Low-Cost and Scalable Production of Perovskite Mini-Modules

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Wright Center for Photovoltaics Innovation and Commercialization (PVIC)

2022 PACT Workshop
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PEROVSKITE RESEARCH AT UT

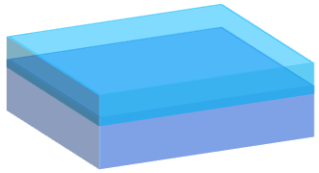
- State-of-art equipment for perovskite fabrication and characterization
- A diverse team with complementary expertise, including 5 tenure faculty, 3 research professors, 3 postdocs, 12 graduate students, and 3 undergraduates (25+ researchers)
- Academic and industrial collaboration (NREL, First Solar, UW, US-MAP, PACT, LLNL, AFRL, NRL, Ameslab)
- High-efficiency perovskite solar cells (>24% for single-junction & >26% for perovskite tandems)
- High-throughput and scalable perovskite mini-modules (> 100 cm^2) production.

CLIMATE CONTROL ROOM

The climate control room at PVIC, The University of Toledo

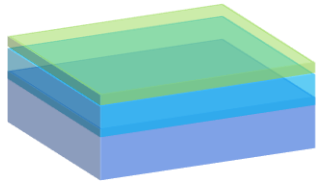
- Room area: 376 ft^2 (35 m^2)
- Maintaining at 25 °C and 25% RH
- Slot-die coater, blade coater, spin coater, annealing station, soldering station, solar simulator, etc.
- Ventilation connected to each processing facility

MODULE FABRICATION PROCESS



Glass/FTO

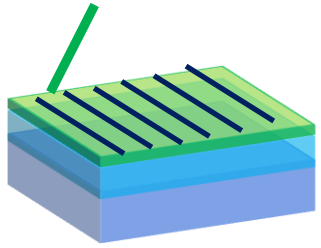
Blade-coating or **slot-die coating** HTL



Glass/TCO/HTL

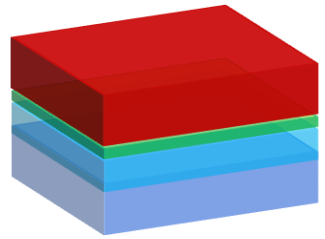
P1 scribe

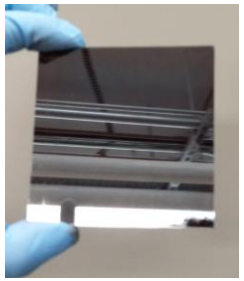
532 nm laser



Glass/TCO/HTL

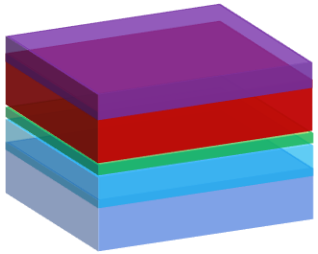
Blade-coating or **slot-die coating** perovskite





Glass/TCO/HTL/PVSK

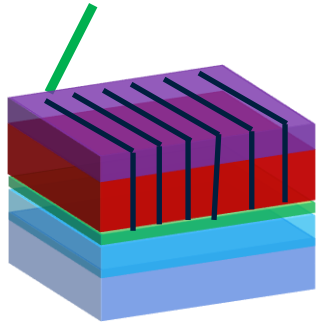
PVD ETL



Glass/TCO/HTL/PVSK /ETL

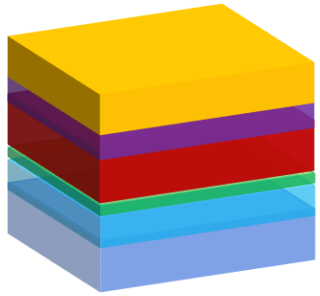
P2 scribe

532 nm laser



Glass/TCO/HTL/PVSK /ETL

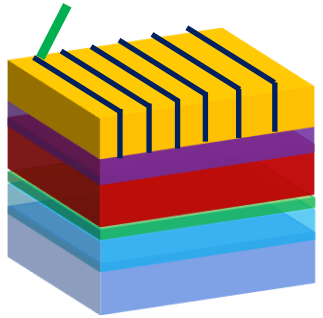
PVD Metal



Glass/TCO/HTL/PVSK /ETL/Metal

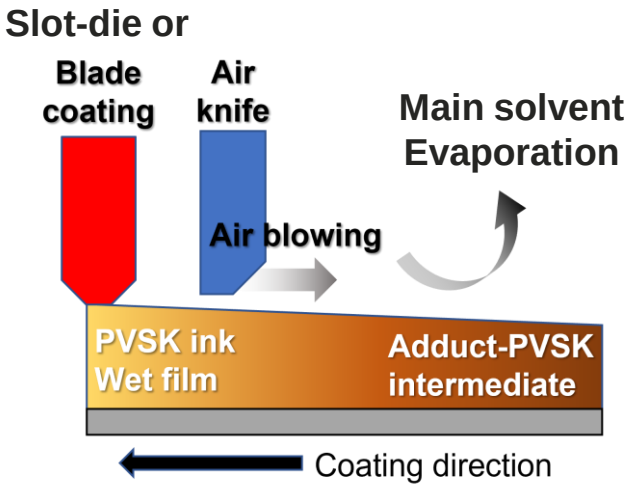
P3 scribe

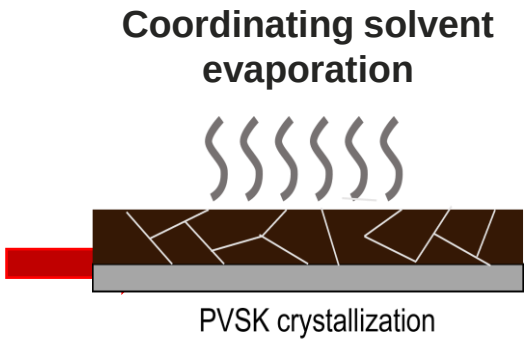
532 nm laser

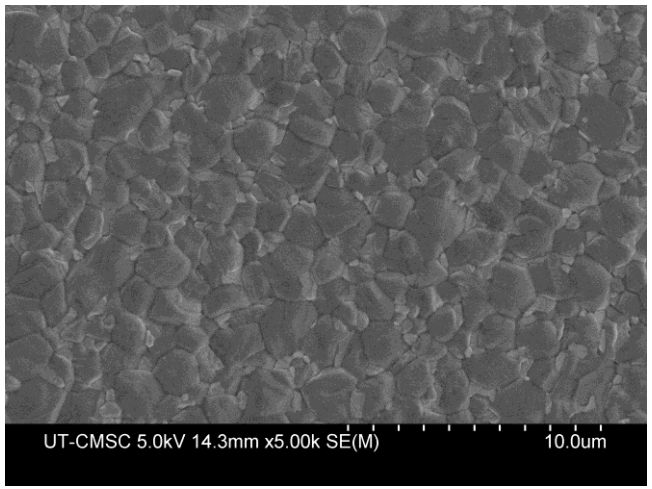


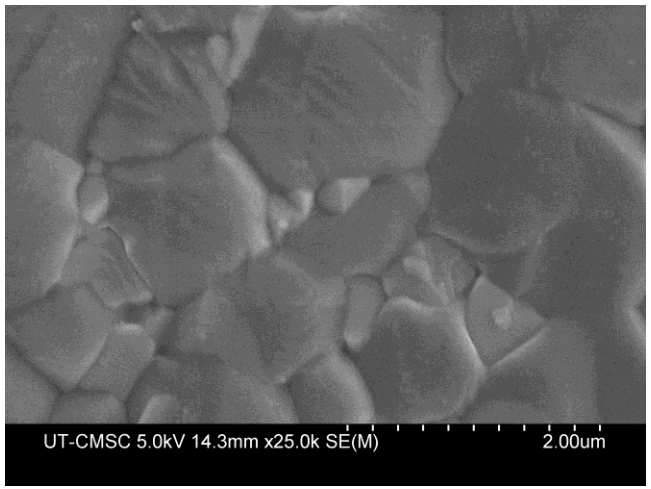
Glass/TCO/HTL/PVSK /ETL/Metal

PEROVSKITE PREPARATION



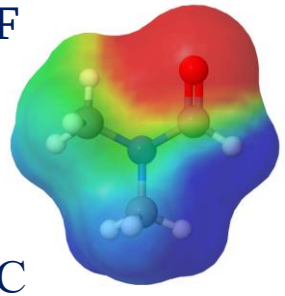






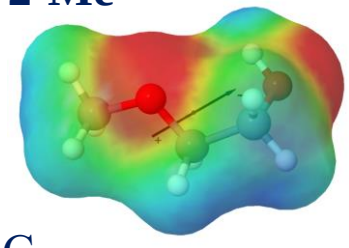
- **Perovskite composition:**
  - 95% $FAPbI_3$ + 5% $MAPbBr_3$
  - 95% $FAPbI_3$ + 5% $CsPbI_3$
- **Main Solvents:**

