量子點(Quantum Dot)及量子點光電應用

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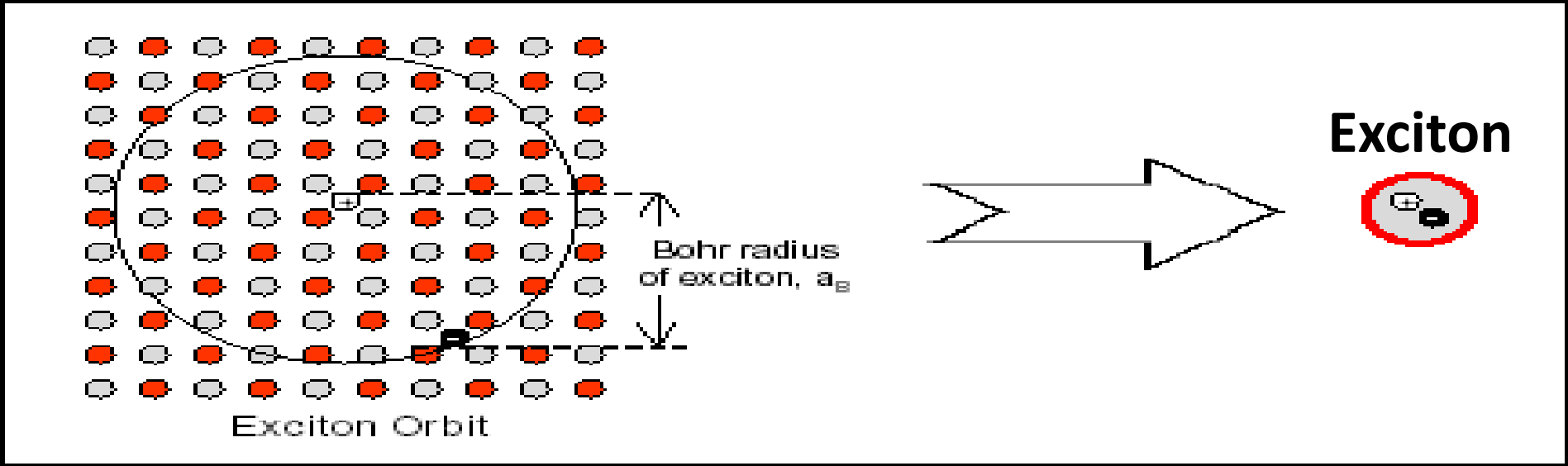
An exciton is composed of an electron and a hole. The effective distance between the electron and the hole within an exciton is called Bohr radius of the exciton.

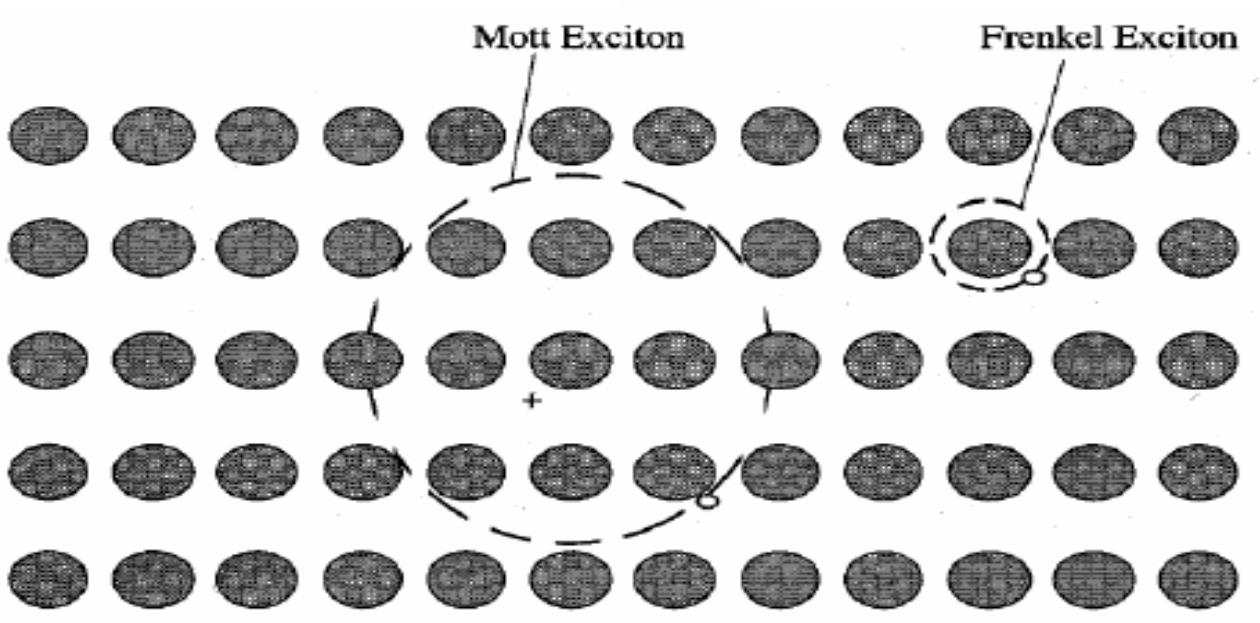


When the length of a semiconductor is reduced to the same order as the exciton radius, i.e., to a few nanometers, quantum confinement effect occurs and the exciton properties are modified.

Two types of Excitons

Wannier (Mott) Exciton
Extends over many unit cells

Frenkel Exciton
Localized to a few unit cell



For a spherical II-VI semiconductor QD, using the confined Wannier exciton Hamiltonian, the energy expression can be modified to give:

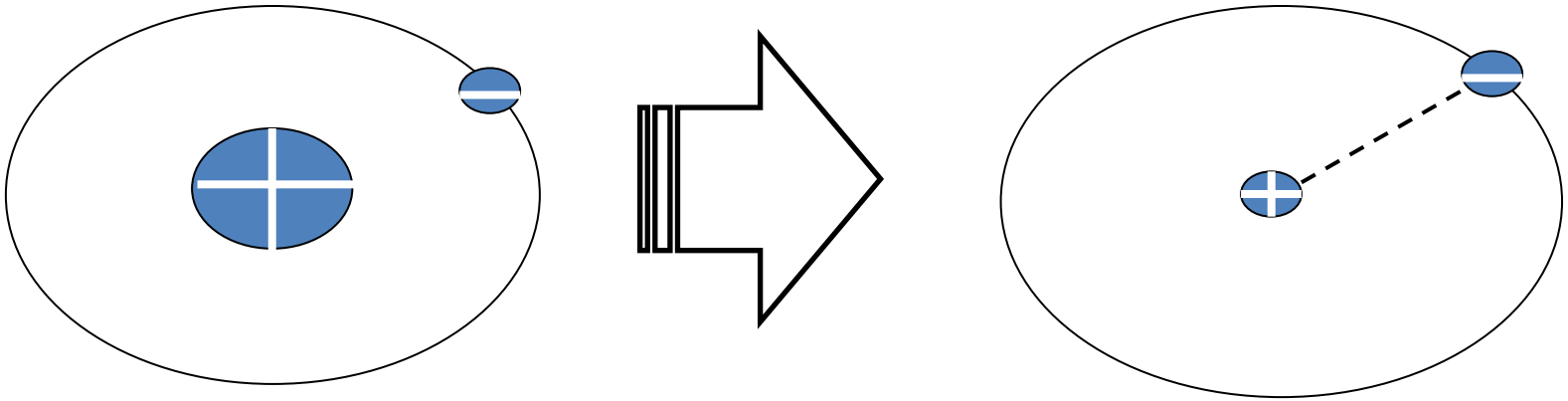
$$E_g(R,n) = E_g + \frac{n(n+1)\hbar^2}{2\mu R^2} - \frac{e^2}{4\pi\varepsilon_0\varepsilon R}$$

QDs

Bulk

Confinement Energy

Bound Exciton Energy



hydrogen like orbital

Electron-hole pair (exciton) relative motion

Eg: band gap of the bulk SC
n: quantum number
R: radius of the QDs
$\mu = (m_e\ m_h) / (m_e + m_h)$
ε： SC dielectric constant
h: Plank' s constant

The treatment is like an electron in hydrogen-like orbital

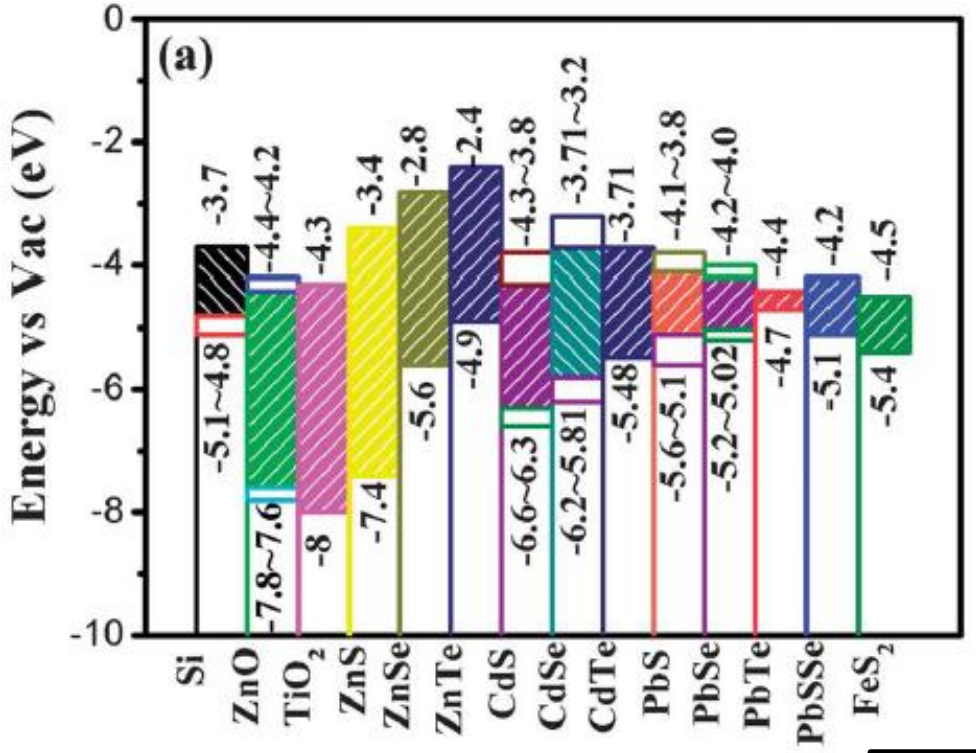
For the electronic transition from the valence band to conduction band (n =1), ignoring small contributions from 1 / R term (strong confinement region):

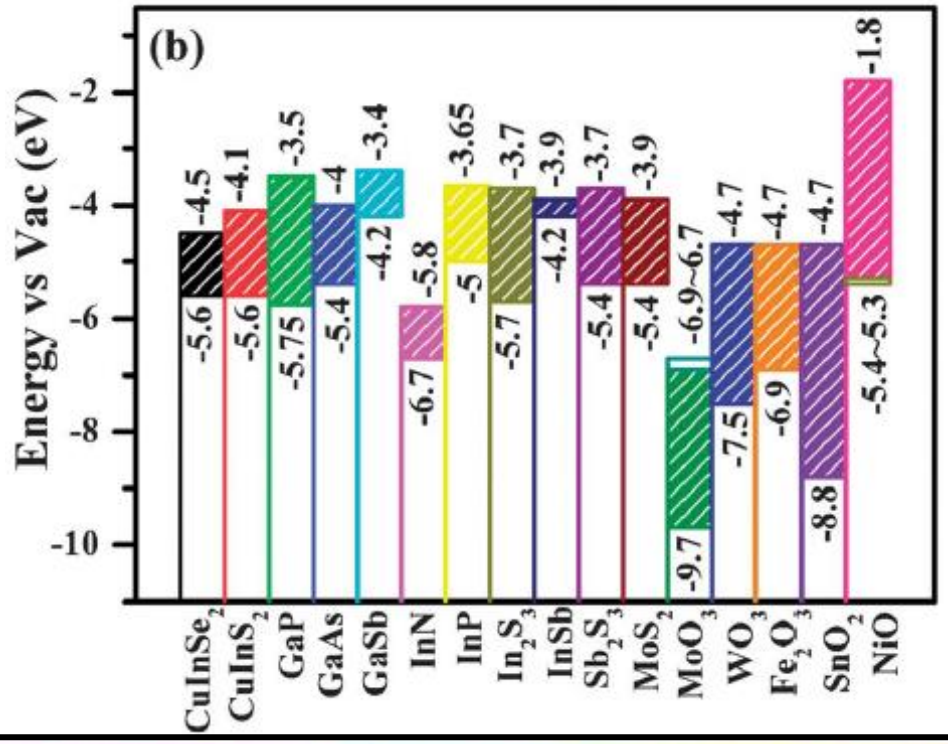
ΔE_g =change in band gap energy due to quantum-size effect

$$E_g(R) = E_g + \frac{\hbar^2}{2R^2}\left(\frac{1}{m_e} + \frac{1}{m_h}\right)$$

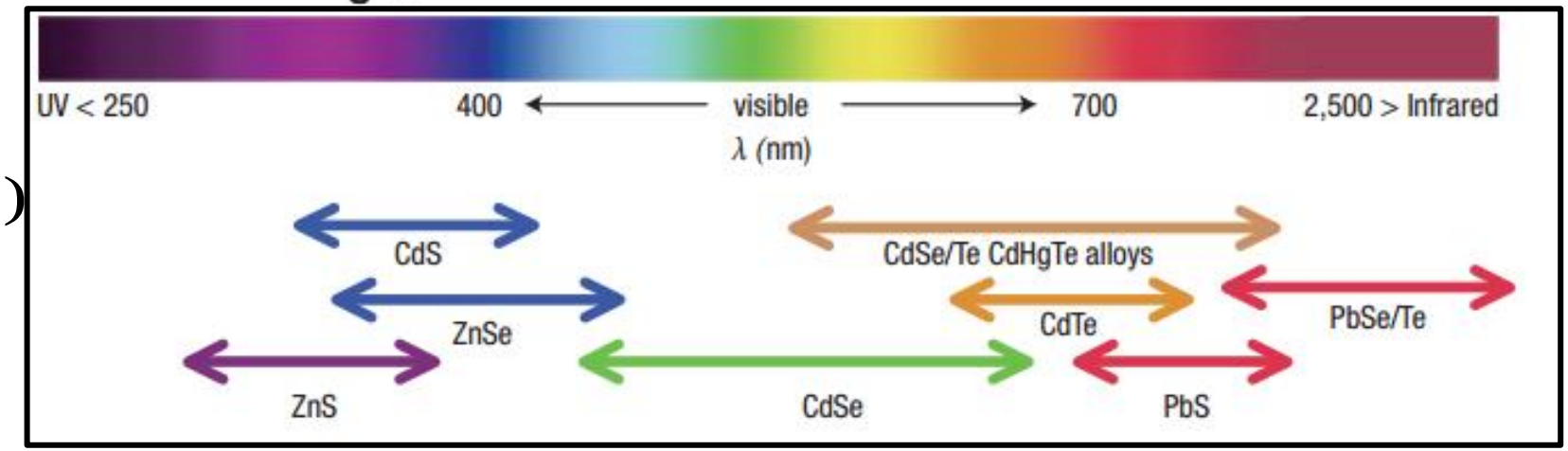
As R ↓ E_g(R) ↑ λ ↓
(Absorption wavelength decreases as QDs particle size decreases)

Energy Level (VB/CB)of Various Semiconductors



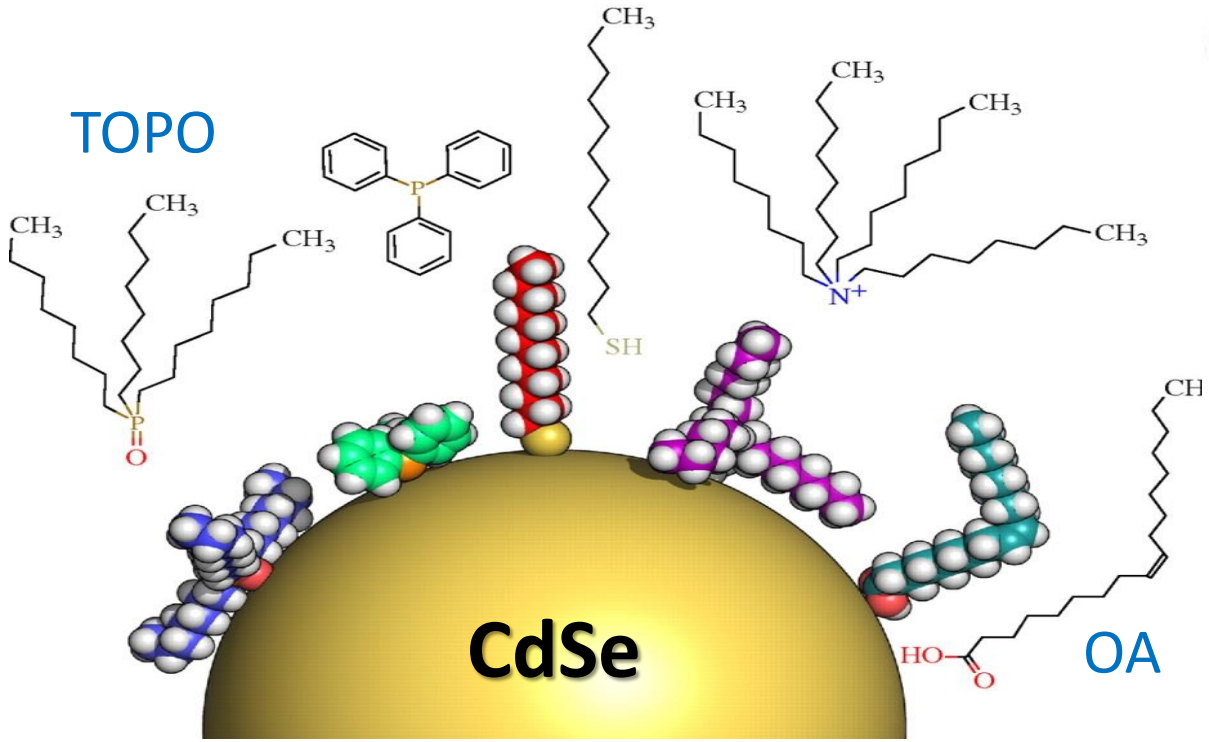


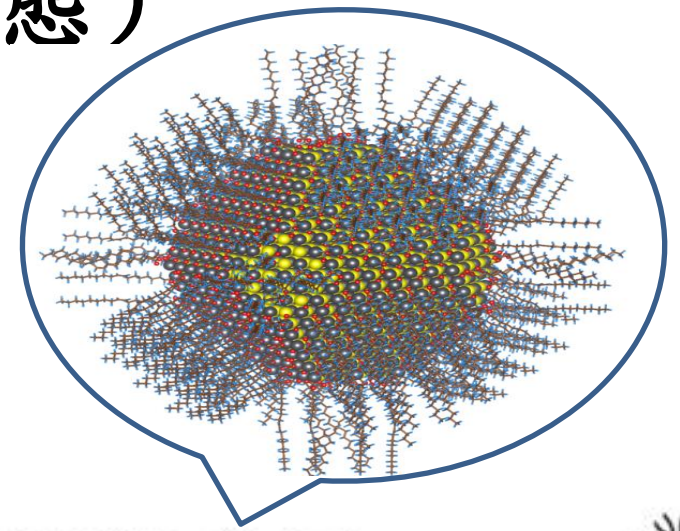
$$E_g(R) = E_g + \frac{\hbar^2}{2R^2}\left(\frac{1}{m_e} + \frac{1}{m_h}\right)$$

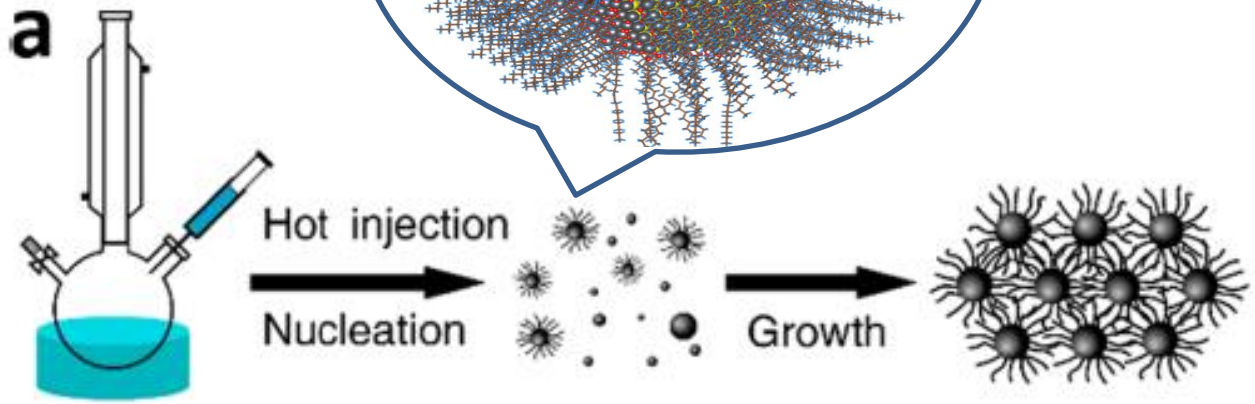


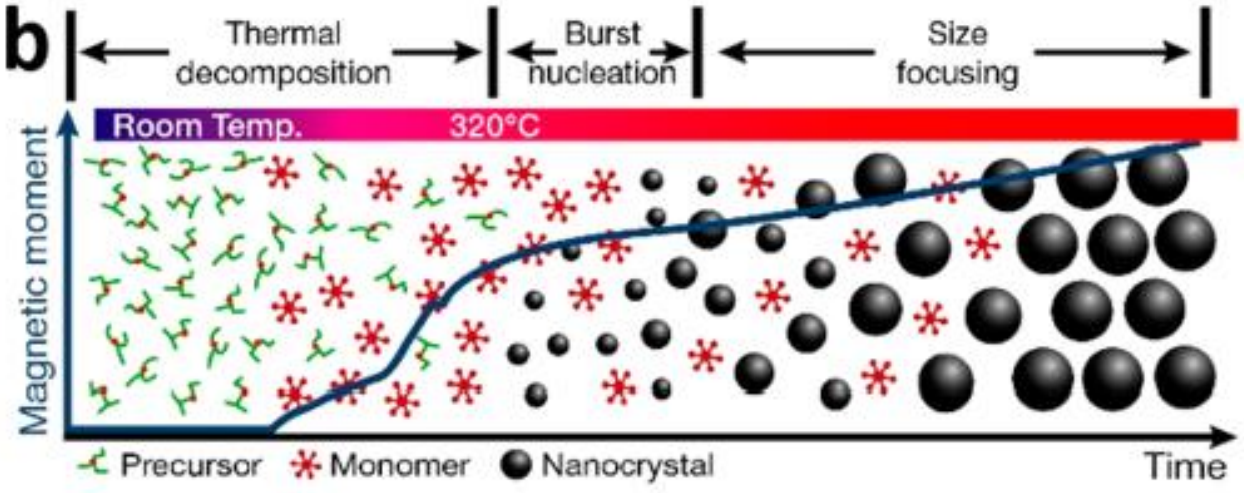
J. Mater. Chem. A, **2013**, *1*, 8694–8709

量子點的合成（溶液態）
(bottom-up process)

