Light-emitting diodes made from cadmium selenide nanocrystals and a semiconducting polymer.

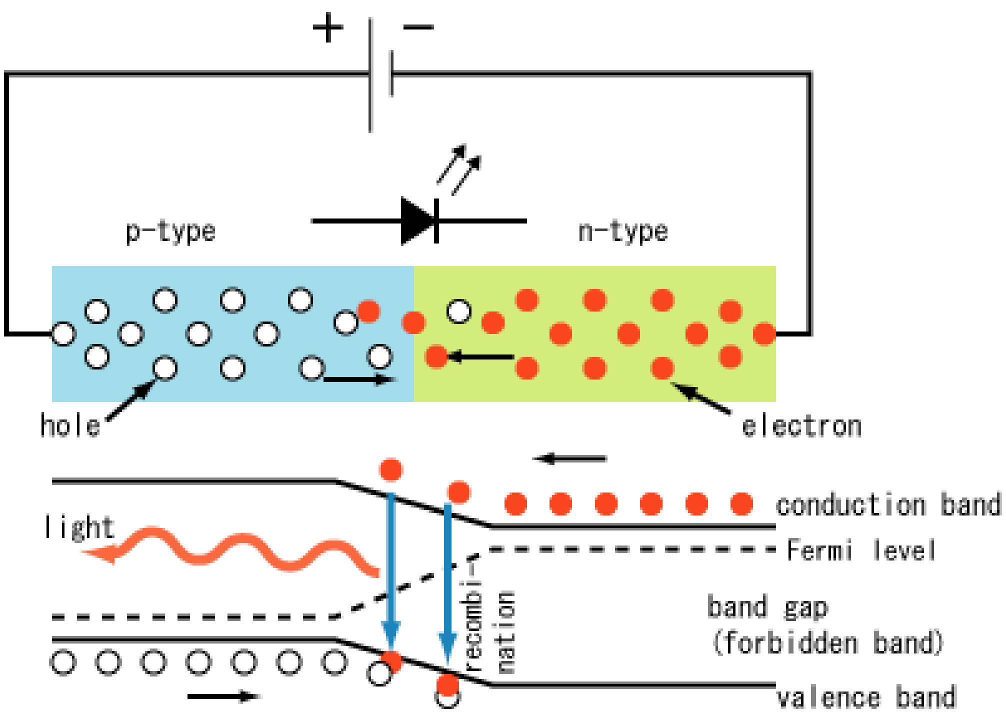
Colvin, V., Schlamp, M. & Alivisatos, A.

Nature **1994**, 370, 354–357.

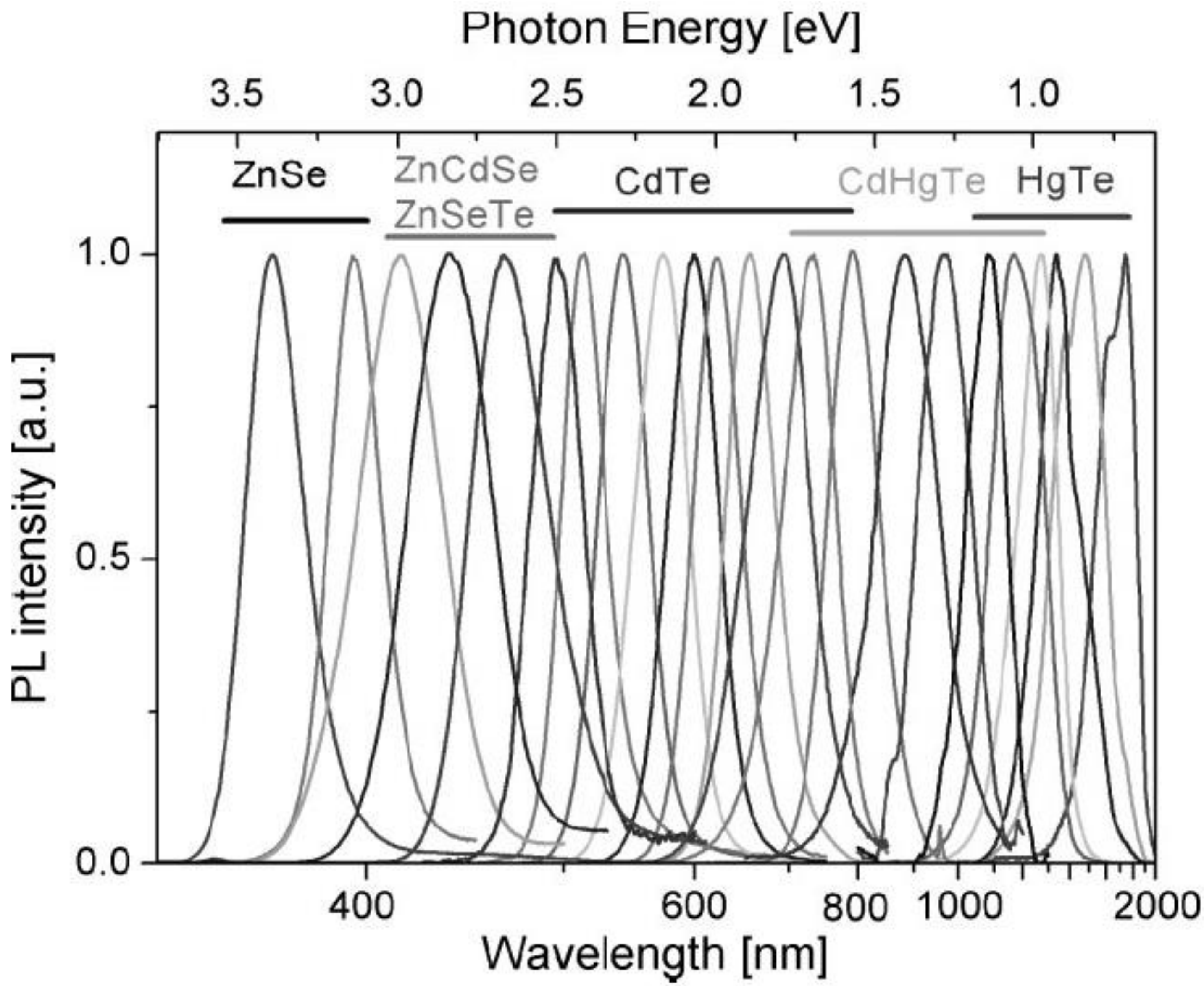
- Hybrid organic/inorganic electroluminescent device: CdSe QDs/PPV (p-paraphenylene vinylene)
- Electrons in CdSe QDs; holes in PPV
- Color can be varied from red to yellow by changing QD size.
- Narrow photoluminescence full-width at half-maximum (FWHM) of less than 30 nm motivated the creation of hybrid organic/inorganic LEDs containing QDs

Light Emitting Diodes (LED)