DMF



BP: 153 ˚C

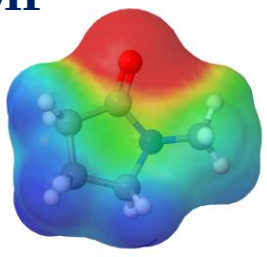
2-Me



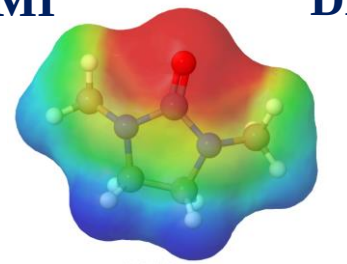
BP: 124 ˚C

- **Coordinating Solvents:**

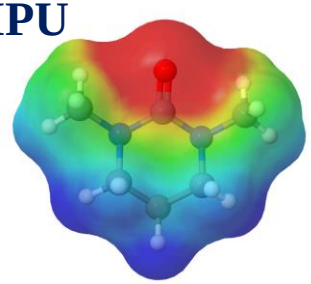
NMP



DMI

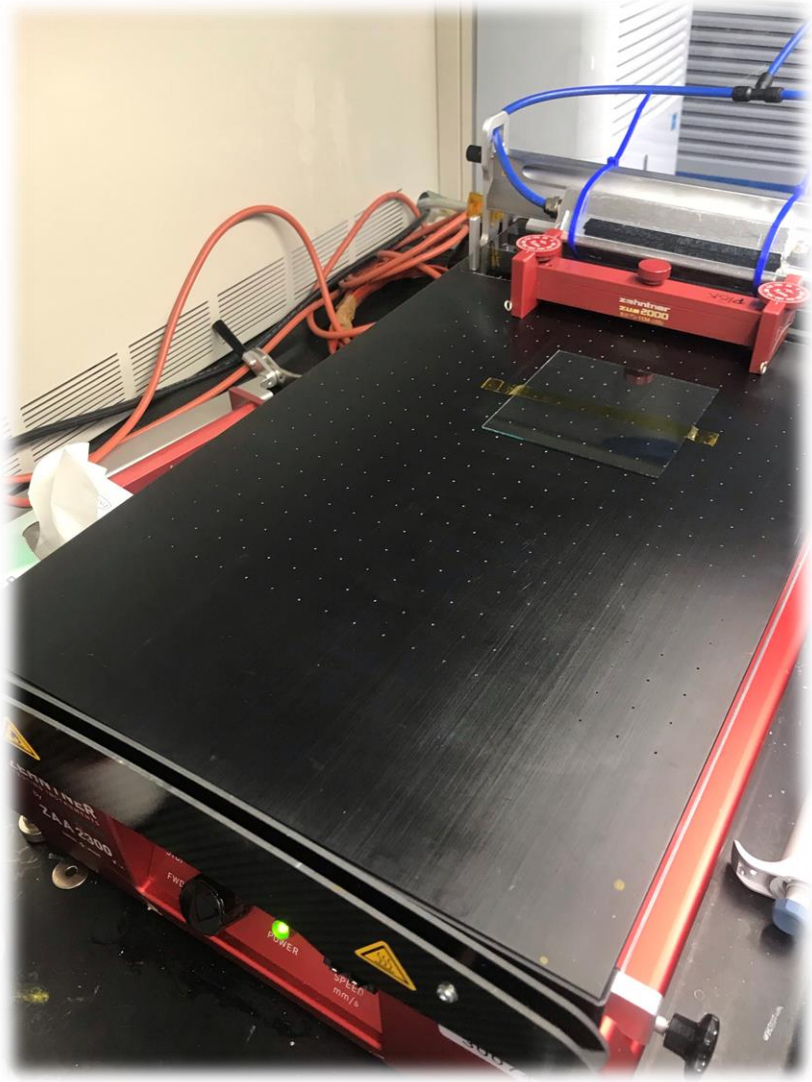


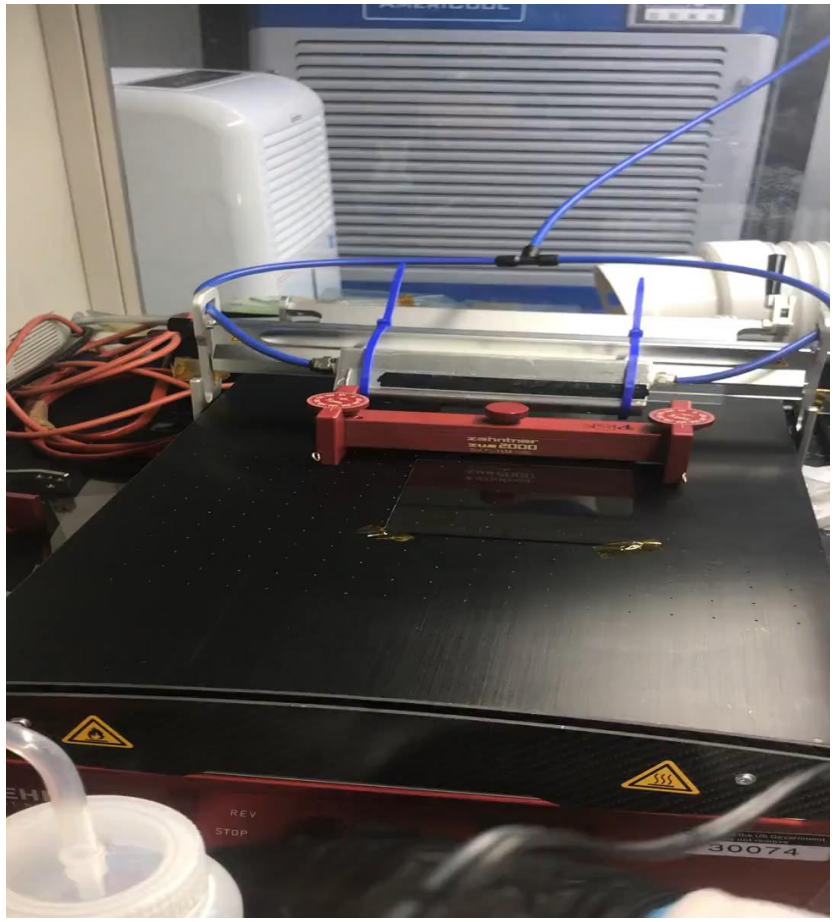
DMPU



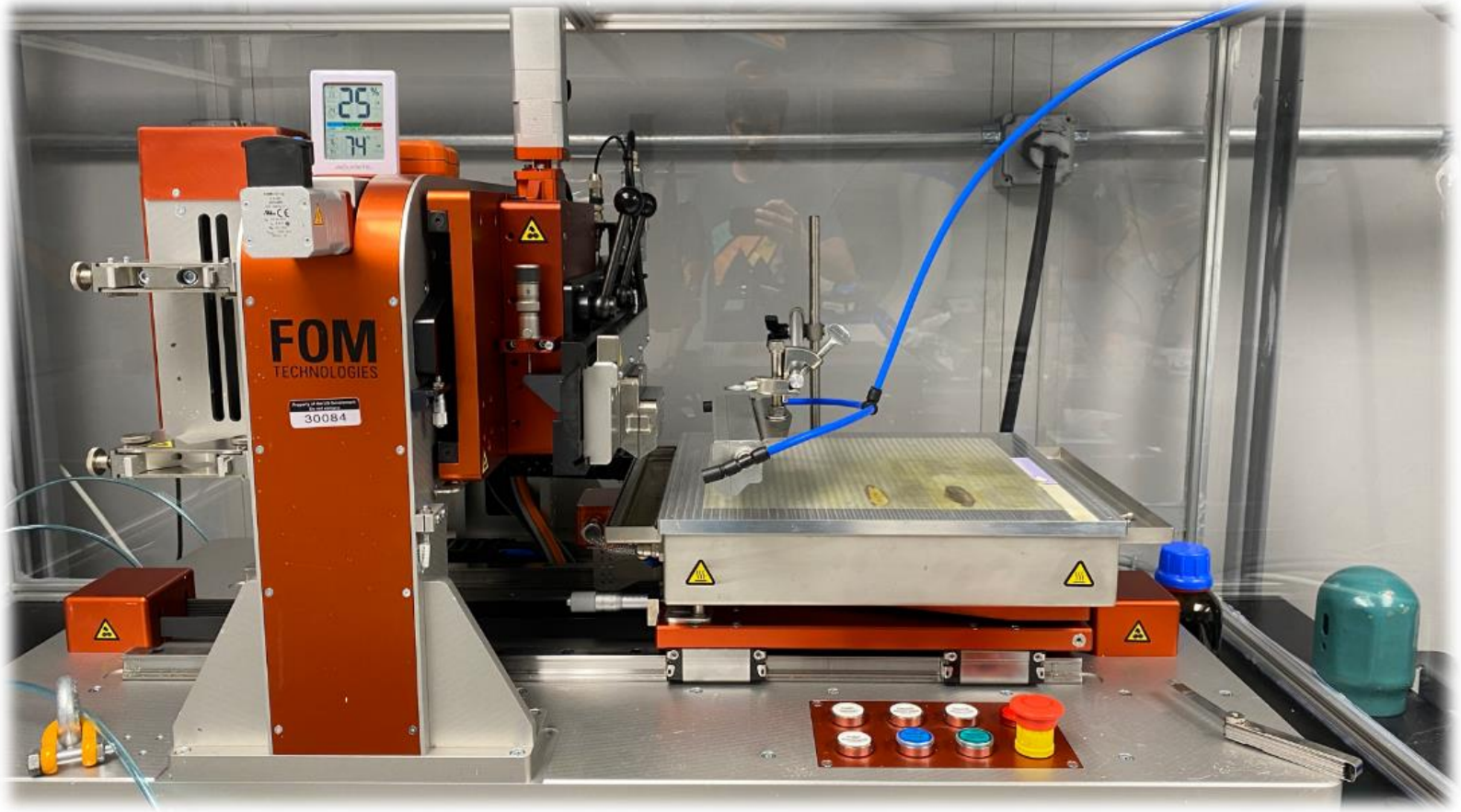
DMF: dimethylformamide; 2-Me: 2-methoxyethanol;
NMP: N-Methyl-2-pyrrolidone; DMI: dimethyl-2-imidazolidinone; DMPU: dimethylpropyleneurea

