부산대학교

Advanced Nano Energy Device Laboratory

나노 에너지 소자 연구실

Min-cheol Kim, Ph.D. (김민철)

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School of Mechanical Engineering
Pusan National University

ANED Lab.
Advanced Nano Energy Device Laboratory

Principal Investigator

김민철 (Kim Min-cheol, Ph.D.)

기계관 Rm 514 (Tel: 2315)

▪ Education & Research Experience

Seoul National University (B.S. 2009 – 2013, Ph.D. 2013 – 2018)

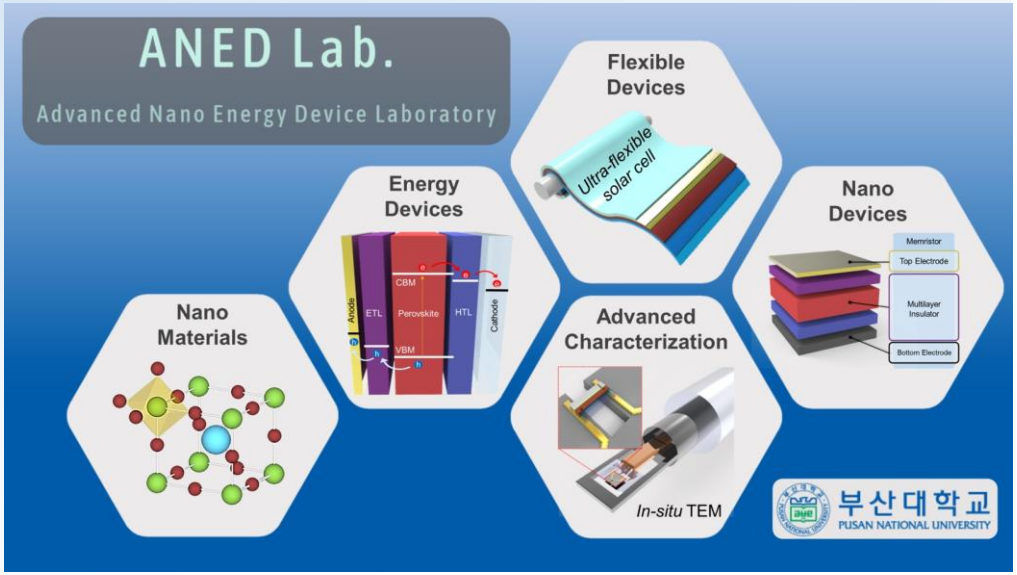
University of California, San Diego (Postdoc 2019 – 2021)

Samsung Electronics (Memory) (Senior researcher 2021.3 – 2021.8)

Pusan National University (Assistant Professor 2021.9 –)

▪ Research overview

- **Renewable Energy Devices**
  Development of energy conversion and storage devices including perovskite solar cells and lithium ion batteries
- **Flexible Nano Devices**
  Development of ultra-flexible electronic devices and investigation on the mechanical degradation mechanism of flexible nano devices
- **Advanced Nano Characterization**
  Study on the physical electronic properties of nano materials *via* advanced characterization tools such as an atomic resolution TEM



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- **Research Summary (22 SCI papers (10 first-authored, average IF = 16.122))**

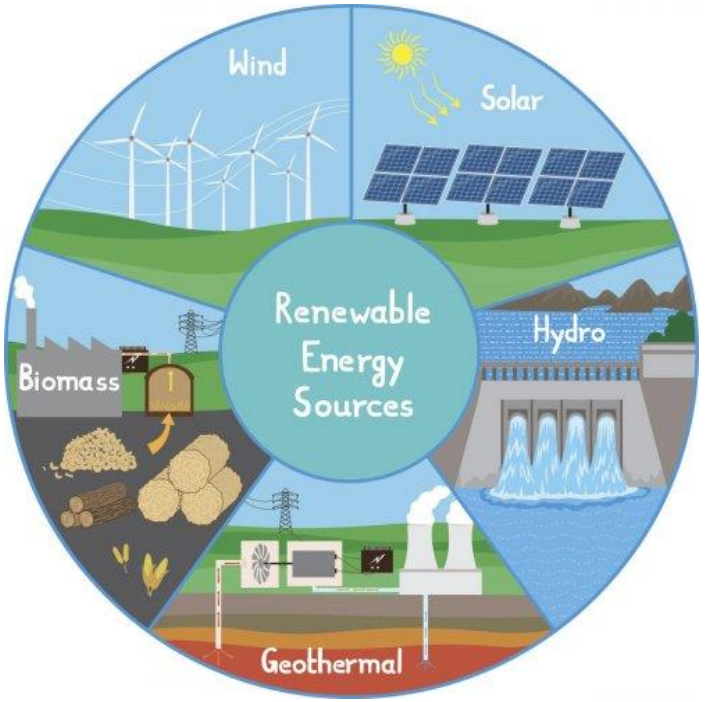
Representative 5 Publications (Recent 3 years)

1. Ultra-flexible perovskite solar cells with crumpling durability: toward a wearable power source
Energy & Environmental Science (2019) (IF: 38.532, JCR <1%)
2. Advanced characterization techniques for overcoming challenges of perovskite solar cell materials
Advanced Energy Materials (2020) (IF: 29.368, JCR <3%)
3. Imaging real-time amorphization of hybrid perovskite solar cells under electrical biasing
ACS Energy Letters (2021) (IF: 23.101, JCR <5%)
4. Moth-eye structured polydimethylsiloxane films for high-efficiency perovskite solar cells
Nano-Micro Lett. (2019) (IF: 16.419, JCR <10%)
5. Degradation of CH 3 NH 3 PbI 3 perovskite materials by localized charges and its polarity dependency
Journal of Mater. Chem. A (2019) (IF: 12.732, JCR <10%)

Introduction : Motivation

Depletion of Fossil Fuel Air Pollution Global Warming

Green vehicles (EV / FCEV)



Future Electronic Devices

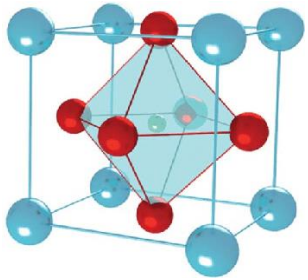
- High energy density (Requires high power)
- Portability (Light-weight)
- Flexible and stretchable
- Human-centered (Health application)

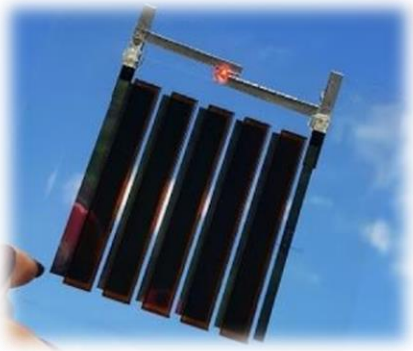
Credit: Aptera

Credit: savvycomsoftware

Credit: DuPont

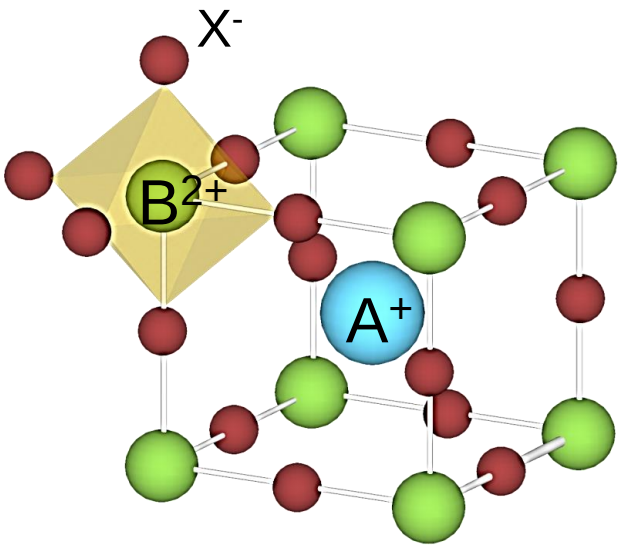
Perovskite Solar Cells





Credit: RSC Advances / Saule Technologies

Introduction : *Perovskite solar cells*



ABX_3

A^+=Organic Cation

B^{2+}=Pb^{2+}, Sn^{2+}

X^-= I^-, Br^-, Cl^-

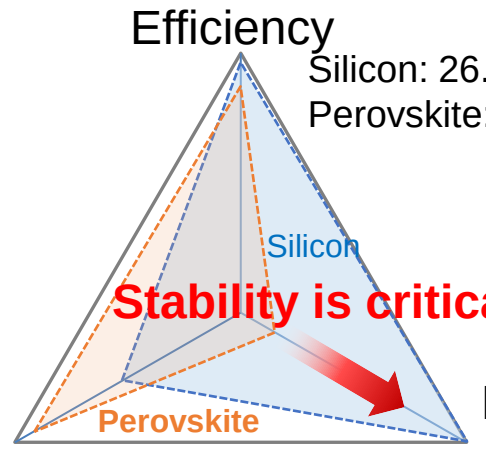
- ✓ High absorption
- ✓ Low binding energy

