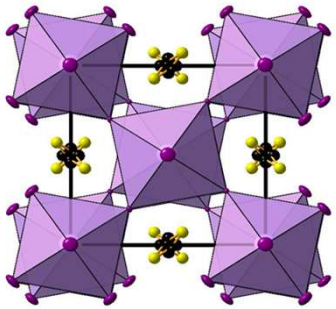
university of groningen

PHOTOPHYSICS& OPTO-ELECTRONICS

Highly efficient hybrid perovskite solar cells by interface engineering

Maria Antonietta Loi



Photophysics & OptoElectronics

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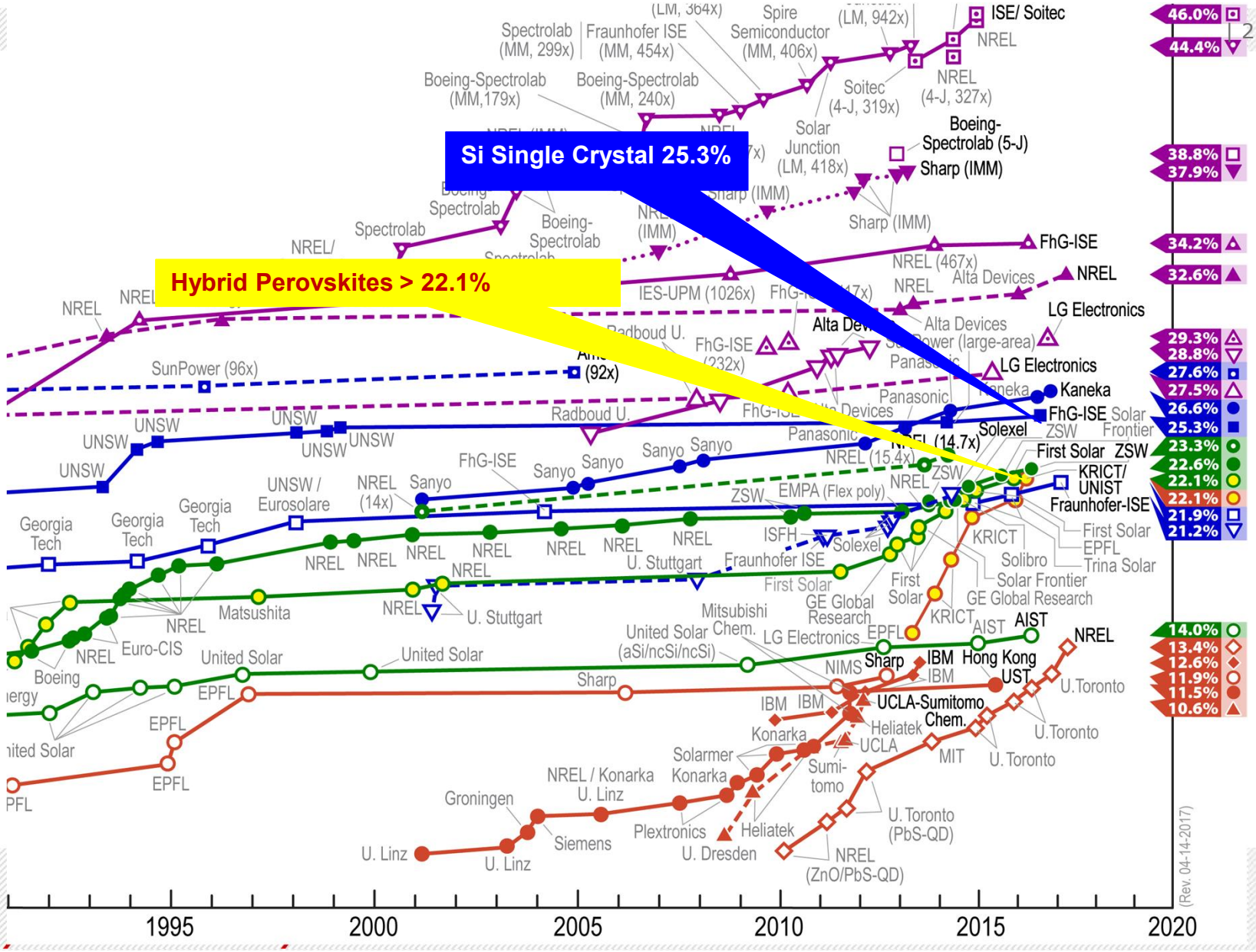
Why Hybrid perovskites?

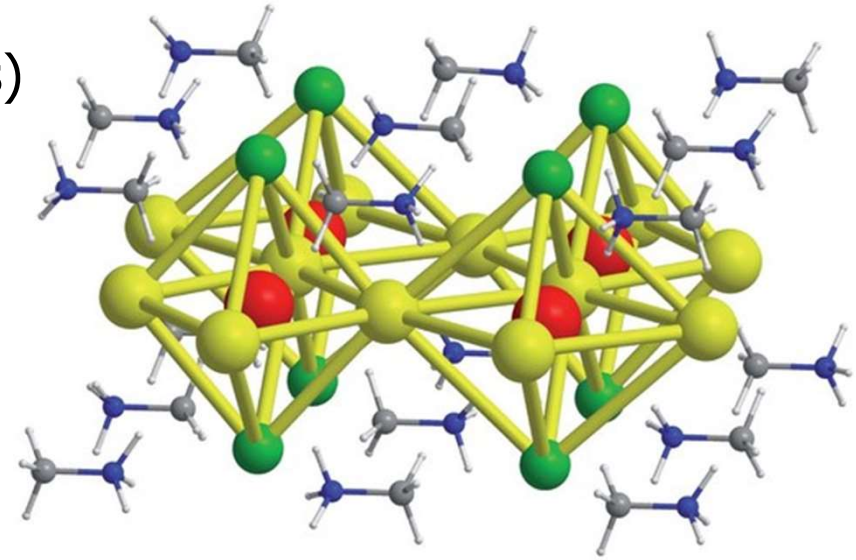


What are HP?

Perovskites adopt the chemical formula ABX_3

A and B are cations of different sizes

X is an anion (oxygen and halogens)



Hybrid Perovskites

- A is small organic cation
- Most popular hybrid perovskites use

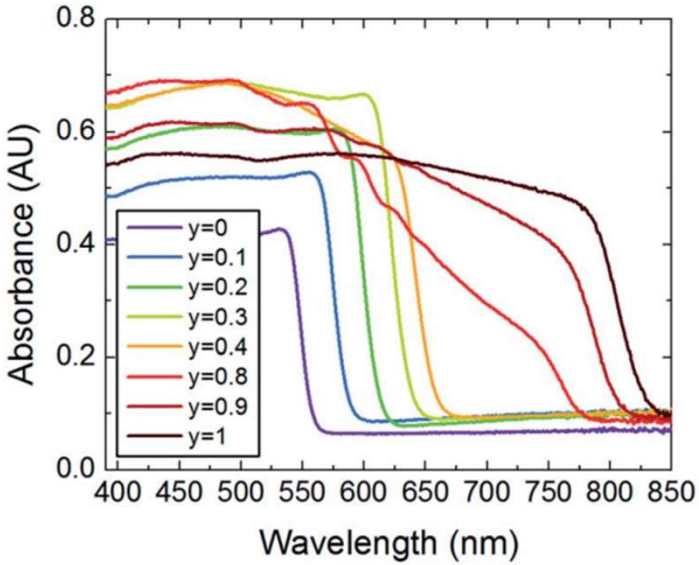
A-cations: $CH_3NH_3^+$ (MA) or $HC(NH_2)_2^+$ (FA)

X-anion (halogens): Cl^-, Br^-, I^-

M. A. Loi & J. C. Hummelen, News & Views, Nature Materials, 12, 1087 (2013)

Important features - pros

› Device efficiencies have increased rapidly from 3.8% in 2009 to more than 20%.



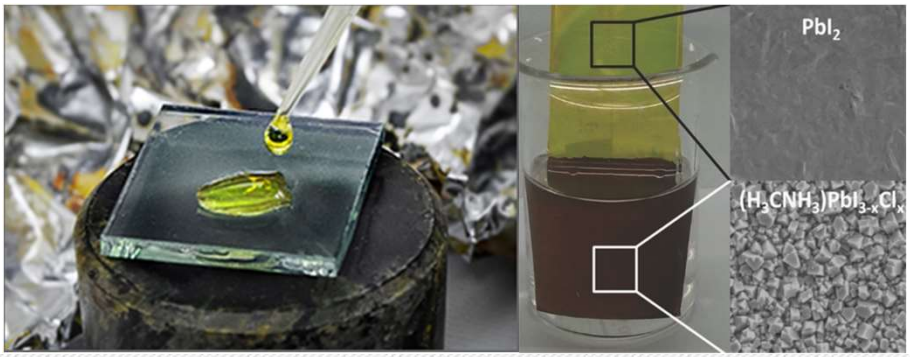
Material Properties

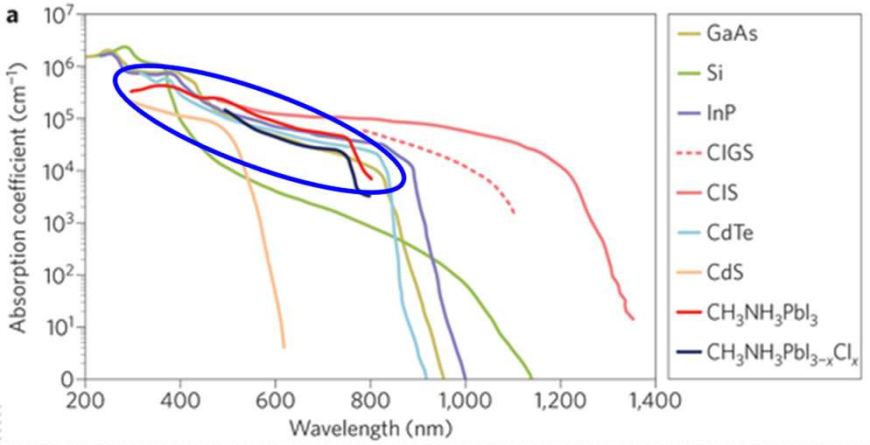
› Solution processable

› Tunable bandgap from Vis to NIR;

› High optical absorption coefficient;

› Long carrier diffusion length;





Science 2014, 345, 542. ; *Nature Comm.* 2014, 5, 3586. ; Adv. Energy Mater. 2014, 4, 1400355 ;