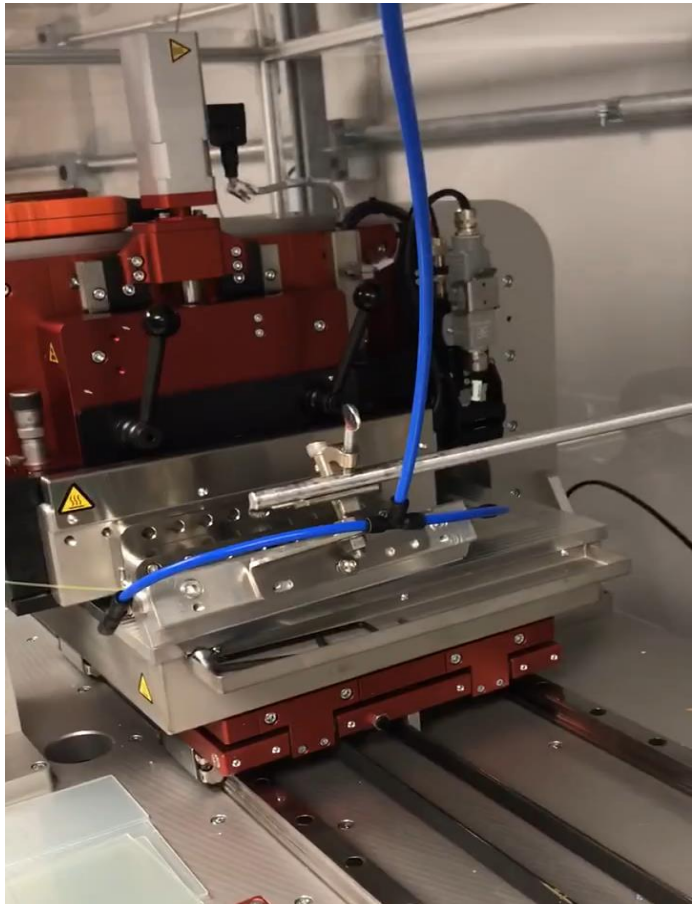
BLADE COATING





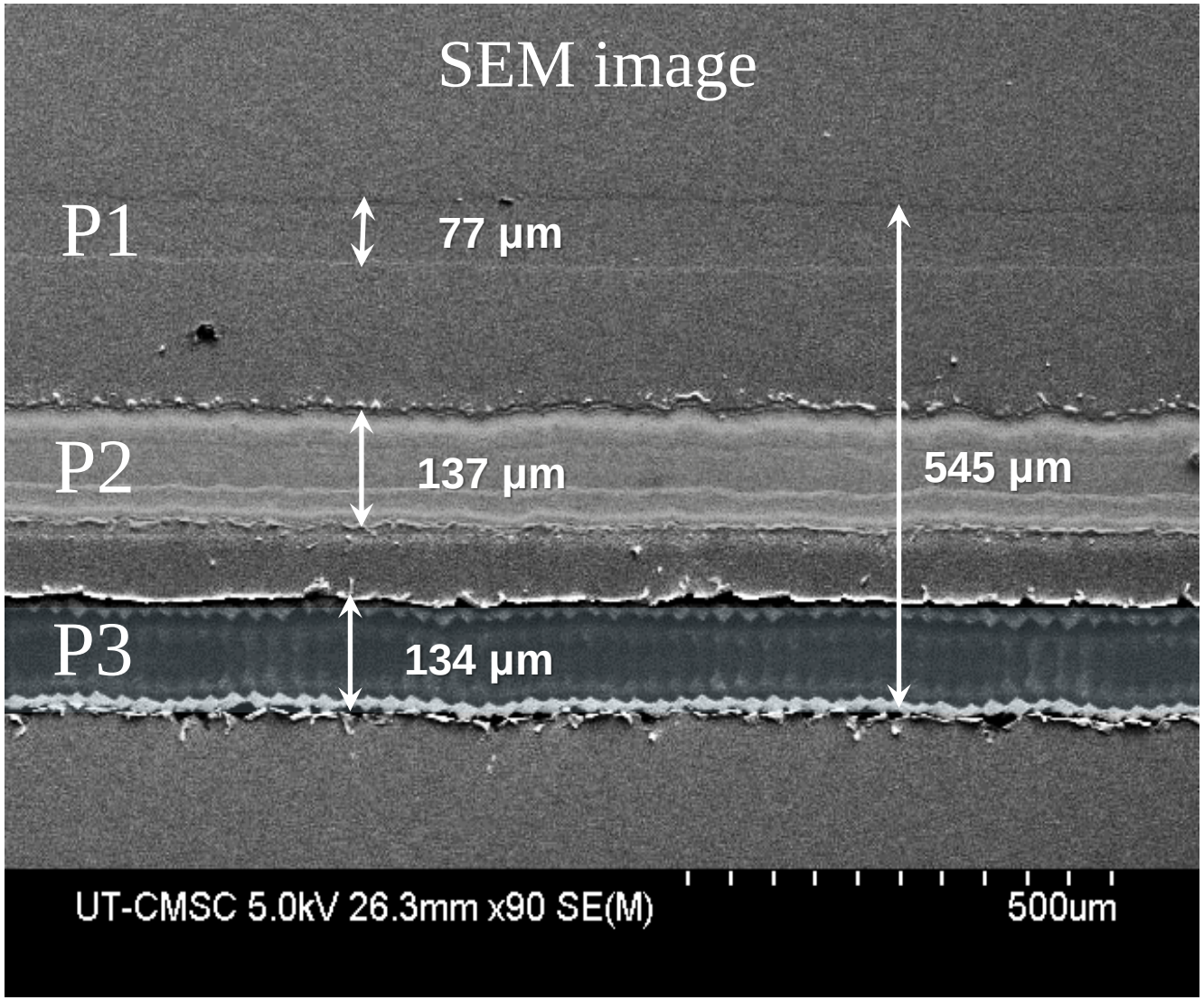
SLOT-DIE COATING

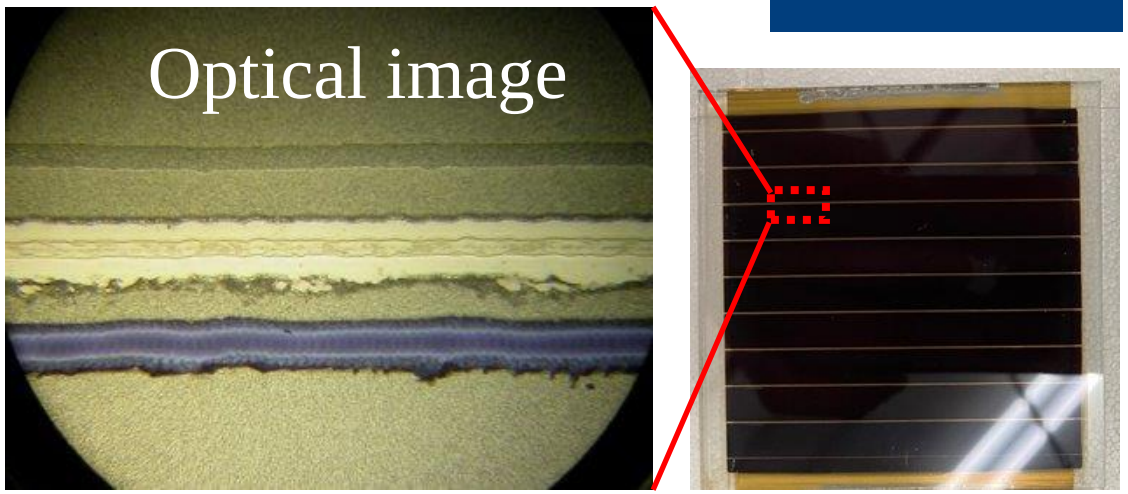


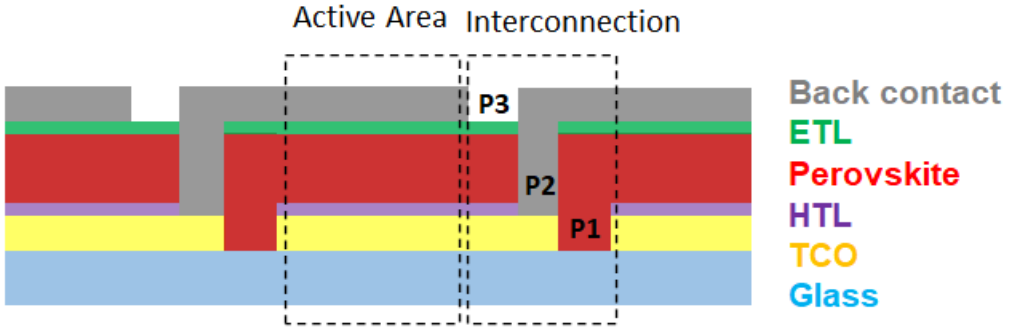