The LED is based on the semiconductor diode. When a diode is forward biased (switched on), electrons are able to recombine with holes within the device, releasing energy in the form of photons. This effect is called electroluminescence and the color of the light (corresponding to the energy of the photon) is determined by the energy gap of the semiconductor.



http://en.wikipedia.org/wiki/Light_Emitting_Diodes

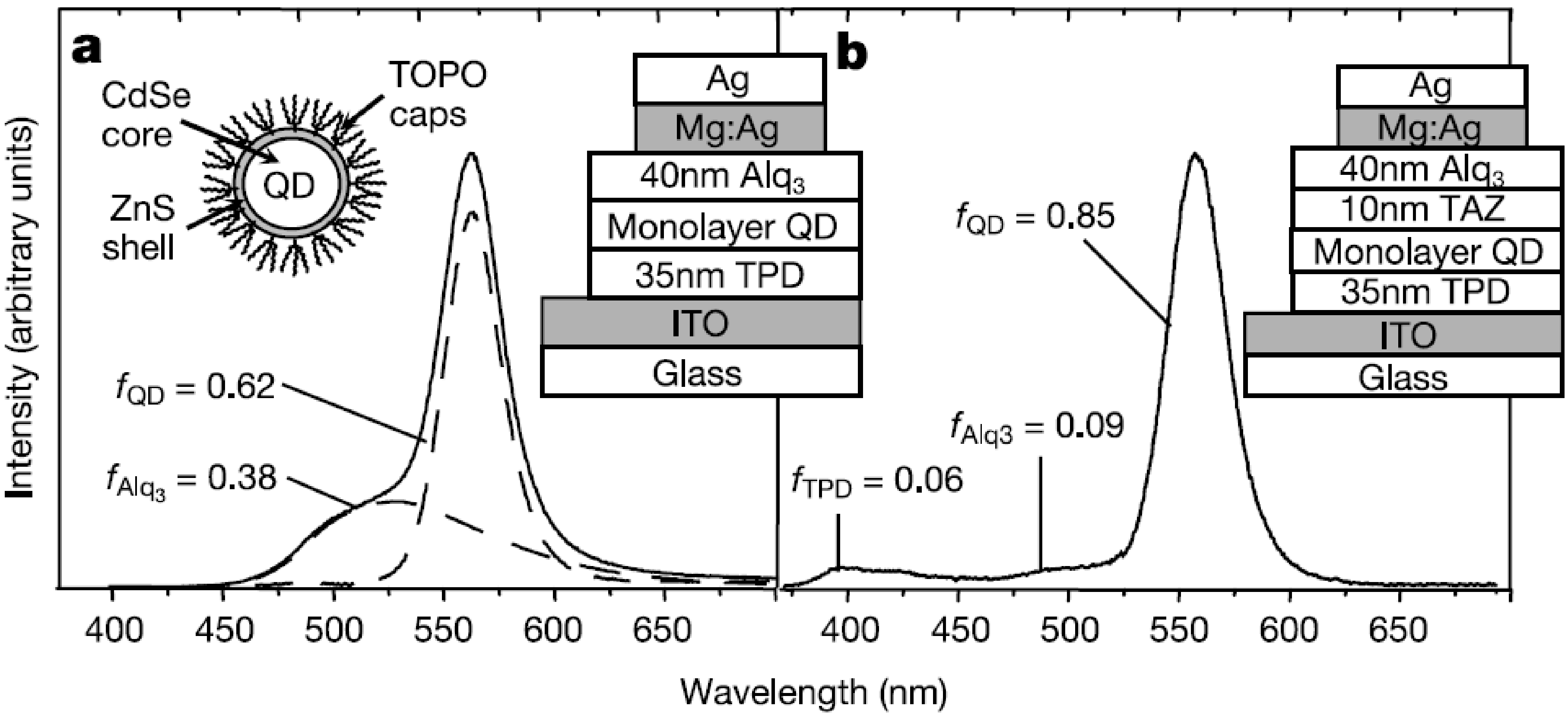


Progress in the Light Emission of Colloidal Semiconductor Nanocrystals
Alexander Eychmüller*, *Small* **2010**, 10, 1364.

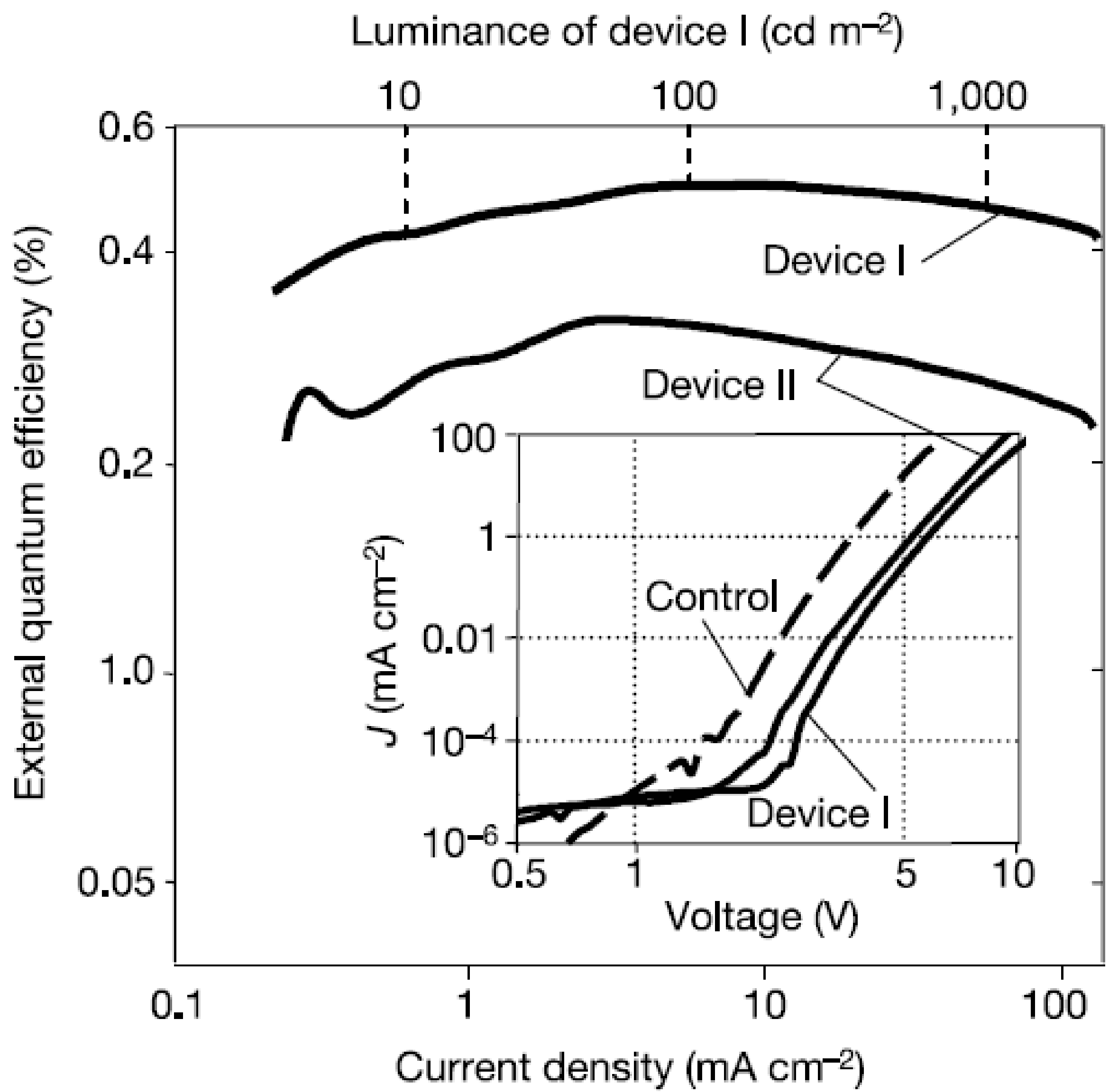
Electroluminescence from single monolayers of nanocrystals in Molecular organic devices