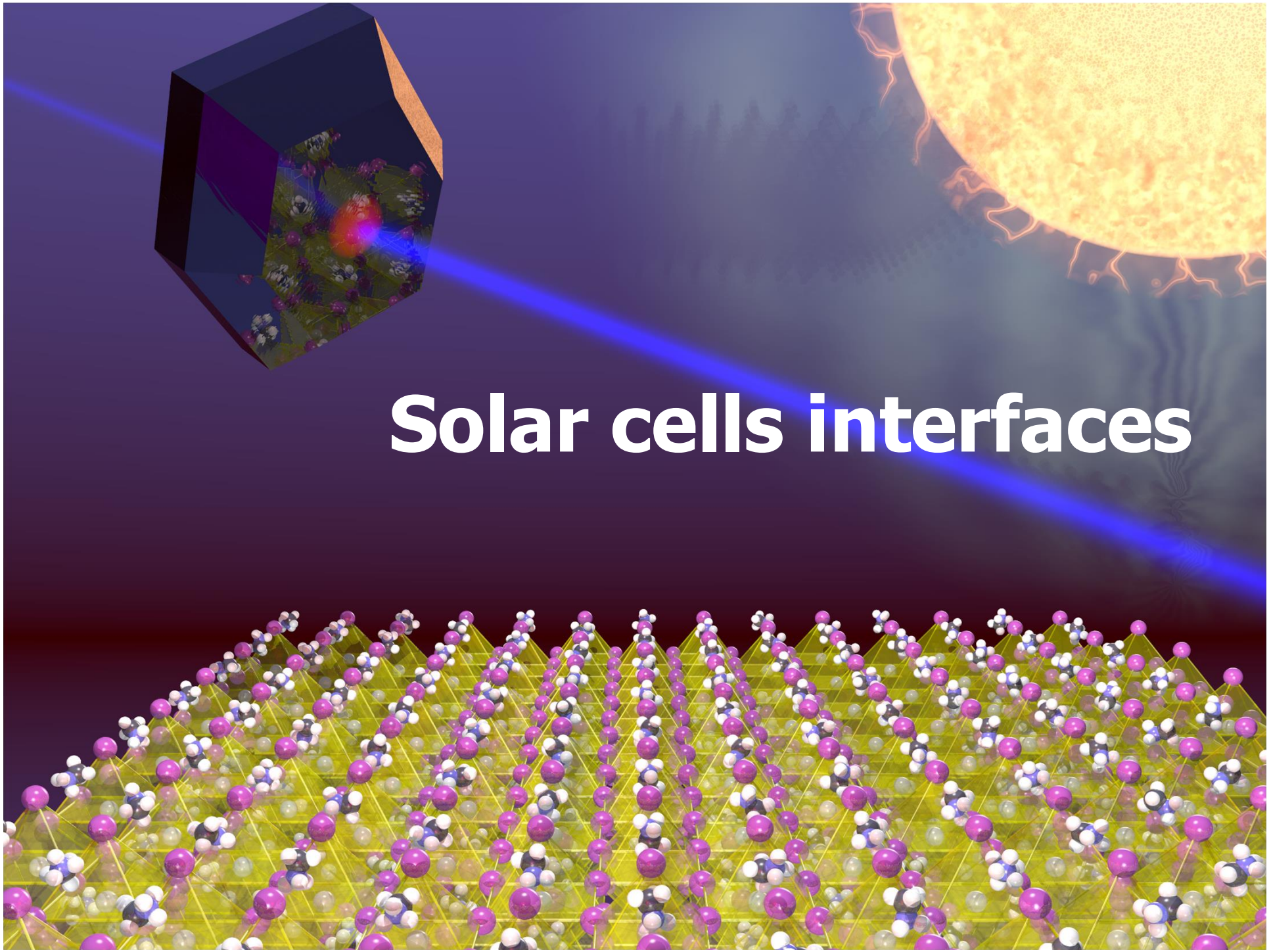
Important features - cons

Drawbacks

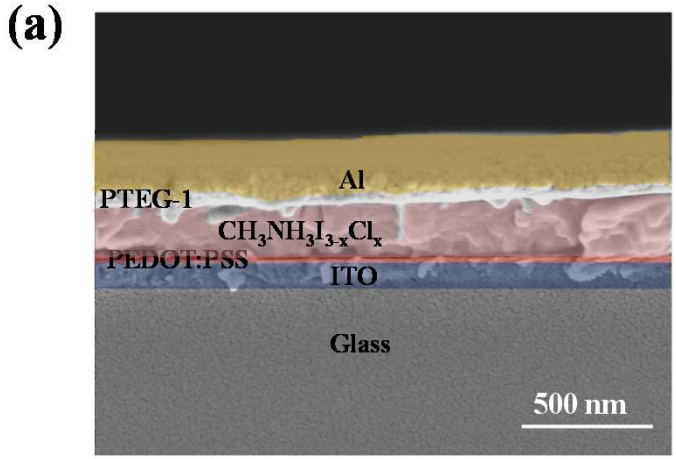
- Materials and/or device instability;
- Hysteresis in current-voltage (JV) curves;
- Toxicity of Pb

Some solutions

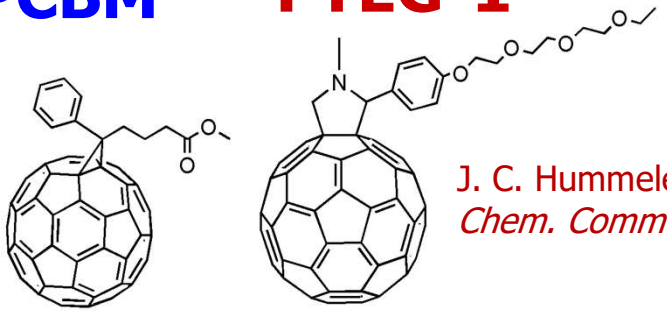
- Chemical management of perovskite compositions;
- Invention of various deposition techniques;
- Search for efficient HEM and EEM
- Non-Pb perovskites


Solar cells interfaces

Varying the nature of the interface

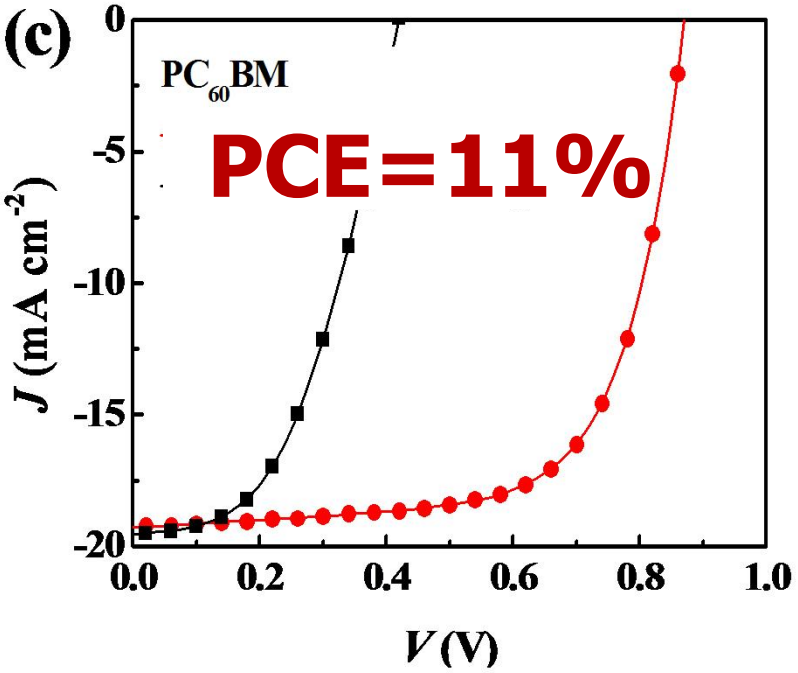


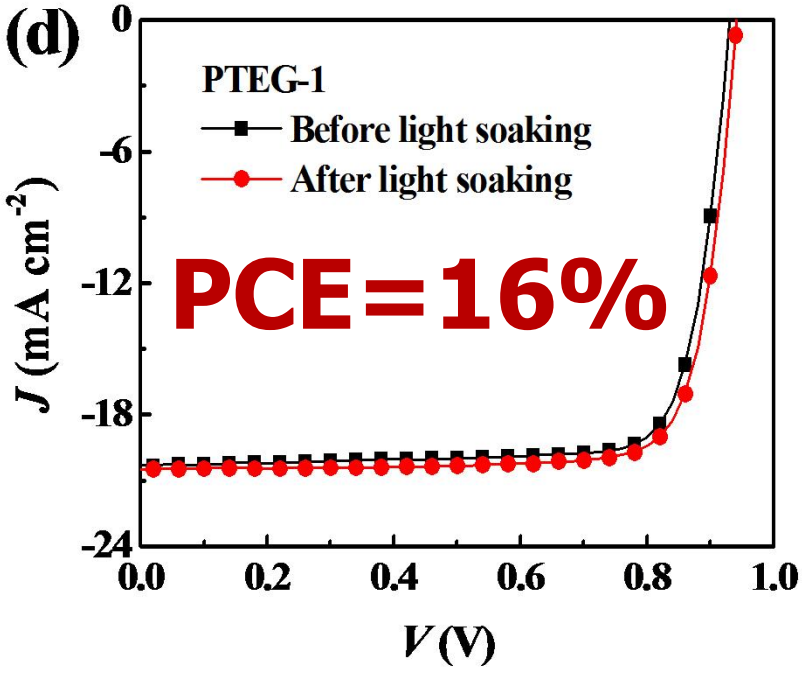
PCBM **PTEG-1**



J. C. Hummelen, et al.
Chem. Commun., 50, 10645 (2014)

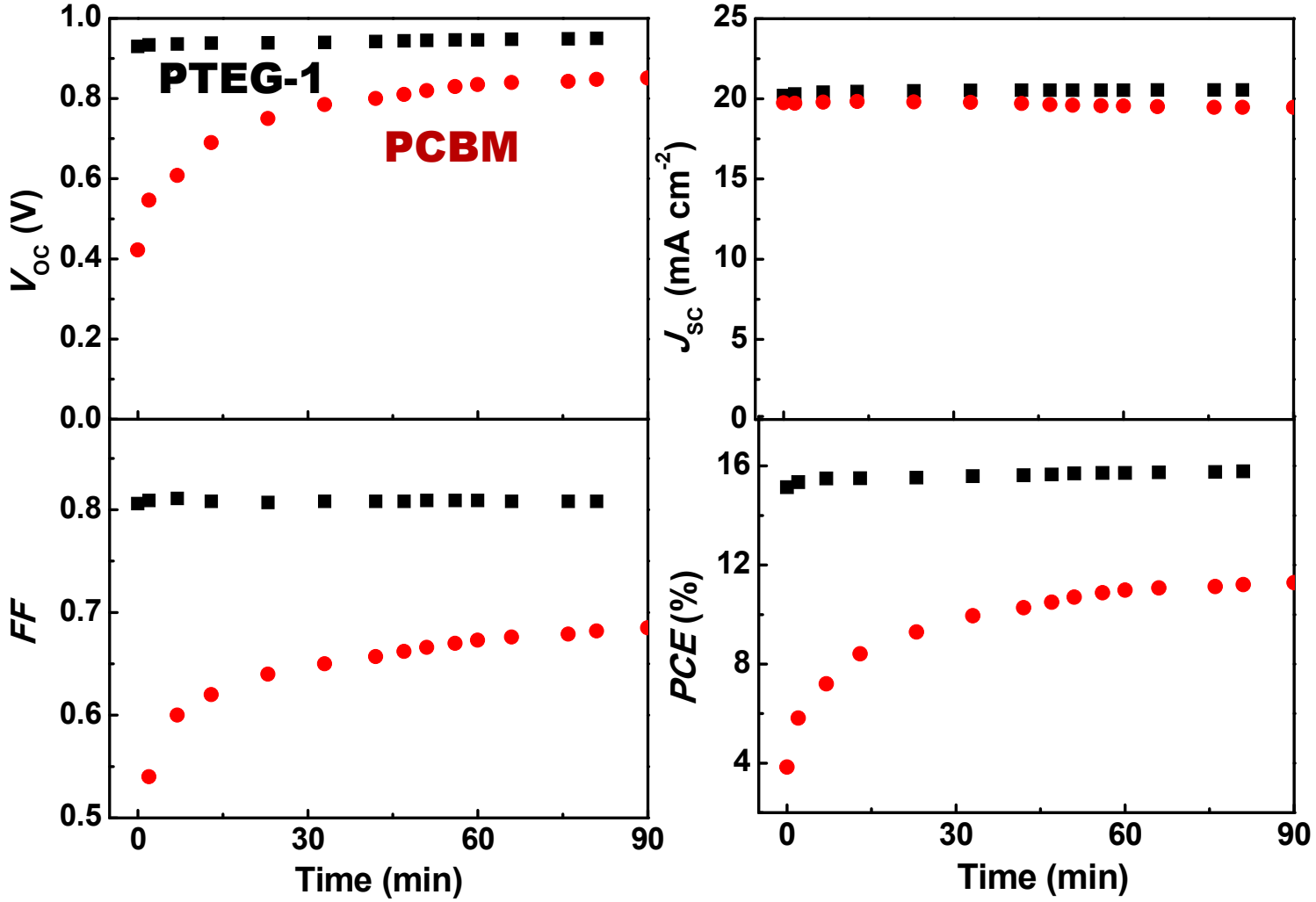
$\varepsilon_r = 3.7$ $\varepsilon_r = 5.7$





