CHM 696-11: Week 9

Instructor: Alexander Wei

Semiconductor Nanoparticles, Nanorods, and Nanowires:

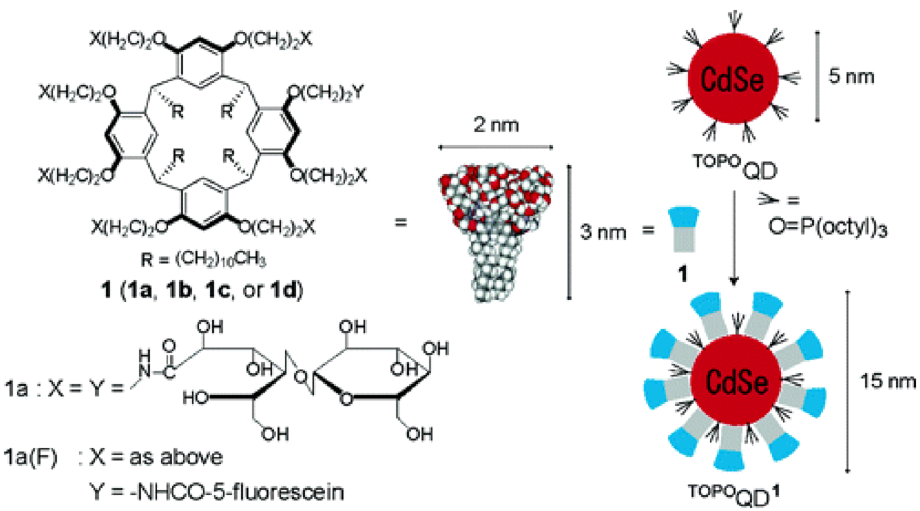
Properties and Applications

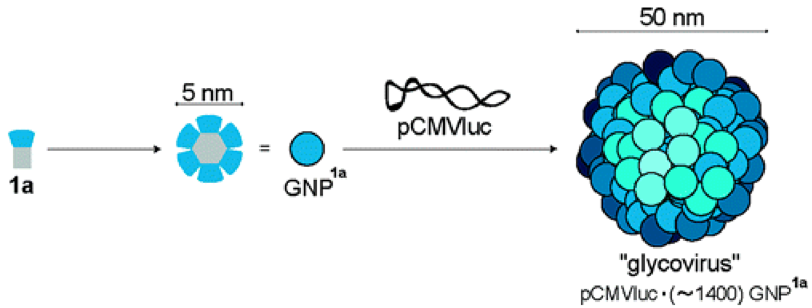
Recent review:

H. M. Mansur, *WIREs: Nanomed. Nanobiotechnol.* **2010**, *2*, 113

Cell uptake of lipid-encapsulated Q-dots

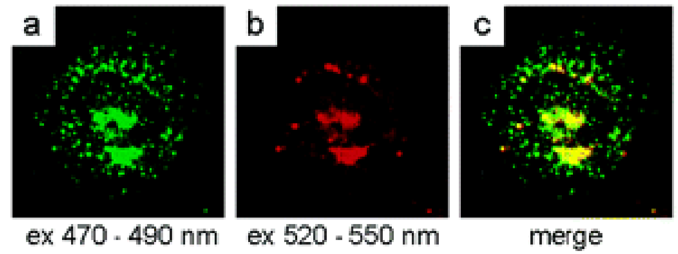
Glycocluster-coated Q-dots vs. "glycovirus":
Osaki et al, *J. Am. Chem. Soc.* **2004**, *126*, 6520.



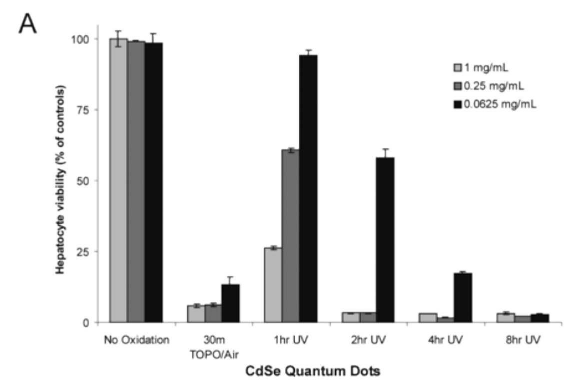


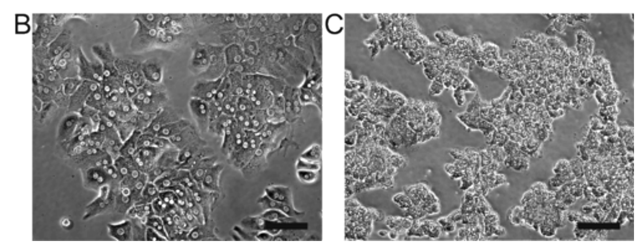
Uptake rate: 50 nm > 15 nm >> 5 nm

Red (QD) +green (glycocluster) fluorescence



Cytotoxicity of uncapped Q-dots:
Derfus et al, *Nano Lett.* **2004**, *4*, 11.