- Produce perovskite films using a scalable slot-die coating technique under ambient conditions.

MONOLITHIC INTEGRATION



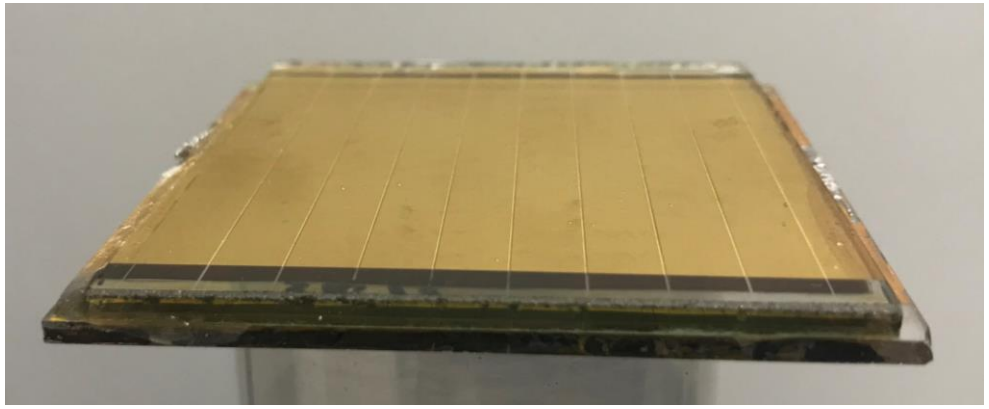




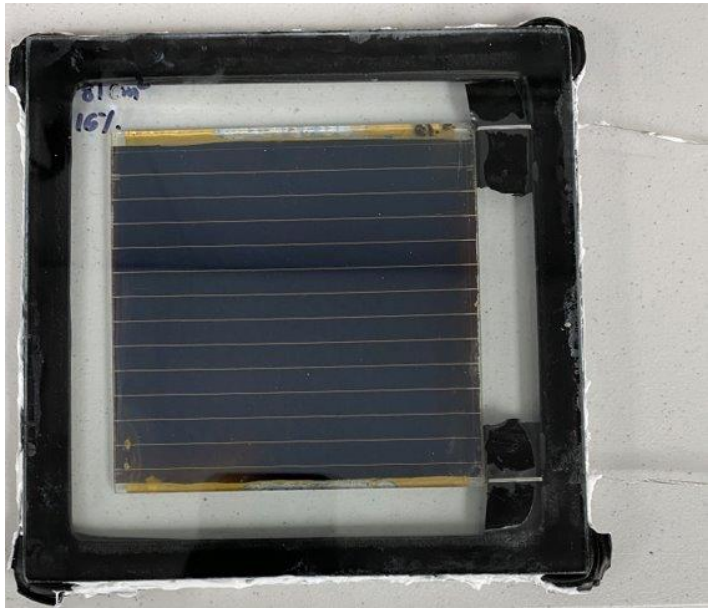
- Stripe Cell width = 6.6 mm
- Geometric FF= 93%