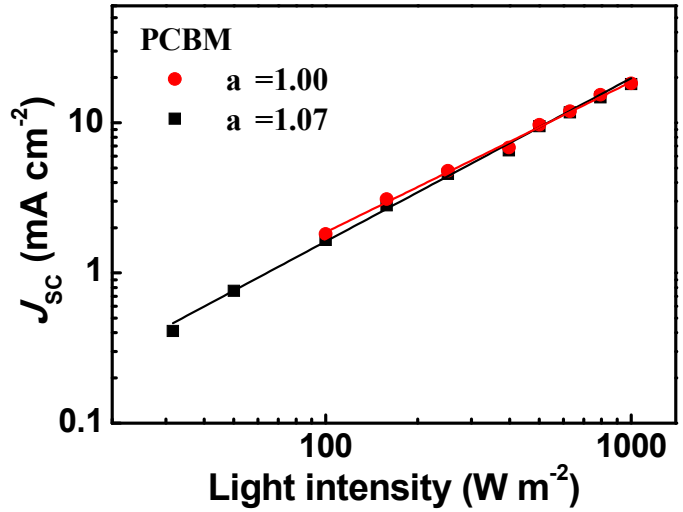
S. Shao, ...MAL, Energy Environ. Sci., 9, 2444 (2016)

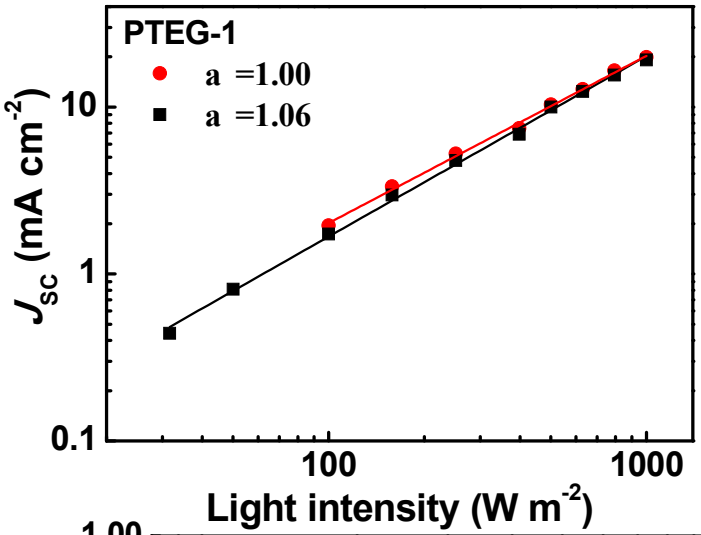
Variation of the device parameters with light soaking time

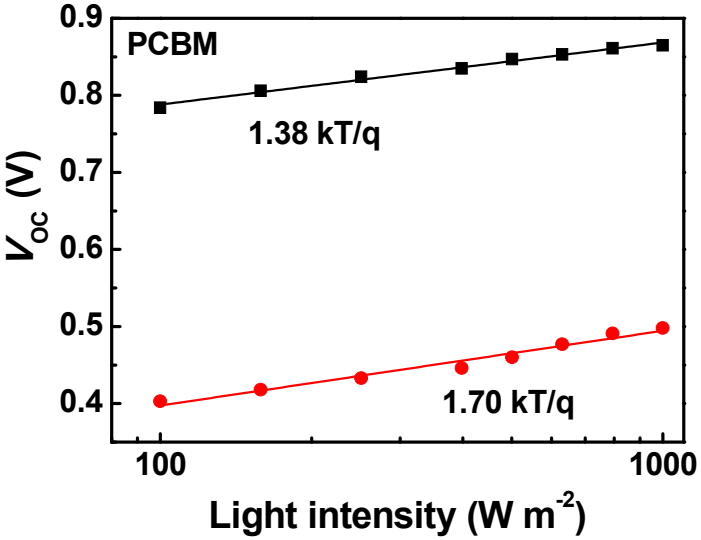


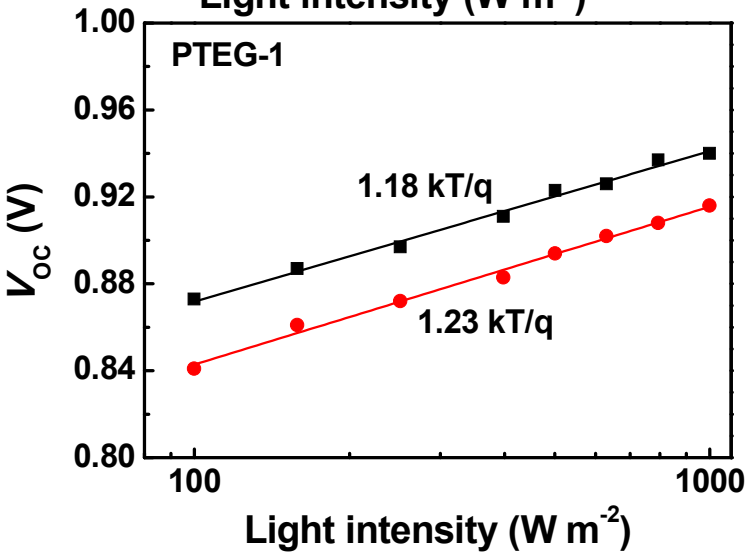
S. Shao, ...MAL,
Energy Environ. Sci., 9, 2444 (2016)

Light intensity dependent J_{sc} and V_{oc}







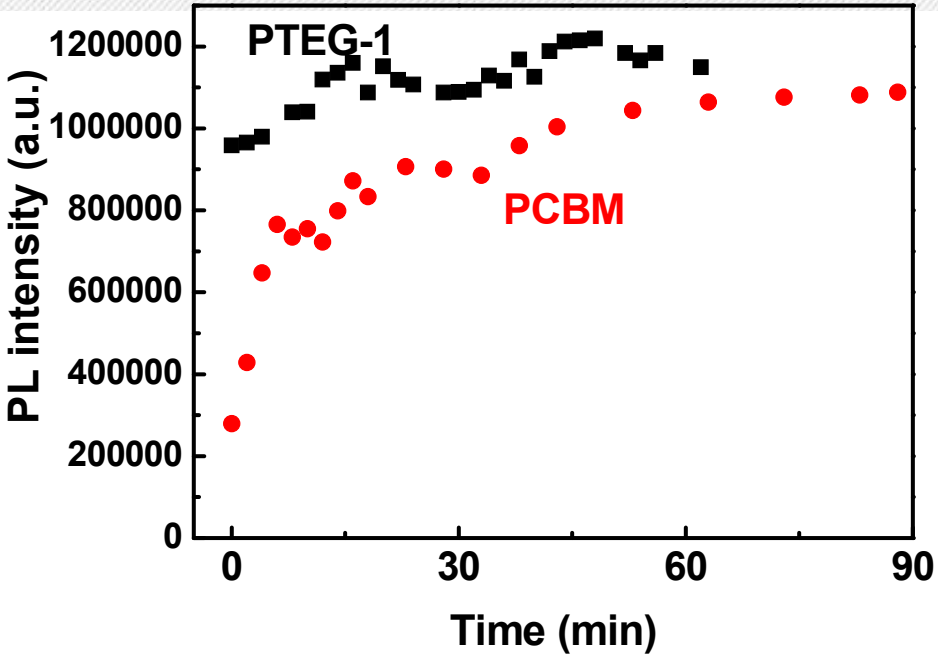


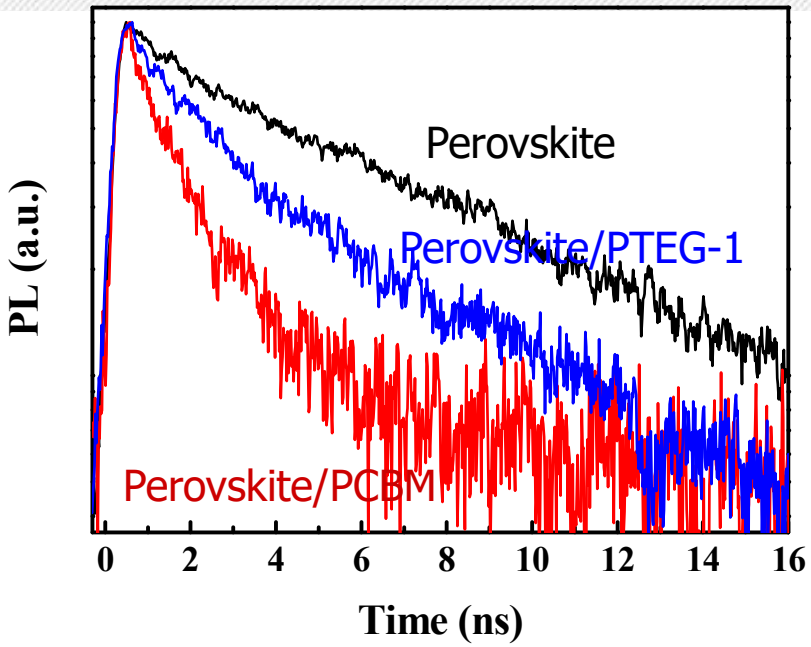
- Bimolecular recombination is not involved in the light soaking