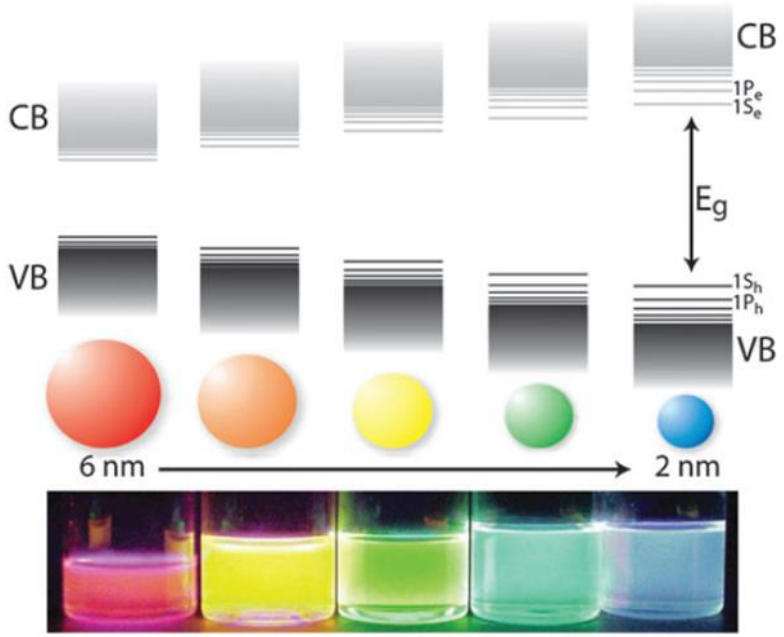






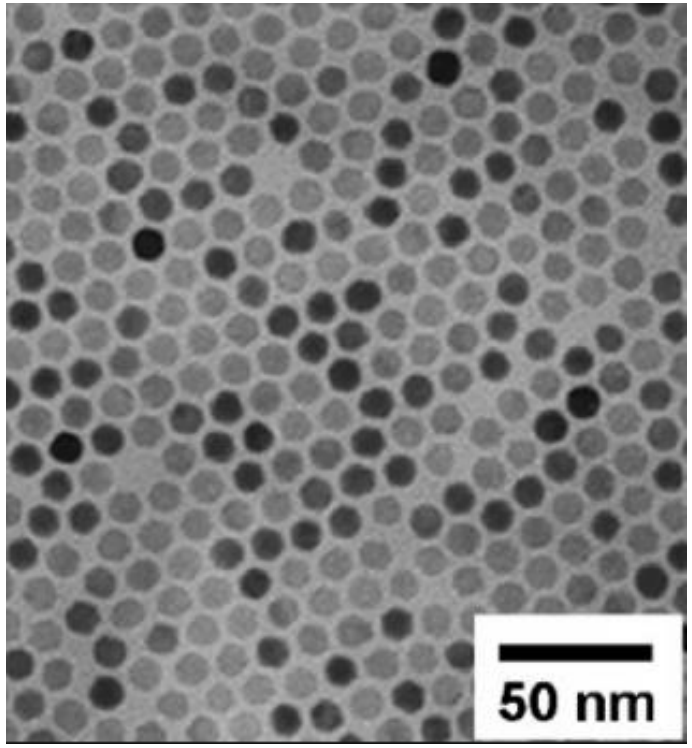


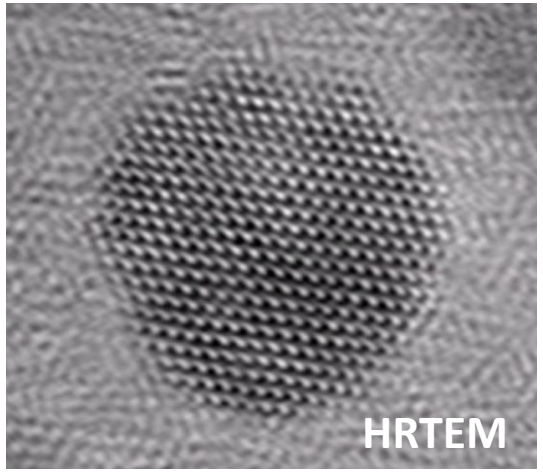
What should we know-Type I &Type II

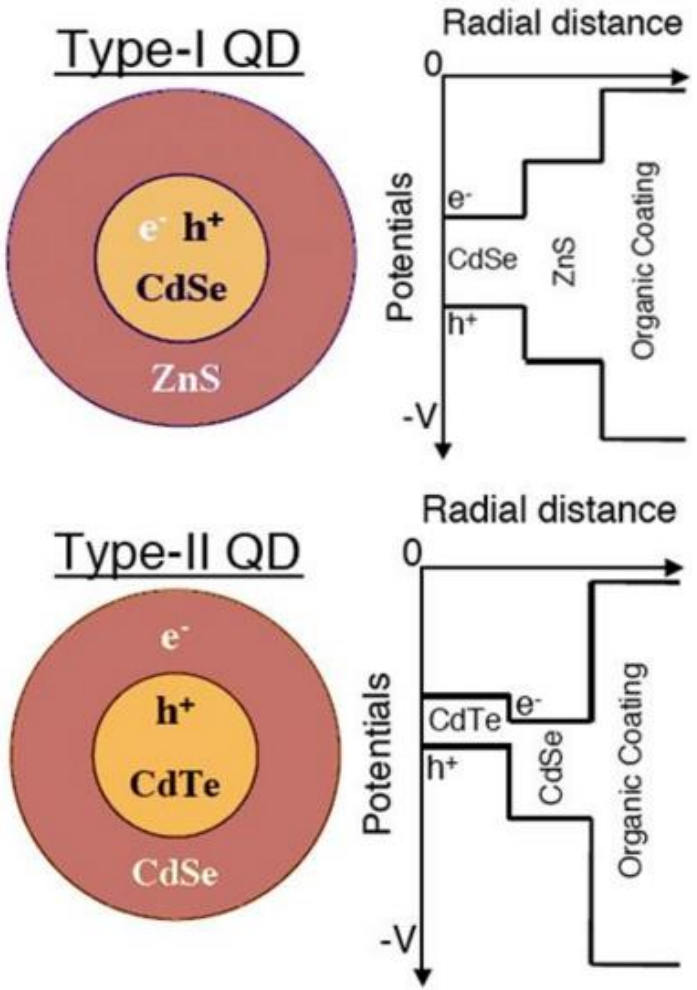


Control band gap by varying the CdSe size

CdSe/ZnS





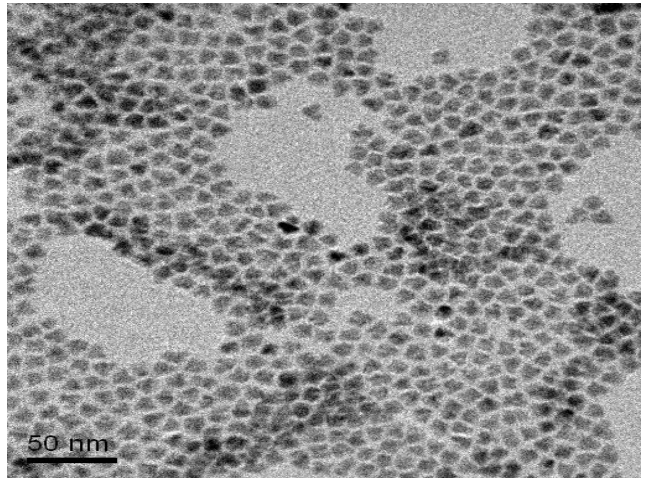


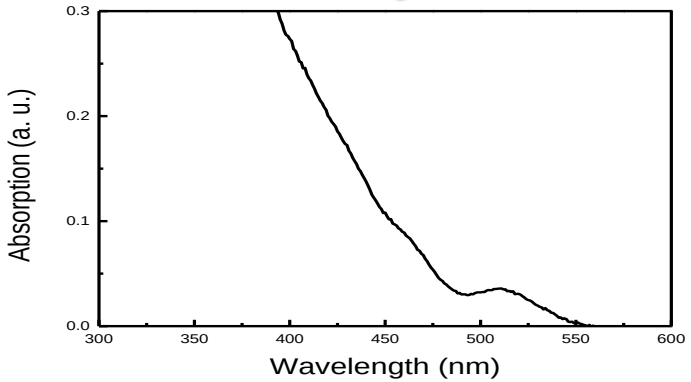
Energy level alignment

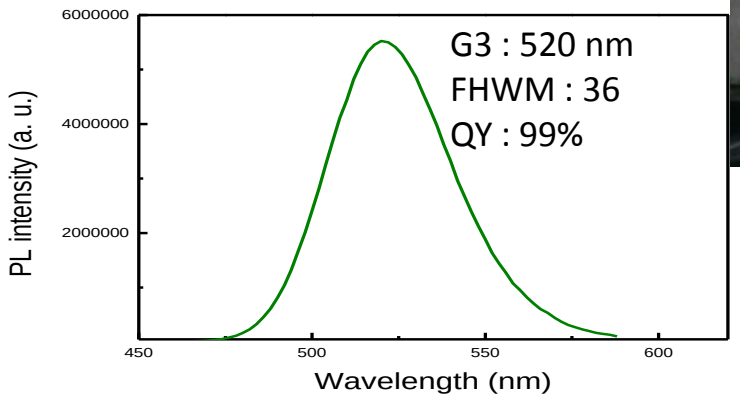
Synthetic Protocol in My Lab

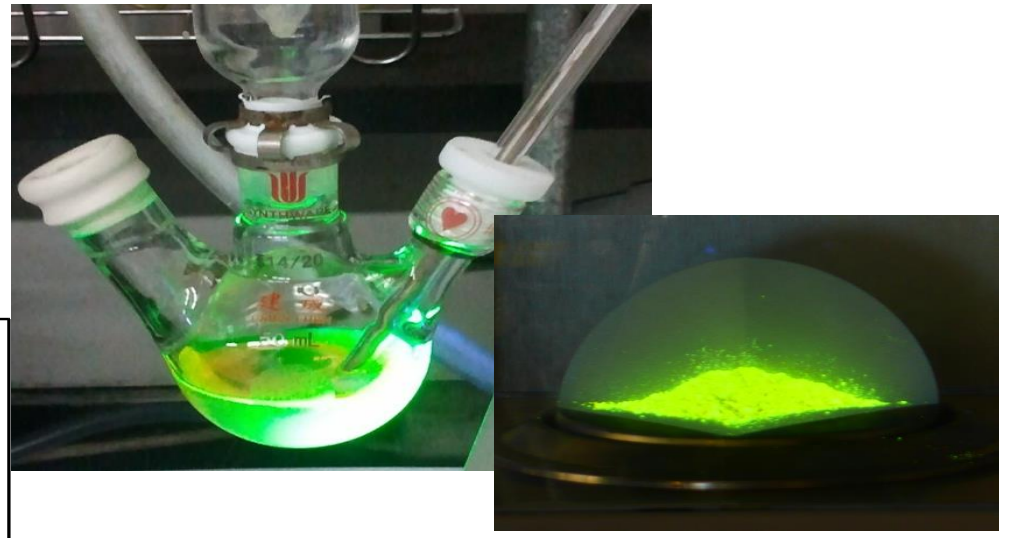
CdSeSZnS Alloy Quantum Dots for QLED

QD-G

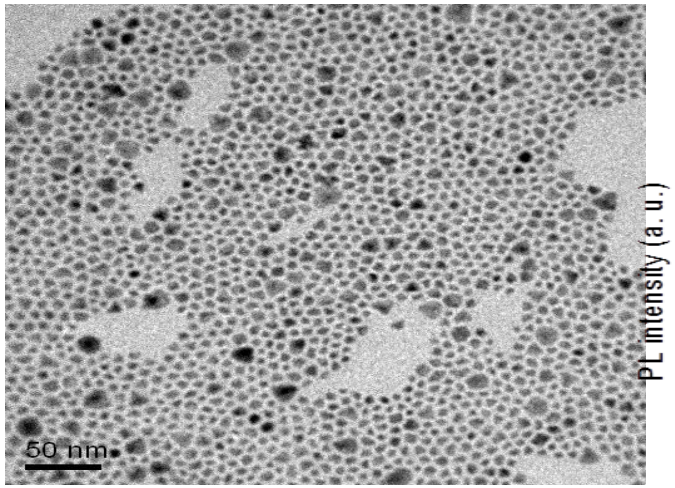


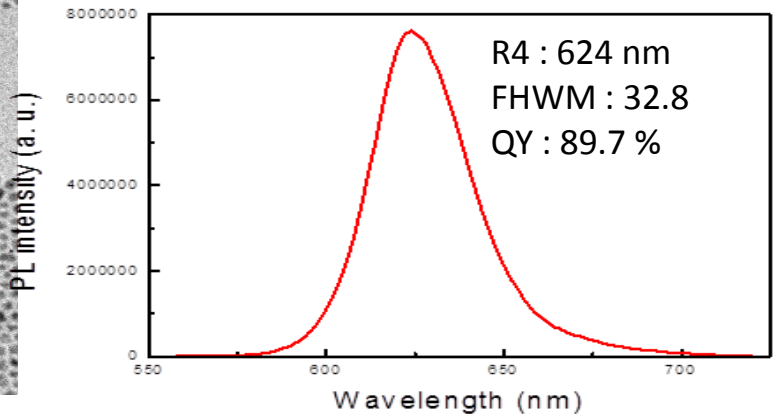


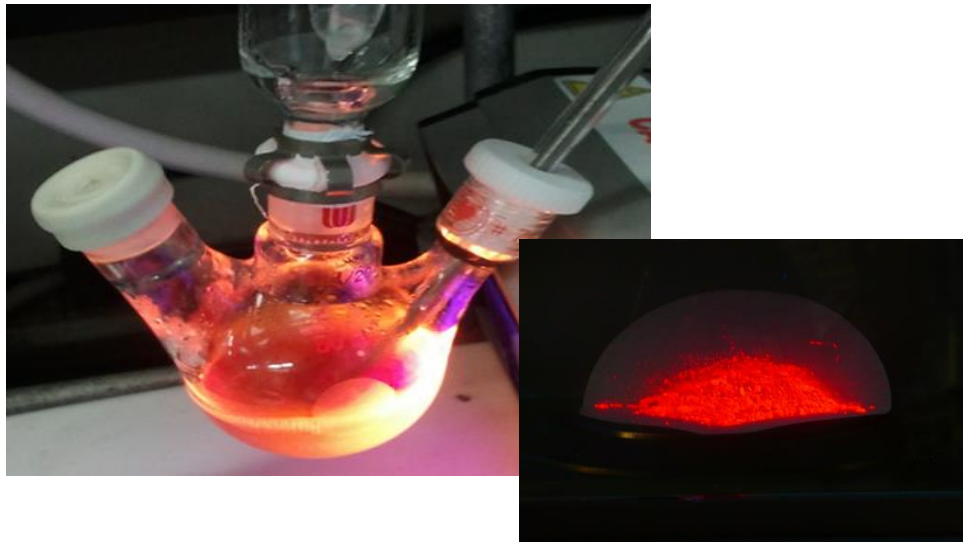




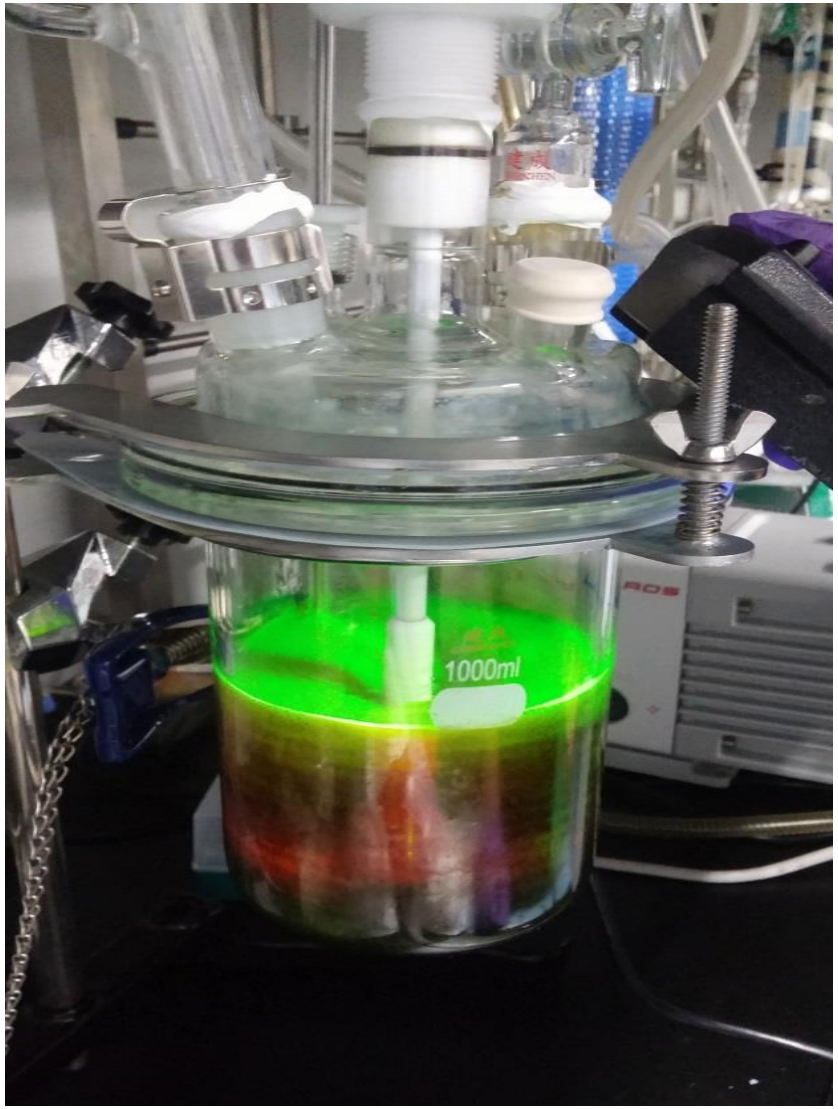
QD-R

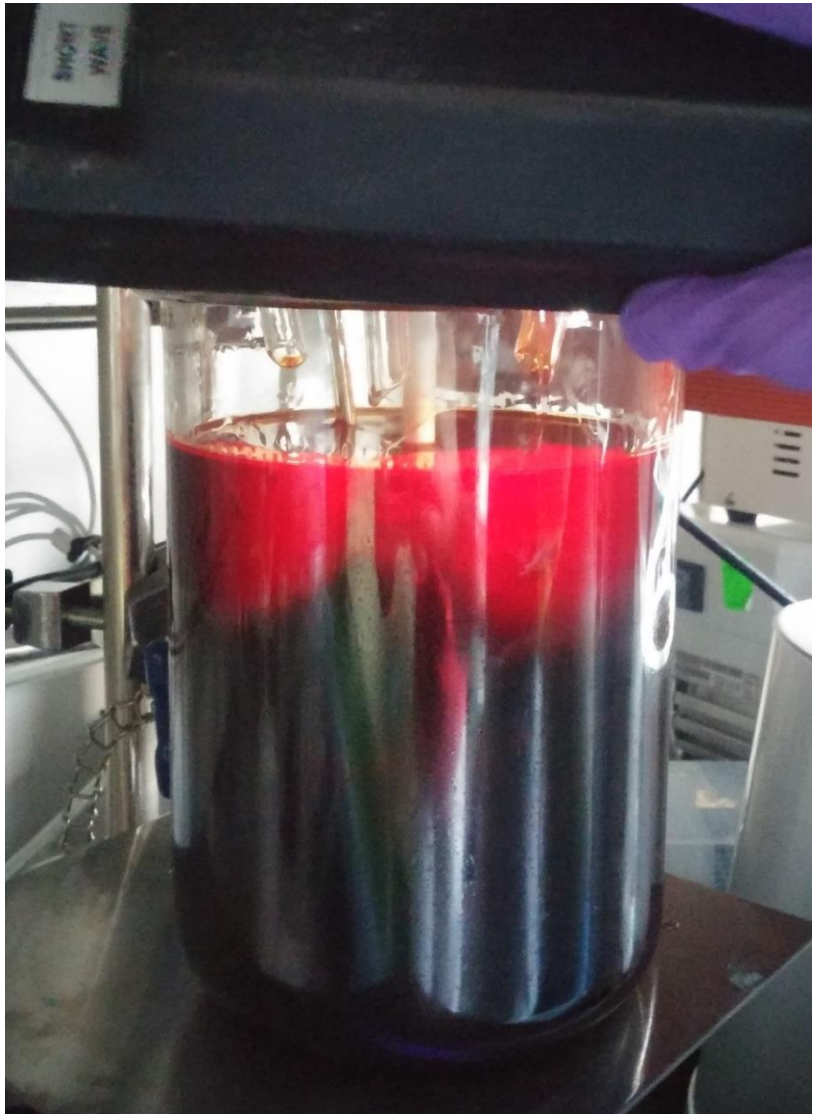




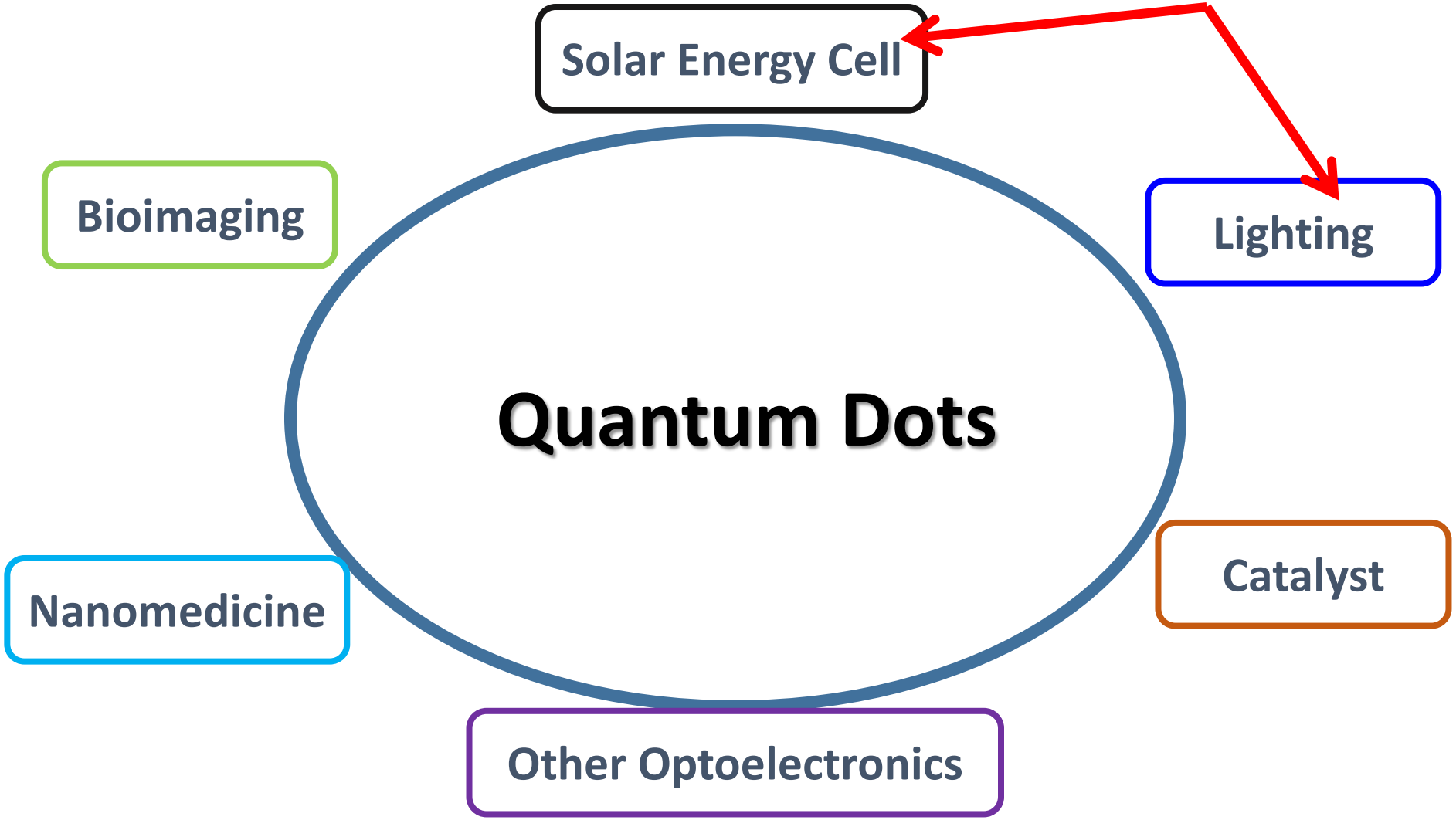


Mass Production: 50-100 g/pot



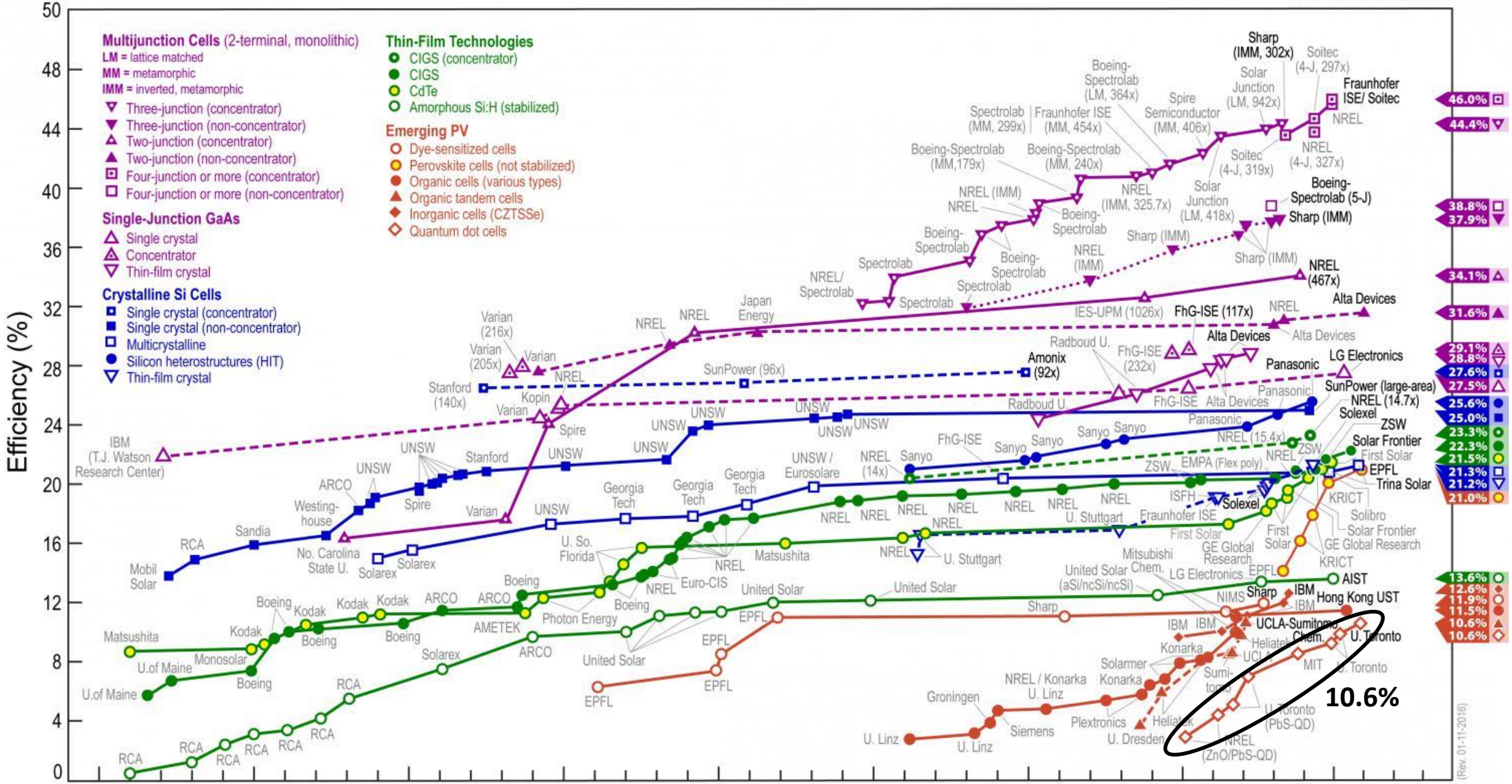


Potential Applications



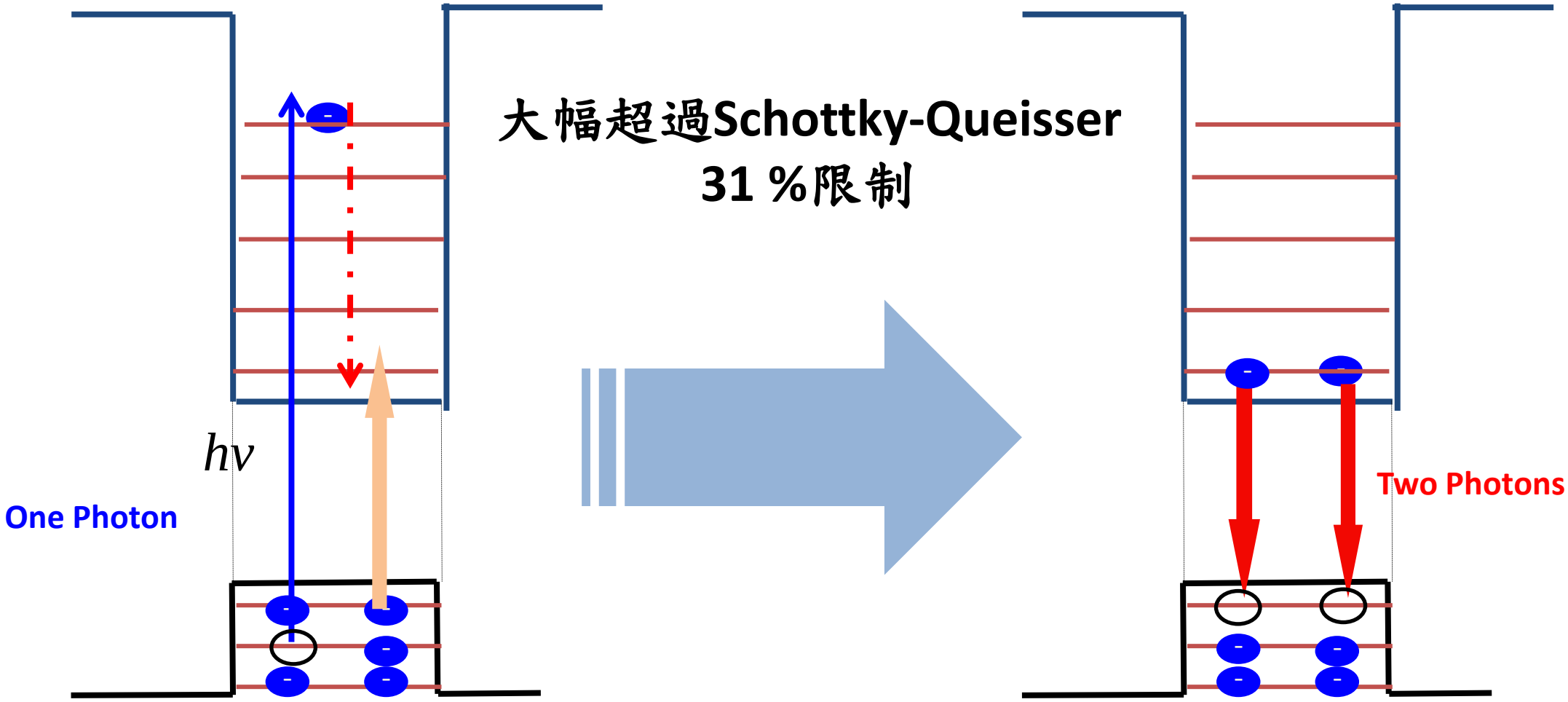
Best Research-Cell Efficiencies For Various Types of Solar Cells

NREL
NATIONAL RENEWABLE ENERGY LABORATORY



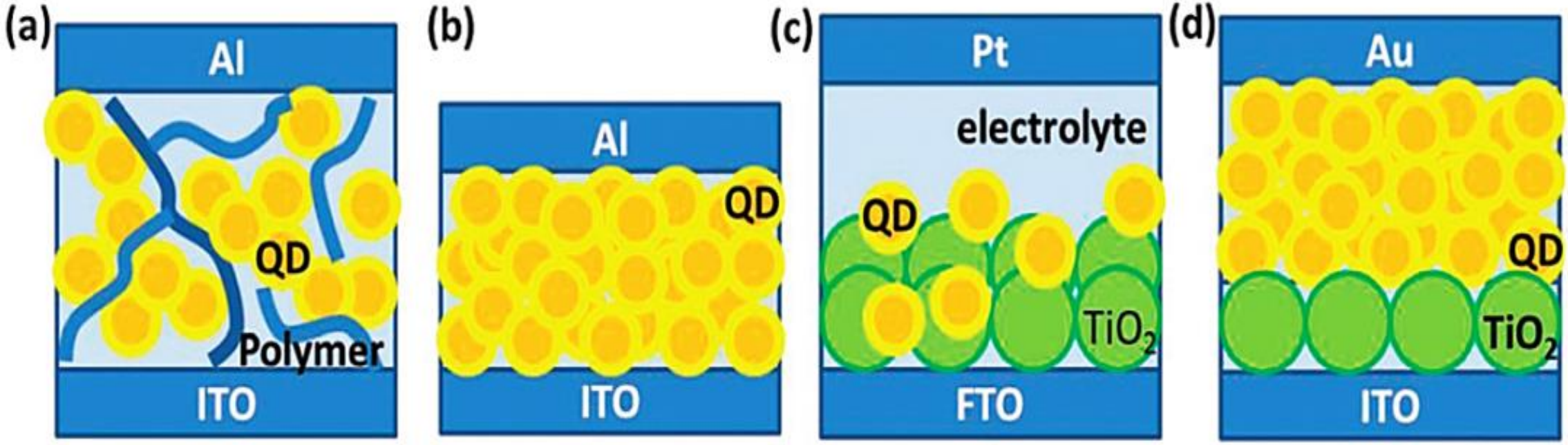
