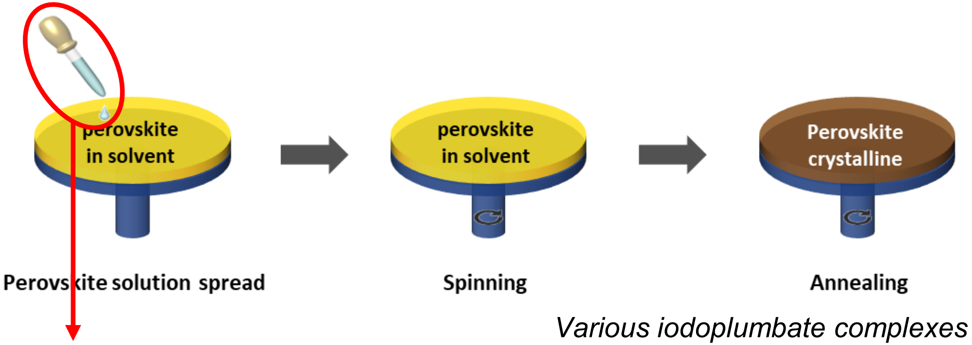
Starting July 2024

Space Application

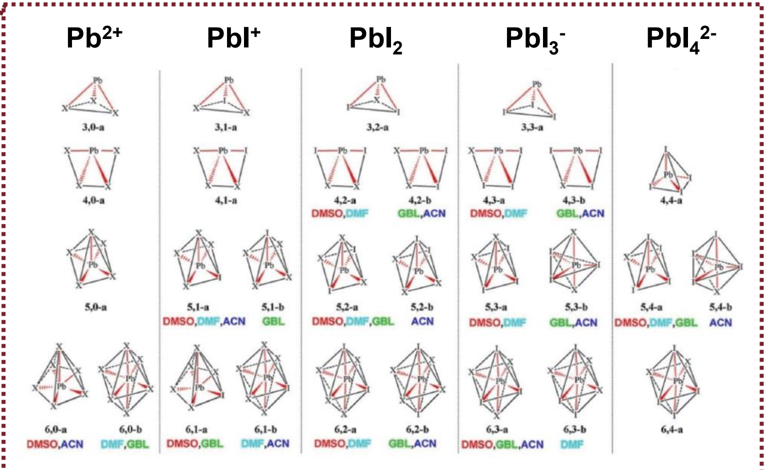
II. Research - Solution

II. Research - Solution

Perovskite Precursor Solution

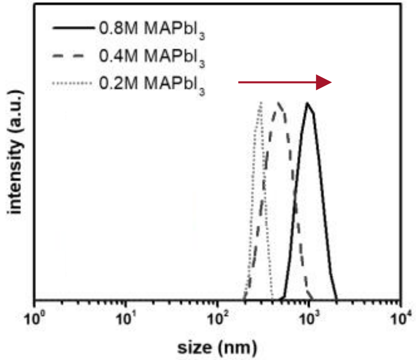


Various iodoplumbate complexes

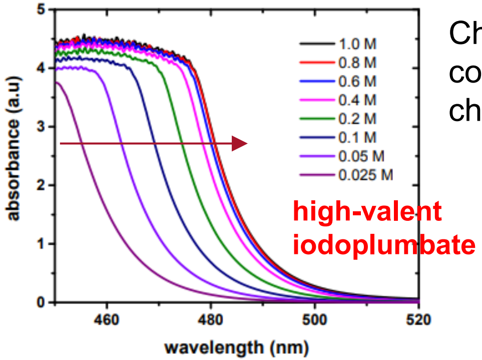


E. Radicchi et al., ACS Appl. Energy Mater.,2019, 2, 3400–3409

Effects of Solution Concentration



Colloid size changes



Chemical coordination changes

II. Research - Solution

Perovskite Precursor Solution

J. Kim et al., J. Am. Chem. Soc., 2020, 142, 6251−6260

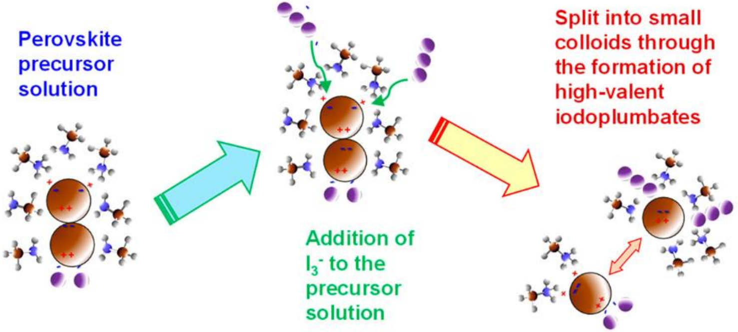
JACS JOURNAL OF THE AMERICAN CHEMICAL SOCIETY

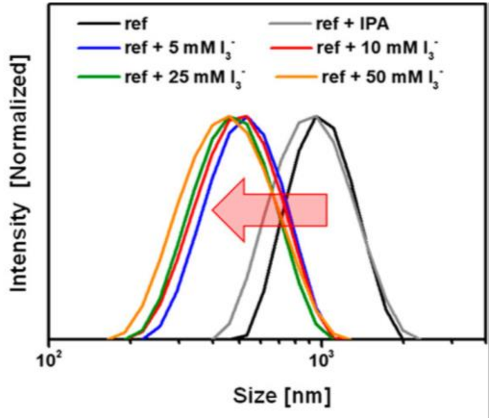
pubs.acs.org/JACS Article

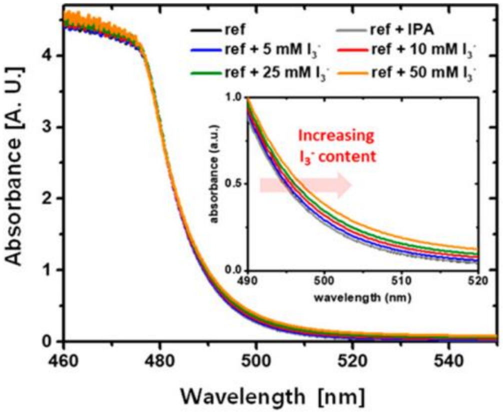
Unveiling the Relationship between the Perovskite Precursor Solution and the Resulting Device Performance

Jincheol Kim,★ Byung-wook Park,★ Jongho Baek, Jae Sung Yun, Hyoung-Woo Kwon, Jan Seidel, Hanul Min, Simao Coelho, Sean Lim, Shujuan Huang, Katharina Gaus, Martin A. Green, Tae Joo Shin, Anita W. Y. Ho-baillie,* Min Gyu Kim,* and Sang Il Seok*

$MAPbI_3$ + I^{3-} Solution





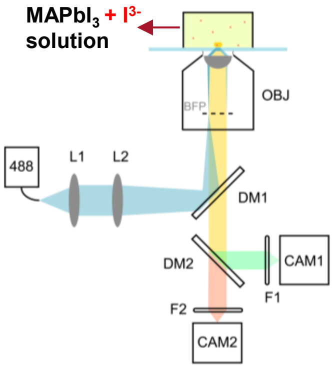


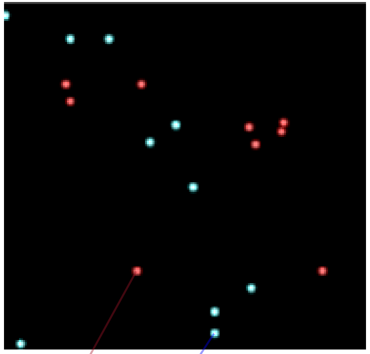
J. Kim et al., J.Am.Chem.Soc., 2020, 142, 6251−6260

II. Research - Solution

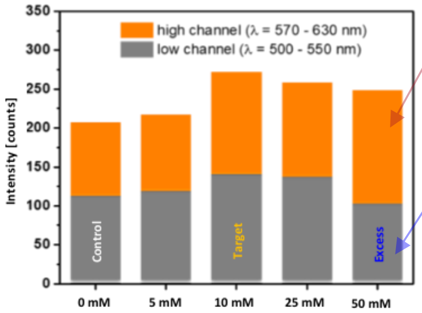
Perovskite Colloid Imaging and EXAFS

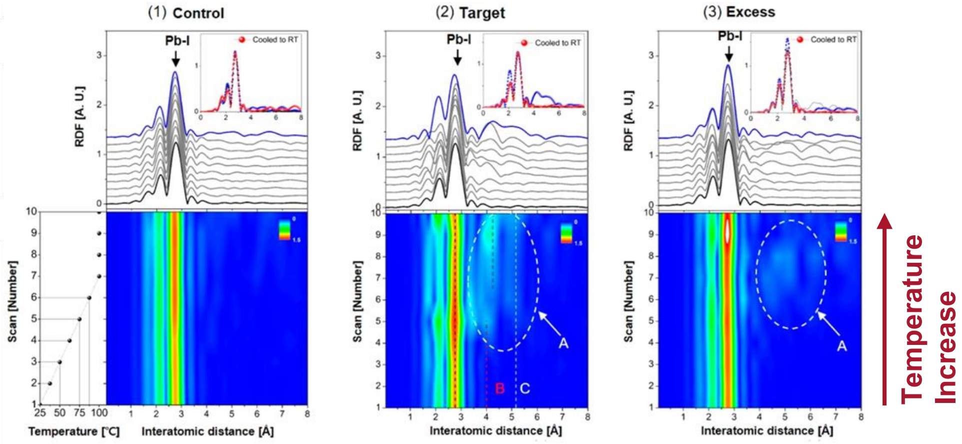
J. Kim et al., J. Am. Chem. Soc., 2020, 142, 6251−6260