- Suppressed trap assisted recombination with light soaking

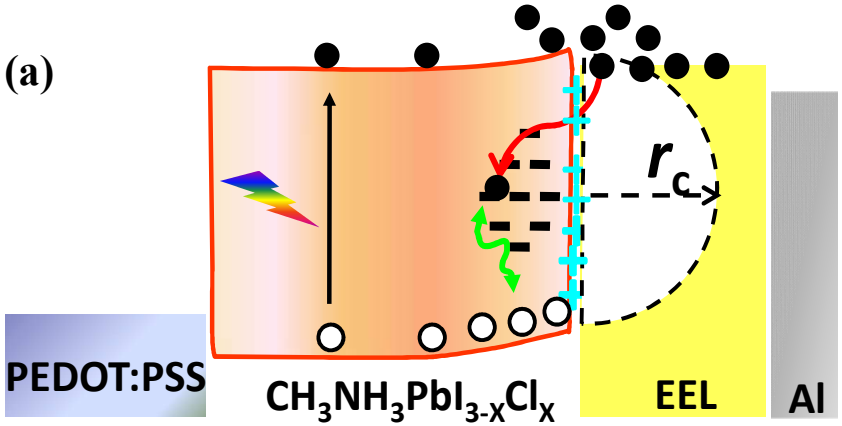
- Lower trap assisted recombination in device using PTEG-1 as EEL

Steady state and time resolved PL





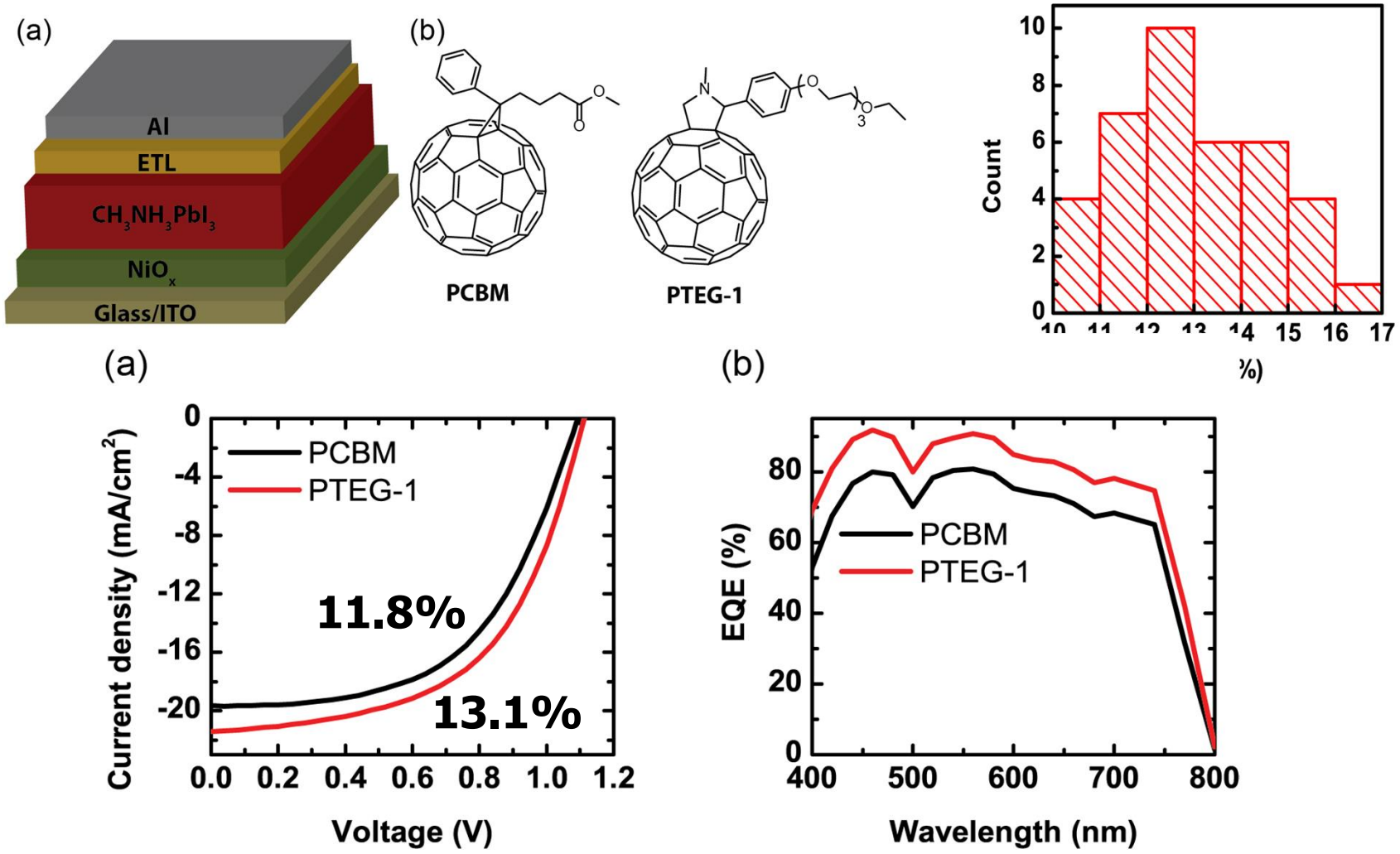
- **Trap-filling with light soaking**
- **Lower charge recombination at perovskite/PTEG-1 interface.**



Summary

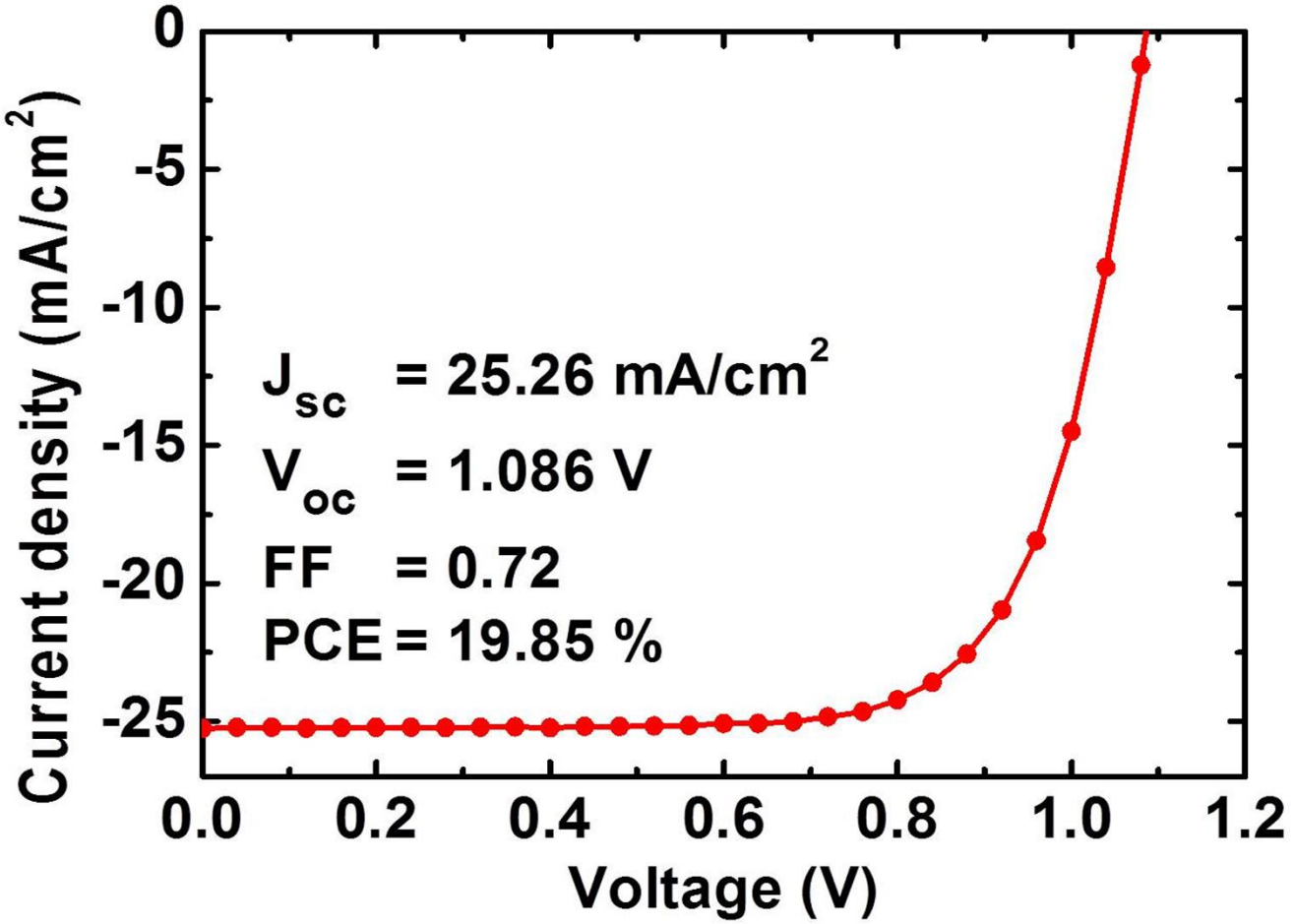
- **The surface electron traps dominate the light soaking effect in HPSCs.**
- **Severe light soaking effect in HPSCs using PCBM as EEL due to the trap-assisted recombination at HP/PCBM interface.**
- **Negligible light soaking effect in HPSCs using the high dielectric constant fullerene PTEG-1.**
- **The reduced light soaking is due to suppressed trap-assisted recombination at HP/PTEG-1 interface.**

