

Perovskite Module Scaling and Stability



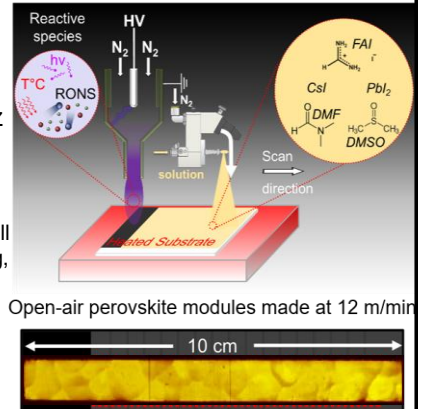
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Former members: Oliver Zhao, Michael Hovish, Will Scheideler, Florian Hilt, Adam Printz, Jinbao Zhang, Andrew Sleugh, Hannah Elmaraghi

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Open-air perovskite modules made at 12 m/min

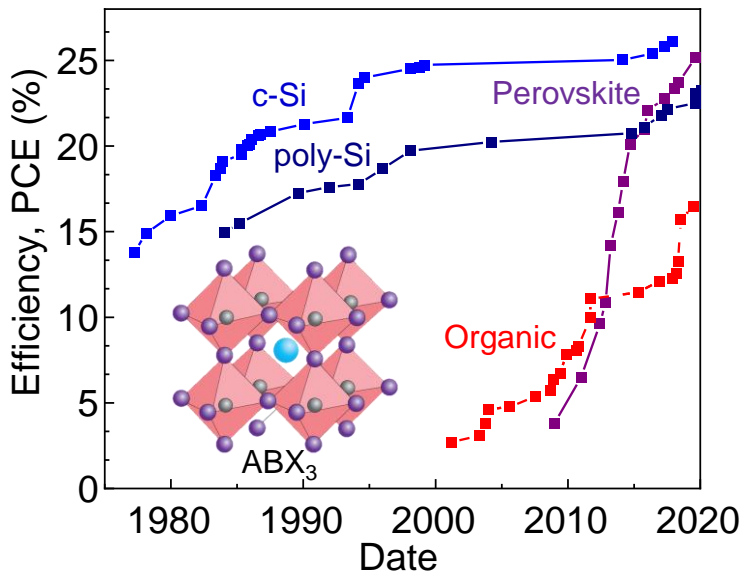
Work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number DE-EE0008559.

Previous seed support by the Stanford Precourt Energy Institute and the Stanford Global Climate and Energy Program.

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1

Rapid Rise of Perovskite Solar Cells: Processing, Cost and Efficiency



Tunable composition

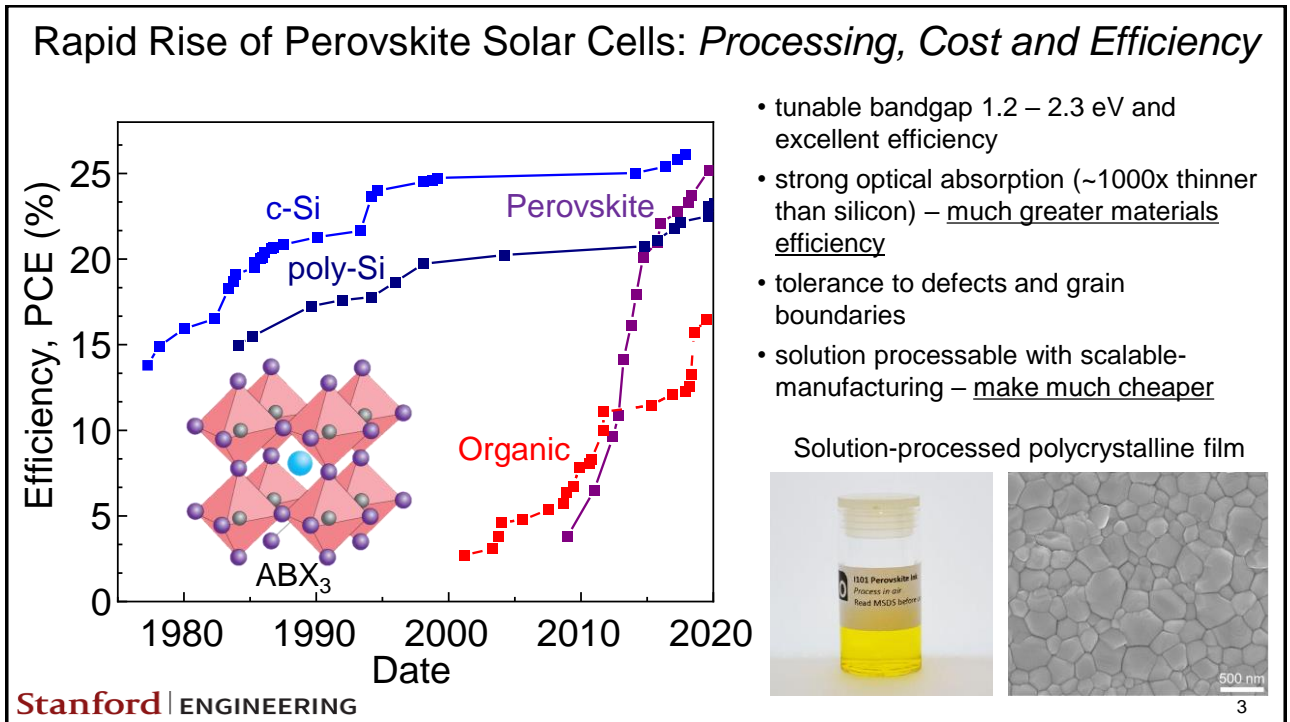
- A** methylammonium (CH_3NH_3^+), formamidinium ($\text{CH}_2(\text{NH}_2)_2^+$), Cs^+ , Rb^+ ...
- B** Pb^{2+} , Sn^{2+}
- X** I^- , Cl^- , Br^-

