ZnO nanowire based solar cells

Eray S. Aydil

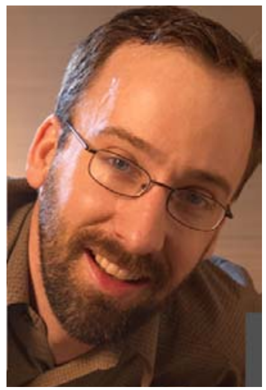
Chemical Engineering and Materials Science Department

Acknowledgements: National Science Foundation NIRT Program
Minnesota Initiative for Renewable Energy and the Environment (IREE)

Janice Boercker

Kurtis Leschkies

Dr. Joysurya Basu



Prof. David Norris

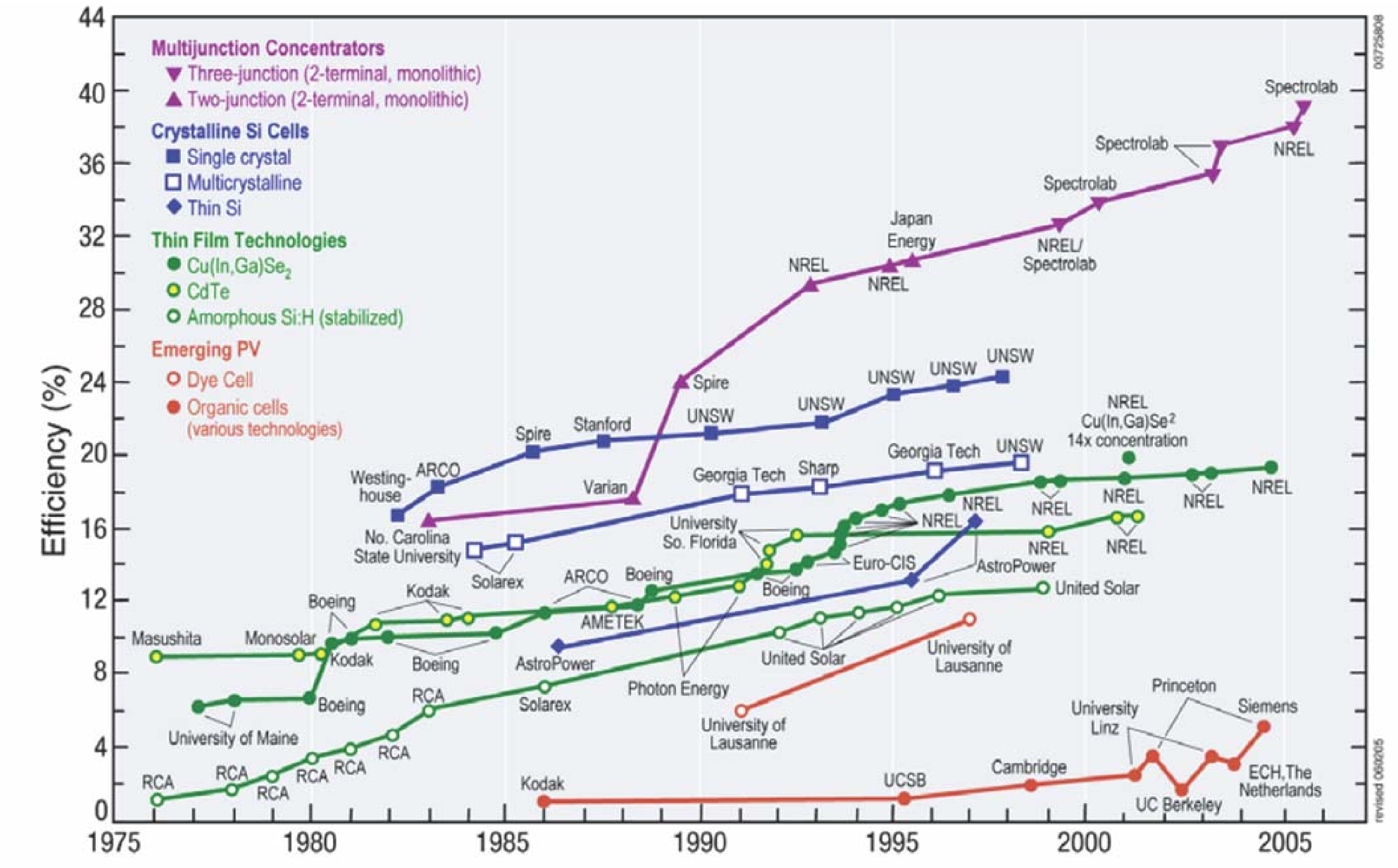
Prof. C. Barry Carter

Emil Enache-Pommer

Prof. Uwe Kortshagen

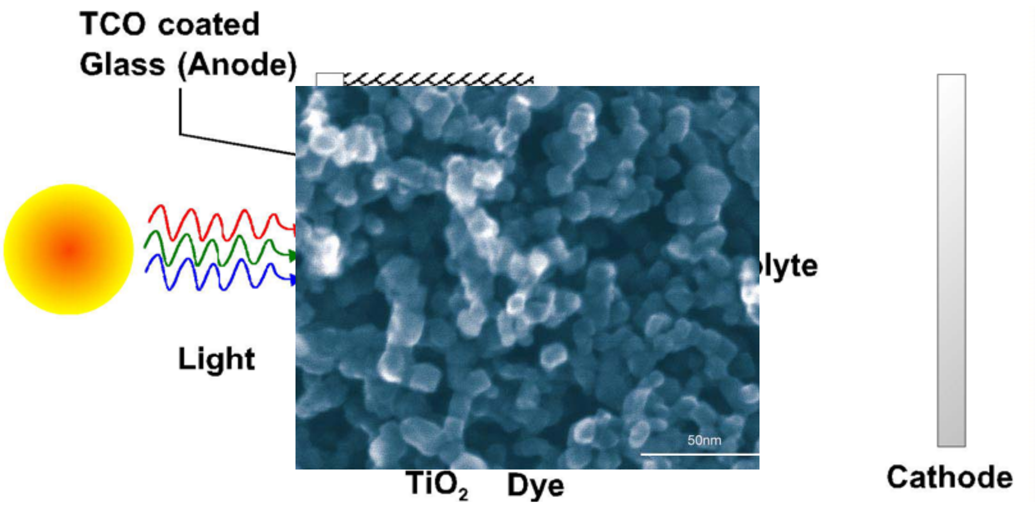
Dr. Divakar Ramachandran

State-of-the-art in solar cells



United States Department of Energy Report on the Basic Energy Sciences Workshop on Solar Energy Utilization by N. S. Lewis et al. (2005) and from *J. Crystal Growth* 275, 292 (2005) by T. Surek.