Bawendi, *Nature.* **2002**, 420, 800.

- Hybrid light-emitting diode (LED) that combines the ease of processability of organic materials with the narrow-band, efficient luminescence of colloidal quantum dots (QDs).
- To isolate the luminescence processes from charge conduction, they fabricate a quantum-dot LED (QD-LED) that contains only a single monolayer of QDs, sandwiched between two organic thin films.
- Solution photoluminescence quantum efficiencies of QDs can exceed 50%, and by controlling the QD diameter during synthesis, the peak emission wavelength can be tuned continuously from 470 nm to 630 nm.
- In the devices, where QDs function exclusively as lumophores, a 25-fold improvement in luminescence efficiency (1.6 cdA^{-1} at 2,000 cdm^{-2}) over the best previous QD-LED results.


a
CdSe
core
TOPO
caps
QD
ZnS
shell
Ag
Mg:Ag
40nm Alq3
Monolayer QD
35nm TPD
ITO
Glass
fQD = 0.62
fAlq3 = 0.38
b
Ag
Mg:Ag
40nm Alq3
10nm TAZ
Monolayer QD
35nm TPD
ITO
Glass
fQD = 0.85
fAlq3 = 0.09
fTPD = 0.06
Intensity (arbitrary units)
400
450
500
550
600
650
Wavelength (nm)

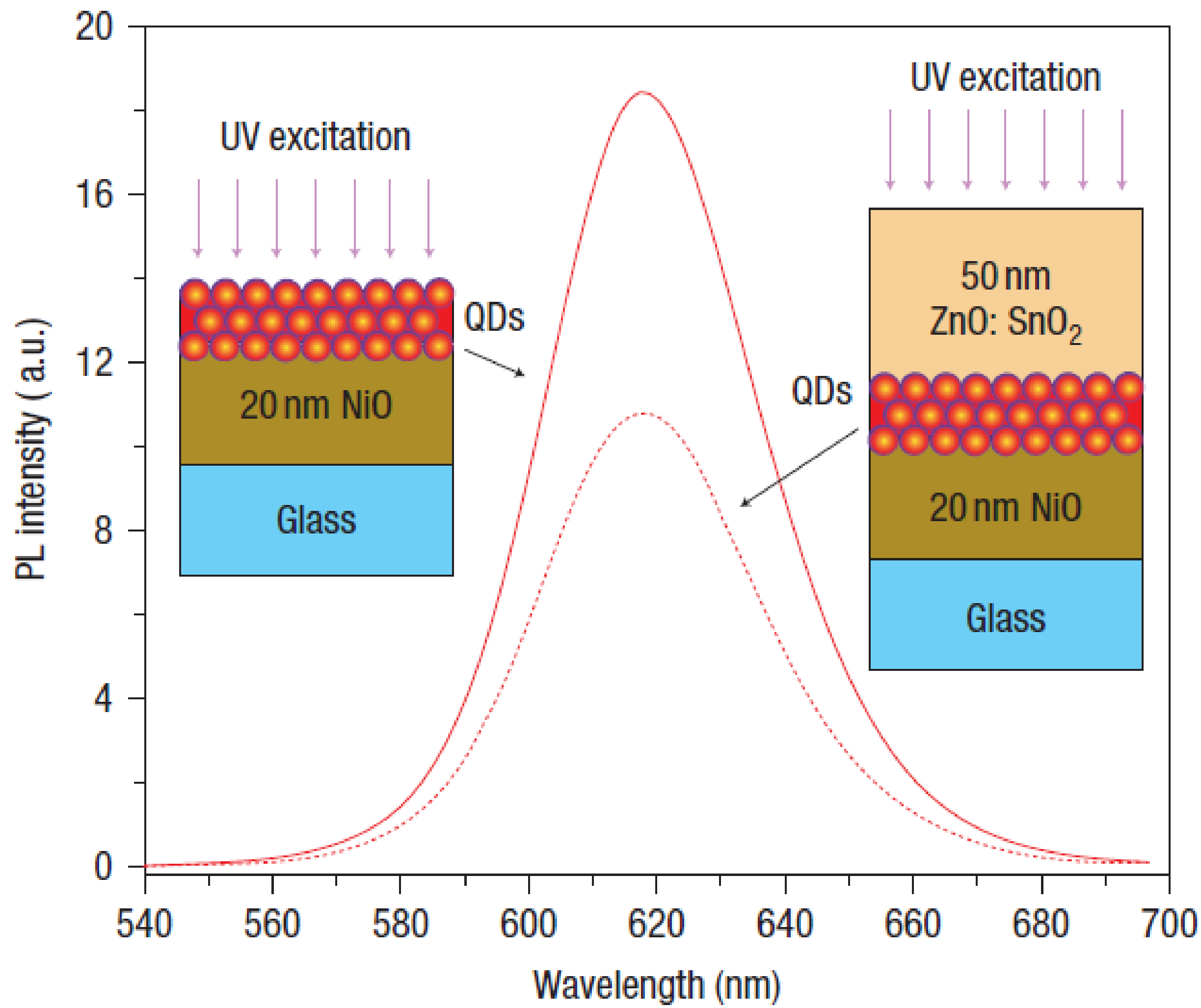
The peak efficiency of device I is $\eta = 0.52\%$ at 10 mA cm^{-2} and 6.6 V, which corresponds to a luminance of 190 cdm^{-2}.