Solution-processed polycrystalline film

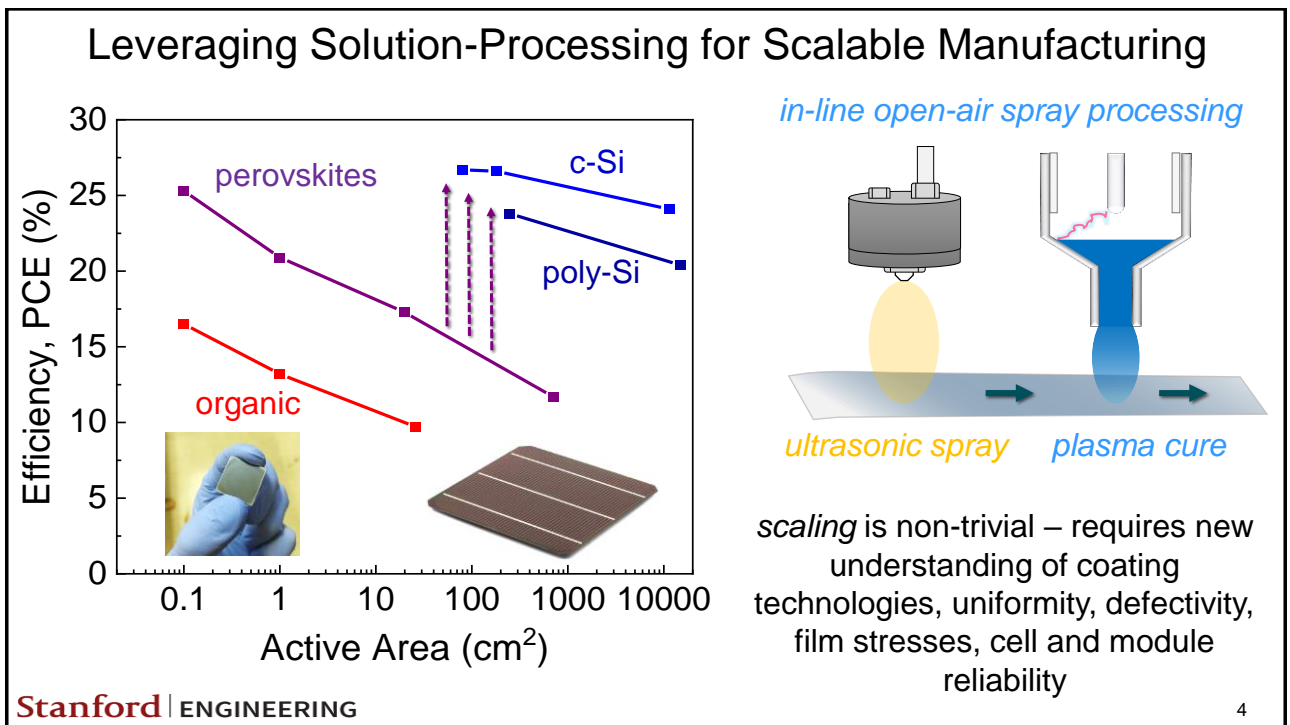


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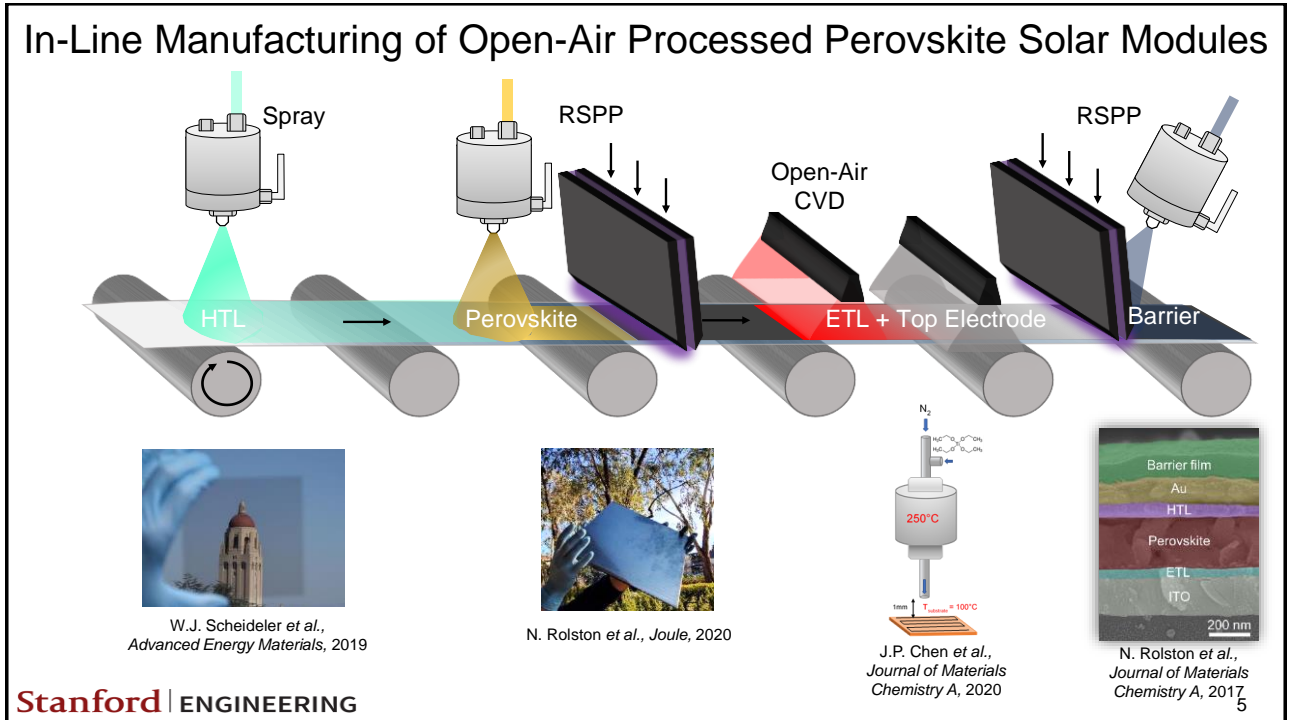
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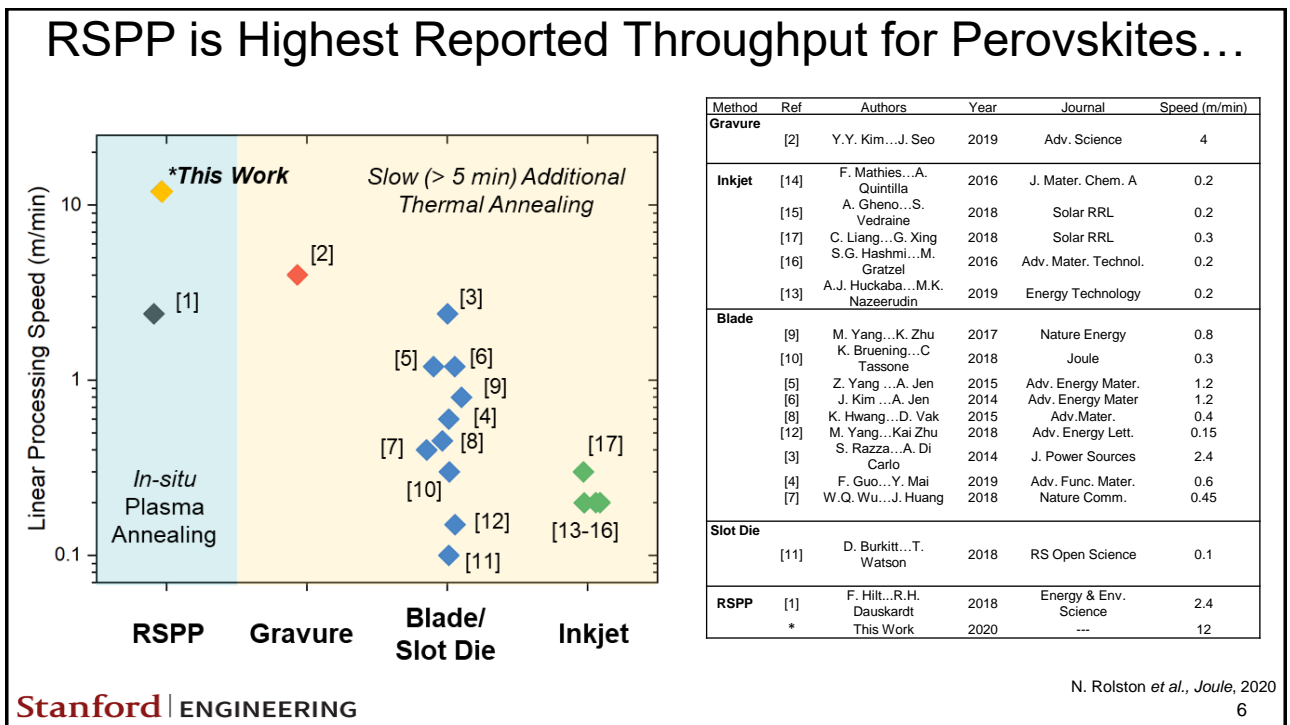
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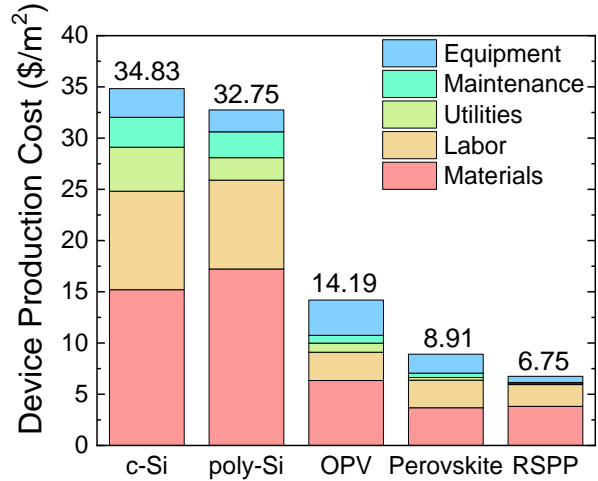
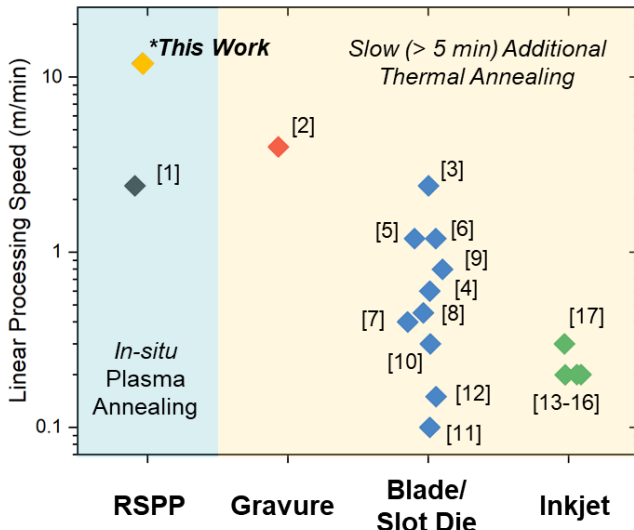
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6