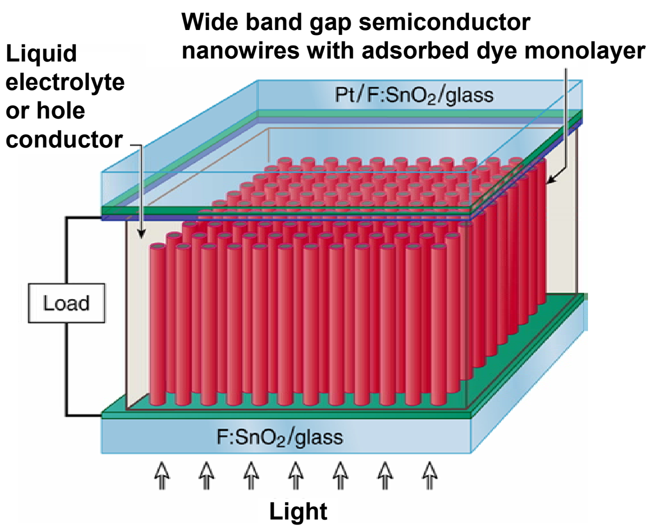
Dye Sensitized Solar Cells



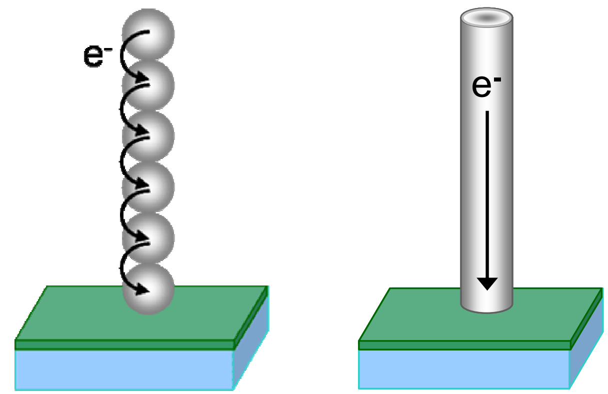
- Nanocrystalline, mesoporous TiO_2 photoelectrode on TCO.
- TiO_2 is photosensitized with a monolayer of dye.
- Efficient light harvesting with large dyed surface area:
  ~ 1000 × flat film

O'Regan & Grätzel, Nature 353, 737 (1991).
Grätzel, Nature 414, 338 (2001).

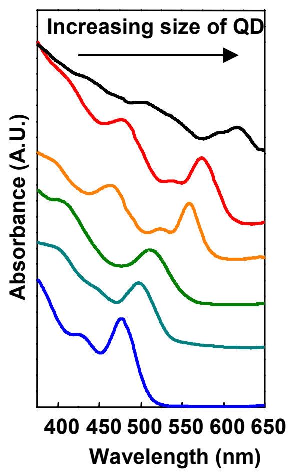
Emerging alternatives to DSSCs



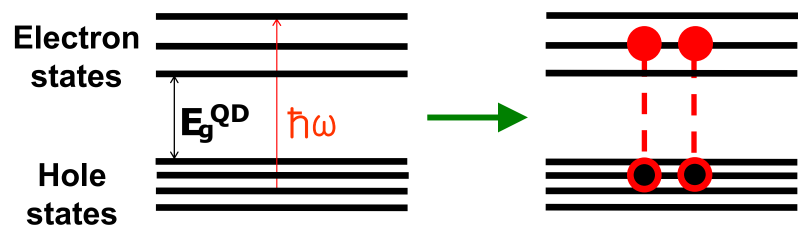
Dye-sensitized nanowire solar cell



Nanowires provide a direct path to the substrate for efficient charge collection.



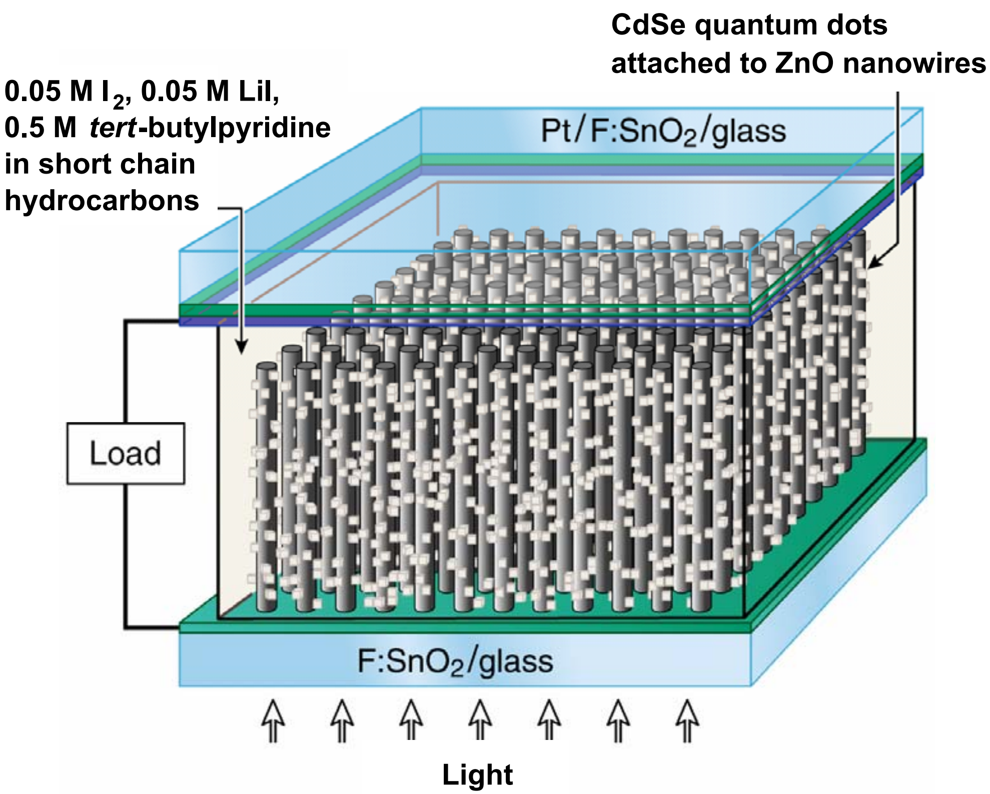
Device optical absorption spectrum can be tuned through selection of QD material and size.

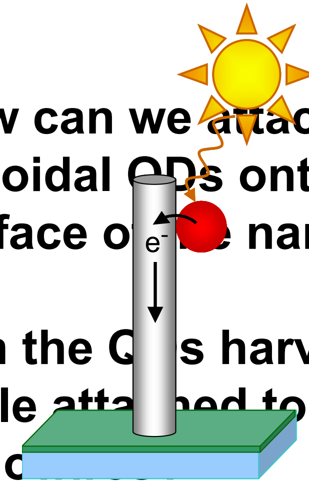


Colloidal QDs can generate multiple electron-hole pairs per absorbed photon.

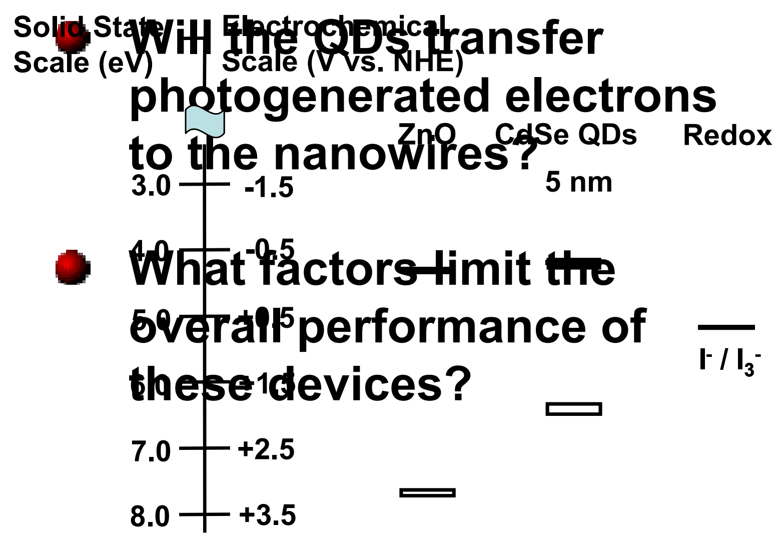
(1) Baxter *et al.*, *Nanotechnology*, 2006. (2) Law *et al.*, *Nature Mater.*, 2005.
(3) Nozik, *Physica E*, 2003. (4) Schaller *et al.*, *Phys. Rev. Lett.*, 2005. (5) Ellingson *et al.*, *Nano Lett.*, 2005.

