Optimized Interconnecting Layers for Monolithic Perovskite/Organic Tandem Solar Cells

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HI ERN Helmholtz Institute Erlangen-Nürnberg

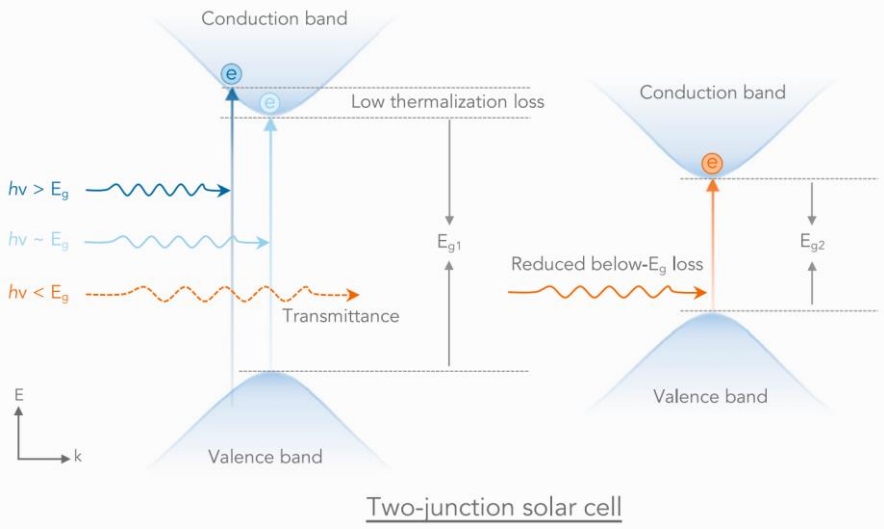
part of JÜLICH Forschungszentrum

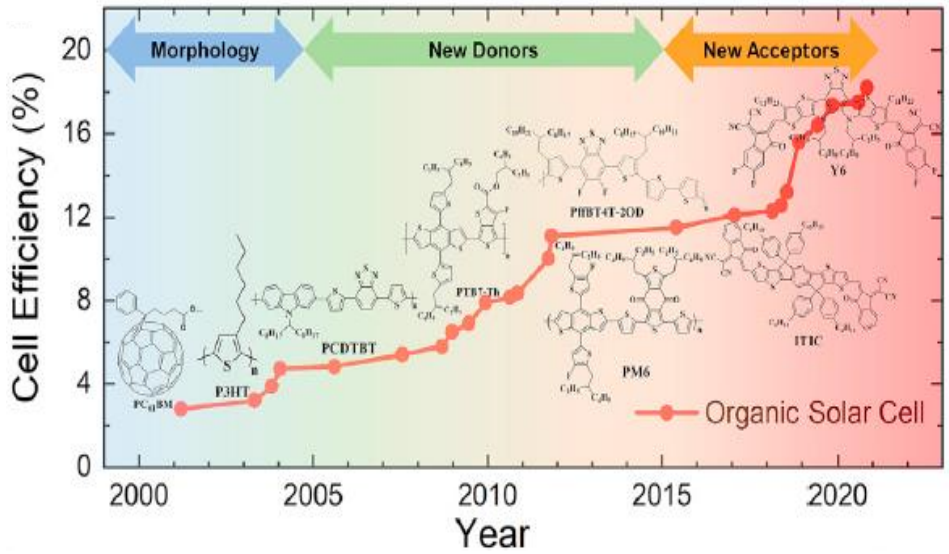
in cooperation with FAU Friedrich-Alexander Universität Erlangen-Nürnberg, HZB Helmholtz Zentrum Berlin

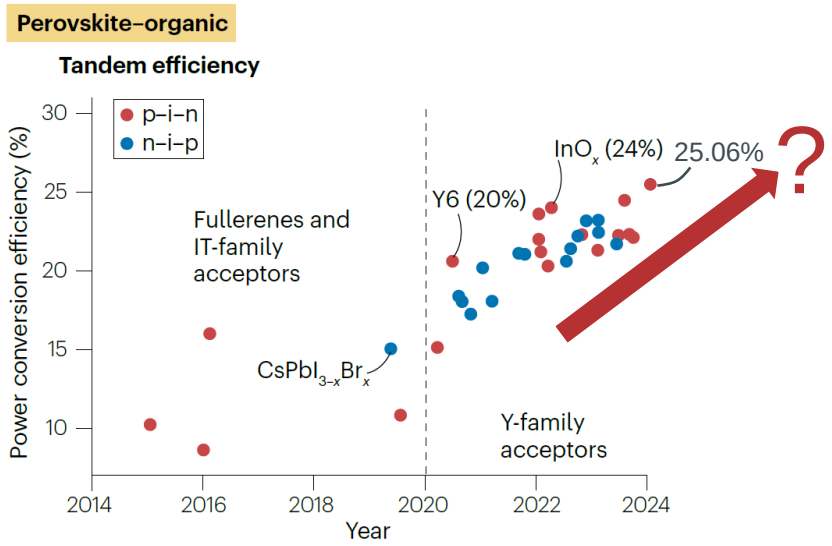
Outline

- ❑ Optimized interconnecting layers for n-i-p P-O TSCs
- ❑ Optimized interconnecting layers for p-i-n P-O TSCs

Background







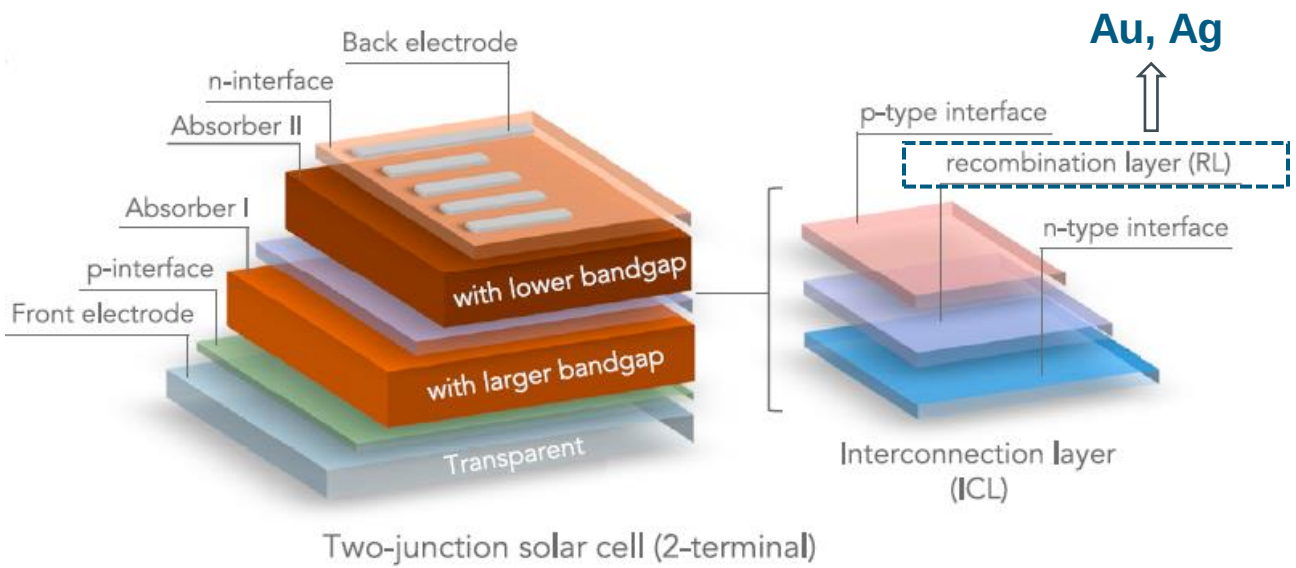
NBG organic semiconductors:

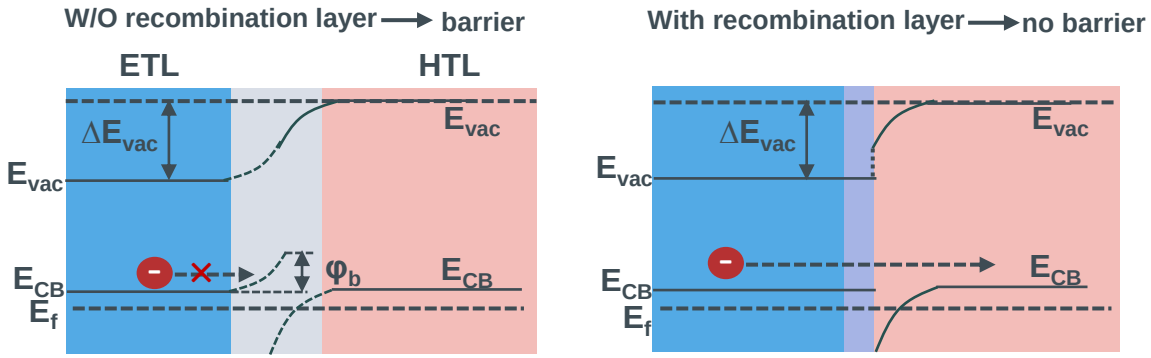
- ❑ NIR absorption
- ❑ Nontoxicity
- ❑ Good orthogonal solution processibility
- ❑ Stable components

❑ Where is the limitation from?

(1) *Joule*, *7*(3), 484-502;
(2) *Chem. Rev.* 2022, 122, 18, 14180–14274
(3) *Nature*, 2022, 604. 280-286.

Losses in ICLs

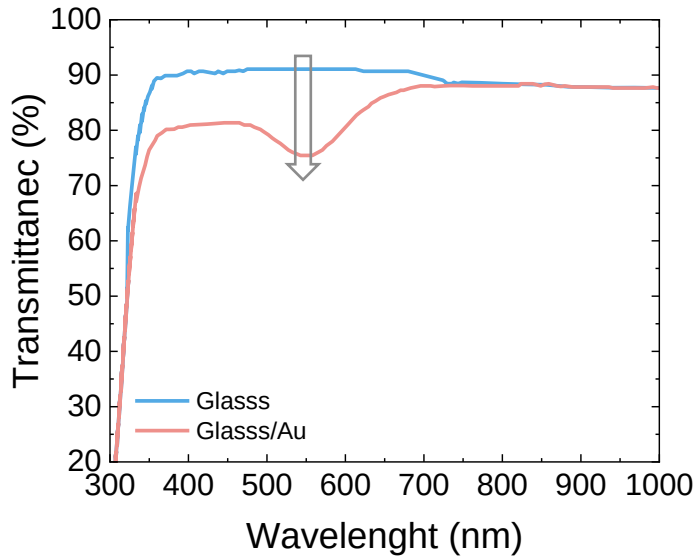




- Metal thin layers reduce energetic and electrical loss.

An ideal ICL should provide:

- Ohmic contact
- High optical transparent
- Chemical protection ability
- Sufficient recombination sites
- Low contact resistance

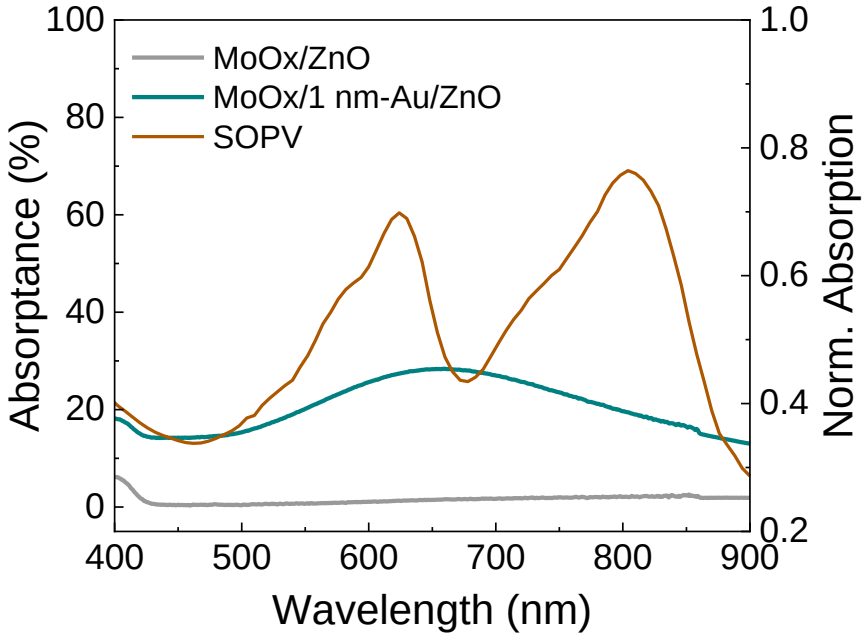


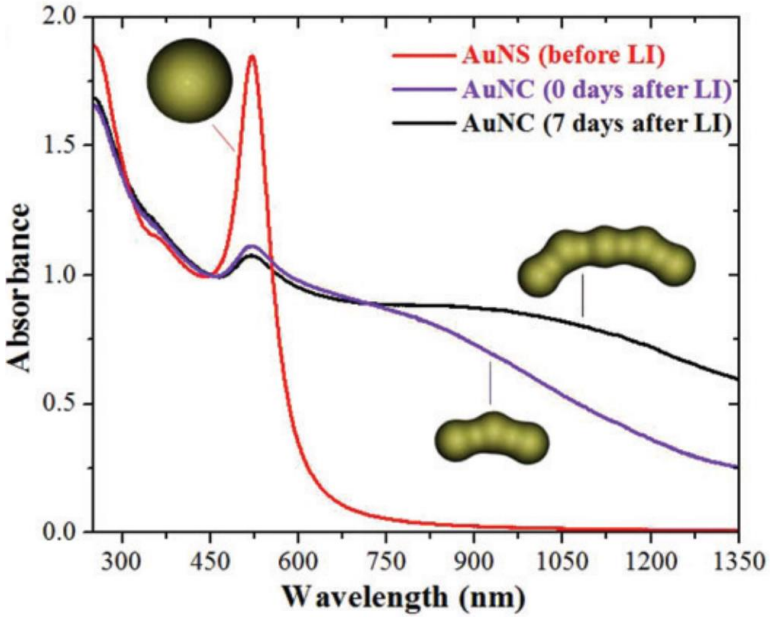
- Metal thin layers increase optical losses.