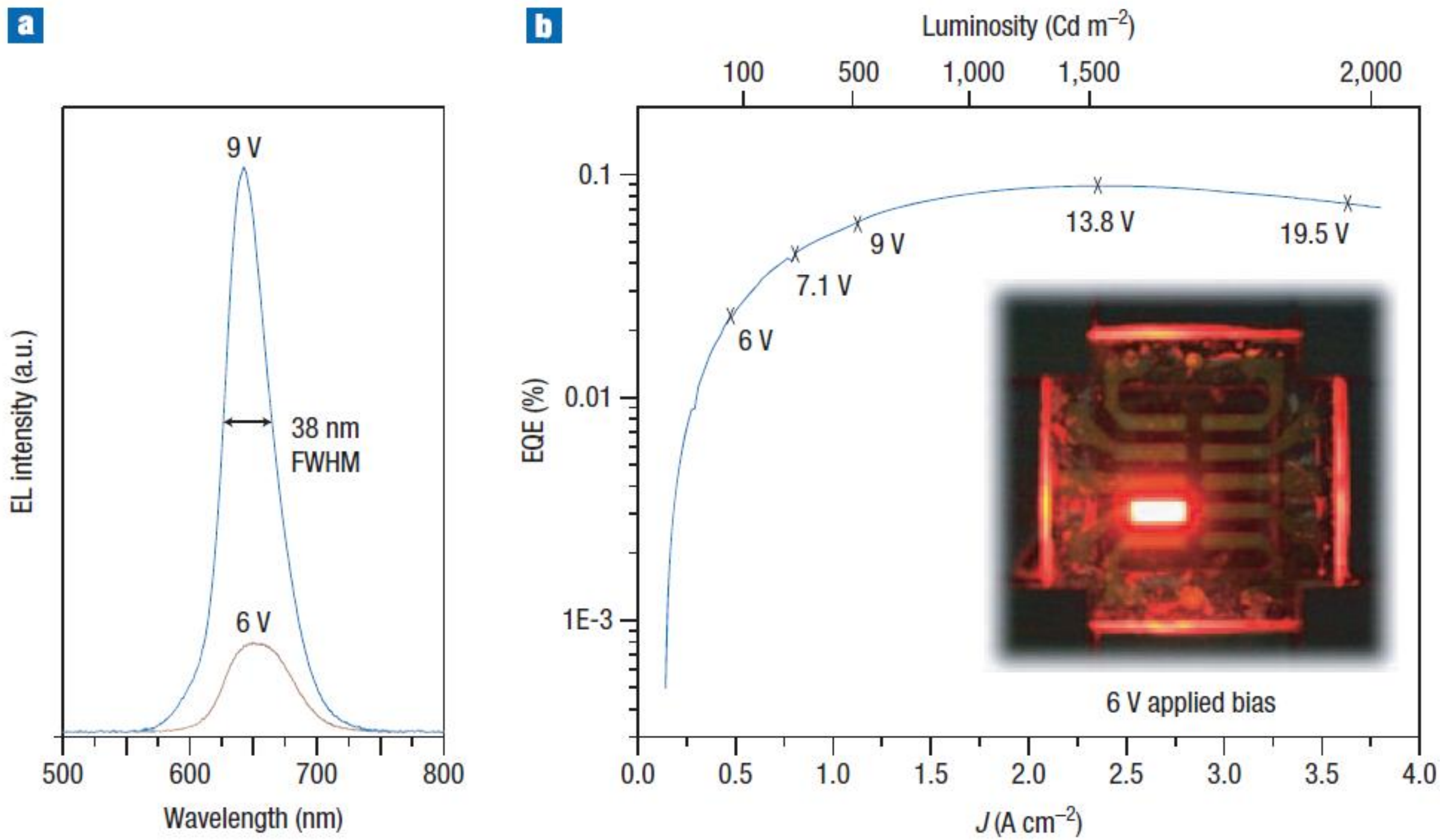
Colloidal quantum-dot light-emitting diodes with metal-oxide charge transport layers

Bulovic and Bawendi, *Nature Photonics* **2008**, 2, 34.

- Colloidal quantum dots are uniquely suited for use as lumophores in light emitting devices.
- To be a viable platform for colour-tunable electrically pumped lasers, the present-generation quantum-dot LEDs must be modified to withstand the extended, high-current-density operation needed to achieve population inversion.
- This requirement necessitates a quantum-dot LED design that incorporates robust charge transport layers.



Use amorphous, radiofrequency (RF)-sputtered metal oxides as QD-LED charge transport layers, deposited at room temperature to be broadly compatible with colloidal QDs and many other films.



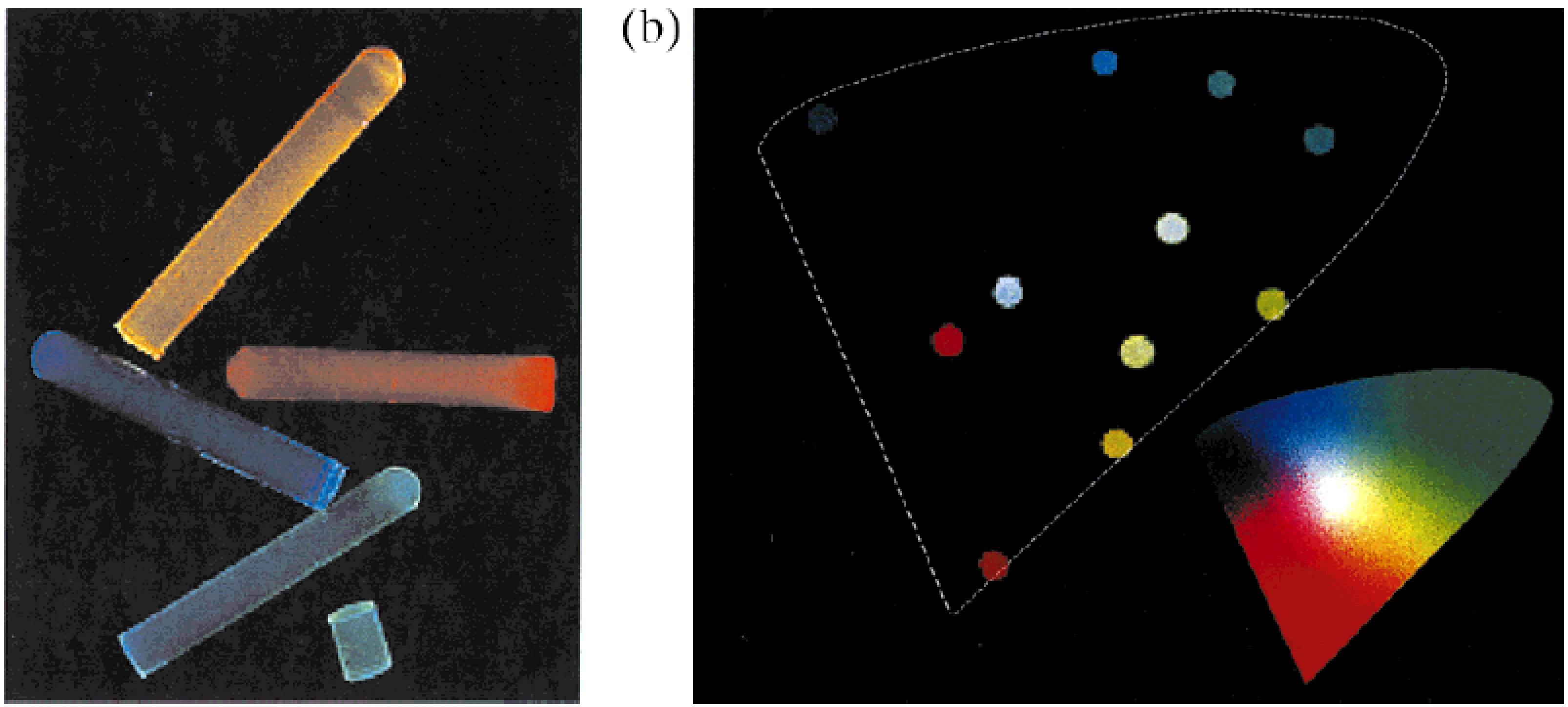
Use of sputtered, amorphous inorganic semiconductors as robust charge transport layers and demonstrate devices capable of operating at current densities exceeding 3.5 A cm-2 with peak brightness of 1,950 Cd m-2 and maximum external electroluminescence efficiency of nearly 0.1%, which represents a 100-fold improvement over previously reported structures.