25.5%
High performance

- ✓ Ionic bonding
- ✓ Soft and polarizable

Low stability
& High flexibility

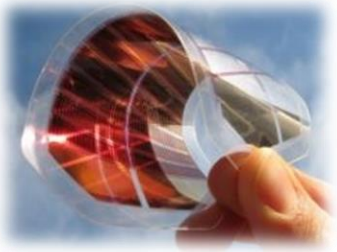
Golden triangle analysis



Silicon: 0.70 $/Watt
Perovskite: 0.35 $/Watt

Silicon> 27 years
Perovskite: 0.3 year

Flexible / Light-weight Devices



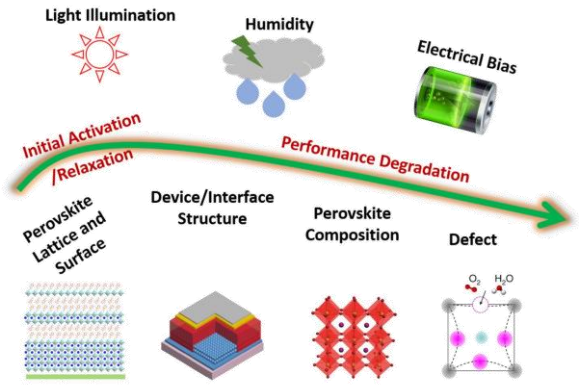
Ultra-flexibility
Credit: NREL

Portability
Credit: Lightyear

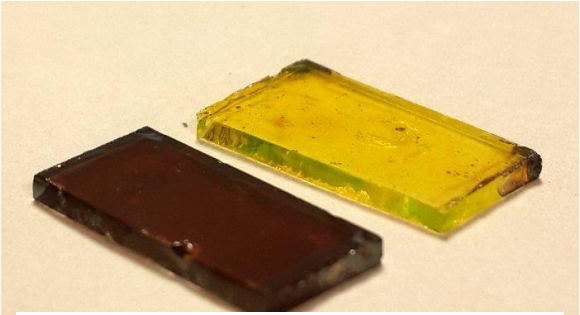
Introduction : *Perovskite solar cells*

3 main issues in Perovskite solar cells

Stability Issues



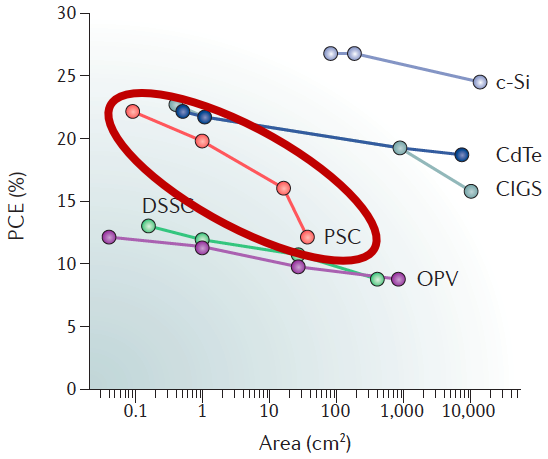
Credit: ©Science China Press
https://www.eurekalert.org/multimedia/pub/198000.php



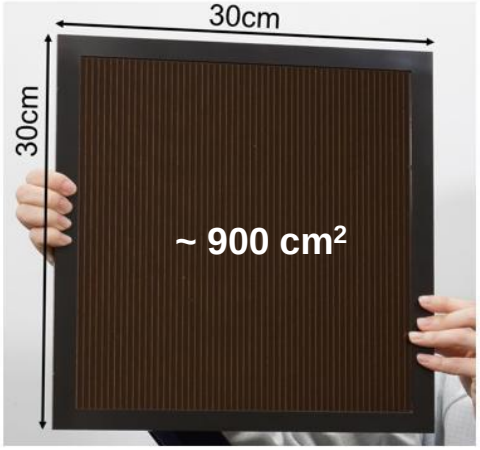
A fresh perovskite solar film (L) and a degraded film exposed to air and light for just six days (R)

https://www.imperial.ac.uk/news/165809/scientists-discover-next-gen-solar-cells-break/

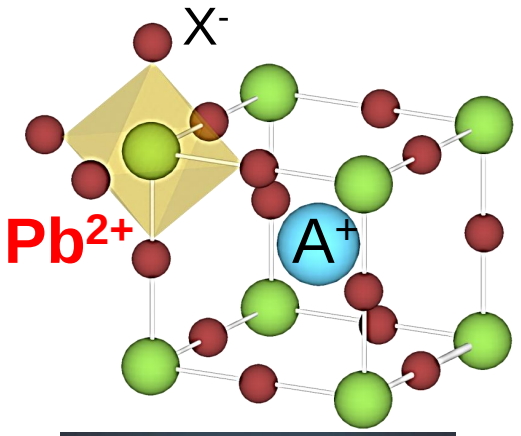
Scalability Issues

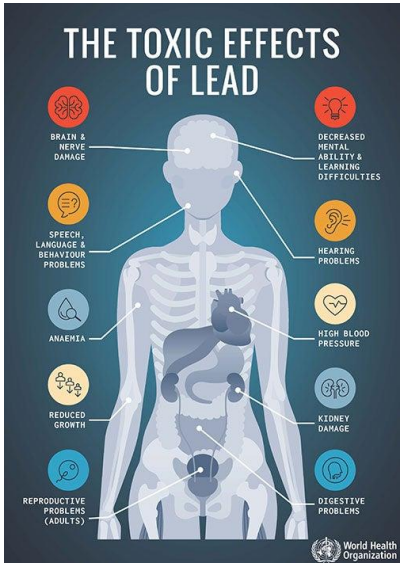


Nature Reviews Materials volume 3, Article number: 18017 (2018)



Environmental Issues

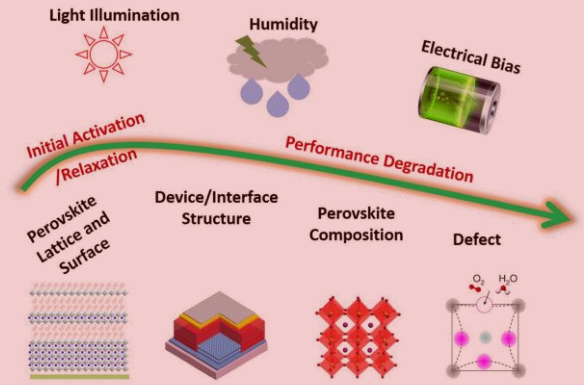




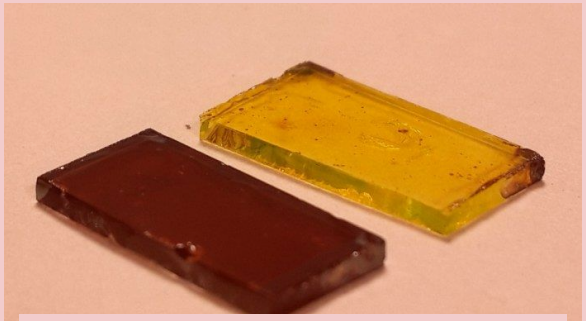
Introduction : *Perovskite solar cells*

3 main issues in Perovskite solar cells

Stability Issues



Credit: ©Science China Press
https://www.eurekalert.org/multimedia/pub/198000.php