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Other photophysical properties of Q-dots

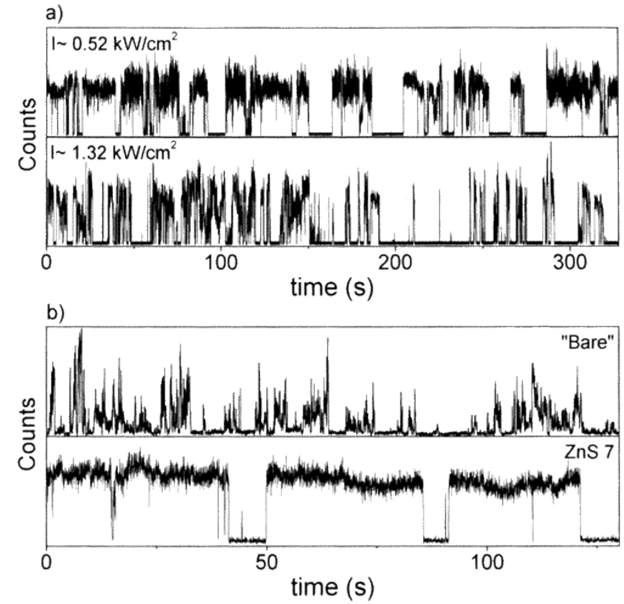
1) Intermittent "blinking" emission

Nirmal et al, *Nature* **1996**, *383*, 802;
Nirmal and Brus, *Acc. Chem. Res*. **1999**, *32*, 407.

Nonradiative photoionization produces temporary "off" state

2.1-nm CdSe QDs, TOPO-coated

CdSe/ZnS core-shell QDs

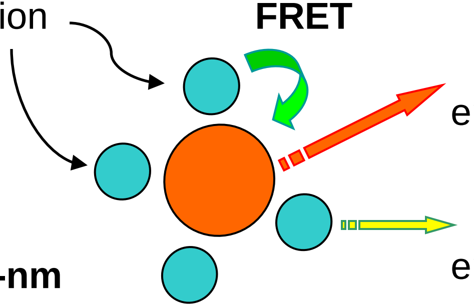


2) Fluorescent resonant energy transfer (FRET) in mixed QD solids

Kagan et al, *Phys. Rev. Lett.* **1996**, *76*, 1517

460 nm excitation

FRET



620 nm emission

540 nm emission

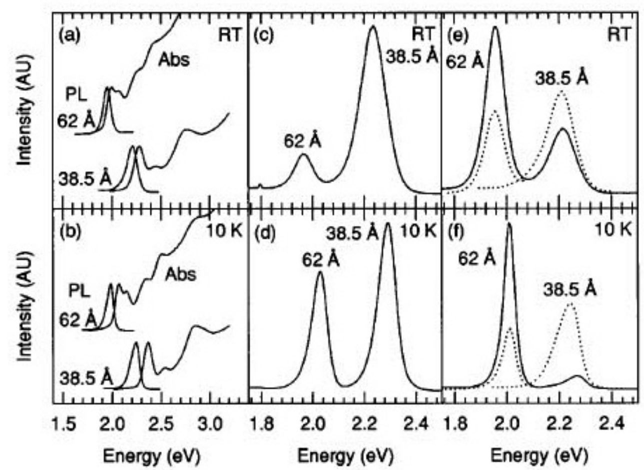
3.85 and 6.2-nm CdSe NPs

Solution (no FRET)

Solid (w/FRET)