(1) *Joule*, *7*(3), 484-502

Parasitic Absorption *Vs* Metal Shape

a typical n-i-p ICL



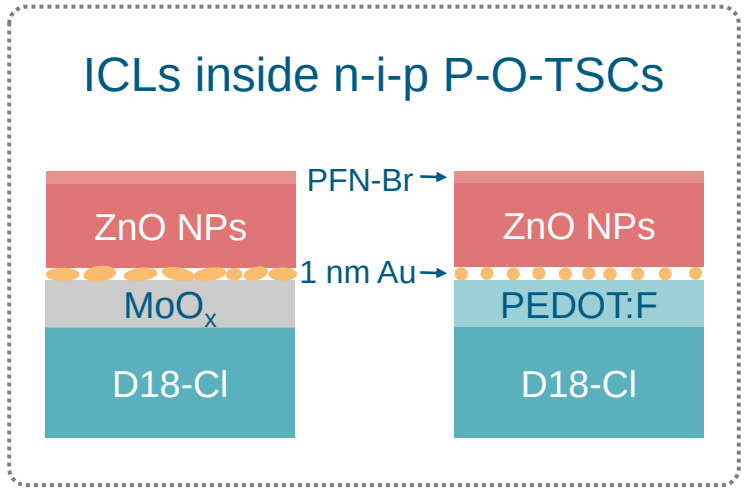


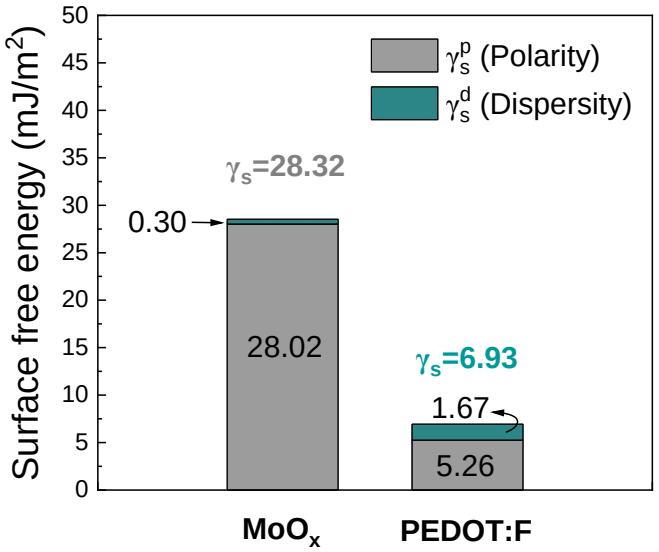
- A broad plasmon absorption band is located in the absorption of OPV sub-cell.

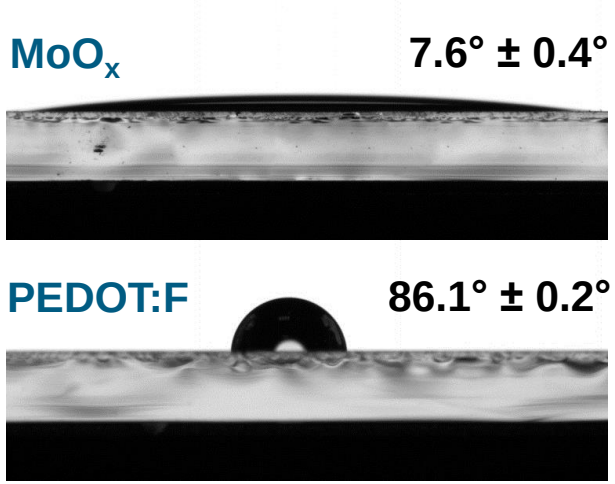
- Localized Surface Plasmon Resonance (LSPR) is related to the shape of metal morphology.[1]

(1) Nanoscale, 2015, 7,13702-13714

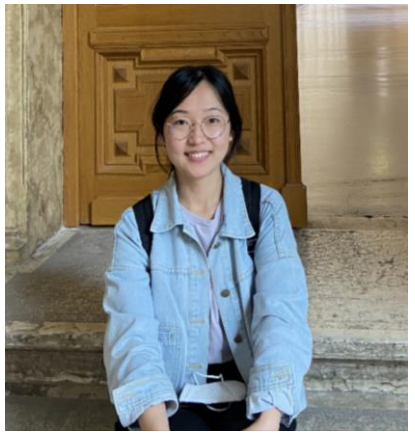
Surface Energies of MoOx *Vs* PEDOT:F







Water contact angles

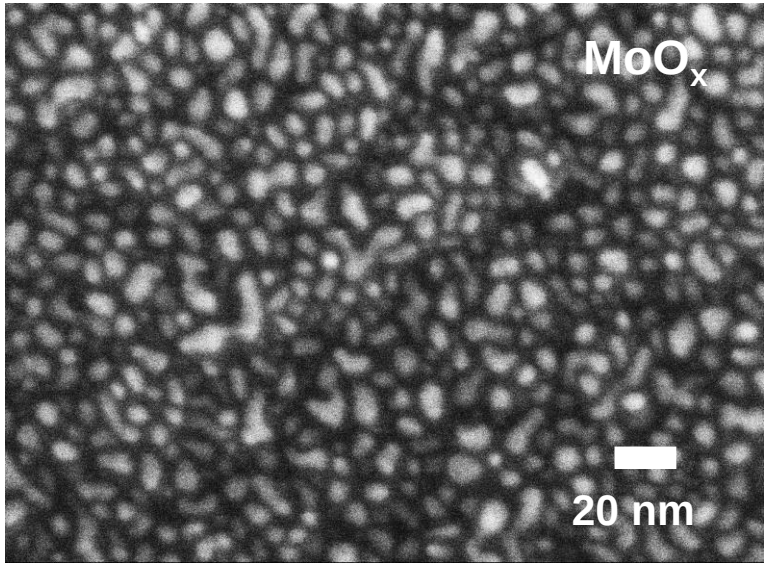


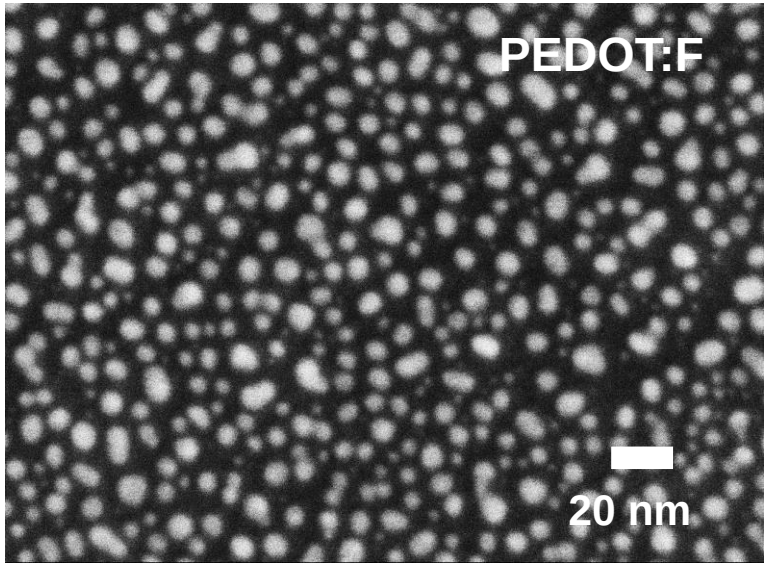
JingJing Tian

- The surface energies of PEDOT:F and MoOx are different.

PEDOT: F was provided by Prof. Yinhua Zhou's group.