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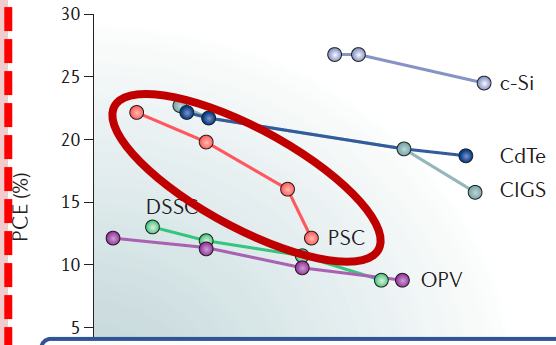

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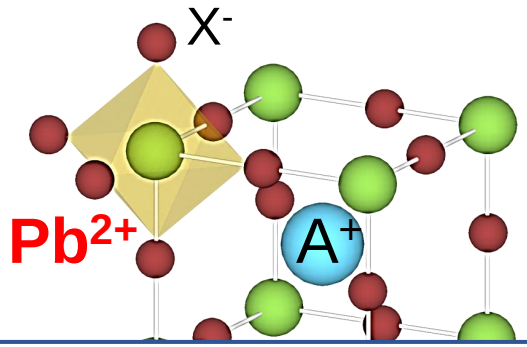


Long-term Stability
Ultra-flexible Devices

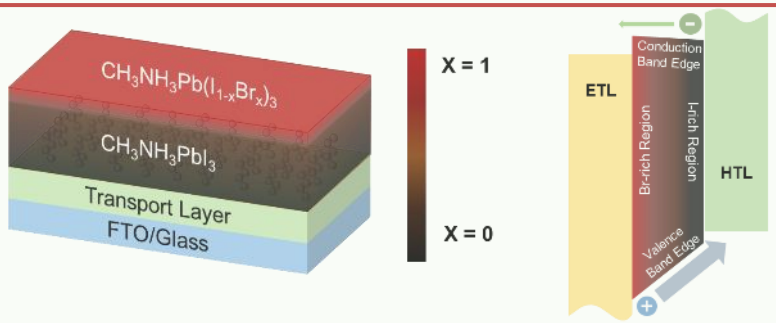
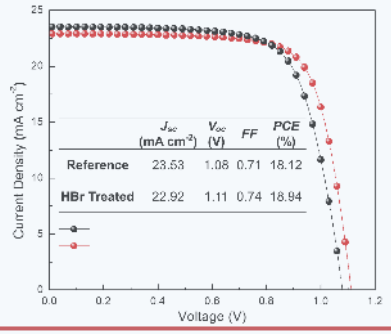
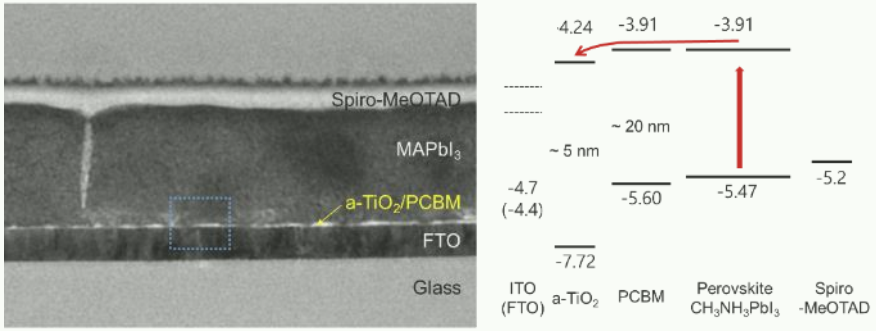
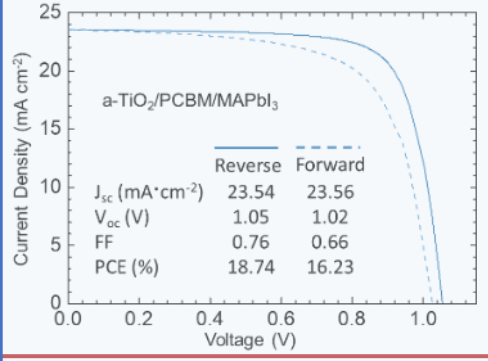
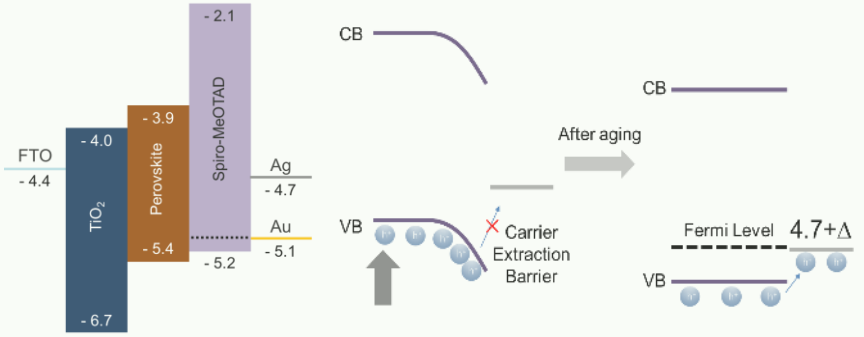
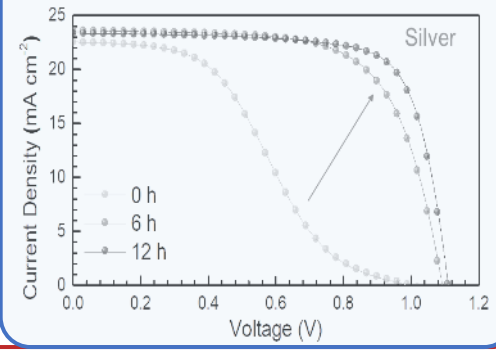
1. Material Stability
- Chemical stability
- Structural stability

2. Mechanical Stability

Research Summary: 1. High Efficient Perovskite solar cells

Nano Letters (2016) (First Author)
Advanced Materials Interfaces (2018) (First Author)
ACS Applied Materials & Interfaces (2019) (First Author)

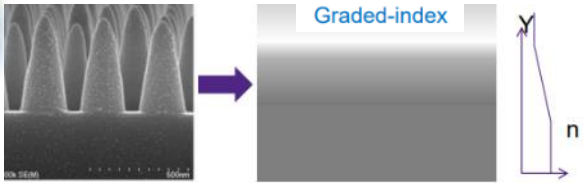
1) Interfacial Engineering for performance enhancement

	Interfacial Engineering (Active / Transport Layer)	Performance Enhancement
Nano Letters (2016) *Hole extraction enhancement via energy level gradient*		
Advanced Materials Interfaces (2018) *Electron extraction enhancement via energy level alignment*		
ACS Applied Materials & Interfaces (2019) *Investigation at interfaces between solar cell & metal electrode*		

Research Summary: 1. High Efficient Perovskite solar cells

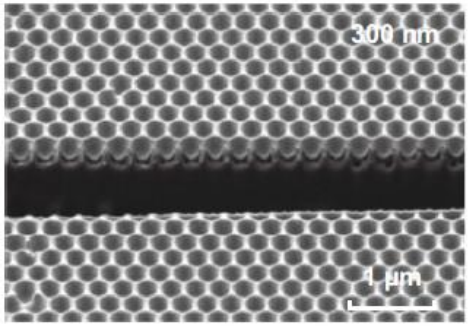
2) Bio-inspired Optical Film for Solar Cells

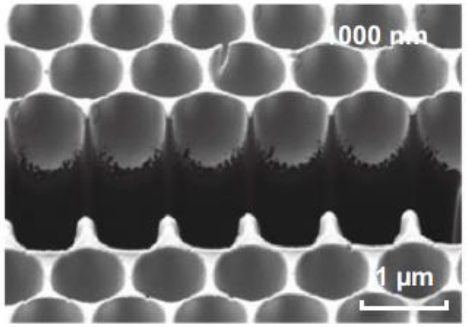
Nano-Micro Lett. (2019) (First Author)

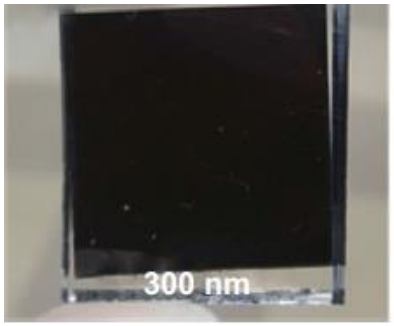


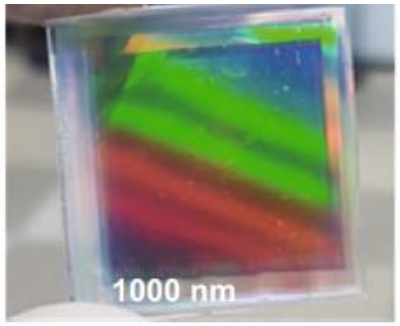
√ 300 nm Moth-eye → Enhancing light transmittance

