High-Efficiency Perovskite-based Thin-Film Solar Cells and Mini-modules

Ioanna Vareli, Huagui Lai, Federico De Giorgi, Jincheng Luo, Severin Siegrist, Radha Kothandaraman, Shiro Nishiwaki Romain Carron, Ayodhya N. Tiwari, Fan Fu

Laboratory for Thin Films and Photovoltaics, Empa - Swiss Federal Laboratories for Materials Science and Technology, Überlandstrasse 129, 8600 Dübendorf, Switzerland

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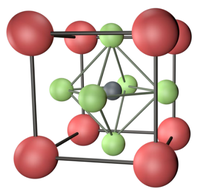
Perovskite solar cells

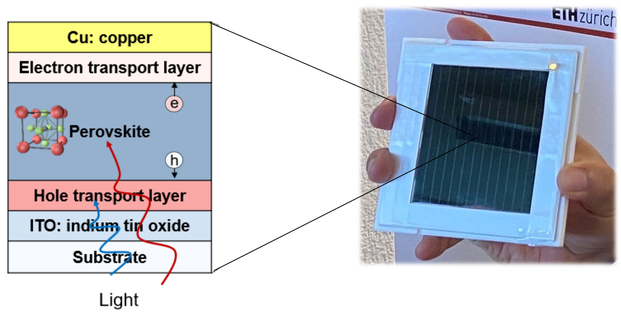
❑ Materials & devices

Crystal structure: ABX_3



A: MA, FA, Cs, Rb
B: Pb, Sn
X: I, Br, Cl

✓ Low cost and low CO_2 footprint
✓ Broadly tunable bandgap (1.2-3.0 eV)
✓ Thin, flexible, lightweight
✓ Colorful & see-through



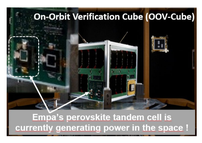
10 cm x 10 cm

❑ Potential applications

BIPV & AgriVoltaics

Indoor PV & IoT

Aerospace



Mobility

HZB Helmholtz Zentrum Berlin
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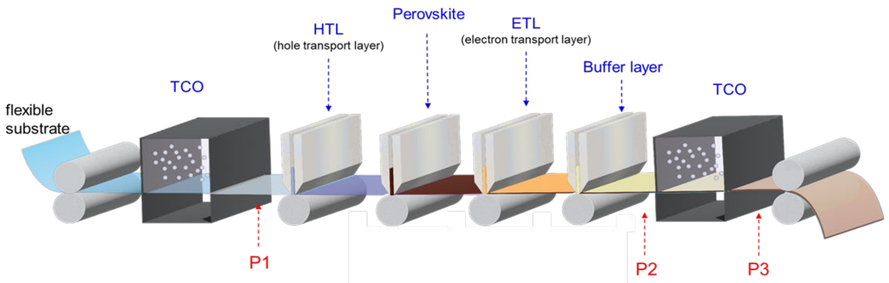
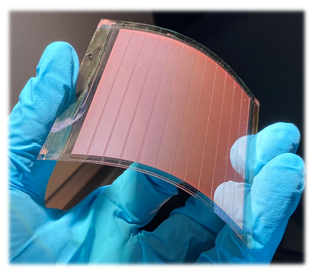
RAPID CUBES

❑ Our vision: High-throughput **R2R** manufacturing **of flexible Perovskite Solar Modules**

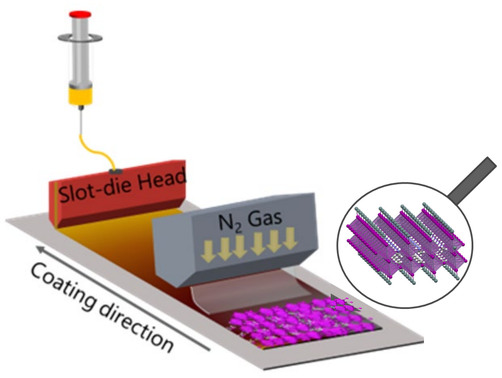




One example of in-line R2R manufacturing of flexible perovskite module using the slot-die coating. Other industrial scalable methods, such as the vacuum-based method or vacuum/solution hybrid process are also possible.

