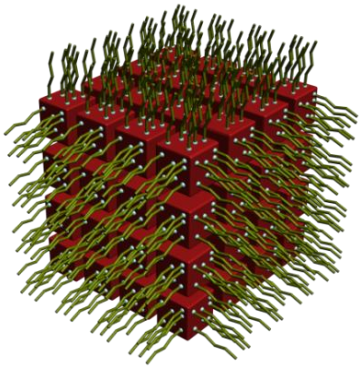
FUNSOM
功能纳米与软物质研究院
Institute of Functional Nano & Soft Materials

NANO-CIC
苏州纳米科技协同创新中心

SOOCHOW UNIVERSITY
UNTO A FULL GROWN MAN

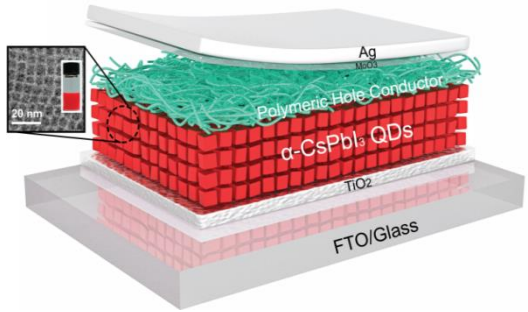
Perovskite Quantum Dot Solar Cells: Where Perovskite Meets Nanotechnology



Jianyu Yuan
(袁建宇)

Associate Professor

Email: jyyuan@suda.edu.cn



Institute of Functional Nano & Soft Materials (**FUNSOM**), **Soochow University**

Dr. Shujuan Huang's visit to FUNSOM (2018)

Outline

- Suzhou & FUNSOM
- Introduction of Perovskite QD
- Efficient Perovskite QDs Solar Cells

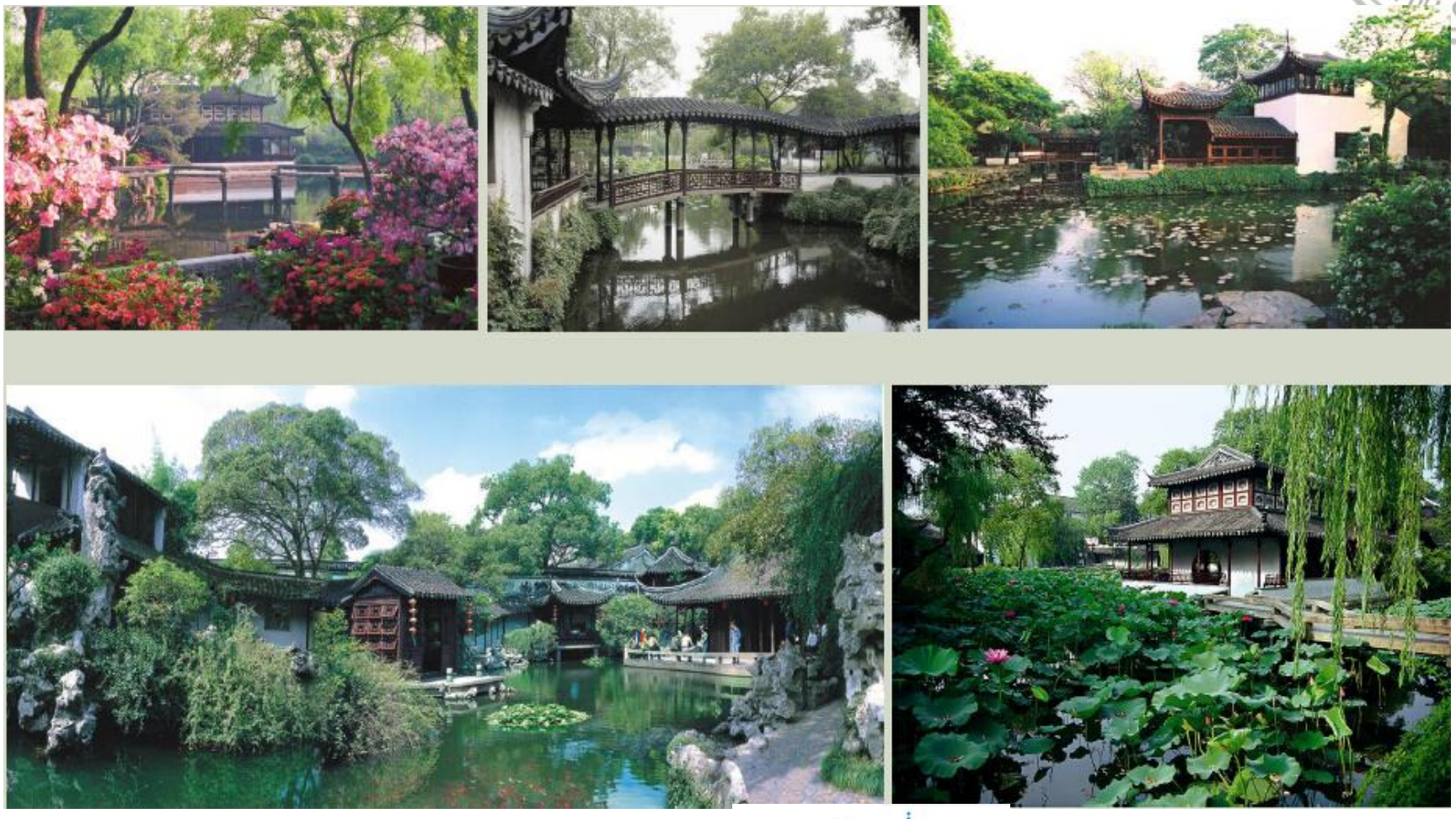
Something About Suzhou

苏州
蘇州
Suzhou
Soochow

- Suzhou is know as “Oriental Venice”;
- With a history of over 3000 years.
- A major city in the Eastern China;
- Adjacent to Shanghai;

*“Just as there is paradise in heaven, there are **Suzhou** and **Hangzhou** on earth !”*

Suzhou (Where Classical Meets Modern)!



Classical Gardens:

UNESCO
United Nations Educational, Scientific and Cultural Organization
World Heritage Convention

Suzhou (Where Classical Meets Modern)!

SIP: Suzhou-Singapore Industrial Park (From1995….)

About our Institute:

Institute of Functional Nano & Soft Materials (FUNSOM)

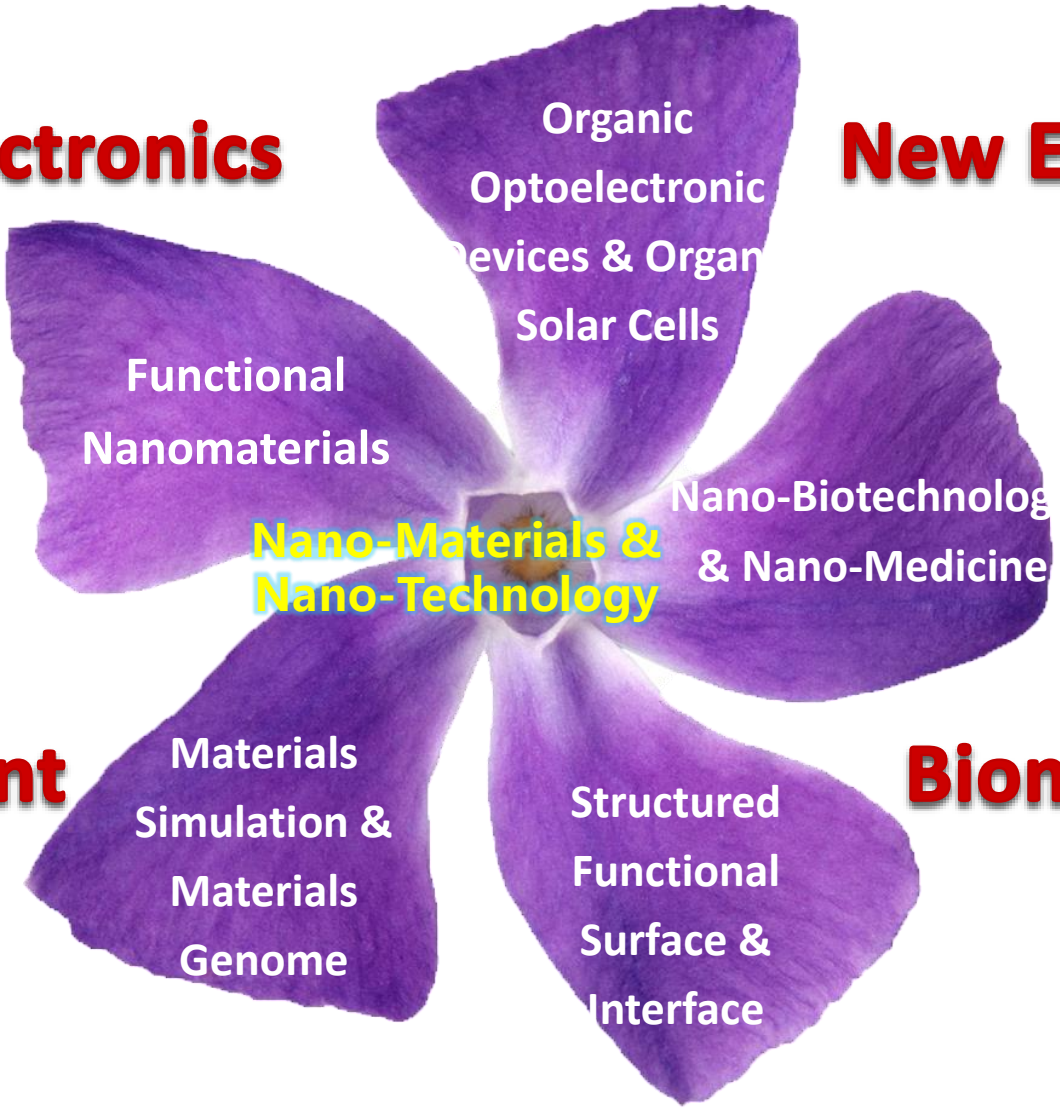
Prof.
Shuit-Tong Lee
(李述汤)

FUNSOM
功能纳米与软物质研究院
Institute of Functional Nano & Soft Materials

- Director,
- Fellow, CAS
- Fellow, TWAS
- Associate Editor, ACS Nano
- Total Citation > 60,000 ;
- H-index=123

- 40 Principal Investigators with overseas background
- ~30 Professors, Associate Professors and Lectures
- A strong supporting team of over 20 peoples
- ~400 undergraduates, ~600 graduate students

Research Areas



US$ 101.83 M funding and 1778 Papers since Establishment in 2008

“Education-Research-Industry” Triangle

CNST - 2010

- In 2011, awarded as one of the first 17 ‘Pilot Colleges’ by the Ministry of Education, China

Nano-CIC - 2013

- One of the first 14 National Collaborative Innovation Centers

FUNSOM - 2008

Jiangsu Key Laboratory for Carbon-based Functional Materials & Devices

- In 2017, Ranked No.1 in the Performance Evaluation in Jiangsu Province

IOO, Jiangsu Industrial Technology Research Institute - 2016

- Funding ~360 Million RMB
- Jointly established by:
  a. Jiangsu Province Industry Research Institute
  b. Government of Wujiang District, Suzhou
  c. Prof. Lee’ team

“Open for New Position”

Website: http://funsom.suda.edu.cn/

FUNSOM 苏州大学功能纳米与软物质研究院 Institute of Functional Nano & Soft Materials

一、招聘学科/方向

材料学、化学、物理学、生物学或其它相关学科，纳米科学技术相关领域，包括但不限于:

1、功能纳米材料与器件;
2、有机光电材料与器件;
3、光学与光学工程;
4、结构化功能表面与界面;
5、纳米生物医学;
6、新型表征技术及设备;
7、材料模拟与设计;
8、电子显微技术及其应用。

二、岗位及待遇

对于国家“四青”人才提供协议年薪、安家补贴、学术启动经费，以及必要的办公条件和场所。具体岗位及待遇如下:

1、岗位：特聘教授、博士生导师。年龄原则上应在40周岁以下（1979年1月1日以后出生）。

2、薪酬：35-60万元（“四青”人才50万起） + 论文、项目奖励，上不封顶。

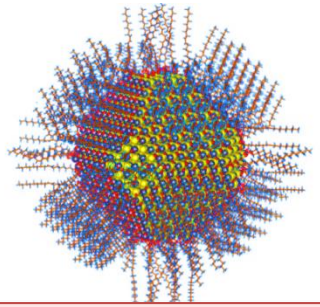
3、安家补贴：120-375万（含地方政府配套补贴）。提供精装修的过渡性人才公寓，拎包入住。

4、学术启动经费：200-300万元。可根据需要另行提供大型仪器设备费。

Outline

- Suzhou & FUNSOM
- **Introduction of Perovskite QD**
- Efficient Perovskite QDs Solar Cells

Why Perovskite QD Solar Cells

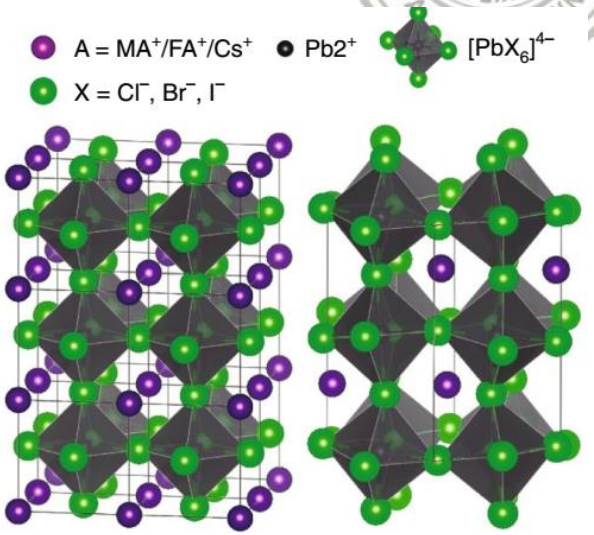


PbS

QD Solar Cells

Quantum Confinement Effect

Processing



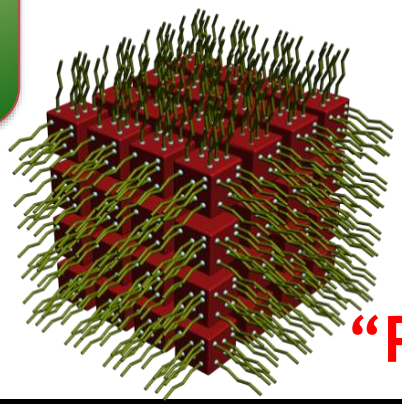
Thin-Film Perovskite Solar Cells

Adv. Mater. 2013, 25, 5772.
Adv. Mater. 2018, 30, 201704871.
Adv. Mater. 2018, 30, 201707572.
Adv. Funct. Mater. 2016, 26, 713.
Adv. Energy Mater. 2018, 8, 1701194.
Adv. Energy Mater. 2018, 7, 1602667.