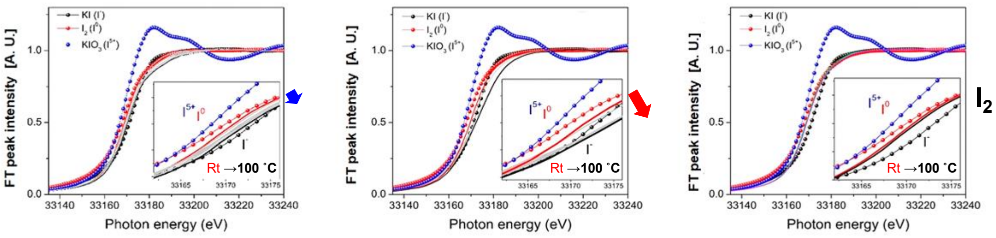


Total internal reflection fluorescence microscopy





Extended X-ray absorption fine structure (EXAFS, Pb L_{III}-edge)

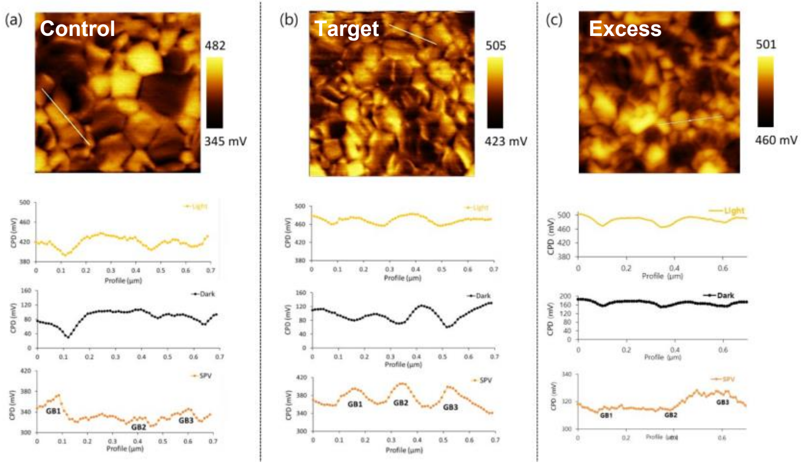


Extended X-ray absorption fine structure (EXAFS, I K-edge)

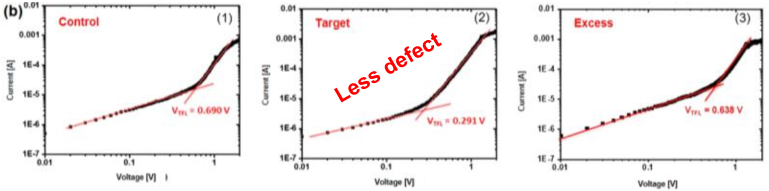
II. Research - Solution

Electronic and Device Performance Characteristics

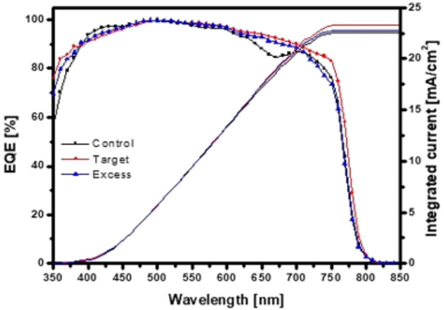
J. Kim et al., J. Am. Chem. Soc., 2020, 142, 6251−6260

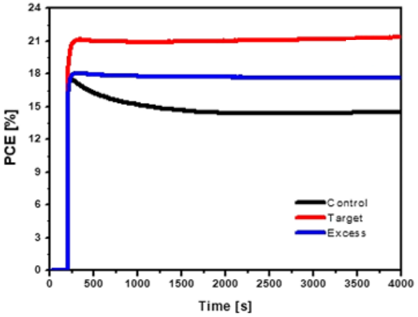


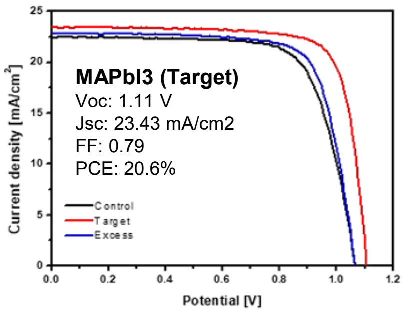
Spatial CPD maps & Surface photovoltage (SPV) profiles

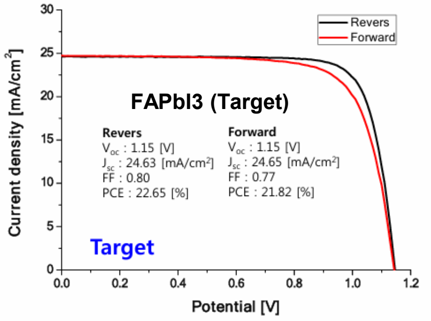


Space charge limiting current









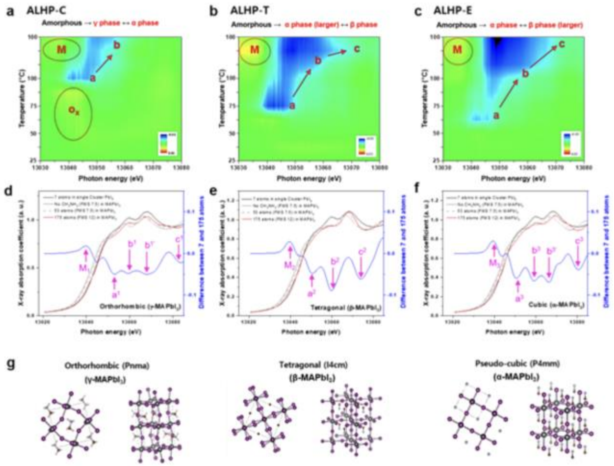
II. Research - Solution

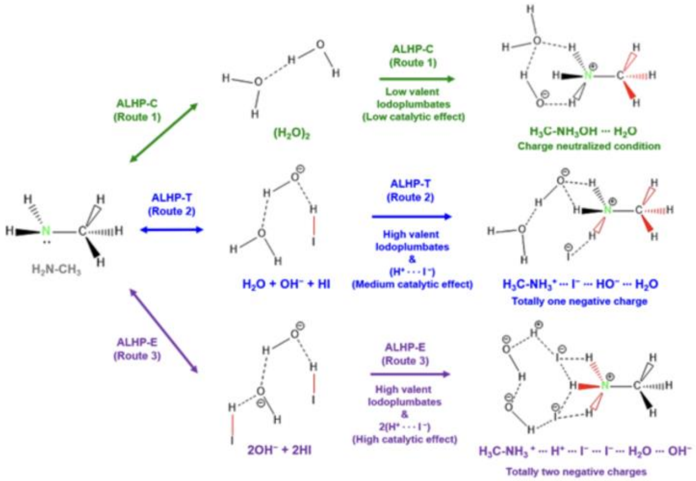
RESEARCH ARTICLE

ADVANCED MATERIALS
www.advmat.de

Stabilization of the Alkylammonium Cations in Halide Perovskite Thin Films by Water-Mediated Proton Transfer

Byung-wook Park, Jincheol Kim, Tae Joo Shin, Yung Sam Kim, Min Gyu Kim,* and Sang Il Seok**





B. Park[ǂ], J. Kim[ǂ] et al., Adv. Mater., 2023, 35, 2211386

II. Research - Solution

Surfactant-assisted Perovskite Solution Control

Gyeong G. Jeon

Contents lists available at ScienceDirect

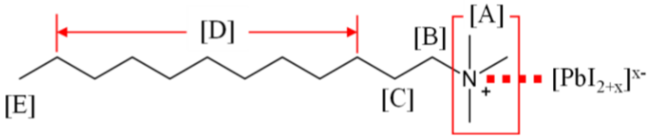
Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

ELSEVIER

Surfactant-assisted colloidal size and charge control in perovskite solutions for high-performance and stable solar cells

Gyeong G. Jeon [a], Sang Eun Yoon [a], Jonghoon Han [b], Hye W. Chun [a], So Jeong Shin [a], Min Jun Choi [a], Sang Uk Park [a], Seo-Jin Ko [c], Shujuan Huang [b], Nochang Park [d], Jong H. Kim [a,*], Jincheol Kim [b,*]



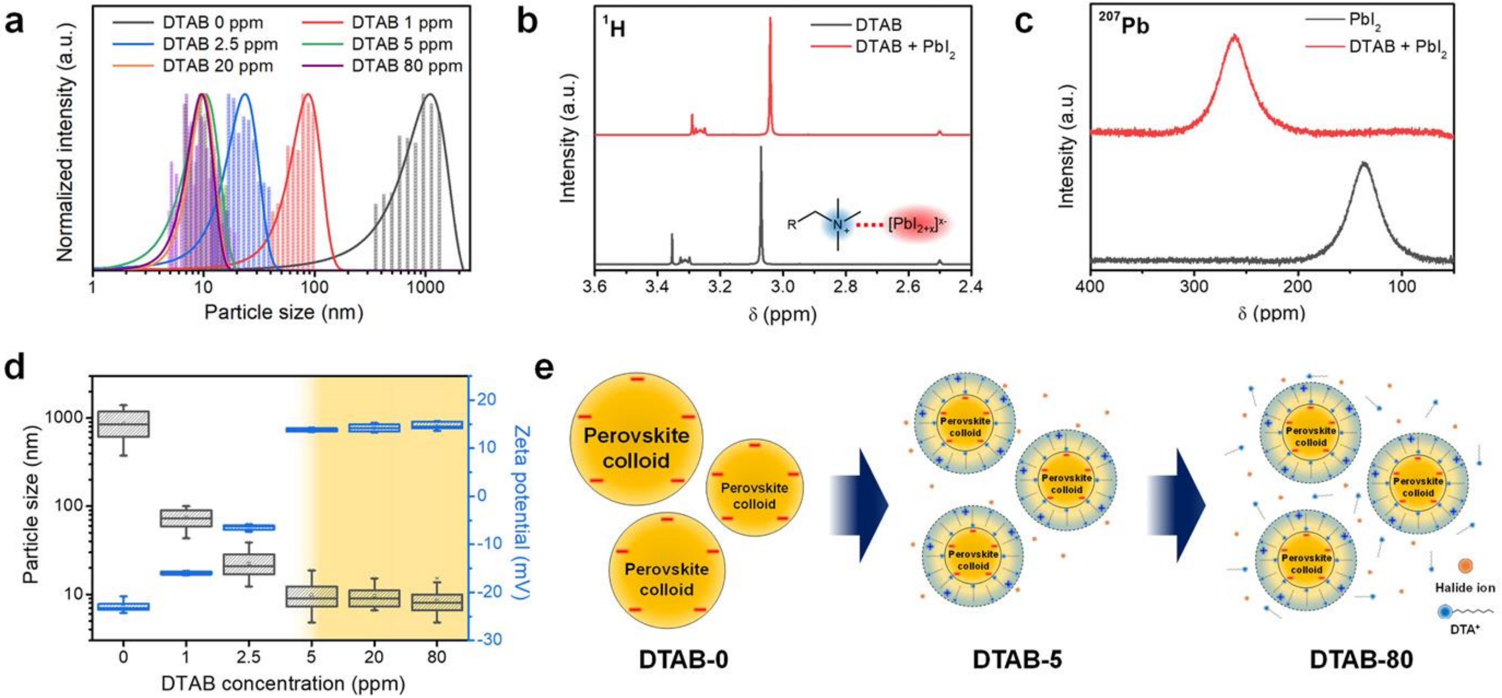
Surfactant: Dodecyltrimethylammonium bromide (DTAB)