Surface energy *Vs* shapes of Au NPs

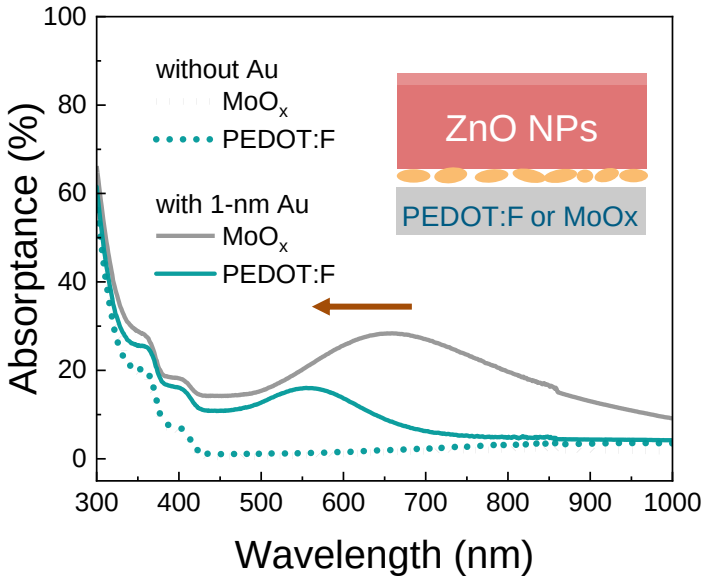


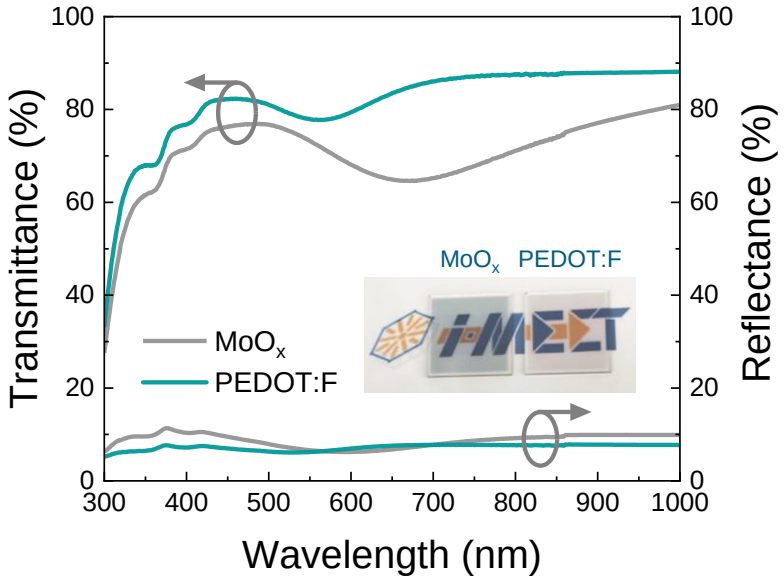


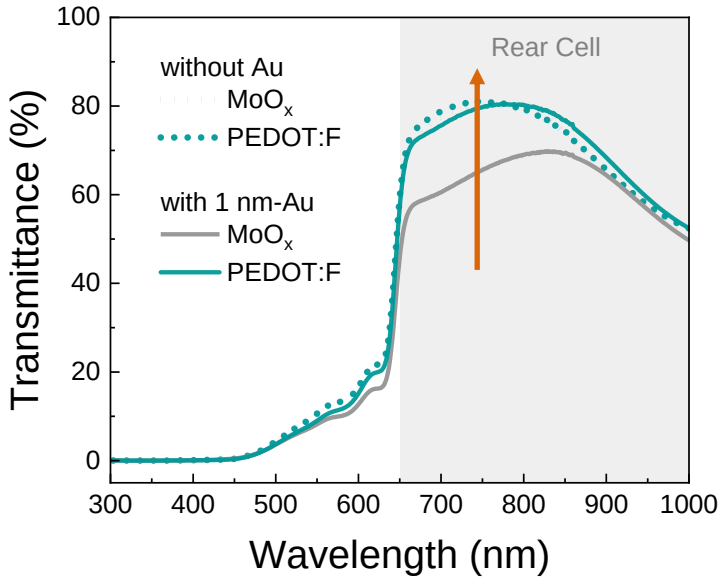
Au NPs on the surface of PEDOT:F:

- ❑ form more regular and round shapes
- ❑ Lower coverage

Optical properties

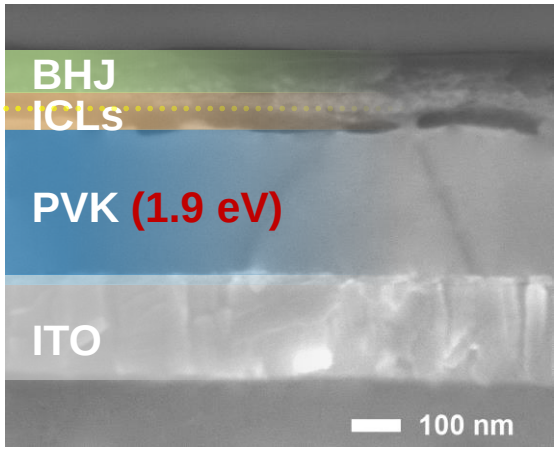


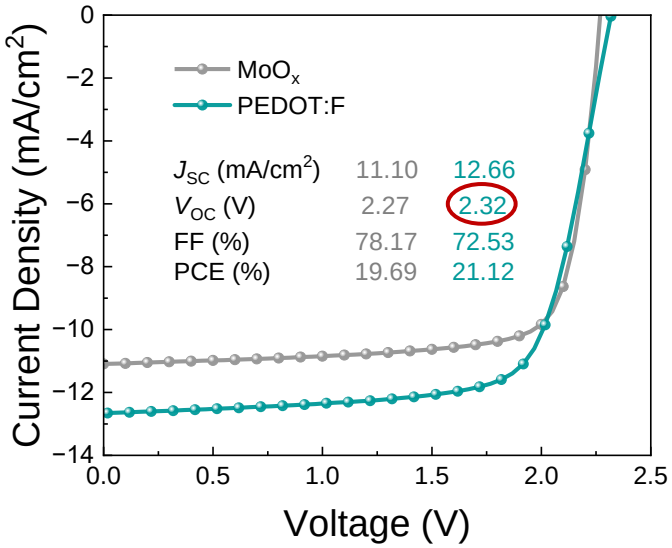


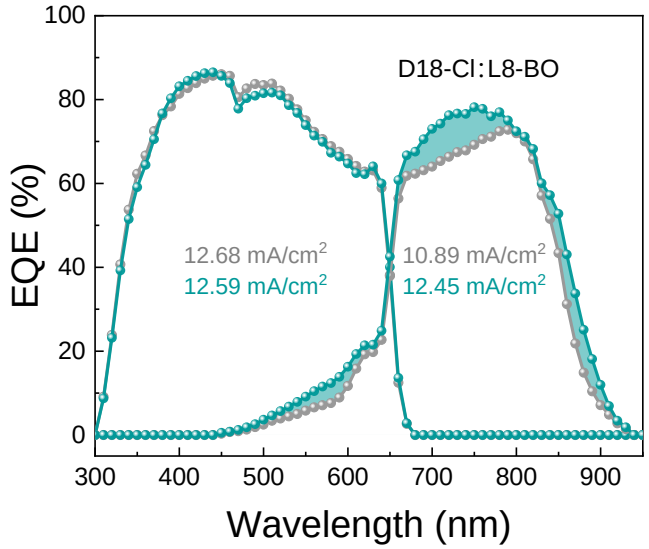


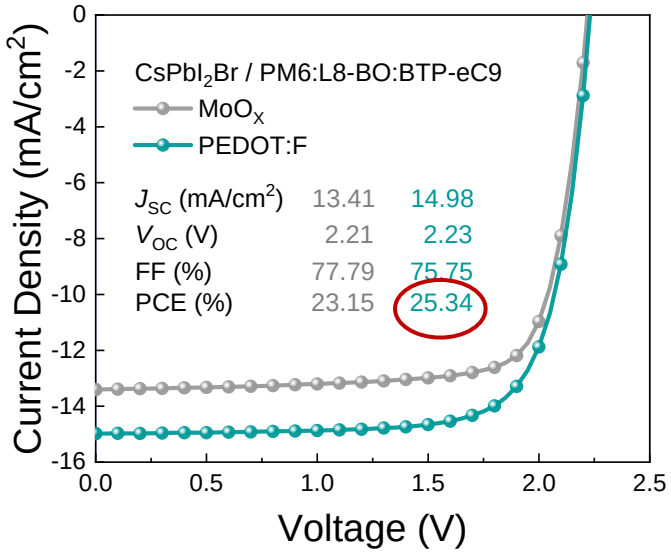
- The plasmon absorption is shifted outside the absorption window of rear organic absorber in the near-infrared (NIR) region.
- The similar optical transmission behavior is observed in the half-stacked tandems.