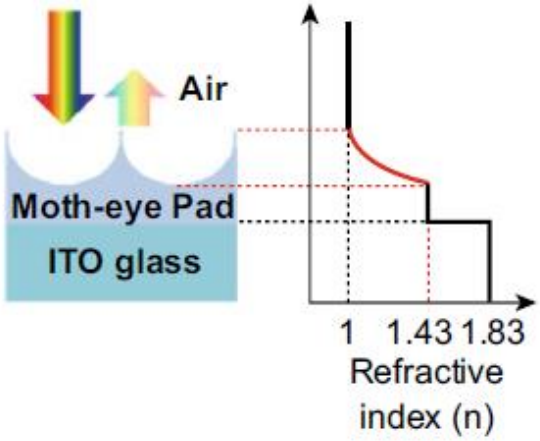
√ 1000 nm Moth-eye → Beautiful coloration due to diffraction grating effect

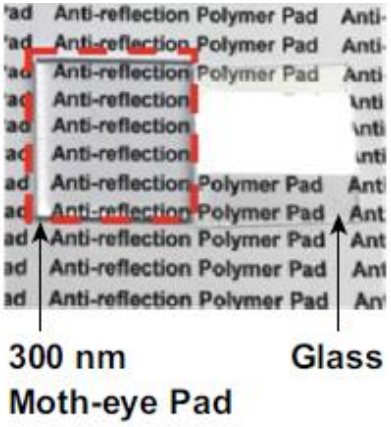


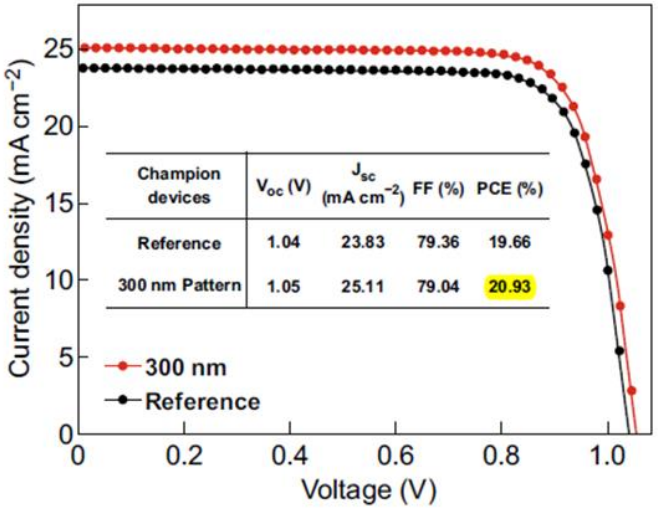












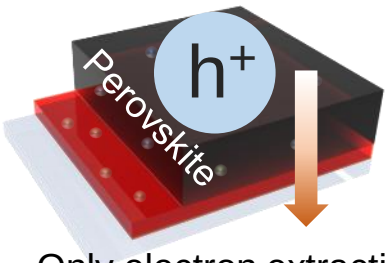
Research Summary: 2. Stability of Perovskite solar cells