Unique Photophysical Process for QDs in Solar Energy Cell

Auger Process: Multi-exciton Generation



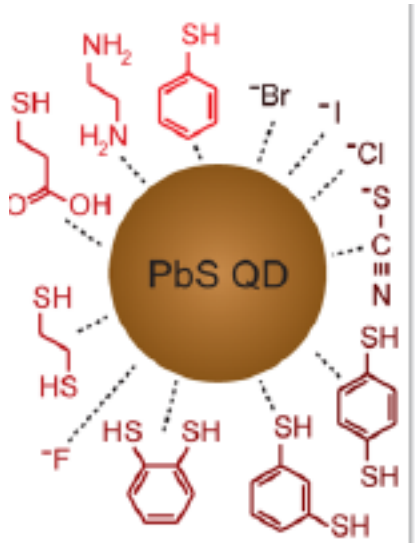
Important Gaining Factor for Photovoltaic

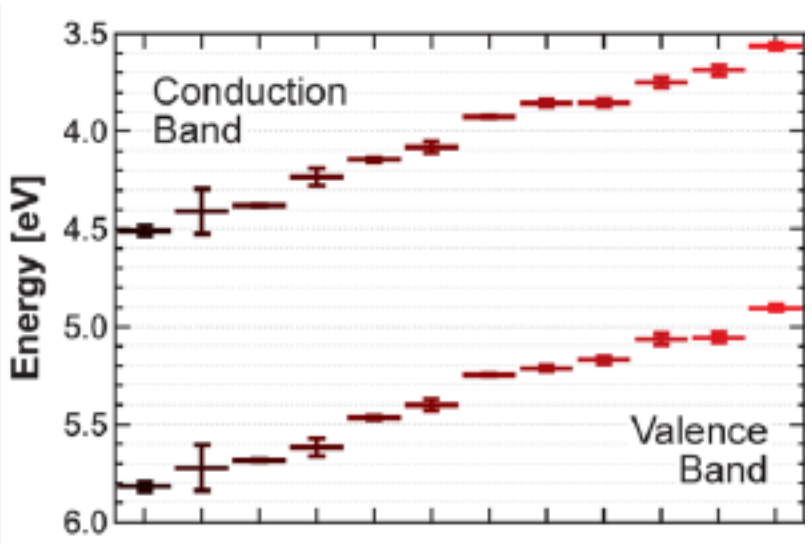
The application of **Quantum Dots** in solar energy

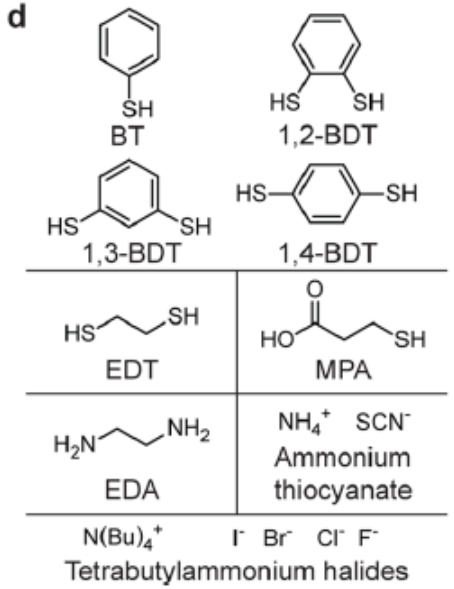


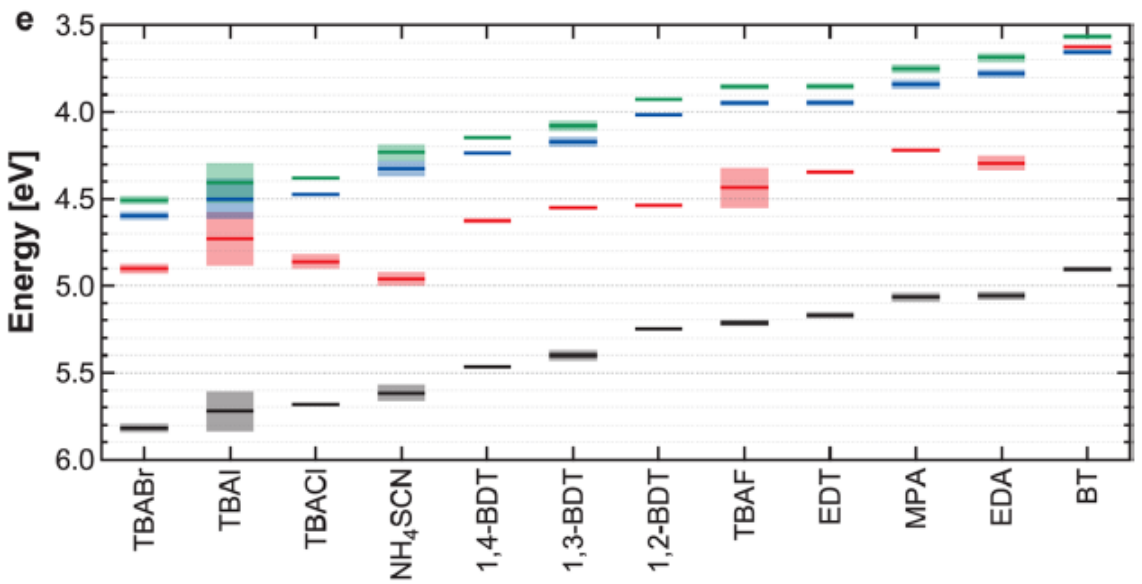
四類型量子點太陽能電池的結構 (a) 混合塊材異質結面太陽能電池 (b) Schottky結面太陽能電池 (c) 量子點敏化太陽能電池 (d)空乏區異質結面量子點太陽電池

QDs surface modification-organic ligands



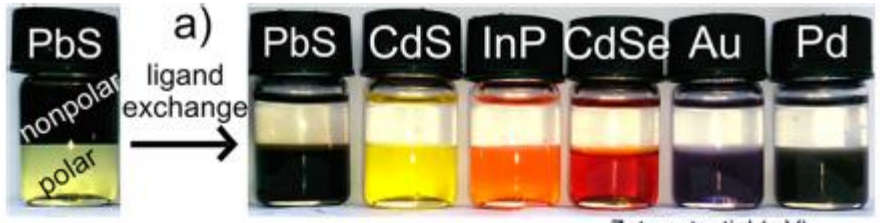


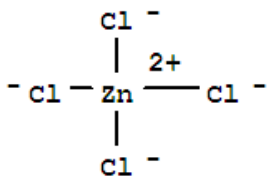


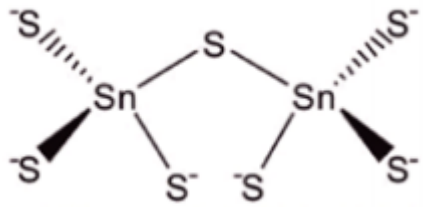


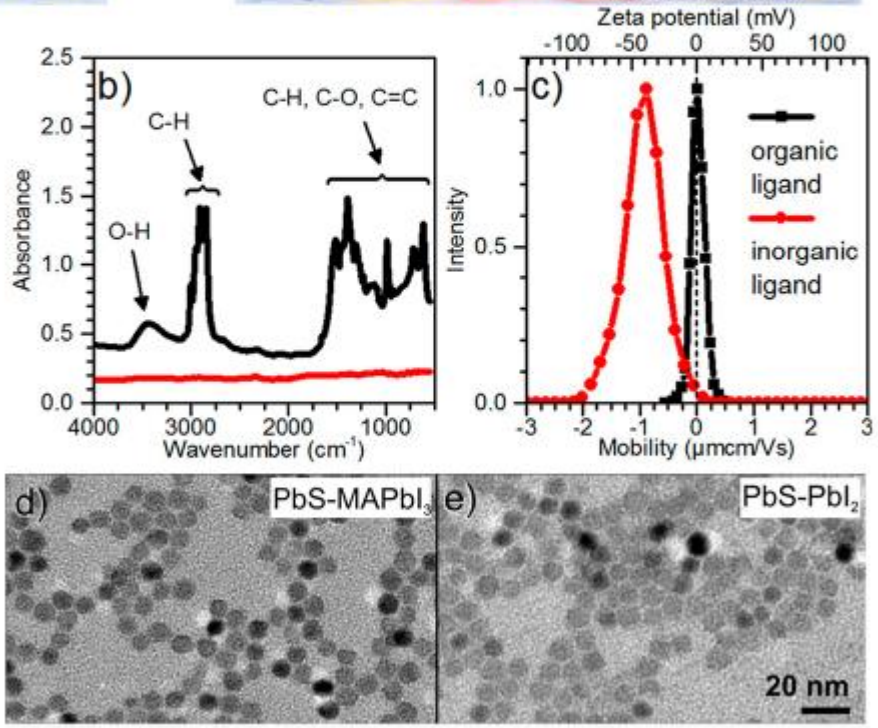
ACS nano., 2014, 5863-5872

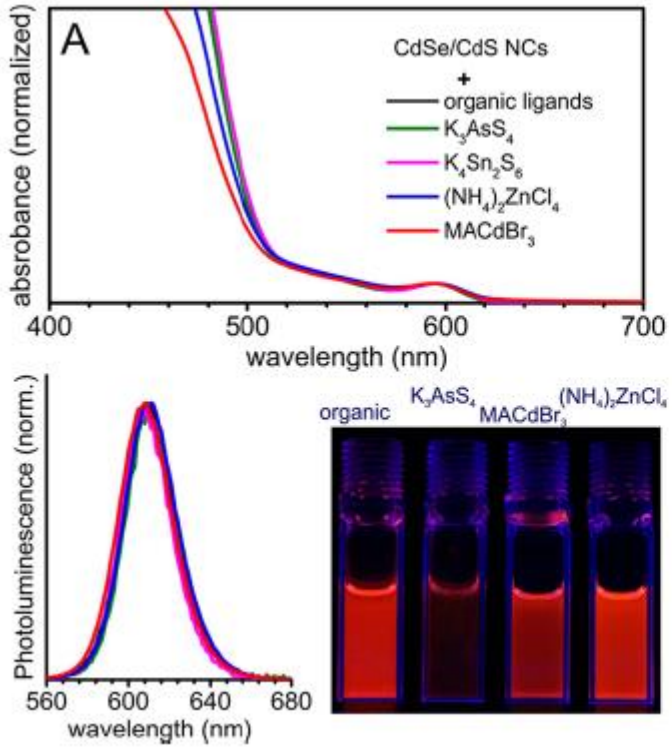
QDs surface modification-Inorganic ligands

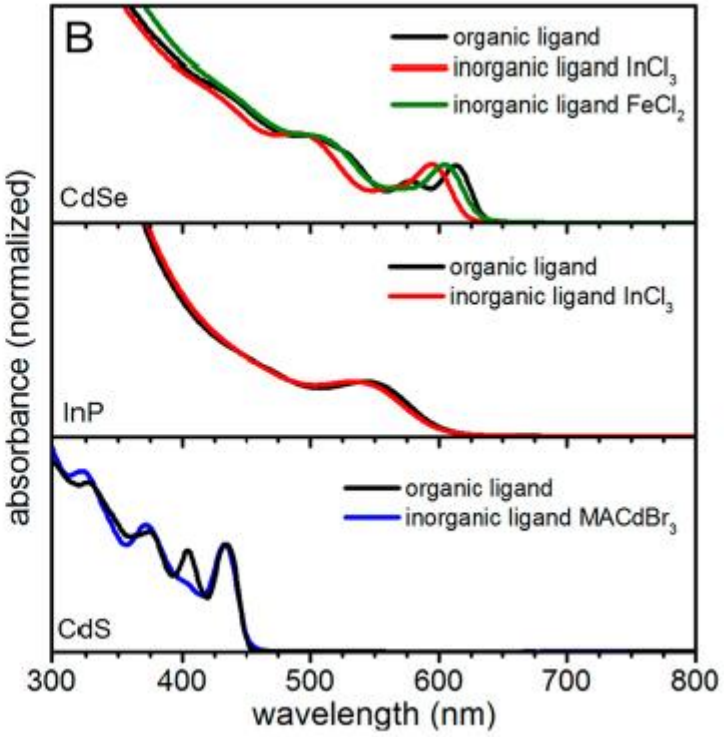






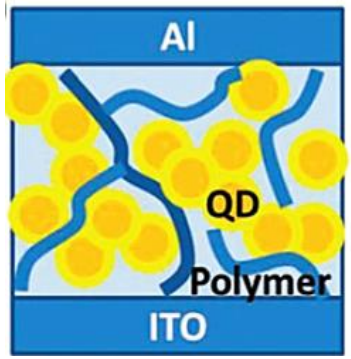




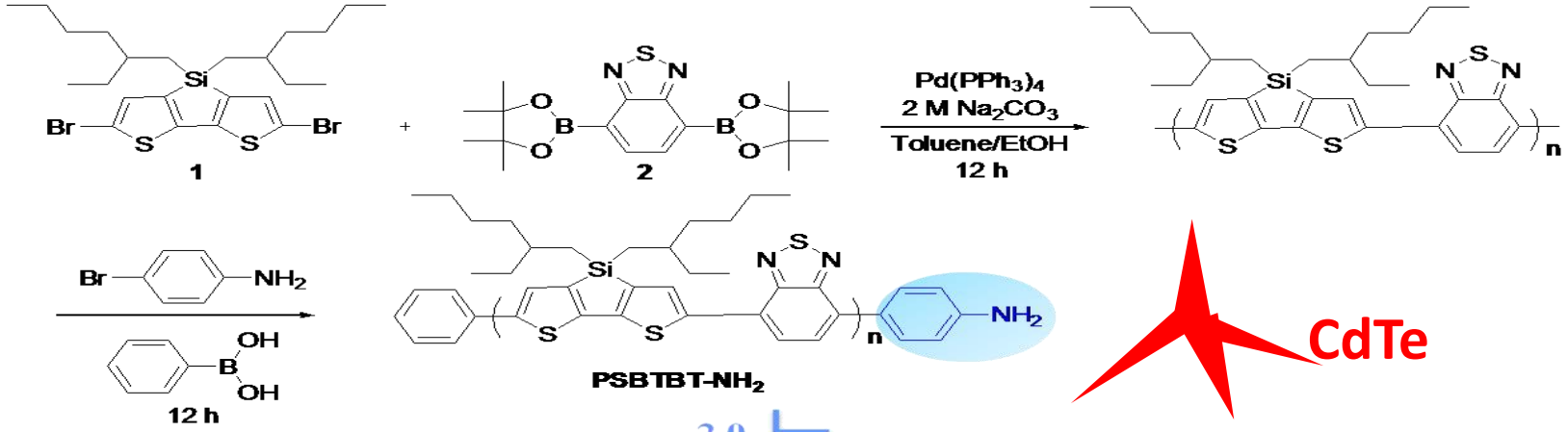


J. Am. Chem. Soc. **2014**, 136, 6550−6553

(1) 混合塊材異質結面太陽能電池
(hybrid bulk-heterojunction solar cells)



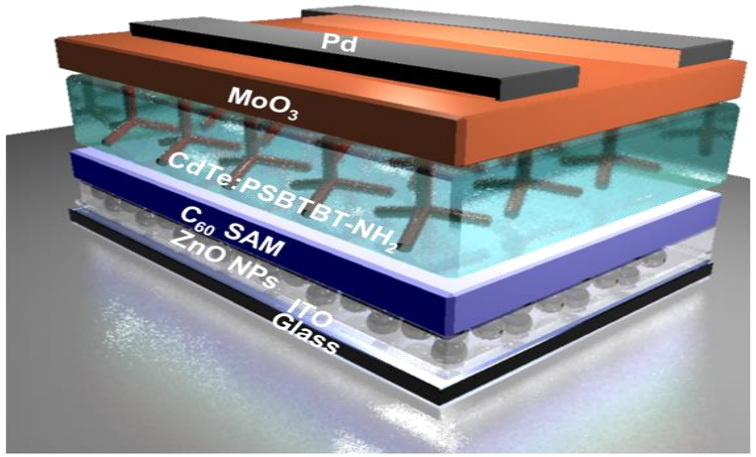
a)



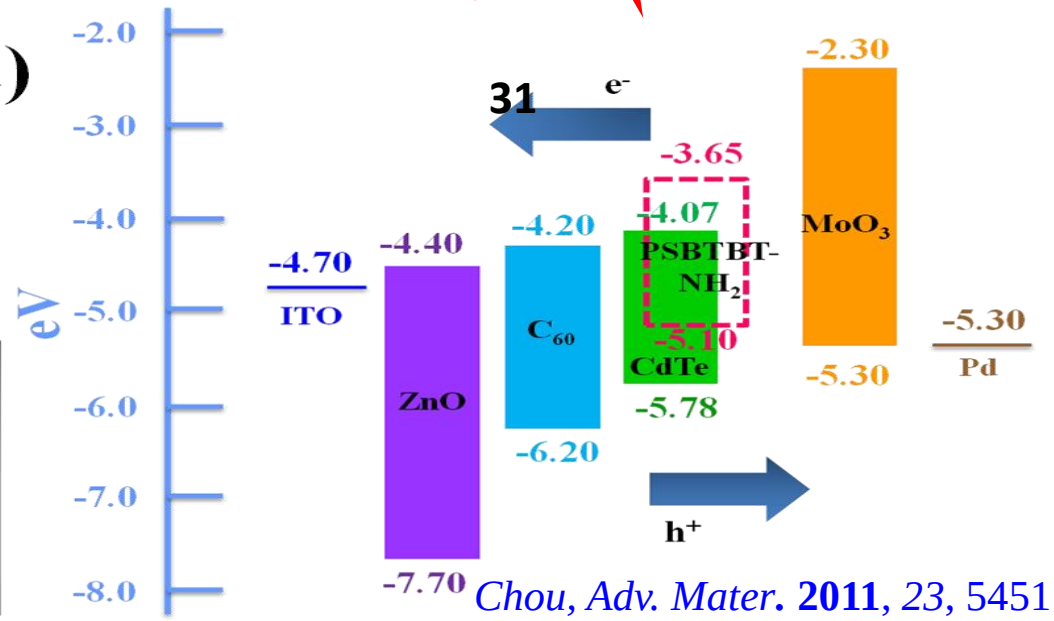
CdTe

b)