Perovskite QD

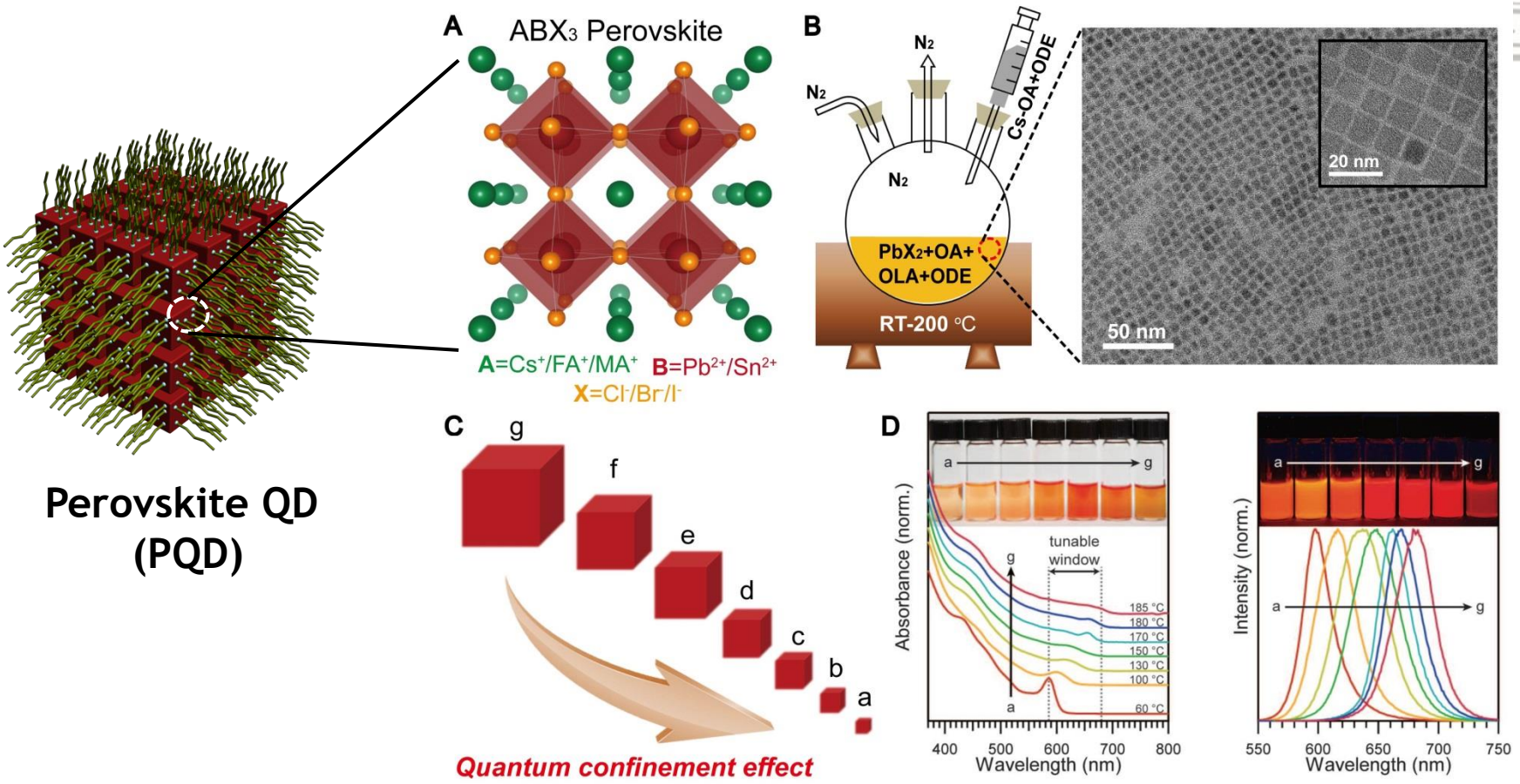
(PQD) Solar Cells

Started from June 2017



"PQD"

Emerging Perovskite QD PV

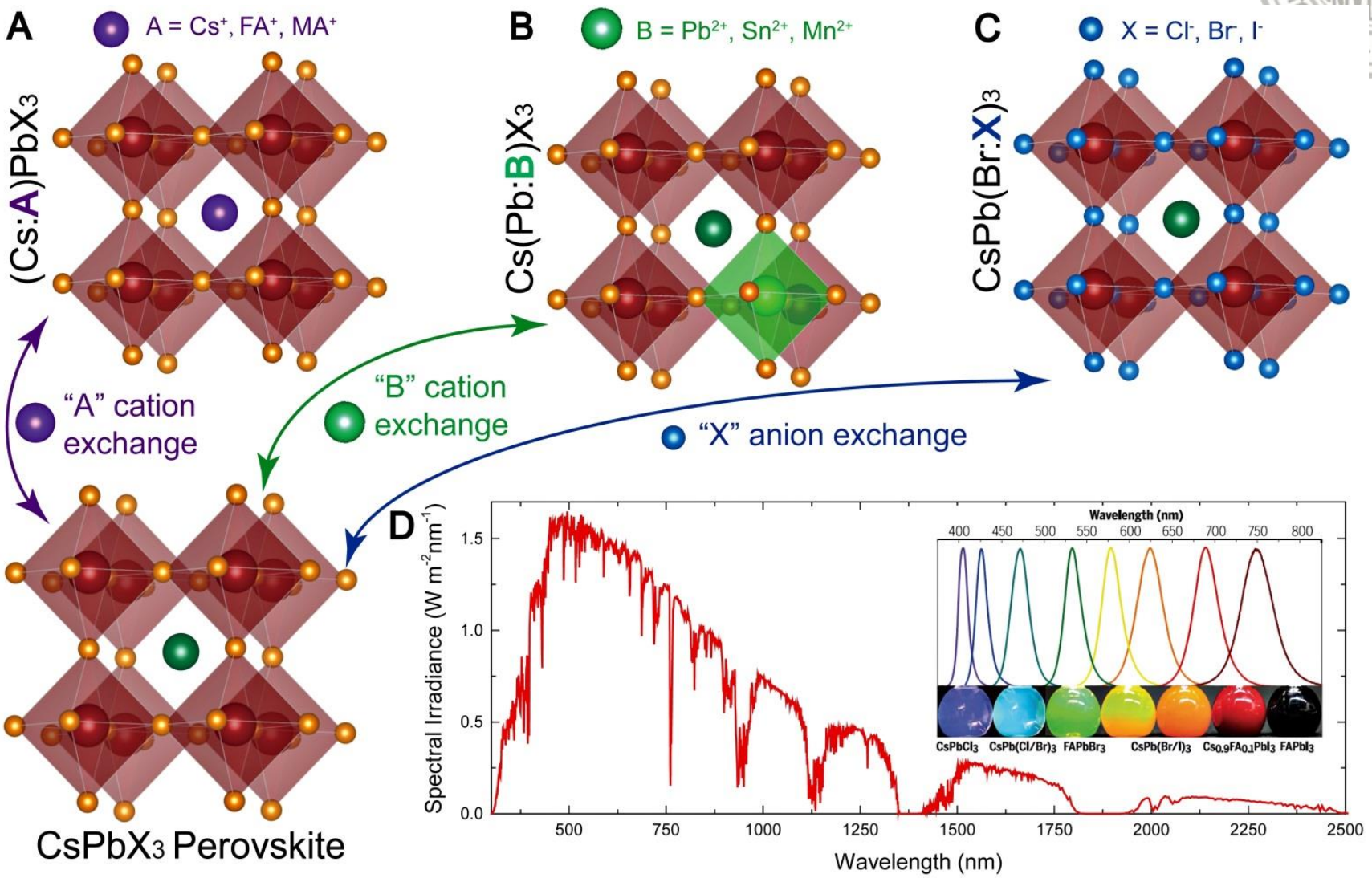


Perovskite QD (PQD)

- High PL quantum yields (~100%)
- Tunable bandgap
- Flexible compositional control
- Crystalline strain benefits.

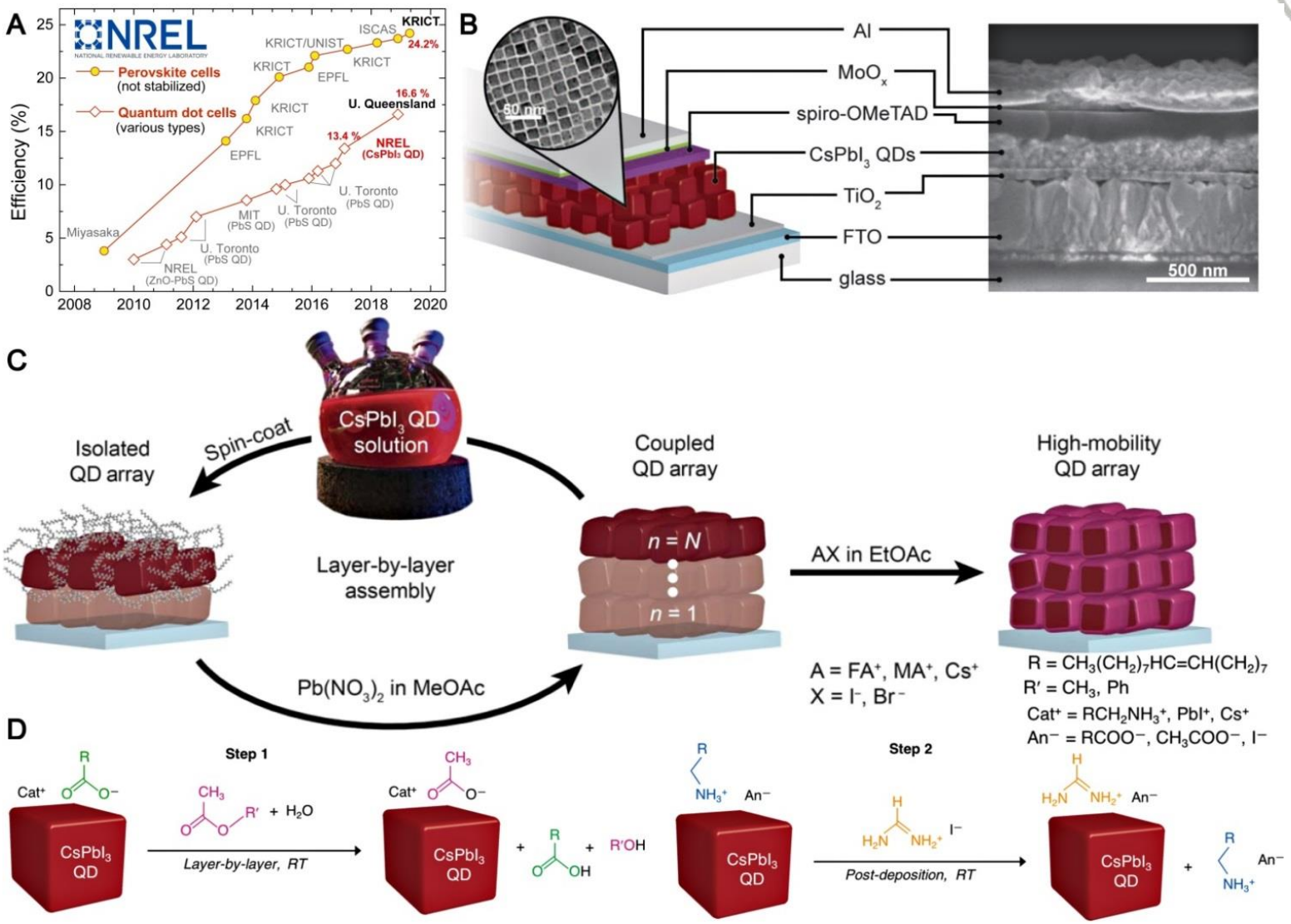
Kovalenko *et al.*, ***Nano Lett***. 2015, *15*, 3692; **Luther** et. Al., ***Science***, 2016, *354*, 92.

Ion Exchanges



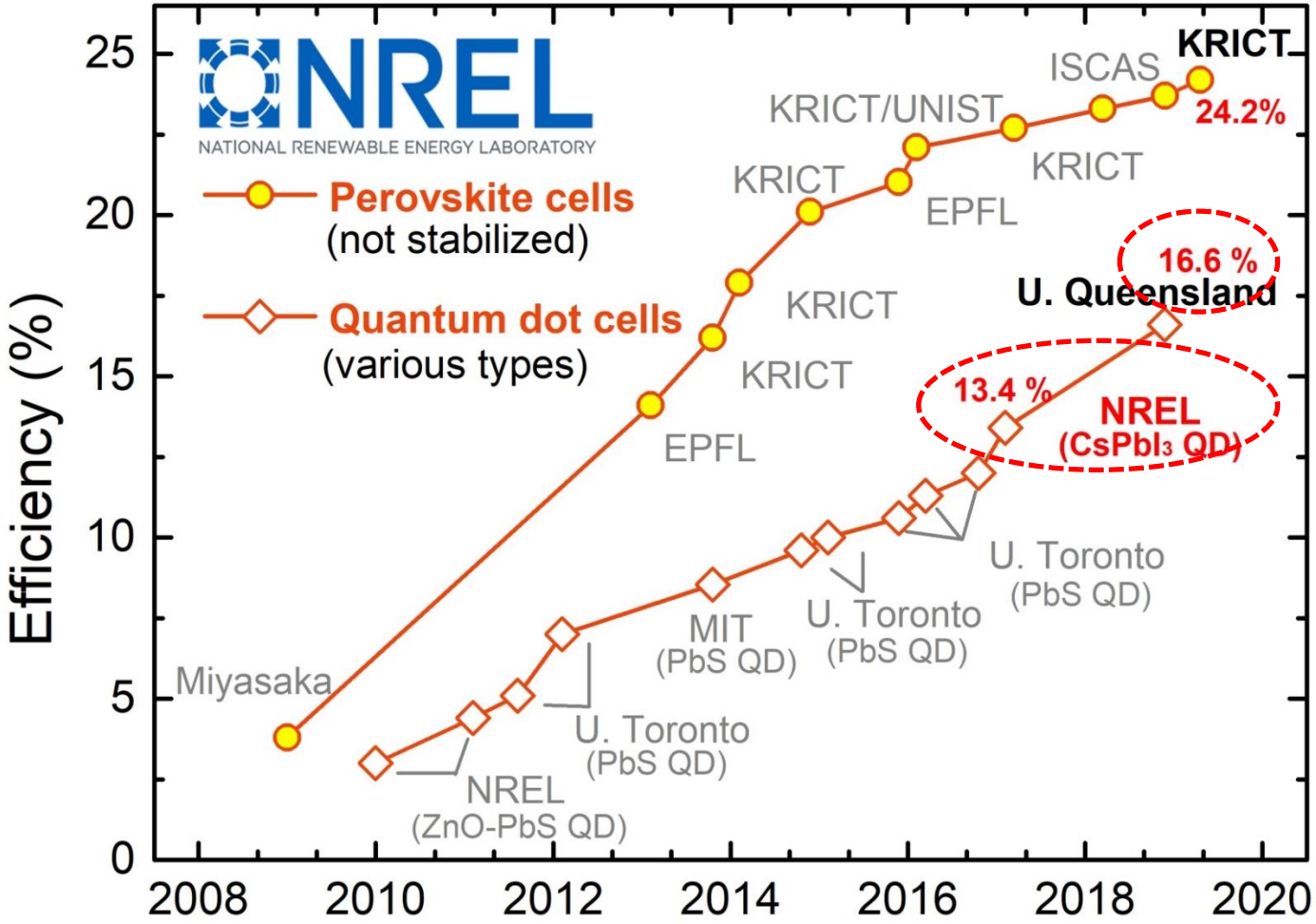
Kovalenko *et al.*, *Nano Lett.* 2015, 15, 5635-5640.

Pioneering Research of PQD Solar Cells



Luther et. Al., ***Science***, 2016, *354*, 92; *Sci. Adv.*, 2017, 3, eaao4204.

Rapid Progress of Perovskite and QDs based Solar Cells



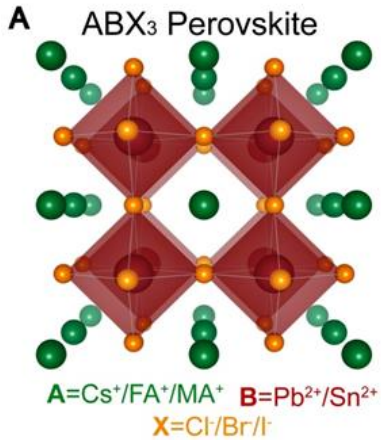
Perovskite QDs?

Bawendi et. al. ***Nat. Mater.***, 2014, 13, 796; Sargent et. al. ***Nat. Mater.***, 2017, 16, 258; Luther et. Al., ***Science***, 2016, 354, 92.

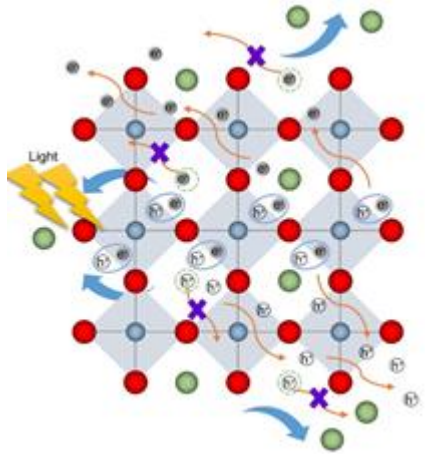
Outline

- Suzhou & FUNSOM
- Introduction of Perovskite QD
- **Efficient Perovskite QDs Solar Cells**

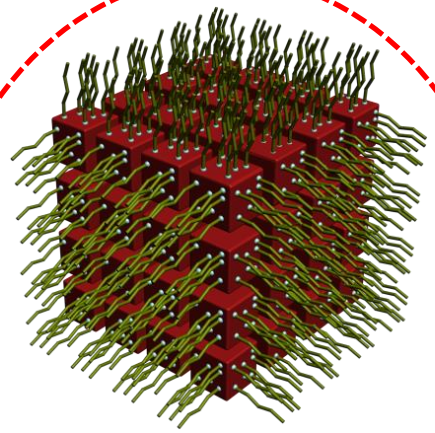
Research of Efficient PQD Solar Cells



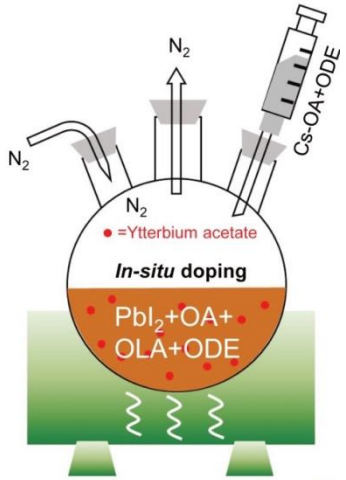
Composition control



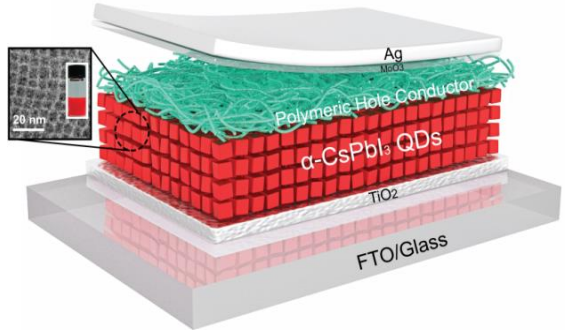
Solid-state treatment



Perovskite QD (PQD)