1) Chemical instability of perovskite materials

J. Mater. Chem. A (2019) (First Author)

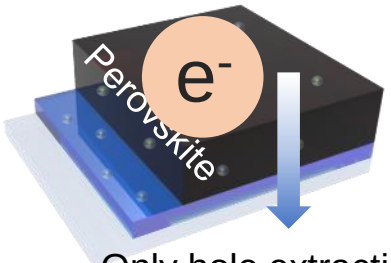
Attainment of carrier asymmetry

Hole Dominant



Only electron extraction

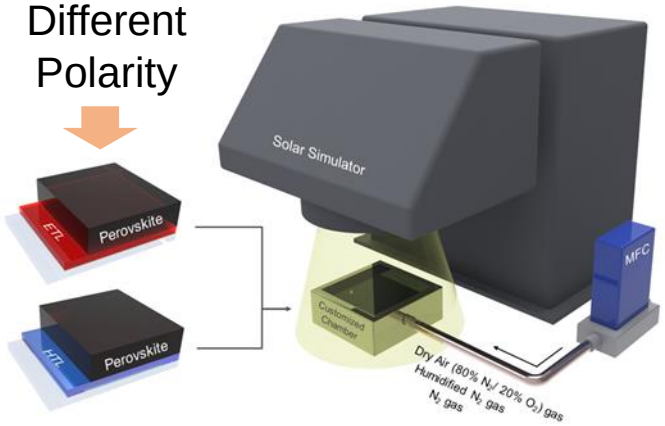
Electron Dominant



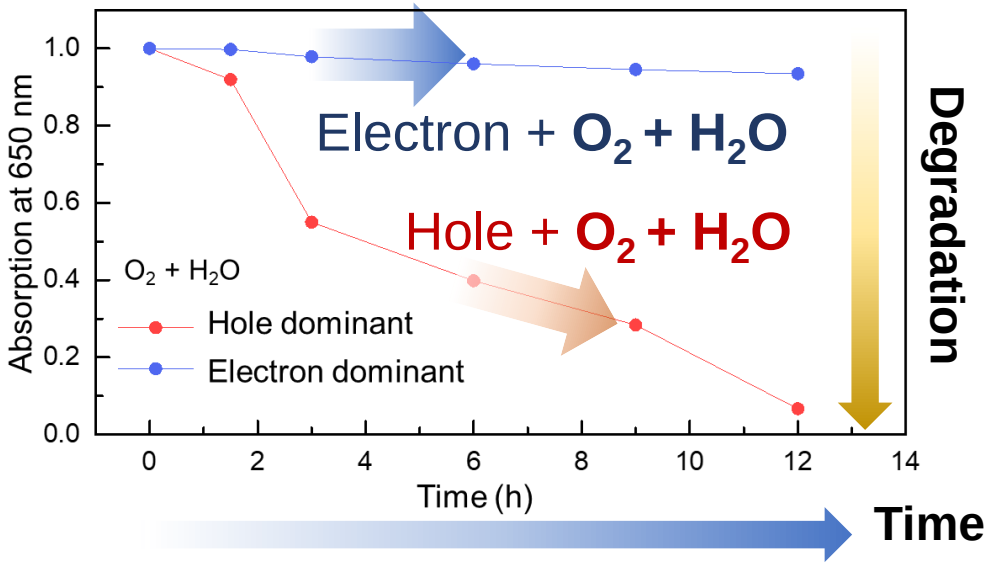
Only hole extraction

Experimental Setup

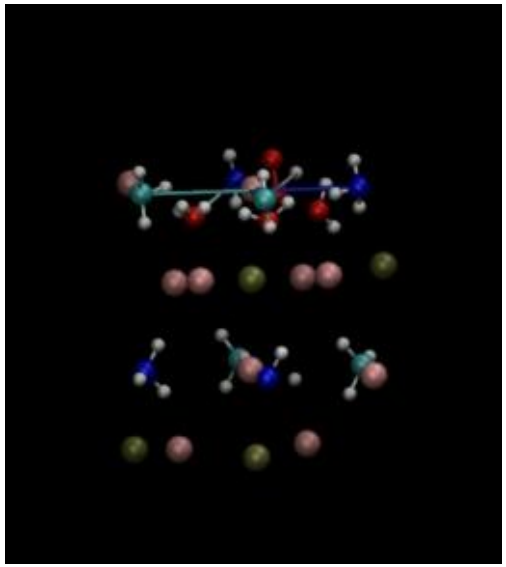
Different Polarity



Experimental Results



DFT Calculation

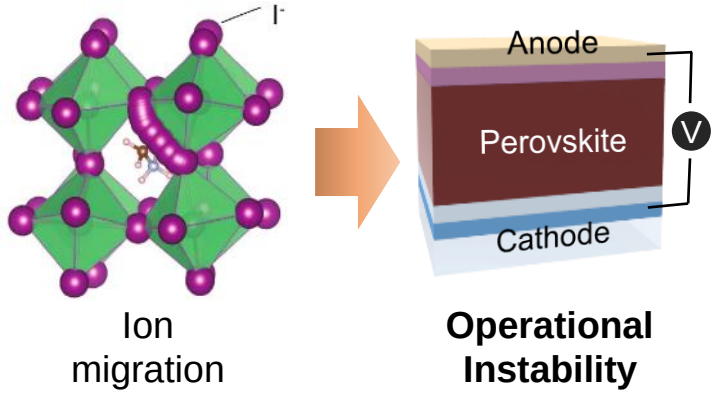


Research Summary: *2. Stability of Perovskite solar cells*

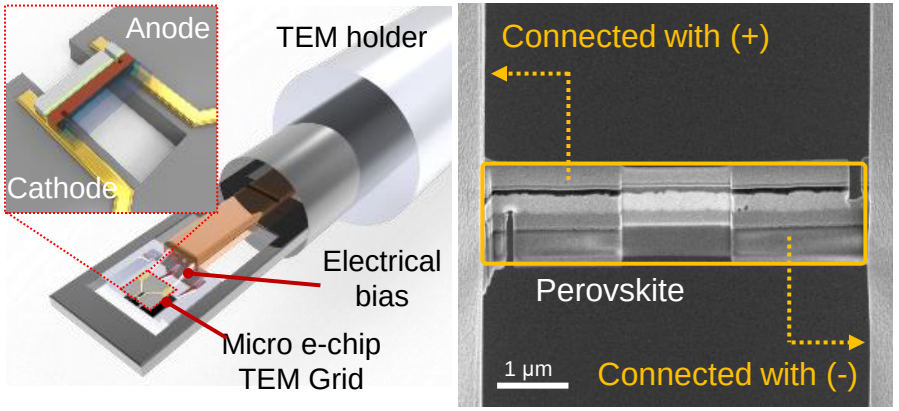
2) Operational instability of perovskite materials

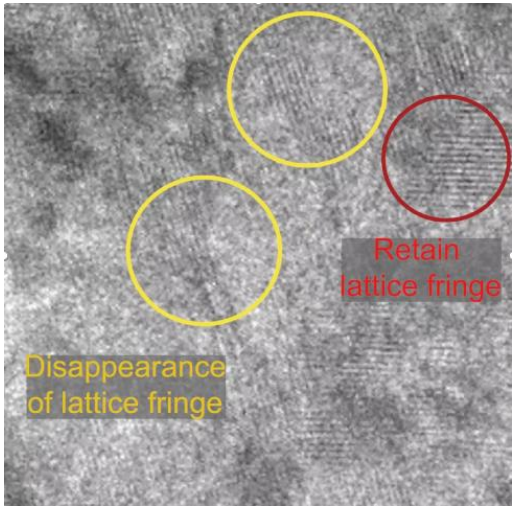
ACS Energy Letters (2021) (First Author)

Operational Instability

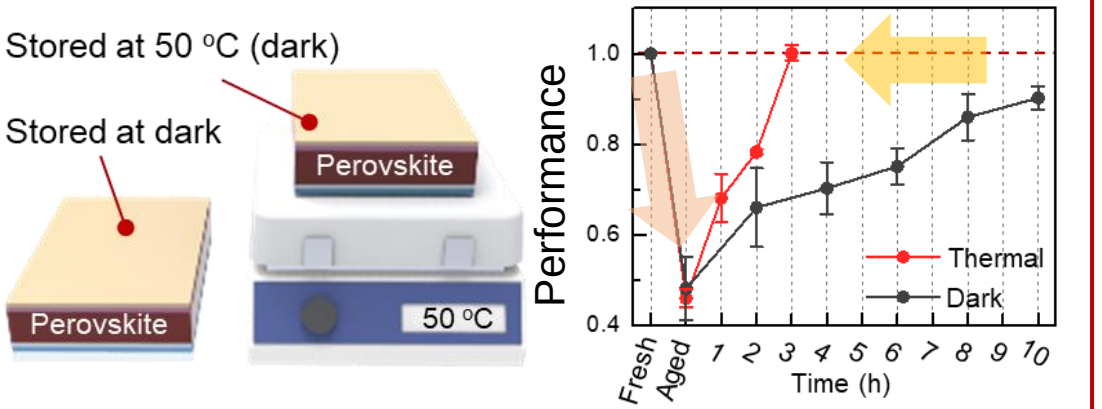


In-situ TEM configuration





Solution

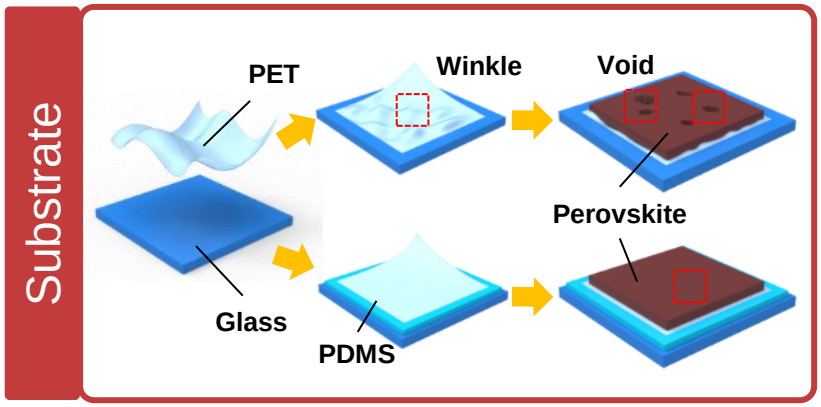


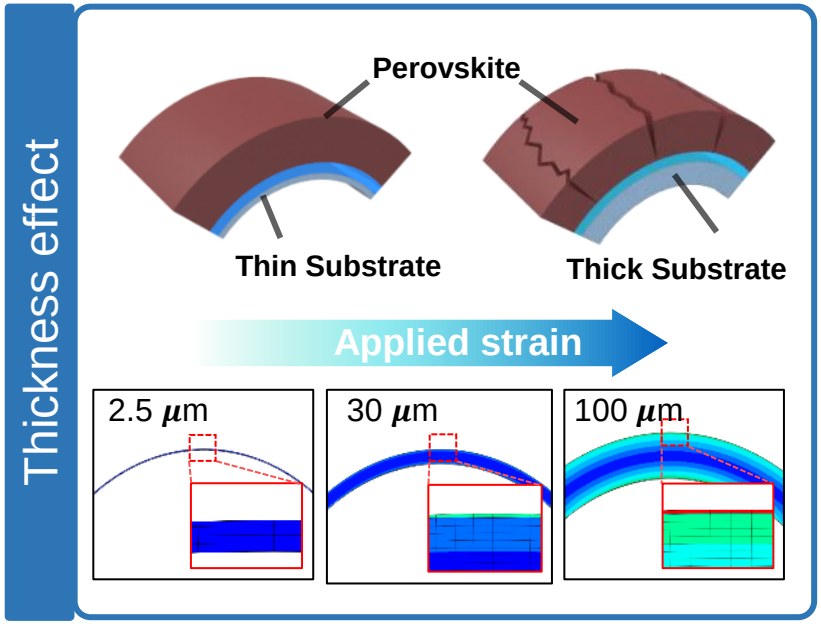
Solution for the operational instability of PSCs