Quantum-dot-sensitized solar cells

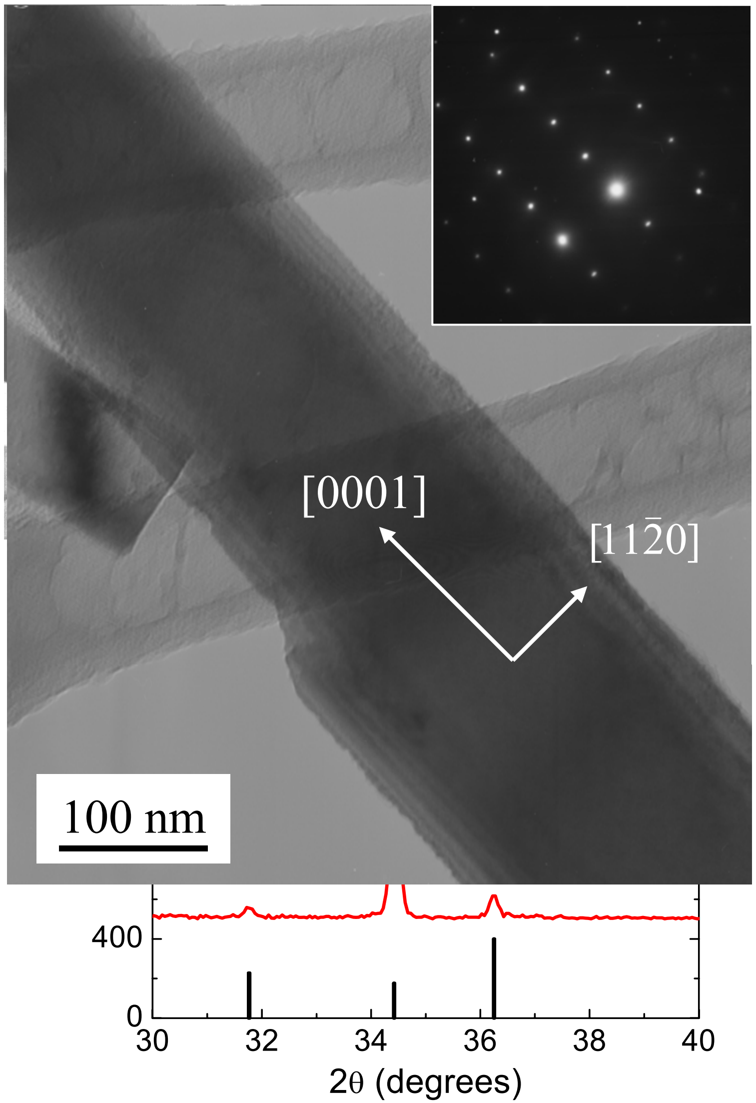


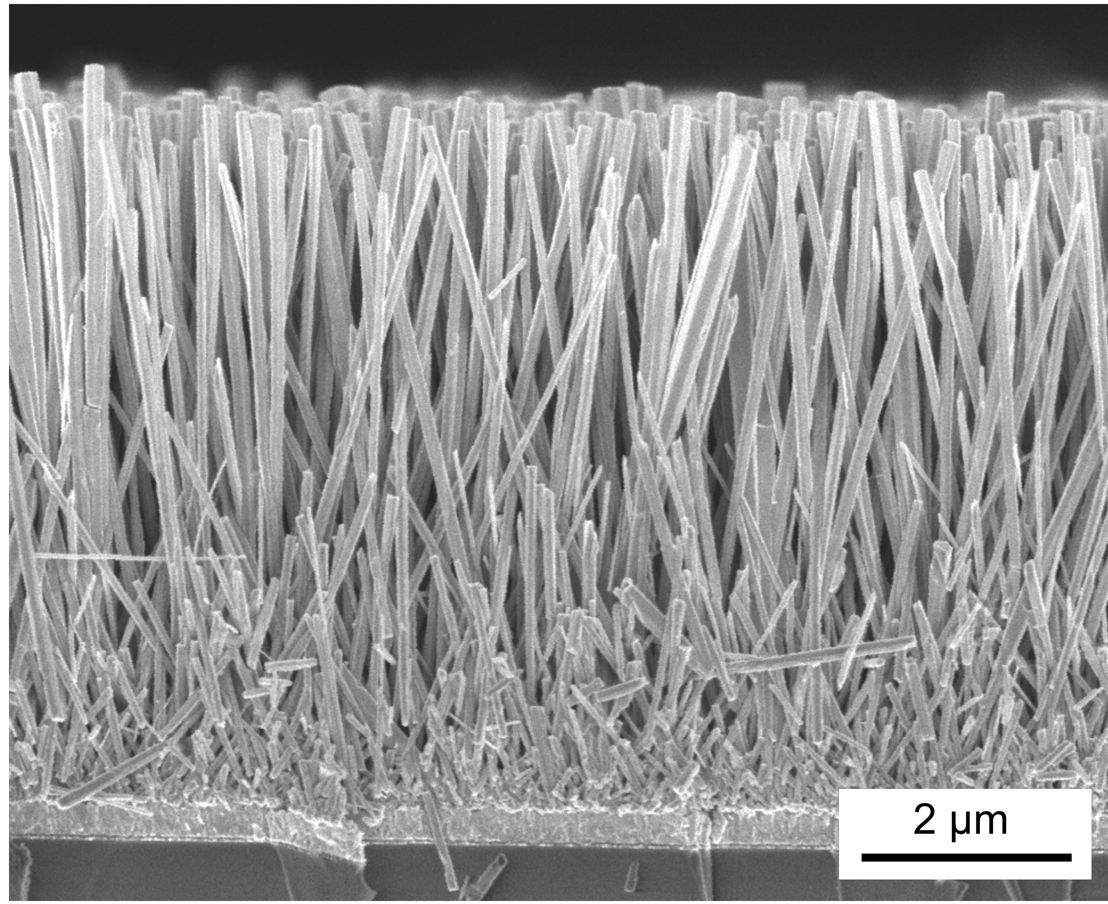


- How can we attach colloidal QDs onto the surface of the nanowires?
- Can the QDs harvest light while attached to the nanowires?
- Will the QDs transfer photogenerated electrons to the nanowires?
- What factors limit the overall performance of these devices?



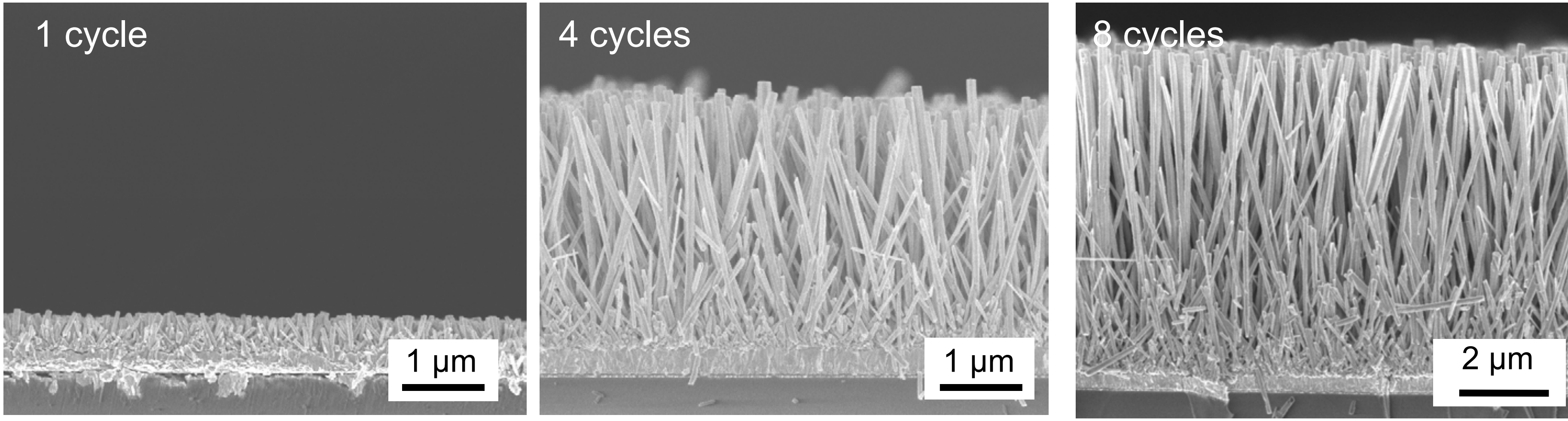
Low temperature ZnO nanowire growth from zinc nitrate and Methenamine solution