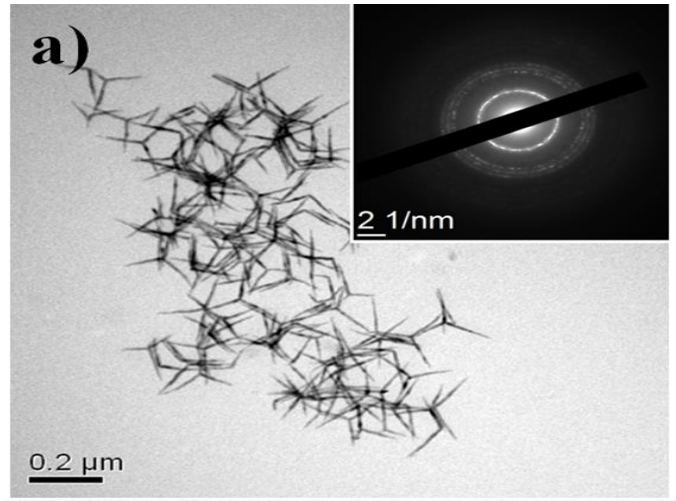
PSBTBT/CdTe : 3.5% ,
world record (2011)

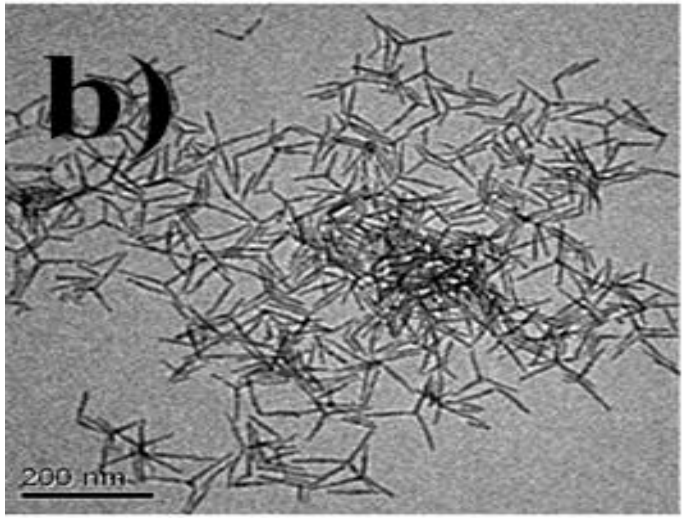


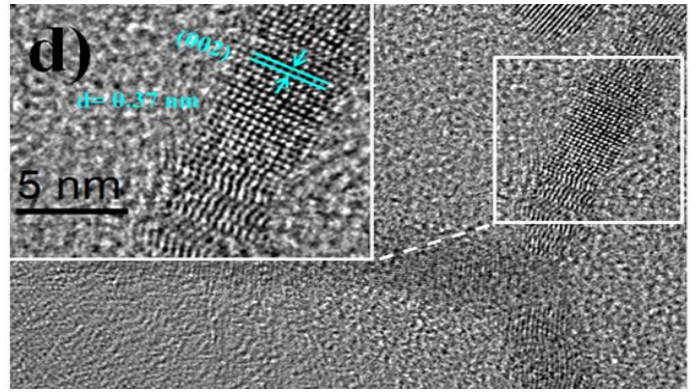
c)

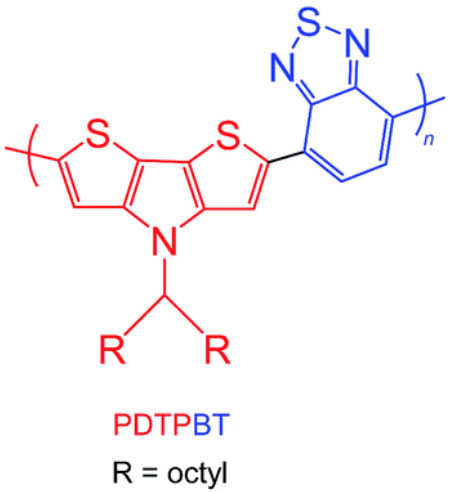


Chou, Adv. Mater. **2011**, *23*, 5451



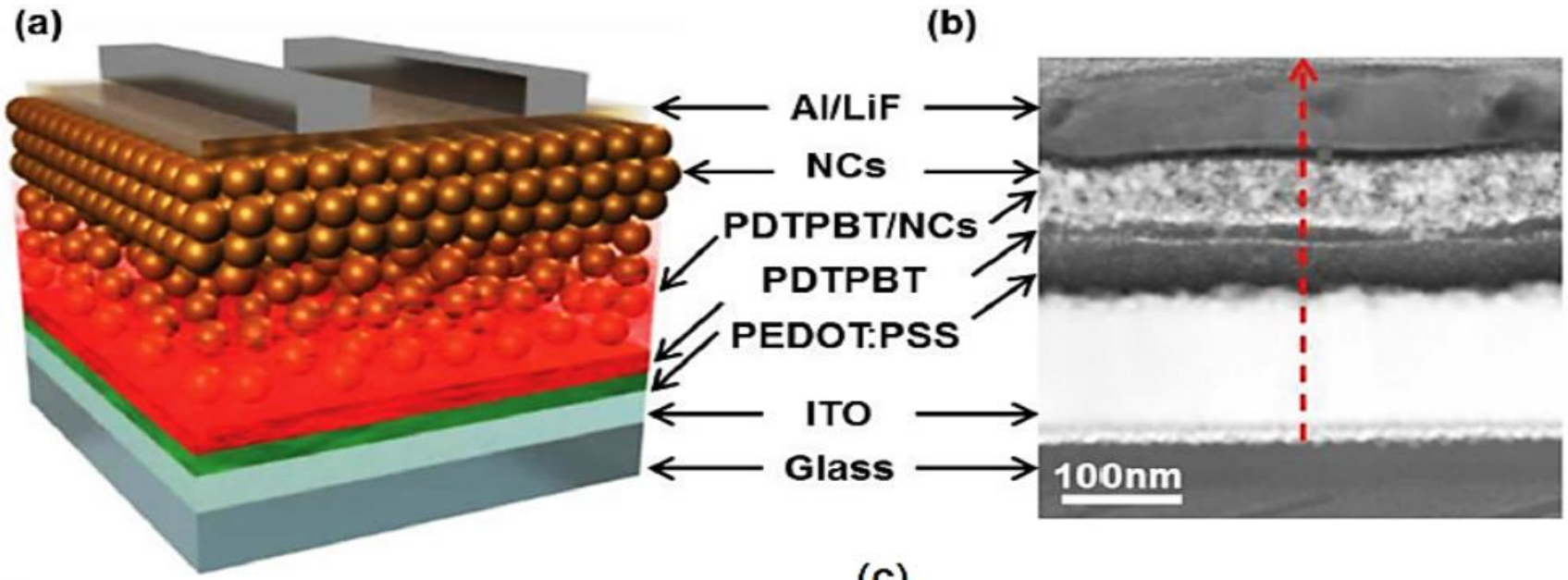


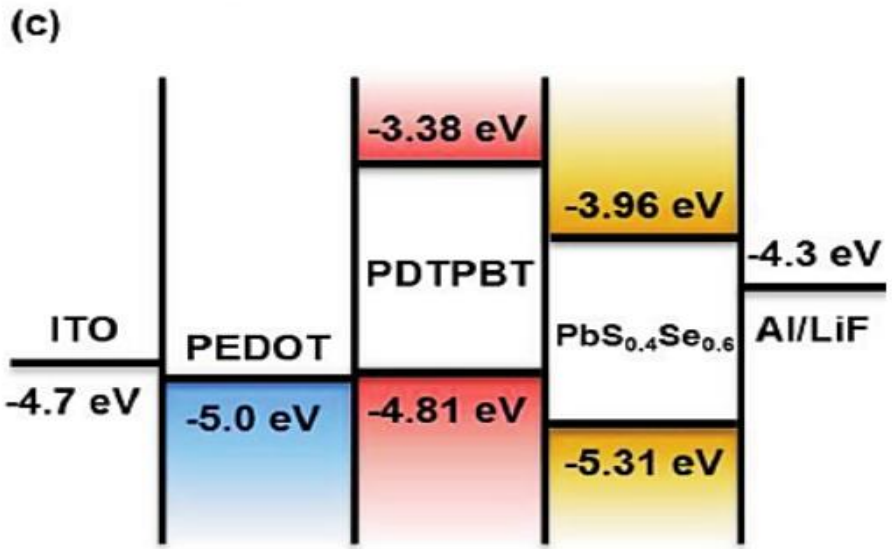


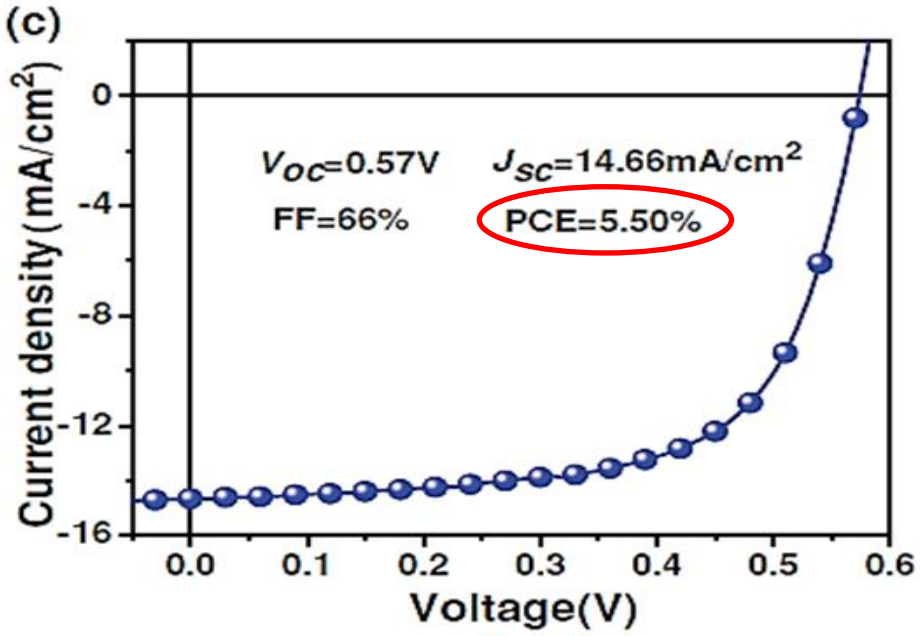


PDTPBT

R = octyl

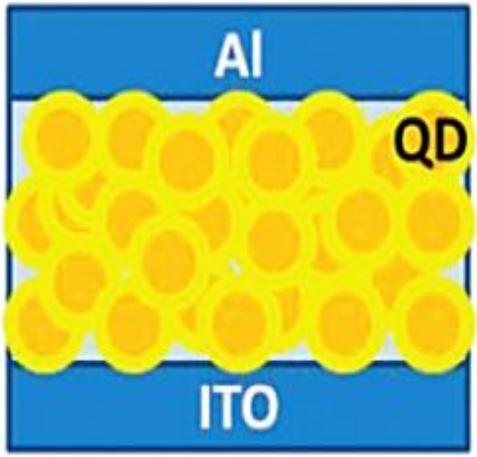


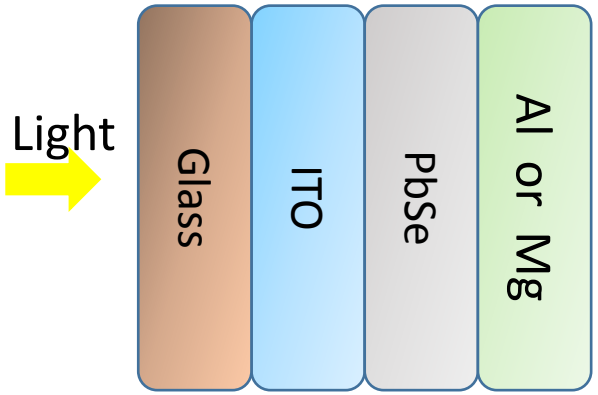




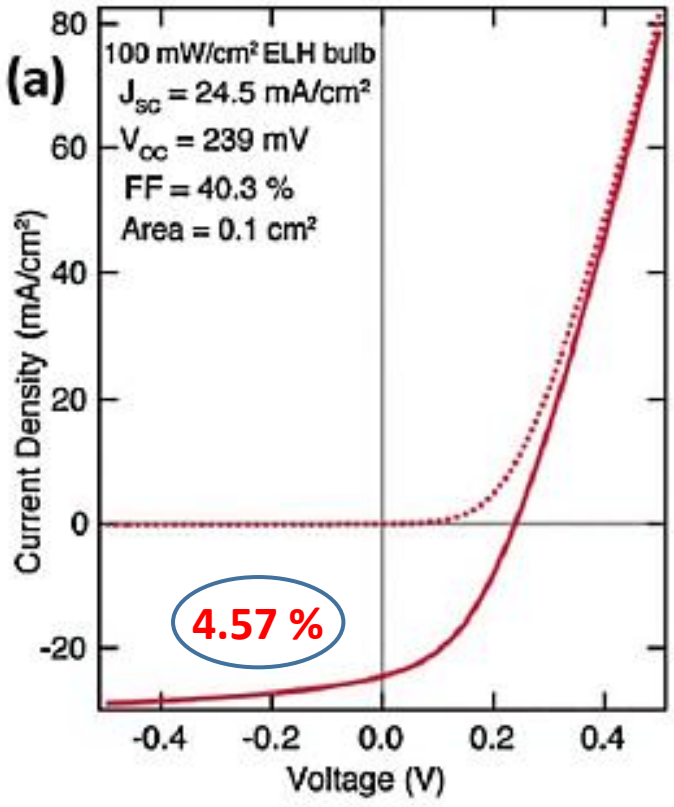
Advanced Materials, **25**, 5772 (2013)

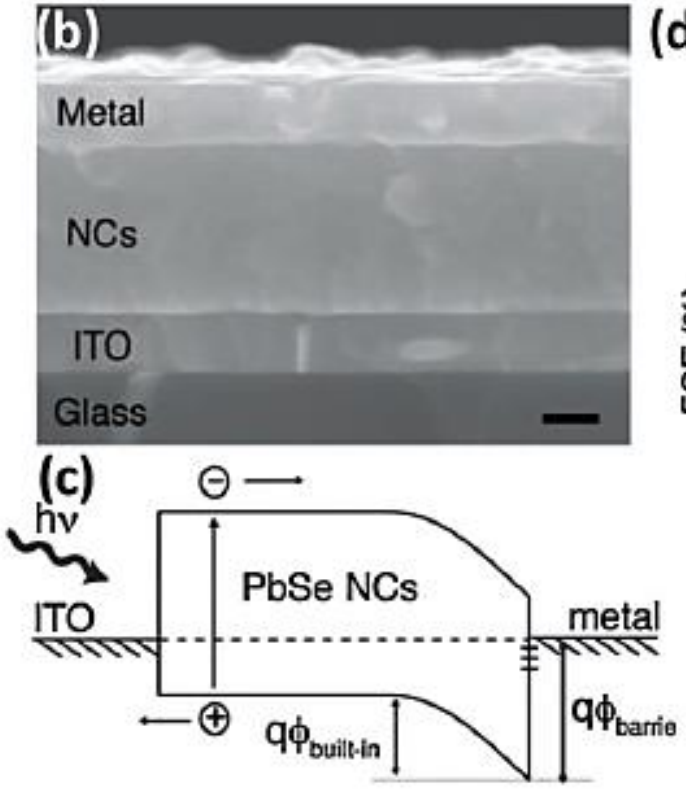
(2) Schottky結面太陽能電池 (Schottky junction solar cell)

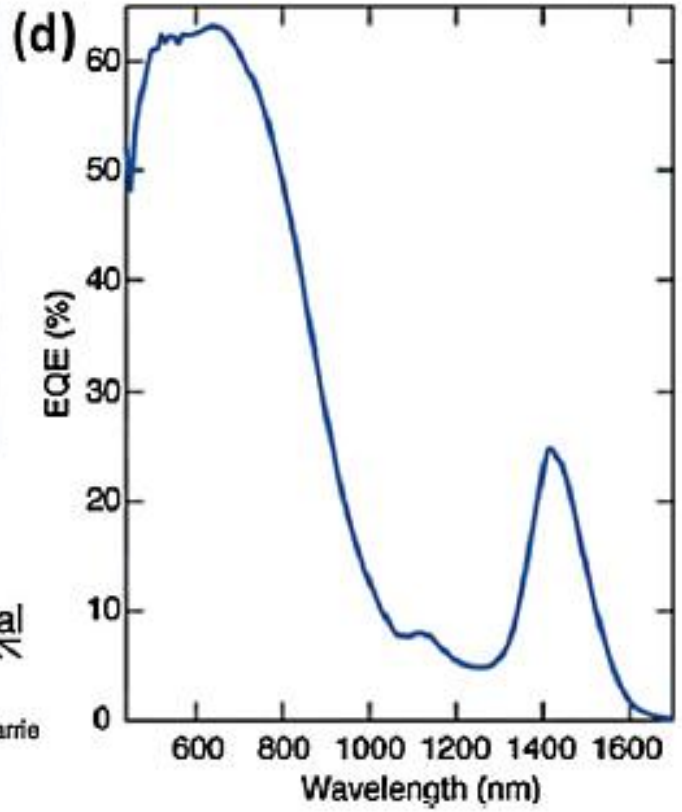


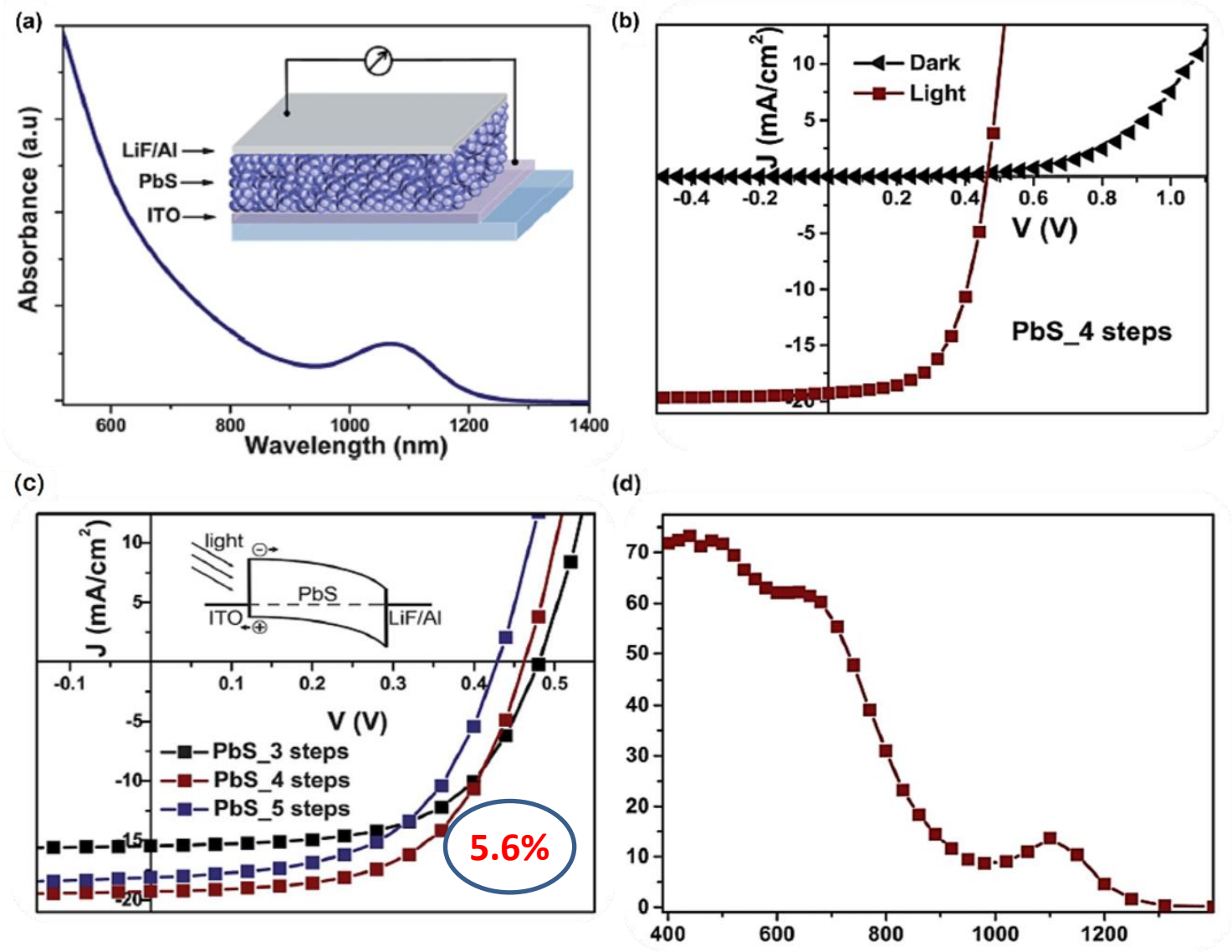


Nano Lett., **2008**, *8*, 3488–3492









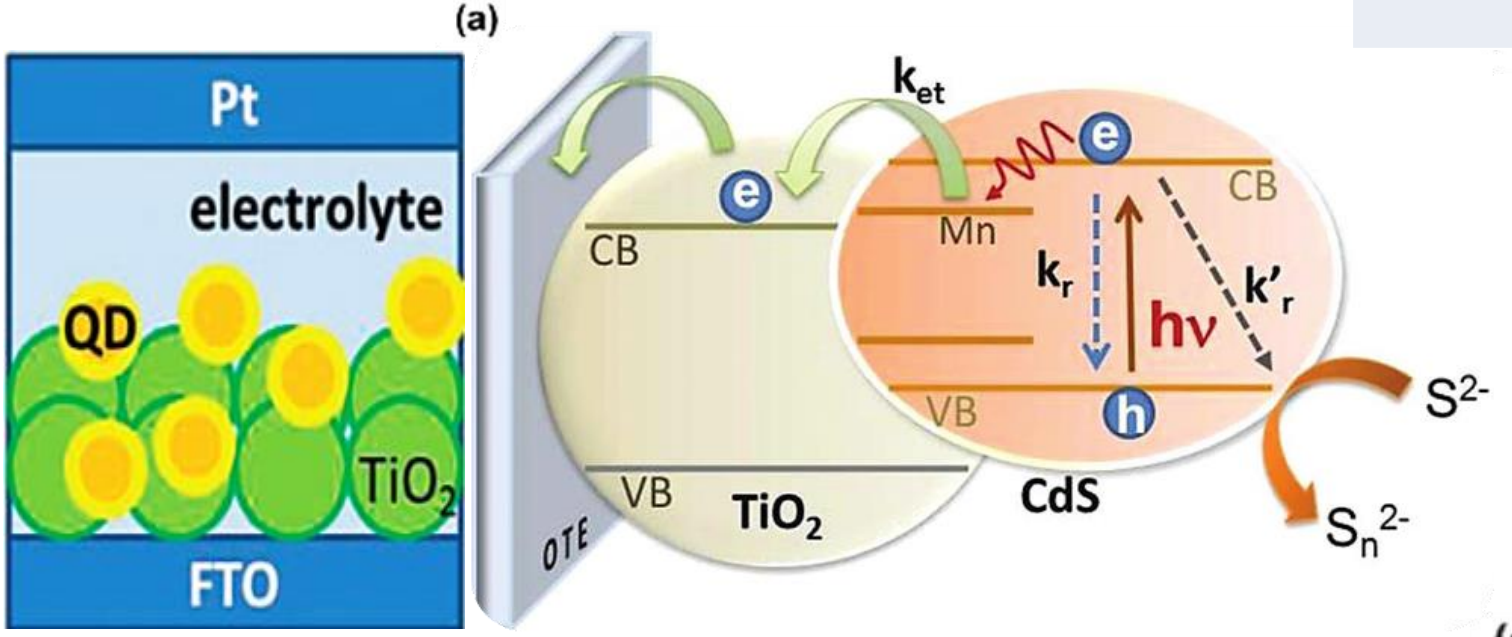
(a)元件組成示意圖與量子點吸收圖譜 (b)清洗4次的硫化鉛量子點組成元件的I-V曲線 (c)不同清洗次數的硫化鉛點組成元件的I-V曲線與費米能階平衡後的能帶示意圖 (d)清洗4次的硫化鉛量子點組成元件的吸收圖譜

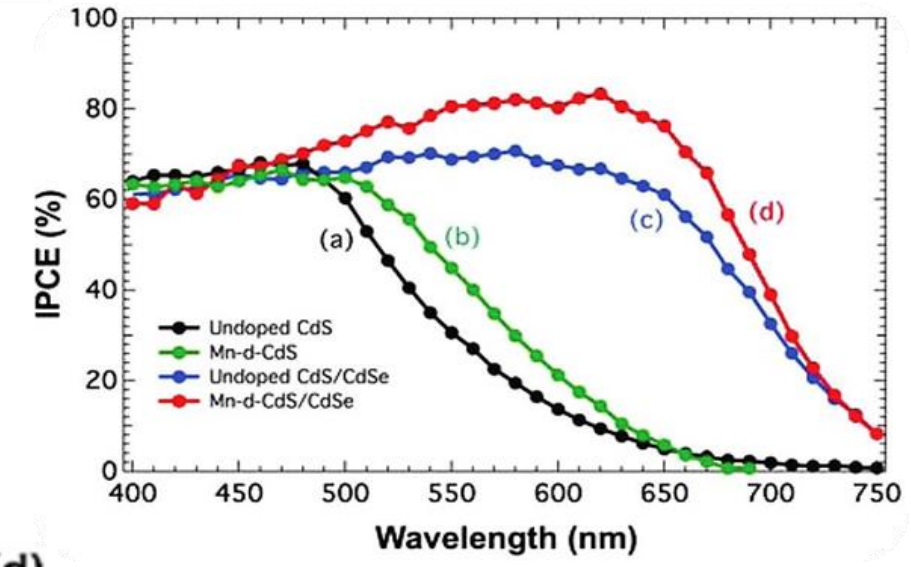
Energy Environmental Science, **6**, 3054 (2013).