J. Kim* et al., Chem. Eng. J., 2025, 519, 164991

II. Research - Solution

Colloid properties

Gyeong G. Jeon

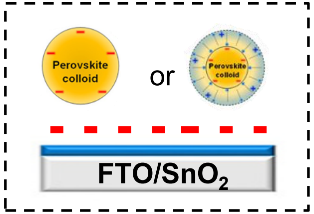


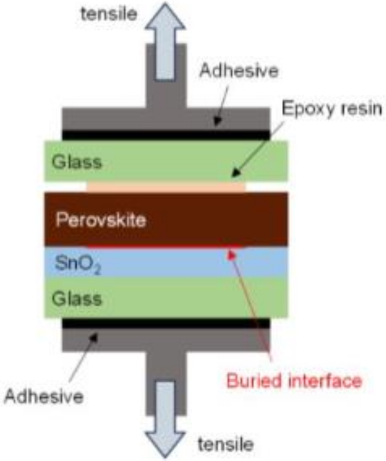
J. Kim* et al., Chem. Eng. J., 2025, 519, 164991

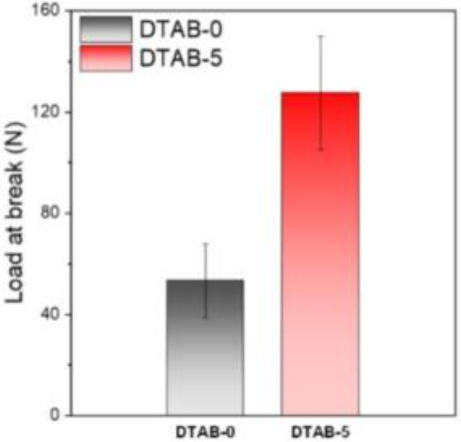
II. Research - Solution

Gyeong G. Jeon

Perovskite film characterisation (Adhesion)





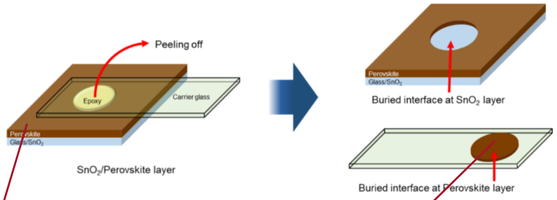


J. Kim* et al., Chem. Eng. J., 2025, 519, 164991

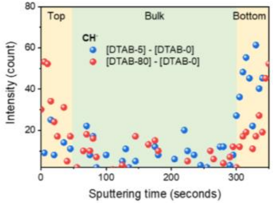
II. Research - Solution

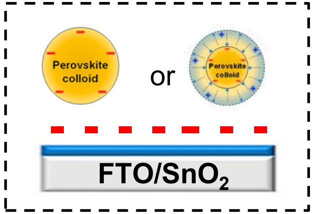
Perovskite film characterisation

Gyeong G. Jeon

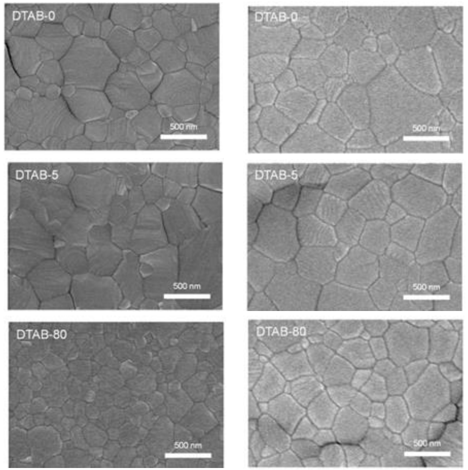


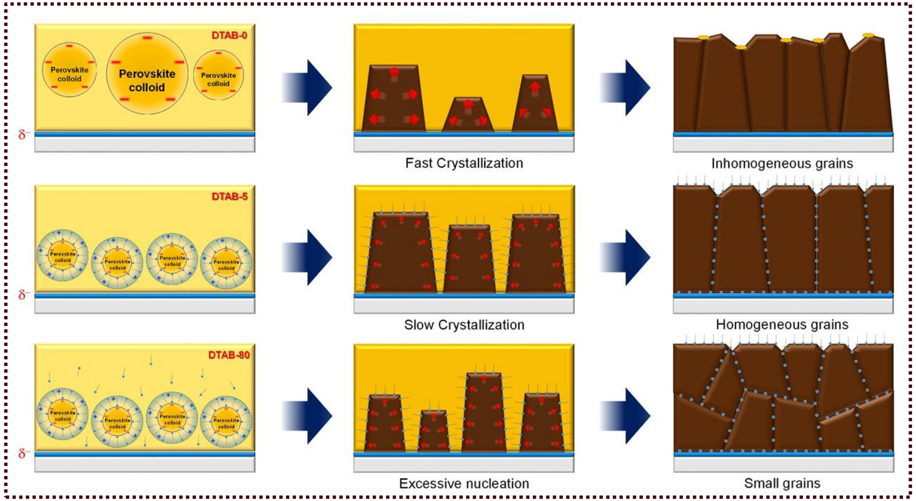
ToF-SIMS



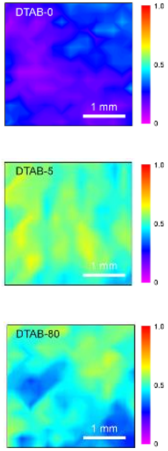


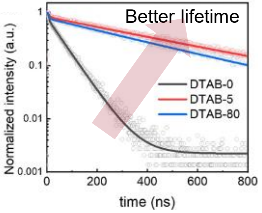
Top **Buried**

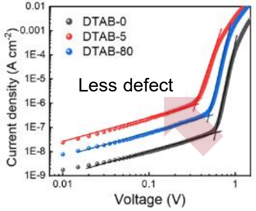




PL mapping





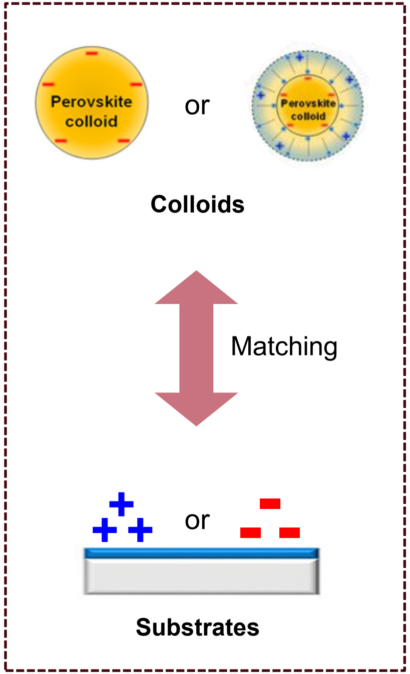


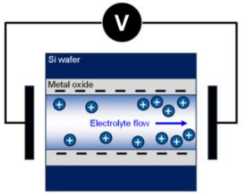
J. Kim* et al., Chem. Eng. J., 2025, 519, 164991

II. Research - Solution

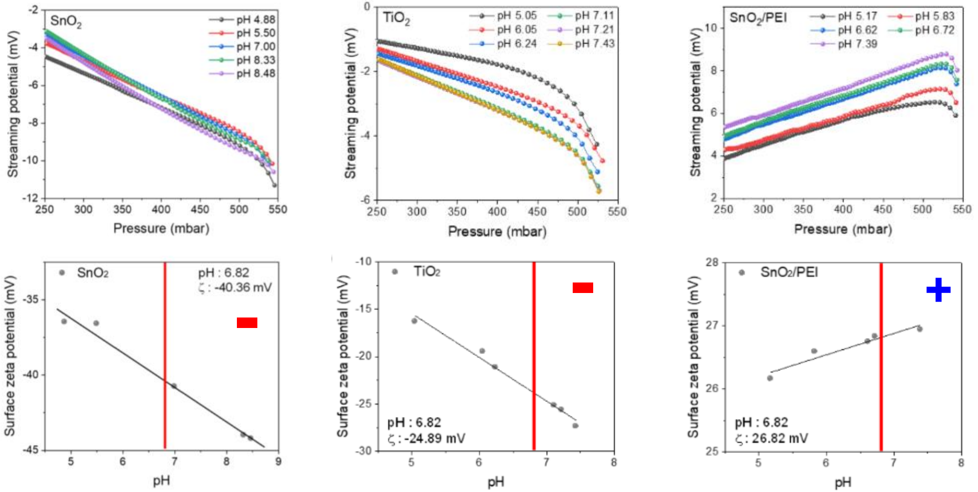
Gyeong G. Jeon

Substrate charges





Surface zeta potential
(Substrate surface charge)