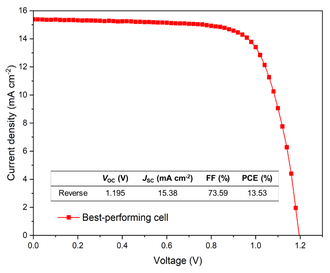
Upscaling Perovskite Solar Cells

❑ Slot-die Coating (Solution-based method)

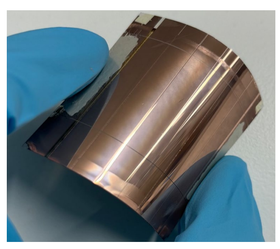


✓ Solution-based method
✓ High performance
✓ High speed & low temperature deposition
✓ Facile composition, additive, and passivation engineering
✓ Compatible with high throughput R2R process
× Toxic solvent
× Edge effect

■ P-i-n perovskite solar cells (10 cm x 10 cm^2)

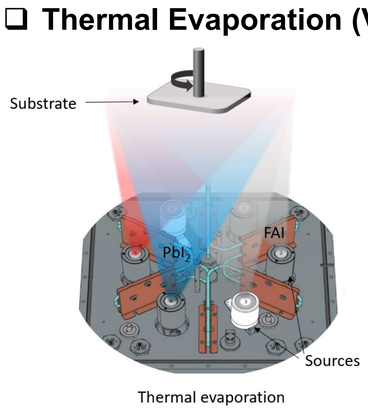


	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)
Reverse	1.195	15.38	73.59	13.53



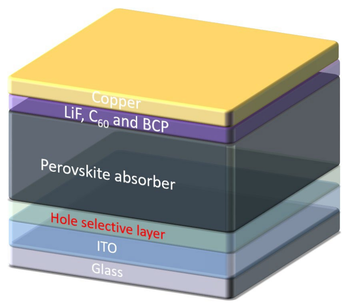
■ Flexible WBG perovskite module achieving a PCE of 13.53%.

❑ Thermal Evaporation (Vacuum-based method)

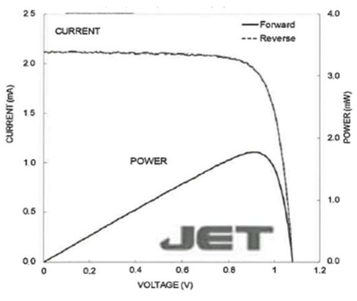


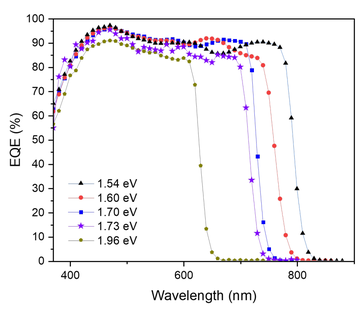
Thermal evaporation

✓ Solvent free
✓ Conformal coating
✓ Controllable thickness
✓ Industrial mature technology
× Challenges in composition and passivation engineering
× Reproducibility



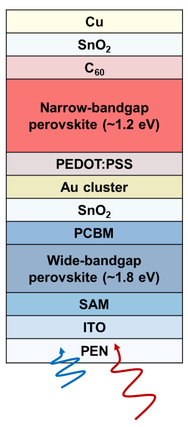
✓ **Thermally evaporated p-i-n** perovskite solar cells over broad range of **bandgaps**.
✓ Certified record efficiency of **20.2 %** @ 0.09 cm^2

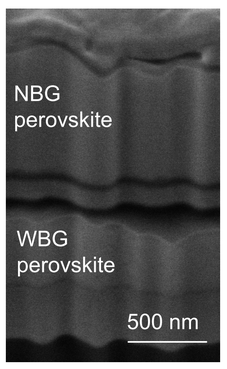


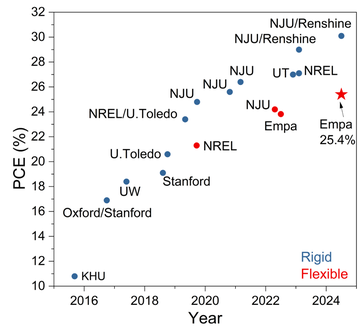


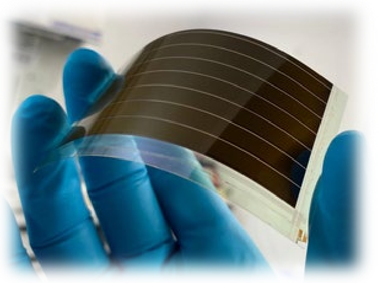
Thin-film tandem solar cells with record efficiencies

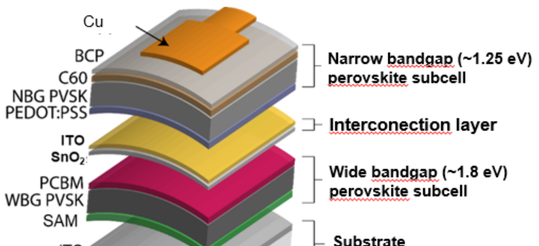
❑ Flexible 2 terminal all-perovskite tandem solar cell