(c)量子點敏化太陽能電池

化學沉澱法(chemical bath deposition, CBD)或連續離子吸附法(SILAR)將量子點直接成長在二氧化鈦上

QDSC vs. DSSC	QDSC	DSSC
Active layer	Quantum dots	Organic dye
Electrolyte	S^{2-}/S_n^{2-}(avoid metal corrosion)	I^-/I_3^-

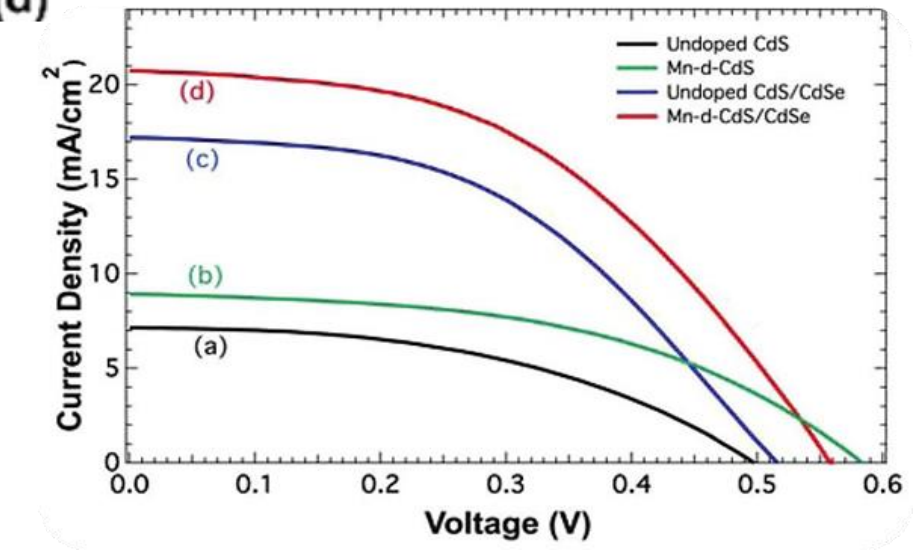




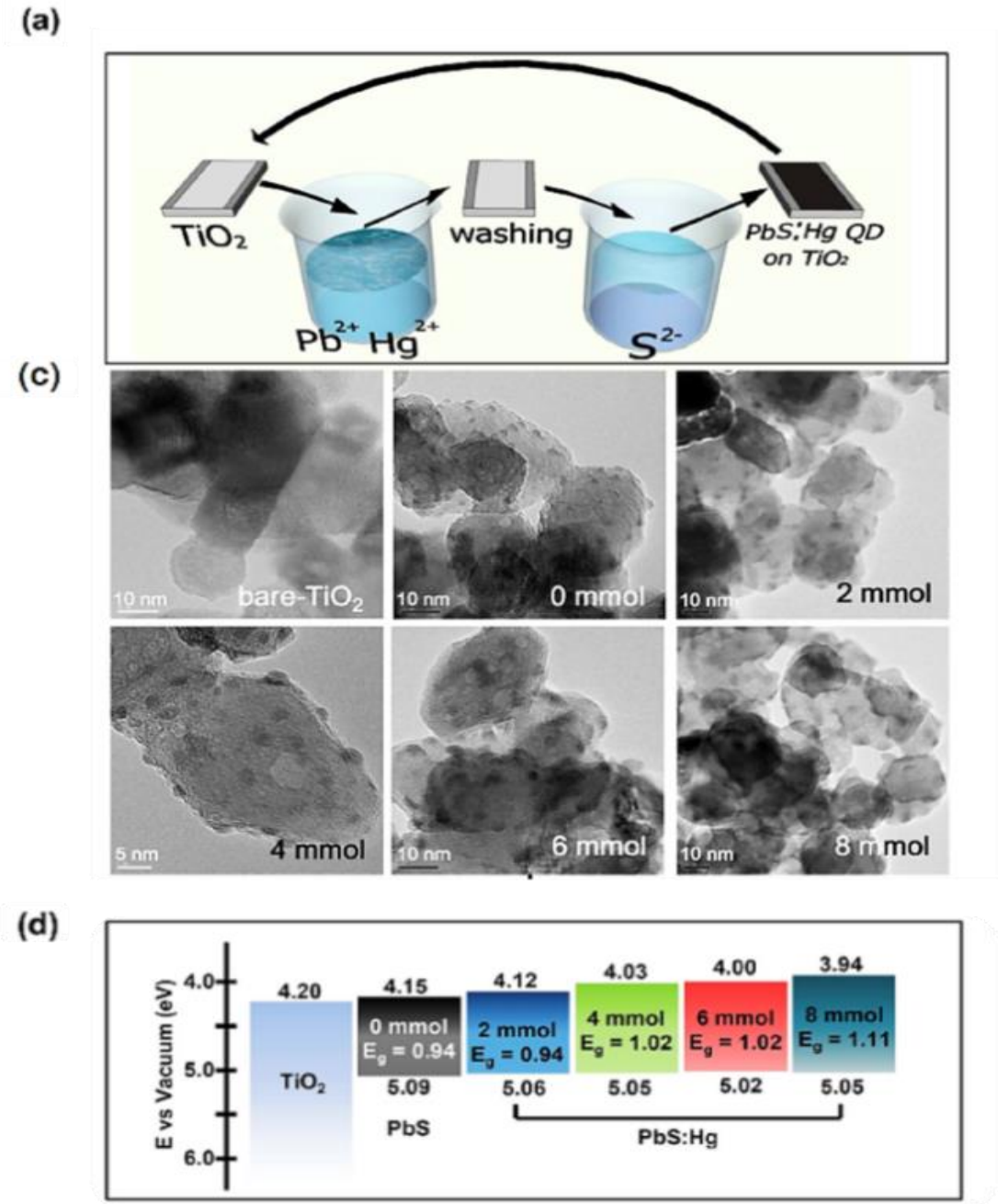
(c)

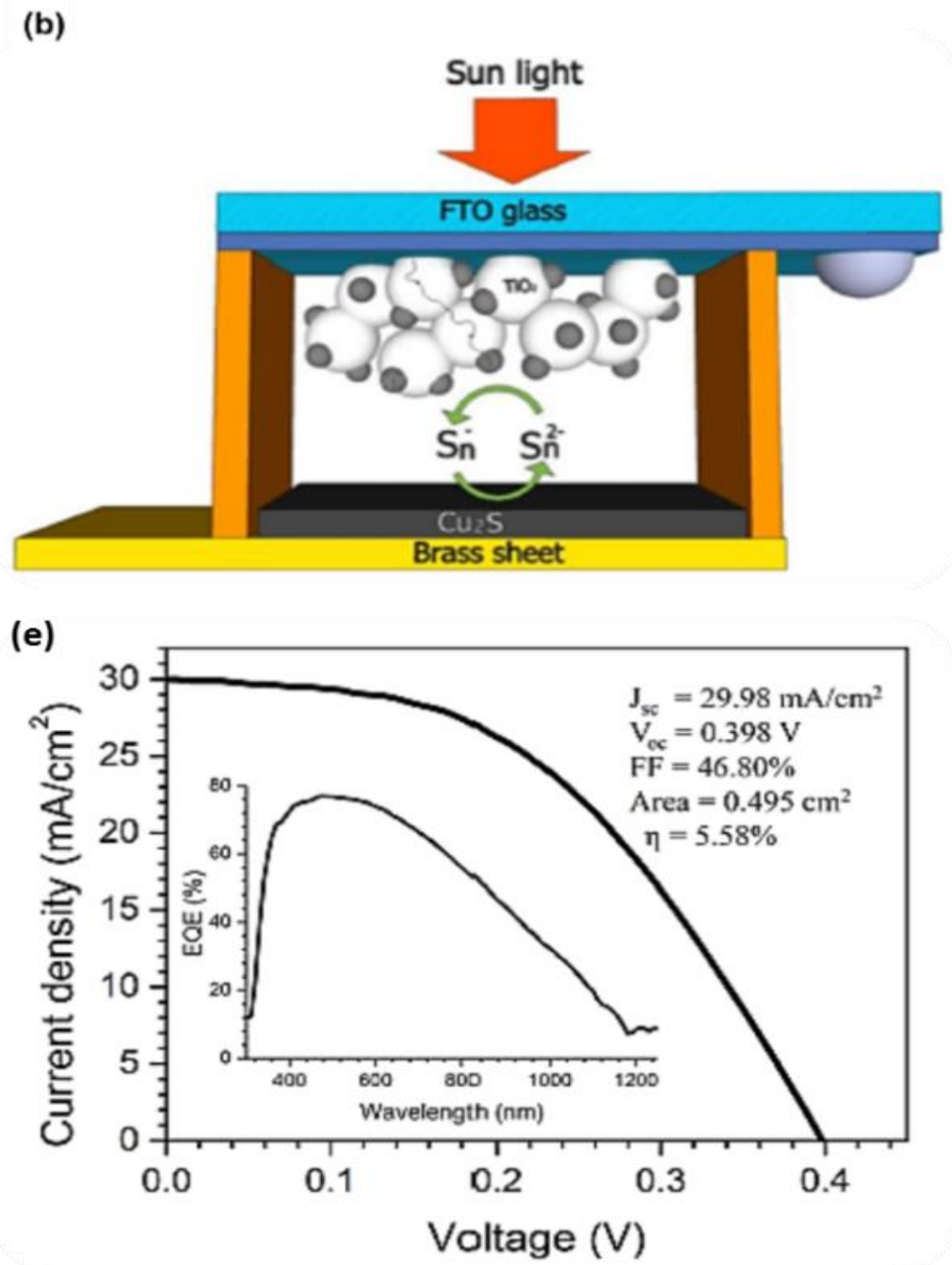
sample	J_{SC} (mA/cm²)	V_{OC} (mV)	*ff*	η (%)
CdS	7.2	496	0.46	1.63
Mn-d-CdS	8.9	583	0.49	2.53
CdS/CdSe	17.2	516	0.47	4.19
Mn-d-CdS/CdSe	20.7	558	0.47	5.42

(d)



J. Am. Chem. Soc. **134**, 2508 (2012)

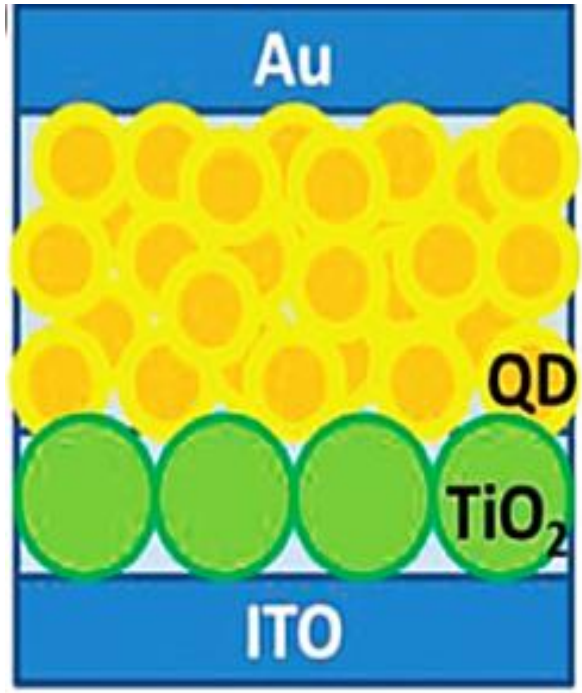


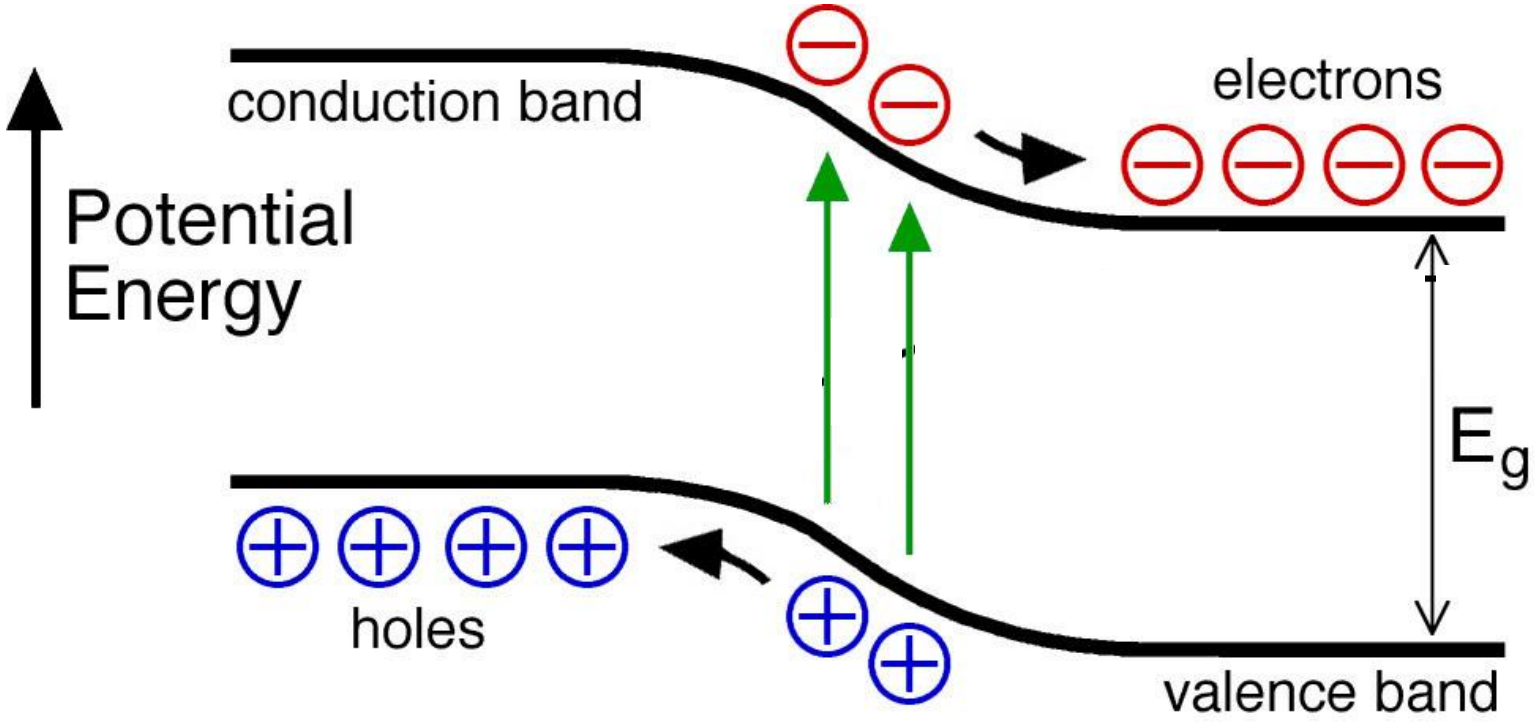


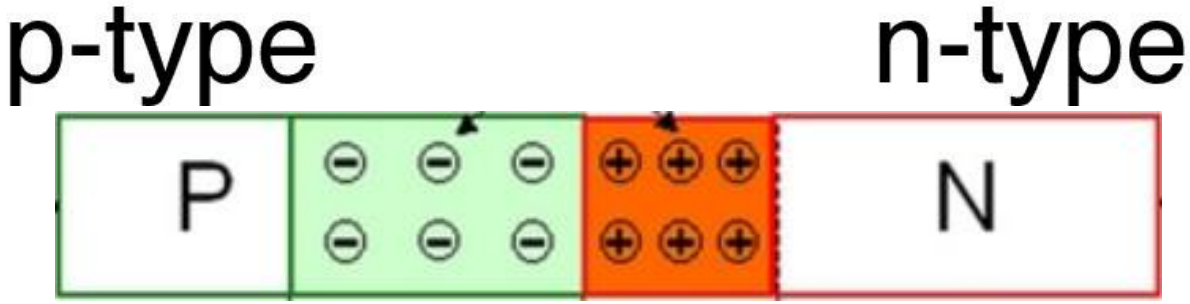
Scientific Reports, **3**, 1050 (2013)

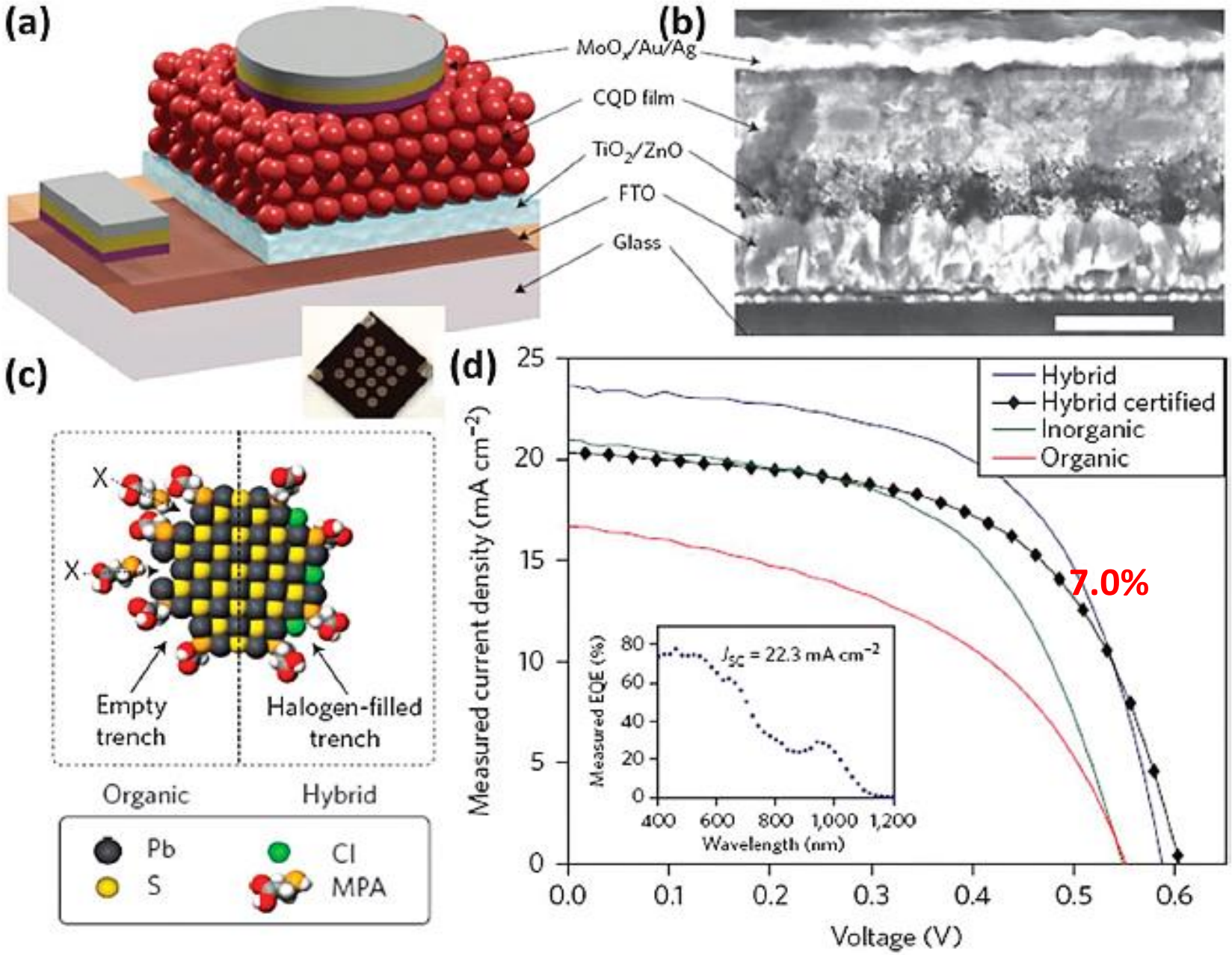
(4)空乏區異質結面量子點太陽電池 (p/n type solar cells)