MODULE PACKAGING

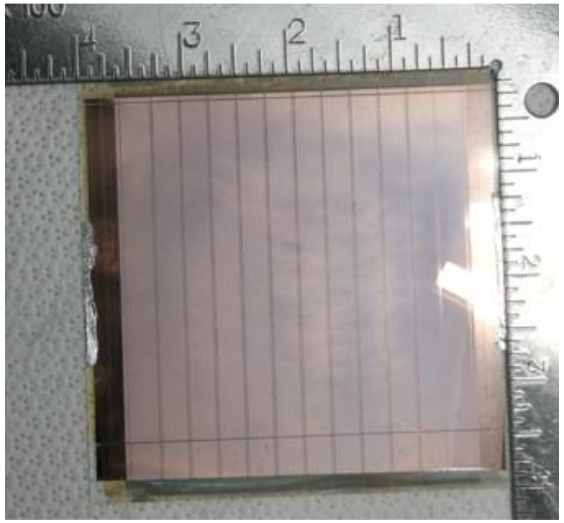
UV-curable epoxy

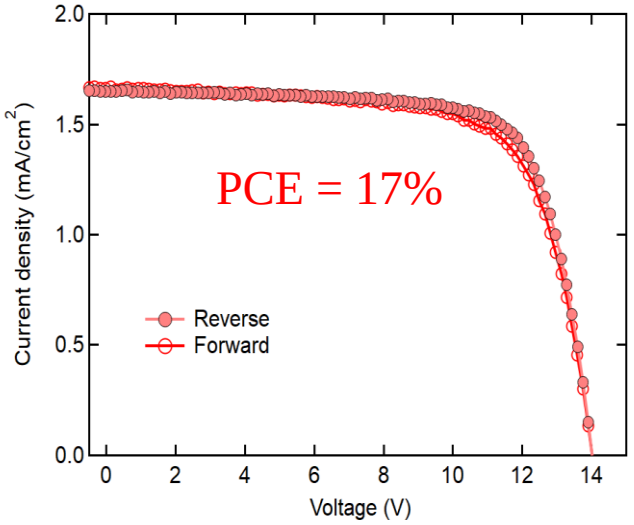


PIB edge sealing

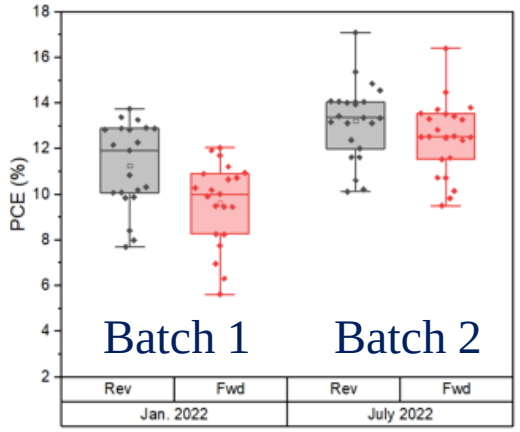


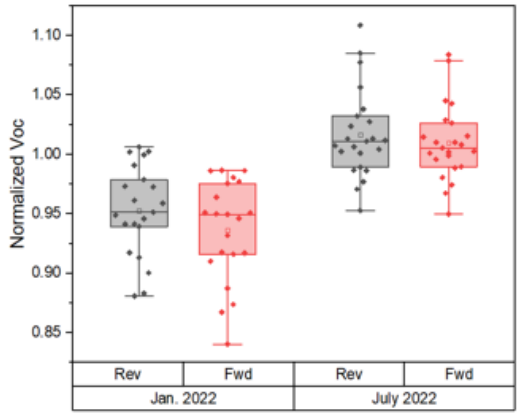
PIN PEROVSKITE MINI-MODULES

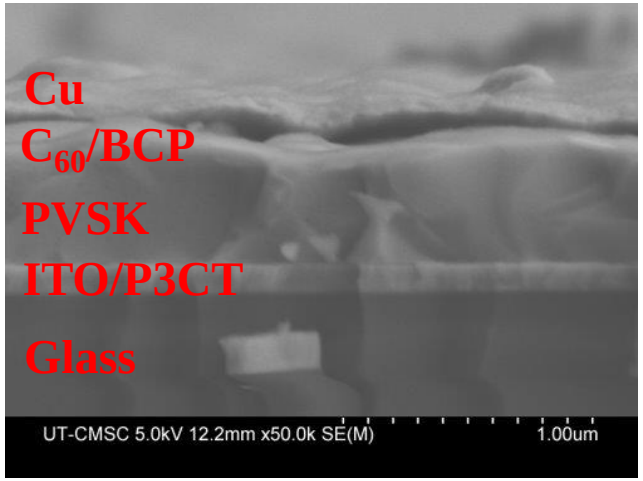


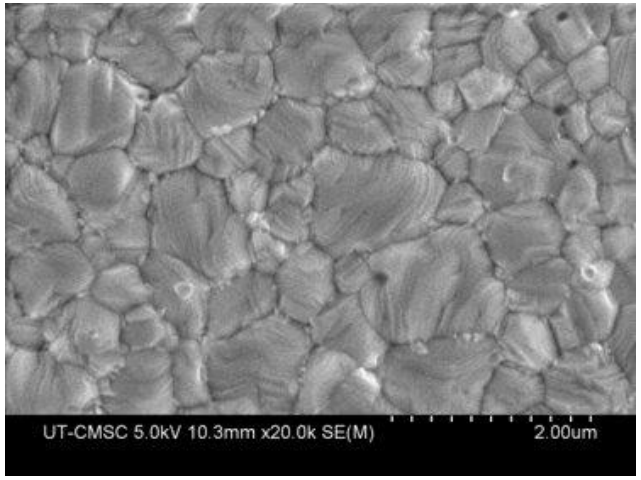


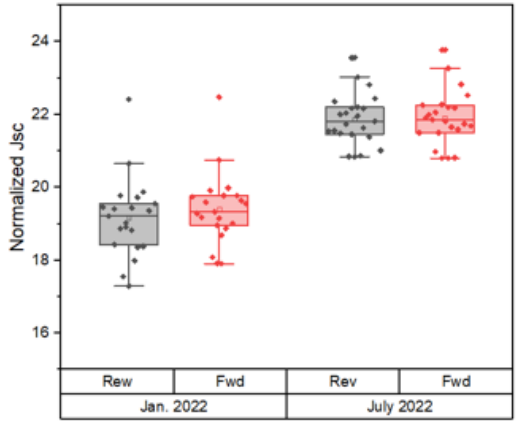
Statistics of 4” modules sent to PACT

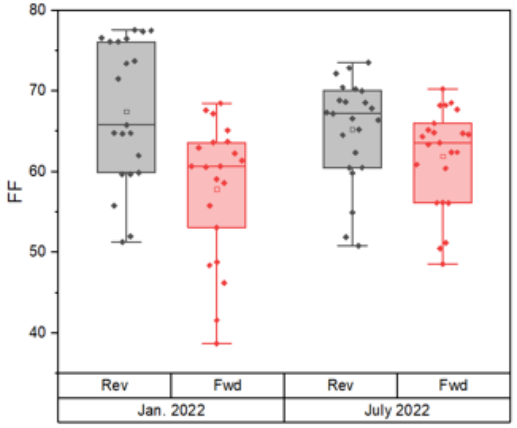