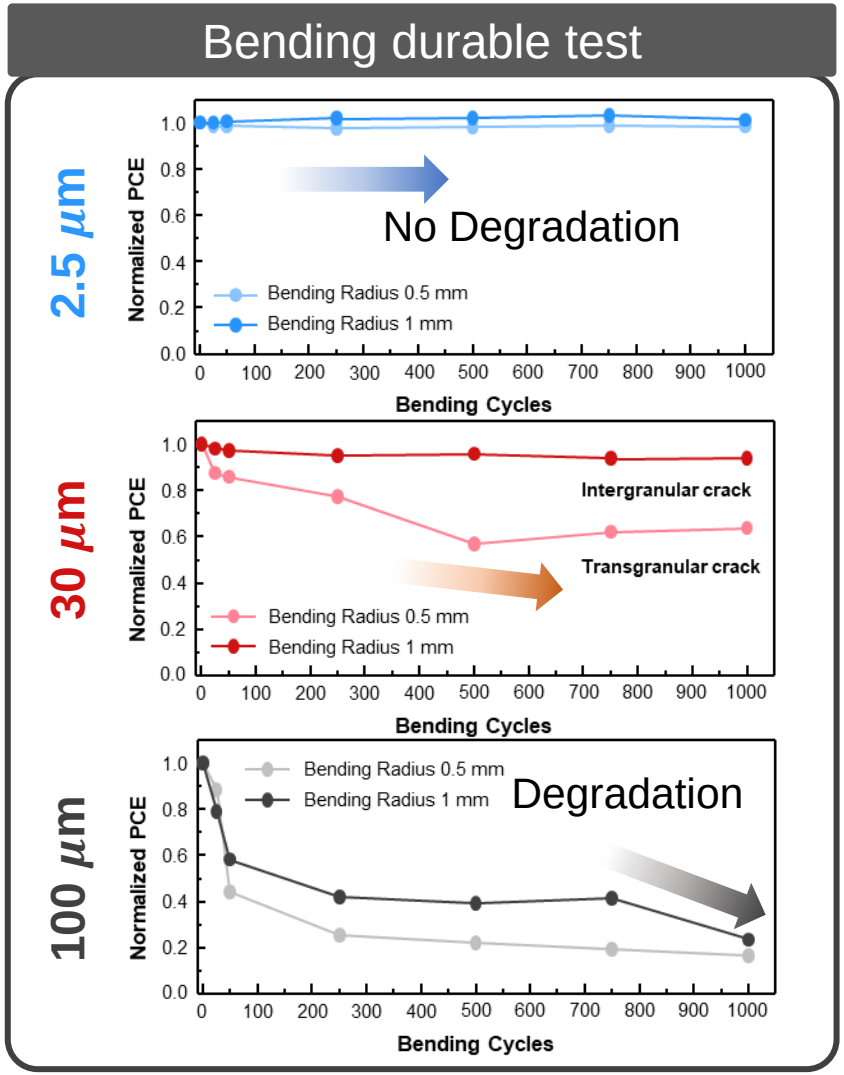
Research Summary: 3. Ultra-flexible (Foldable) Solar Cells

Foldable / Crumpling Durable Ultra-flexible Solar Cells

Energy & Environ. Sci. (2019) (First Author)



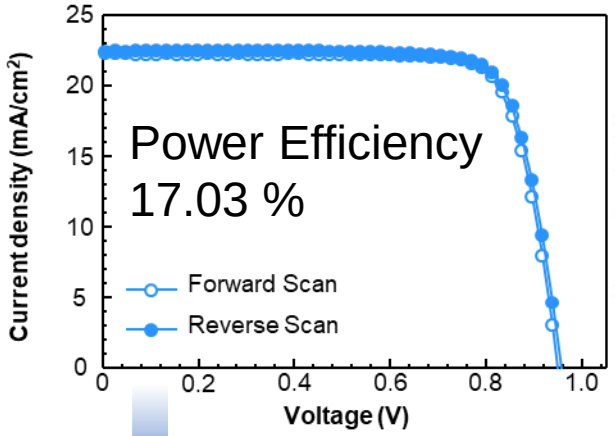




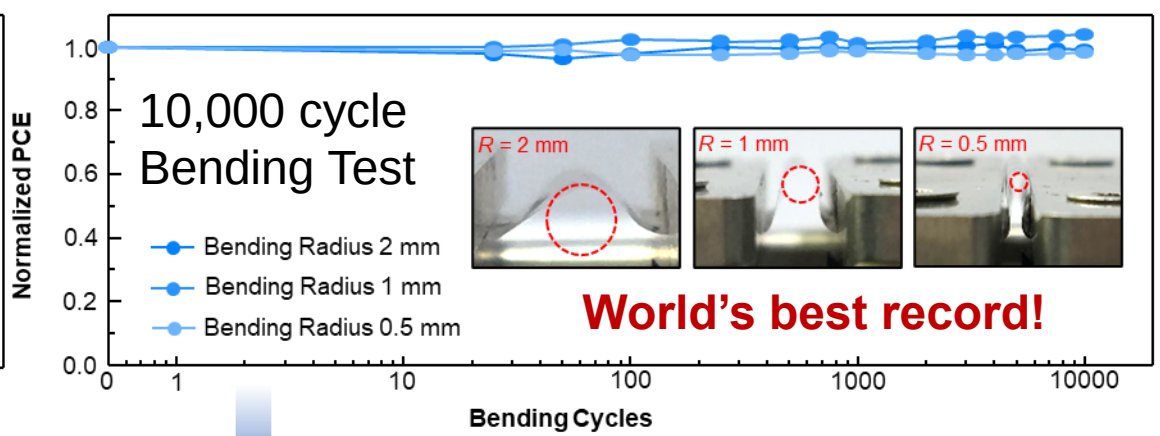
Research Summary: 3. Ultra-flexible (Foldable) Solar Cells

Foldable / Crumpling Durable Ultra-flexible Solar Cells

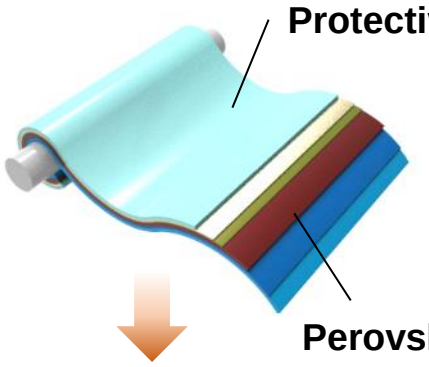
Energy & Environ. Sci. (2019) (First Author)

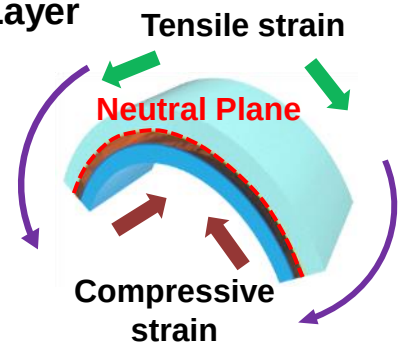


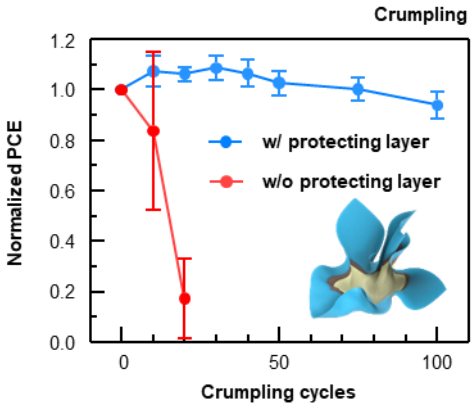
Equivalent to rigid solar cells

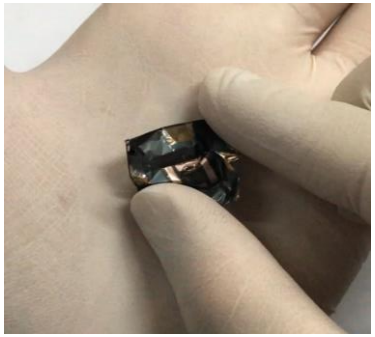


Endure **10,000 cycles** of bending test







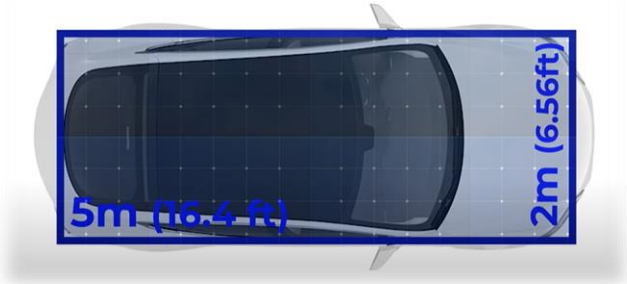


The first crumpling durable (Foldable) solar cells by introducing neutral plane protective layers