298 K

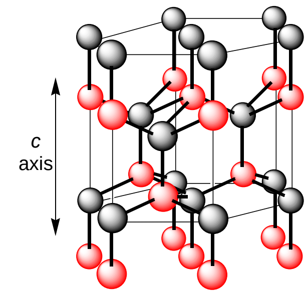
10 K



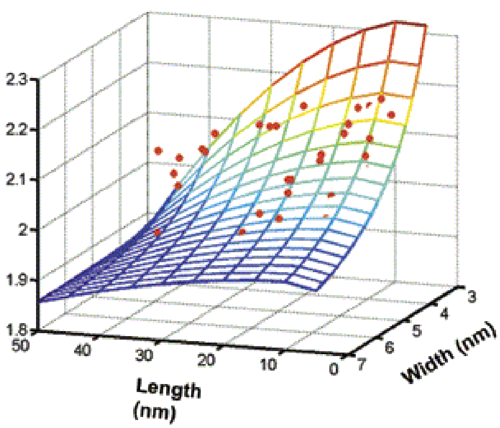
Anisotropic Q-dots: quantum rods

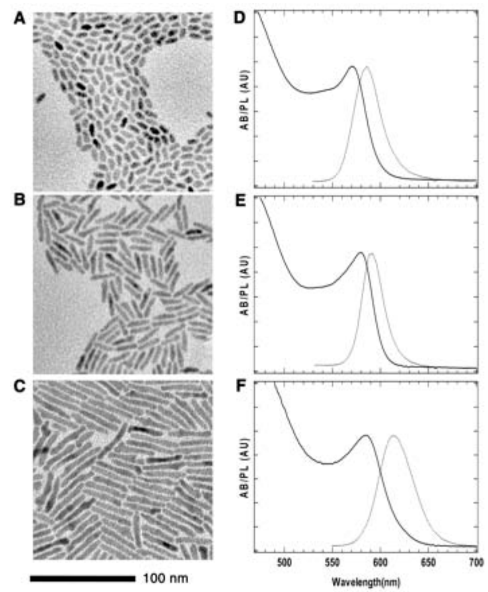
Linearly polarized emission from wurtzite CdSe nanorods:

Peng et al, *Nature* **2000**, *404*, 59; Hu et al, *Science* **2001**, *292*, 2060;
Li et al, *Nano Lett*. **2001**, *1*, 349.



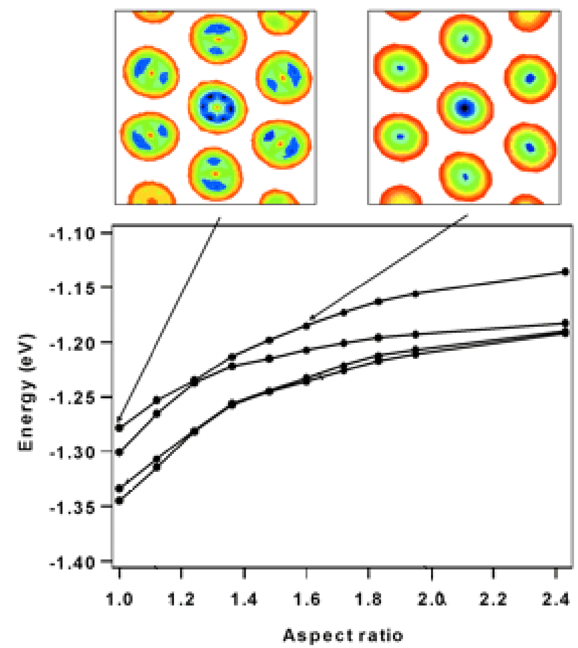
Nanorod emission as a function of aspect ratio



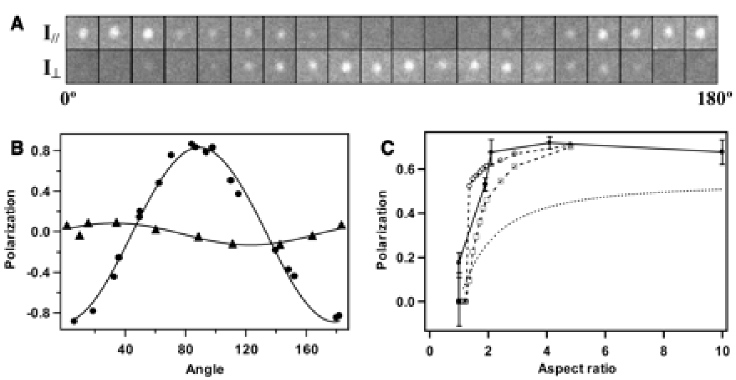


Change in HOMO with aspect ratio:

Se($p_{x,y}$)   Se(p_z)