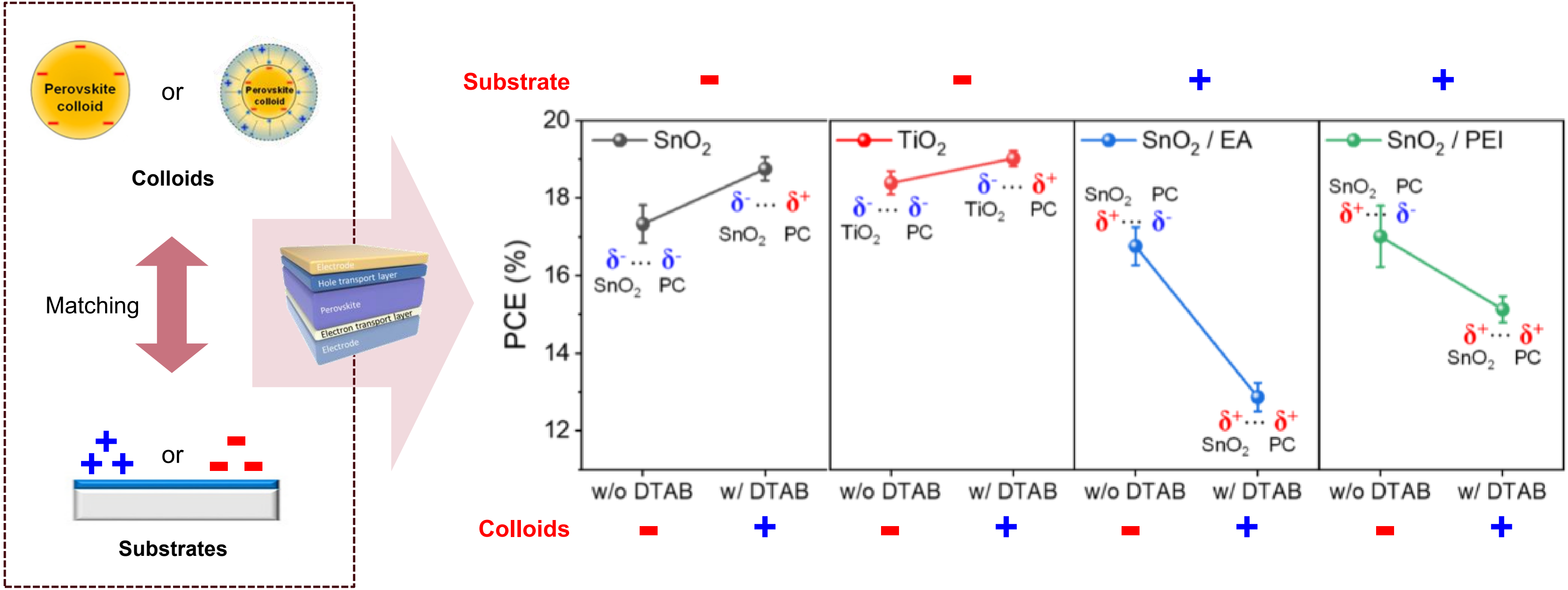


J. Kim* et al., Chem. Eng. J., 2025, 519, 164991

II. Research - Solution

Photovoltaic performance

Gyeong G. Jeon



J. Kim* et al., Chem. Eng. J., 2025, 519, 164991

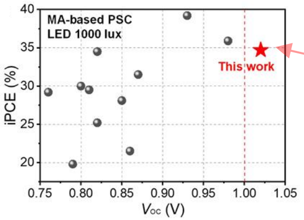
II. Research - Solution

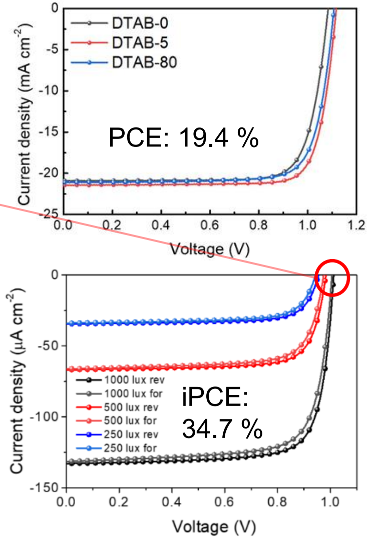
Photovoltaic performance

Gyeong G. Jeon

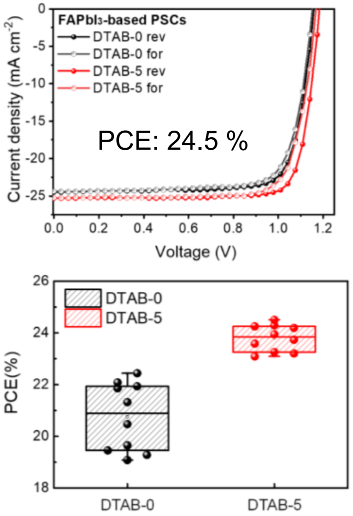
MACQUARIE University
SYDNEY · AUSTRALIA

$MAPbI_3$

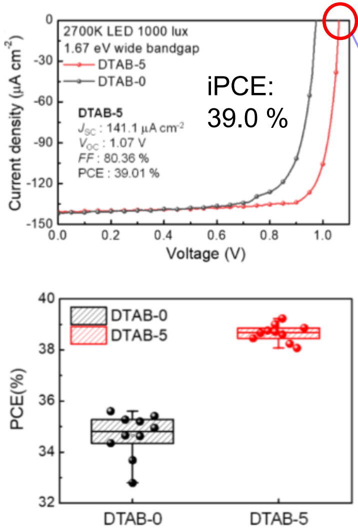


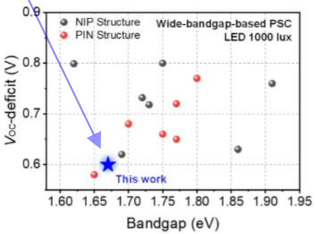


$FAPbI_3$



Wide Bandgap (1.67 eV)





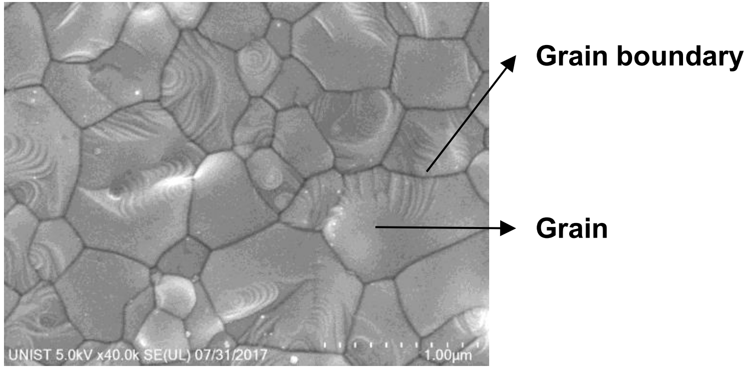
Controlling and matching colloidal charges is important

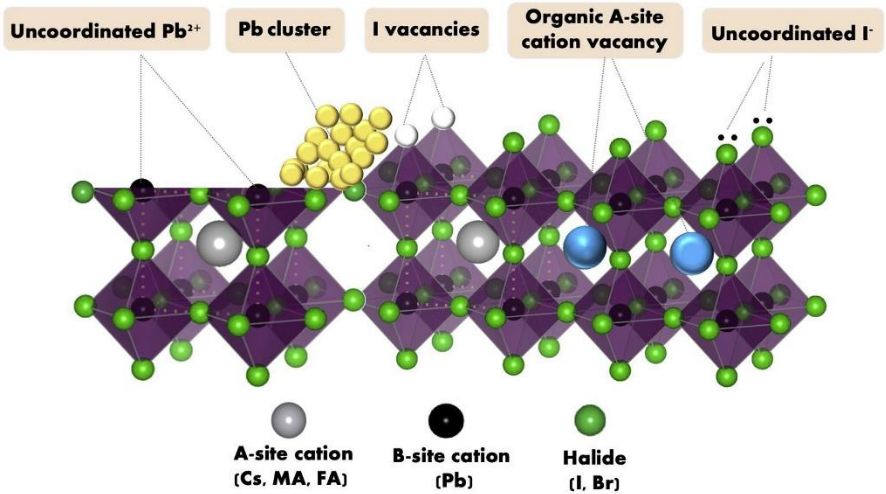
J. Kim* et al., Chem. Eng. J., 2025, 519, 164991

II. Research - Film

II. Research - Film

Organic-Inorganic Perovskite Films





Defects (perovskite) $10^{15} \sim 10^{18}$ cm^{-3}

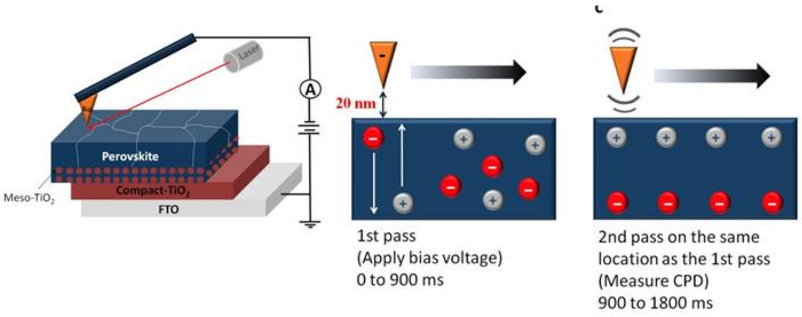
Power conversion efficiency > 27%

(Thanks to **defect tolerance**)