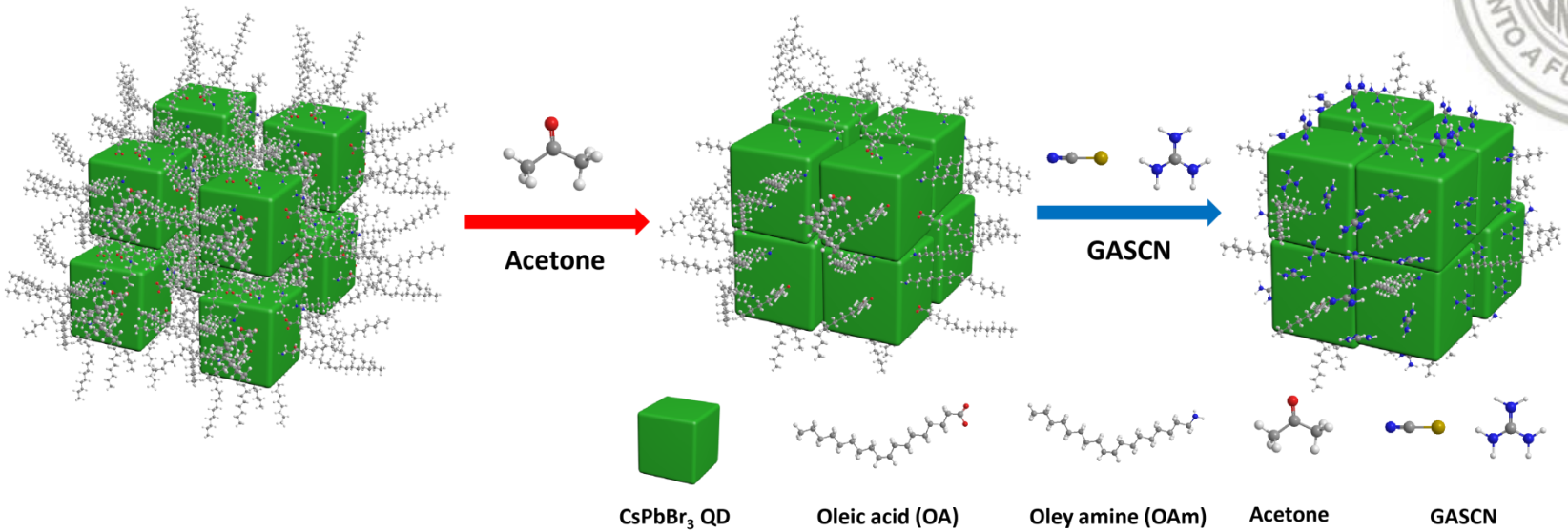


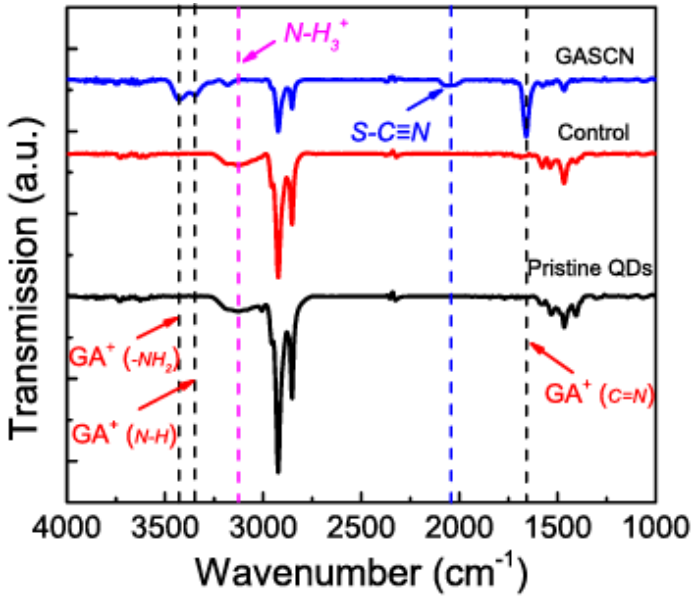
In-situ modification

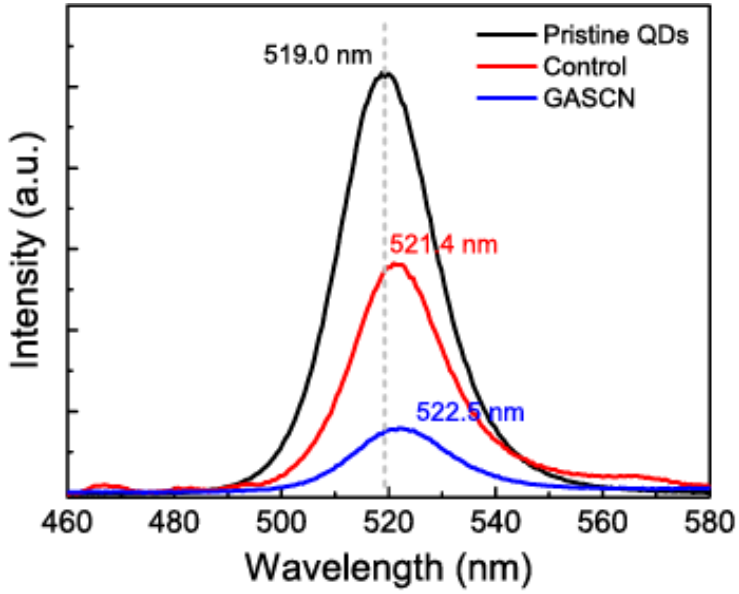


Device engineering

Composition Control: $CsPbBr_3$ QD Solar Cell

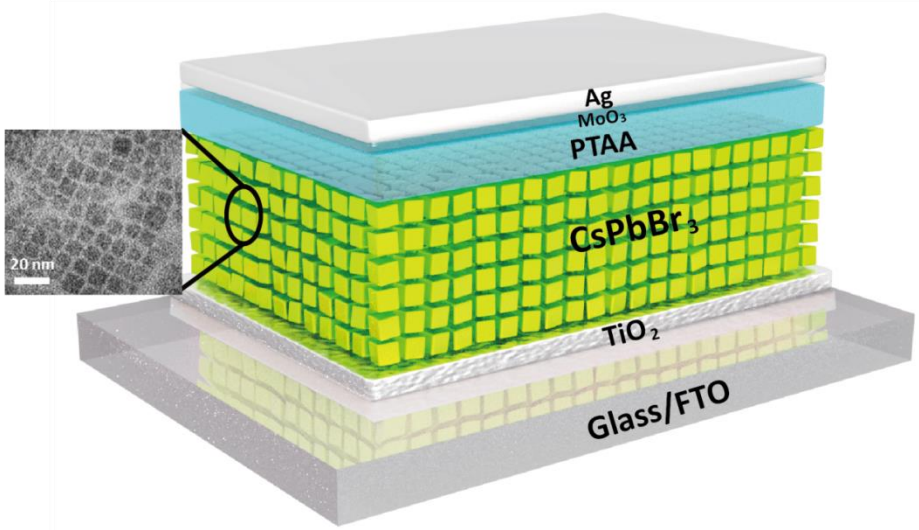


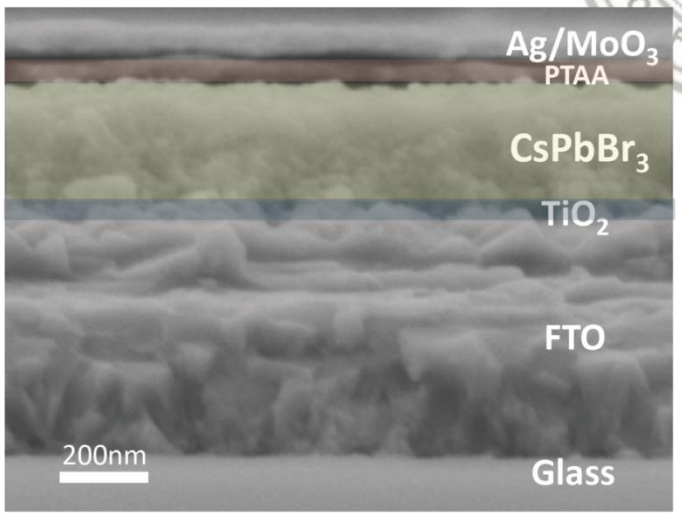


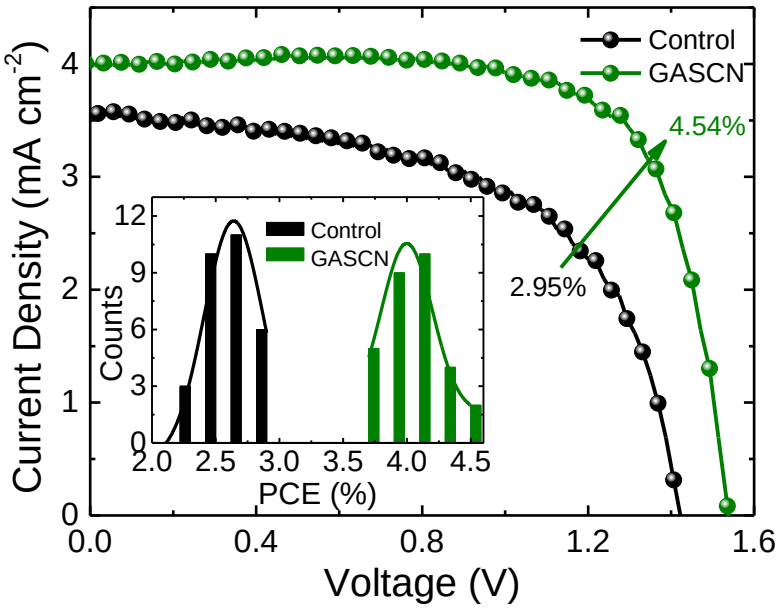


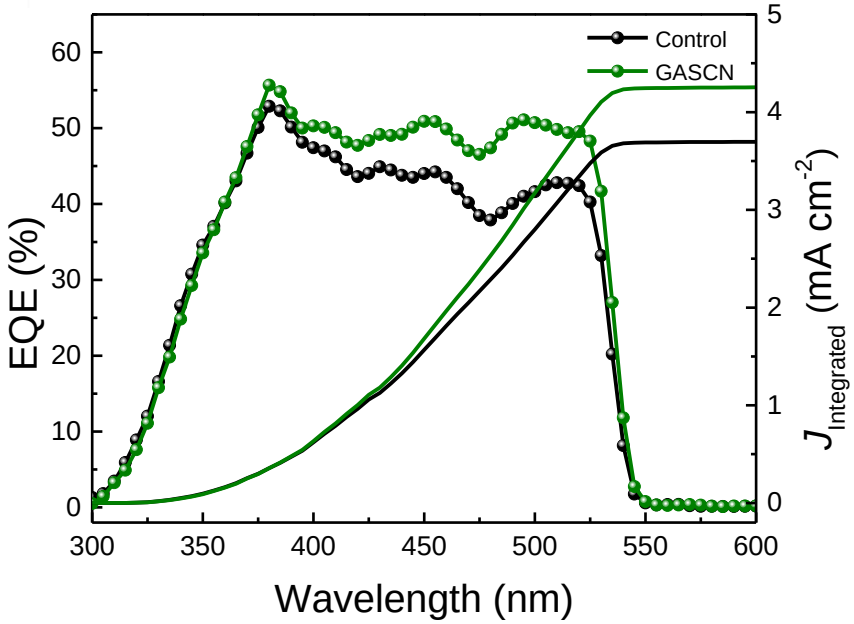
X. Zhang, J. Yuan*, W. Ma* et al. ***to be submitted***.

~5% $CsPbBr_3$ QD Solar Cell

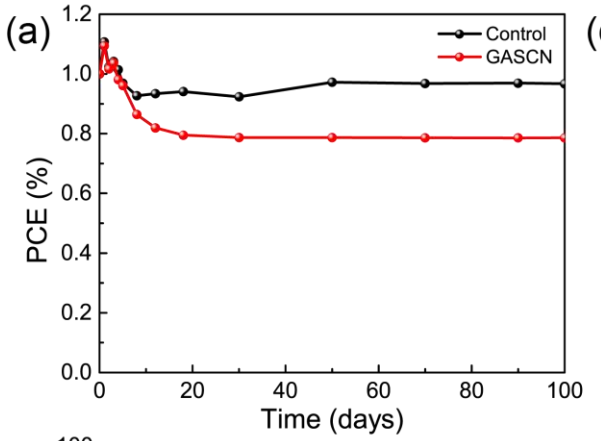


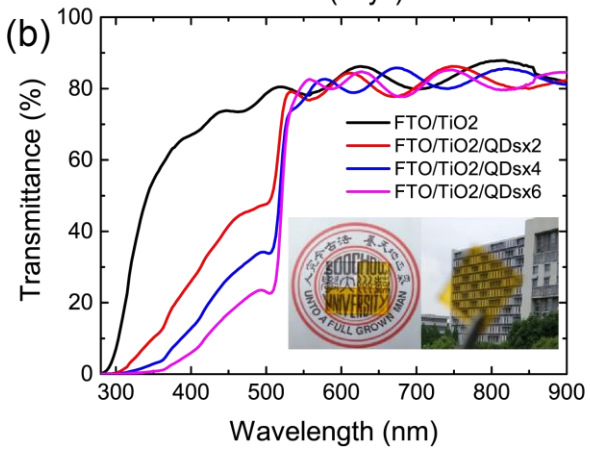


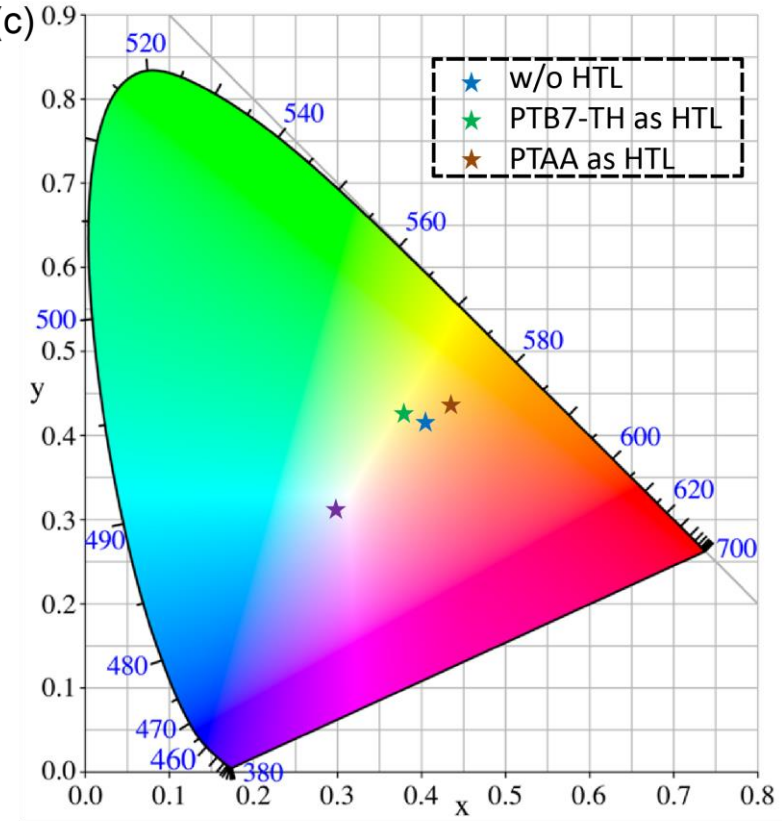




Semitransparent and Stable QD Solar Cell

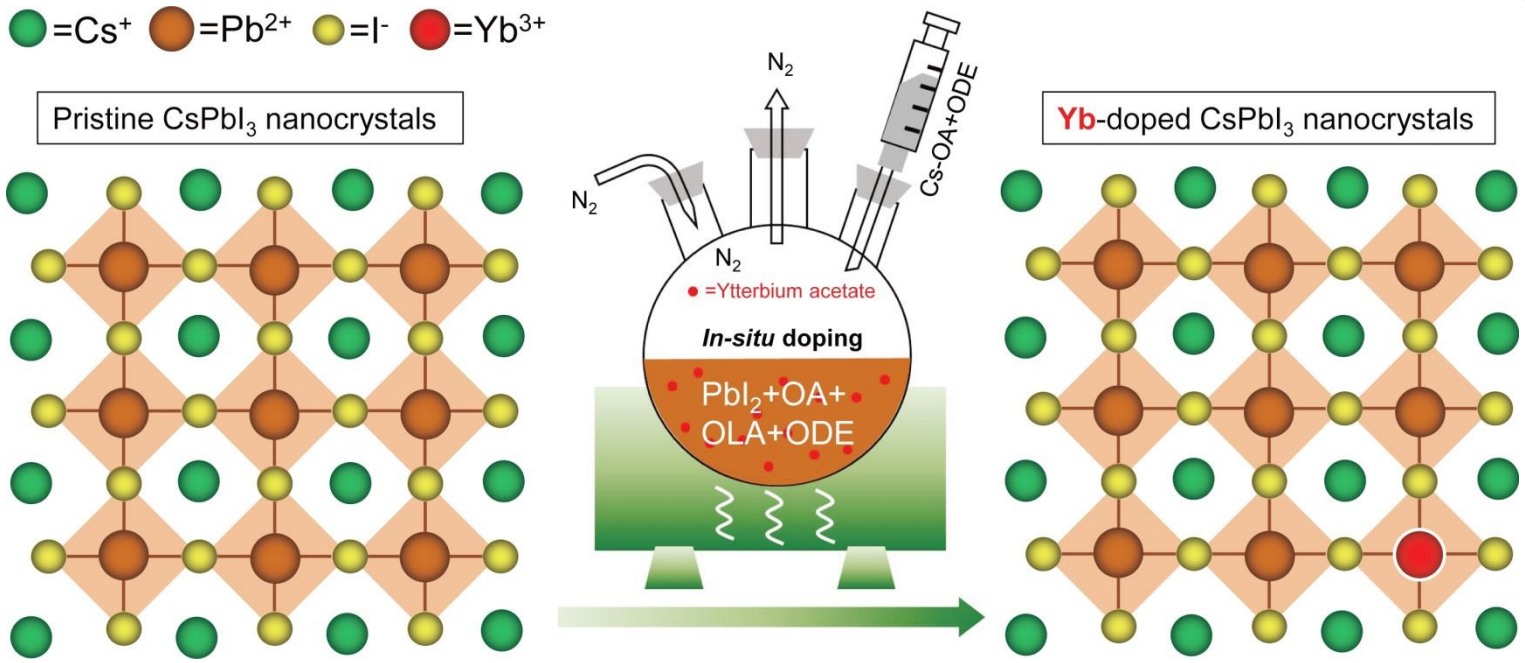






Sample	CIE (x, y)	CRI	CCT (K)
w/o HTL	(0.298, 0.310)	88	3687
PTB7-Th	(0.405, 0.415)	84	4302
PTAA	(0.436, 0.434)	86	3251