Emission of single quantum rod as a function of polarization angle

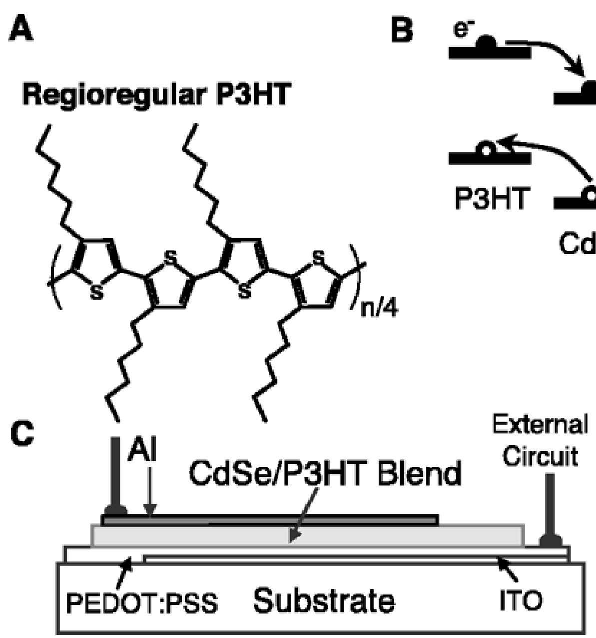


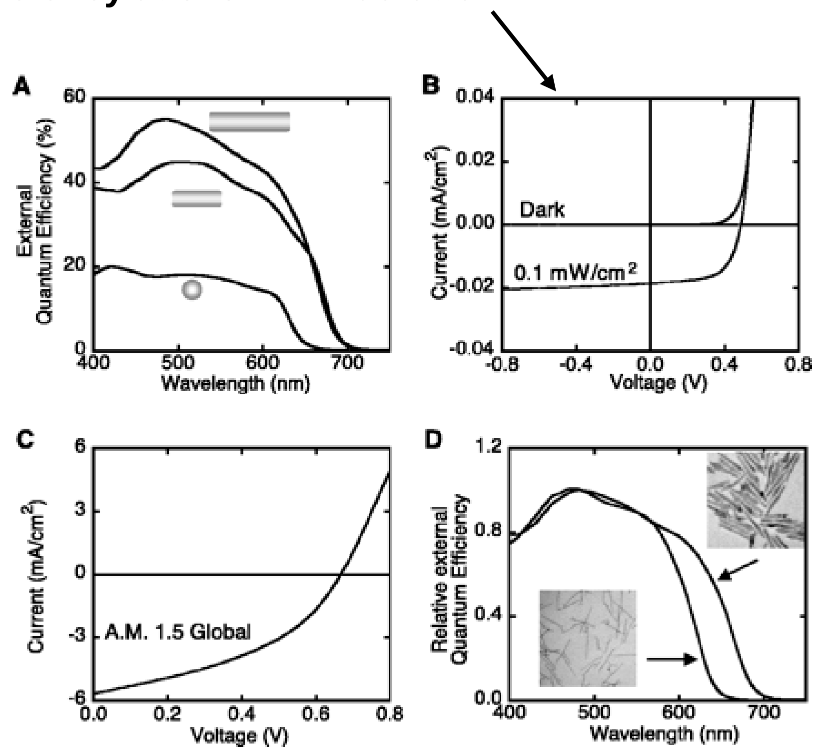
Quantum nanorods: photovoltaic applications

Hybrid nanorod-polymer solar cells: Huynh , Dittmer, and Alivisatos, *Science* **2002**, *295*, 2425.

Inorganic solar cells: up to 10% power efficiency
Organic (conducting polymer) solar cells: ~2.5% efficiency

Hybrid nanorod-polythiophene solar cell: 6.9% efficiency at 515 nm irradiation





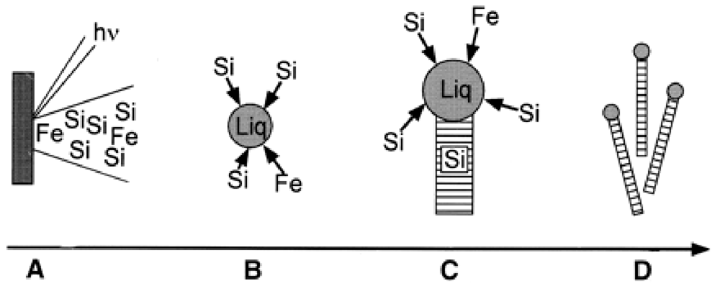
Simulated daylight

Semiconductor nanowires: synthesis

Review: Law, Goldberger, and Yang, *Annu. Rev. Mater. Sci.* **2004**, *34*, 83

Laser-catalyzed vapor-liquid-solid (VLS) growth of nanowires (NWs)

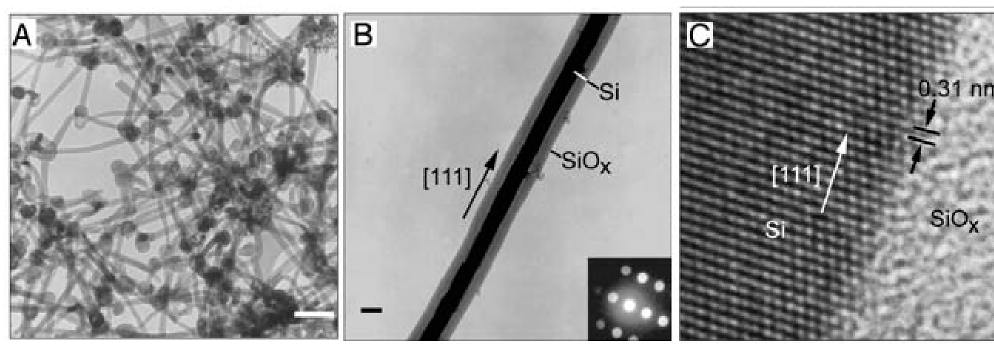
Si NWs: Morales and Lieber, *Science* **1998**, *279*, 208



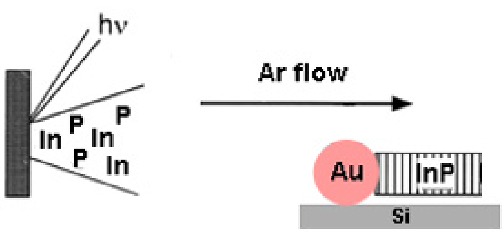
Laser ablation (high temps.)