H. Lu et al. iScience 2020, 23, 8, 101359

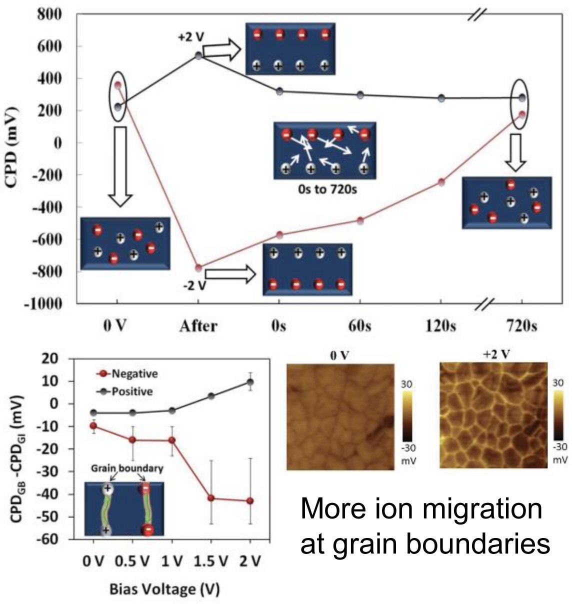
II. Research - Film

Kelvin probe force microscopy – voltage and light bias



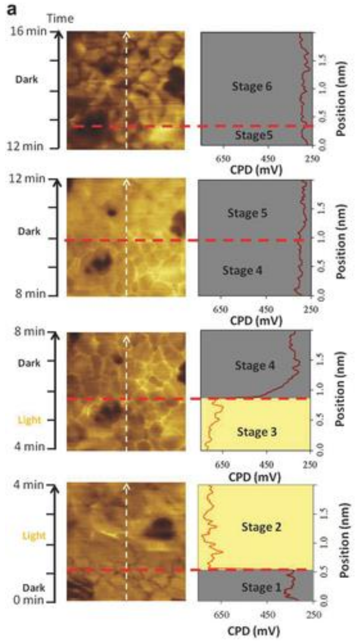
Kelvin probe force microscopy (KPFM)

Bias-response



More ion migration at grain boundaries

Light-response



J. Yun et al., Adv. Ener. Mater. 2016, 6, 13, 1600330

II. Research - Film

Kelvin probe force microscopy – perovskite degradation study

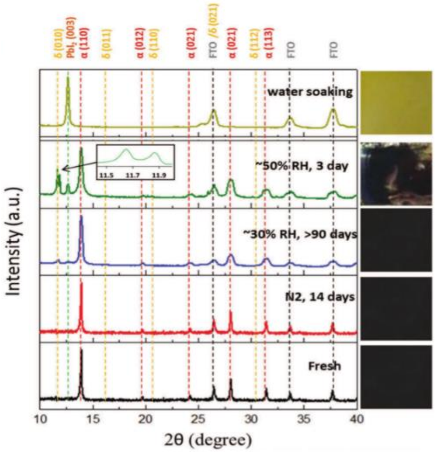
FULL PAPER

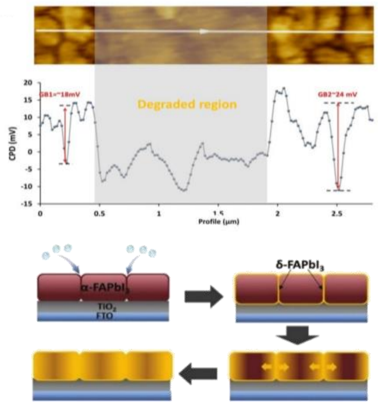
Perovskite Solar Cells

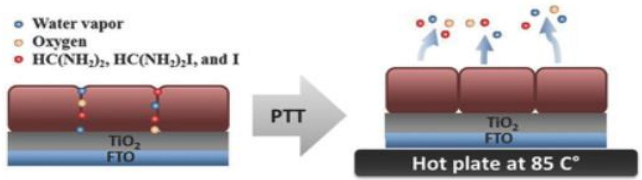
ADVANCED FUNCTIONAL MATERIALS
www.afm-journal.de

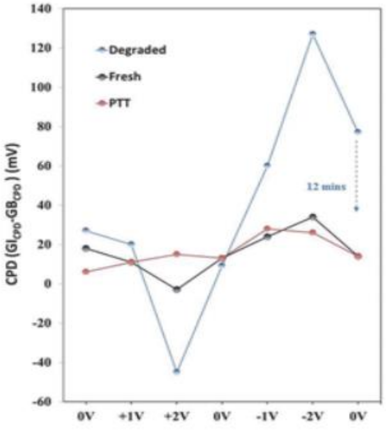
Humidity-Induced Degradation via Grain Boundaries of $HC(NH_2)_2PbI_3$ Planar Perovskite Solar Cells

Jae Sung Yun, Jincheol Kim, Trevor Young, Robert J. Patterson, Dohyung Kim, Jan Seidel, Sean Lim, Martin A. Green, Shujuan Huang, and Anita Ho-Baillie**

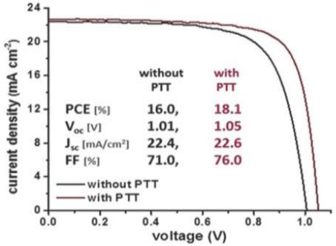


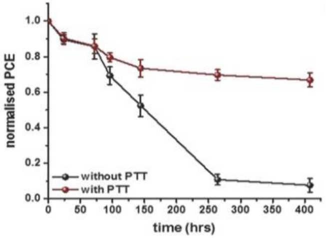






PTT reduced mobile ions at the grain boundaries





J. Yun[ǂ], J. Kim[ǂ] et al., Adv. Func. Mater. 2018, 28, 11, 1705363

II. Research - Film

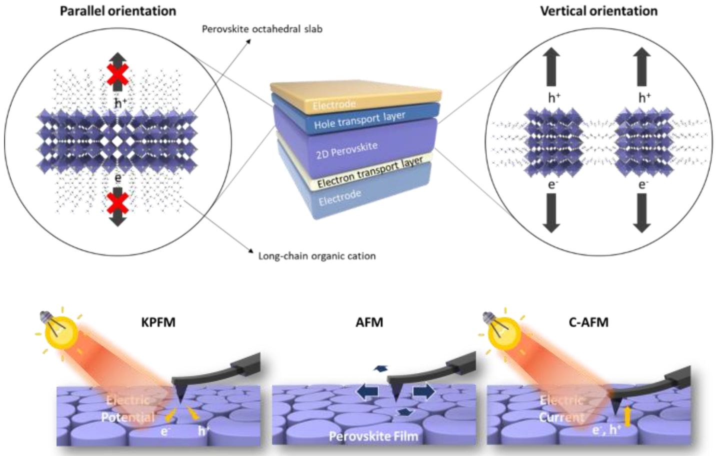
Nanoscale characterisation – 2D perovskite

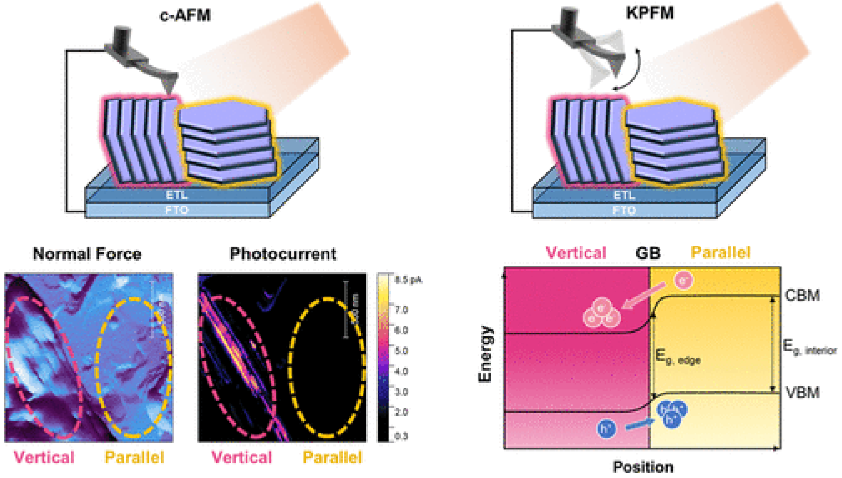
Hongjae Shim

Probing Nanoscale Charge Transport Mechanisms in Quasi-2D Halide Perovskites for Photovoltaic Applications

Hongjae Shim, Abhinav S. Sharma, Rishabh Mishra, Jonghoon Han, Jihoo Lim, Dawei Zhang, Zhi Li Teh, Jongsung Park, Jan Seidel, Michael P. Nielsen, Martin A. Green, Shujuan Huang,* Jae Sung Yun,* and Jincheol Kim*

ACS NANO



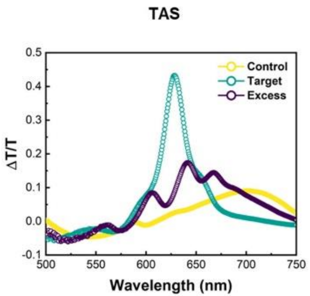


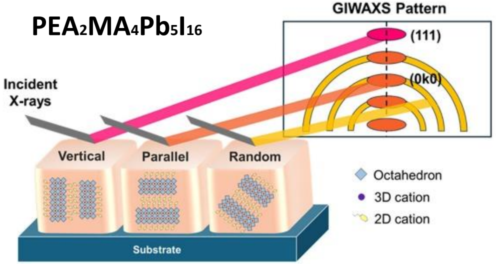
J. Kim* et al., ACS Nano 2024, 18, 45, 31002–31013