In-situ Passivation by Lanthanide Doping

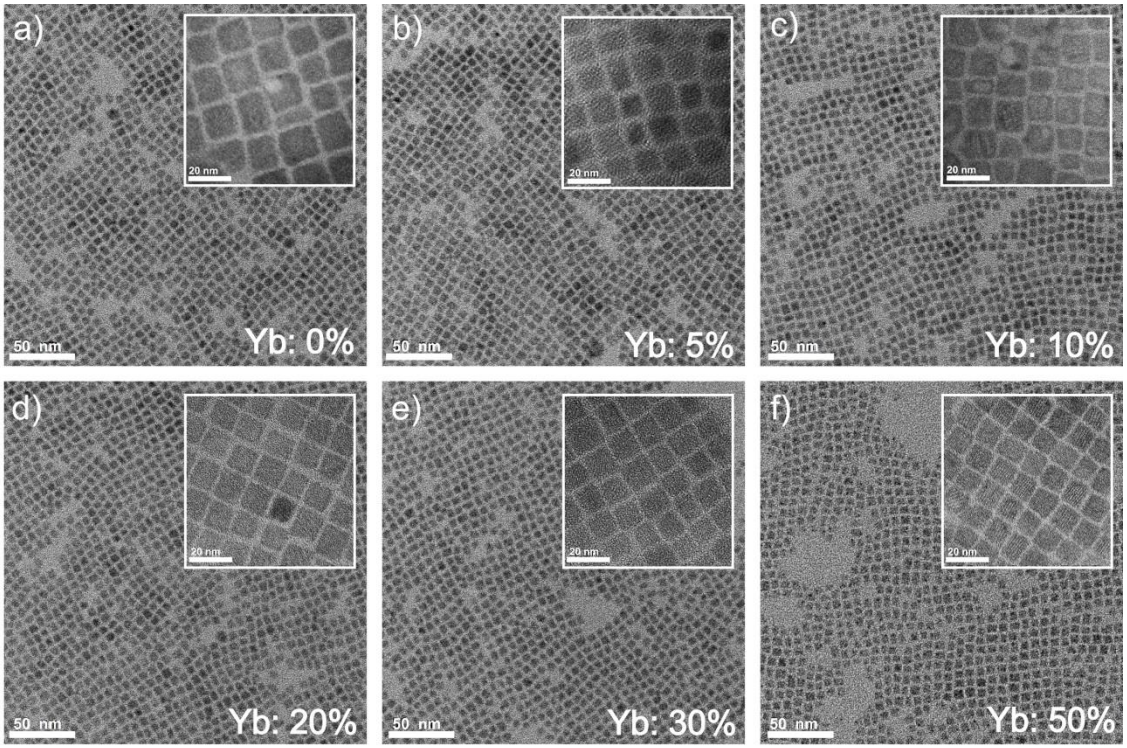


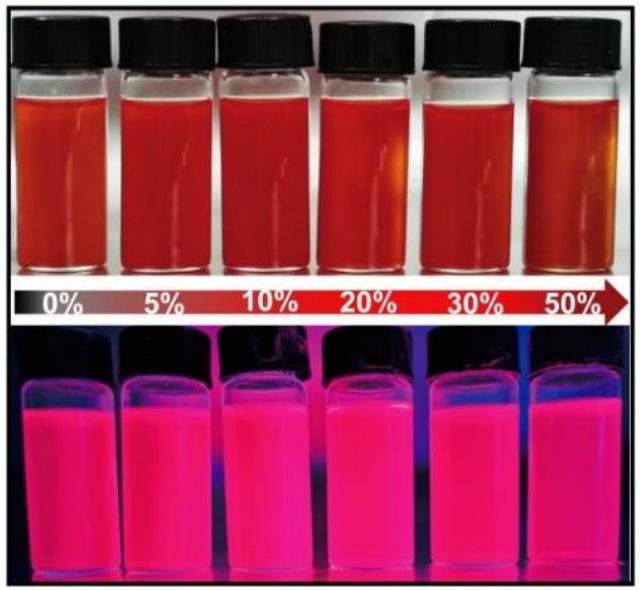
Ytterbium (Yb) Doping:

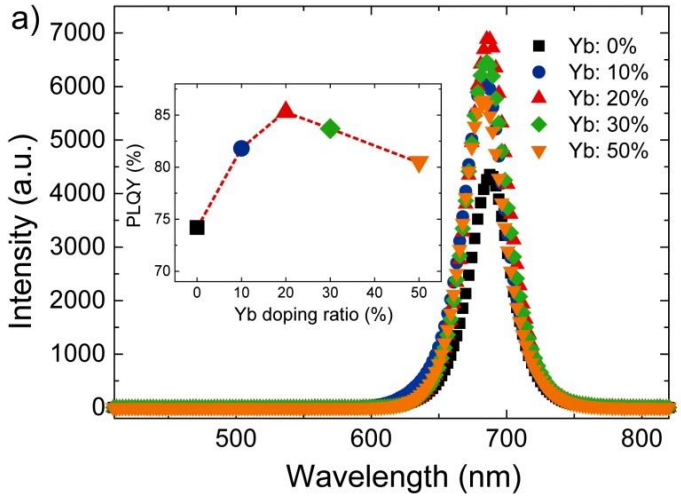
- Reduce the defects and trap states caused by surface and lattice vacancies
- Improve QD photoluminescence quantum yield (PLQY)
- Improve carrier transport and phase stability

J. Shi, J. Yuan*, W. Ma* et al. *J. Mater. Chem. A 2019, In press.*

QD Size Distribution and Optical Properties



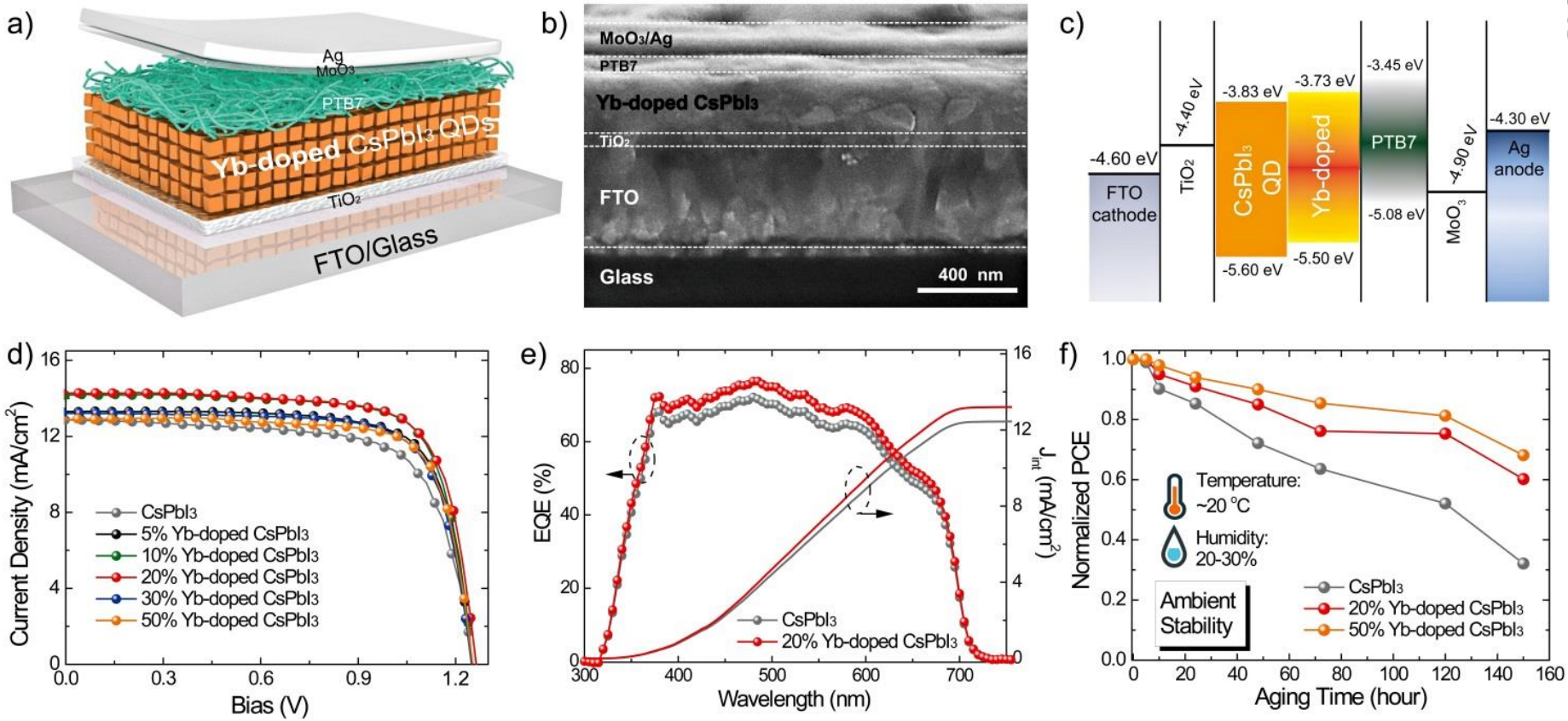




Ytterbium (Yb) Doping:

- Negligible effect on QD size and distribution;
- Slightly effect on optical bandgap and PL;
- Significantly improve the PLQY (less trap states).

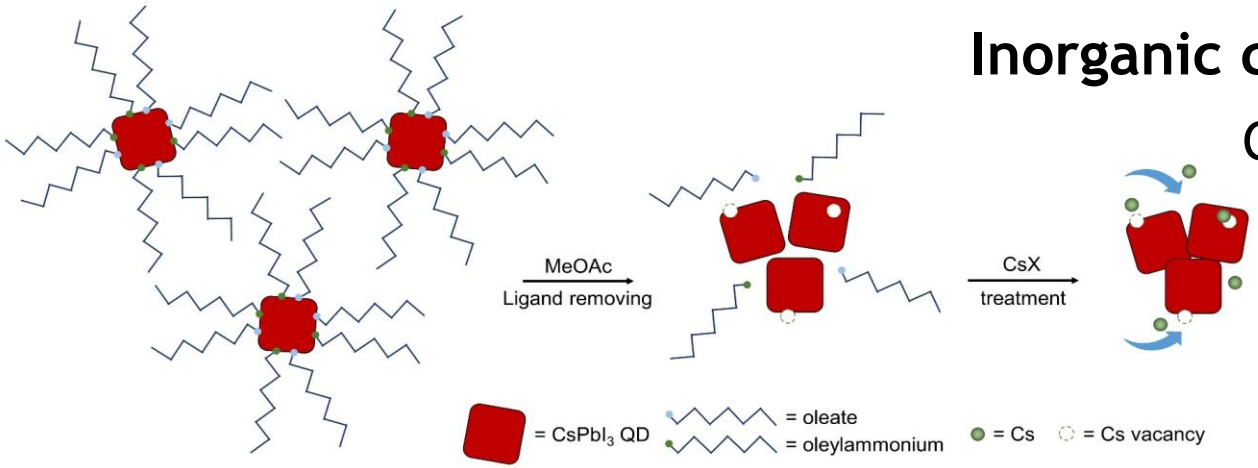
Perovskite QD Solar Cell Performance



Ytterbium (Yb) Doping:

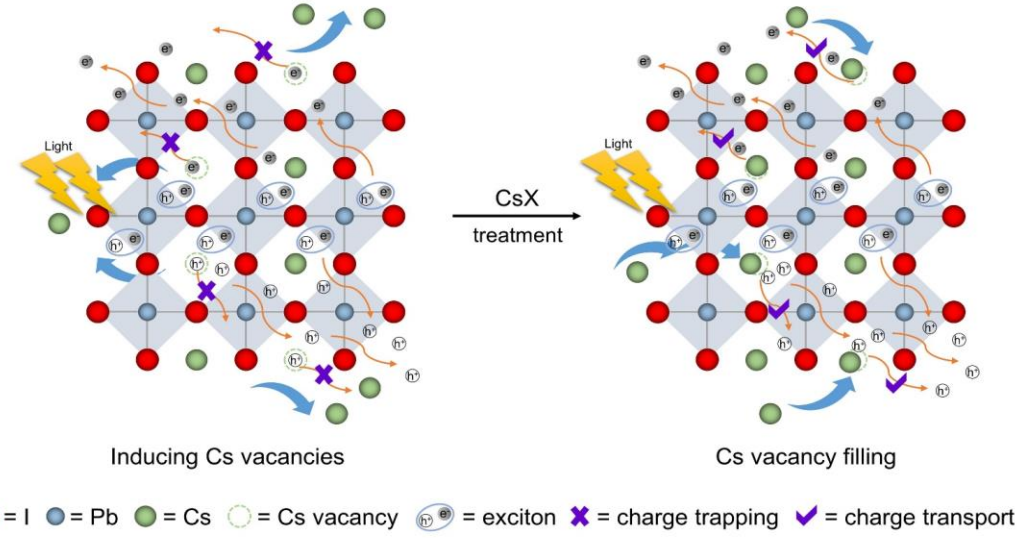
- Improved short-circuit current (Jsc) and efficiency (12.06% to **13.12%**)
- Significaty improved ambient stability (phase stability)

PQD Film Post-Treatment: Cs^+ Cation



Inorganic cesium salts:

$CsAc$, Cs_2CO_3, $CsNO_3$ etc.