Liquid particle growth

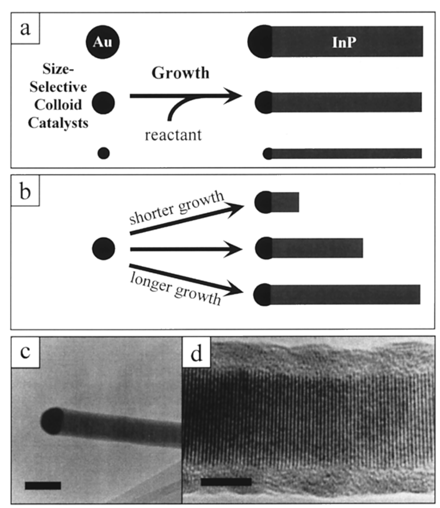
Si NW growth above eutectic temp.

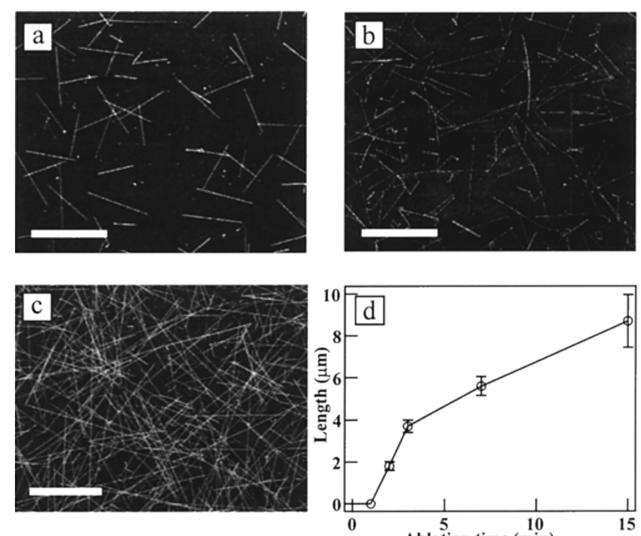


Semiconductor NWs: Gudiksen and Lieber, *J. Am. Chem. Soc.* **2000**, *122*, 8801; Gudiksen, Wang and Lieber, *J. Phys. Chem. B* **2001**, *105*, 4062.



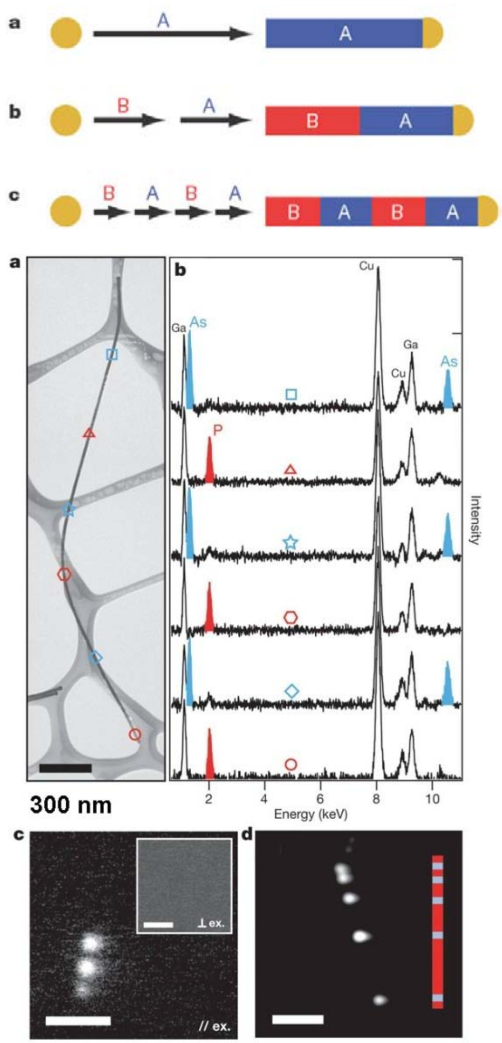
Au nanoparticle as 'solvent':