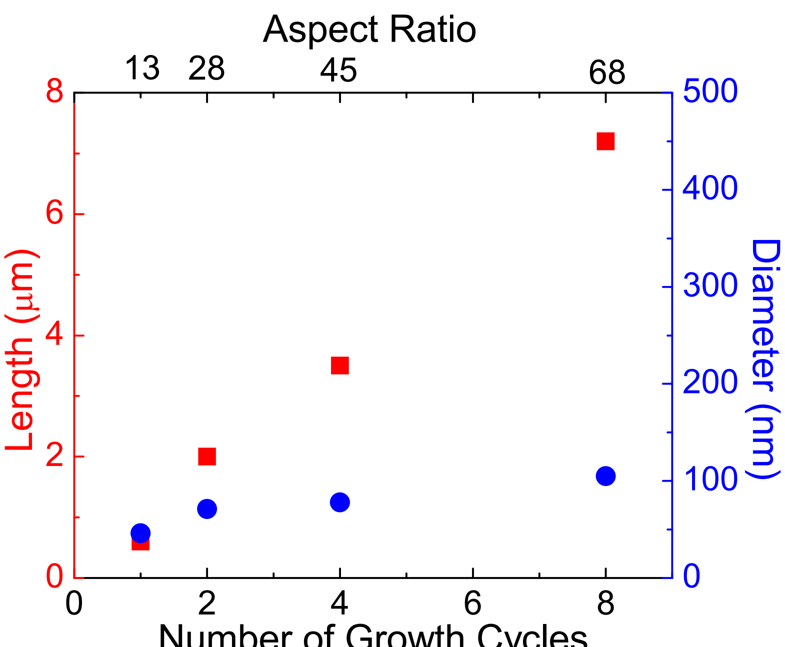


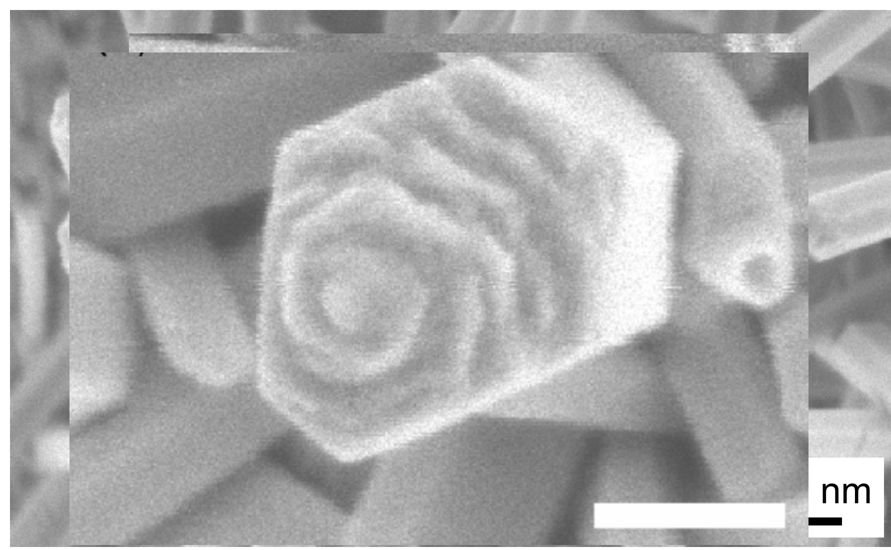


Baxter, Walker, van Ommering, and Aydil, *Nanotechnology* **17,** S304 (2006).