RSPP is Highest Reported Throughput for Perovskites...

...and lowest device cost of any solar technology



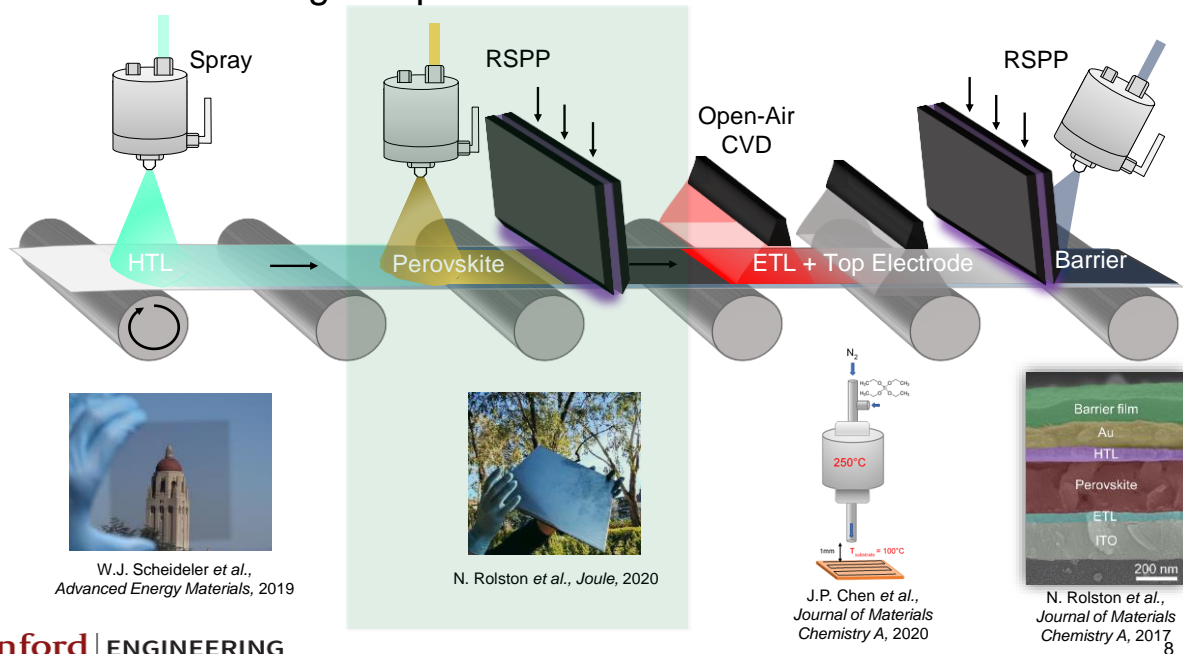
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N. Rolston et al., Joule, 2020