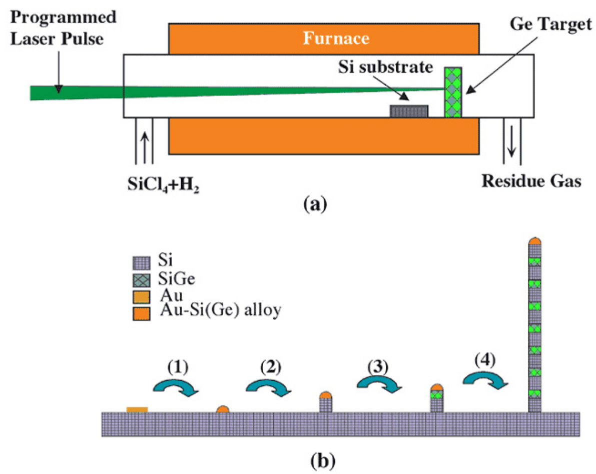


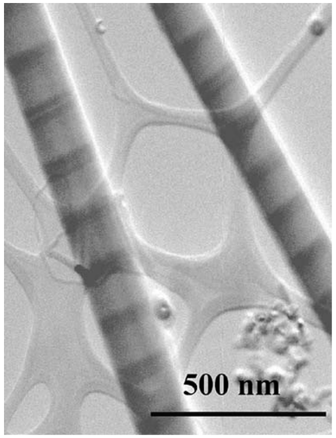
Semiconductor nanowire heterostructures

GaAs/GaP "striped" nanowires:
Gudiksen et al, *Nature* **2002**, *415*, 617.

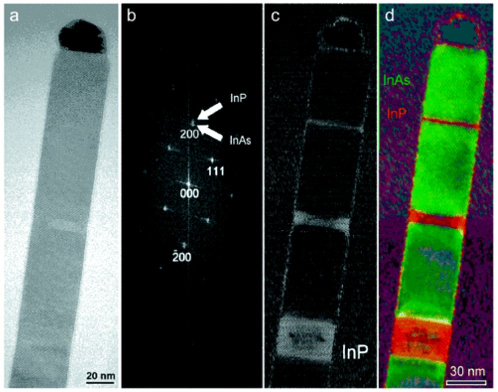


Si/SiGe superlattice nanowires:
Wu, Fan, and Yang, *Nano Lett.* **2002**, *2*, 83.



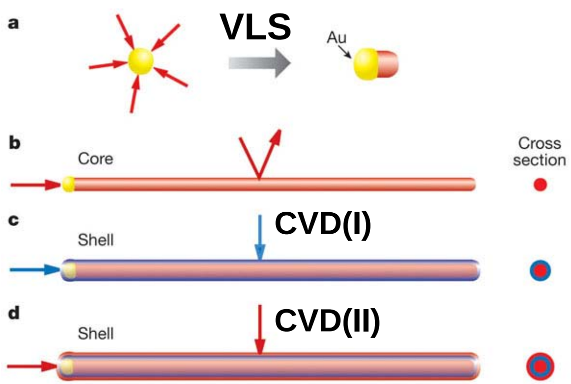


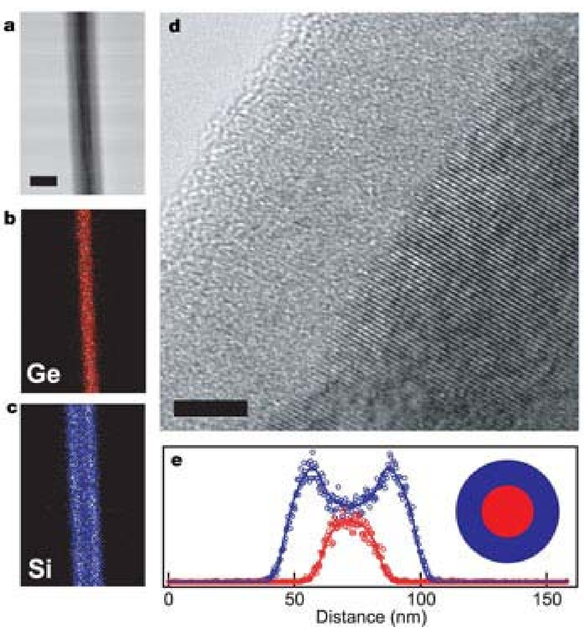
InAs/InP superlattice nanowires
by chemical-beam epitaxy:
Bjork et al, *Nano Lett.* **2002**, *2*, 87.