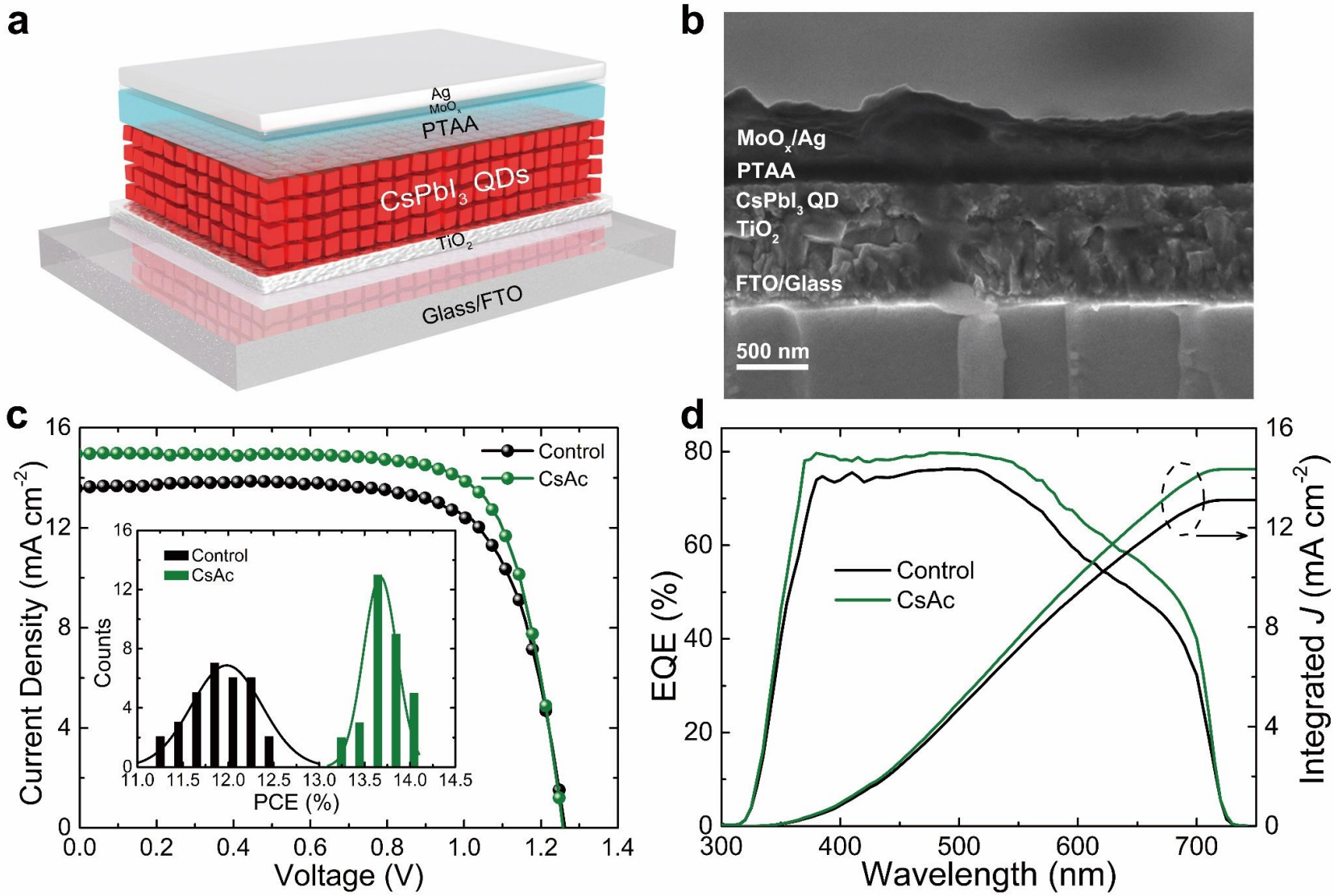


- Cs vacancies
- Traps after ligand exchange

Charge transport and recombination loss

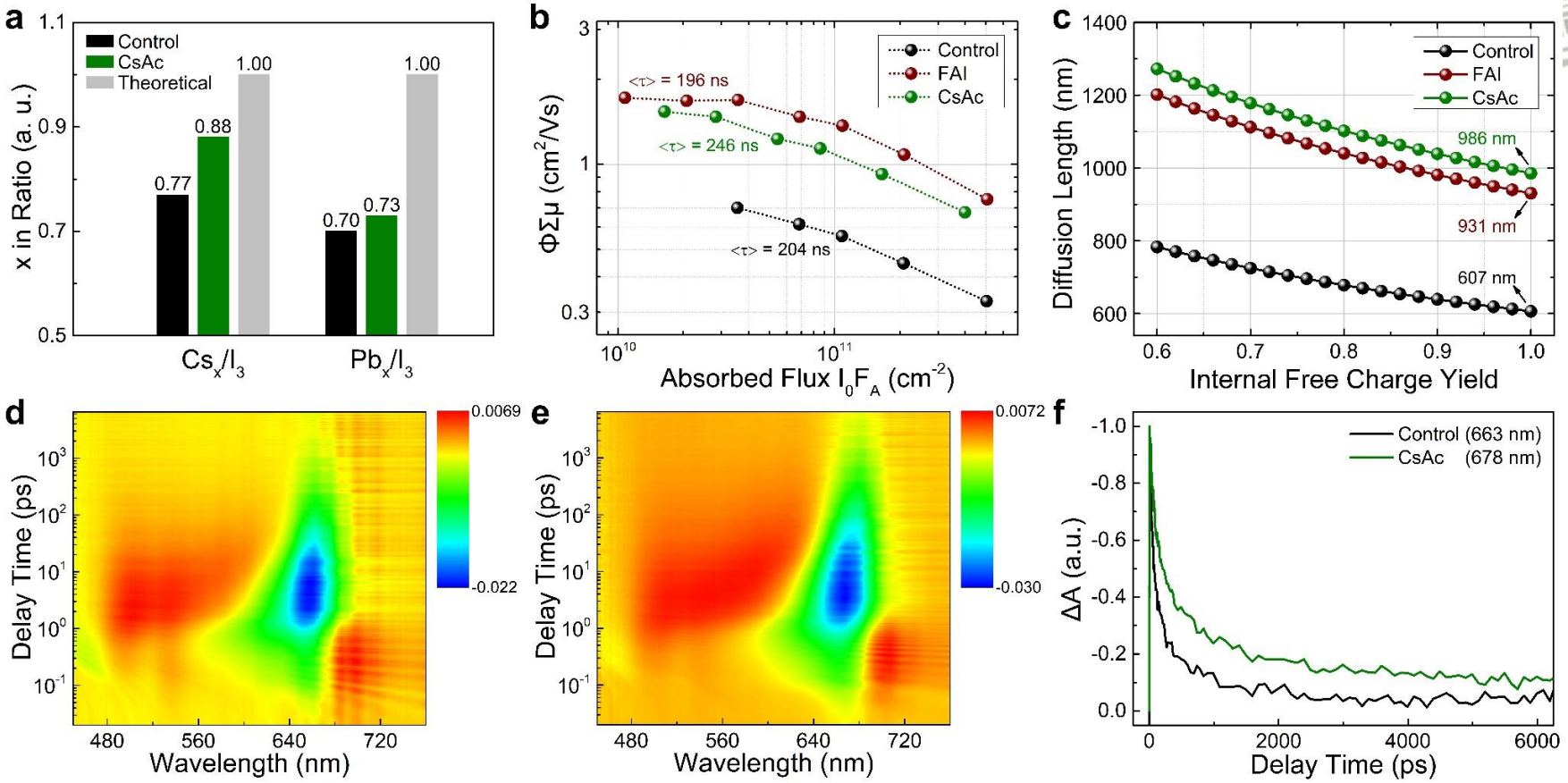
X. Ling, J. Yuan*, W. Ma* et al. *Adv. Energy Mater.* 2019, 9, 1900721.

14.1% $CsPbI_3$ PQD Solar Cells



X. Ling, **J. Yuan***, **W. Ma*** et al. ***Adv. Energy Mater.*** 2019, 9, 1900721.

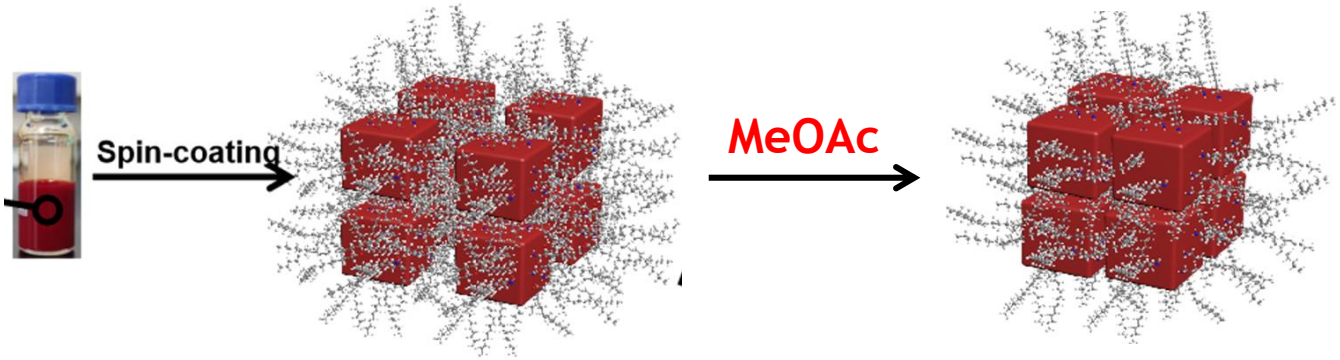
Well Passivated $CsPbI_3$ PQDs by Cs^+ Cation



- Desirable surface composition, enhanced electron coupling;
- Improved charge transport and reduced recombination loss

X. Ling, J. Yuan*, W. Ma* et al. *Adv. Energy Mater.* 2019, 9, 1900721.

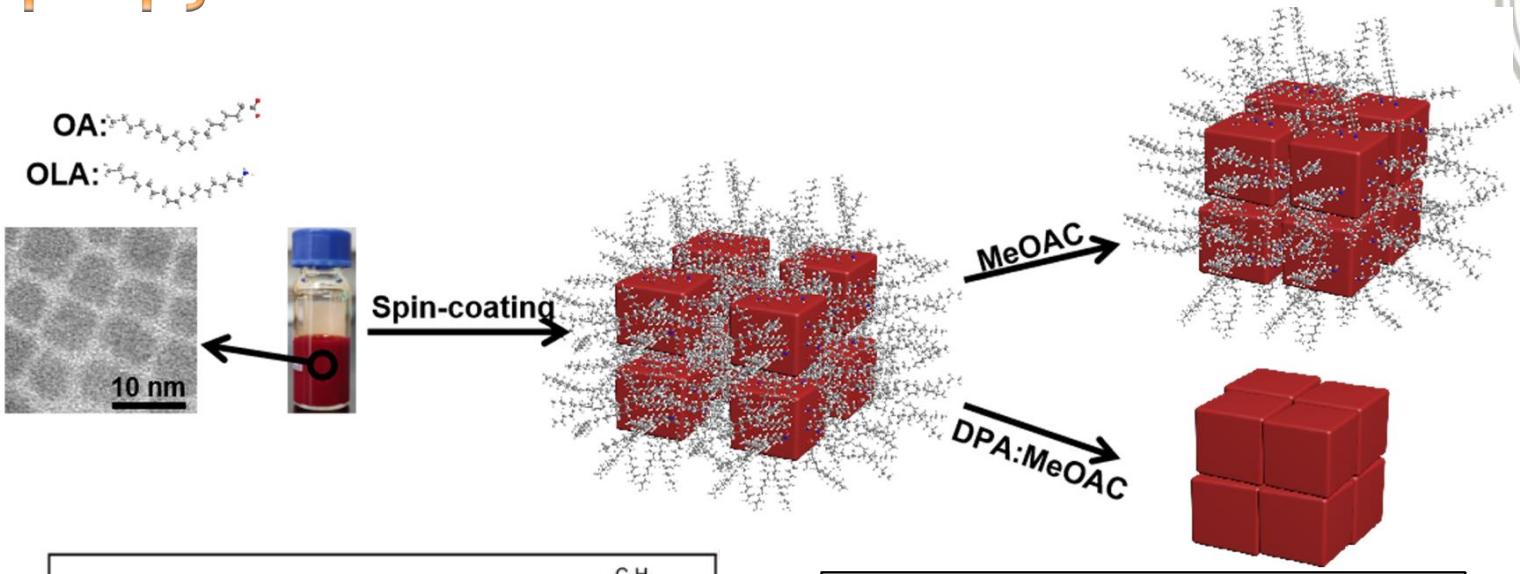
Highly Conductive and Reproducible $CsPbI_3$ QD Film

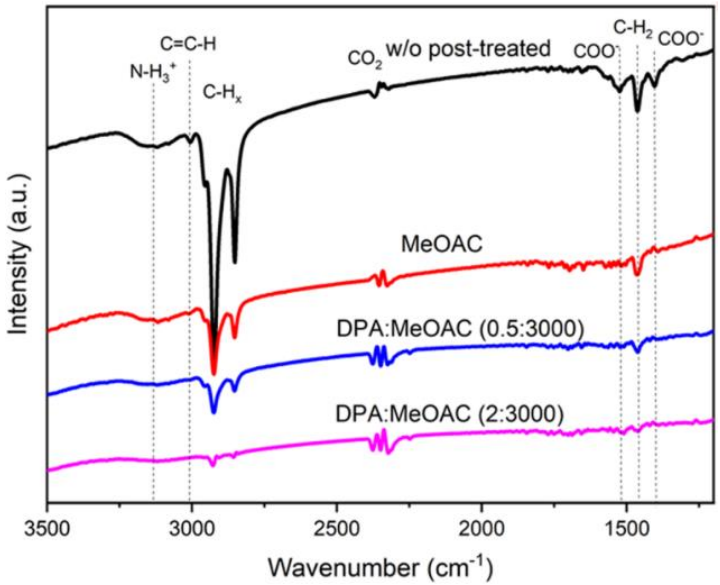


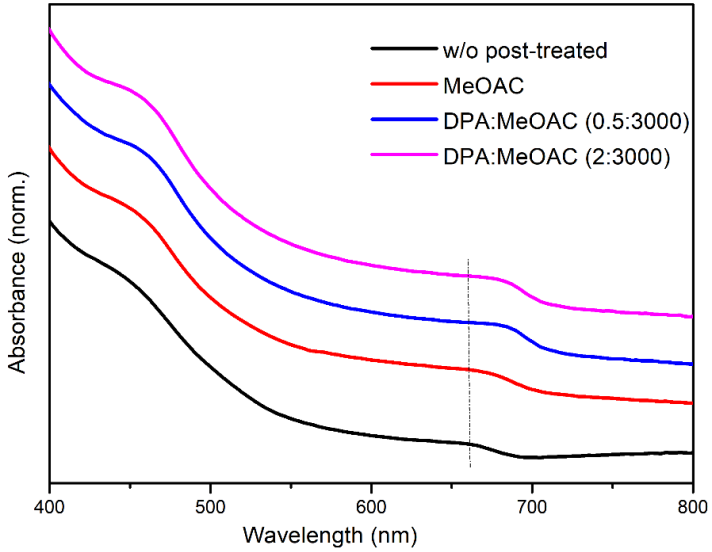
	NiO_x	P3CT	PEDOT:PSS	PTAA
MeOAC				
MeOAC (DPA)				

Y. Wang, J. Yuan*, W. Ma* et al. *to be submitted*.

Di-n-propylamine Post-treatment



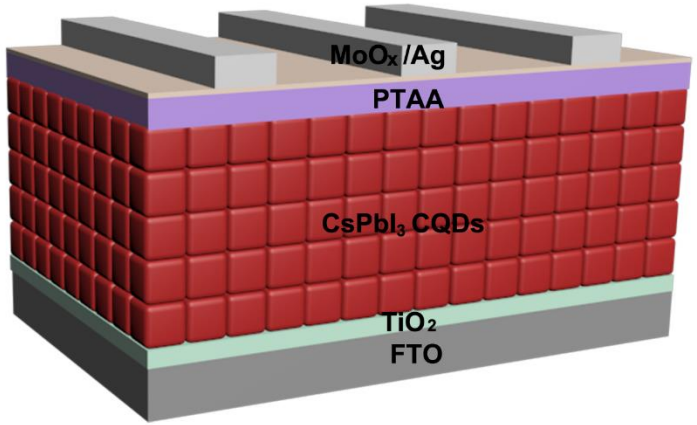


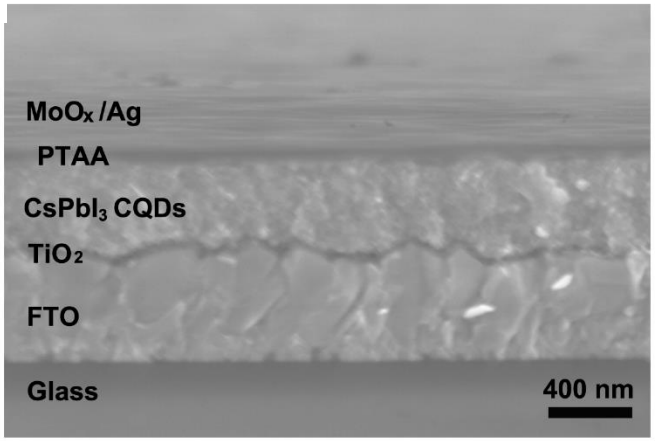


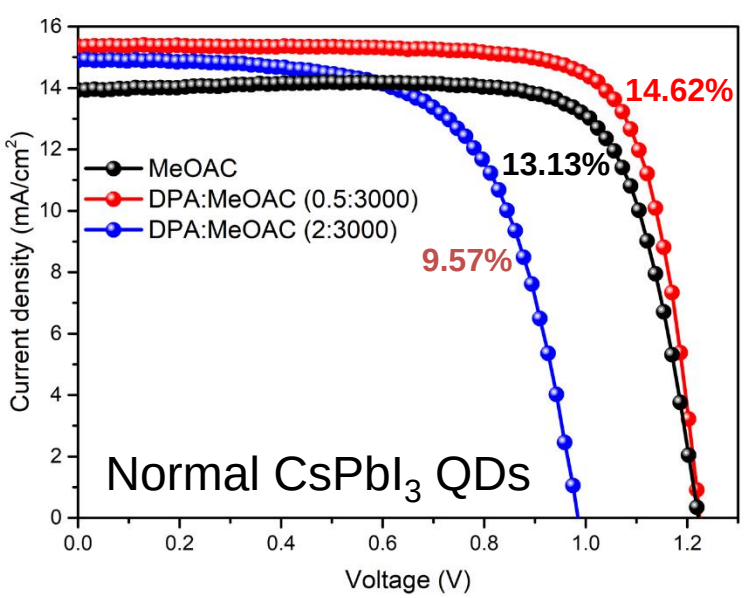
DPA promotes the removal of long chain insulated ligands and increases the coupling of $CsPbI_3$ CQD array.