Control of ZnO nanowire dimensions

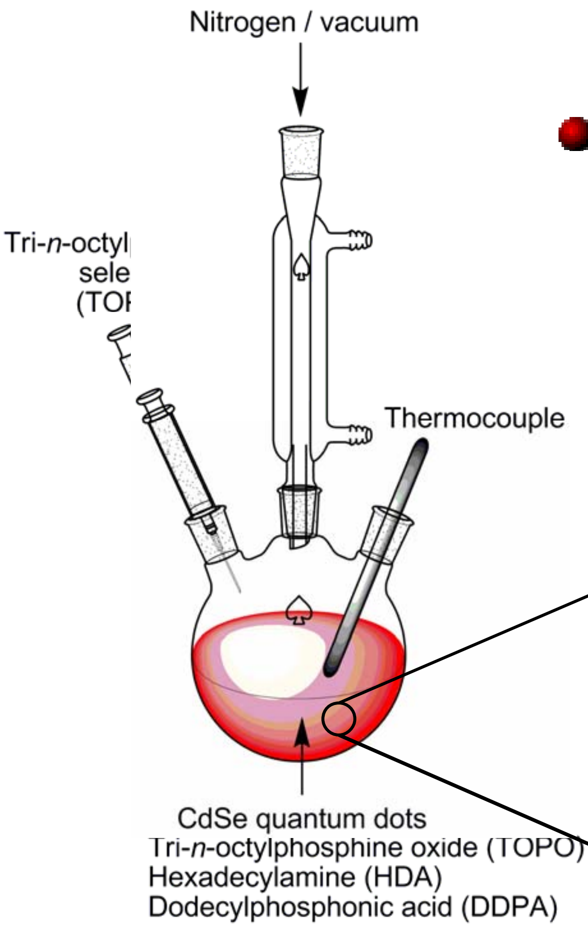


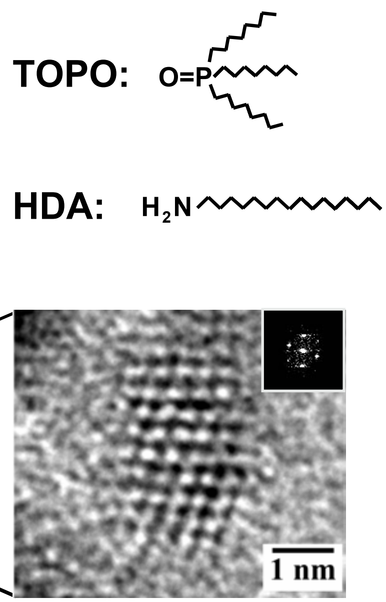


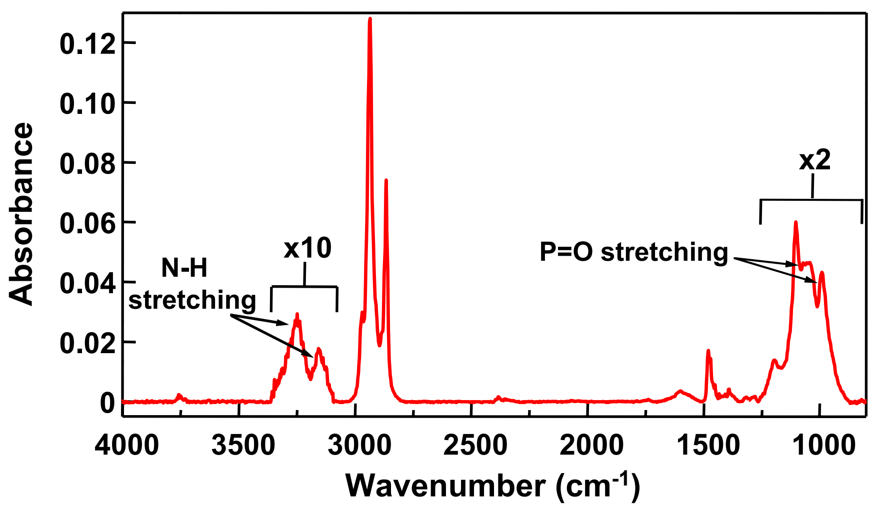


CdSe quantum dots

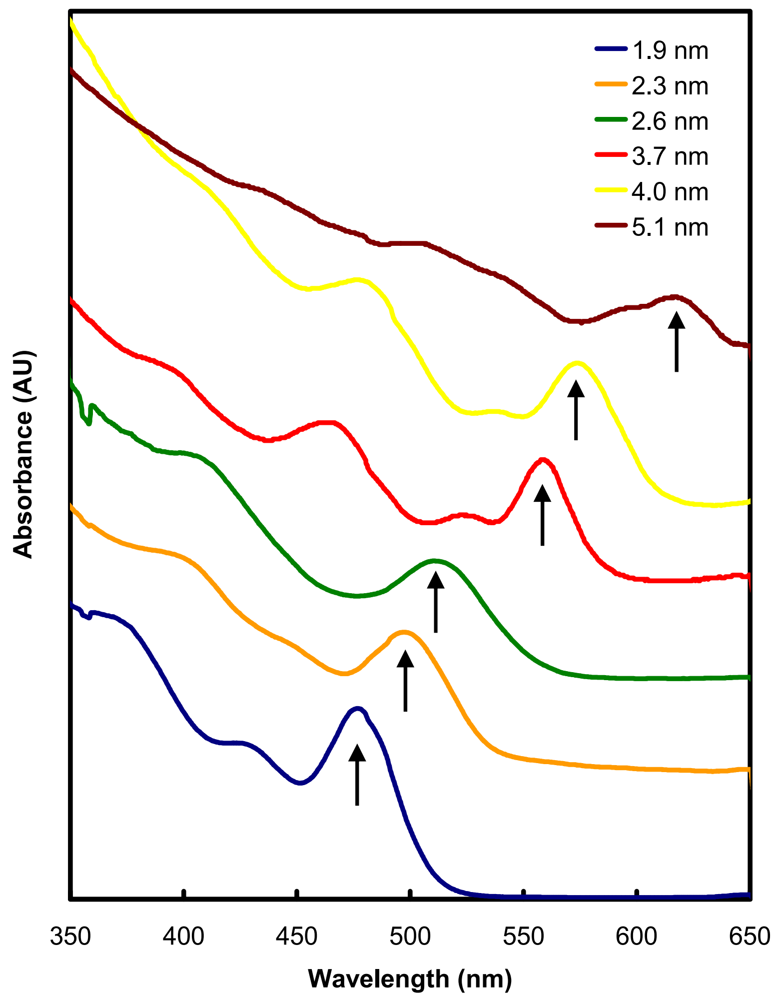
- "One-pot synthesis" from CdO and tri-*n*-octylphosphine selenide (TOPSe) in hexadecylamine (HDA) with tri-*n*-octylphosphine oxide (TOPO),
- QDs are single-crystals with diameters of 3–4 nm and surface-coordinated with TOPO and HDA.



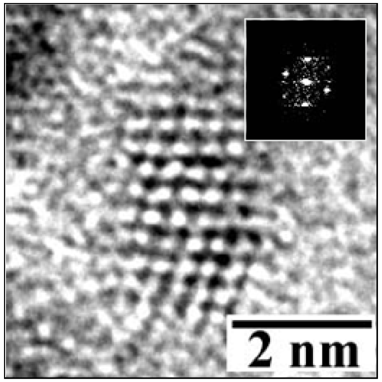


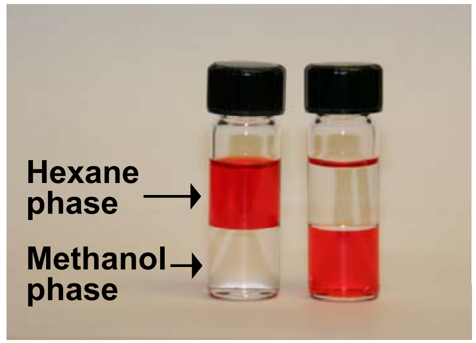


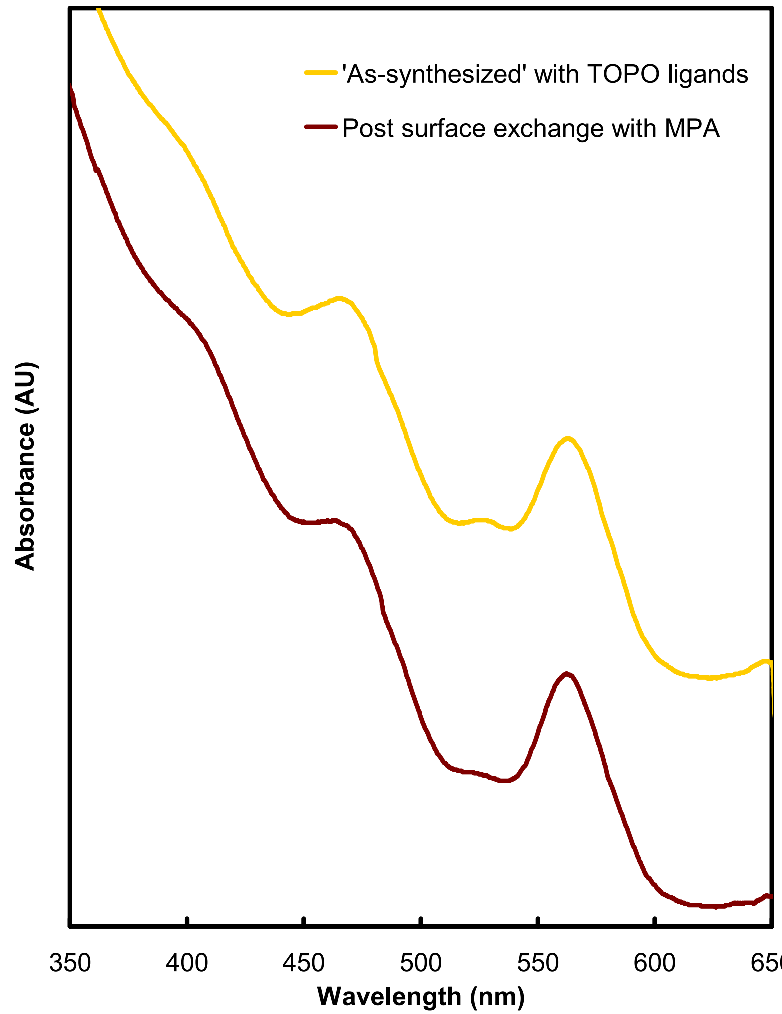
CdSe quantum dot size controlled by reaction time