7

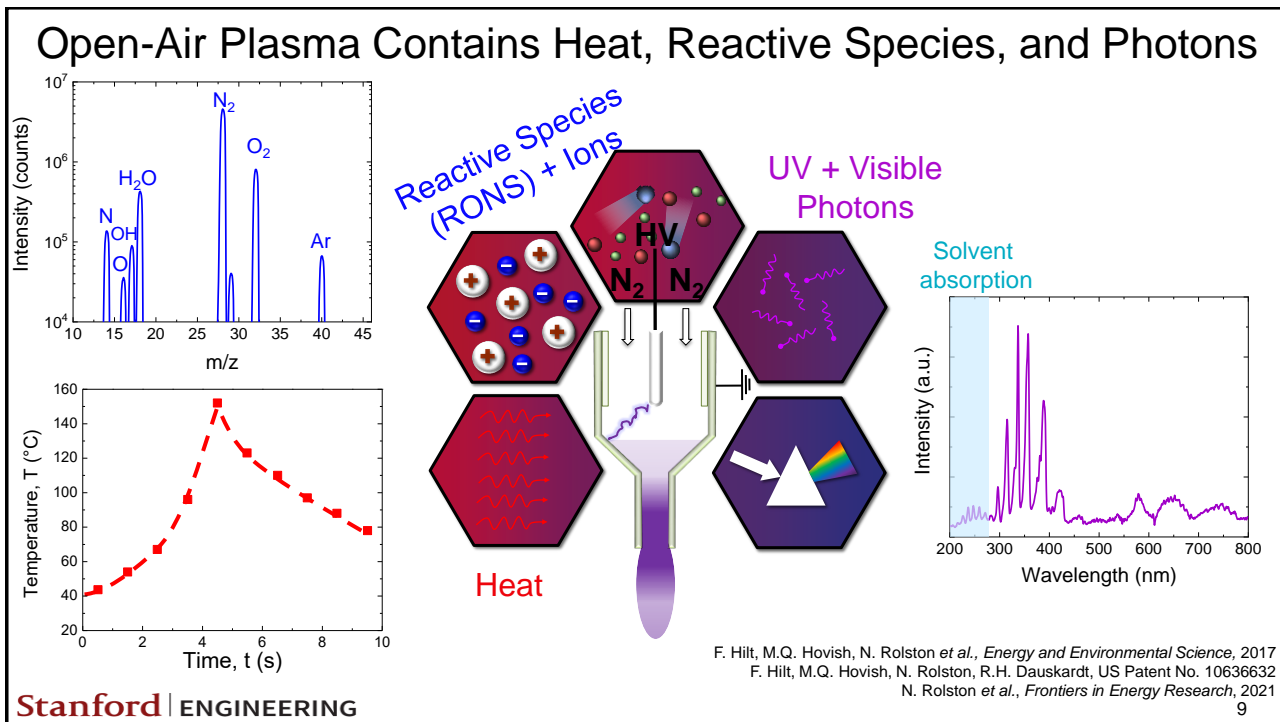
7

In-Line Manufacturing of Open-Air Processed Perovskite Solar Modules



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8



9

Open-Air Spray Plasma Processing Capabilities

Capacitively Coupled Plasma

- low temperature
- Ar, N₂ plasma gas

linear plasma head

Surfx Corporation

Blown Arc Discharge Plasma

- medium temperature
- N₂, O₂, air plasma gas

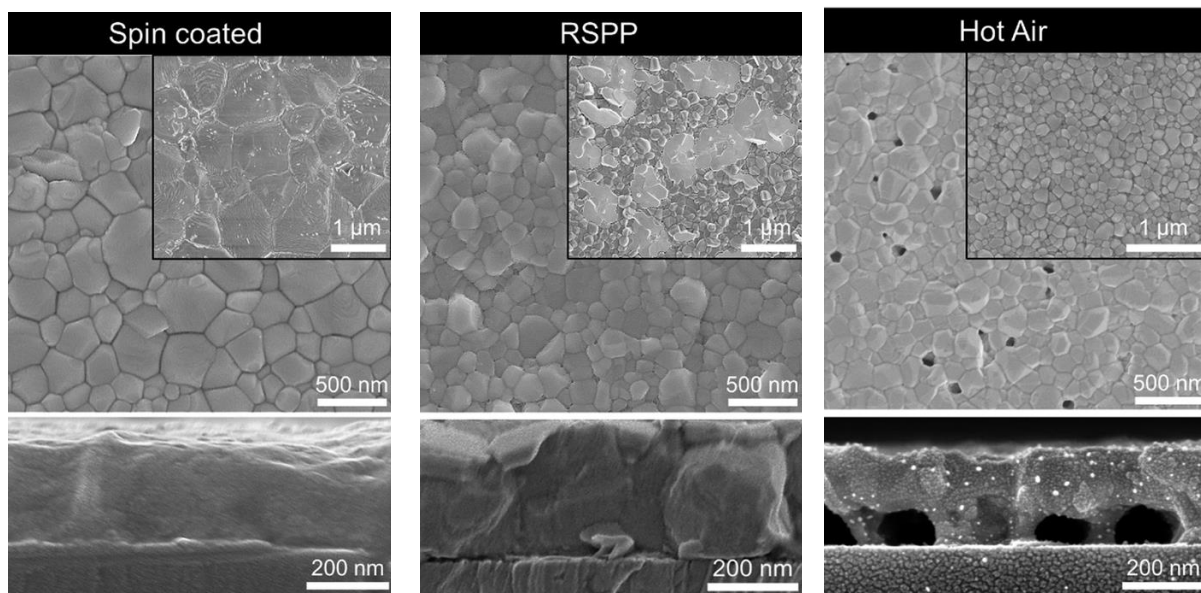
slit plasma nozzle

Plasmatreat Corporation

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10

RSPP Creates Dense Perovskite Films, More than Hot Air



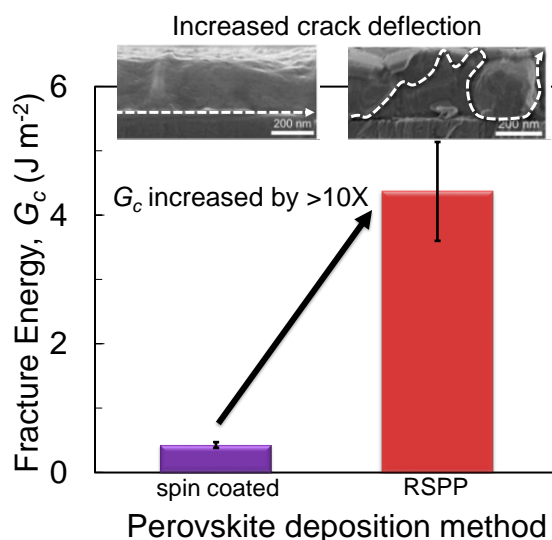
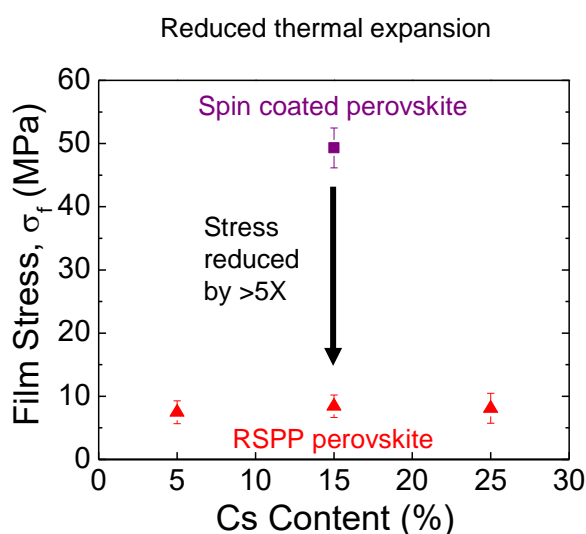
F. Hilt et al., *Energy and Environmental Science*, 2017

11