Further device engineering

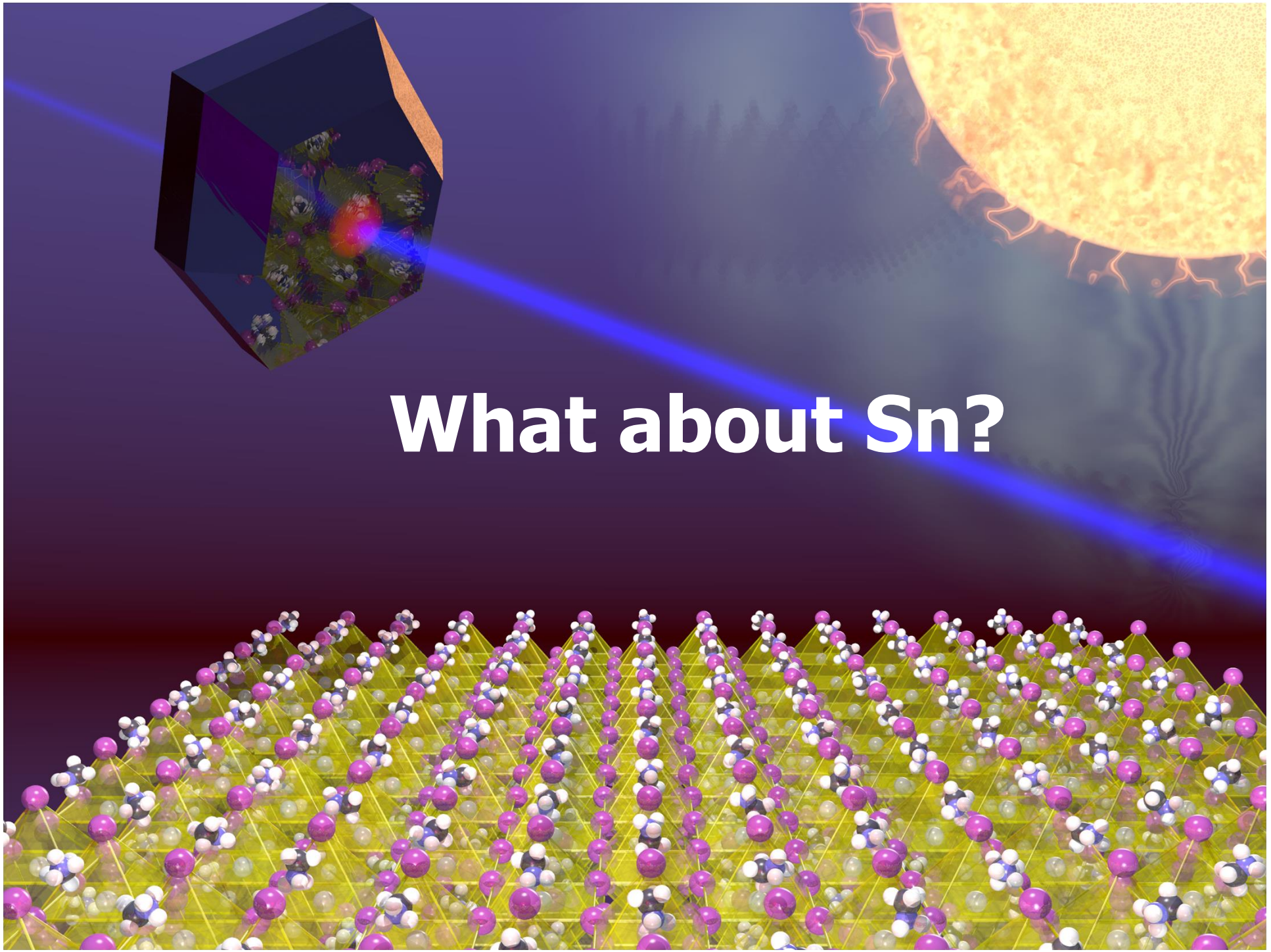


B. G. H. M. Groeneveld,.....MAL, APL Materials 5, 076103 (2017)

Further device engineering



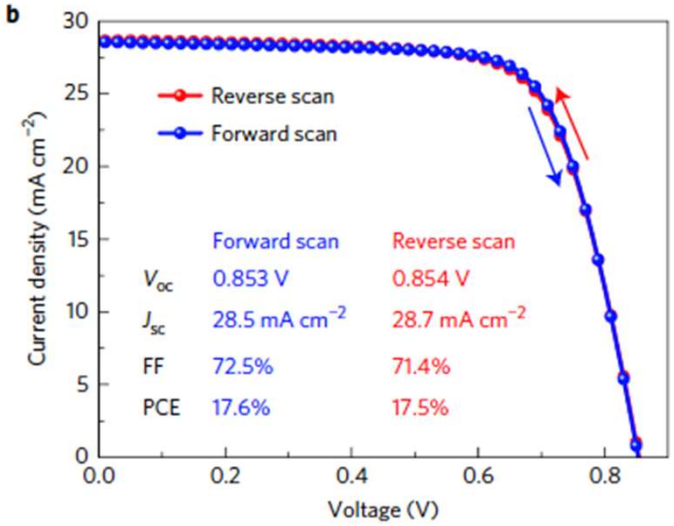
S. Adjokaste, ...MAL, in preparation


What about Sn?

Sn Perovskites

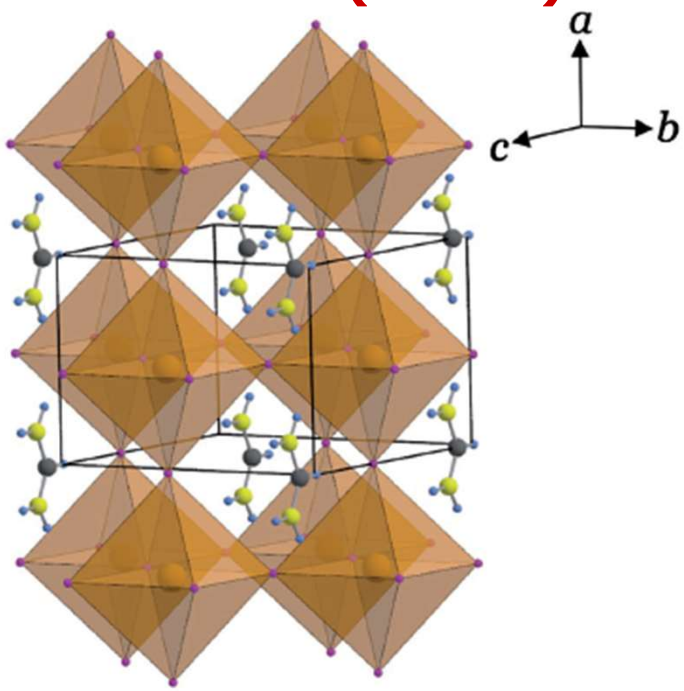
- Rather low efficiencies for solar cells (6%)
- Huge problem of self doping fast oxidation of Sn^{2+} into more stable Sn^{4+}
  - Introduction of (SnF2) as a reducing agent
- Only with mixture of Pb and Sn recently achieved good performances

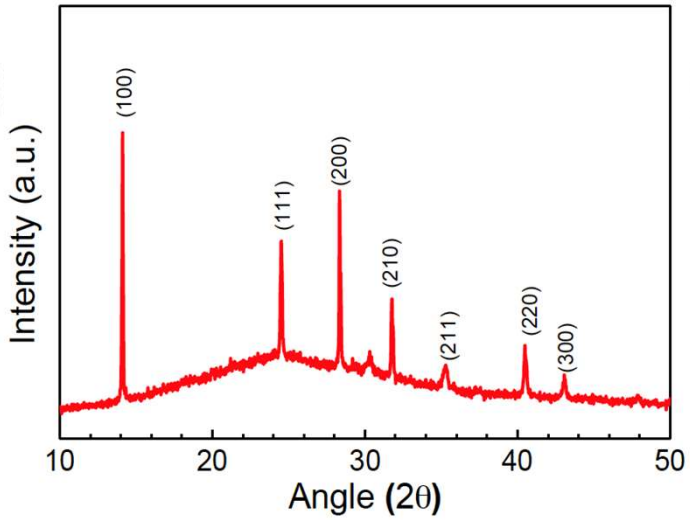
D. Zhao et al Nature Energy 2, 17018 (2017)

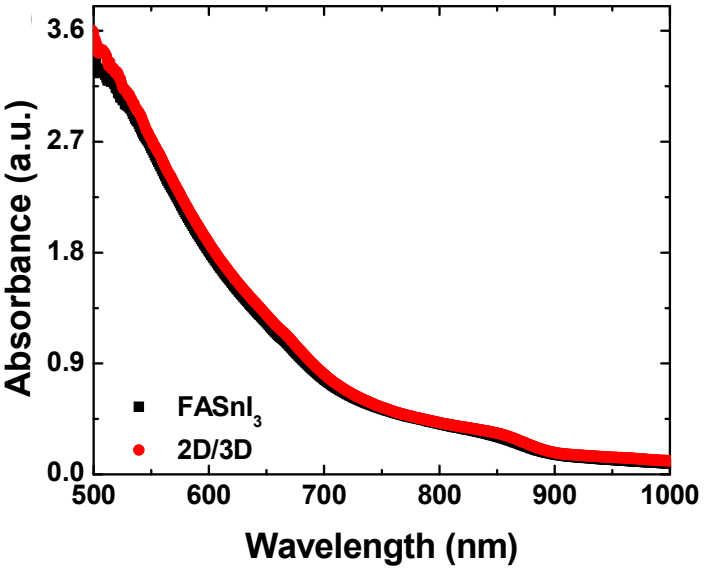


$FASnI_3$

orthorhombic (Amm2)