Full color emission from II-VI semiconductor quantum dot-polymer composites,

Bawendi, *Adv. Mater.* **2000**, 12, 1102.

II-VI QDs mixed with Polyaurylmethacrylate (PLMA)

(a) (b)



Quantum Yields

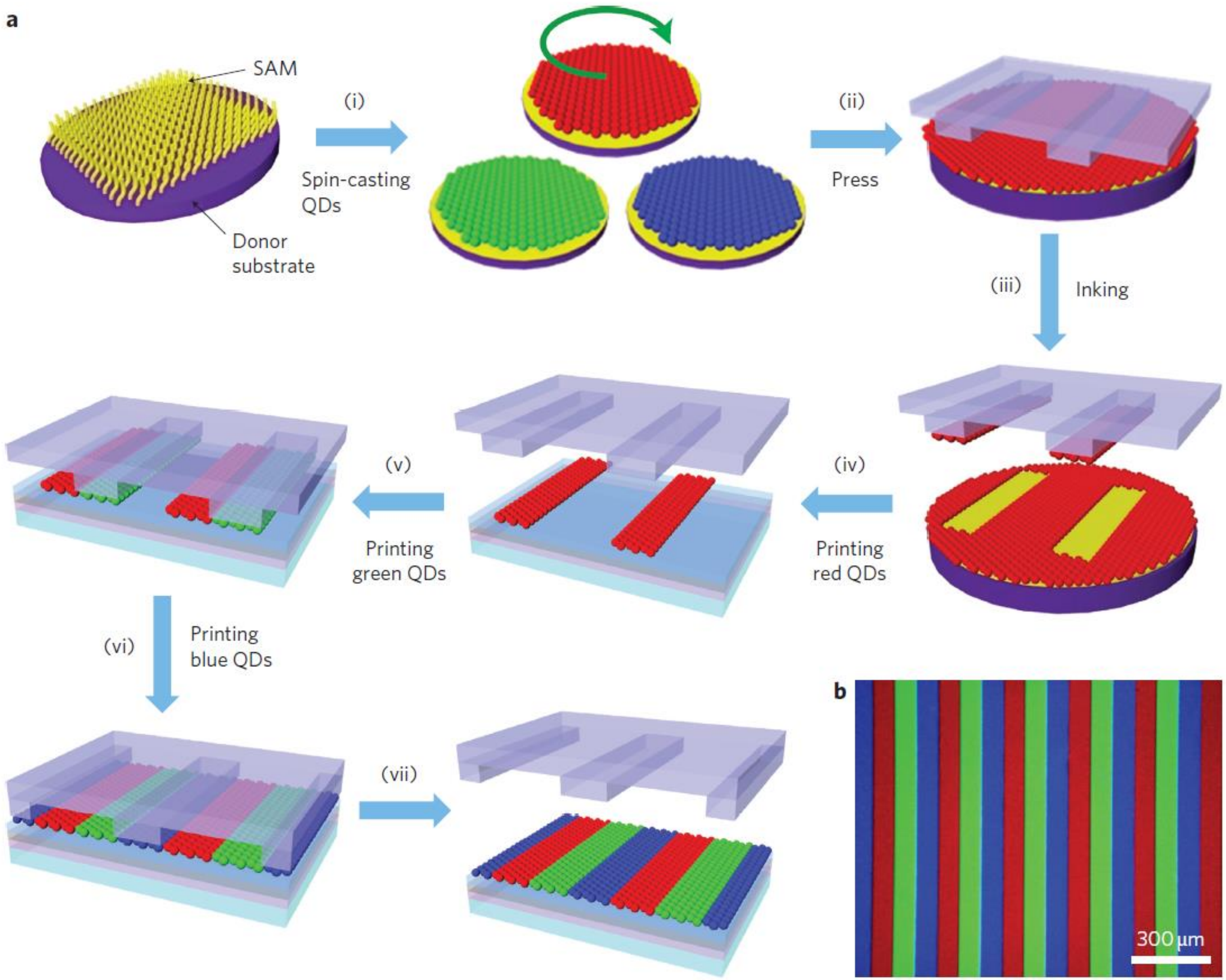
Core radius [a]	In dilute solution [%] [b]	In polymer matrix [%] [c]
28 Å	27	22
23 Å	30	24
13 Å	49	40
10 Å	36	30