Performance of n-i-p P-O TSCs





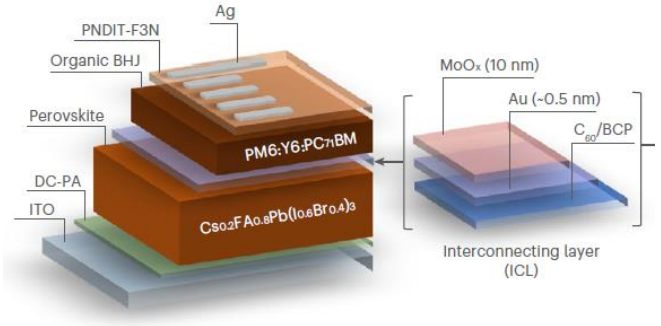




- A record *Voc* is achieved when combining with D18-Cl:L8BO.
- The currents of two sub-cells are well balanced.
- A high PCE of 25.34% is achieved when combining with PM6:BTP-eC9:L8BO.

To be submitted

ICLs for p-i-n structure



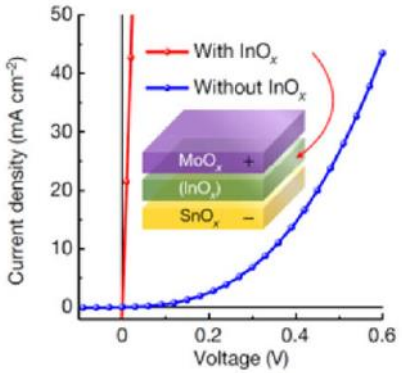
Nature Energy, 2024, 1-11

Metal Oxides:
- ❑ Pro: high conductive and transmittance
- ❑ Con: damage underlying functional layers; high vacuum deposition.

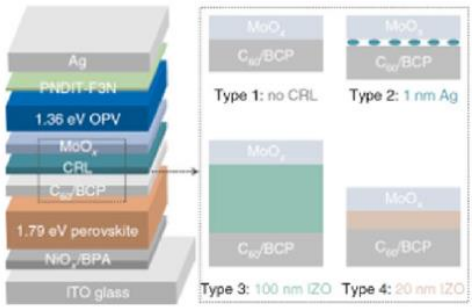
Metal (oxide)-free
- ❑ Pro: simply process.
- ❑ Con: low PCE (22.31%).

Need further optimization.

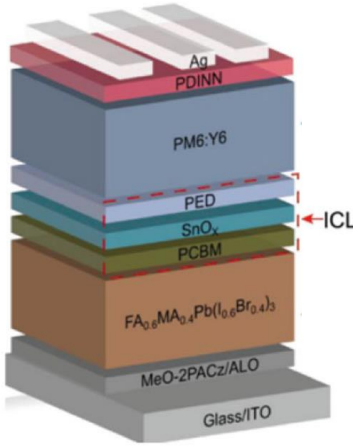
Thin metal layer (Ag/Au):
- ❑ Pro: high conductive
- ❑ Con: parasitic loss



Nature **2022**, 604, 280.

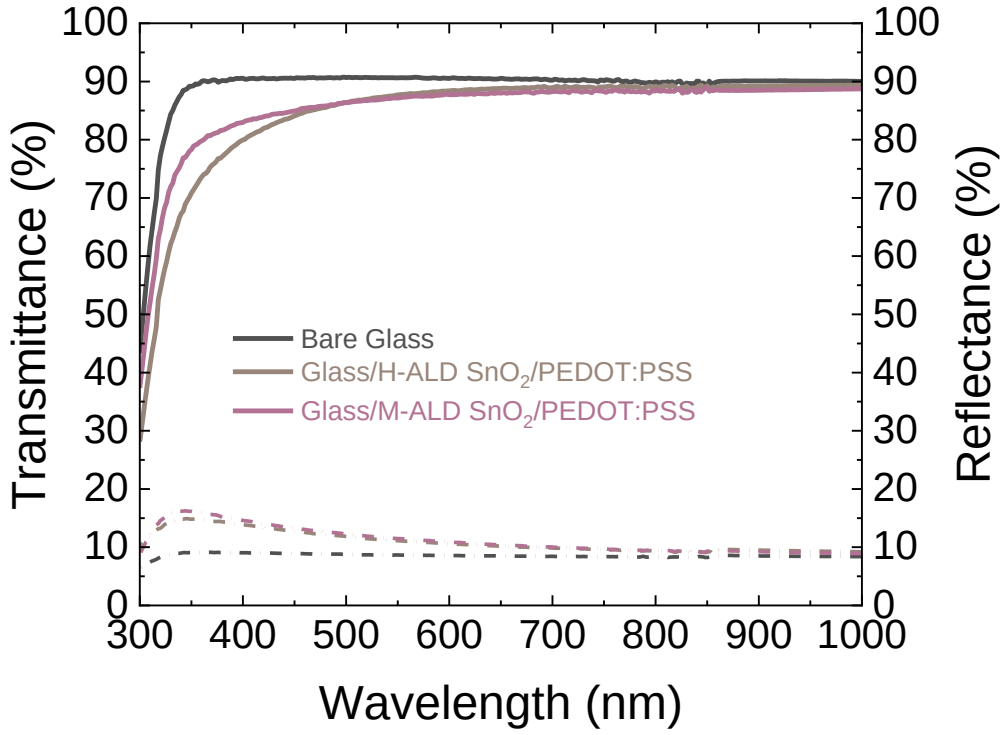


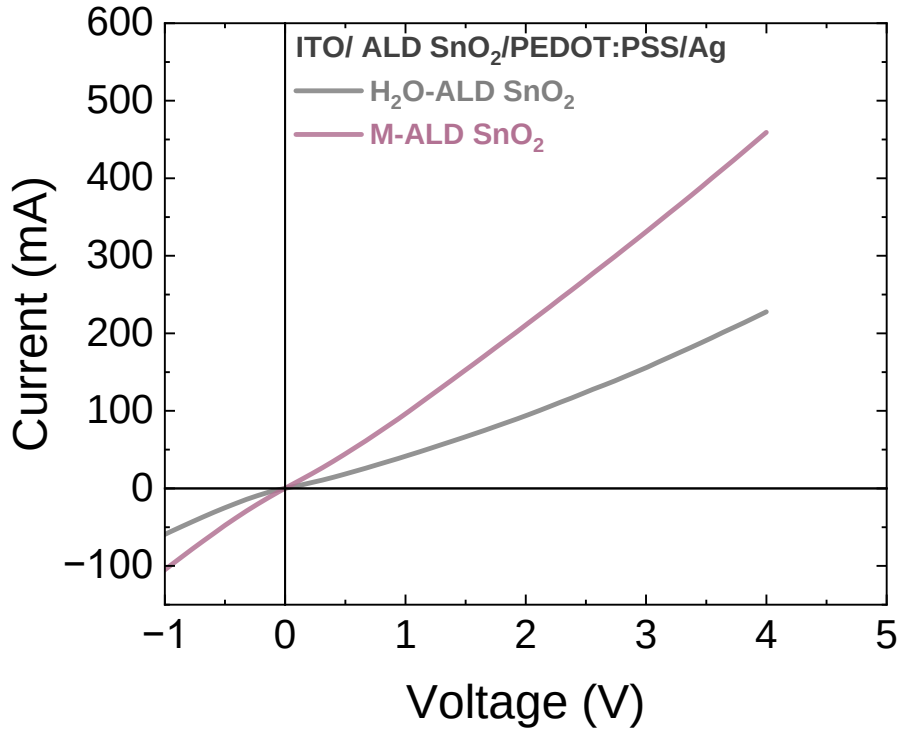
Nat. Energy **2022**, 7, 229.