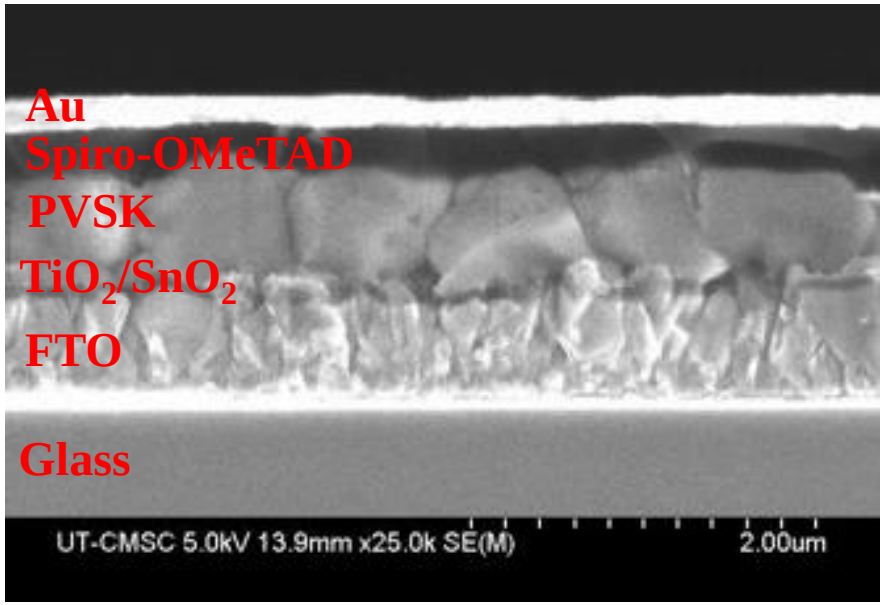


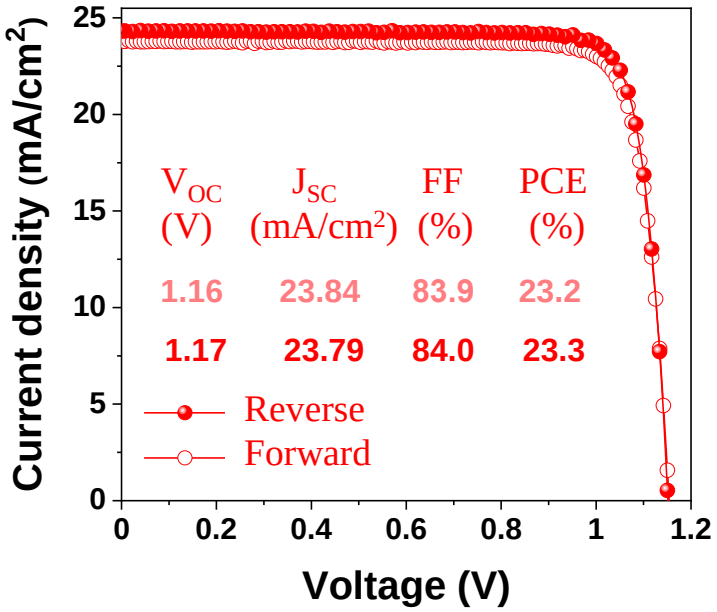


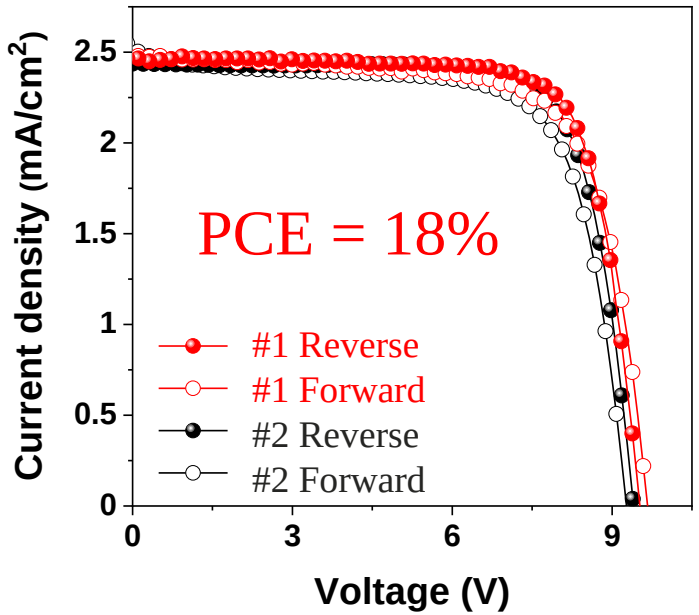


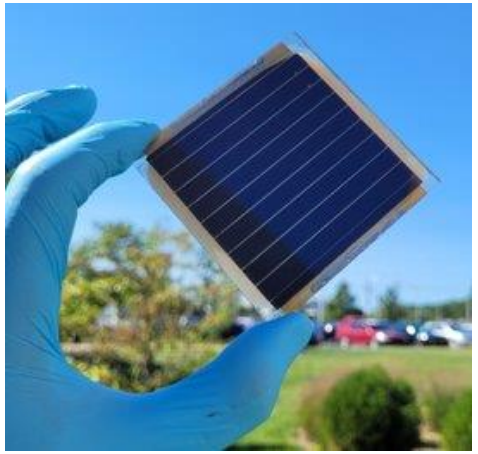


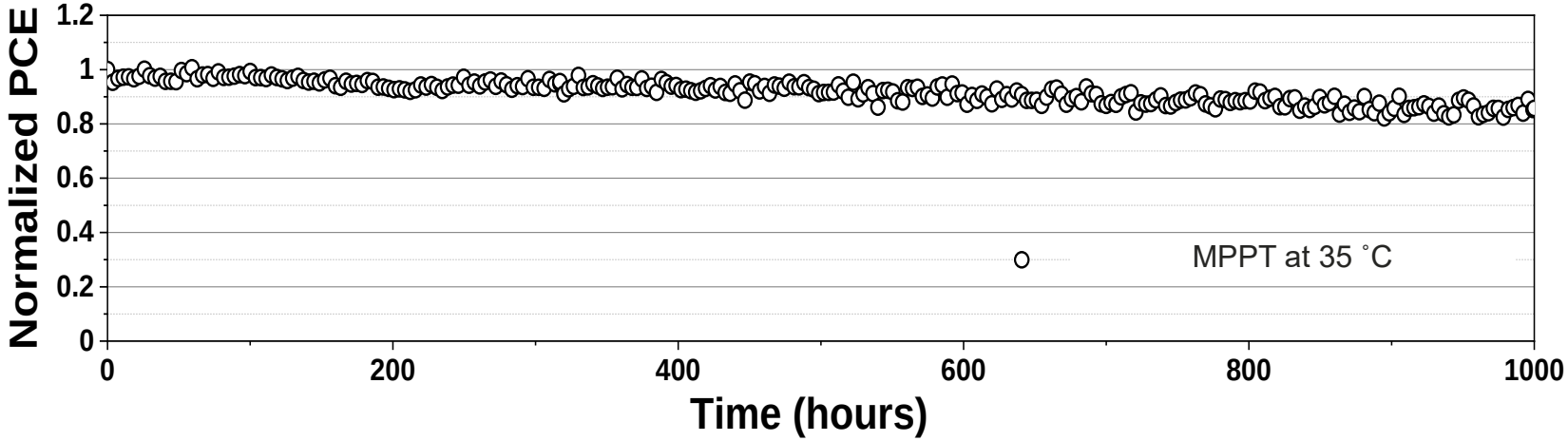
NIP PEROVSKITE MINI-MODULES





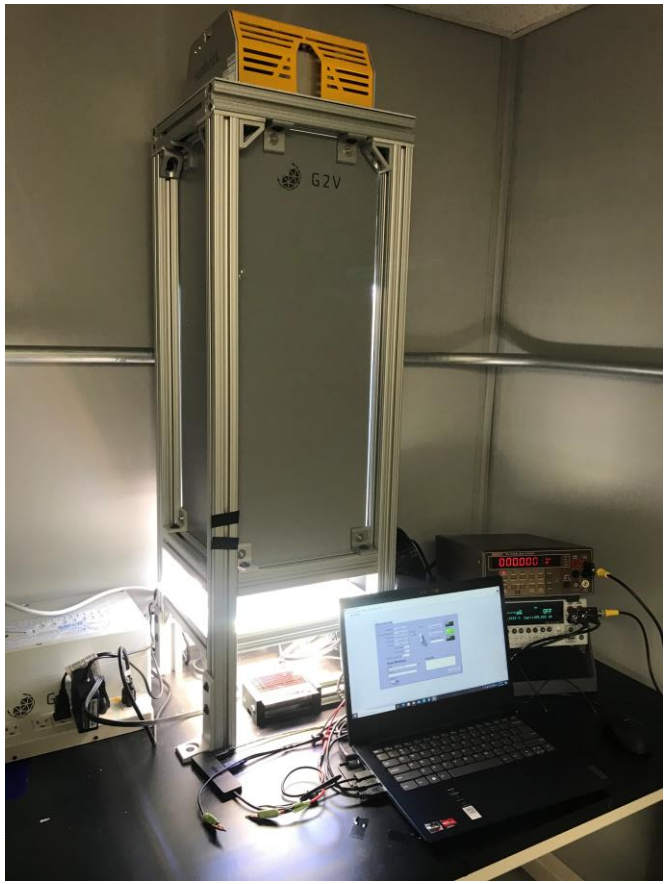






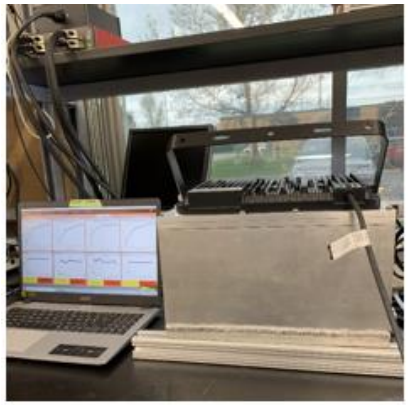
STABILITY MEASUREMENT

LED solar simulator



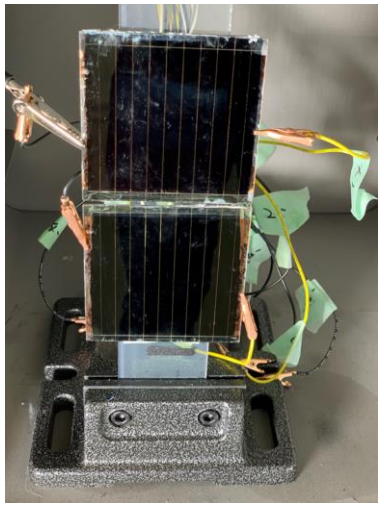
Illumination area:
300 mm x 300 mm

Multi-channel MPPT