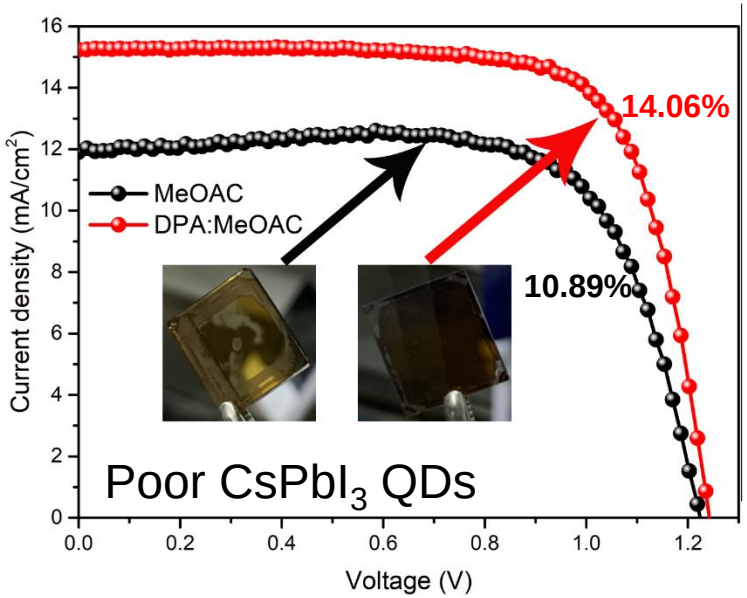
Y. Wang, J. Yuan*, W. Ma* et al. *to be submitted*.

~15% and Reproducible $CsPbI_3$ PQD Solar Cells



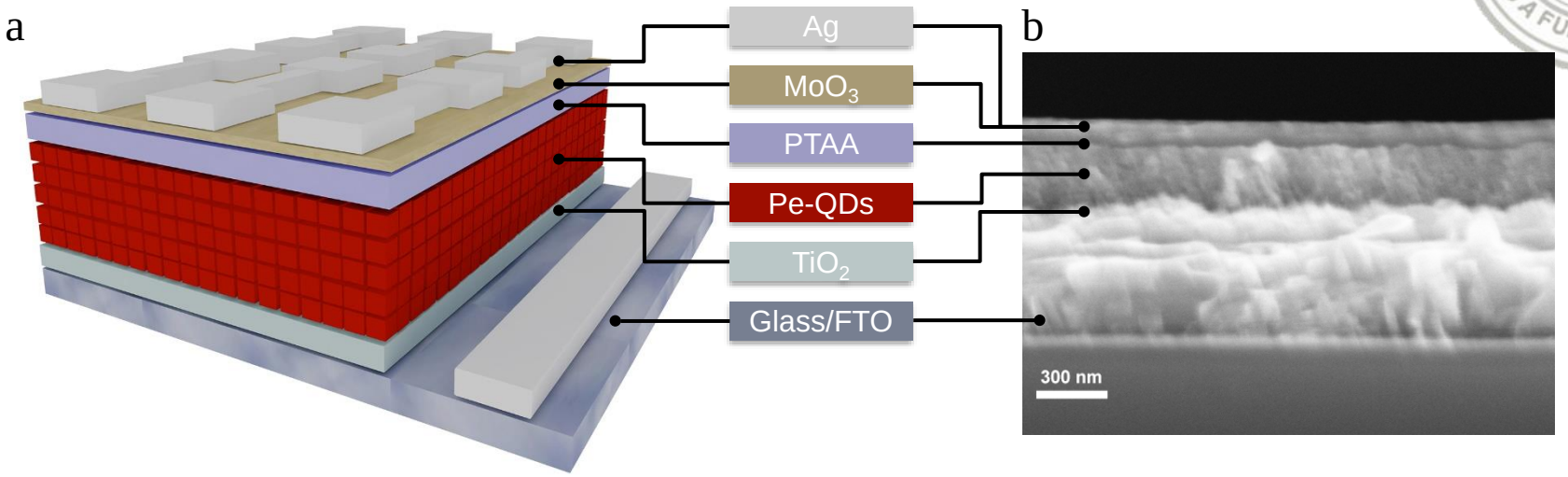


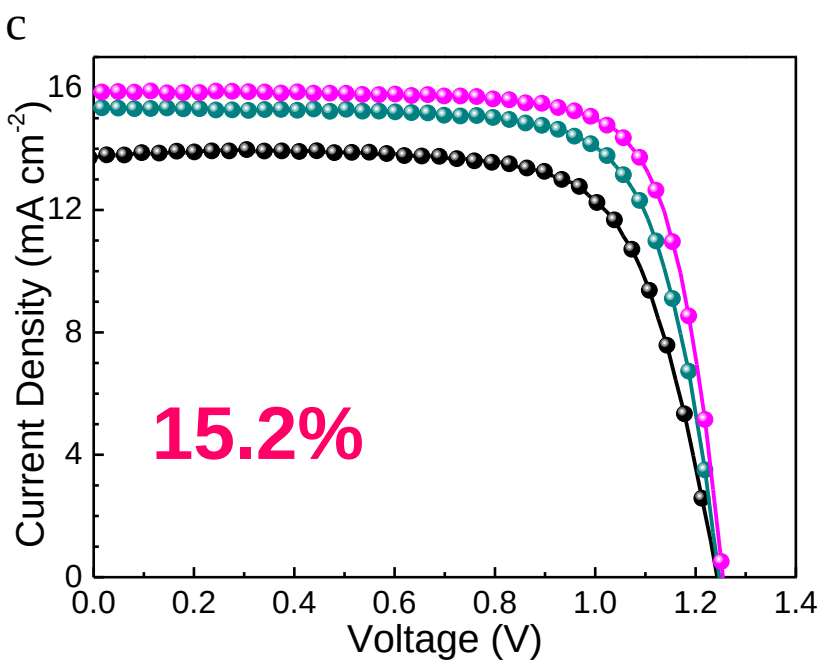


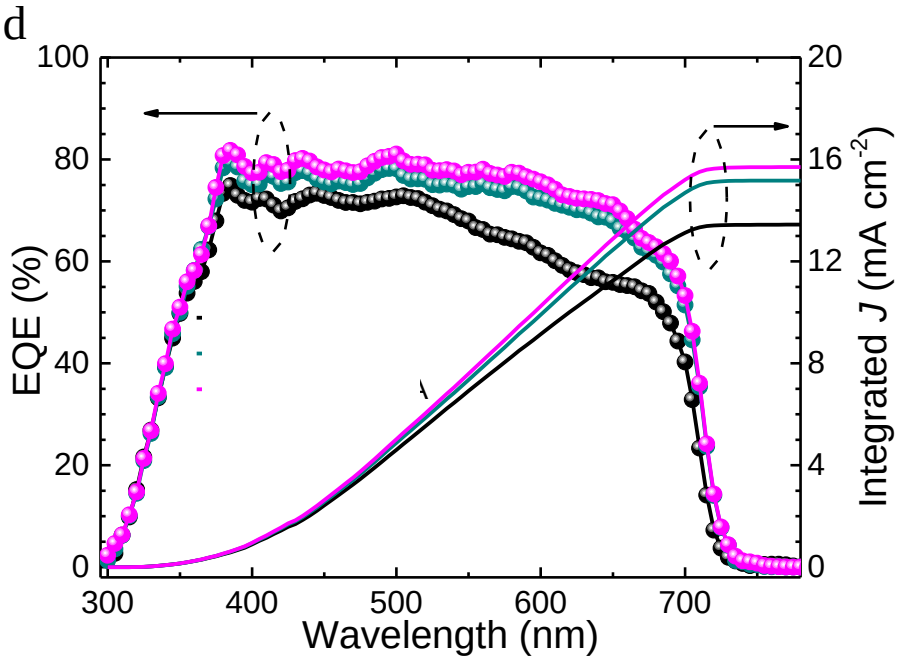


Y. Wang, J. Yuan*, W. Ma* et al. *to be submitted*.

$CsPbI_3$ PQD Solar Cells with Efficiency of15.2%



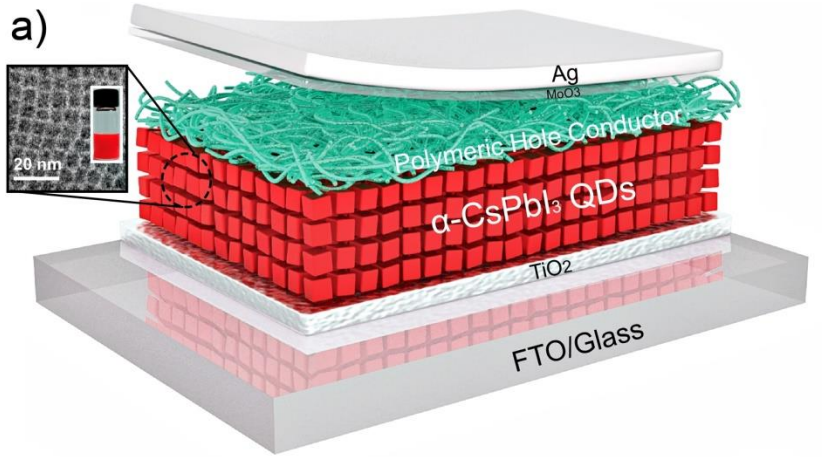


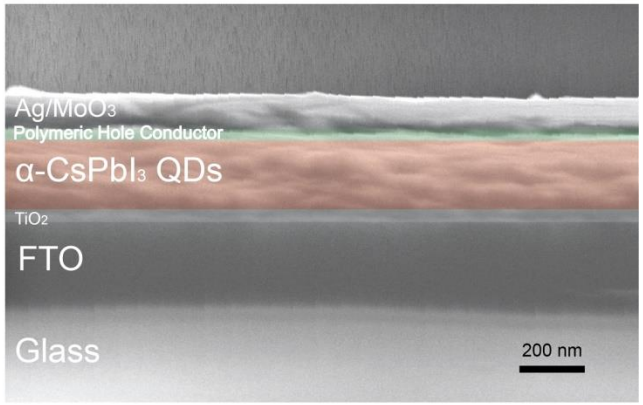


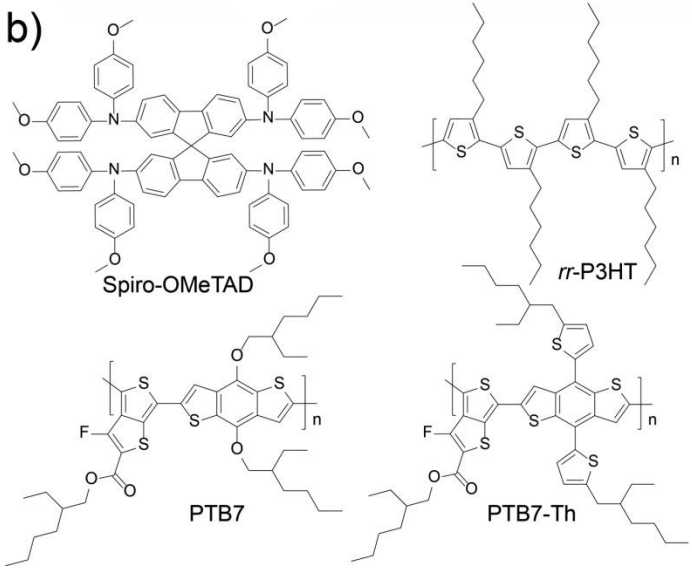
X. Ling, **J. Yuan***, **W. Ma*** et al. ***to be submitted***.