Adv. Funct. Mater. 2023,2308794

Optimized ALD SnO_2 film for p-i-n ICLs

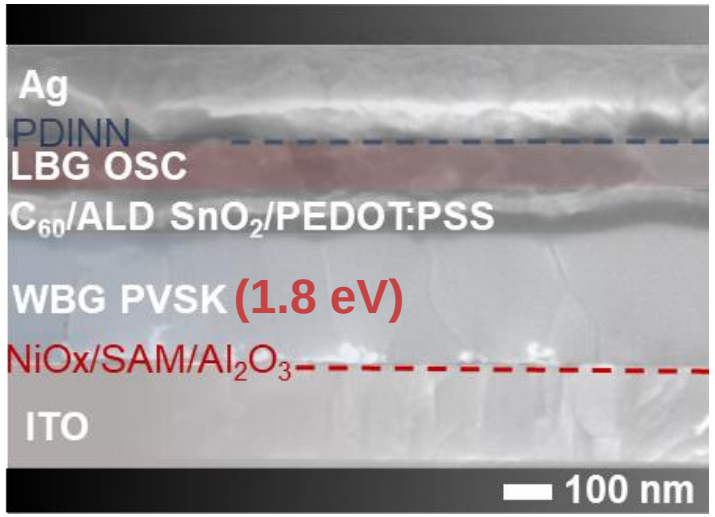




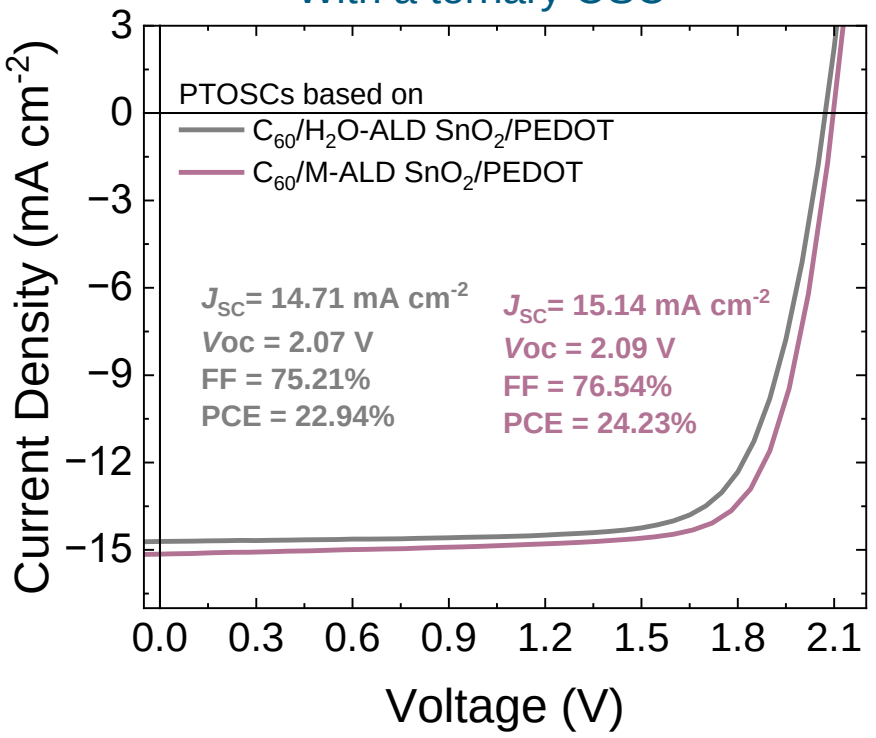
Vertical conductivity

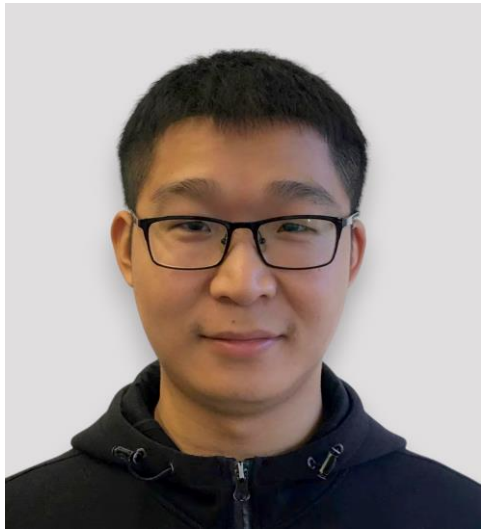
- M-ALD SnO_2 show similar a optical property to that of H_2O-ALD SnO_2.
- The electrical property of M-ALD SnO_2 is improved significantly: reducing the electrical loss.

Performance of p-i-n P-O TSCs



With a ternary OSC

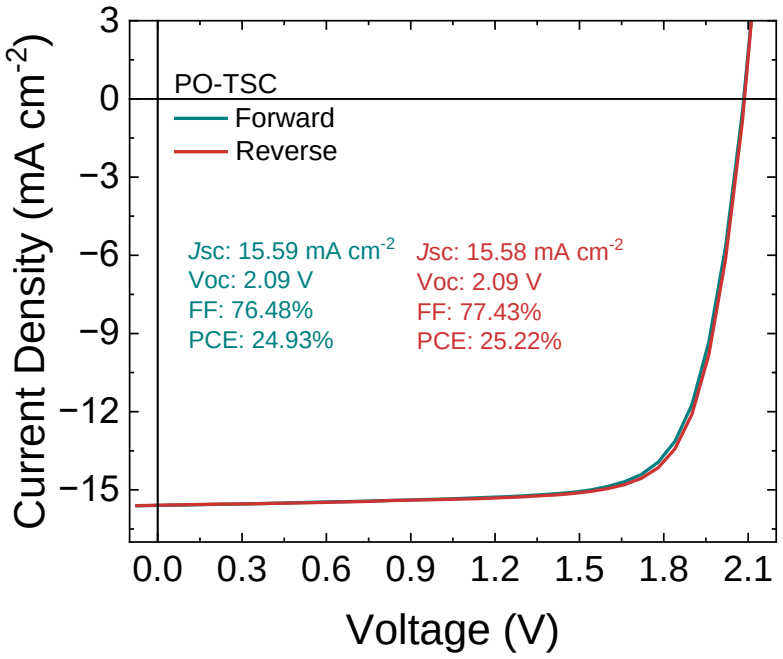


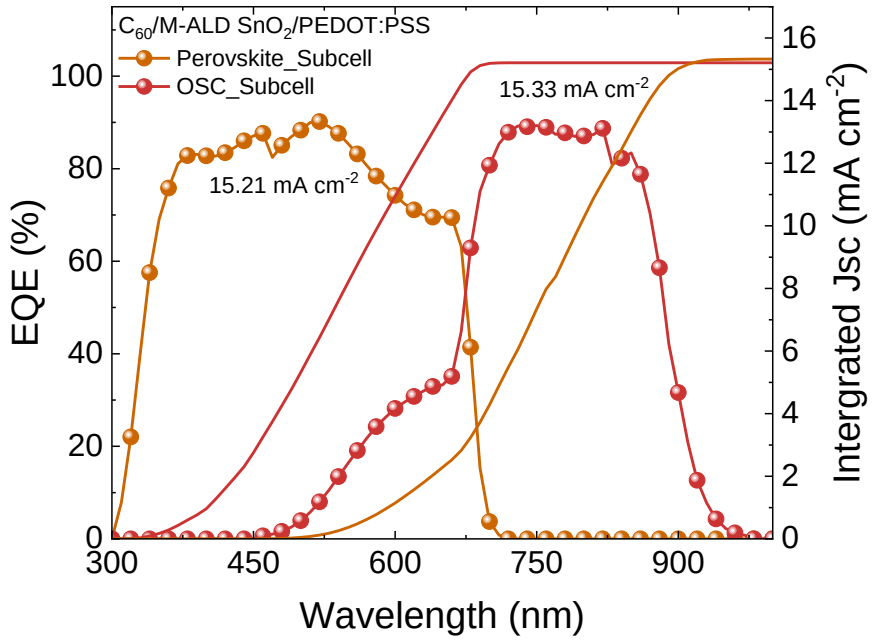


Kaicheng Zhang

- With M-ALD SnO_2-based ICL, the current of PO-TSCs is improved.