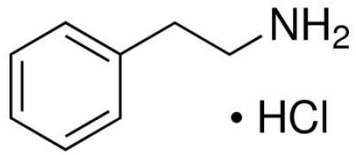




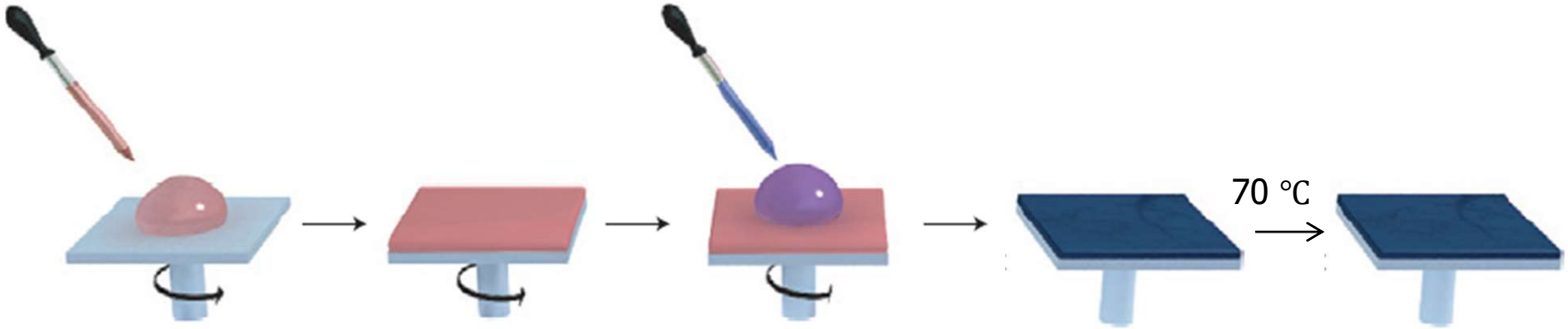


Good charge transport
Narrow band gap

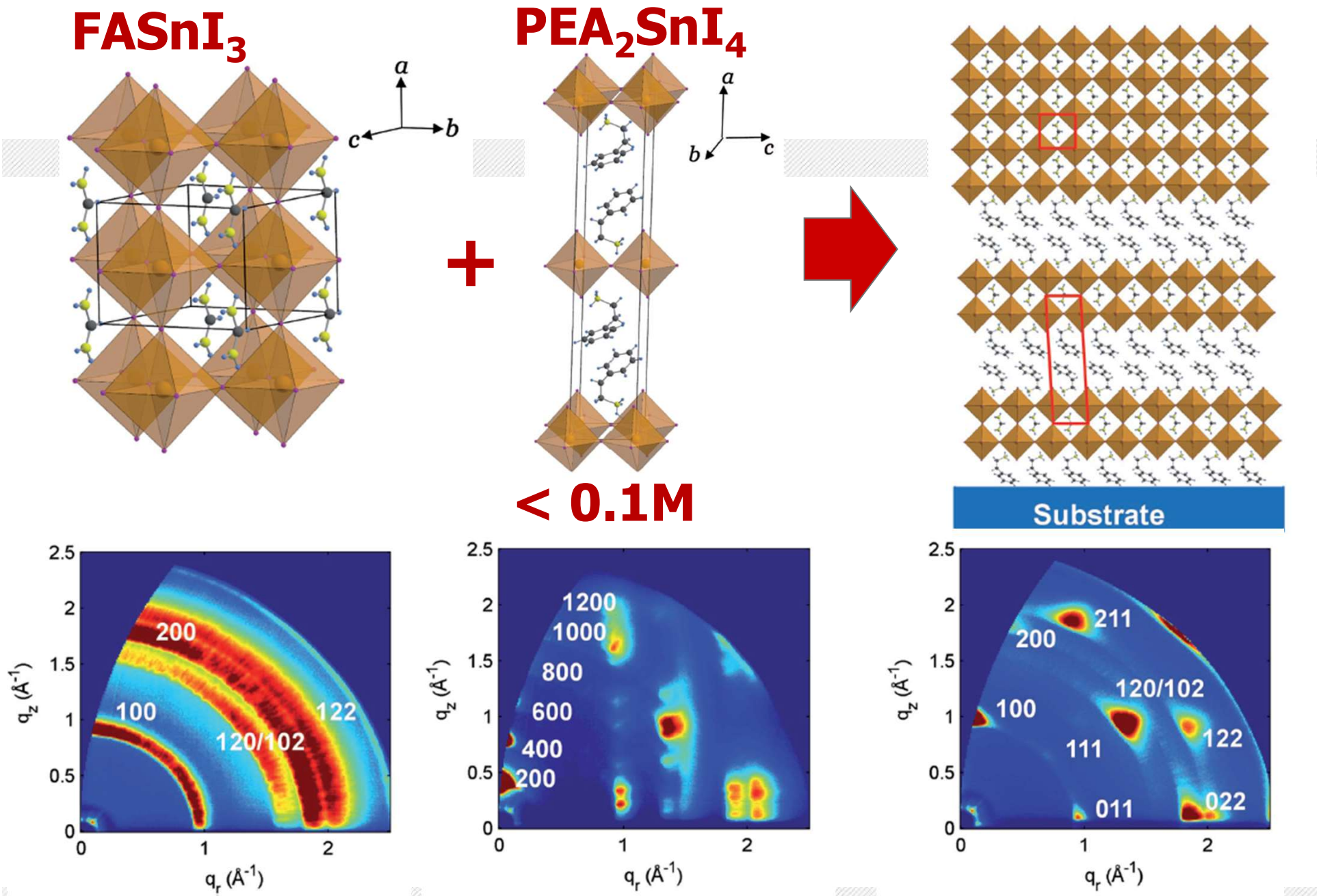
Introducing PEAI into $FASnI_3$



Phenethylamine Hydroiodide (PEAI)



Solution spreading **Spinning** **Anti-solvent dripping** **$FASnI_3$ film** **$FASnI_3$ film**



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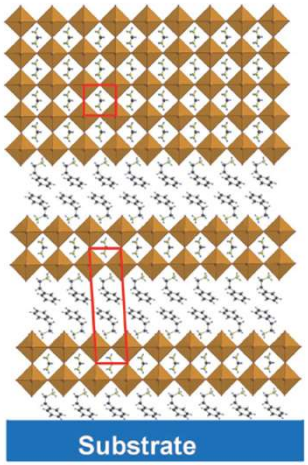
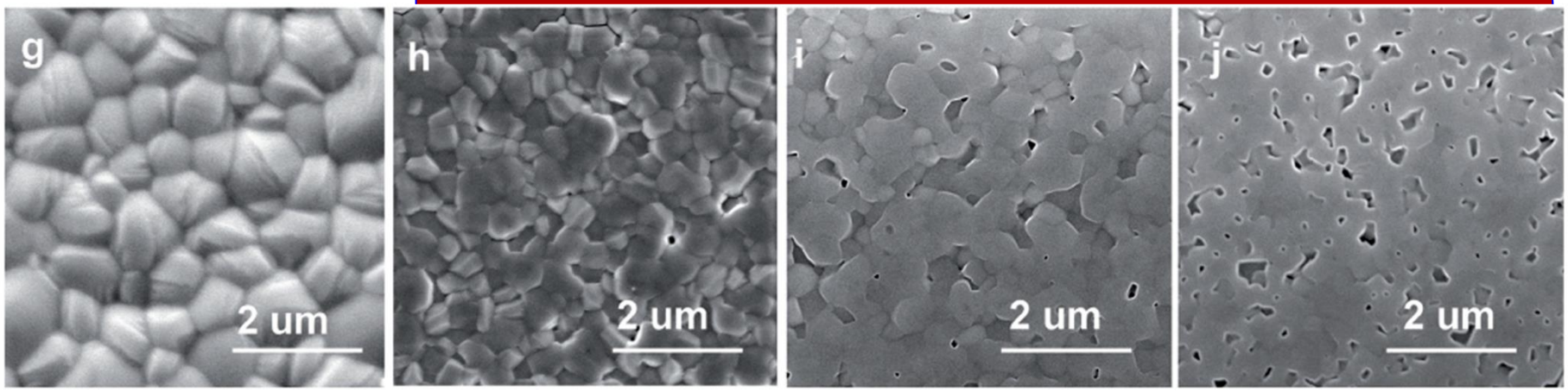
Shao...MAL, Adv. Energy Mater. (2017)

Large reorganization



$FASnI_3$

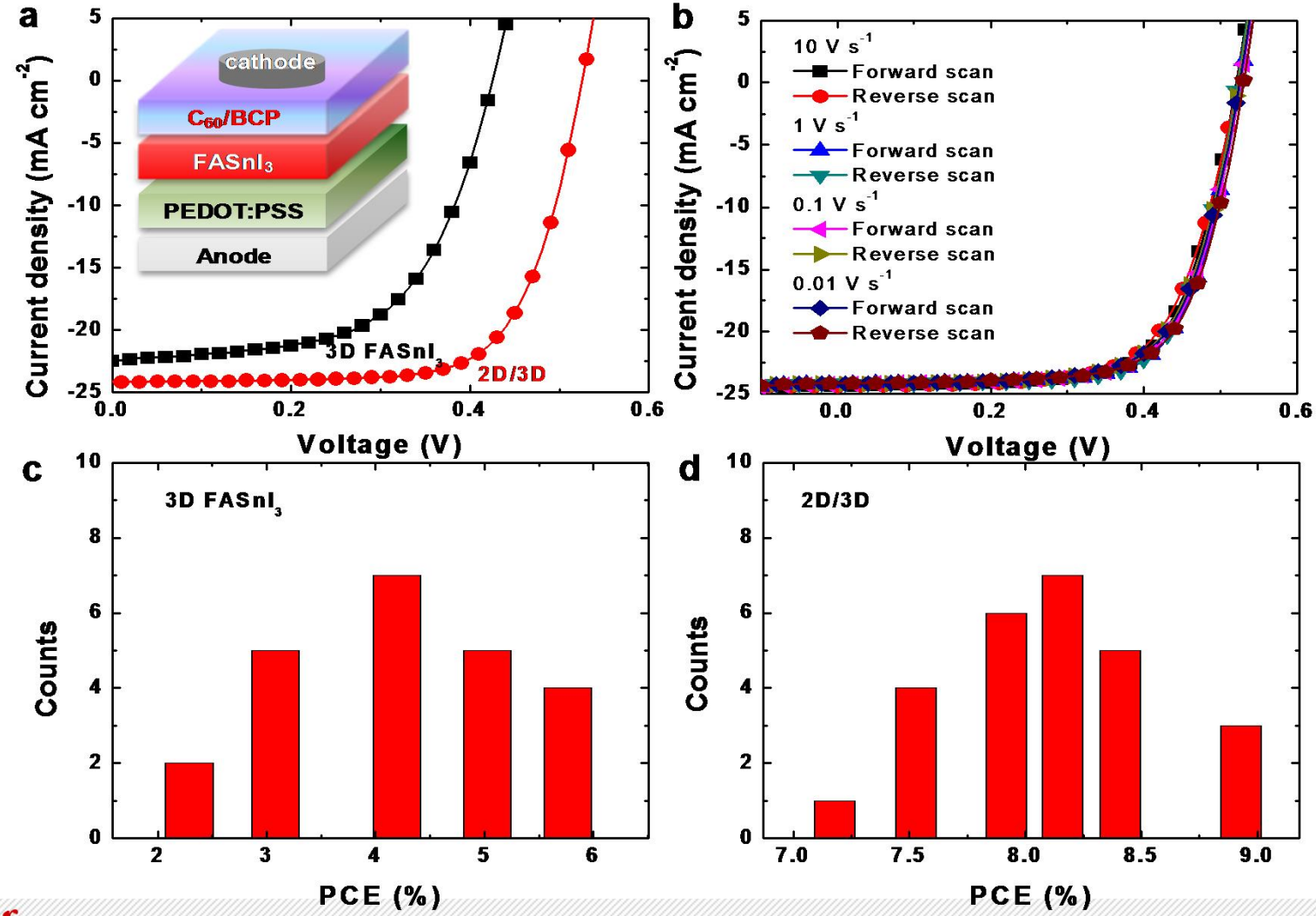
$FASnI_3$ + PEA_2SnI_4



3D | 0.08 M 2D | 0.12 M 2D | 0.16 M 2D

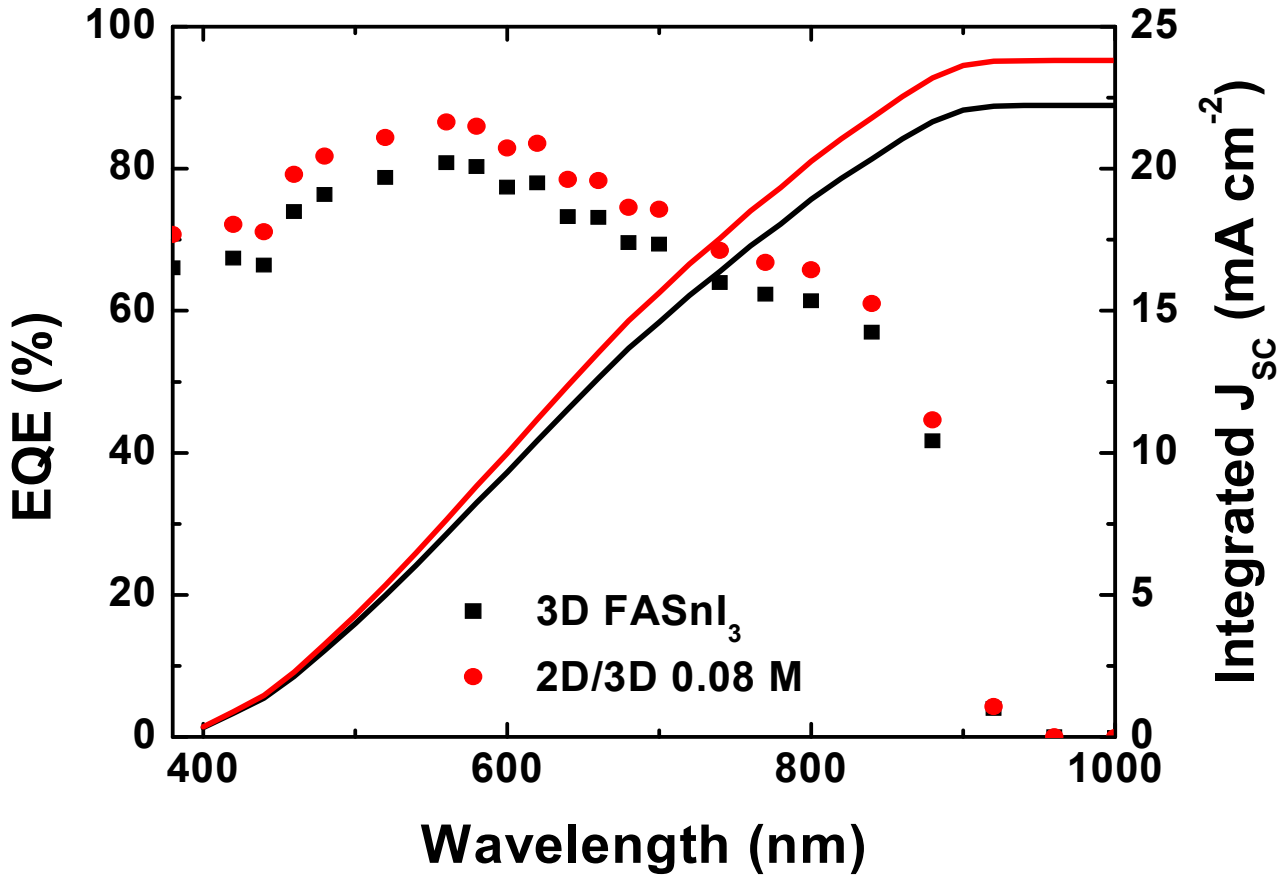
Shao...MAL, Adv. Energy Mater. (2017)