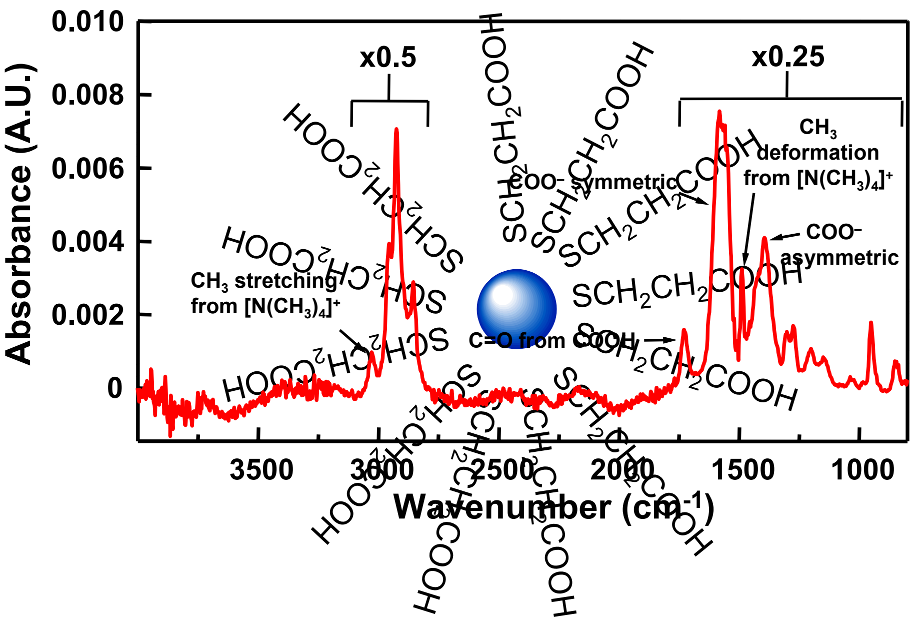


Replace Alkyl ligands on CdSe with X-R-Y

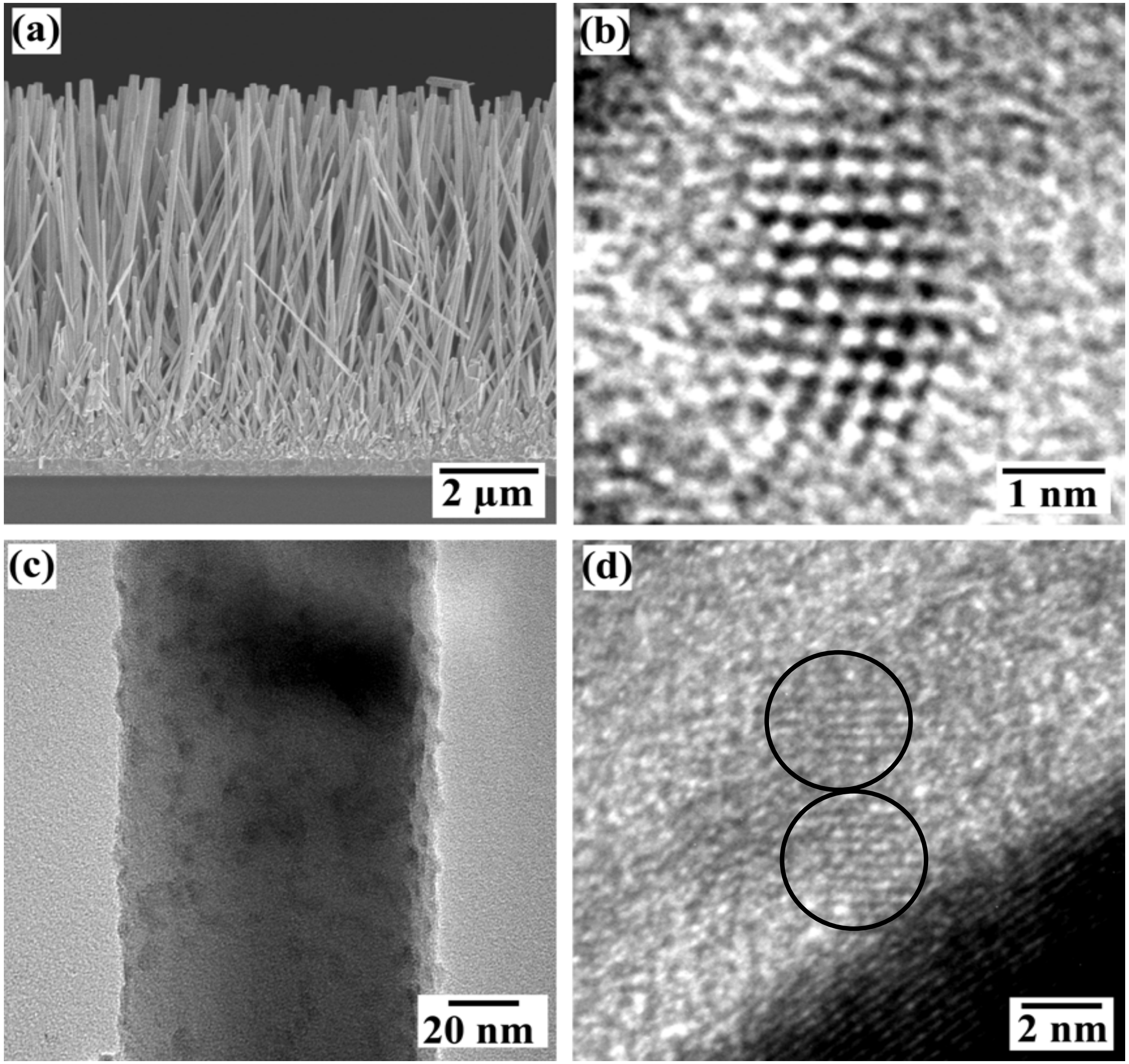