Thermal cycling

Damp-heat chamber



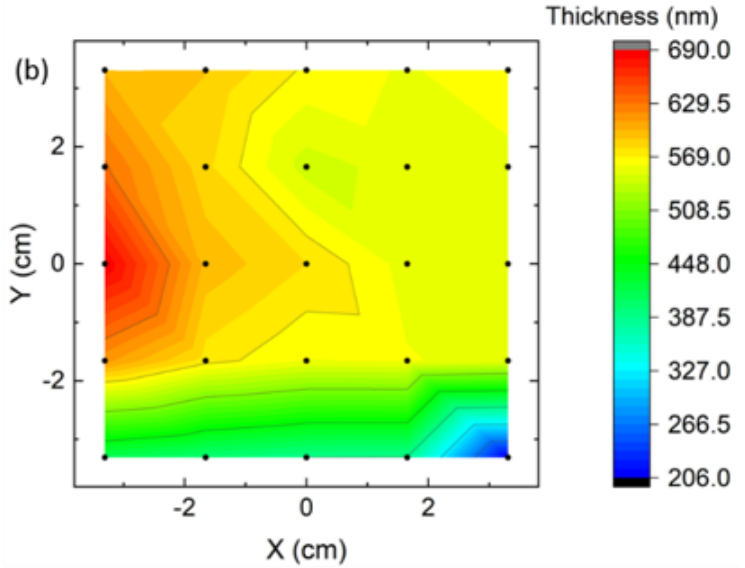
1,500 hours aging at 85 °C
under one-sun illumination

CHARACTERIZATION TOOLS

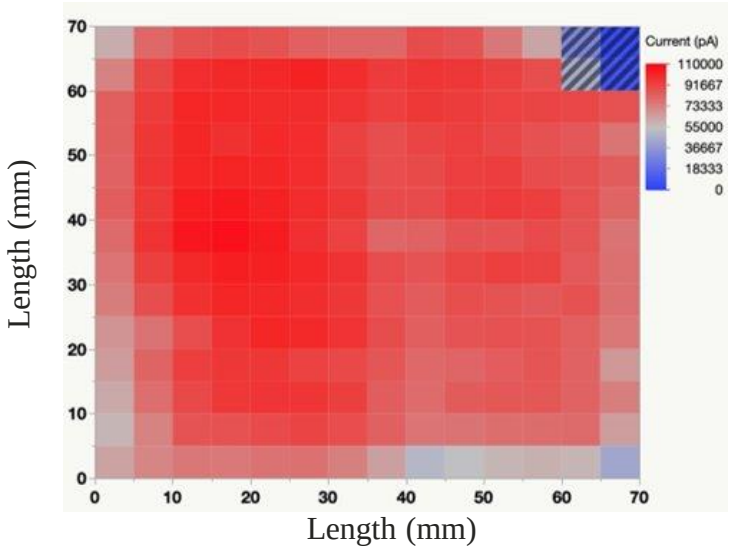
WRIGHT CENTER for PHOTOVOLTAICS INNOVATION AND COMMERCIALIZATION

THE UNIVERSITY OF TOLEDO

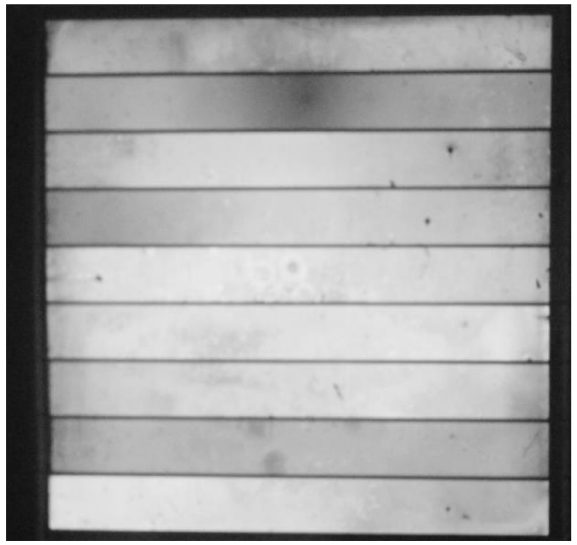
Ellipsometry



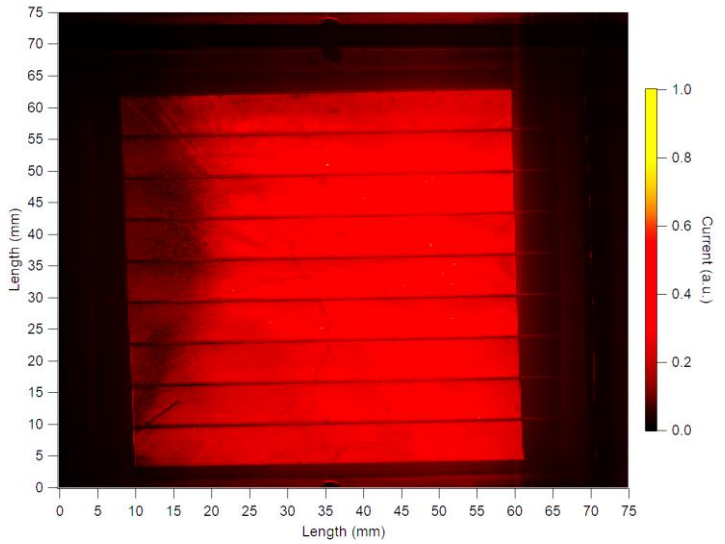
ERE (iV_{OC})



EL



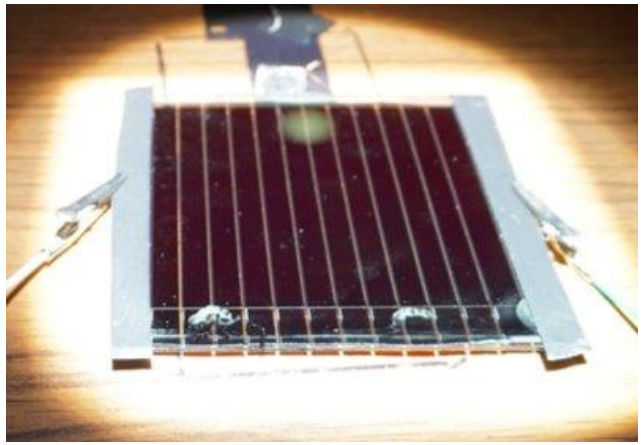
LBIC (EQE)