Built-in potential can reduce exciton recombination

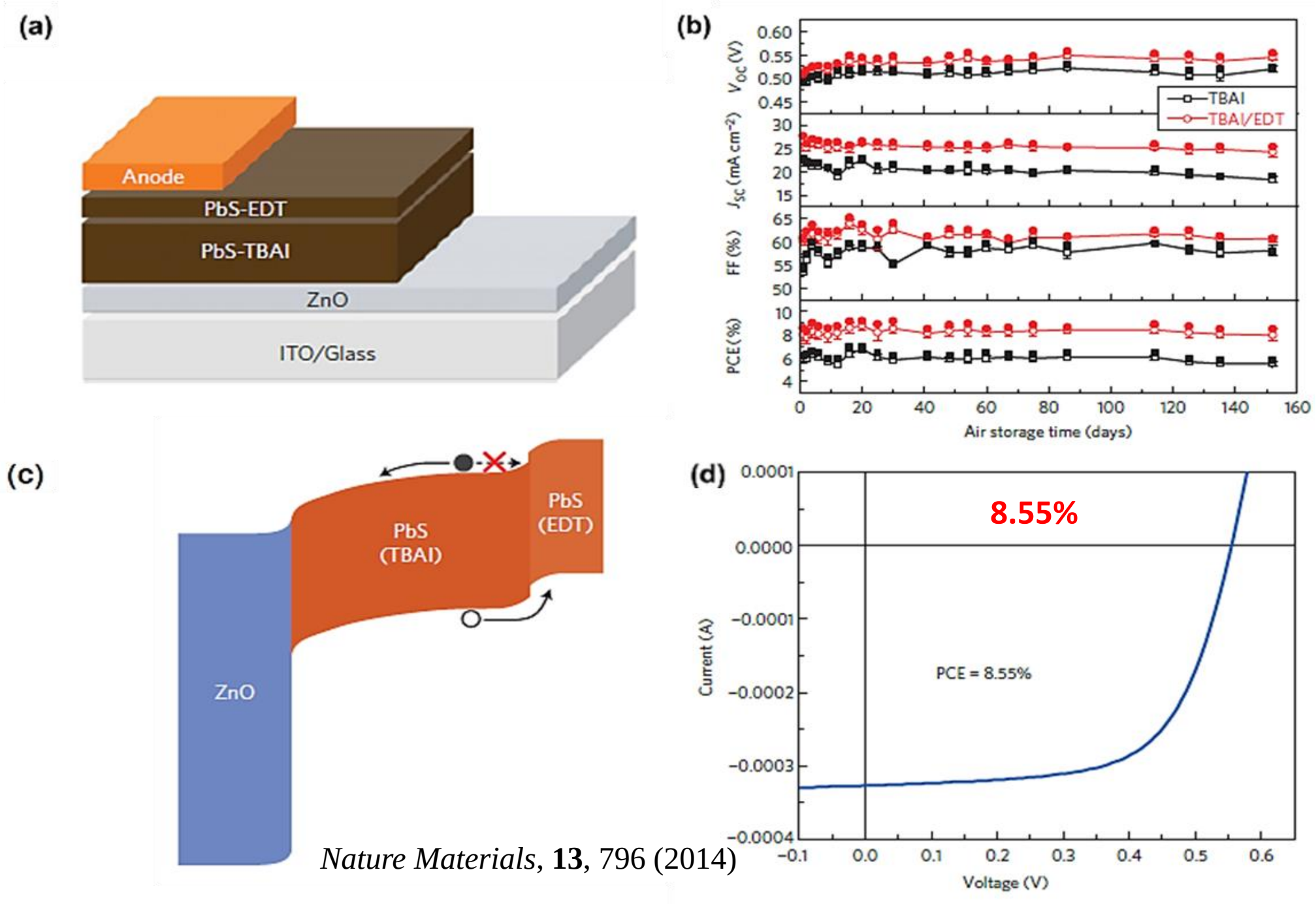




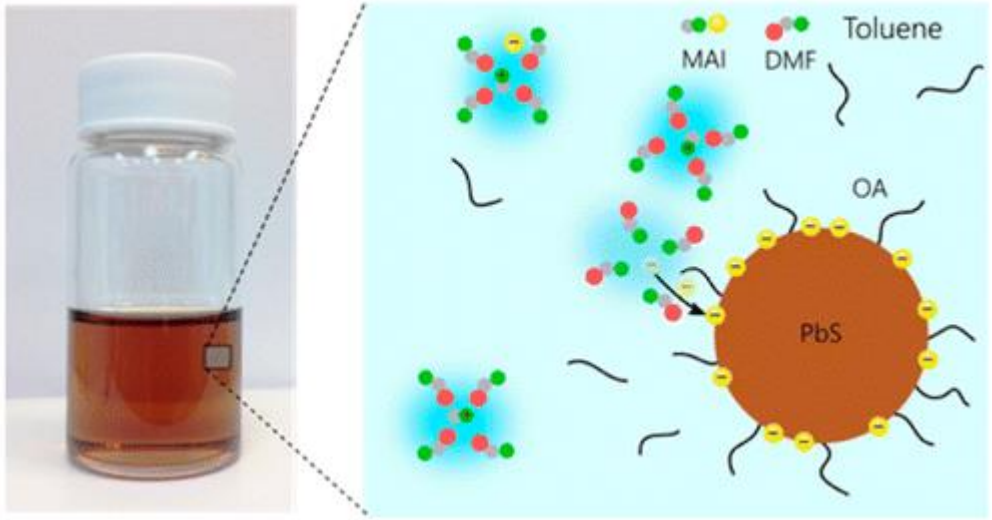


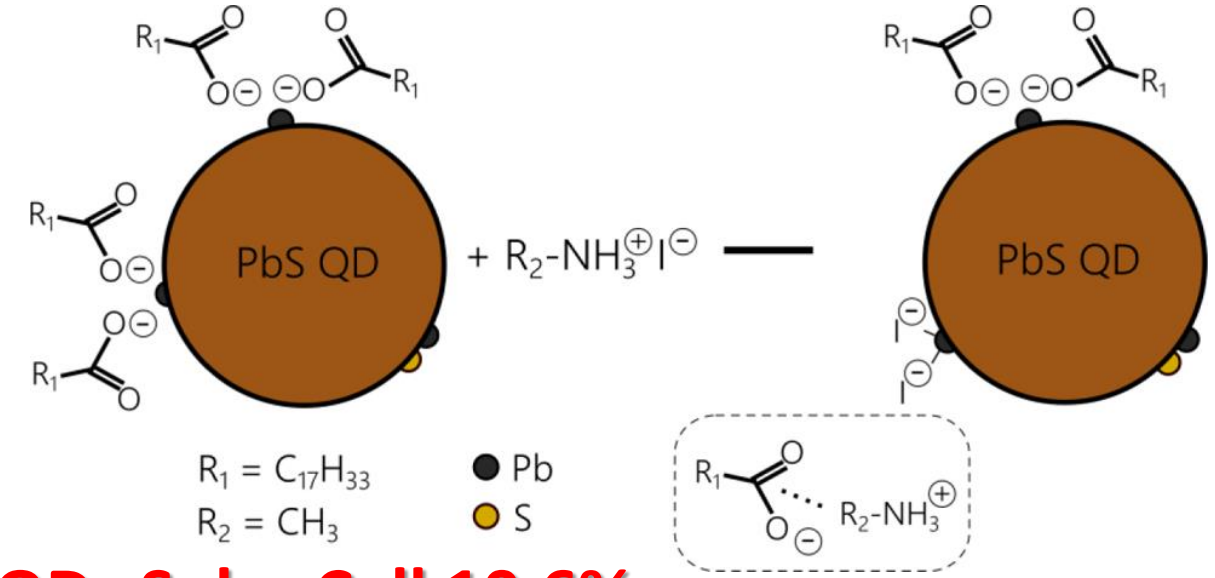


Nature Nanotechnology, **7**, 577 (2012)

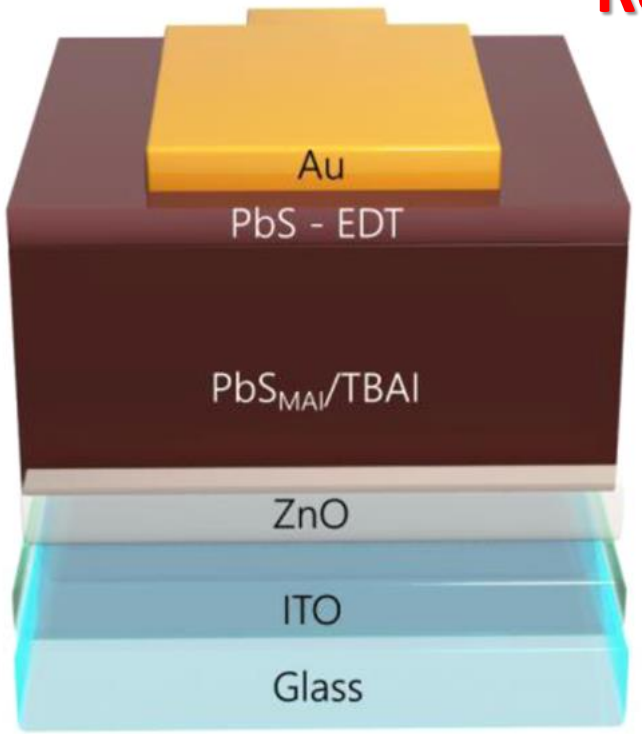


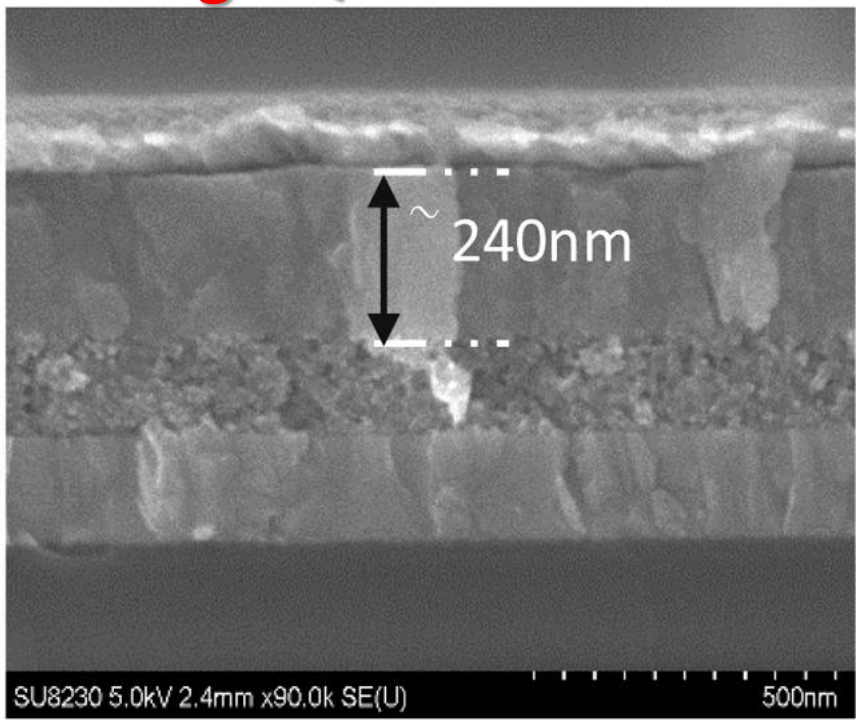
Nature Materials, **13**, 796 (2014)

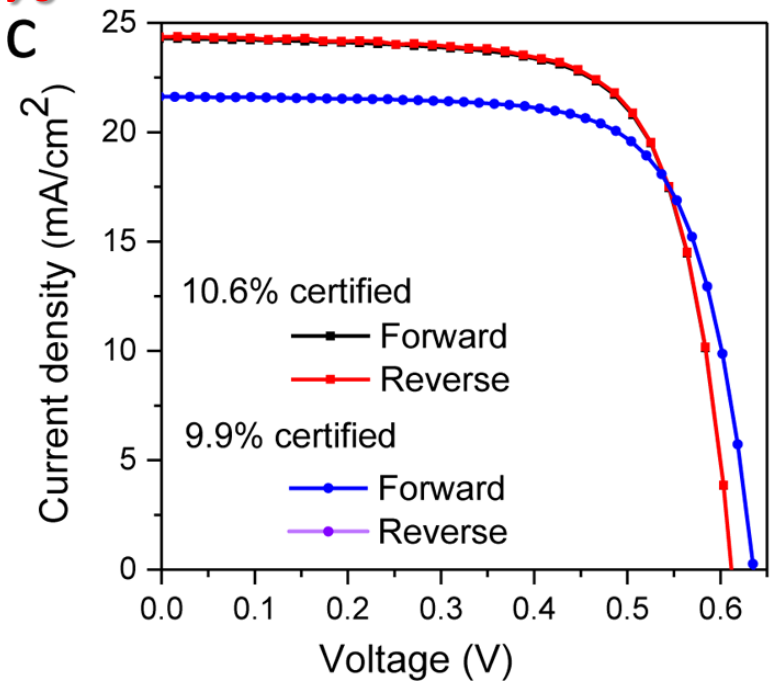




Record High QDs Solar Cell 10.6%

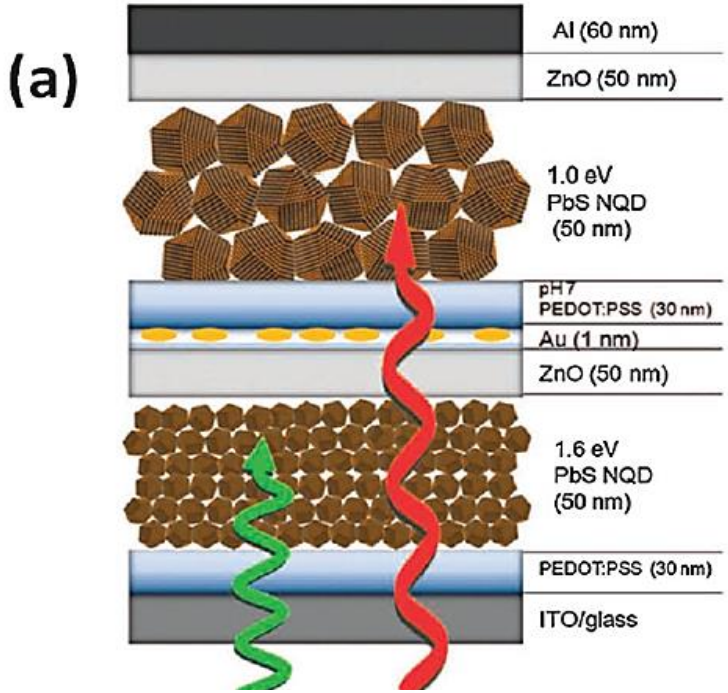


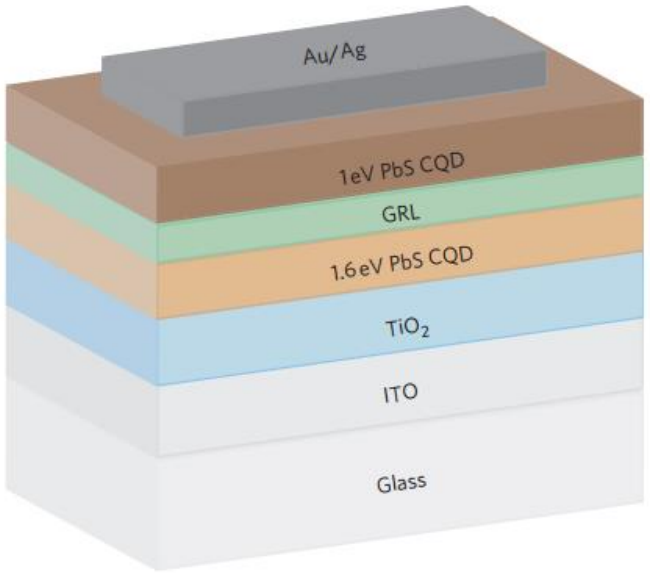


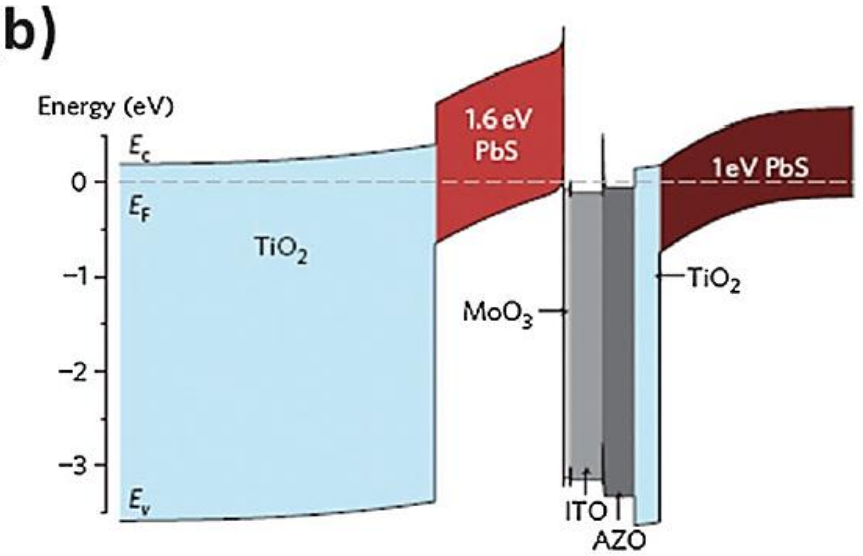


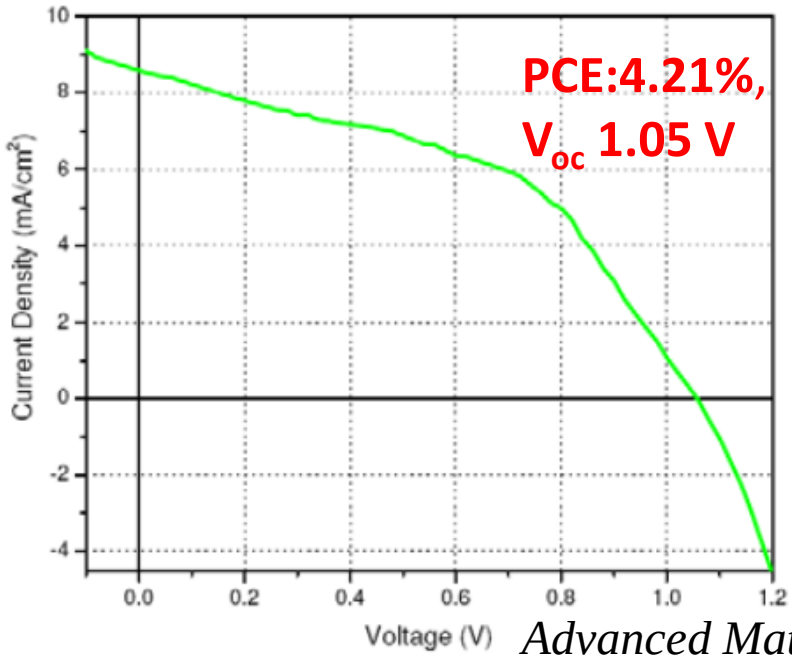
Nano Lett. **2016**, *16*, 4630−4634

串疊(Tandem)太陽能電池







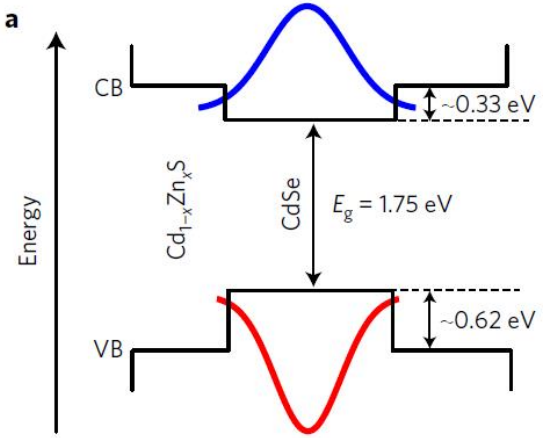


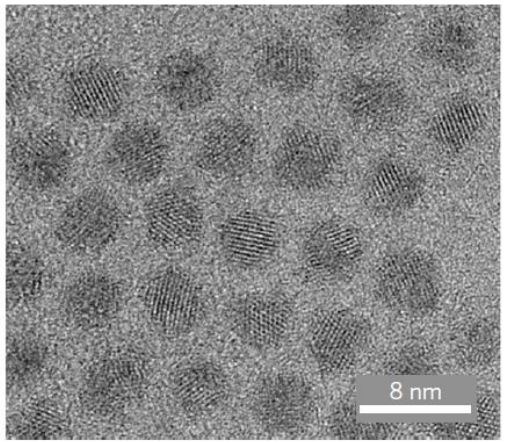
Advanced Materials, **23**, 3144 (2011)

(5) The QDs Solar Concentrator

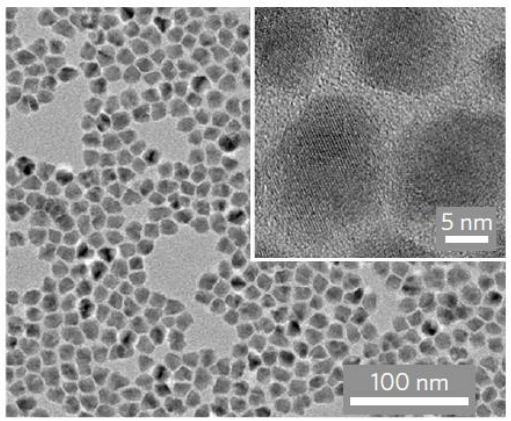
Doctor-blade deposition of quantum dots onto standard window glass for low-loss large-area luminescent solar concentrators

Hongbo Li†, Kaifeng Wu†, Jaehoon Lim, Hyung-Jun Song and Victor I. Klimov*

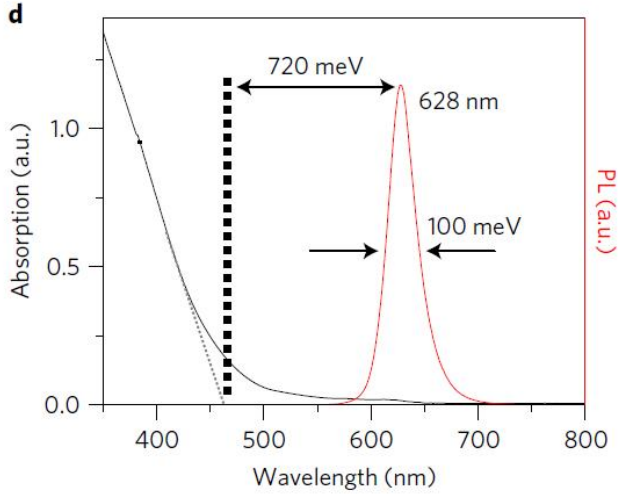




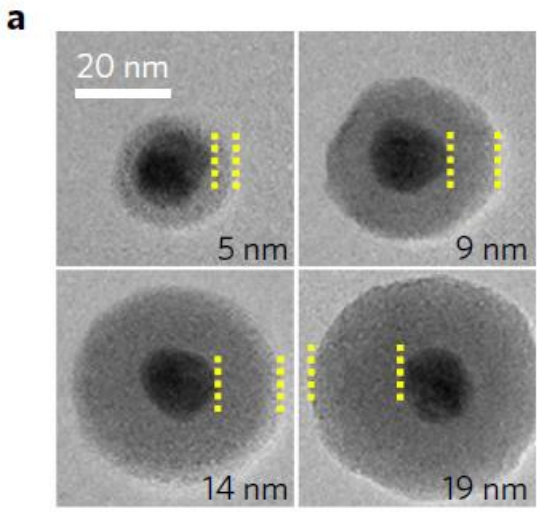
CdSe-QDs

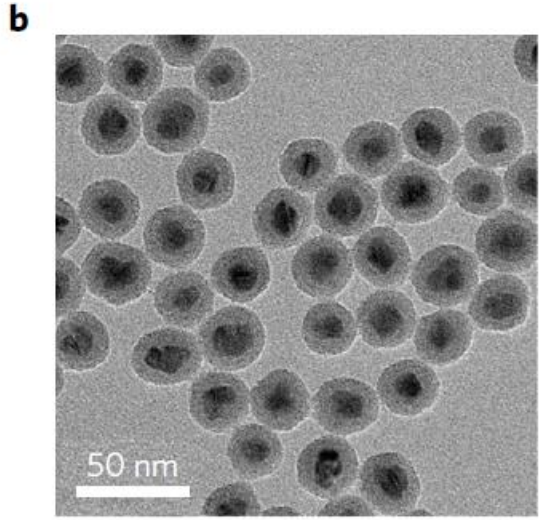


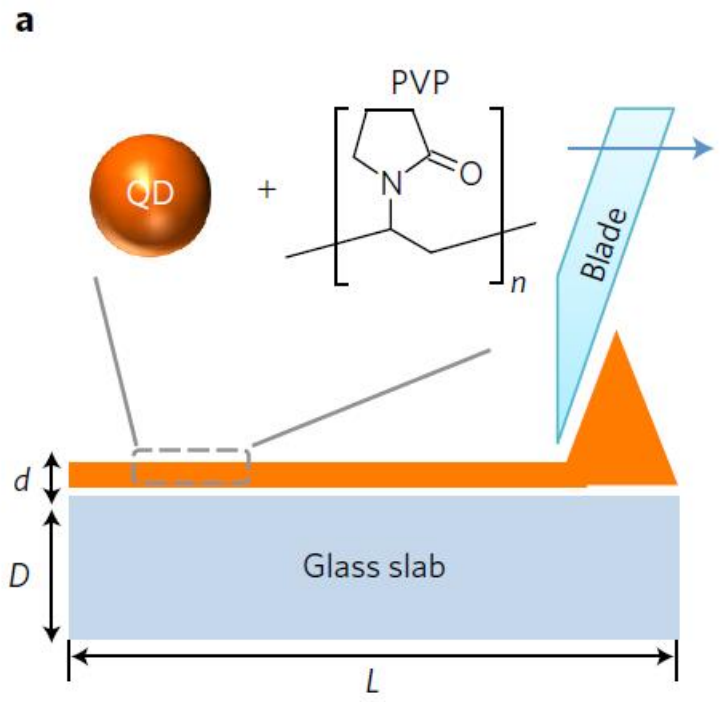
CdSe/Cd1-*x*Zn*x*S g-QDs

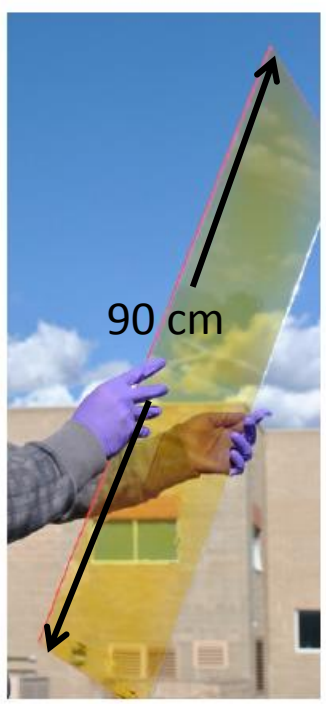


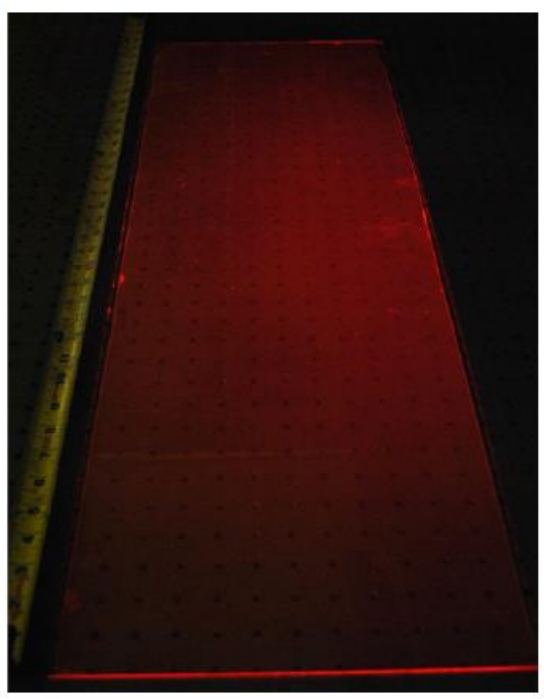
Nature Energy **2016**, DOI: 10.1038





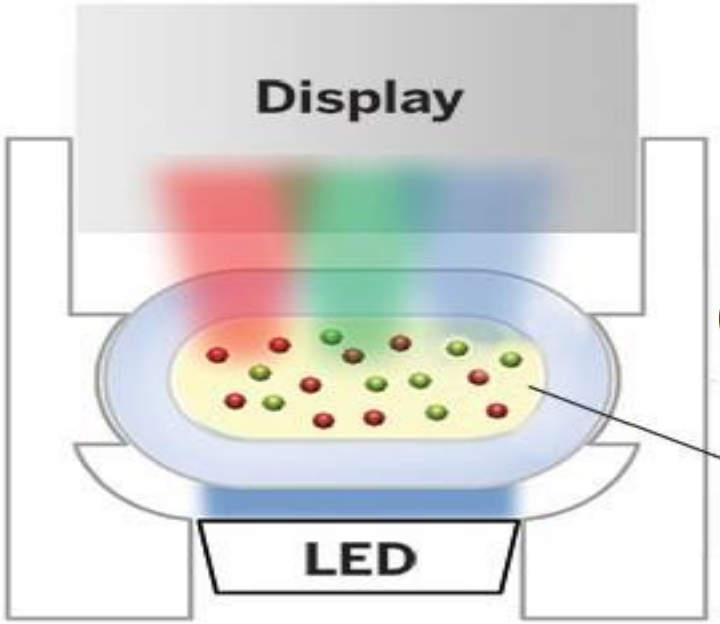






These values yield h_{ext} of about 1.9%, which is about a factor of 3.4 below the `break-even' efficiency