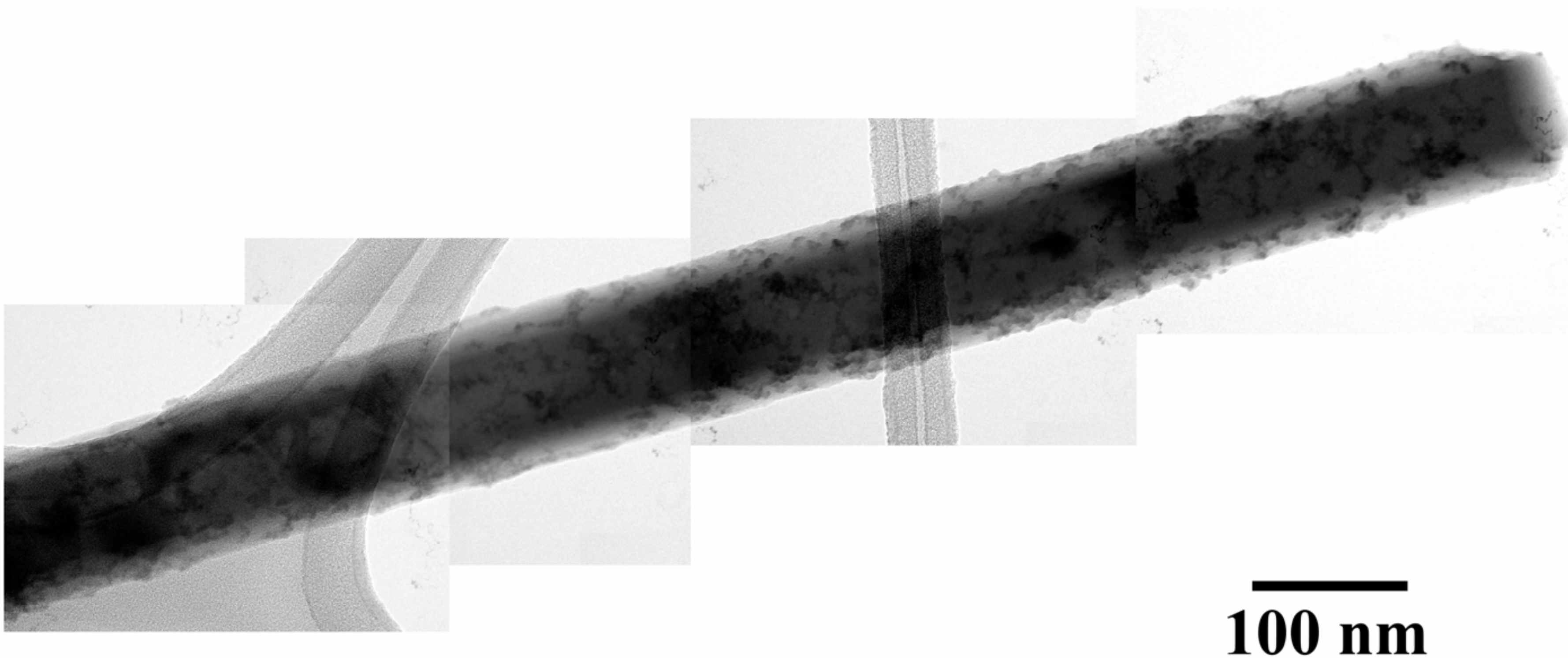




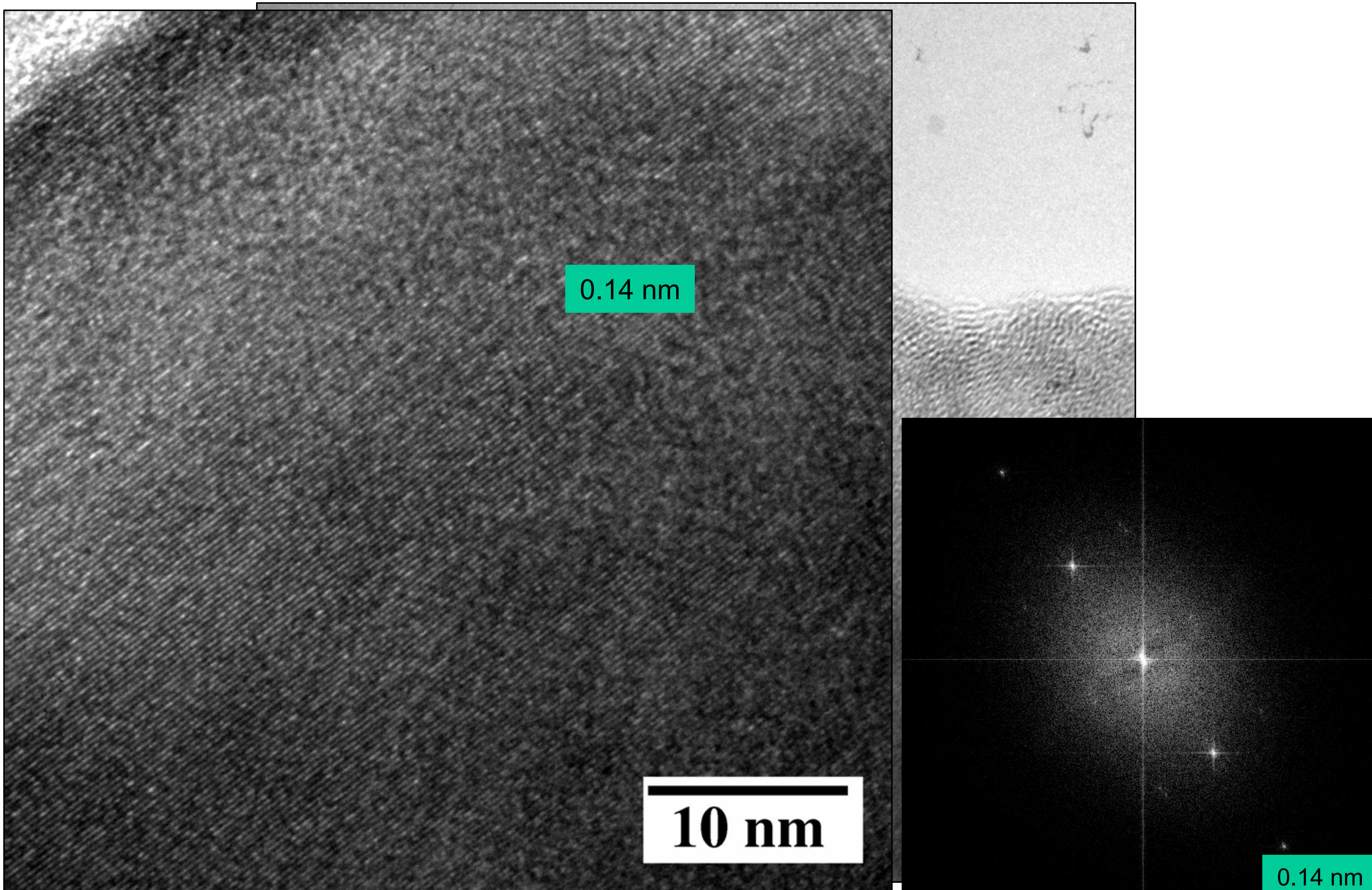
CdSe quantum dots adsorbed on ZnO Nanowires