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11

Rapid Curing and Film Morphology Improves Mechanical Properties



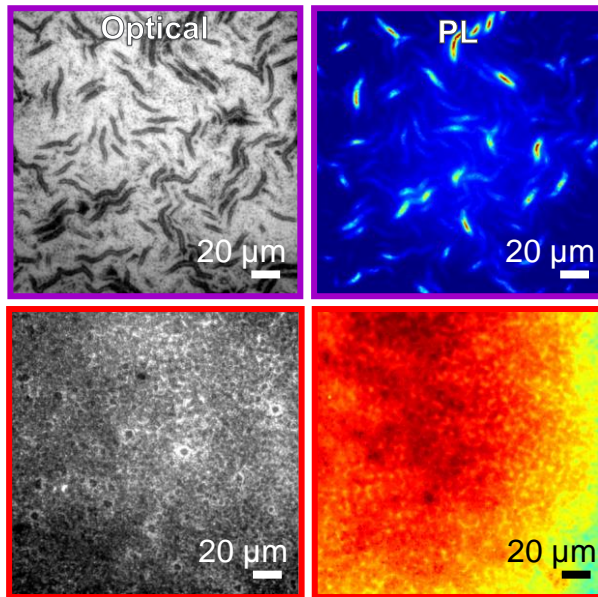
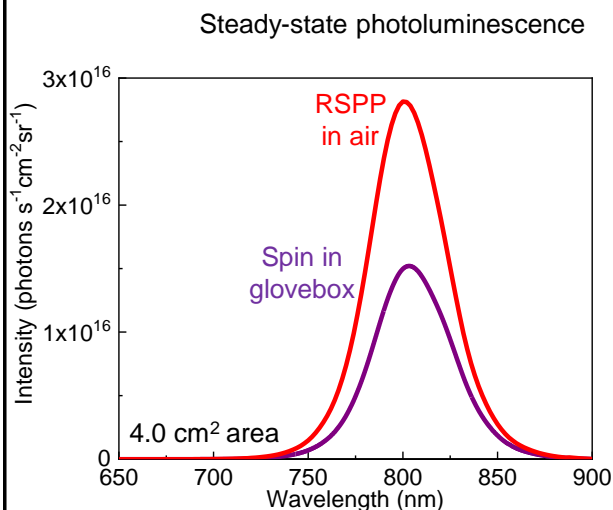
M.Q. Hovish et al., *Journal of Materials Chemistry A*, 2019

12

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12

RSPP Improves Luminescence on Length Scales from Nm to Cm



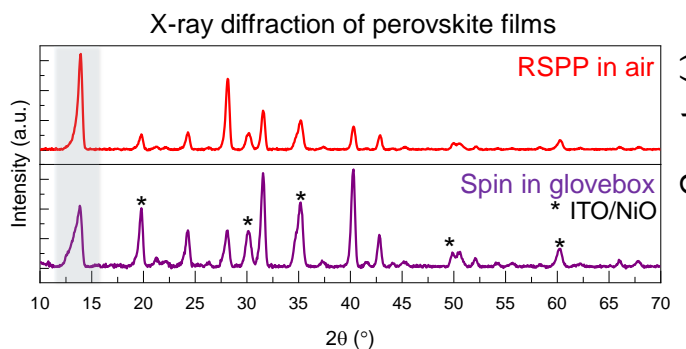
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N. Rolston et al., *Joule*, 2020

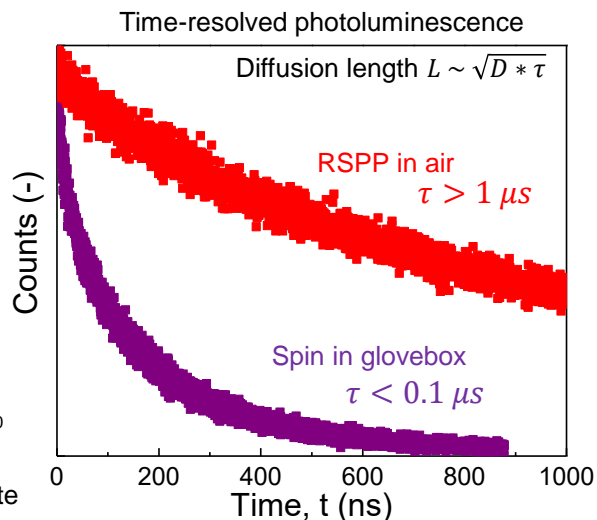
13

13

RSPP Improves Perovskite Crystallinity and Carrier Lifetimes



Main (100) perovskite peak sharper for RSPP perovskite



RSPP diffusion length $\sim 10 \mu m$, enabling new designs for perovskite architectures