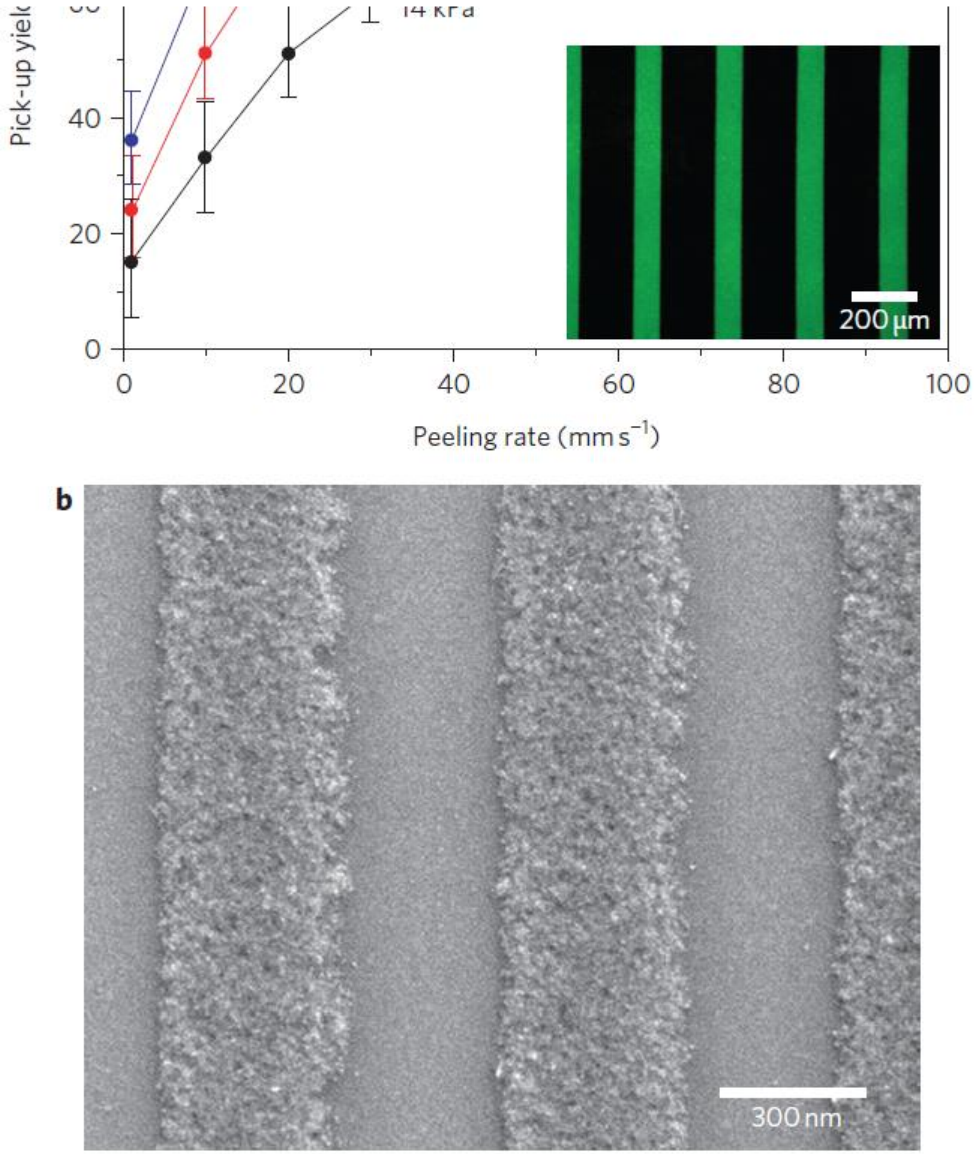
Full-colour quantum dot displays fabricated by transfer printing

JY Choi and JM Kim, *Nature Photonics* **2011**, 5, 176.

- High quantum yields, extremely narrow emission, spectral tunability and high stability.
- large-area, full-colour quantum dot display, including in flexible form
- solvent-free transfer of quantum dot films and the compact structure of the quantum dot networks → Printed quantum dot films exhibit excellent morphology, well-ordered quantum dot structure and clearly defined interfaces.