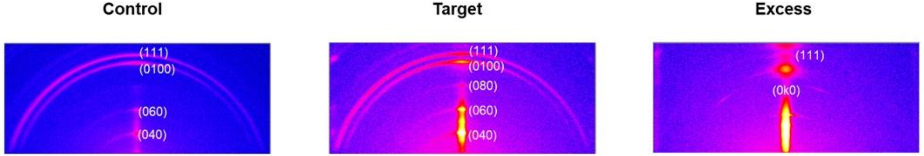
II. Research - Film

Nanoscale characterisation – 2D perovskite

Hongjae Shim

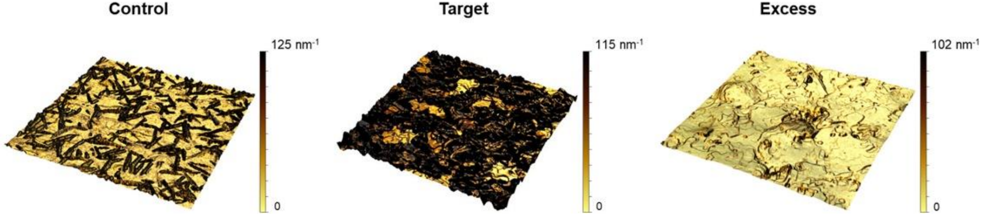






Parallel & Vertical Crystal Detection

(*MACl concentration affects the orientation)



Topography overlaid with local slope maps

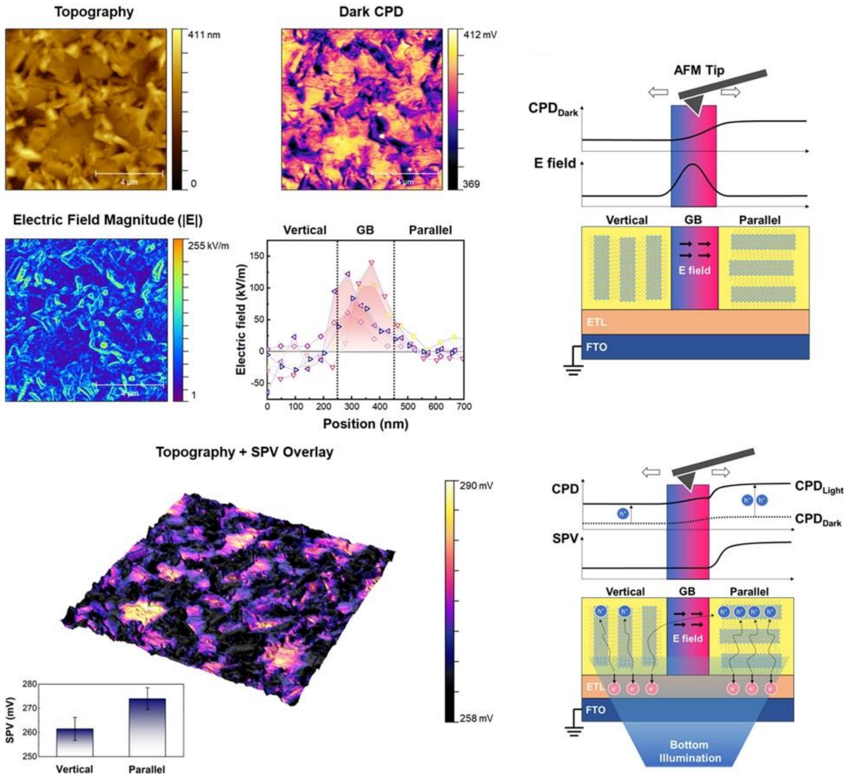
(bright: parallel grains, dark: vertical grains)

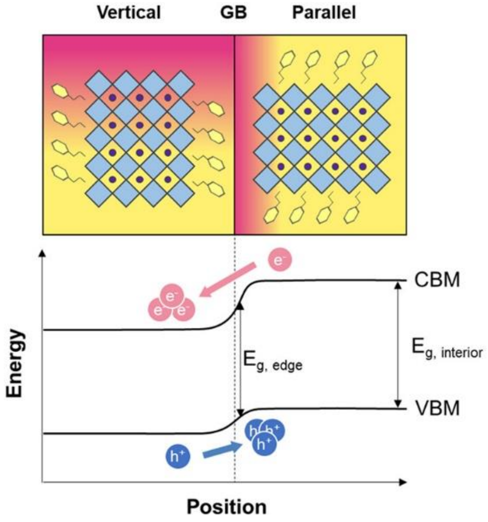
J. Kim* et al., ACS Nano 2024, 18, 45, 31002–31013

II. Research - Film

Nanoscale characterisation – 2D perovskite

Hongjae Shim





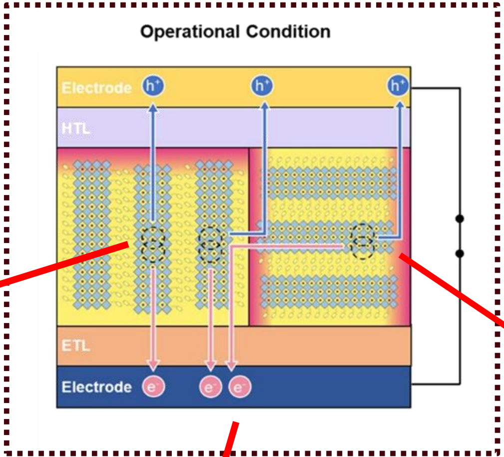
Carrier movement
@interface between vertical and parallel

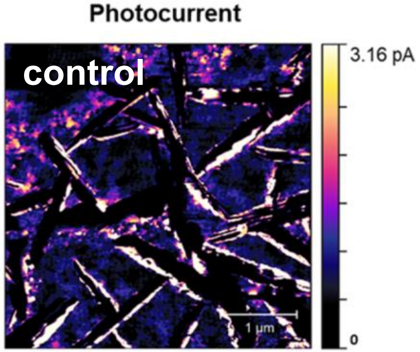
J. Kim* et al., ACS Nano 2024, 18, 45, 31002–31013

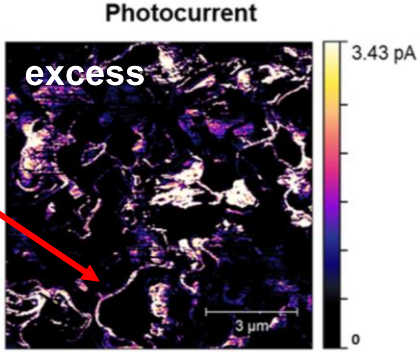
II. Research - Film

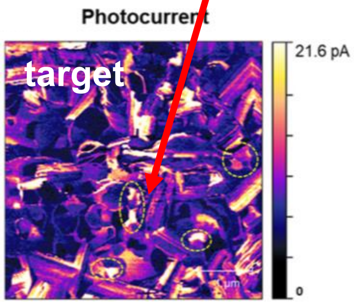
Nanoscale characterisation – 2D perovskite

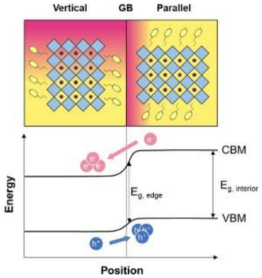
Hongjae Shim











J. Kim* et al., ACS Nano 2024, 18, 45, 31002–31013

II. Research - Film

REVIEW

ADVANCED MATERIALS
www.advmat.de

Scanning Probe Microscopy of Halide Perovskite Solar Cells

Minwoo Lee, Lei Wang, Dawei Zhang, Jiangyu Li, Jincheol Kim, Jae Sung Yun,* and Jan Seidel**

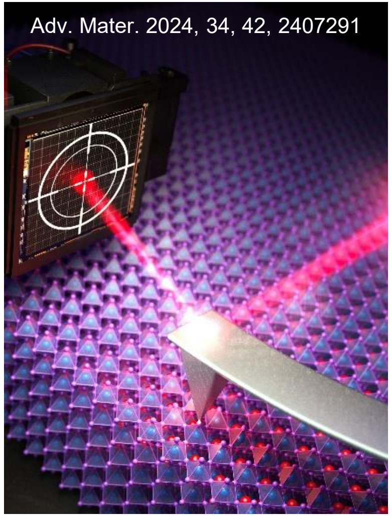


Table 1. Summary of SPM techniques for halide perovskite materials.

Techniques	Properties	Merits	Limitations	Uses in perovskite
AFM[a]	Topography	• Conductive substrate not required	• Both sample and tip subjected to lateral forces	• Morphology (grain size, facet) • Roughness (degradation)
c-AFM[b]	Topography Conductivity	• Examines topography and electronic properties • No interference between topography and electronic structure due to separate detection systems	• Conductive substrate required • Contact mode, can damage delicate and soft surfaces	• *I–V* curve (local hysteresis, photovoltaic characteristics) • Charge transport (transport layer properties) • Conductivity (charge and ionic conductivity)
PFM[c]	Topography Piezoresponse	• Scans topography and piezoresponse • Examines ferroelectric domains	• Contact mode, can damage delicate and soft surfaces	• Piezoelectric property (ionic motion) • Ferroelectric property (dipole induced charge transport) • Ferroelastic property (local strain)
KPFM[d]	Topography Surface potential	• Measures contact potential difference (CPD) between the tip and sample	• Conductive substrate required • Difficult to determine absolute Fermi level (EF) value without internal calibration	• •Local surface potential (Ion migration, external stimuli) • Work function and the evolution of surface photovoltage under illumination (open-circuit potential mapping, transport layer properties) Cross-sectional KPFM (interfacial charge transport)
s-SNOM[e]	Topography Surface chemistry	• Provides nanometer-scale spatially resolved absorption, reflection, and optical spectra including FTIR[f], Raman, pump-probe, photoluminescence, and THz spectroscopy.	• Complicated and delicate measurement setup • Requires accurate laser alignment	• Chemical nano-scale spatial mapping (Degradation, local chemical heterogeneity) • Charge dynamics (local recombination, degradation)
STM[g]	Atomic surface structure	• Highest resolution (<10 pm)	• Requires conductive surfaces • challenging sample preparation (e.g., Ultrasmooth surface)	• Analyzing surface defects and structural inhomogeneity • Observing atomic structure of the surface
STS[h]	local density of electronic states	• Provides atomic-level local electronic property information	• Low signal-to-noise ratio • Sensitive to environmental conditions • Requires conductive surfaces and ultrasmooth surface	• Analyzing electronic properties • Determining energy level distribution