Core-shell nanowires and nanotubes

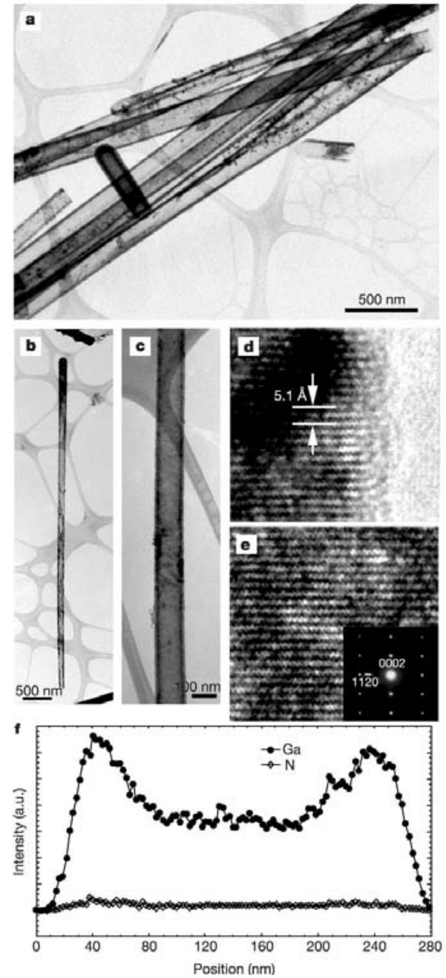
Co-axial nanowires by VLS/CVD:
Gudiksen et al, *Nature* **2002**, *415*, 617.

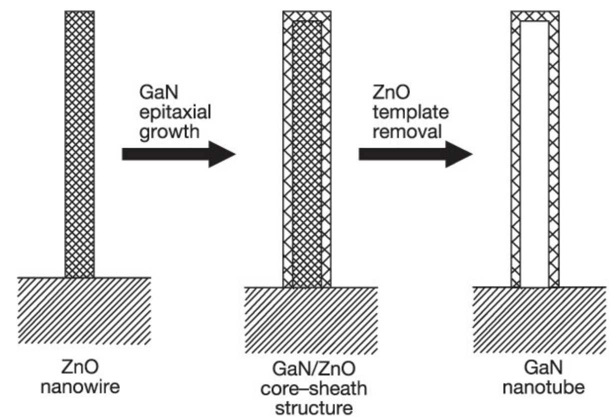




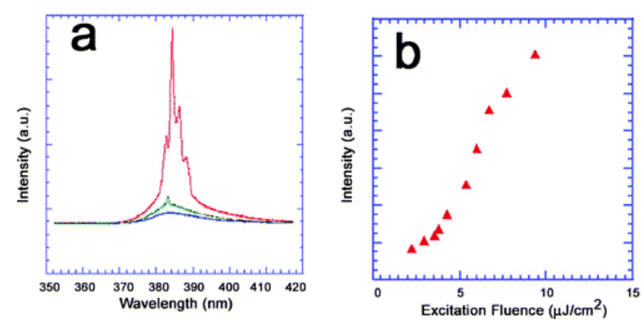
Energy-filtered TEM imaging: element-specific

Templated synthesis of GaN nanotubes:
Goldberger et al, *Nature* **2003**, *422*, 599.





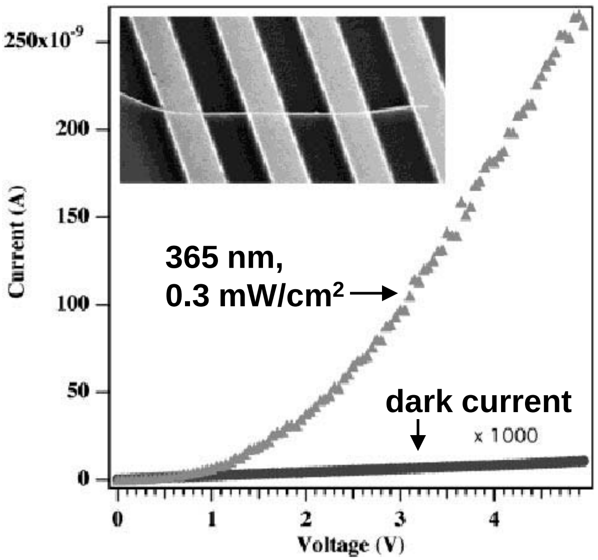
GaN has a wide band gap (3.42 eV); near-UV lasing capabilities



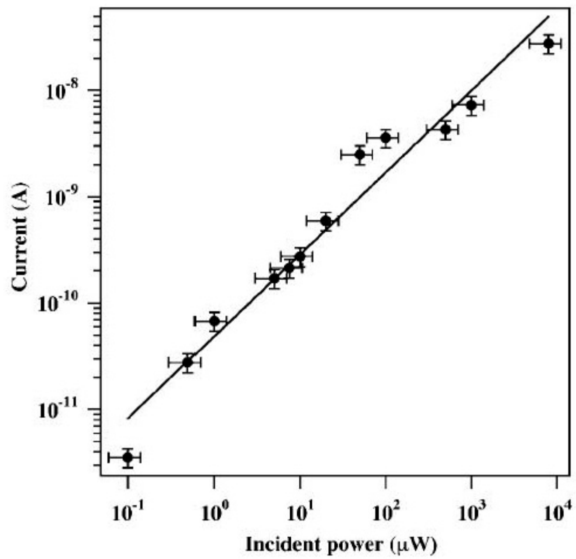
Choi et al, *J. Phys. Chem. B* **2003**, *107*, 8721.