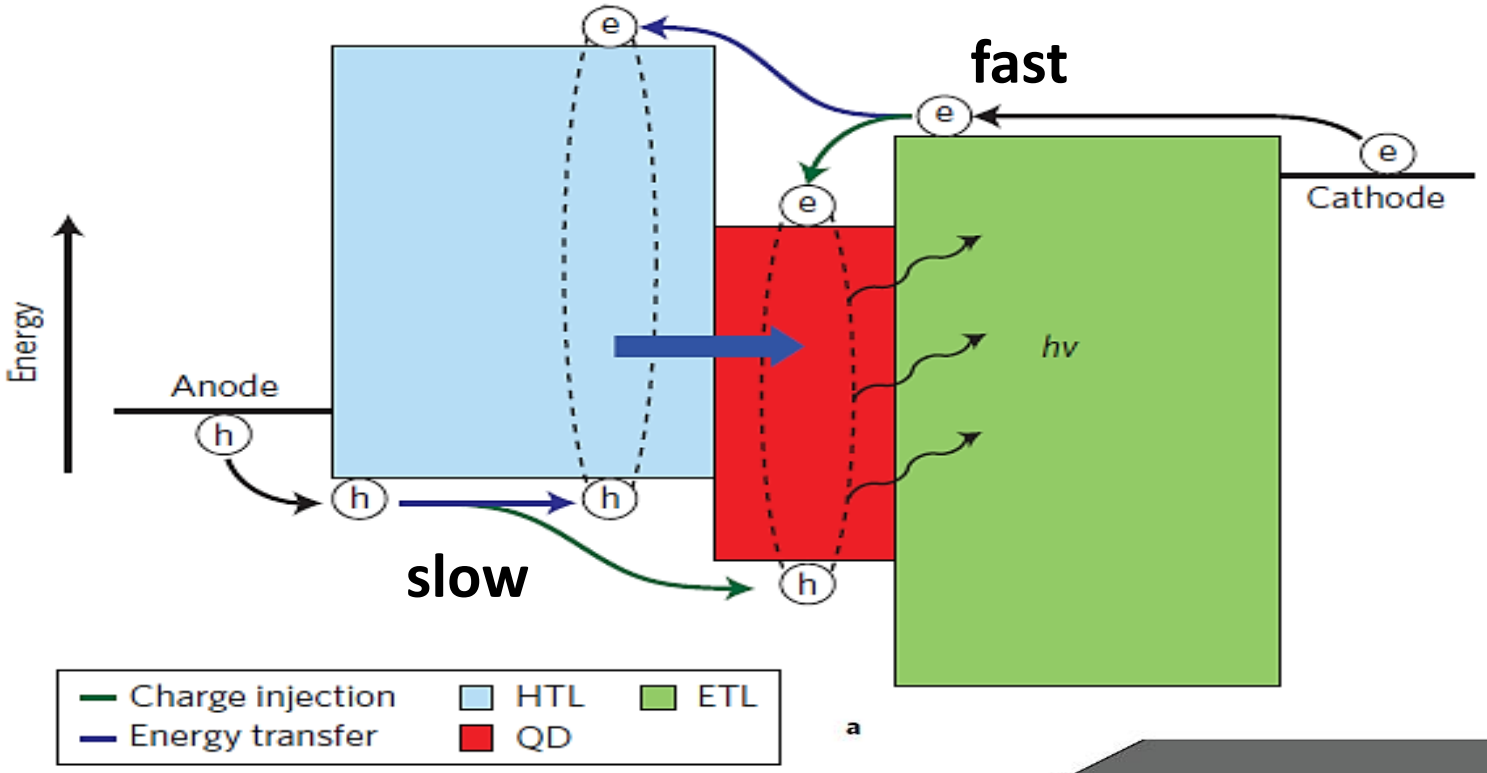
Application of Quantum Dots
Emphasis in QLED

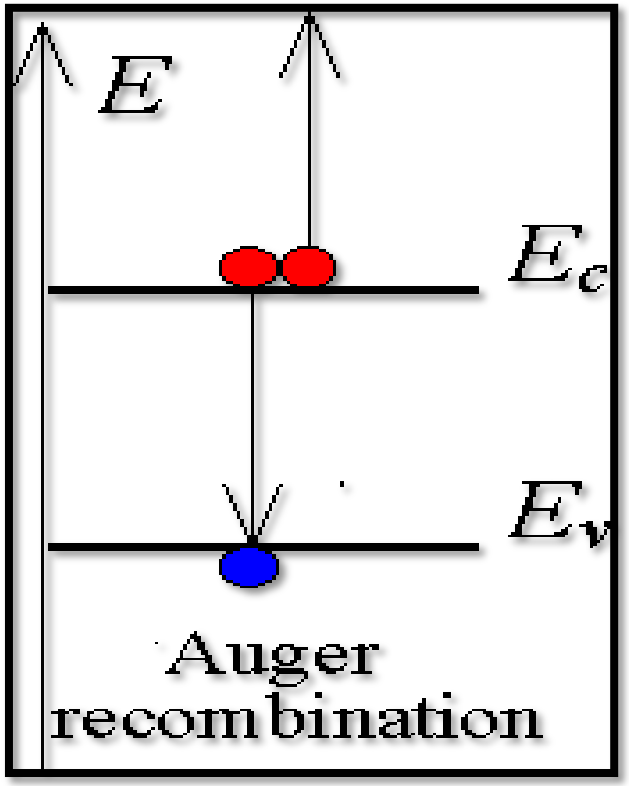


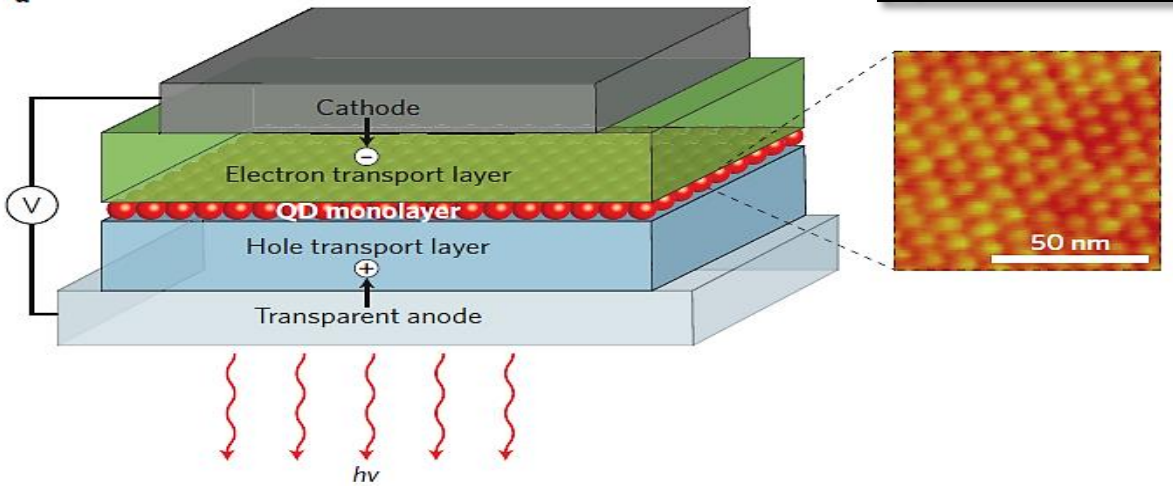
QD-LED

Quantum dot optic

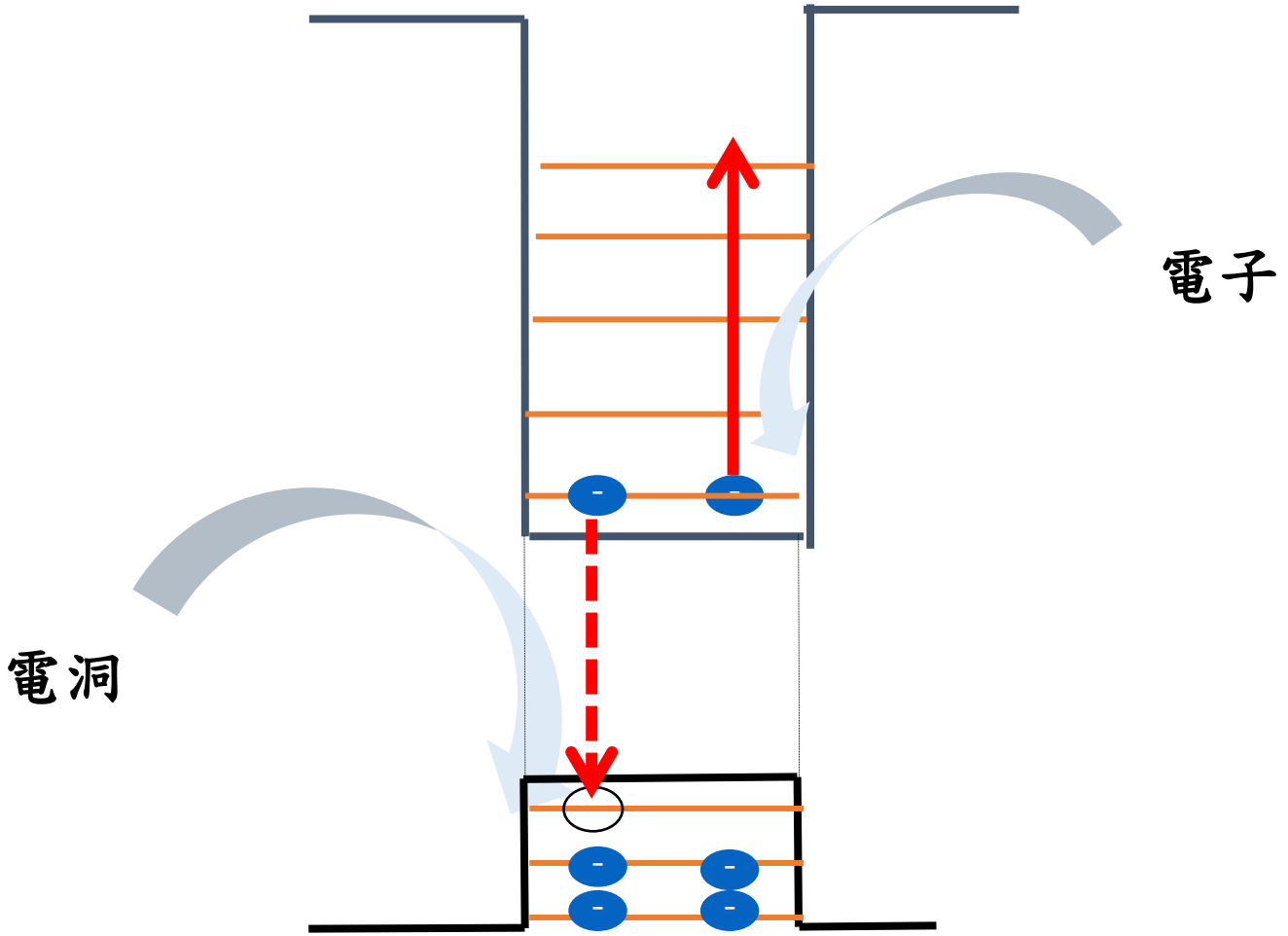
Hurdles in QD-LED: Auger Recombination, Instability (Oxygen, H_2O)







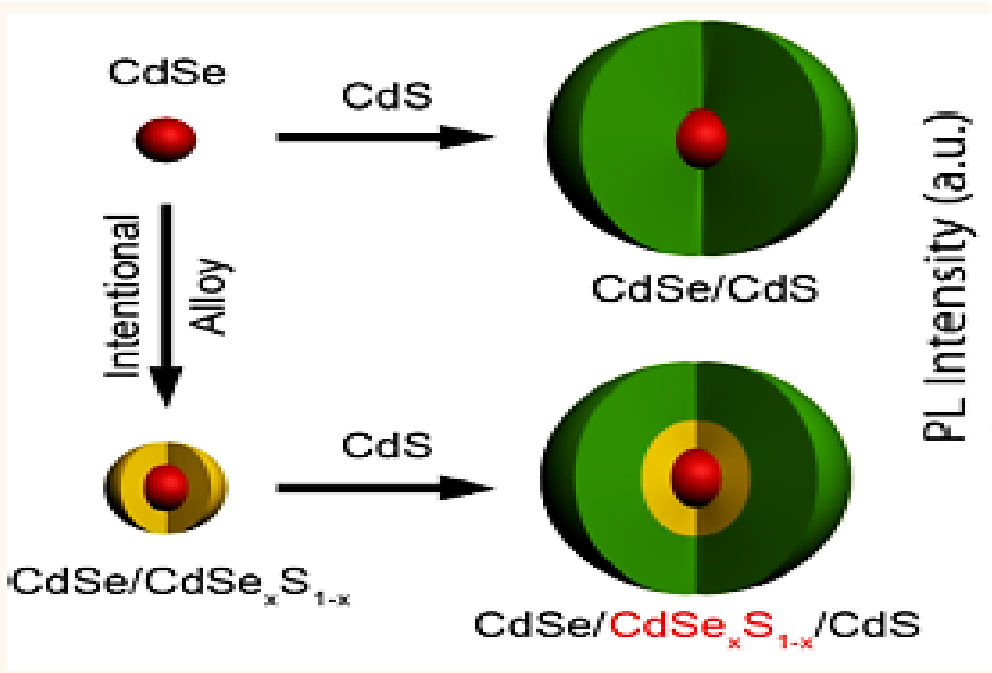
Another Auger Process: Auger Recombination

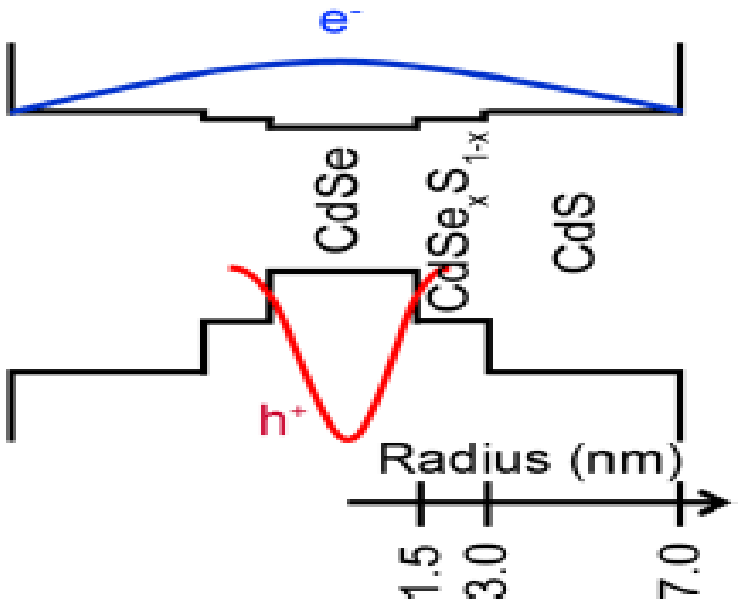


Retardation Factor for QLED

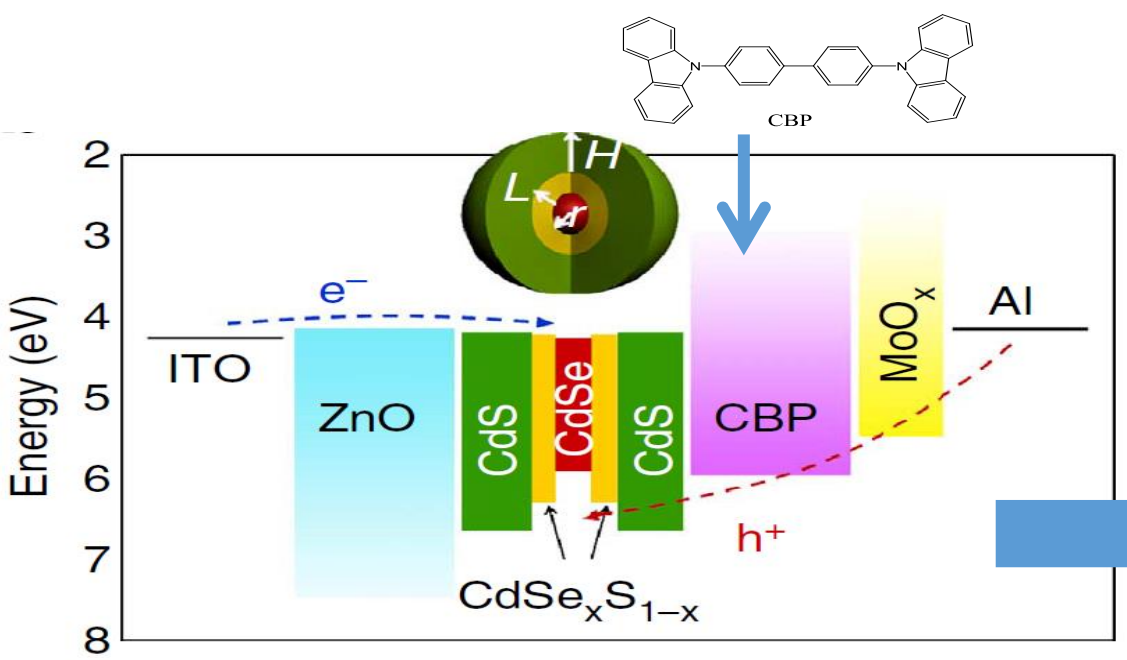
Controlled Alloying of the Core–Shell Interface in CdSe/CdS Quantum Dots for Suppression of Auger Recombination

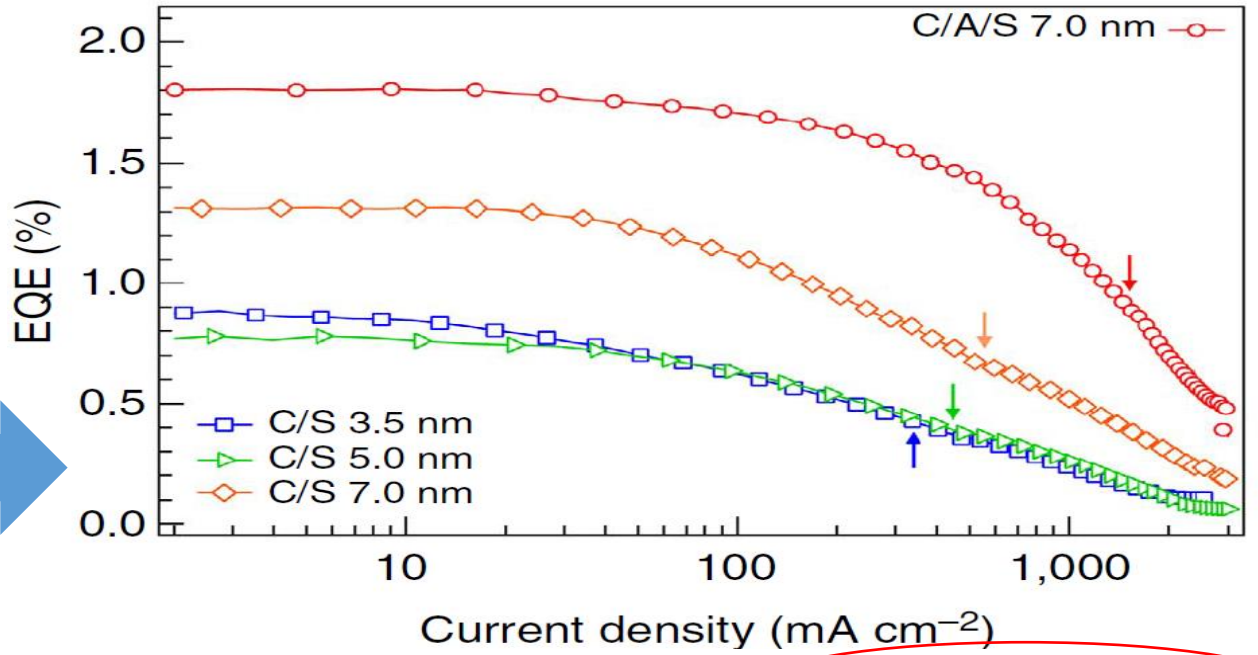
Wan Ki Bae,‡ Lazaro A. Padilha,‡ Young-Shin Park, Hunter McDaniel, Istvan Robel, Jeffrey M. Pietryga,* and Victor I. Klimov*