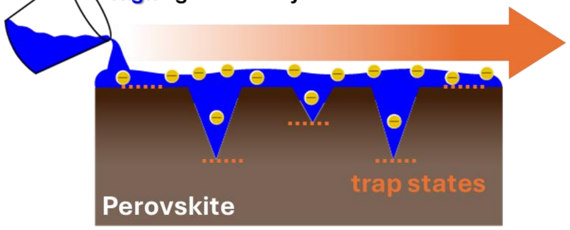
[a] AFM: Atomic Force Microscopy; [b] c-AFM: Conductive Atomic Force Microscopy; [c] KPFM: Kelvin probe force microscopy; [d] PFM: piezoresponse force microscopy; [e] s-SNOM: scattering scanning near-field optical microscopy; [f] FTIR: Fourier Transform Infrared Spectroscopy; [g] STM: Scanning Tunneling Microscopy; [h] STS: Scanning Tunneling Spectroscopy

II. Research - Cell/Module

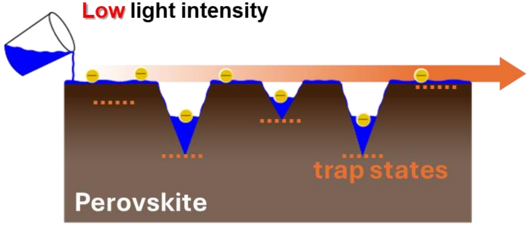
II. Research – Cell/Module

Scheme of charge trapping kinetics

High light intensity



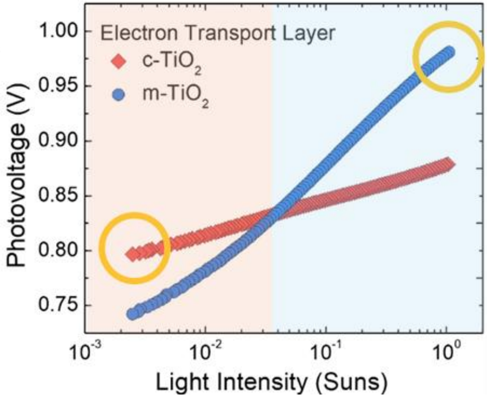
Low light intensity

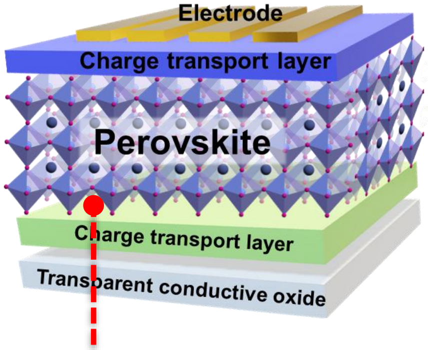


c-TiO_2 : low defect density

m-TiO_2 : photodoping
& favorable band bending
But high interface traps

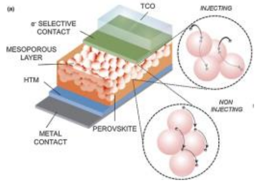
Indoor ⟷ Outdoor



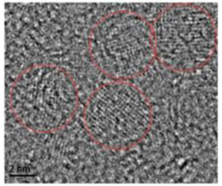


Interfacial engineering (perovskite/ETL)

Al_2O_3 nanoparticle



Graphene Quantum Dot



High performance in Outdoor ≠ Indoor
Controlling Interface trap is most important under indoor conditions

J. Kim et al., Nano Energy 68 (2020) 104321

II. Research – Cell/Module

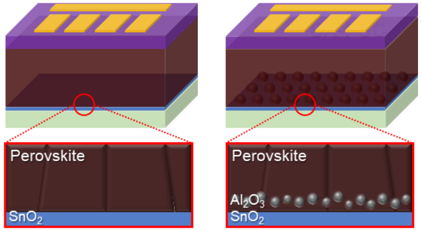
Gyeong G. Jeon

Interface Engineering for Leakage Suppression and Module Stability

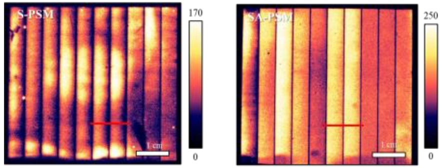
EcoMat WILEY

Mitigation of parasitic leakage current in indoor perovskite photovoltaic modules using porous alumina interlayer

Gyeong G. Jeon[1] | Da Seul Lee[2,3,4] | Min Jun Choi[1] | You-Hyun Seo[4] | Shujuan Huang[5] | Jong H. Kim[1] | Seong Sik Shin[2,3,6,7] | Jincheol Kim[5]

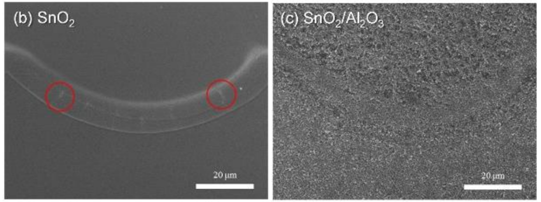


S-PSC SA-PSC



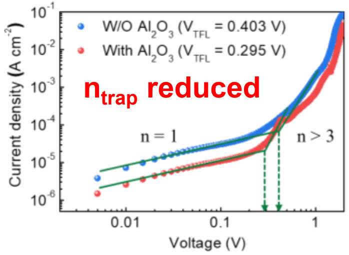
Damage from laser ablation

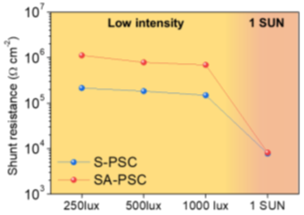
Preventing laser damage

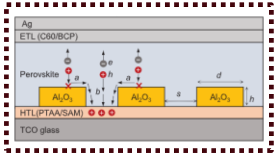


Reduced shunt path

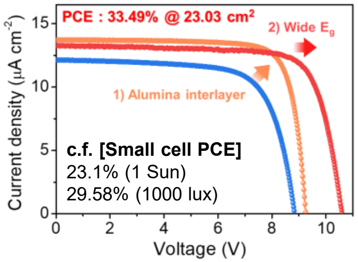
Defect passivation

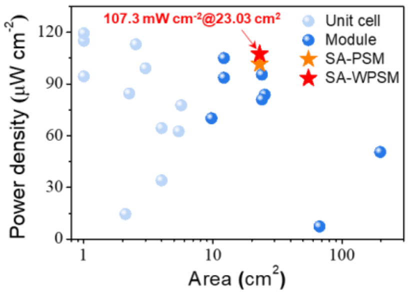






Reduced defect





J. Kim* et al., EcoMat. 2024, 6, 6, e12455

II. Research – Cell/Module

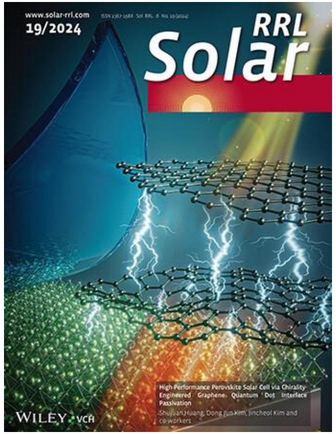
Jonghoon Han

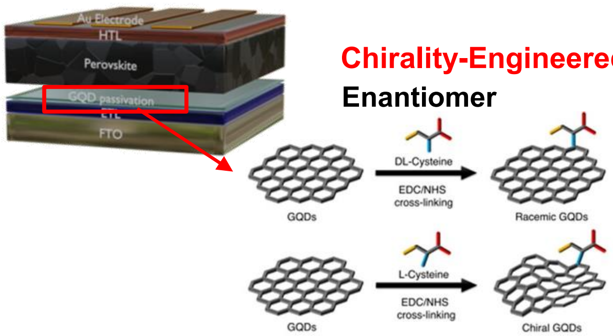
Interface Engineering with Strain-Induced Electric Field

High-Performance Perovskite Solar Cell via Chirality-Engineered Graphene Quantum Dot Interface Passivation

Solar RRL

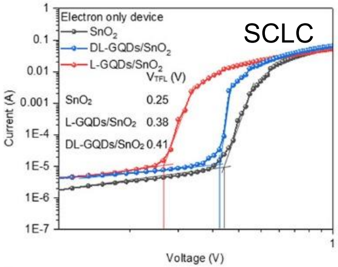
Jonghoon Han, Xinchen Dai, Sandhuli Hettiarachchi, Zhi Li The, Sangwook Park, Sam Chen, Binesh Puthen Veettil, Shujuan Huang, Dong Jun Kim,* and Jincheol Kim**

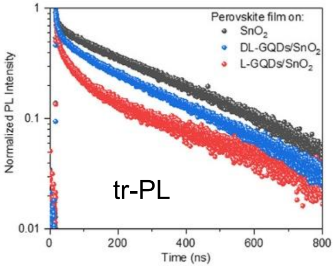


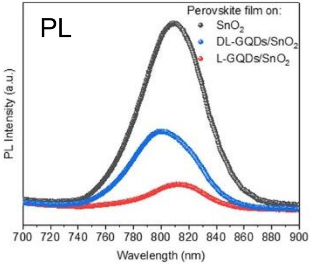


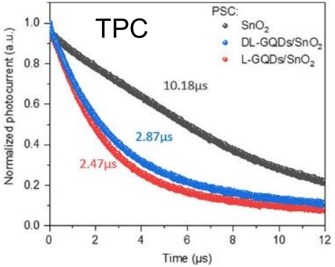
Chirality-Engineered
Enantiomer

Twisted GQD
Strain-induced intrinsic *electric field*
(Out-of-plane direction)