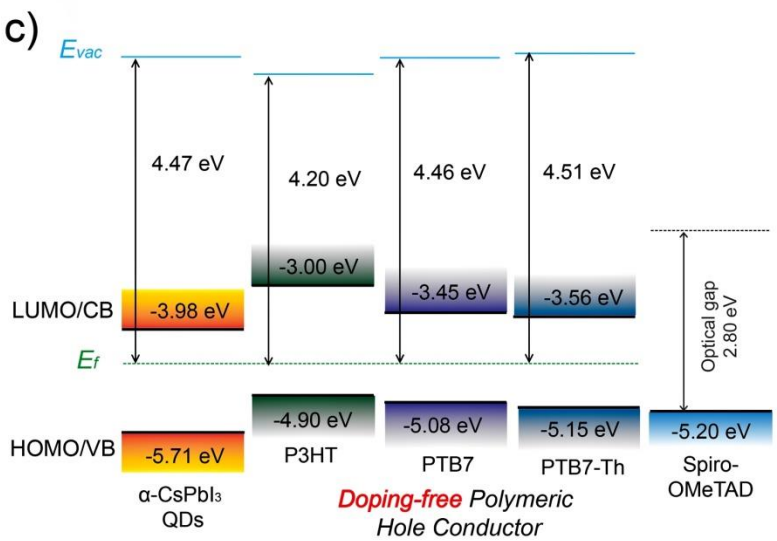
Device Engineering: Interfacial Layer

Efficient α-$CsPbI_3$ Perovskite QDs Solar Cells





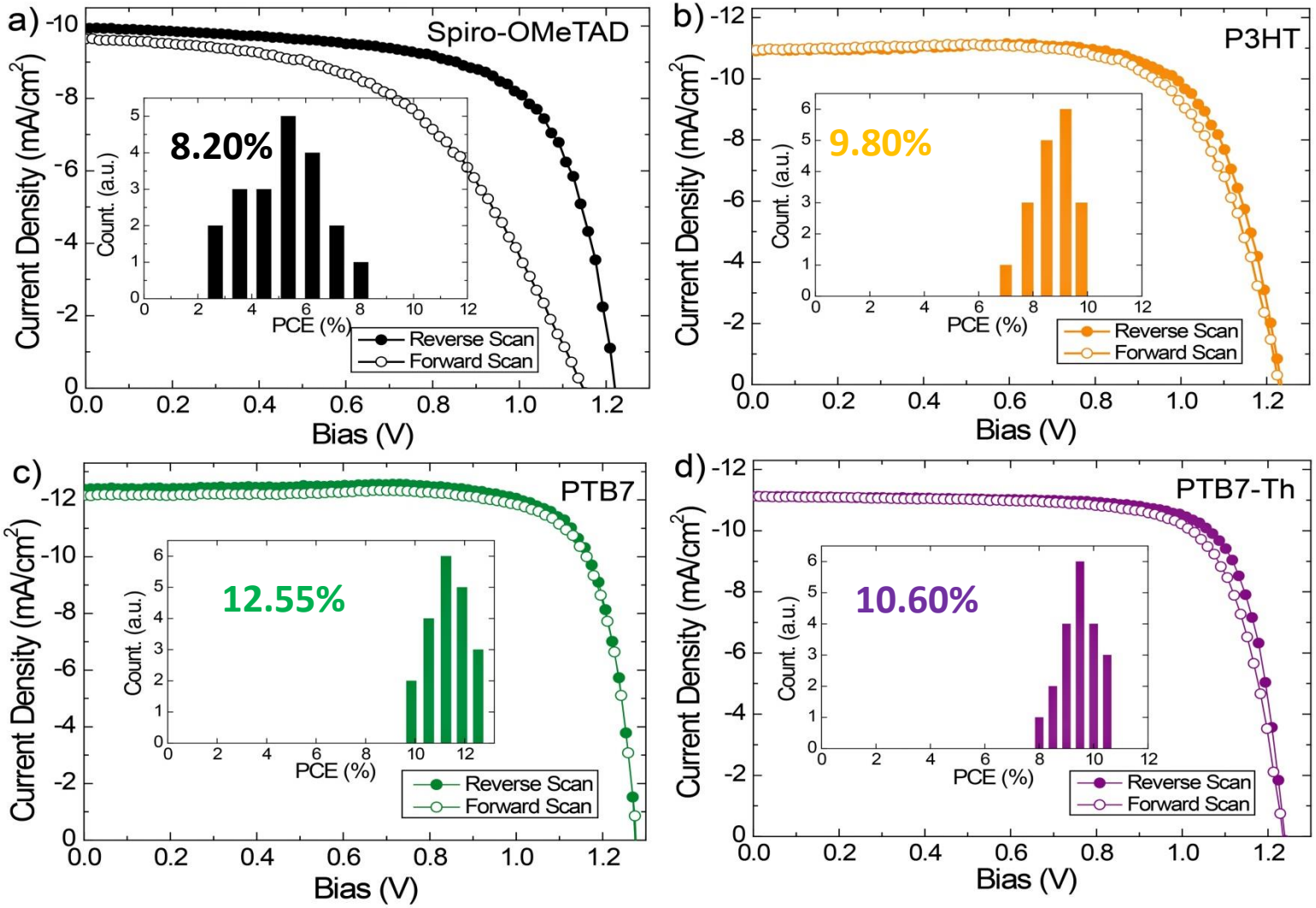




Polymeric Hole Transport Materials: **Efficient and Reproducible!**

J. Yuan, Q. Zhang*, W. Ma* et al. *Joule*, 2018, 2, 2450-2463

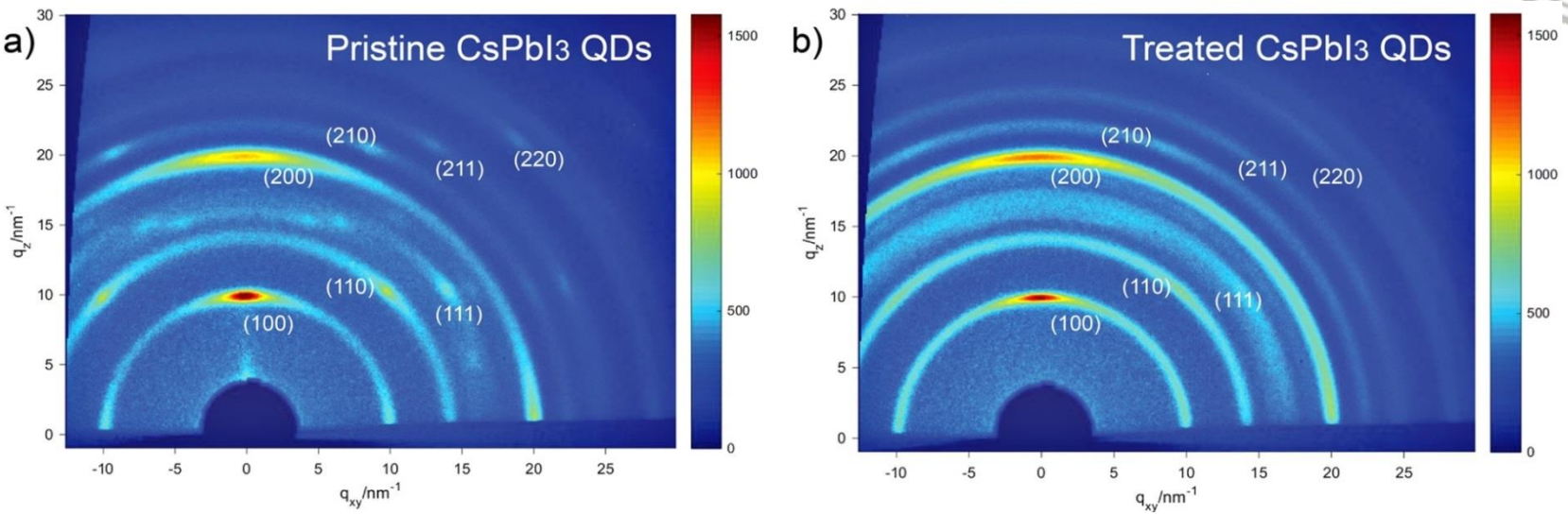
Conjugated Polymer vs. Spiro-OMeTAD

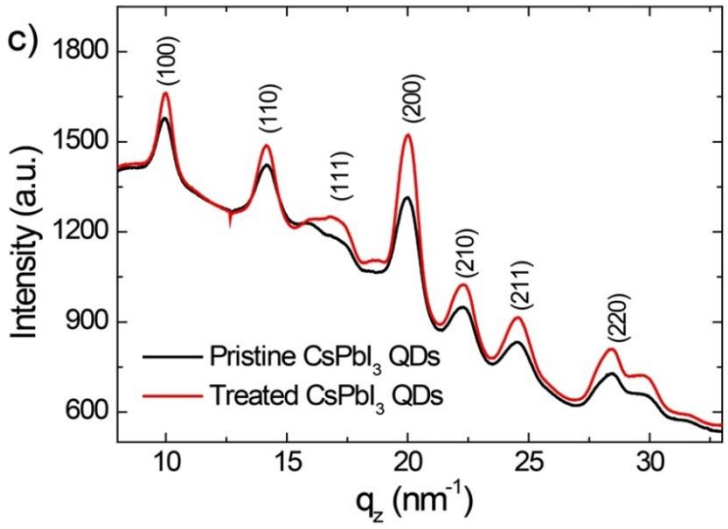


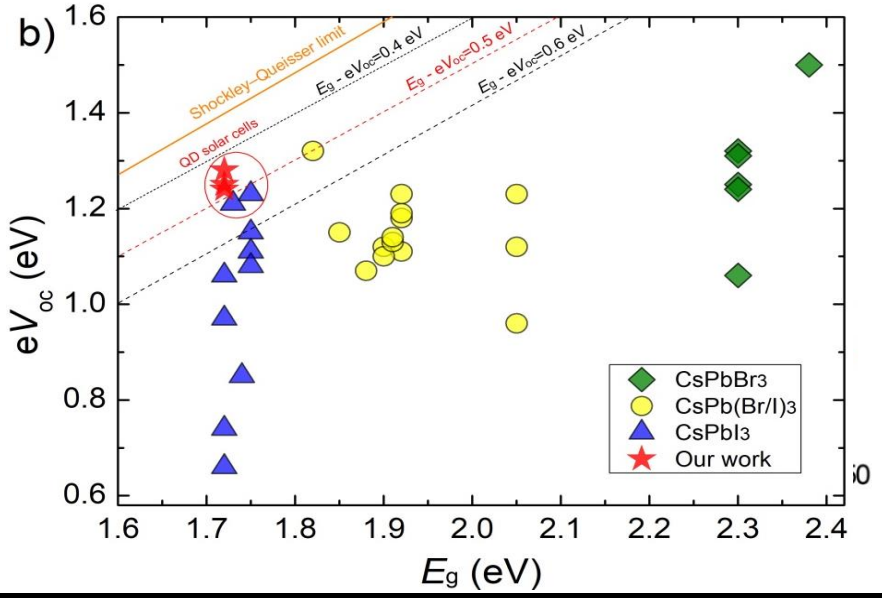
Improved Efficiency and Reproducibility, decreased hysteresis.

J. Yuan, Q. Zhang*, W. Ma* et al. *Joule*, 2018, 2, 2450-2463

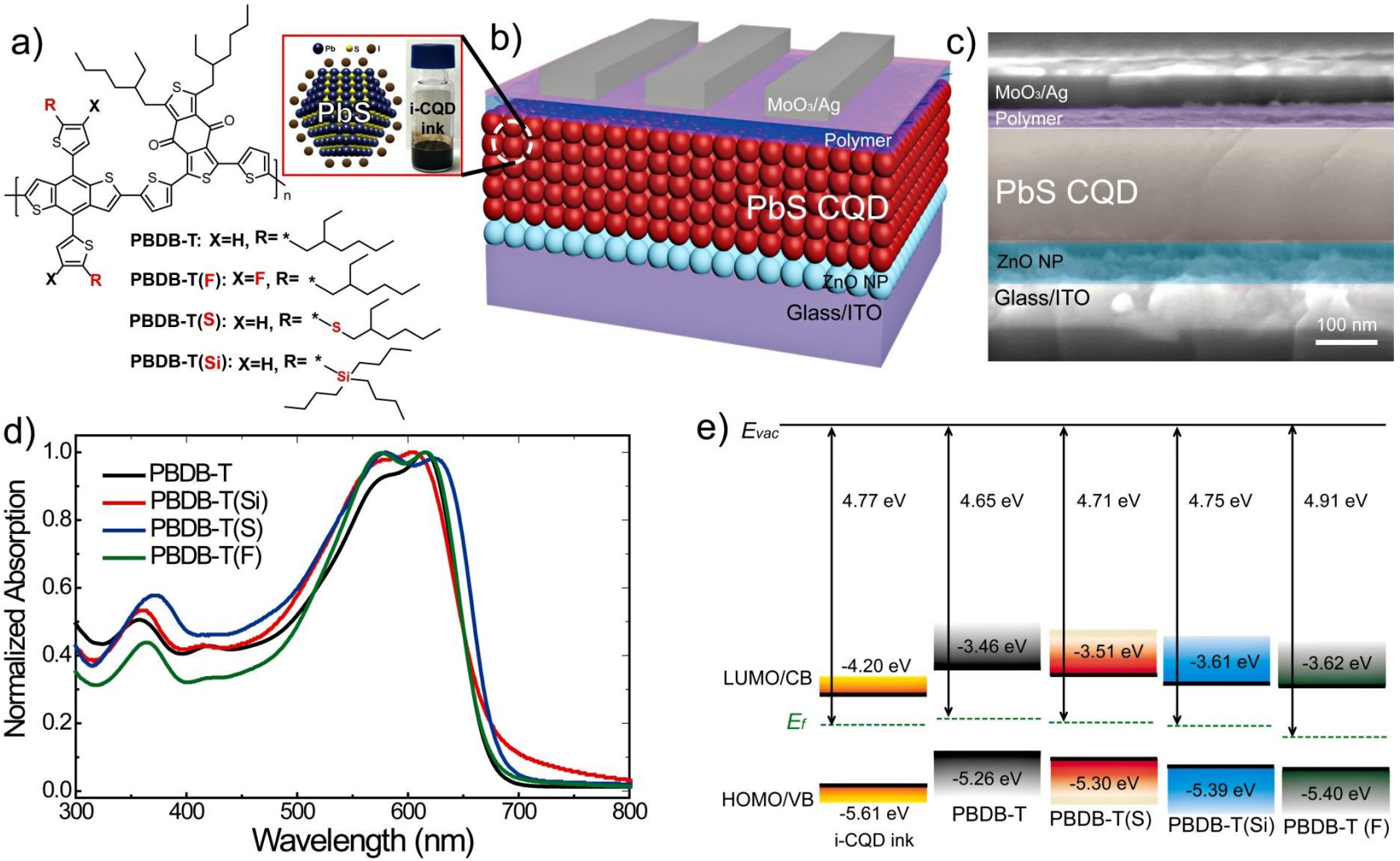
Highly Crystalline $CsPbI_3$ PQD Solar Cells with Extremely Low Voc Loss (~0.43 eV)



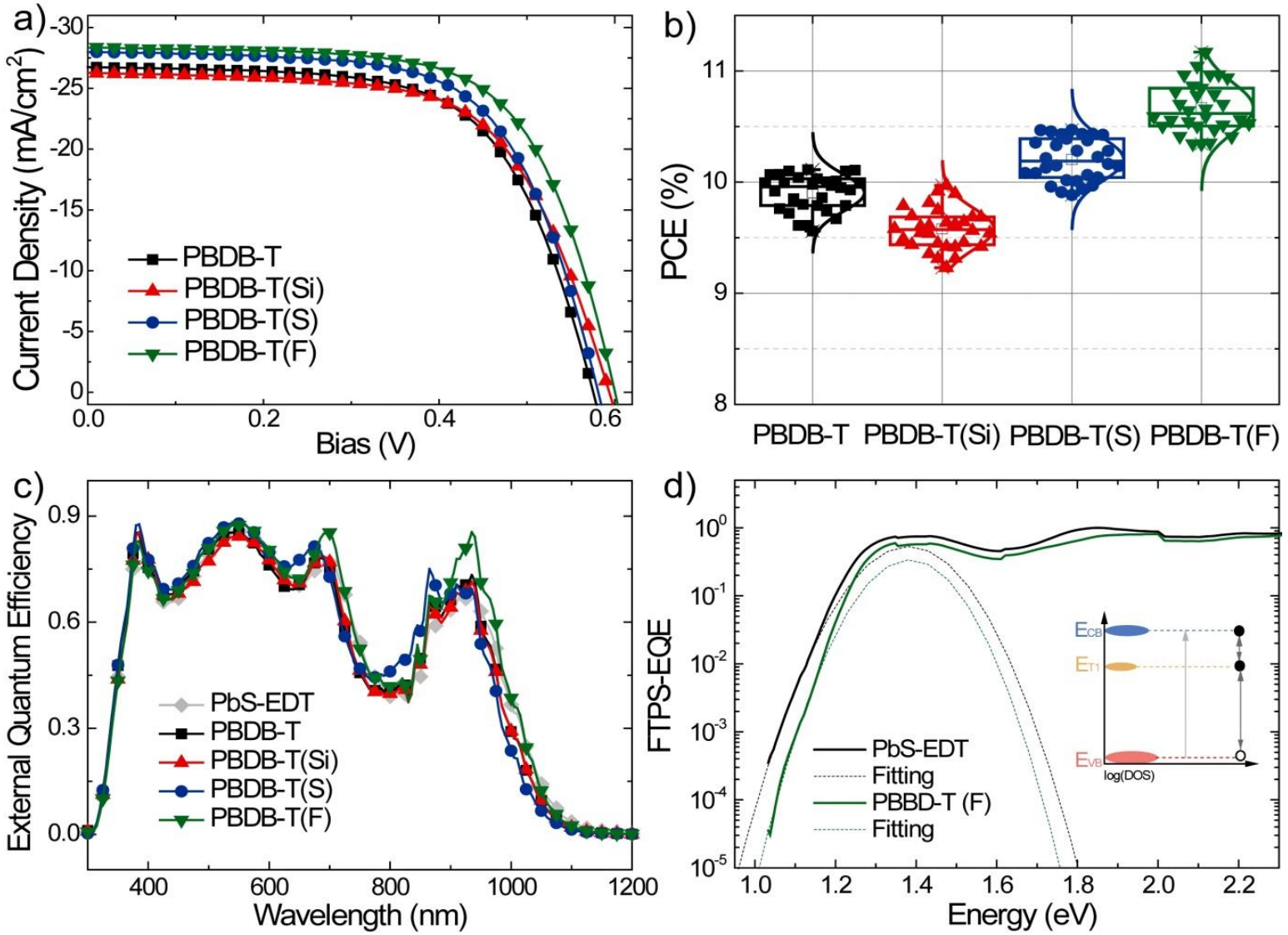




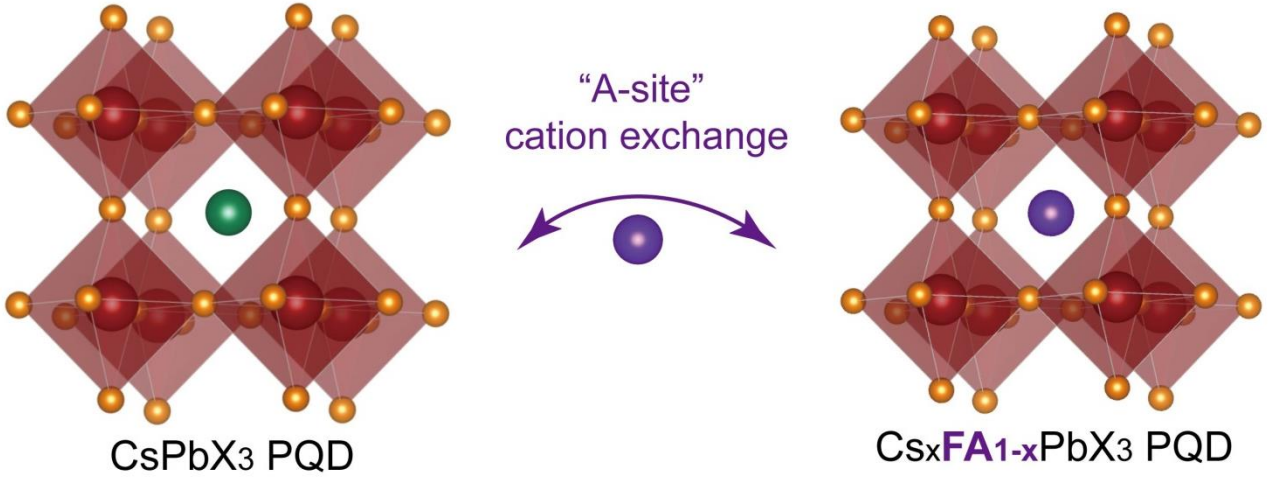
Efficient and Scalable PbS QD Solar Cells: Tailored Polymeric Hole Conductor



11.3% PbS QD Solar Cells: One-Step Fabrication



How to further Improve the Efficiency and Stability?