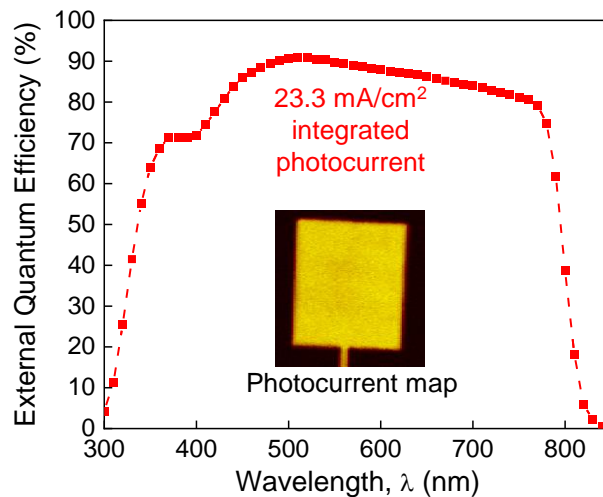
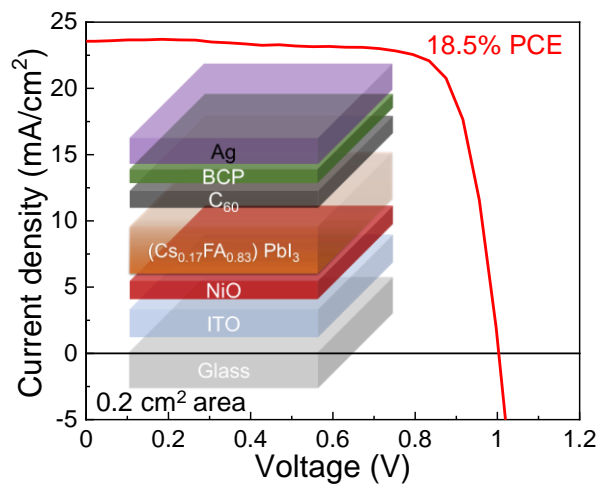
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N. Rolston et al., *Joule*, 2020

14

14

Record Performance for Open-Air Processed Perovskite



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15

15

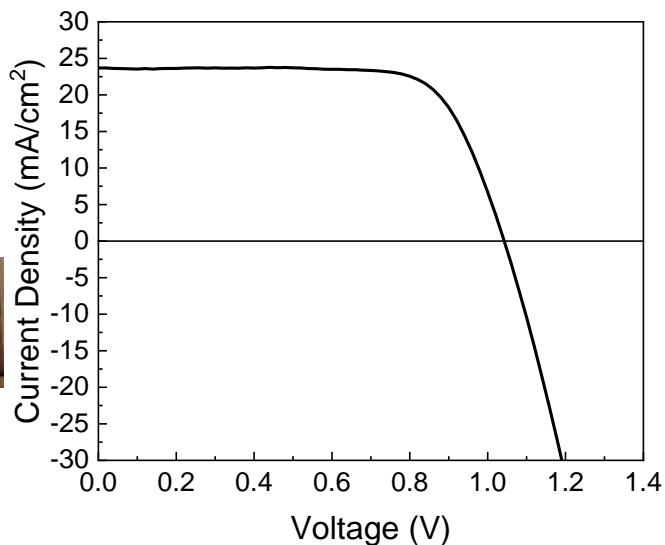
Scalable RSPP Devices with 18% Efficiency

V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	PCE (%)
1.04	23.7	73	18.0

10 cm long device substrate



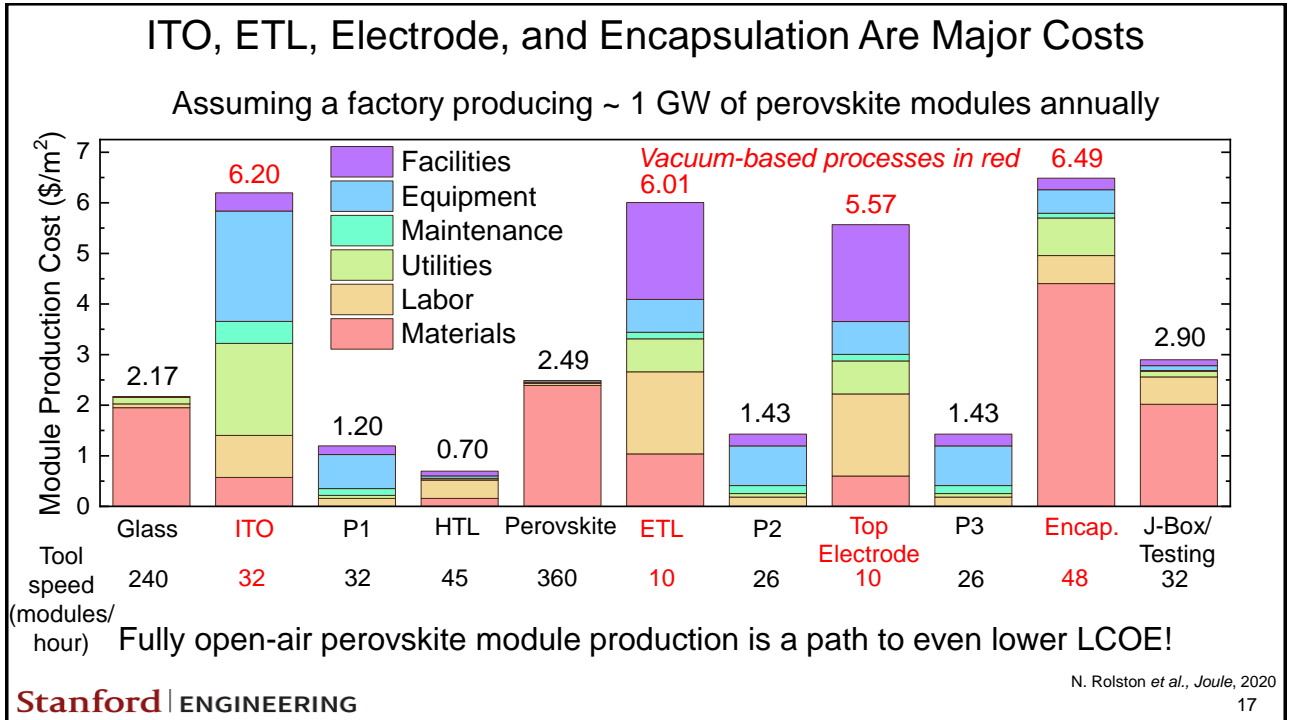
large cell (LBIC image)