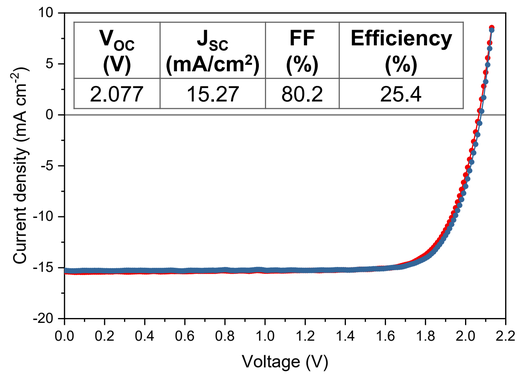








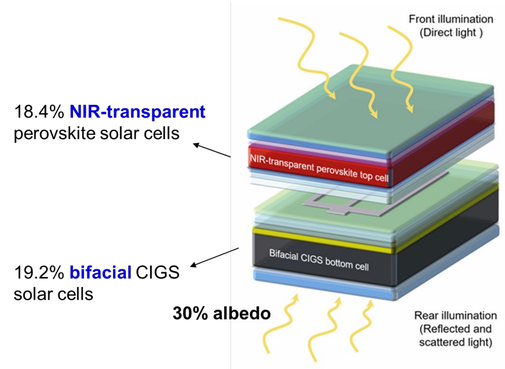


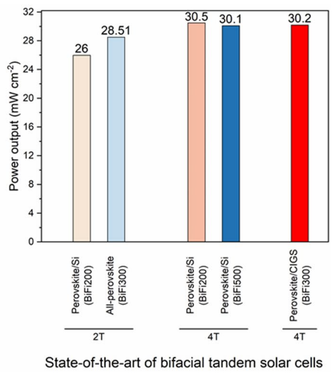


V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)	Efficiency (%)
2.077	15.27	80.2	25.4

➢ We demonstrate >25% flexible all-perovskite tandem solar cell, which is the highest value for flexible polycrystalline thin-film solar cells reported so far

❑ Bifacial 4- terminal perovskite-CIGS tandem solar cell





State-of-the-art of bifacial tandem solar cells

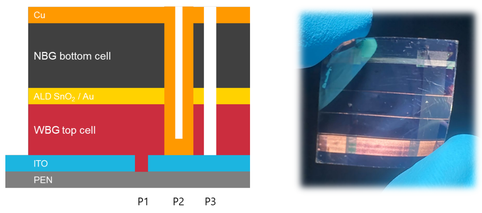
➢ Power output > 30 mW/cm^2 under 30% albedo

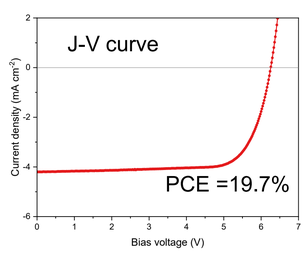
➢ Perovskite-CIGS thin-film tandems could reach similar performance as perovskite-silicon based tandems

Tandem mini-modules

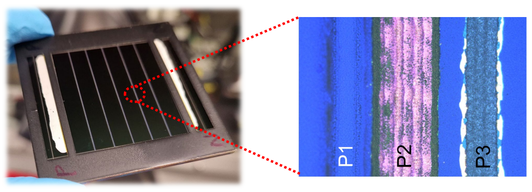
❑ Monolithic interconnection perovskite module

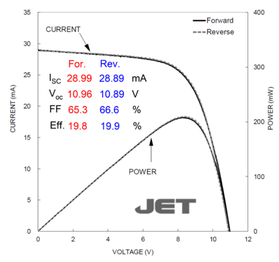
➢ **Flexible all-perovskite tandem solar mini-module**





➢ **2T perovskite-CIGS tandem mini-module**





Conclusions

✓ Perovskite PV technology is ideal for a broad range of applications at low cost, including indoor PV & IoT, BIPV & AgriVoltaics, mobility, and ultra-high efficiency tandems for space applications.
✓ We demonstrate high-efficiency perovskite solar cells by using various industry-scalable methods, including vacuum-based and solution-based methods.
✓ We demonstrate flexible 2T all-perovskite tandem solar cells with power conversion efficiency over 25%, which are the highest values among all polycrystalline thin-film solar cells reported so far.

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Hi-BITS

Corresponding author: Ioanna Vareli, ioanna.vareli@empa.ch, Phone: +41 77 23 666 00