Improving efficiency and reproducibility

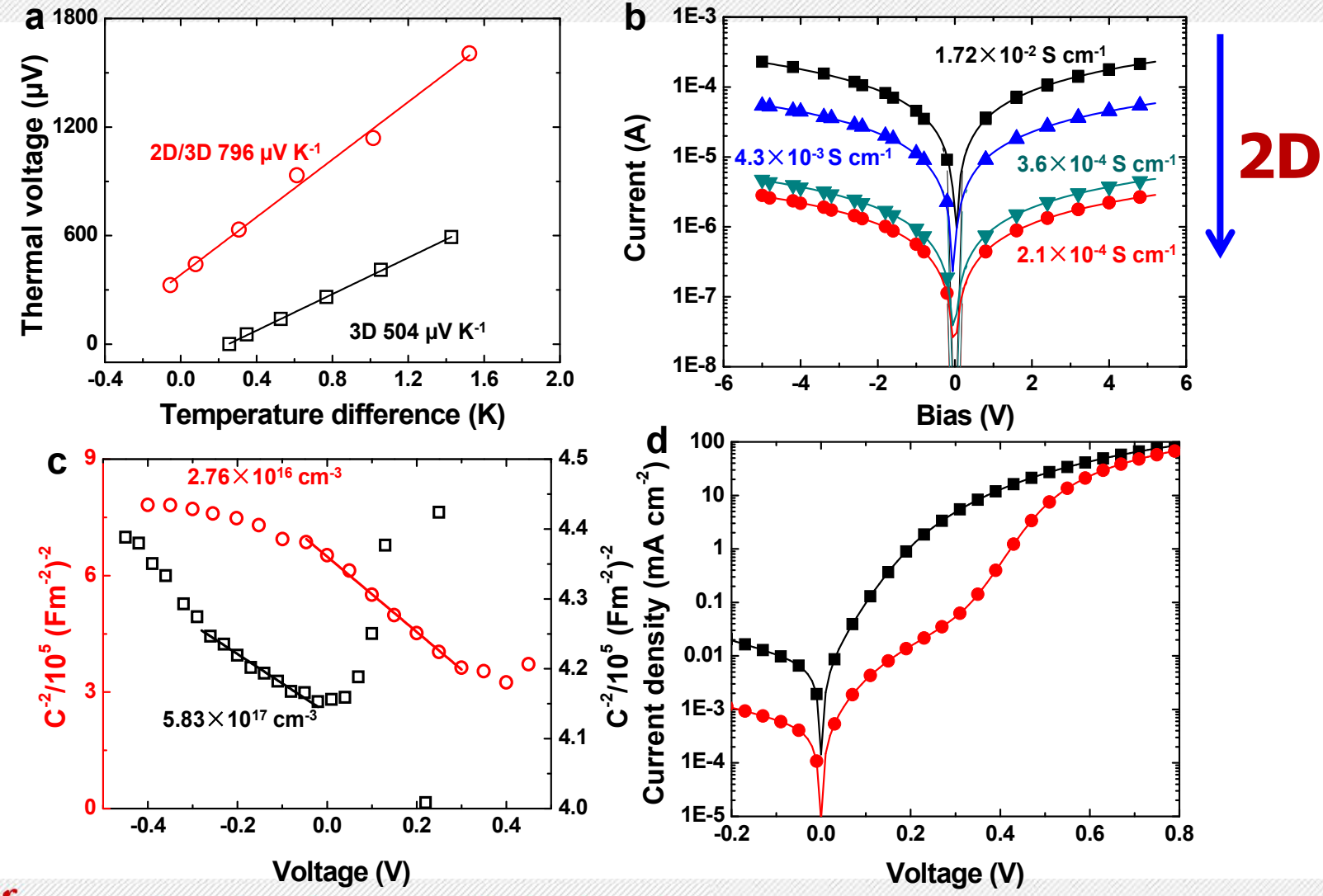


Shao...MAL, Adv. Energy Mater. (2017)

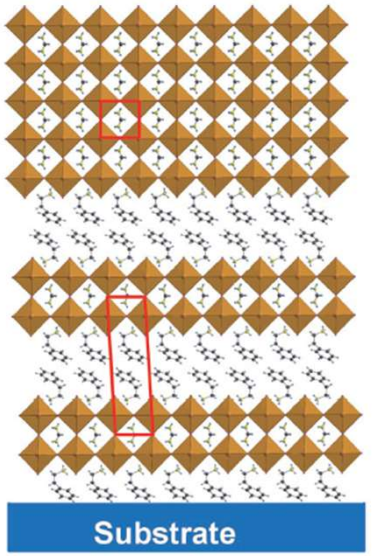
Large current



Transport


a
Thermal voltage (μV)
Temperature difference (K)
2D/3D 796 μV K-1
3D 504 μV K-1
b
Current (A)
Bias (V)
1.72×10-2 S cm-1
4.3×10-3 S cm-1
3.6×10-4 S cm-1
2.1×10-4 S cm-1
2D
c
C-2/105 (Fm-2)-2
Voltage (V)
2.76×1016 cm-3
5.83×1017 cm-3
d
Current density (mA cm-2)
C-2/105 (Fm-2)-2
Voltage (V)

Summary



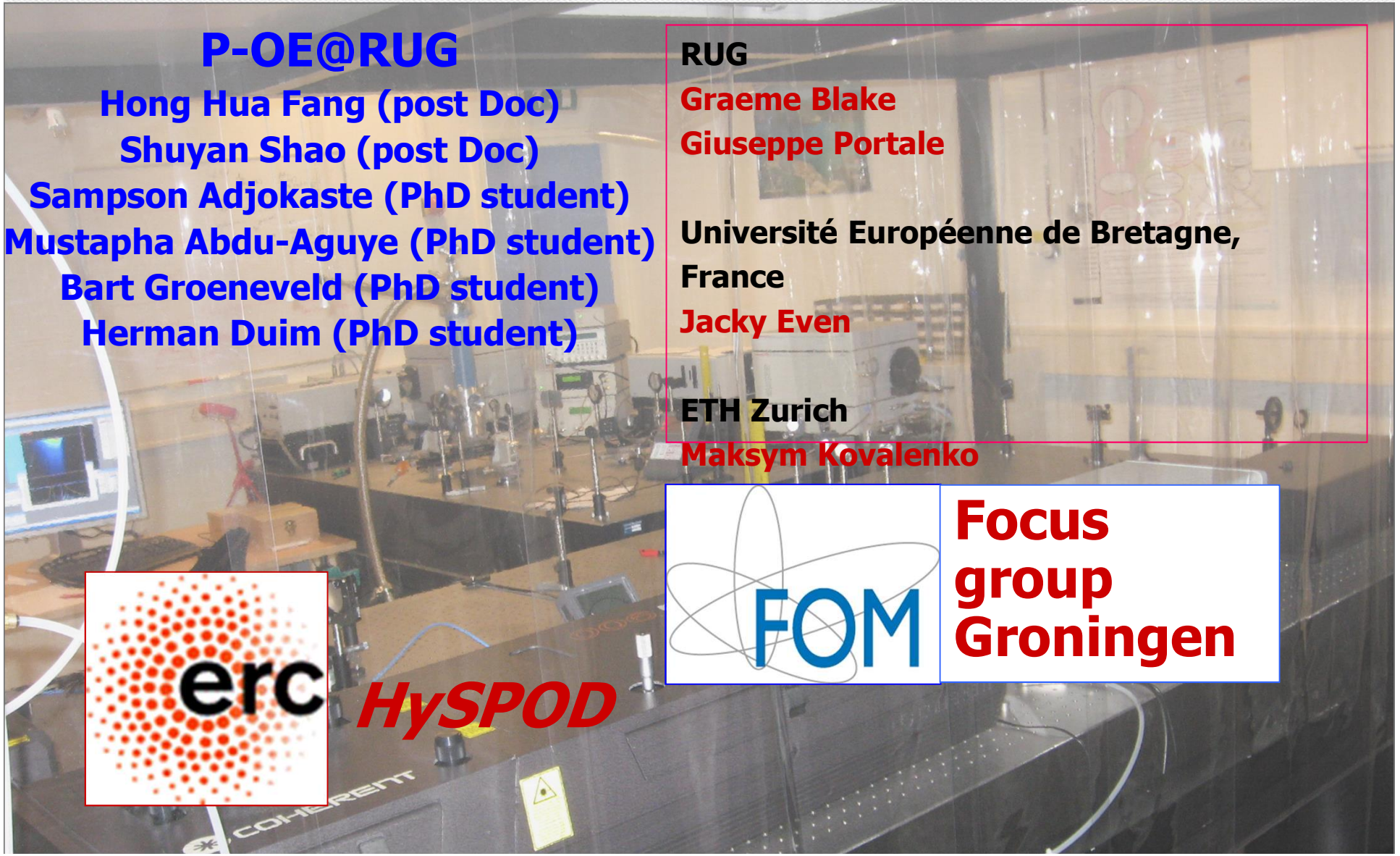
Elimination of the grain boundaries

Preferential orientation of the $FASnI_3$ crystals

De-doping of the $FASnI_3$ film and reduced background carrier density

9% tin perovskite solar cells with improved stability

Acknowledgments



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Herman Duim (PhD student)