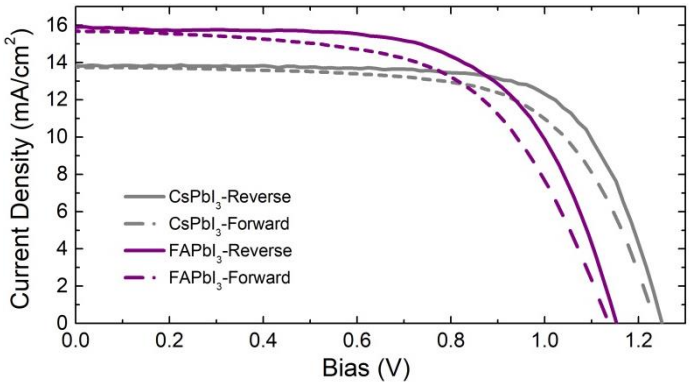


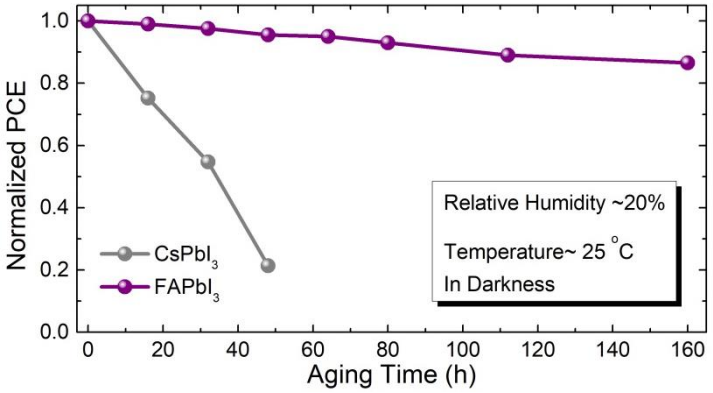
$CsPbI_3$:

- ✓ Enhanced electronic coupling
- ✓ Better charge transport
- • Large optical bandgap (1.73 eV)
- • Phase instability

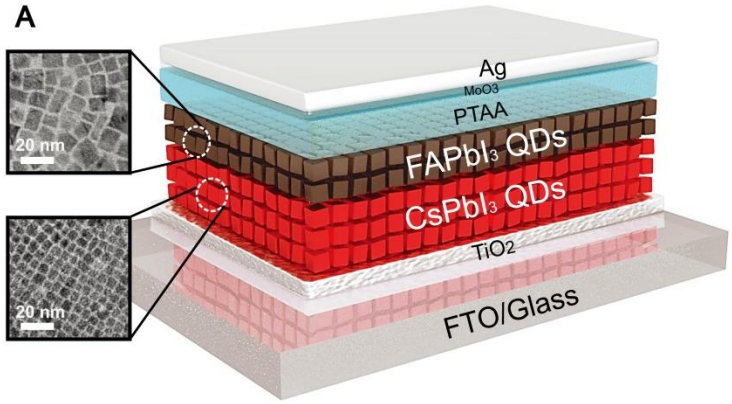
$FAPbI_3$:

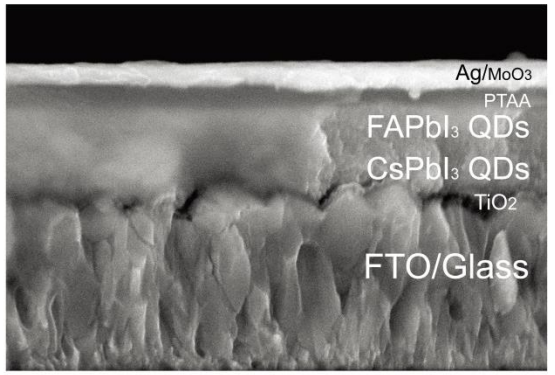
- ✓ Narrow optical bandgap (1.55 eV)
- ✓ Improved phase stability
- • Large size distribution
- • Surface ligand exchange

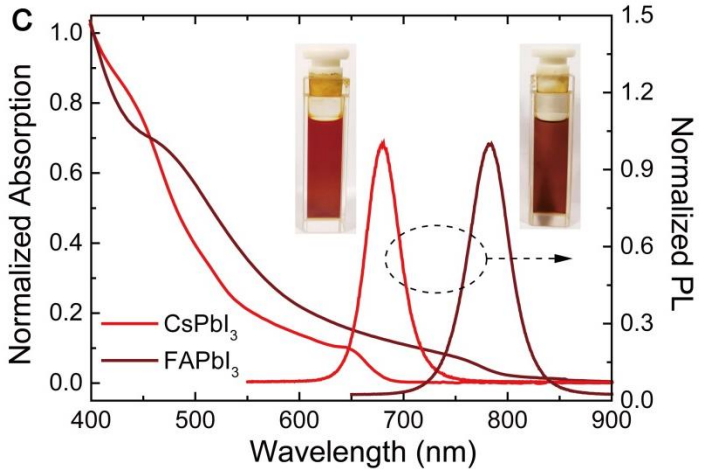


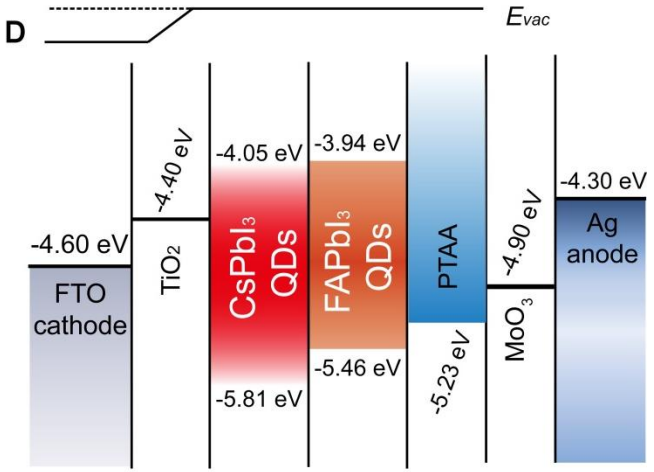


Layer-by-Layer Fabrication of $CsPbI_3$/$FAPbI_3$ PQD









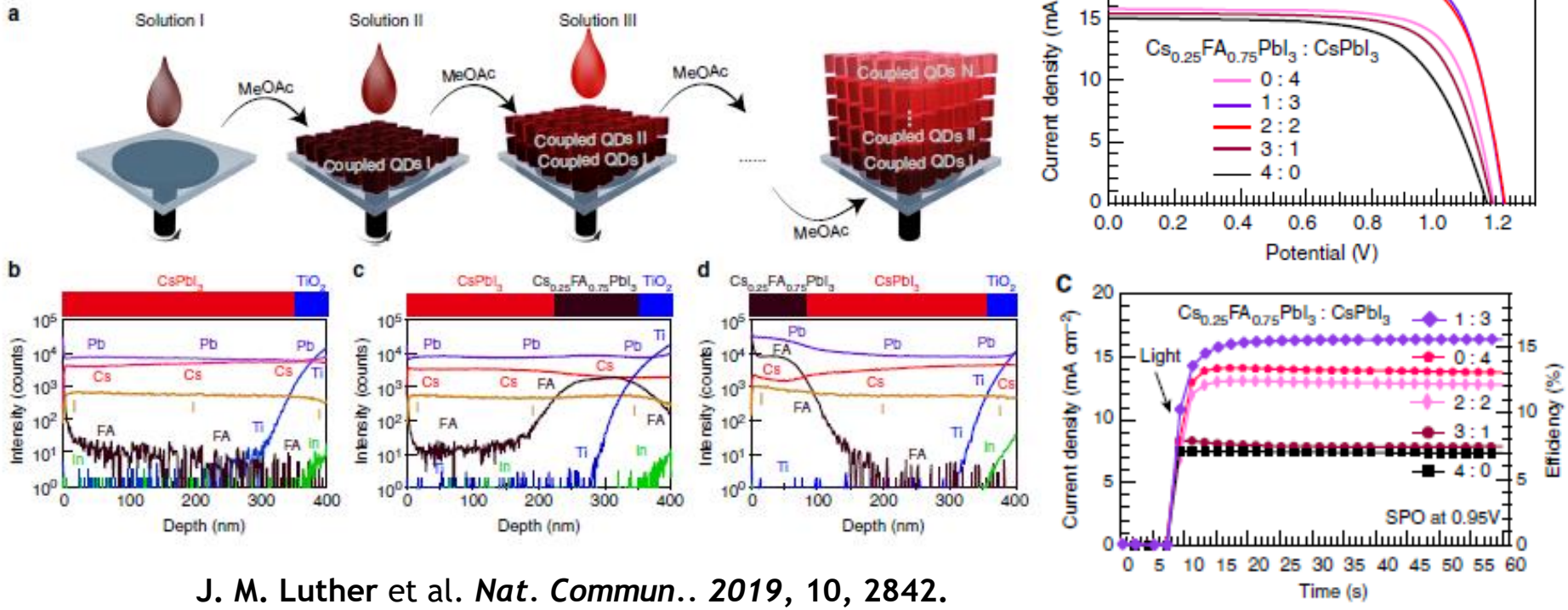
- Advantages of QD film fabrication (layer-by-layer);
- Improved light harvesting in $CsPbI_3$ QD film;
- Graded energy level for efficient charge extraction.

ARTICLE

https://doi.org/10.1038/s41467-019-10856-z OPEN

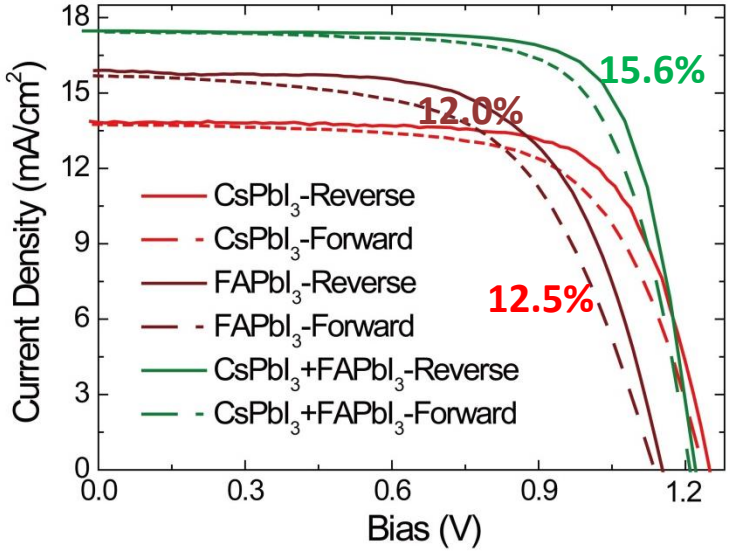
High efficiency perovskite quantum dot solar cells with charge separating heterostructure

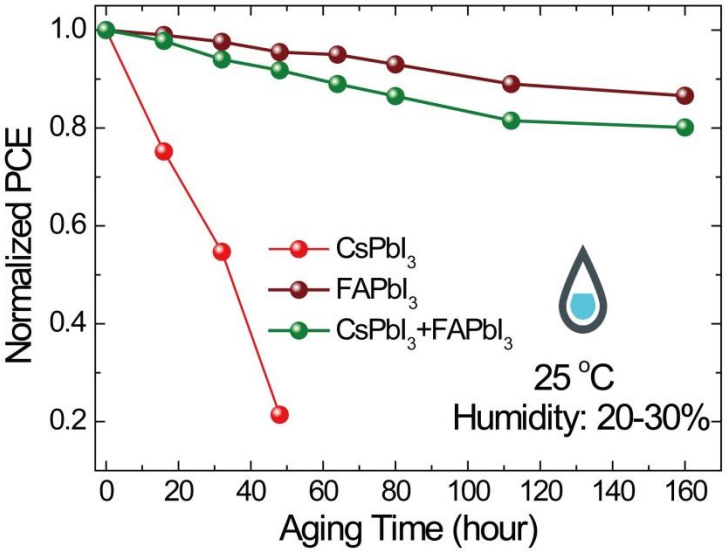
Qian Zhao[1,2,3], Abhijit Hazarika[2], Xihan Chen[2], Steve P. Harvey[2], Bryon W. Larson[2], Glenn R. Teeter[2], Jun Liu[2], Tao Song[2], Chuanxiao Xiao[2], Liam Shaw[4], Minghui Zhang[1], Guoran Li[3], Matthew C. Beard[2] & Joseph M. Luther[2]



J. M. Luther et al. *Nat. Commun.*. *2019*, 10, 2842.

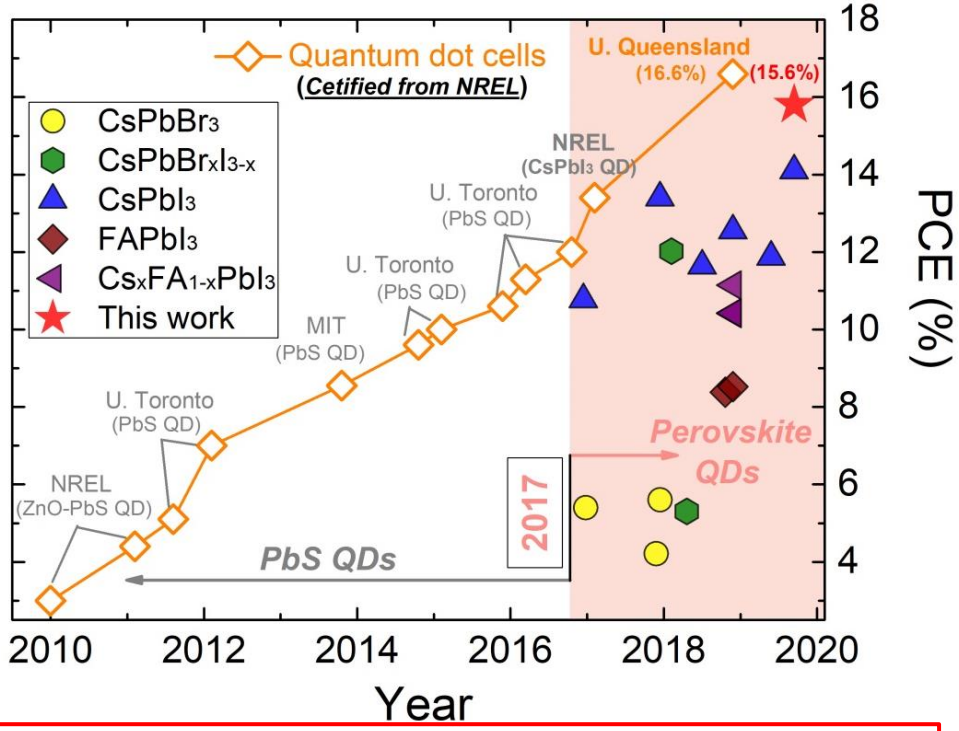
15.6% and Stable QD Solar Cells by $CsPbI_3/FAPbI_3$





- **Improved J_{sc}**
  (QD coupling and absorption)

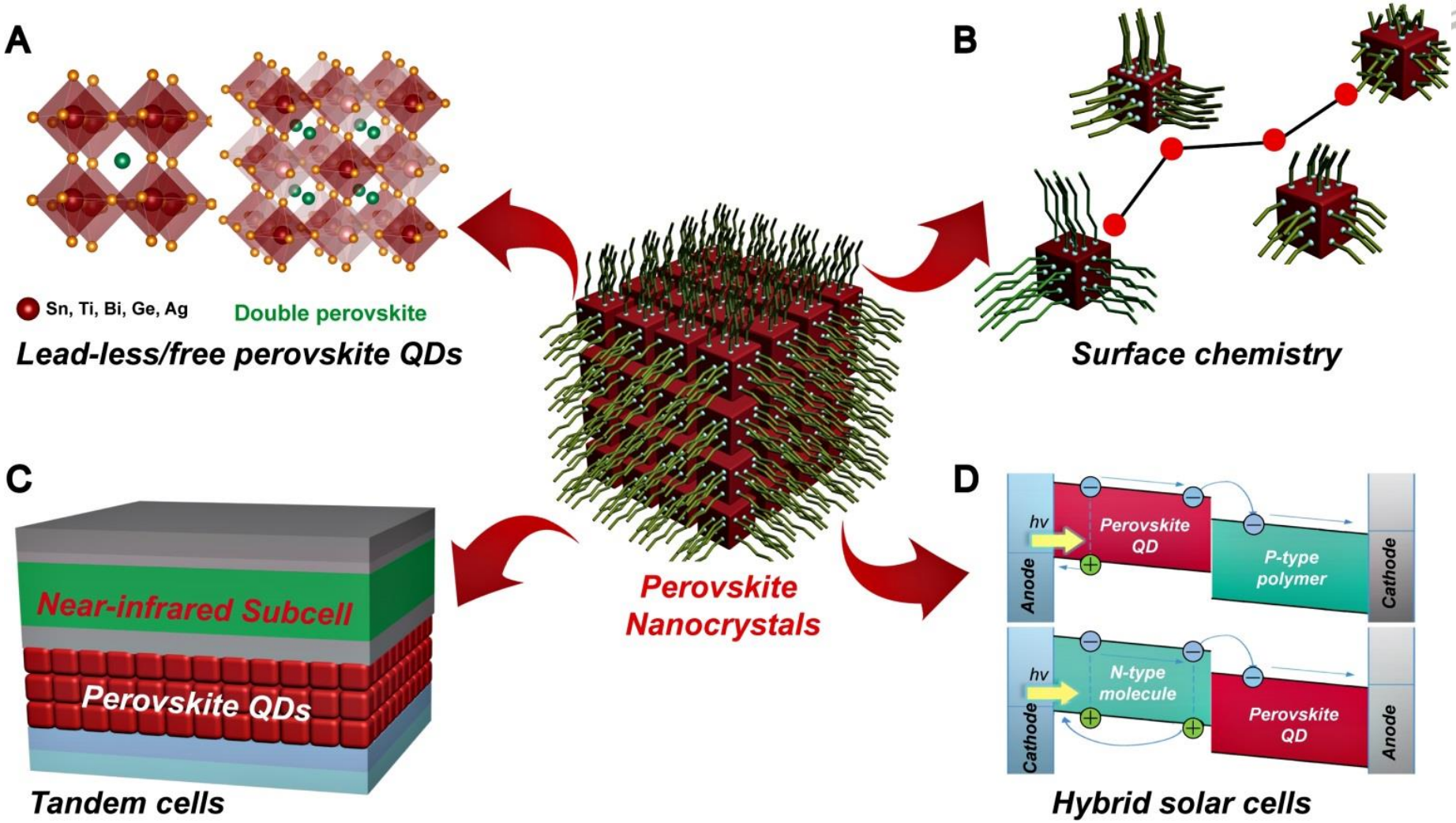
- **Improved ambient stability**
  (Better phase stability of $FAPbI_3$)



PQDs open a new door for CQD solar cells!

F. Li, J. Yuan*, W. Ma* et al. *ACS Energy Lett. 2019, In revision*

Prospective in PQD Solar Cells



J. Yuan, J. M. Luther* et. Al., *review paper under preparation*

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- **Graduate Student:**

PQD Synthesis:
Sijie Zhou, Junwei Shi, Yuli Qian

PQD Device:
Fangchao Li, Xufeng Ling, Yao Wang, Xuliang Zhang

- Collaborator:

Prof. Youyong Li (FUNSOM)
Prof. Xingyu Gao (SSRF)
Prof. Haibin Zhao (Fudan)
Prof. Qiao Zhang (FUNSOM)
Prof. Yuan Zhang (Beihang)

- International Collaborator

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