Research Interest (1): Ultra-flexible Energy Harvesting Devices

Future Plans

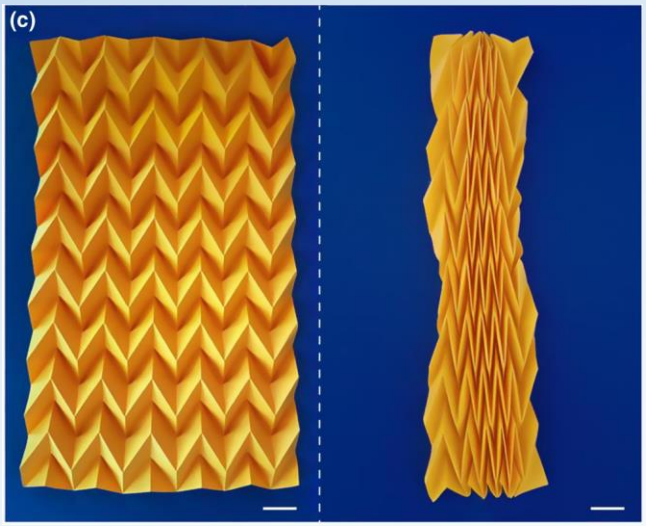
❖ **Foldable Solar Cell Module for Automobiles**

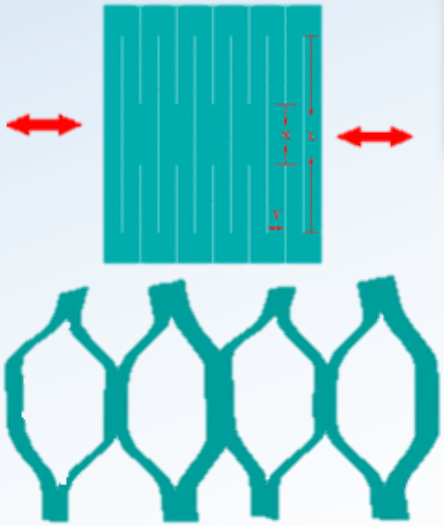


Daily Average

10 [m^2] ×1459 [kwh m^{-2}] / 365 [days] ×
20 % = 8 kWh **~ 77 km**
(Efficiency: 104 Wh/km, Lightyear One)

Origami & Kirigami Approaches





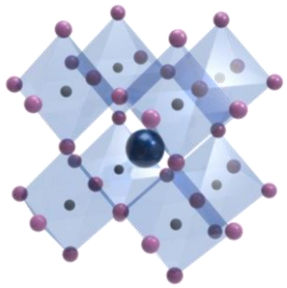
In preparation

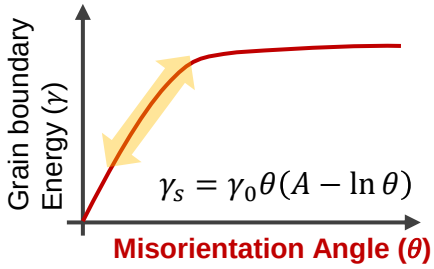
Foldable
Solar Roof / Solar Vehicles

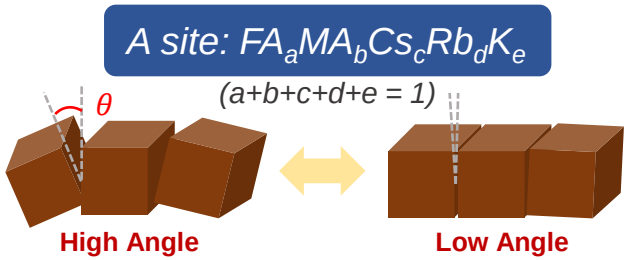
Research Interest (1): Ultra-flexible Energy Harvesting Devices

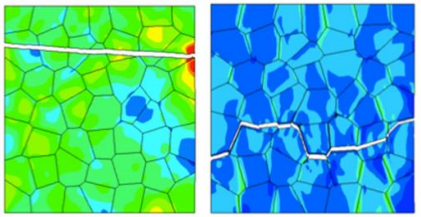
Future Plans

❖ **Investigation on the Mechanical Property of Perovskite Thin Film : Toward Foldable Solar Cell**



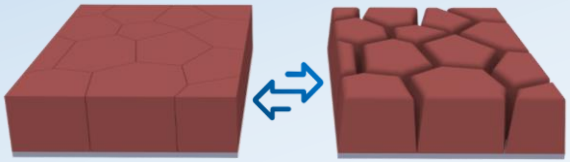






Ultra-flexible Foldable Power sources

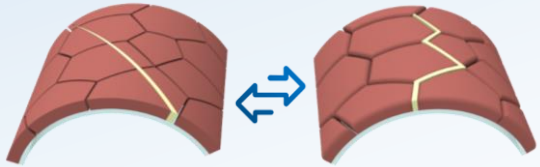
Crystal Growth Engineering



Misorientation angle control

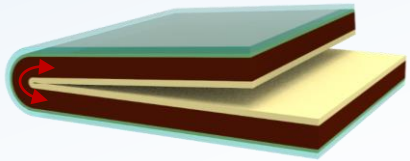
✓ *Mechanical property engineering*
✓ *Optical/Electrical property engineering*

Crack Propagation Engineering



✓ *Crack propagation engineering from misorientation angle control*

Folable Perovskite Solar Cell



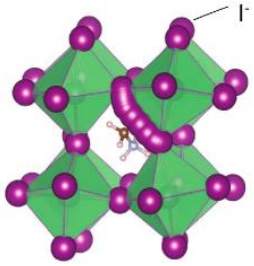
Bending Radius < 0.1 mm
> 10,000 durable

✓ *World's best bending durable perovskite solar cell*

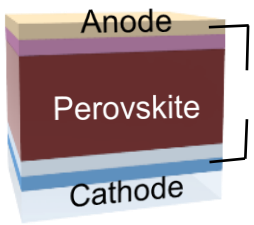
Research Interest (2): Advanced Nanoscale Characterization

❖ Advanced *in-situ* characterization (under electrical biasing)

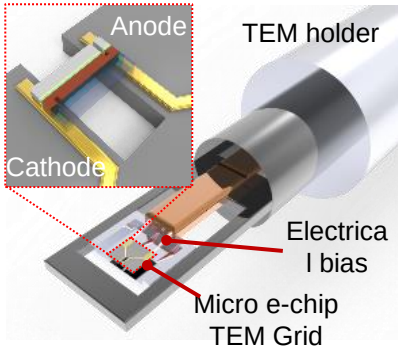
ACS Energy Letters (2021)