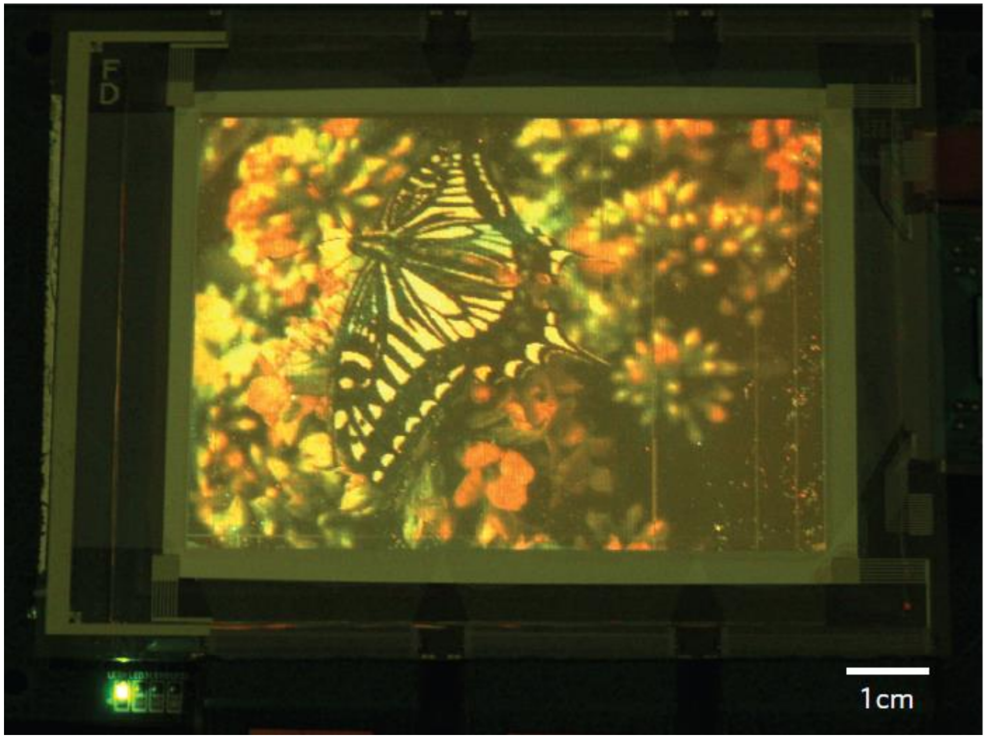
Transfer process



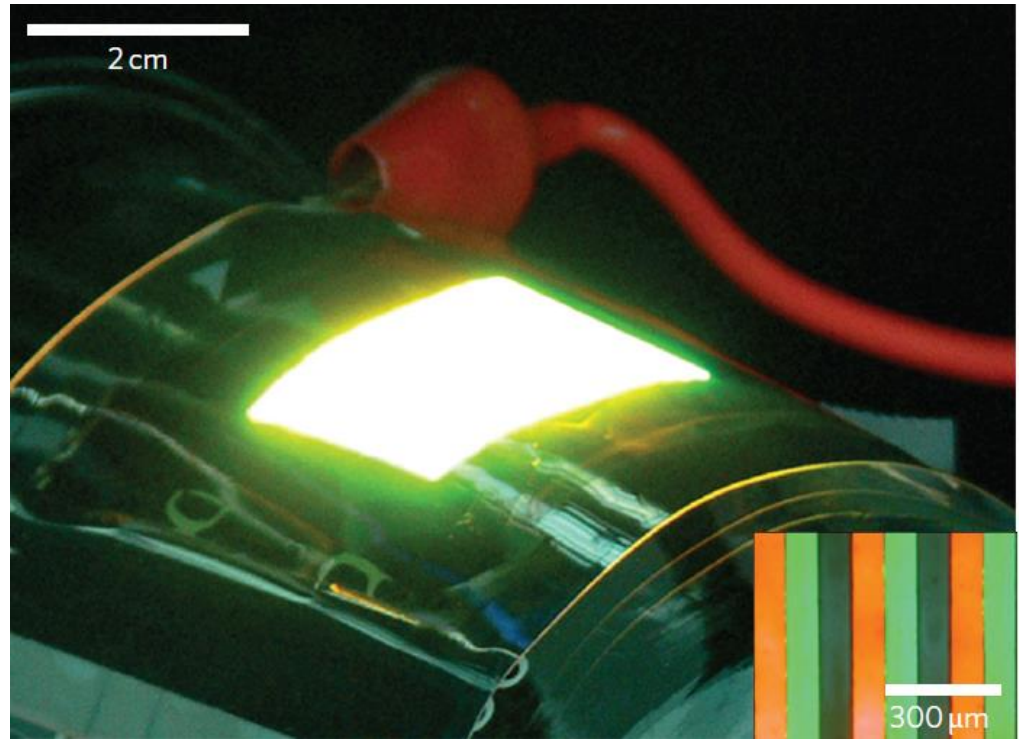


Electroluminescence peak for the printed red, green and blue QDLED are 615, 530 and 480 nm.

Full-colour QD display and its flexible form



QD display with a resolution of 320× 240 pixels



RGB-patterned flexible QD devices ITO/polyethylene naphthalate (PEN)

SAIT, *Nature Photonics* **2011**, 5, 176.

Hybrid Nanorod-Polymer Solar Cells

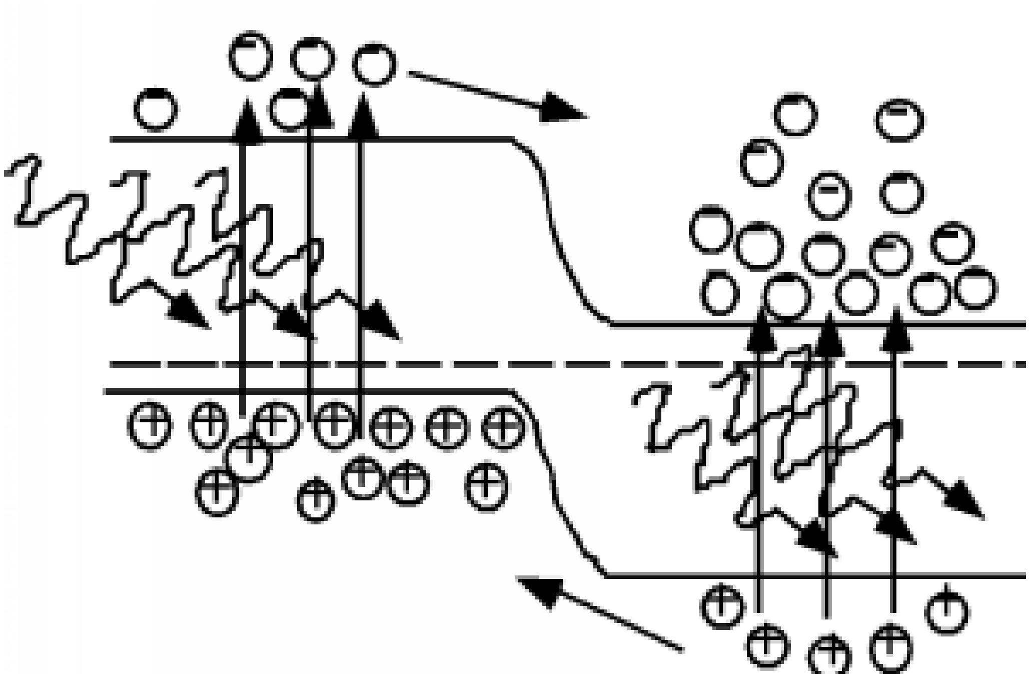
Wendy U. Huynh, Janke J. Dittmer, A. Paul Alivisatos*