MODULE DEGRADATION

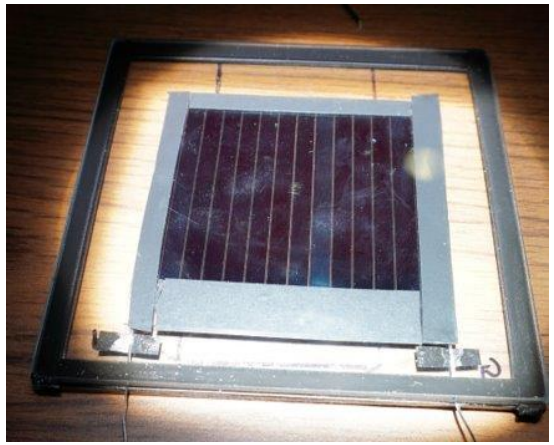
Storage in ambient air

Fresh



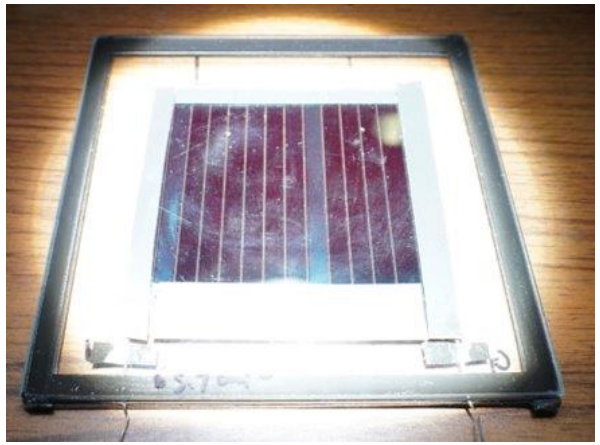
PCE = 14.3%

1 week



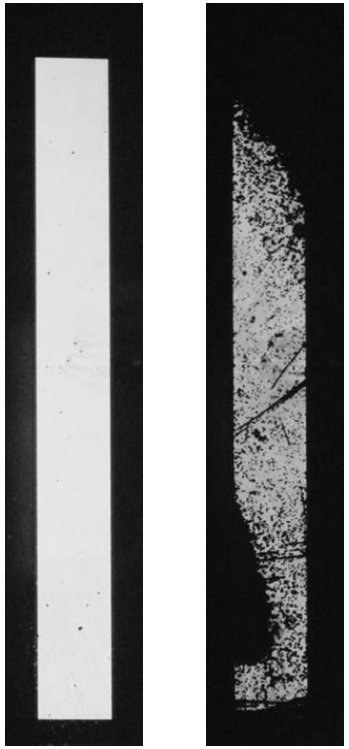
PCE = 13.6%

2 weeks



PCE = 8.6%

EL



Fresh Degraded

- Heterogeneous degradation

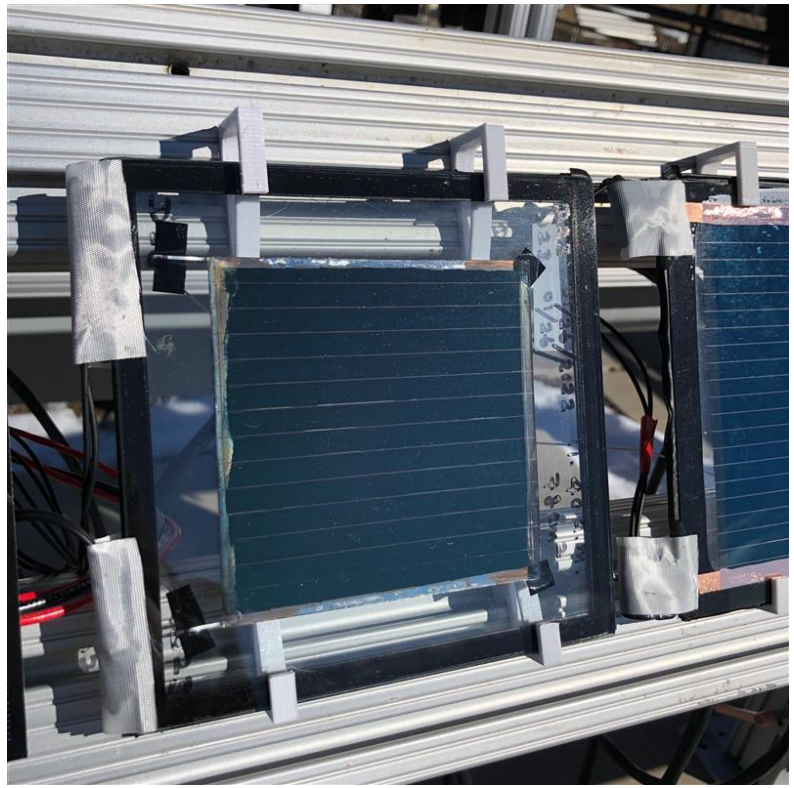
MONITORING DEGRADATION

An example of an in-situ degradation study

- Unencapsulated NIP module (37.5 cm^2)
- 15% initial efficiency
- 9 mA /9.29V stress
- 4.5 h stressing
- ~1% efficiency at end

PACT ACTIVITIES

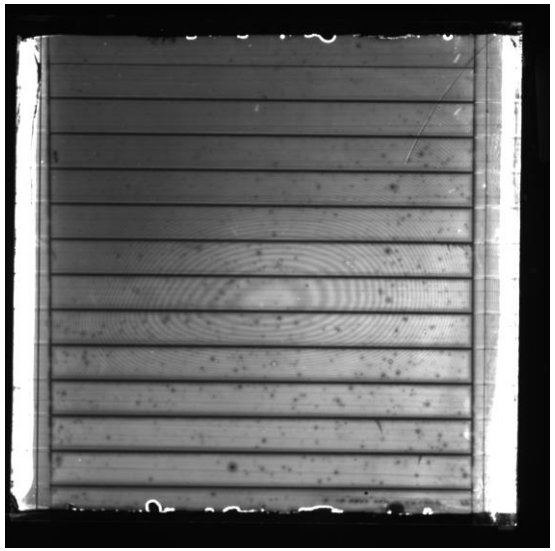
UT module in a PACT's outdoor test



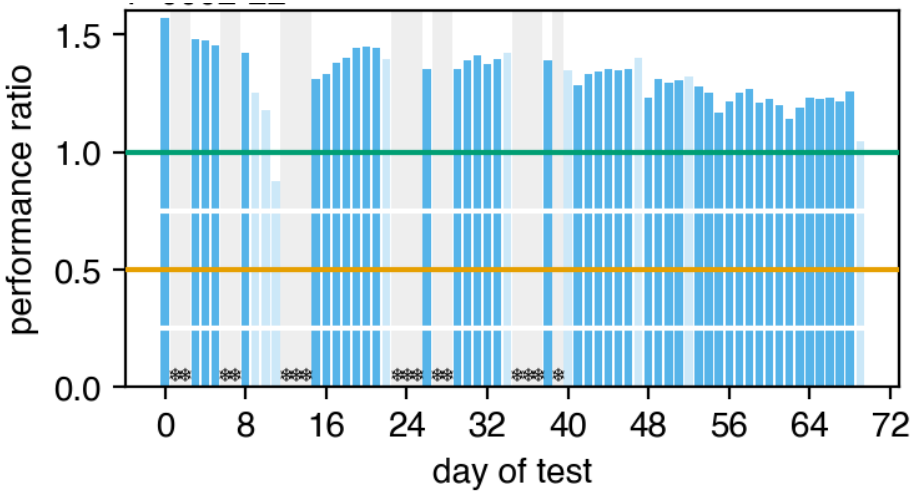
Courtesy of Laura Schelhas (NREL)

- 22 modules were sent to PACT in January.
- 25 modules were sent to PACT in July.
- Smaller and more frequent batches are scheduled.
- Indoor and outdoor reliability testing (including light & temperature, UV-A exposure, thermal cycling, and damp heat).
- Various characterization tools: EL, PL, DLIT, SEM, X-ray, Raman/FTIR, etc.

PL image of a UT module



Outdoor performance of a UT module



PACT Perovskite PV Accelerator for Commercializing Technologies

THE UNIVERSITY OF TOLEDO 1872

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Thank you for your attention!

Acknowledgements

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