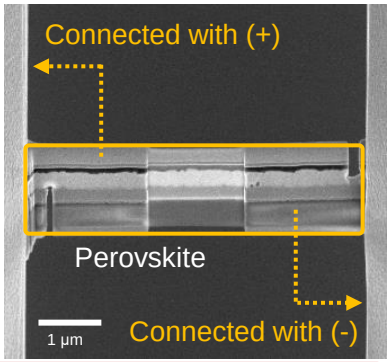


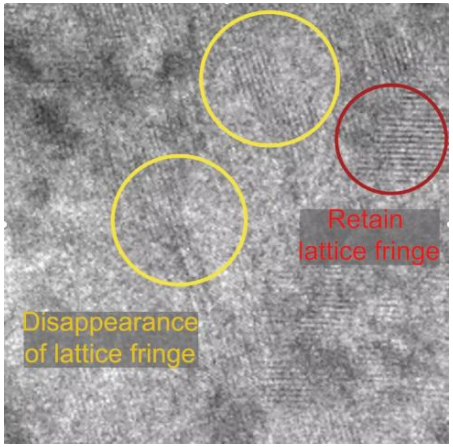
Ion migration



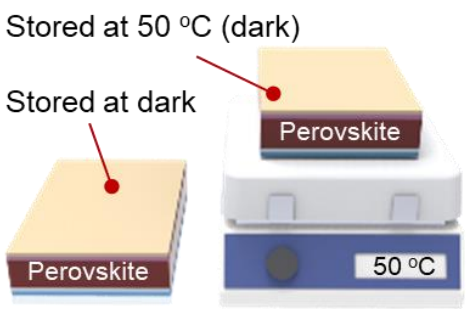
Operational Instability

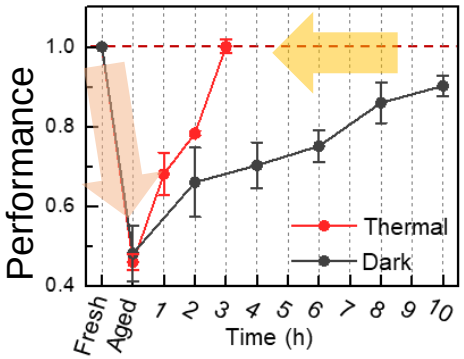




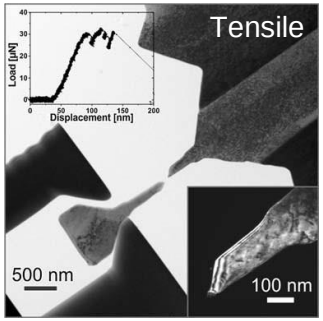


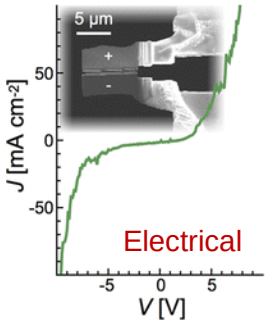
Solution

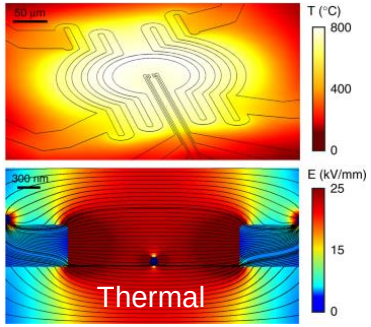




❖ Advanced *in-situ* characterization







MEMS / NEMS characterization

- *in-situ* ***mechanical*** *testing*
- *in-situ* ***electrical*** *testing*
- *in-situ* ***thermal*** *testing*
- …

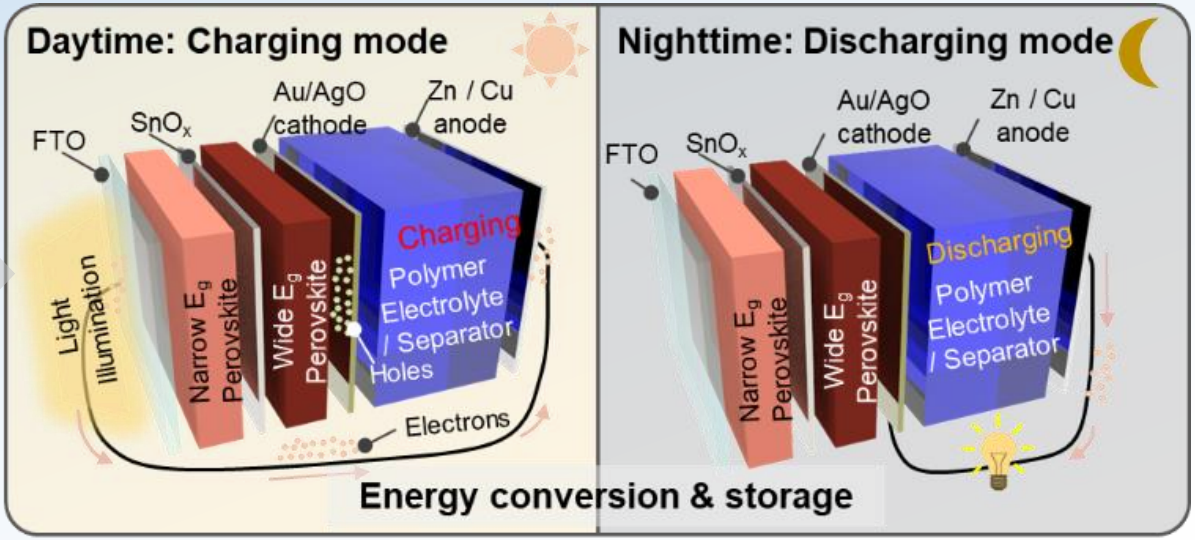
Research Interest (3): Integrated Energy Conversion & Storage Devices

❖ Integrated Flexible Solar Battery

Flexible Solar Cells

+

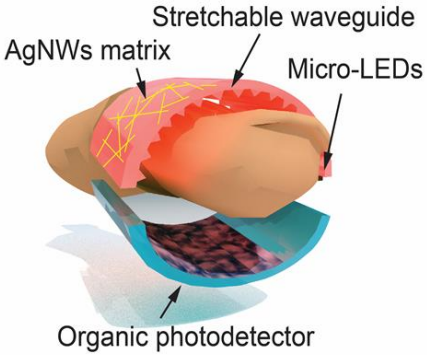
Flexible Battery

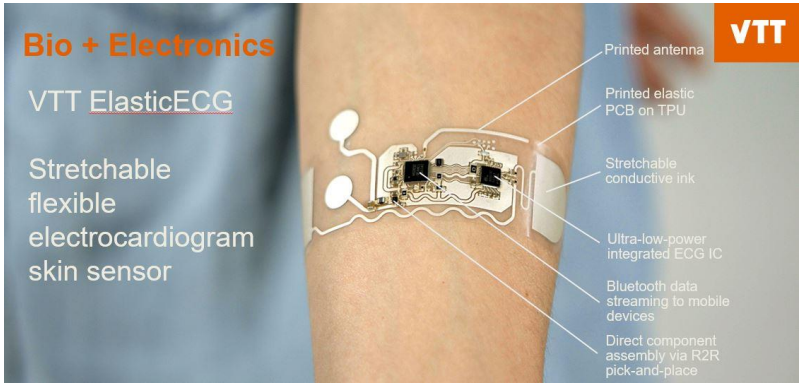


In preparation

❖ Wearable Power Sources

Health-care Application (Self-powered E-skins)





Achievements (Recent 3 years)

❖ First authored paper

1. Ultra-flexible perovskite solar cells with crumpling durability: toward a wearable power source, ***Energy & Environmental Science (2019) (IF: 38.532, JCR <1%)***

2. Advanced characterization techniques for overcoming challenges of perovskite solar cell materials, ***Advanced Energy Materials (2020) (IF: 29.368, JCR <3%)***

3. Imaging real-time amorphization of hybrid perovskite solar cells under electrical biasing, ***ACS Energy Letters (2021) (IF: 23.101, JCR <5%)***

4. Moth-eye structured polydimethylsiloxane films for high-efficiency perovskite solar cells, ***Nano-Micro Lett. (2019) (IF: 16.419, JCR <10%)***

5. Degradation of CH 3 NH 3 PbI 3 perovskite materials by localized charges and its polarity dependency, ***Journal of Mater. Chem. A (2019) (IF: 12.732, JCR <10%)***

6. Effect of metal electrodes on aging-induced performance recovery in perovskite solar cells, ***ACS applied materials & interfaces (2019) (IF: 9.229, JCR <20%)***

7. Interface design of hybrid electron extraction layer for relieving hysteresis and retarding charge recombination in perovskite solar cells, ***Adv. Mater. Interfaces. (2018) (IF: 6.147, JCR <30%)***

8. Effect of TiO2 particle size and layer thickness on mesoscopic perovskite solar cells, ***Applied Surface Science (2019) (IF: 6.707, JCR < 5%)***

Achievements (Recent 3 years)

❖ Co-authored paper

9. Unveiling the Stable Nature of the Solid Electrolyte Interphase between Lithium Metal and LiPON via Cryogenic Electron Microscopy, ***Joule (2020) (IF: 41.248)***

10. Quantitative Specifications to Avoid Degradation during E-Beam and Induced Current Microscopy of Halide Perovskite Devices, ***The Journal of Physical Chemistry C (2020)***

11. Impacts of the hole transport layer deposition process on buried interfaces in perovskite solar cells, ***Cell Reports Physical Science (2020)***

12. High-Efficiency Flexible Perovskite Solar Cells Enabled by an Ultrafast Room-Temperature Reactive Ion Etching Process, ***ACS applied materials & interfaces (2020)***

13. Sustainable design of fully recyclable all solid-state batteries, ***MRS Energy & Sustainability (2020)***

14. Photo-annealed amorphous titanium oxide for perovskite solar cells, ***Nanoscale (2019)***

15. Highly Reproducible Large-Area Perovskite Solar Cell Fabrication via Continuous Megasonic Spray Coating of $CH_3NH_3PbI_3$, ***Small (2019)***

16. Room-Temperature Vapor Deposition of Cobalt Nitride Nanofilms for Mesoscopic and Perovskite Solar Cells, ***Advanced Energy Materials (2020) (IF: 29.368)***

❖ Patents

1. 대면적 페로브스카이트 태양전지의 제조 방법

2. Fabrication method of a large area perovskite solar cell (USA)