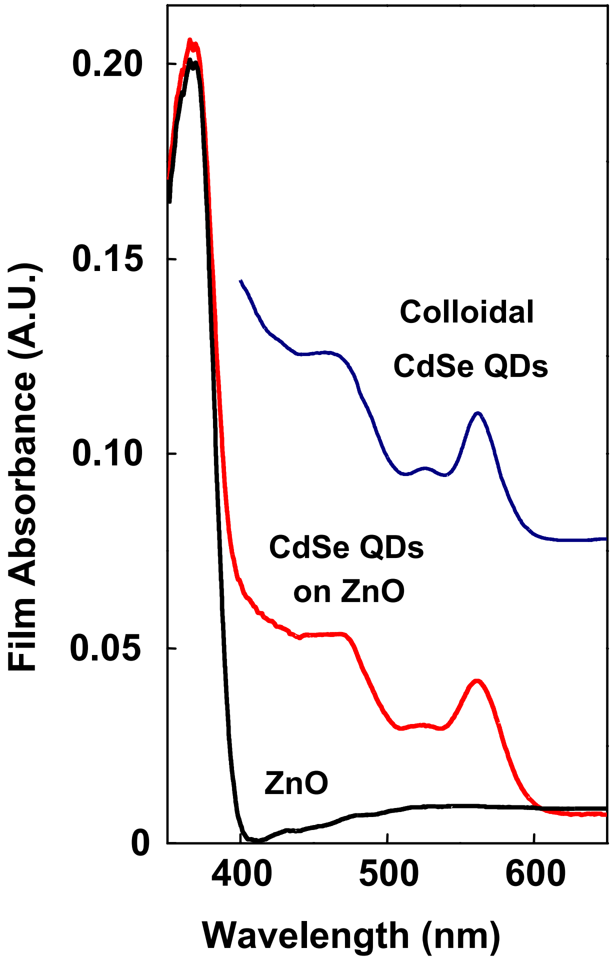
Attaching quantum dots to ZnO nanowires

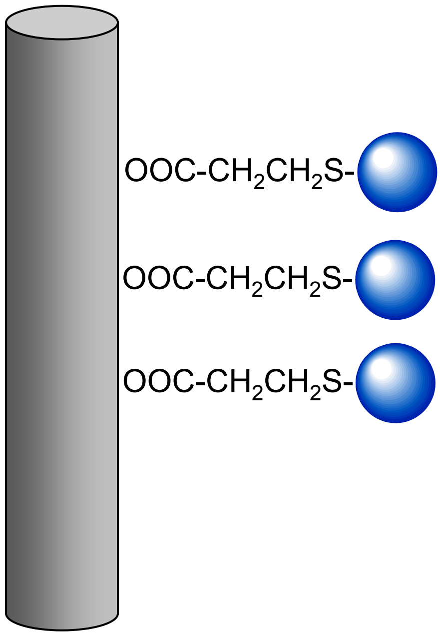


CdSe quantum dots on ZnO nanowires



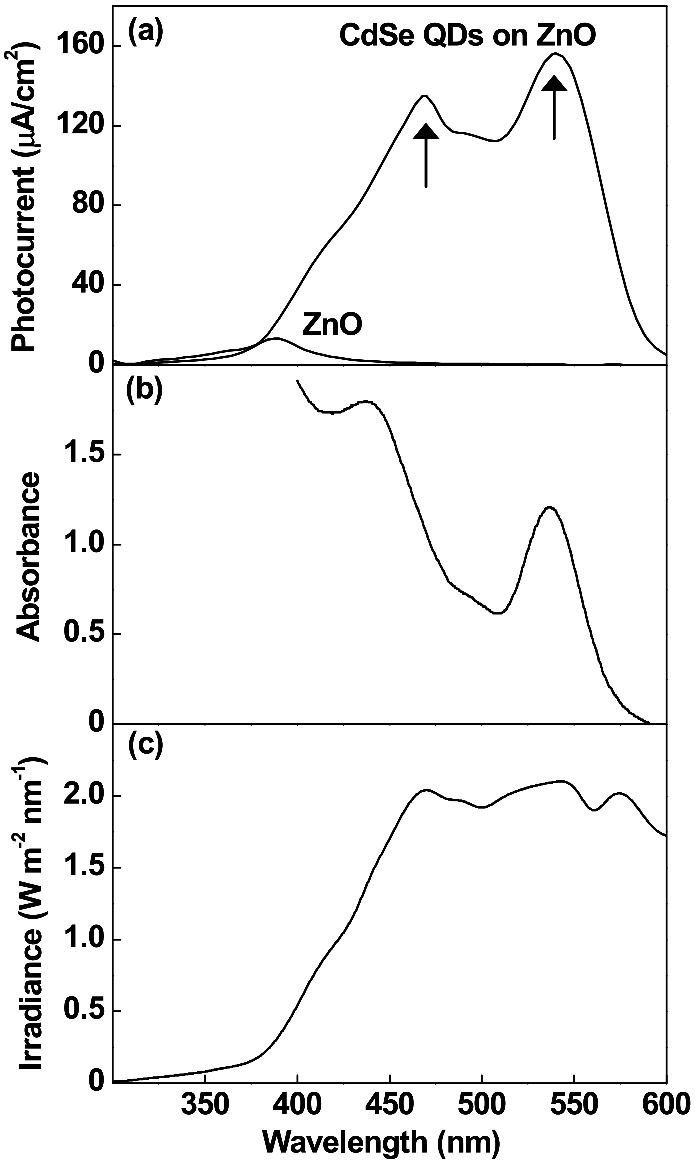
Optical absorption of CdSe QDs on ZnO nanowires

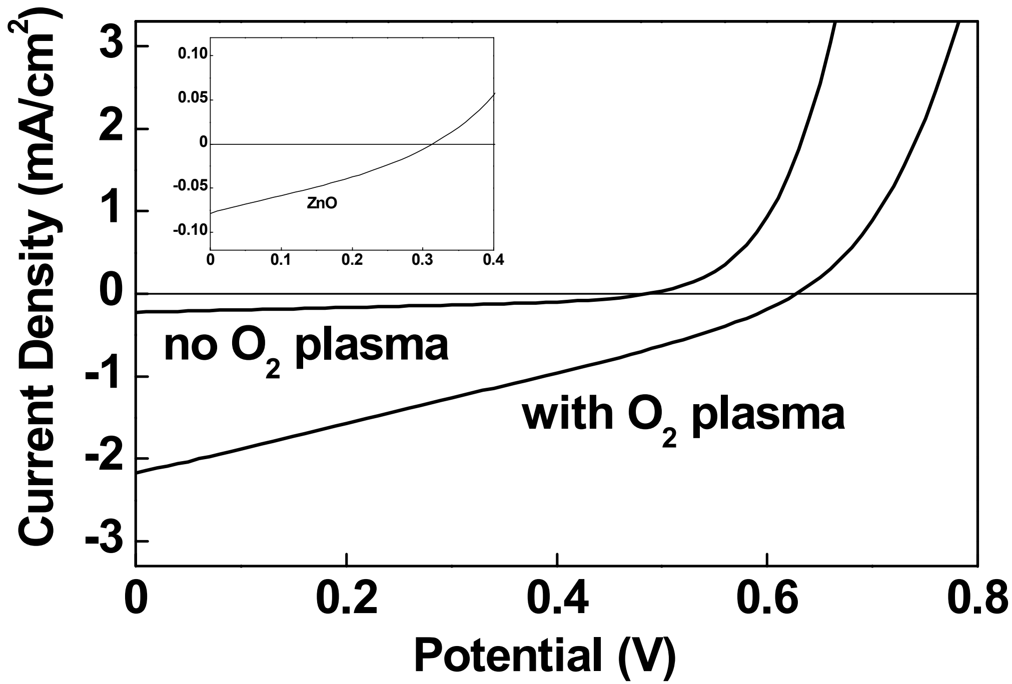




- **QD optical absorption was preserved when QDs were attached to the nanowires.**

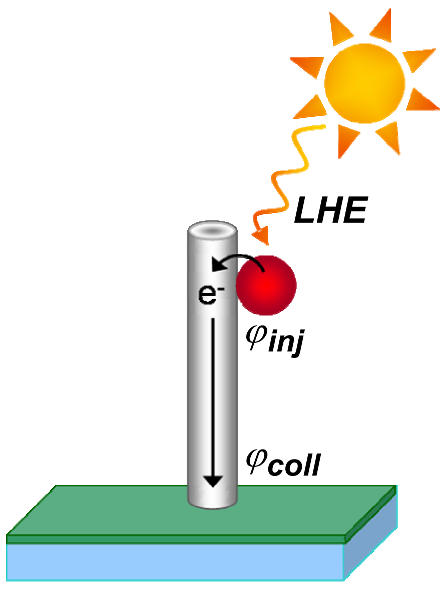
CdSe quantum dot sensitized solar cells



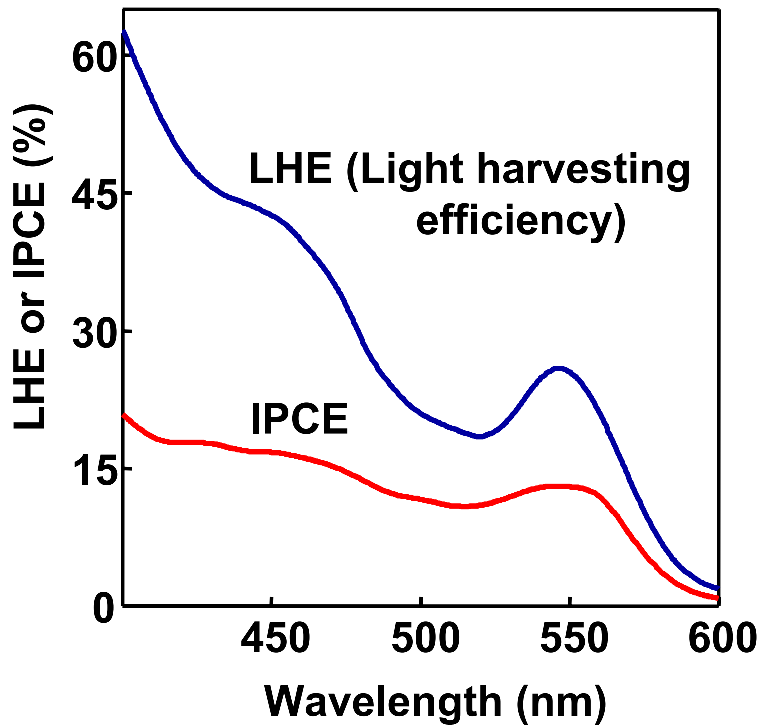


- Photovoltaic effect observed
- Electron transferred from QD to nanowire

CdSe quantum dot sensitized solar cells



$$IPCE = LHE \times \underbrace{\varphi_{inj} \times \varphi_{coll}}_{IQE}$$



- **Internal quantum efficiency (*IQE*) as high as 45–58% between 500–600 nm.**
- **Power conversion efficiency limited by the *LHE* and available nanowire surface area.**

Summary

- CdSe quantum dots and ZnO nanowires form a new type of QDSSC.

- Photogenerated electrons from CdSe transferred into ZnO.

- $I_{sc} \approx 2$ mA/cm^2, $V_{oc} \approx 0.6$ V, $FF \sim 0.3$ for typical QDSSCs. *IQE* as high as 58%.

- Nanowire QDSSCs may be a promising solar cell design.
  - Replace liquid electrolyte.
  - Increase roughness factor of nanowires.