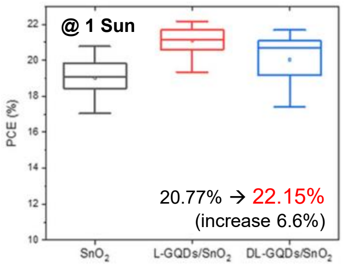




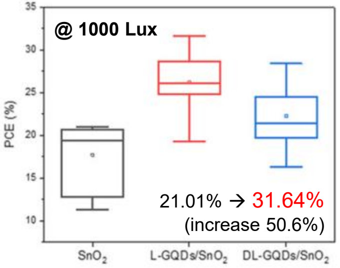


Enhanced charge extraction

Less defects



20.77% → 22.15%
(increase 6.6%)



21.01% → 31.64%
(increase 50.6%)

J. Kim* et al., Solar RRL. 2024, 8, 2400367

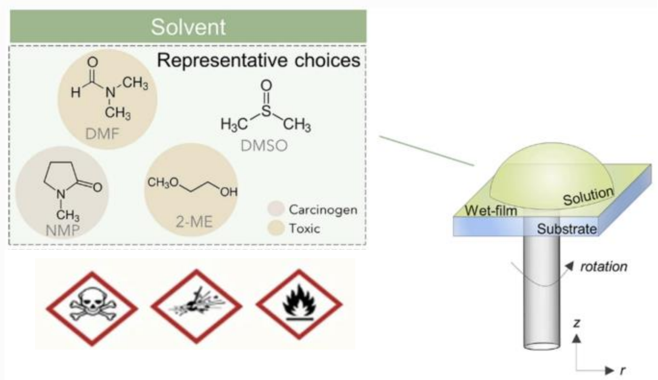
II. Research – Cell/Module

Green manufacturing

Jonghoon Han

MACQUARIE University SYDNEY·AUSTRALIA

Toxic perovskite solution



Usage of eco-friendly solvent
with sustainable fabrication processes

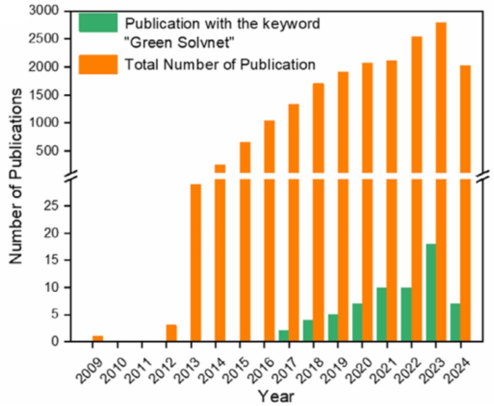
Kwon et al., Nano Convergence 2023, 10, 28

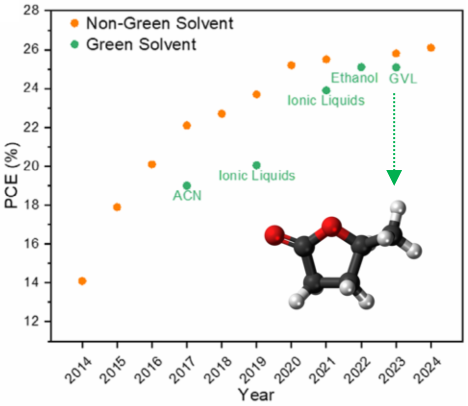
Green Solution Processing of Halide Perovskite Solar Cells: Status and Future Directions

Solar RRL

Review

Jonghoon Han, Ran Hee Kim, Shujuan Huang, Jincheol Kim, and Jae Sung Yun**





Green solvent candidate
Dimethyl sulfoxide (DMSO), Acetonitile (ACN), Ethanol, Water, Ionic liquid, γ-Valerolactone (GVL), Triethyl Phosphate, Dihydrolevoglucosenone, …

J. Kim* et al., Solar RRL. 2024, 2400262

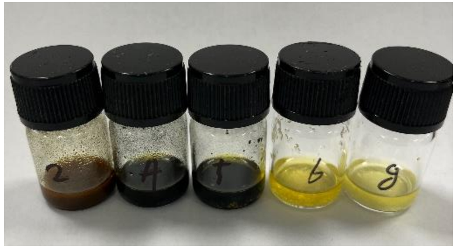
II. Research – Cell/Module

Jonghoon Han   Wonseok chae

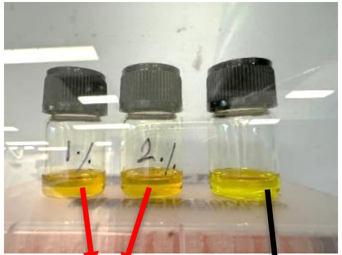
Green manufacturing

100% Green perovskite ink development

Challenge: Low Solubility

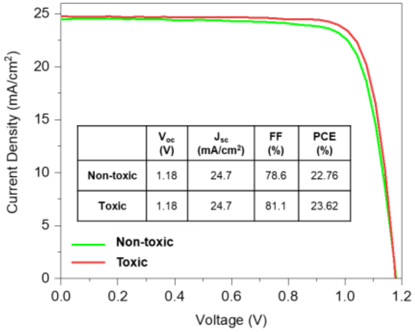


Solution design (additives, solvent mixture)



Non-toxic Ink

Toxic Ink (DMF/DMSO-base)

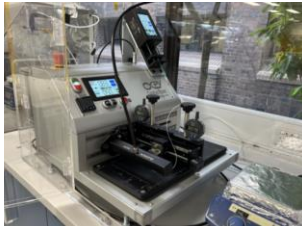


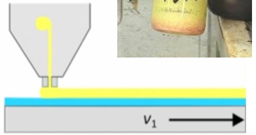
	V_{oc} (V)	J_{sc} (mA/cm²)	FF (%)	PCE (%)
Non-toxic	1.18	24.7	78.6	22.76
Toxic	1.18	24.7	81.1	23.62

In preparation

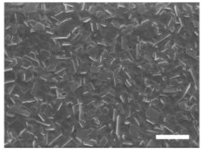
100% Green perovskite module fabrication

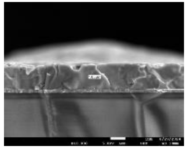
Challenge: large-area film/device fabrication

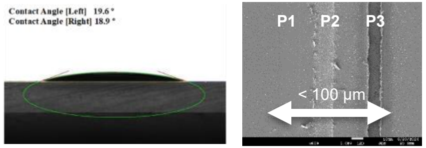


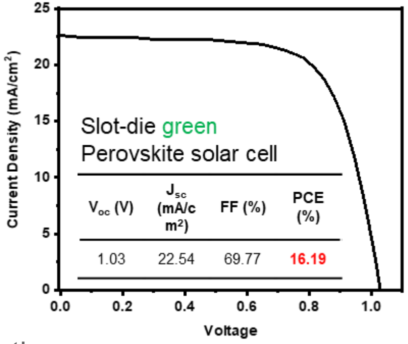


Air knife technic, solution optimisation









V_{oc} (V)	J_{sc} (mA/cm²)	FF (%)	PCE (%)
1.03	22.54	69.77	16.19

In preparation

III. Summary

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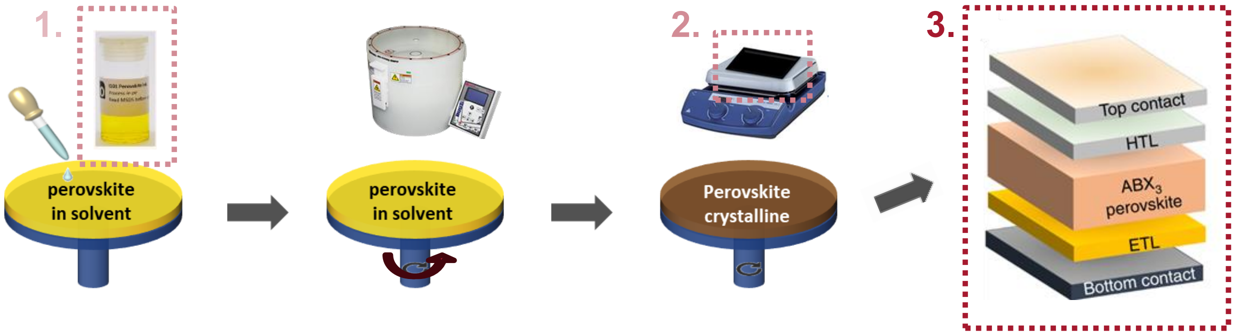
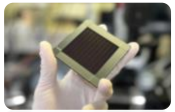
High-performance and scalable green manufacturing (From nano to real)





Target

High-performance

Manufacturability

- Scaling up

- Green (non-toxic)

1. Solution

- **Perovskite precursor control**
  - Colloidal solution properties (e.g., iodoplumbates)
  - Total internal reflection fluorescence microscopy (colloid imaging)
  - Surfactants modify colloidal charges, influencing film quality
  - Charge matching is important

2. Film

- **AFM-based analysis**
  - light and bias responses reveal ion migration
  - CPD variations explain properties (e.g., delta-phase, degradation mechanisms)
  - Carrier dynamics analysed in vertical and parallel planes of 2D perovskites

feedback

3. Cell/Module Fabrication

- **Interface Engineering**
  - Al_2O_3 mesoporous layer passivates defects and prevents laser damage (P1, P2, P3).
  - Chiral GQD engineering creates a twisted graphene structure, generating intrinsic electric fields and enhancing charge extraction.
- **Green perovskite module manufacturing**
  - Green solvents face solubility and scaling challenges.
  - GVL is a promising green fabrication solvent

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KIAT

Thank you

FOR YOUR ATTENTION

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