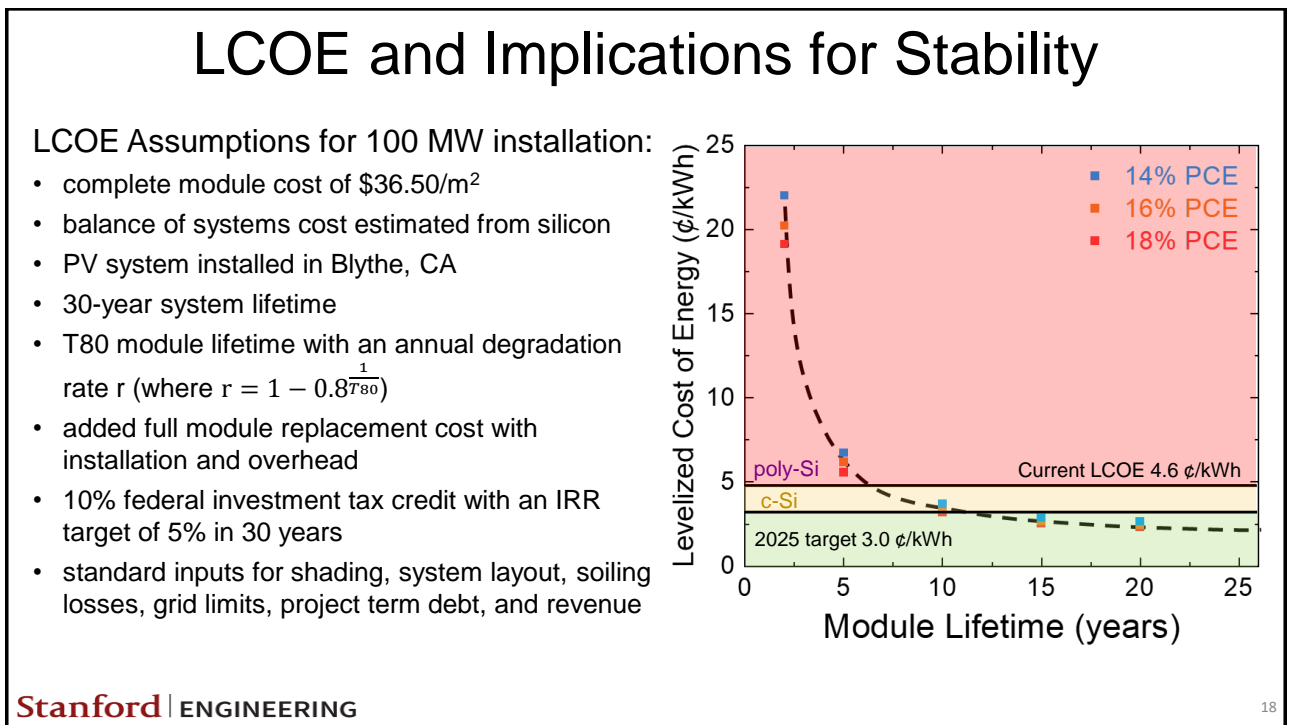
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16

16

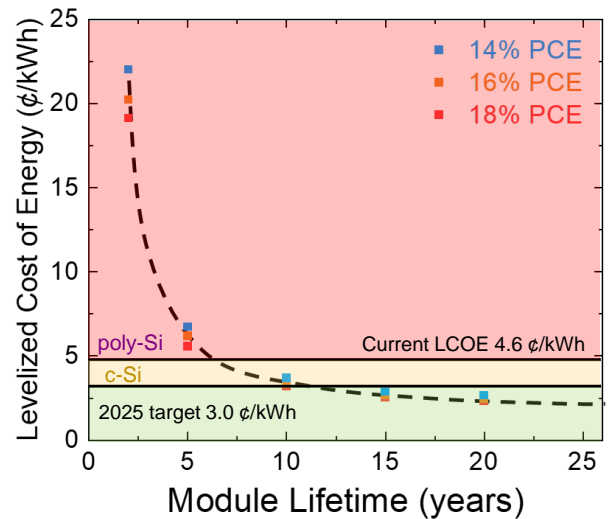
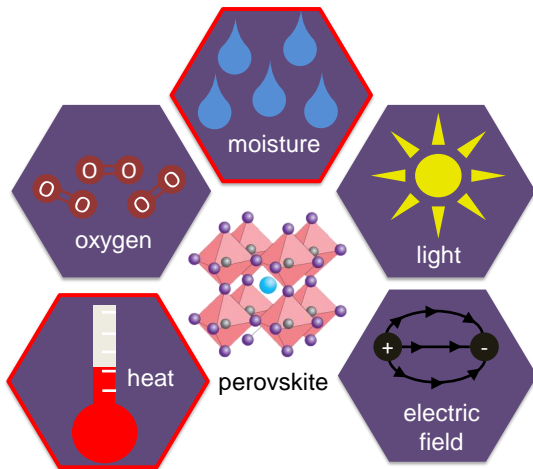


17



18

LCOE and Implications for Stability



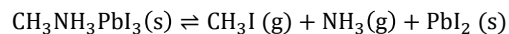
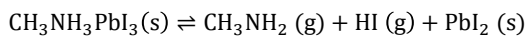
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19

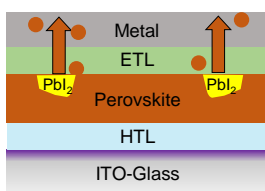
19

Stability of Perovskite Solar Cells

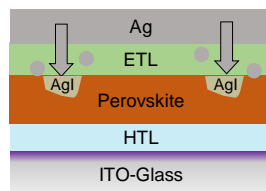
Thermal Degradation



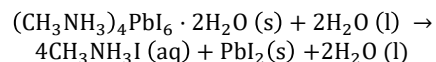
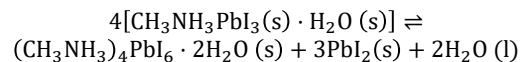
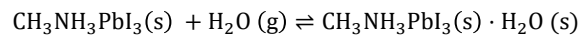
Halide Diffusion



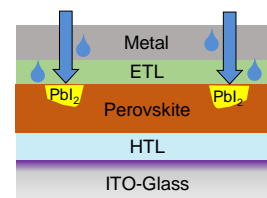
Metal Diffusion



Moisture Degradation



Moisture Diffusion



See e.g. references:

A. Latini, G. Gigli, A. Ciccioli, *Sustainable Energy Fuels* (2017), 1, 1351.

A. M. A. Leguy et al. *Chem. Mater.* (2015), 27, 3397.

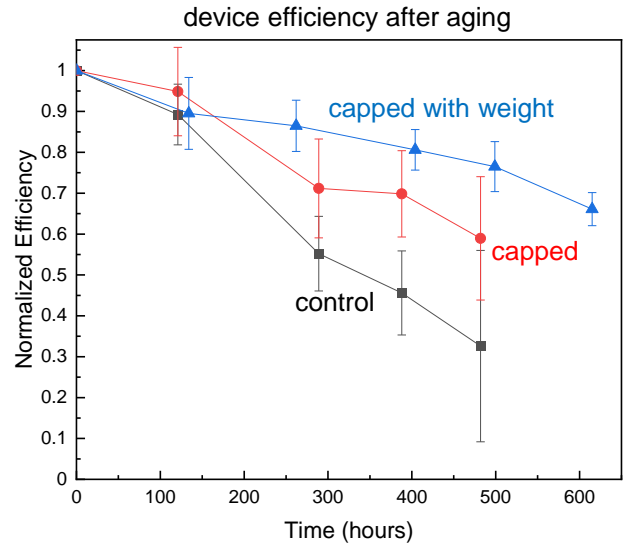
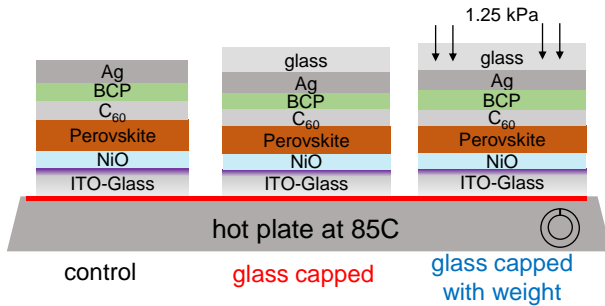
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20