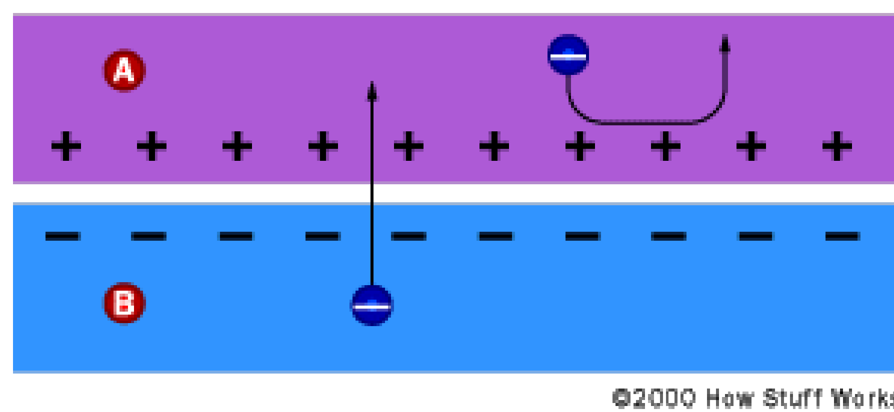
Science **2002**, 295, 2425

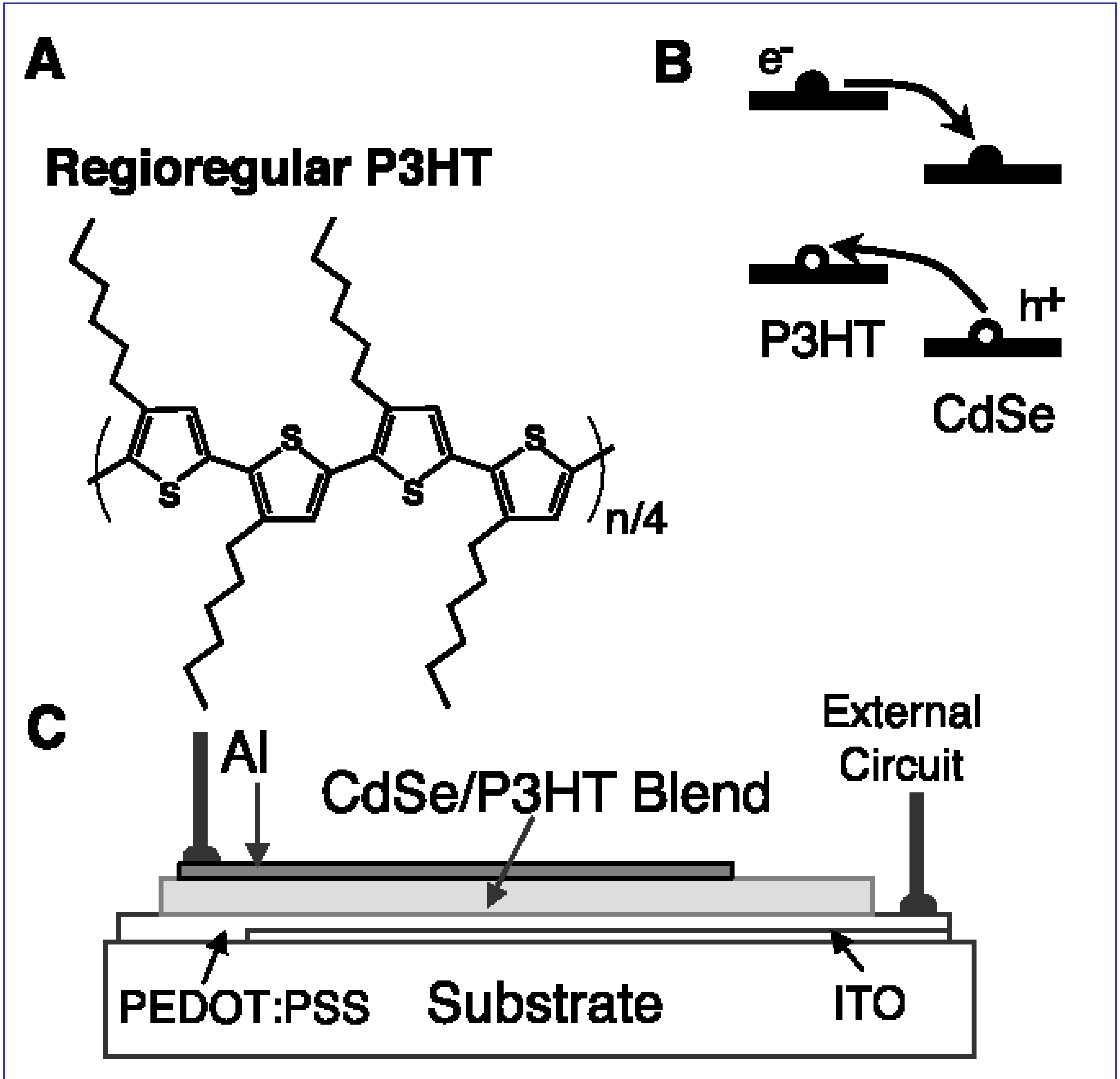
Demonstrate that semiconductor nanorods can be used to fabricate readily processed and efficient hybrid solar cells together with polymers. By controlling nanorod length, they can change the distance on which electrons are transported directly through the thin film device.

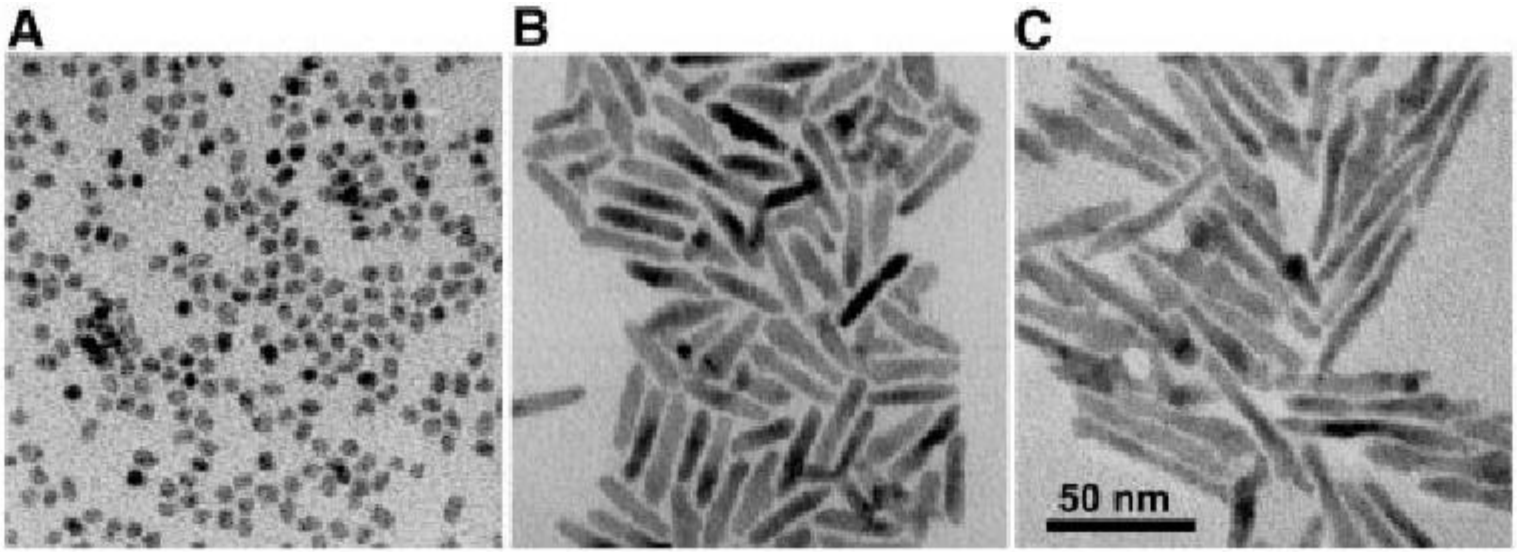
Photovoltalic cell for solar energy conversion

- Photovoltalic cell: Light with λ> band gap → promotion of electrons to conduction band→ attracted to positively charged n-type holes to p-type→ formation of separate electron-hole pair→ electron travel through n-type and produce current.






A
Regioregular P3HT
S
S
S
S
n/4
B
e⁻
h+
P3HT
CdSe
C
Al
CdSe/P3HT Blend
External
Circuit
PEDOT:PSS
Substrate
ITO



Cadmium selenide nanocrystals with aspect ratios ranging from 1 to 10. The samples, (**A**) 7 nm by 7 nm, (**B**) 7 nm by 30 nm, and (**C**) 7 nm by 60 nm.

- Tuning the band gap by altering the nanorod radius enabled us to optimize the overlap between the absorption spectrum of the cell and the solar emission spectrum.
- A photovoltaic device consisting of 7-nanometer by 60-nanometer CdSe nanorods and the conjugated polymer poly-3(hexylthiophene) was assembled from solution with an external quantum efficiency of over 54% and a monochromatic power conversion efficiency of 6.9% under 0.1 milliwatt per square centimeter illumination at 515 nanometers.
- Under Air Mass (A.M.) 1.5 Global solar conditions, we obtained a power conversion efficiency of 1.7%.

For more information on QD-solar cells,
Please refer to *Chem. Rev*. **2014**, 114, 863
By Illan J. Kramer and Edward H. Sargent