RUG
Graeme Blake
Giuseppe Portale

Université Européenne de Bretagne, France
Jacky Even

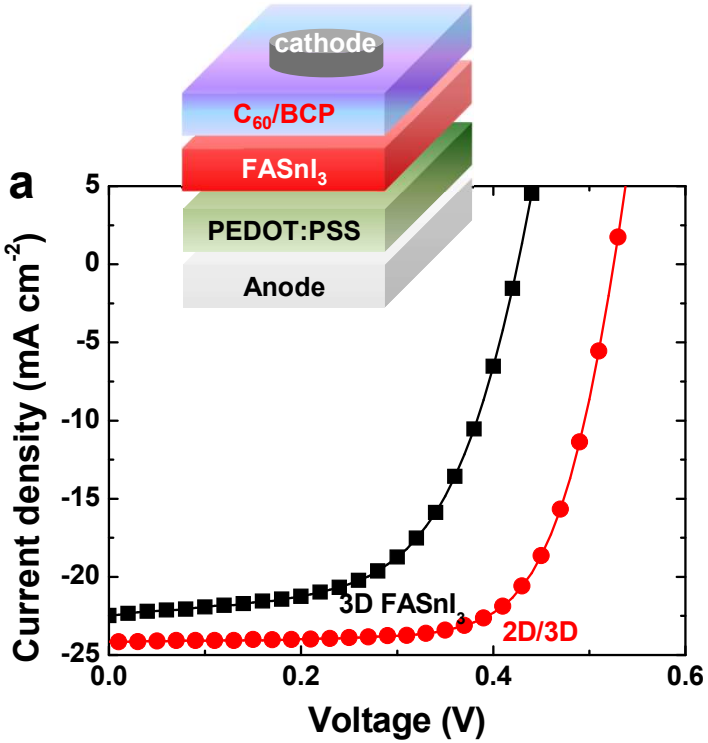
ETH Zurich
Maksym Kovalenko

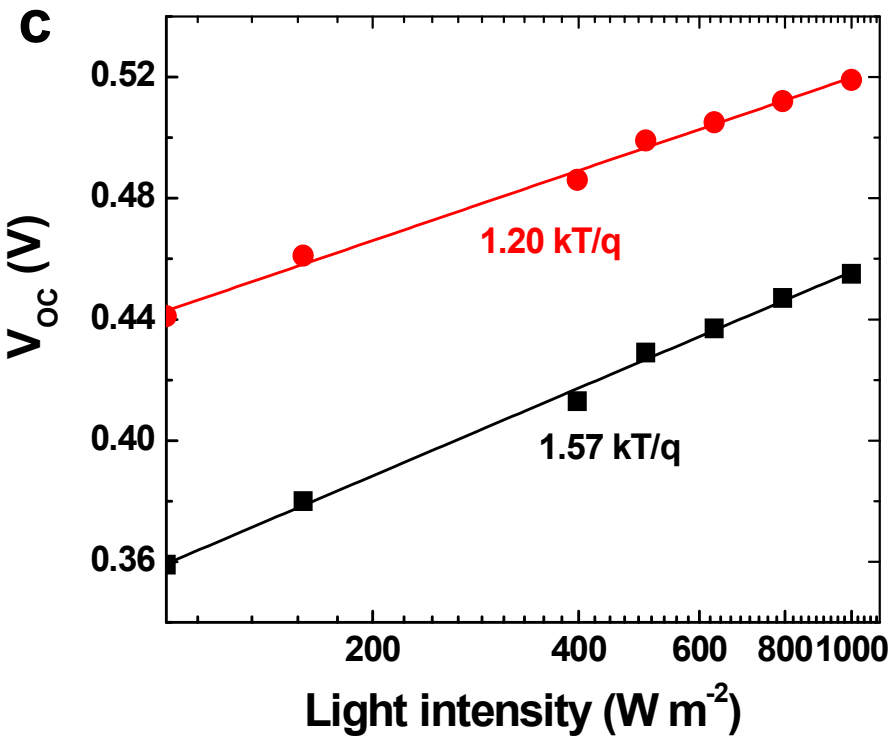
erc

HySPOD

FOM Focus group Groningen

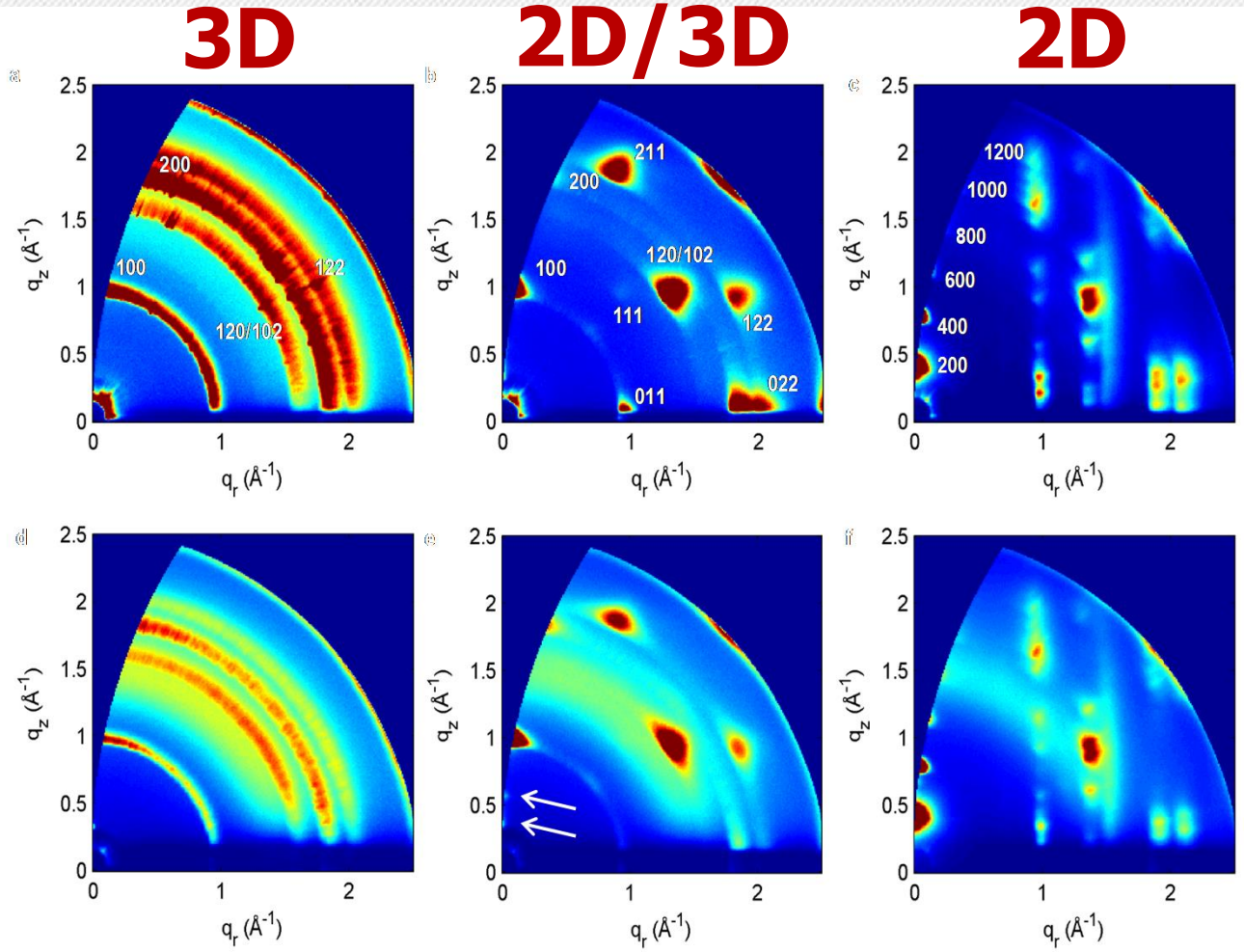
Reduction of traps



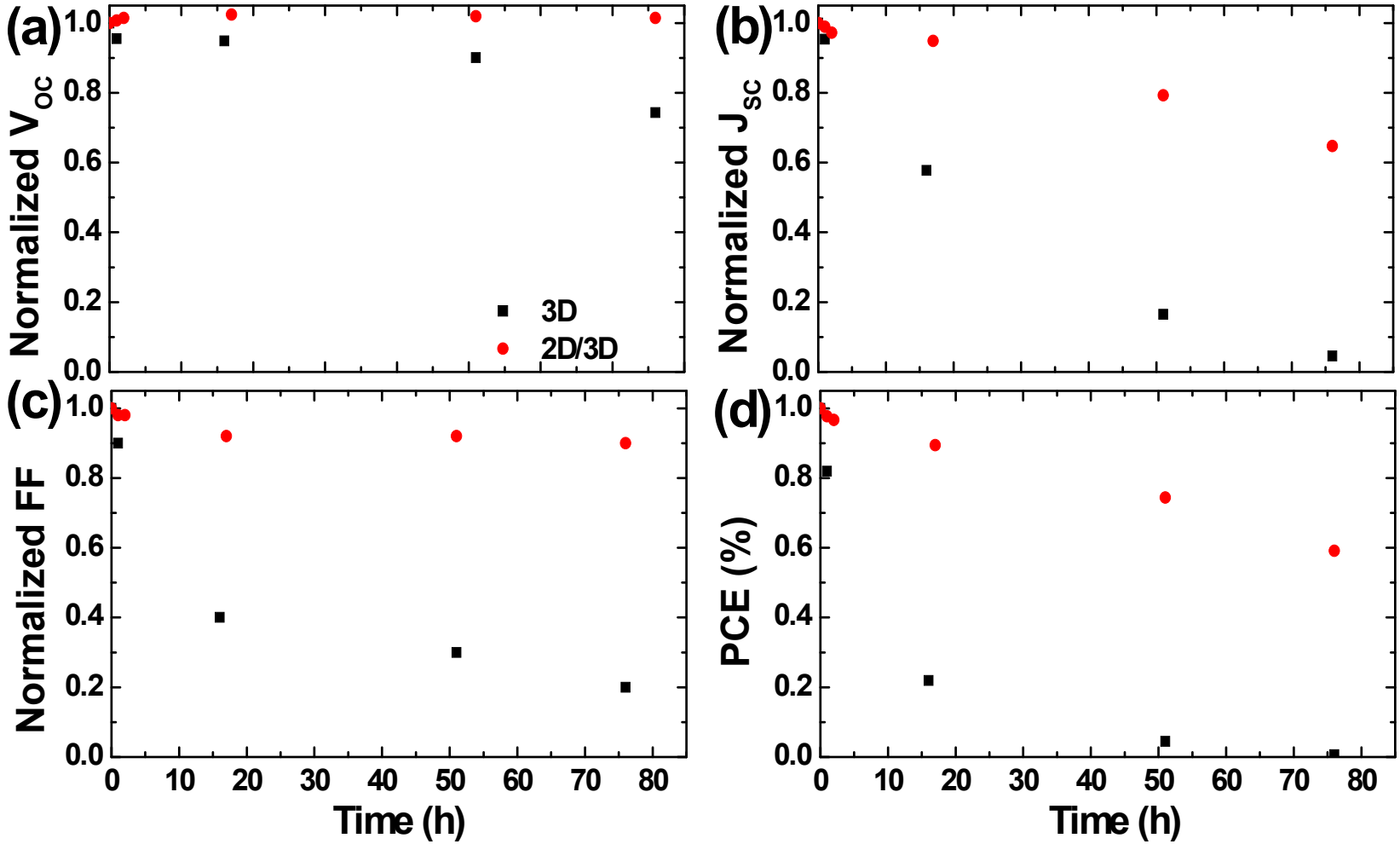


Shao...MAL, Adv. Energy Mater. (2017)

Without annealing



Stability test under 1 sun in ambient conditions



Increased structural stability