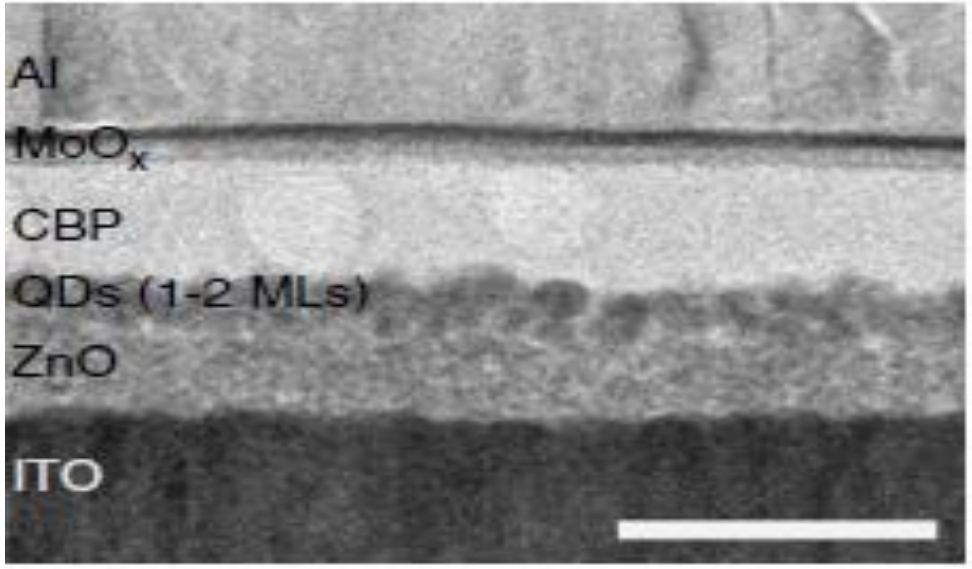


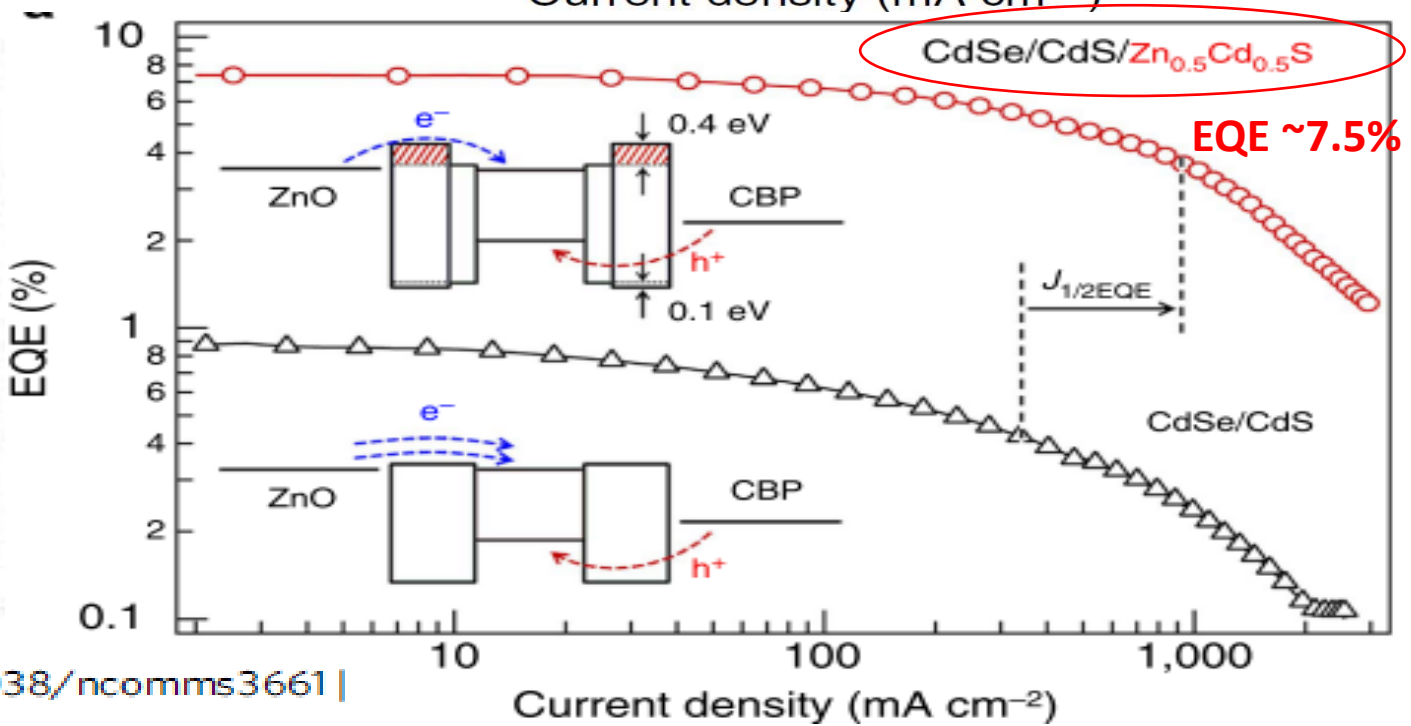


VOL. 7 ▪ NO. 4 ▪ 3411–3419 ▪ 2013 ACSNANO





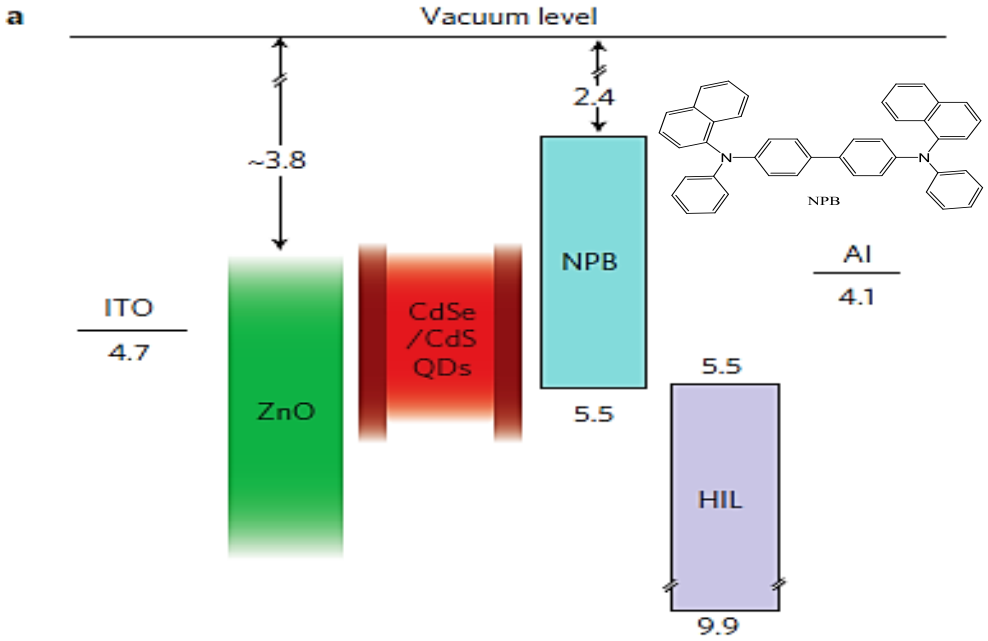


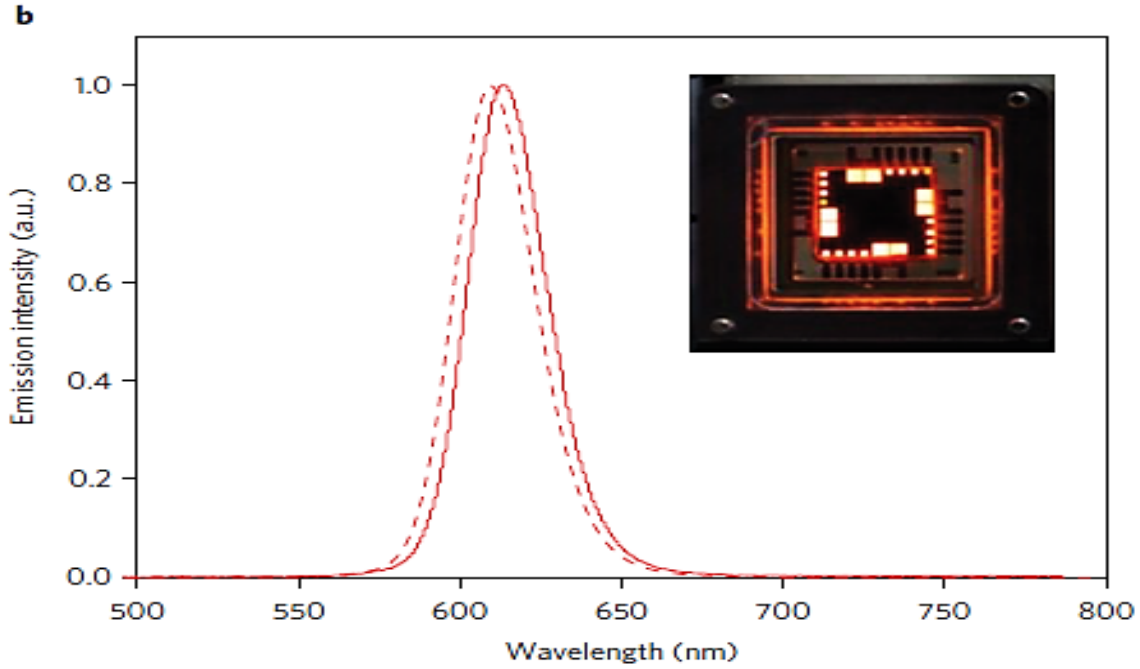


NATURE COMMUNICATIONS | 4:2661 | DOI: 10.1038/ncomms3661 |

High-efficiency quantum-dot light-emitting devices with enhanced charge injection

Benjamin S. Mashford[1], Matthew Stevenson[1], Zoran Popovic[1], Charles Hamilton[1], Zhaoqun Zhou[1], Craig Breen[1], Jonathan Steckel[1], Vladimir Bulovic[2], Moungi Bawendi[3], Seth Coe-Sullivan[1] and Peter T. Kazlas[1]*



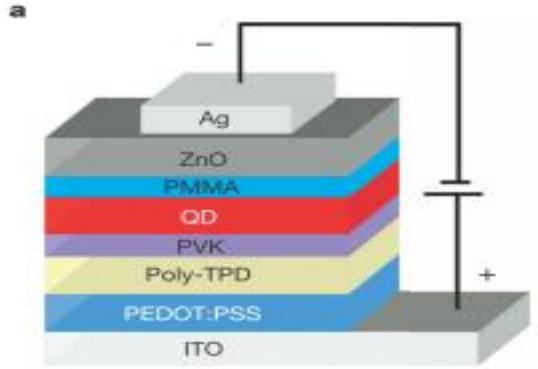


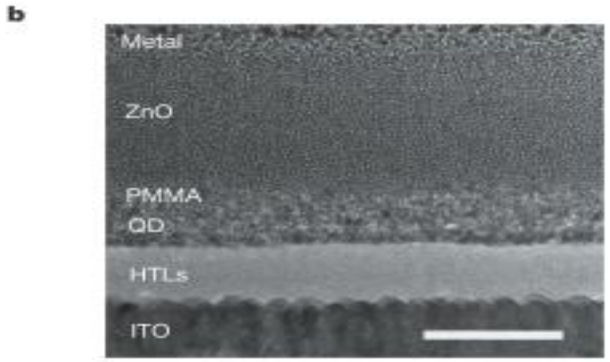
EQE=18%

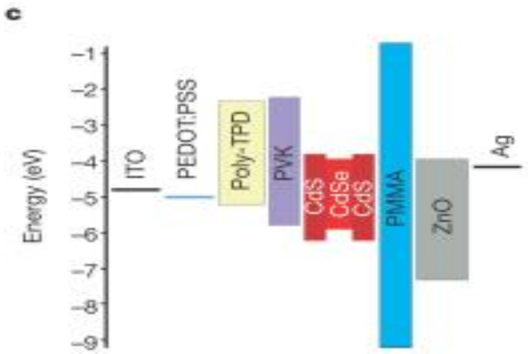
nature

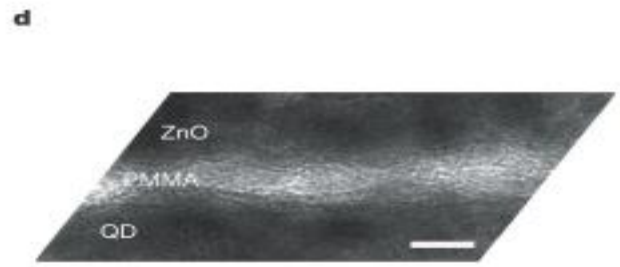
Solution-processed, high-performance light-emitting diodes based on quantum dots

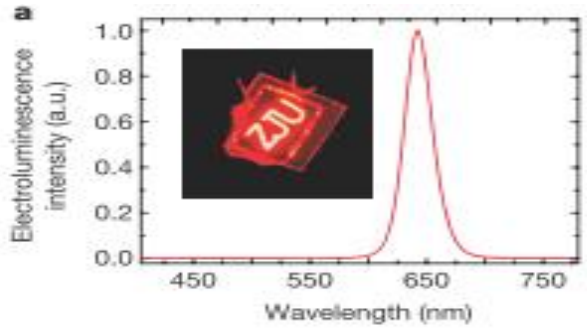
Xingliang Dai[1], Zhenxing Zhang[2], Yizheng Jin[1], Yuan Niu[2], Hujia Cao[2], Xiaoyong Liang[1], Liwei Chen[3], Jianpu Wang[4] & Xiaogang Peng[2]

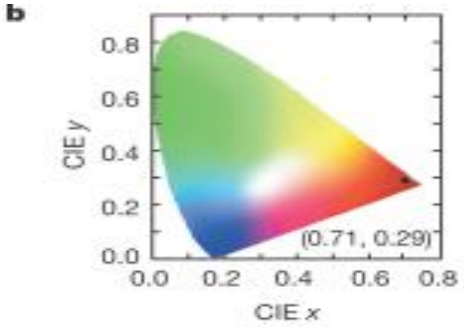


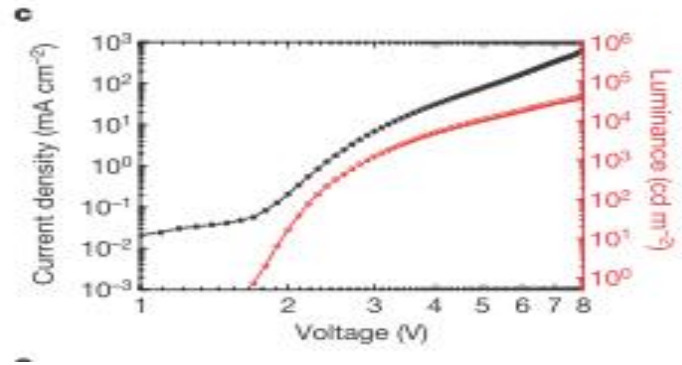


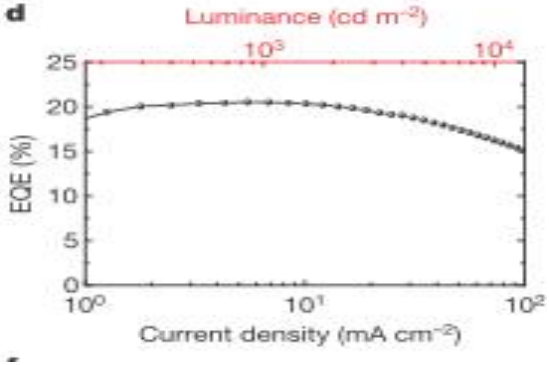








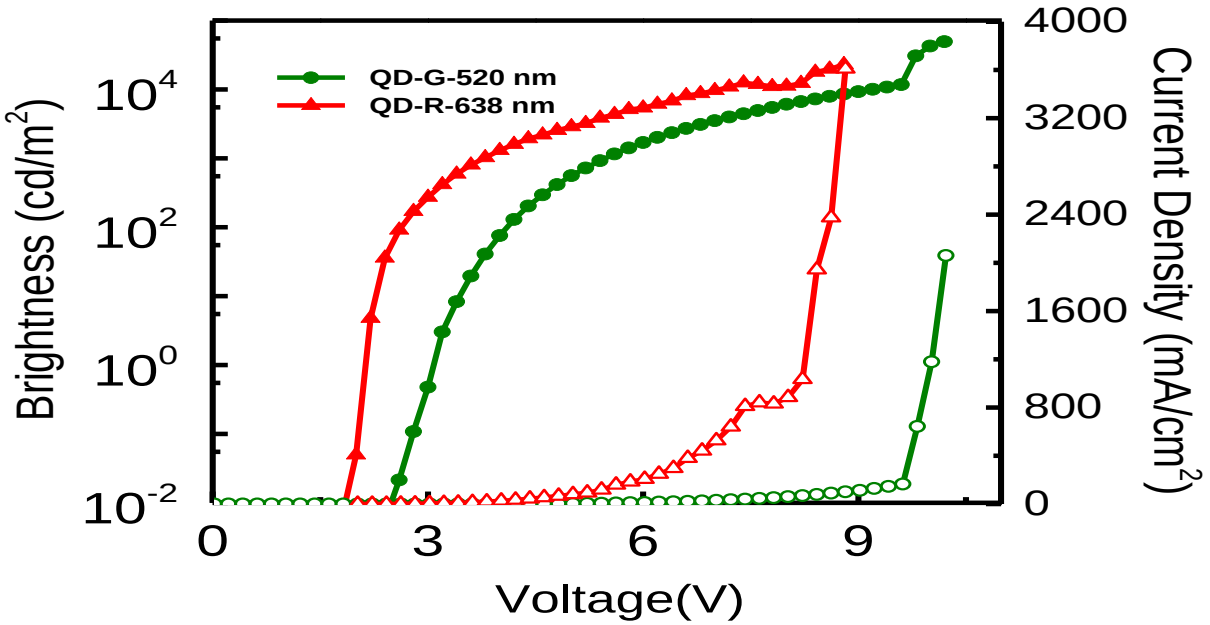


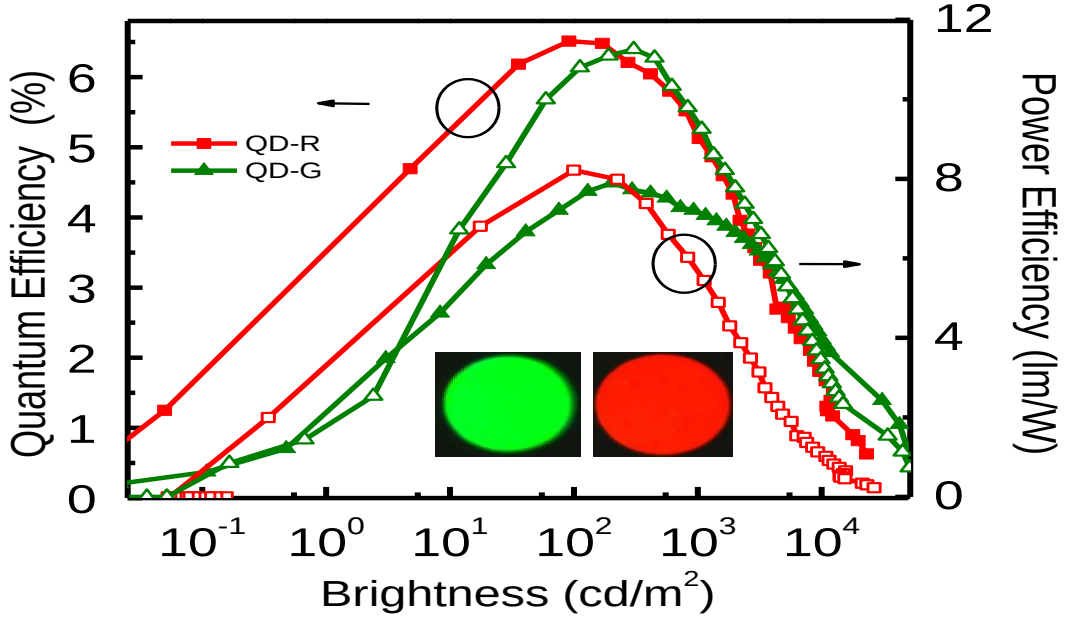


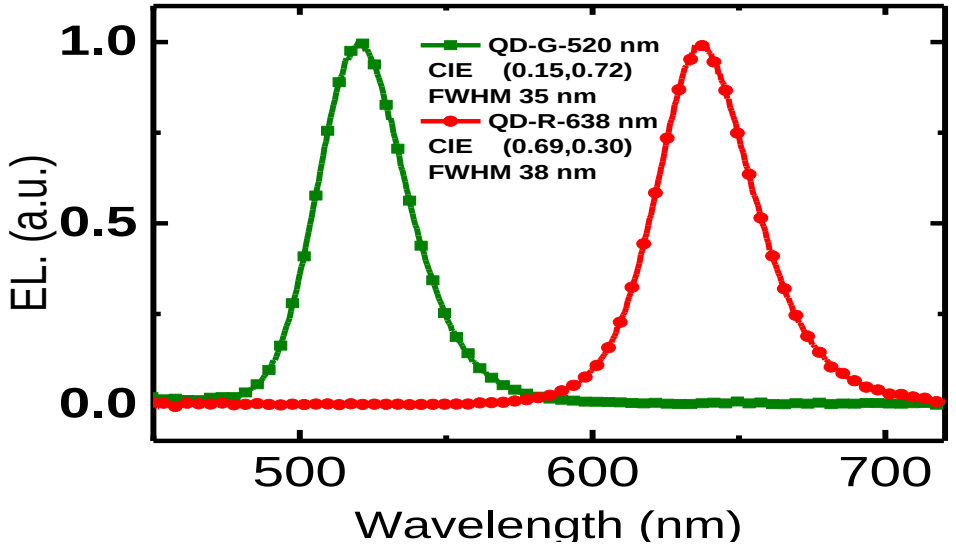
PMMA is prepared to be the electron transporting layer because of the balancing exciton and tunneling effect .

Nature 515, 96–99, 2014.

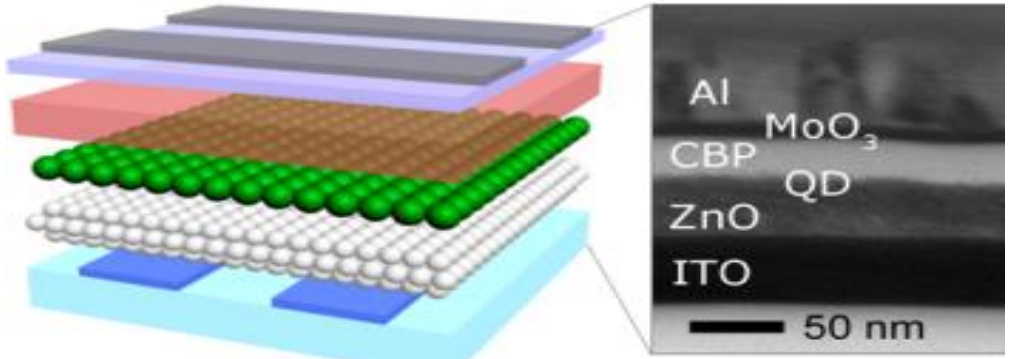
QD-LED Progress in My Lab



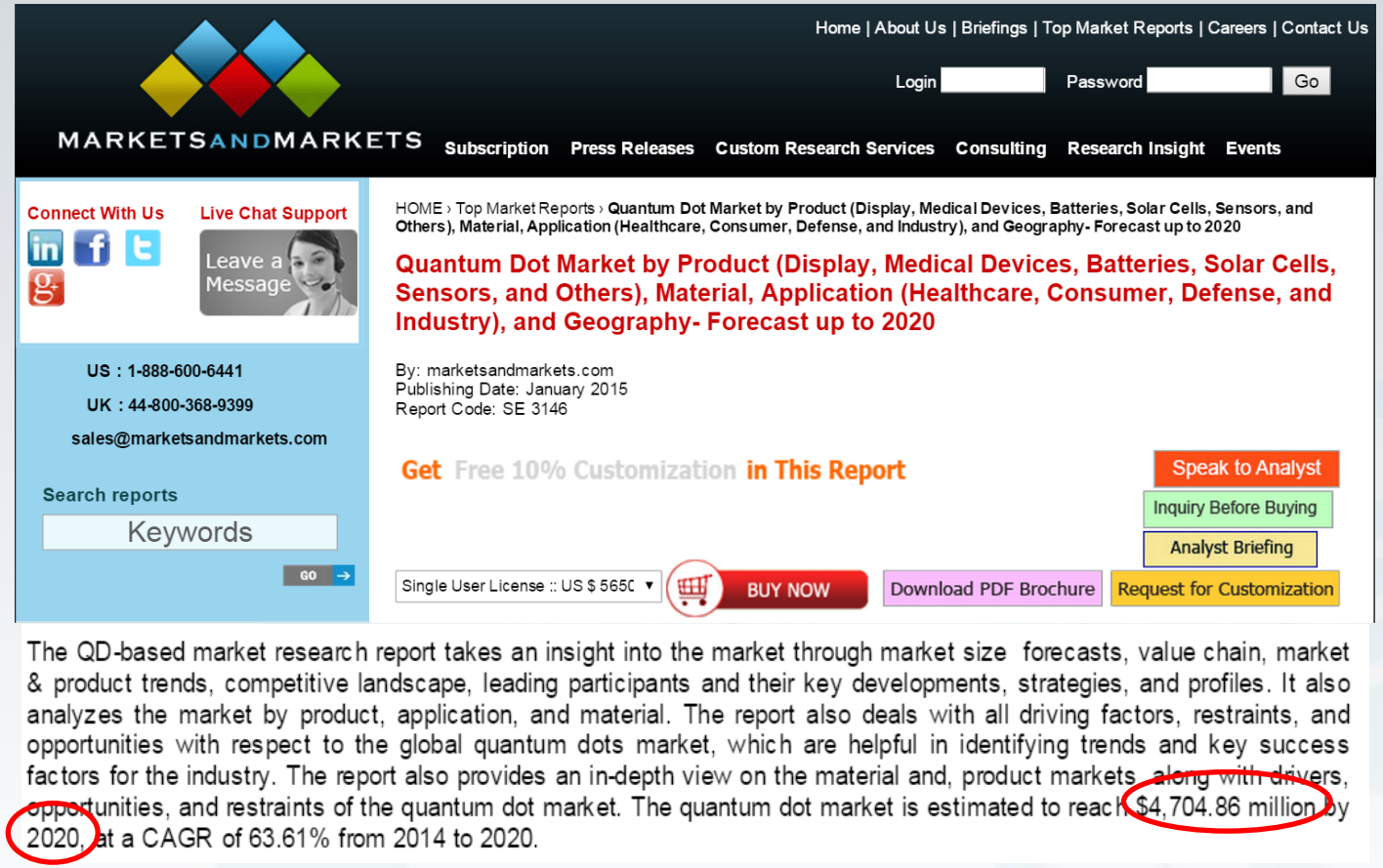




	V_{on} [V]	L_{max} [cd/m²]	I_{max} [mA/cm²]	η_{ext} max [%,cd/A]	η_p max [lm/W]	η at 1000 nit [%, V]
G-520 nm	2.6	49346 (10.2V)	2060.7	4.49%, 15.4	11.0	4.10%, 5.4
R-638 nm	2.0	23042 (8.8V)	3609.3	6.51%, 6.60	7.98	5.12%, 3.8



量子點相關材料未來市場預估



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Quantum Dot Market by Product (Display, Medical Devices, Batteries, Solar Cells, Sensors, and Others), Material, Application (Healthcare, Consumer, Defense, and Industry), and Geography- Forecast up to 2020

By: marketsandmarkets.com
Publishing Date: January 2015
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The QD-based market research report takes an insight into the market through market size forecasts, value chain, market & product trends, competitive landscape, leading participants and their key developments, strategies, and profiles. It also analyzes the market by product, application, and material. The report also deals with all driving factors, restraints, and opportunities with respect to the global quantum dots market, which are helpful in identifying trends and key success factors for the industry. The report also provides an in-depth view on the material and, product markets, along with drivers, opportunities, and restraints of the quantum dot market. The quantum dot market is estimated to reach $4,704.86 million by 2020, at a CAGR of 63.61% from 2014 to 2020.

2020 年 → 47 億美元 = 1500 億新台幣

Thank You for the Attenetion