P-O TSCs with a quaternary organic absorber

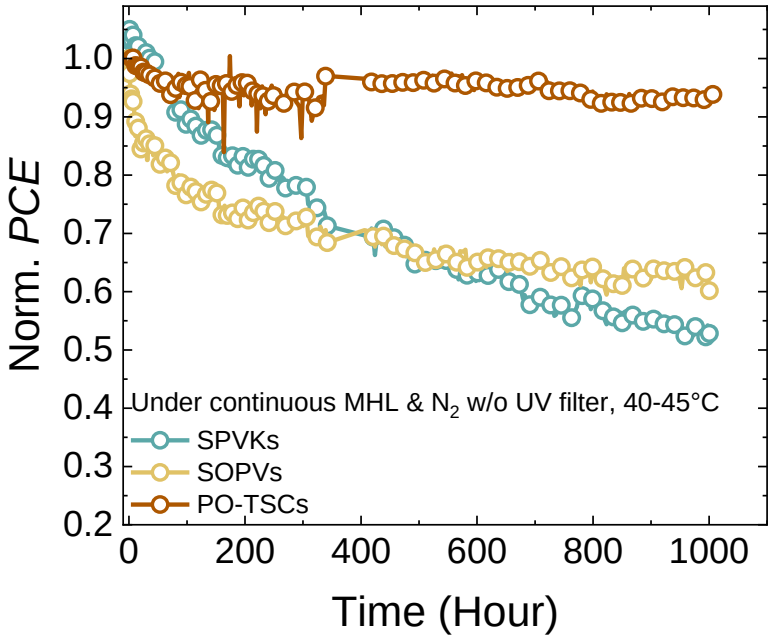




- With a small amount of [70]PCBM, the *Jsc* and FF are further improved, delivering a PCE of 25.22%.

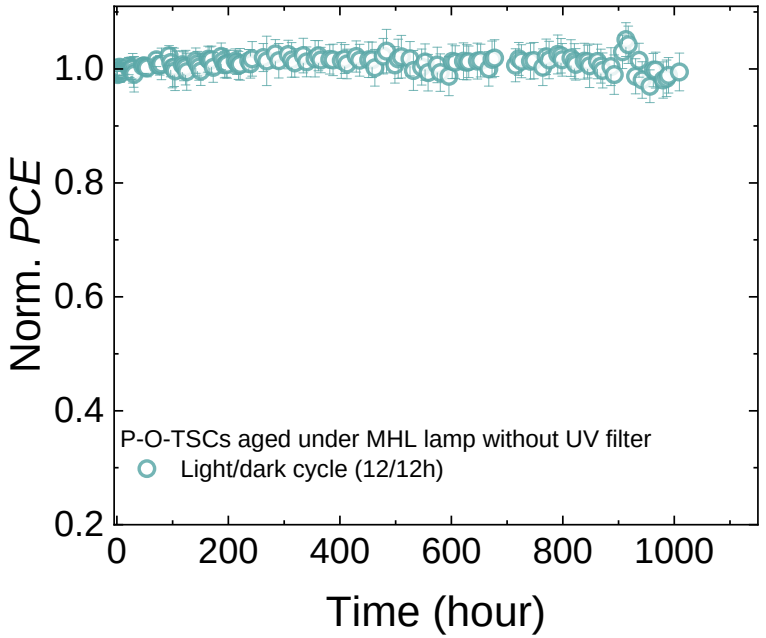
Device Stability

ISOS-L-1I

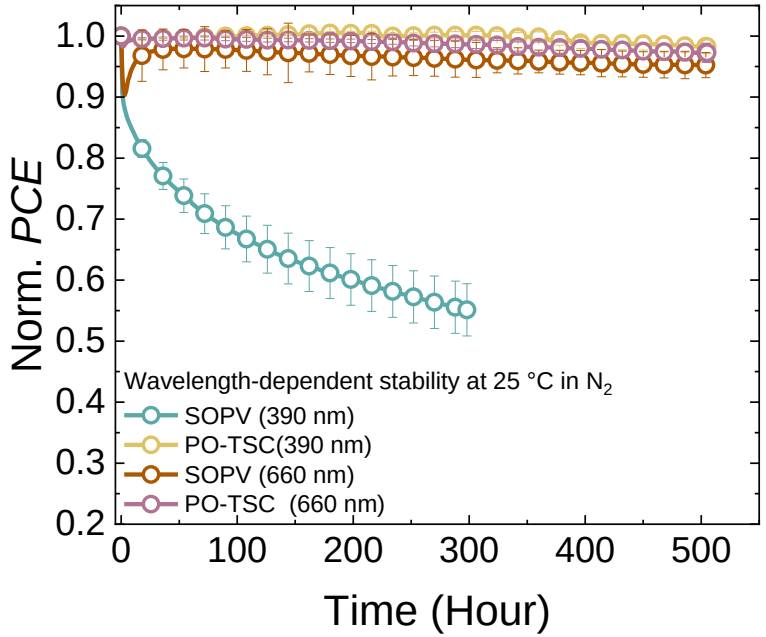


Aged under a 0.85-sun

Light–dark cycling (ISOS-LC)



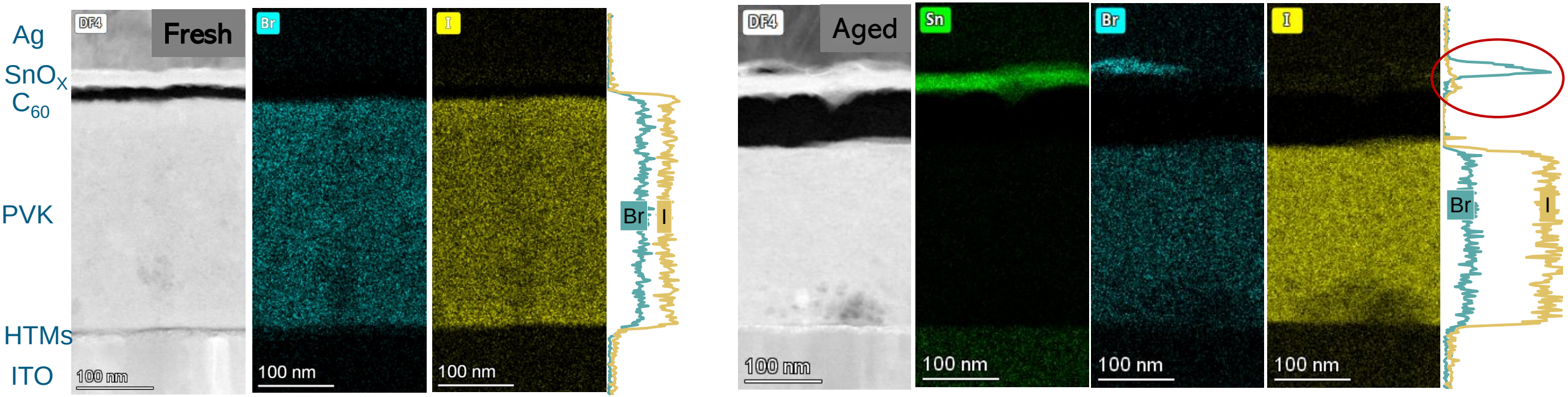
Wavelength-dependent stability



- A long-term stability is achieved, maintaining the initial PCE of 92% under continuous MHL light w/o UV filter.
- No fatigue behaviour is observed, indicating the effective suppression of ion diffusion.
- The organic sub-cell is well protected by the PVK layer.