Semiconductor nanowires: optoelectronic properties

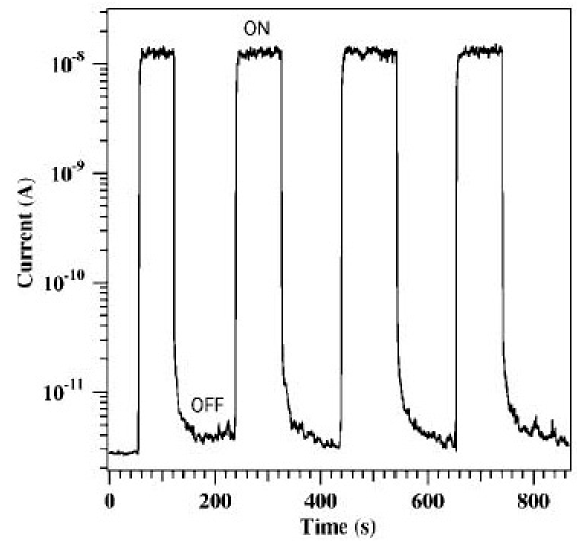
I. Photoconductivity of ZnO nanowires: Kind et al, *Adv. Mater*. **2001**, *14*, 158.



I/V curve of semiconducting wire



Photocurrent @ 355 nm, 1 V



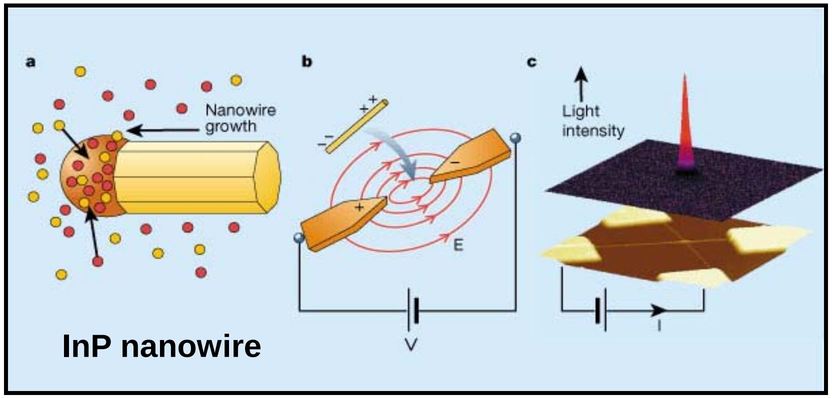
Photoresponsive switching

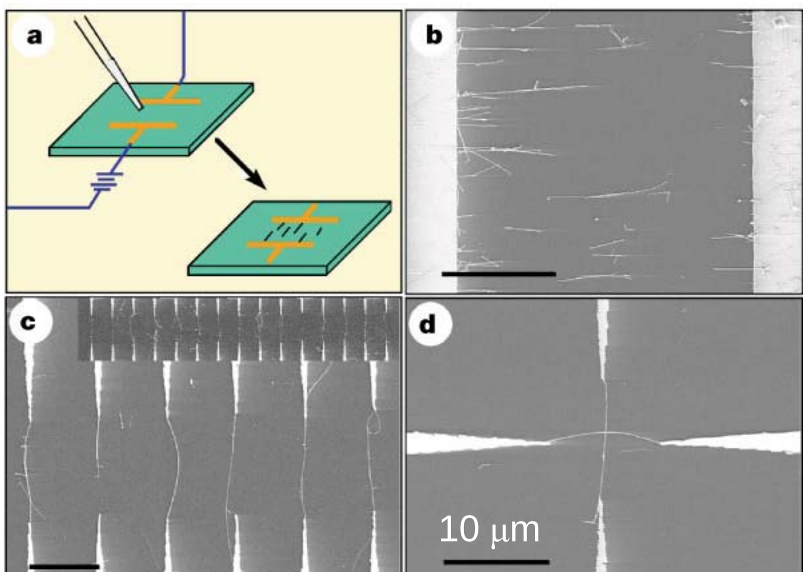
Oxygen adsorption creates depletion layer in dark current: $O_2(g) + e^- \rightarrow O_2^-(ad)$

Photocurrent produces hole-electron dissociation, discharges adsorbed O_2: $O_2^-(ad) + h^+ \rightarrow O_2(g)$

Semiconductor nanowires: optoelectronic properties

II. Nanoscale LED from InP nanowire *p-n* junction: Duan et al, *Nature* **2001**, *409*, 66.





Zn-doped InP nanowire: *p*-type

Te-doped InP nanowire: *n*-type