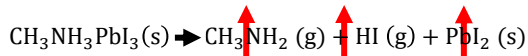
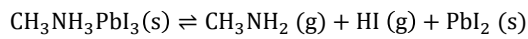
20

Exploring the Role of Encapsulation in Thermal Stability

aged at 85°C in inert N₂ environment



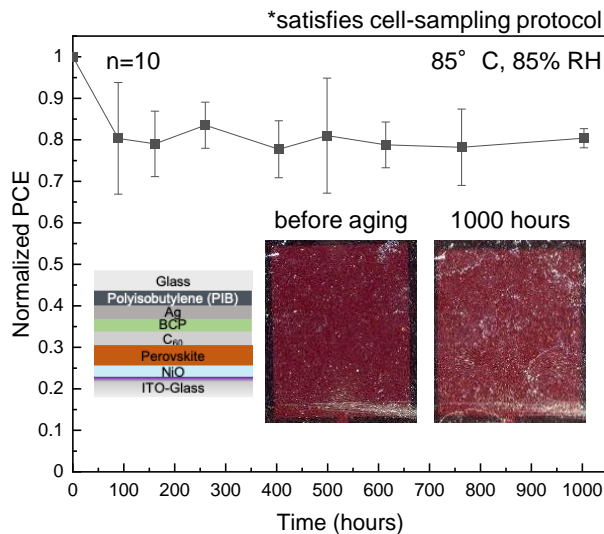
Thermal Degradation



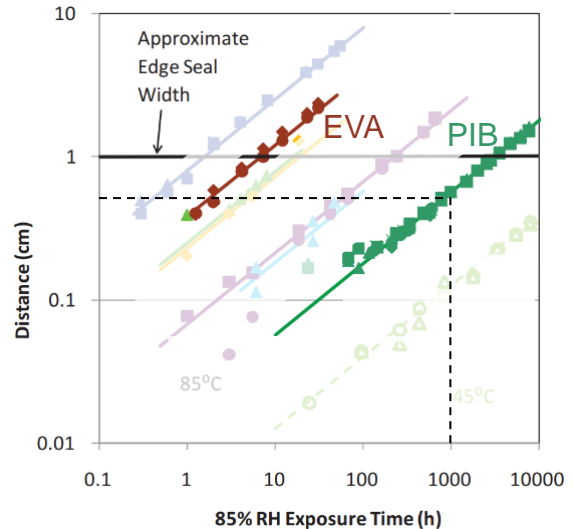
devices after 500 hours

21

1000 Hours Damp Heat Stability



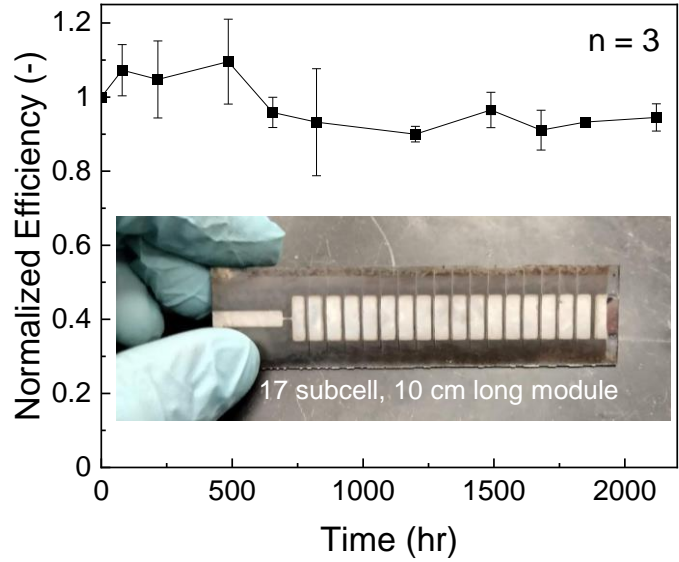
Edge diffusion of water at 85° C, 85%RH [1]



[1] M.O. Reese et al., Quantitative Calcium Resistivity Based Method for Accurate and Scalable Water Vapor Transmission Rate Measurement Rev. Sci. Instr. 82, 085101 (2011).

22

Outdoor Aging of Encapsulated Perovskite Devices

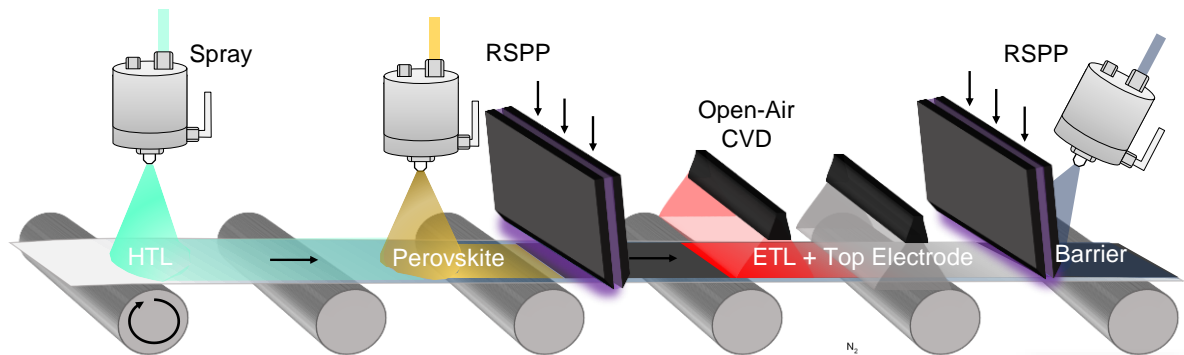


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23

23

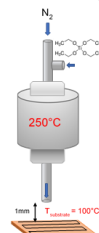
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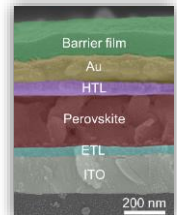
W.J. Scheideler et al., *Advanced Energy Materials*, 2019



N. Rolston et al., *Joule*, 2020



J.P. Chen et al., *Journal of Materials Chemistry A*, 2020



N. Rolston et al., *Journal of Materials Chemistry A*, 2017

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24

24