EDXA Mapping of SPVK (cross-section HRTEM)

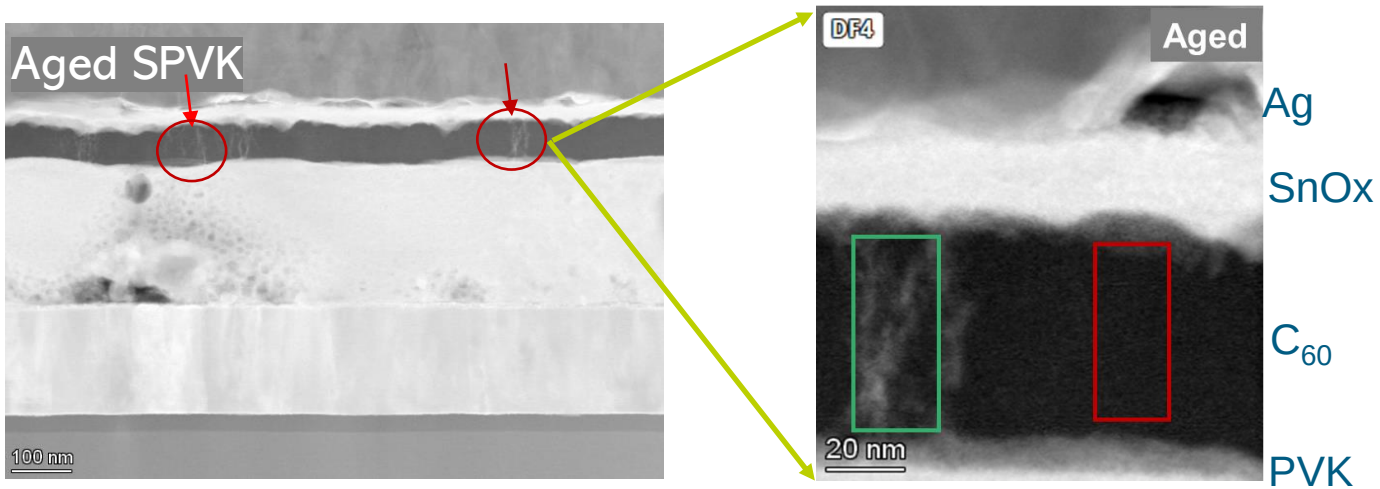
Supported by Dr. Minjian Wu and Dr. Xin Zhou

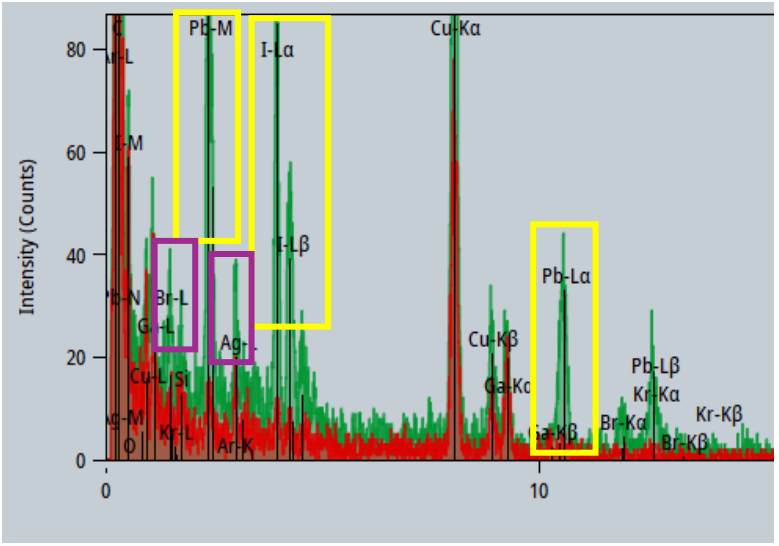


❑ I and Br ions accumulated at SnO_2 layer.

Samples were aged 1000 hrs under a continuous aging condition.

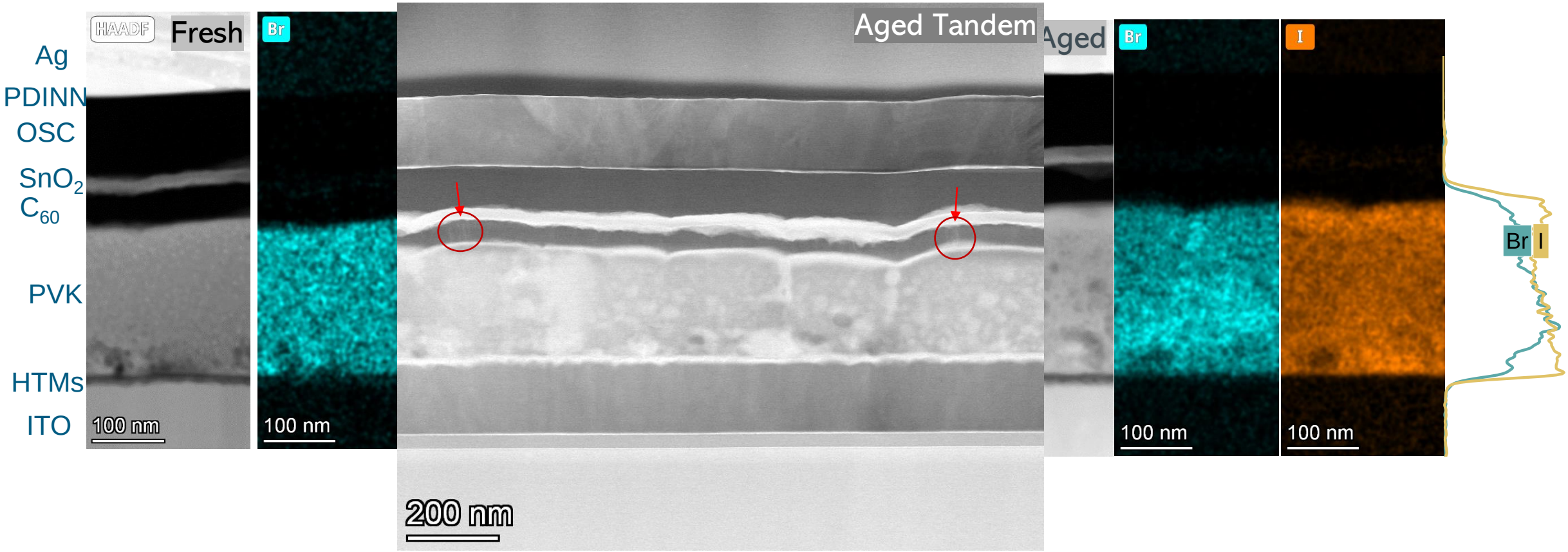
Visible Ion Diffusion Chanels in C_{60}





- “Flocculent-like” features observed in the C_{60} layer for aged SPVK.
- The trace of I, Br, Pb, and Ag in the “flocculent-like” area.

EDXA Mapping of P-O TSCs



- Organic layers including PEDOT:PSS and polymer active layer block the ion diffusion
- Br ions and I ions are slightly redistributed in the bulk.

In preparation

Summary

For n-i-p P-O TSCs:

- the Au-related parasitic absorption is shifted outside the absorption window of rear organic absorber in the near-infrared (NIR) region by controing the shape of Au NPs.
- A high PCE of 25.36% has been achieved.

For p-i-n P-O TSCs:

- A simply metal (oxides)-free ICL is designed by optimizing the ALD process.
- P-O TSCs with high-performance (25.22%) and stability have been realized.