Materials, Electronics and Renewable Energy

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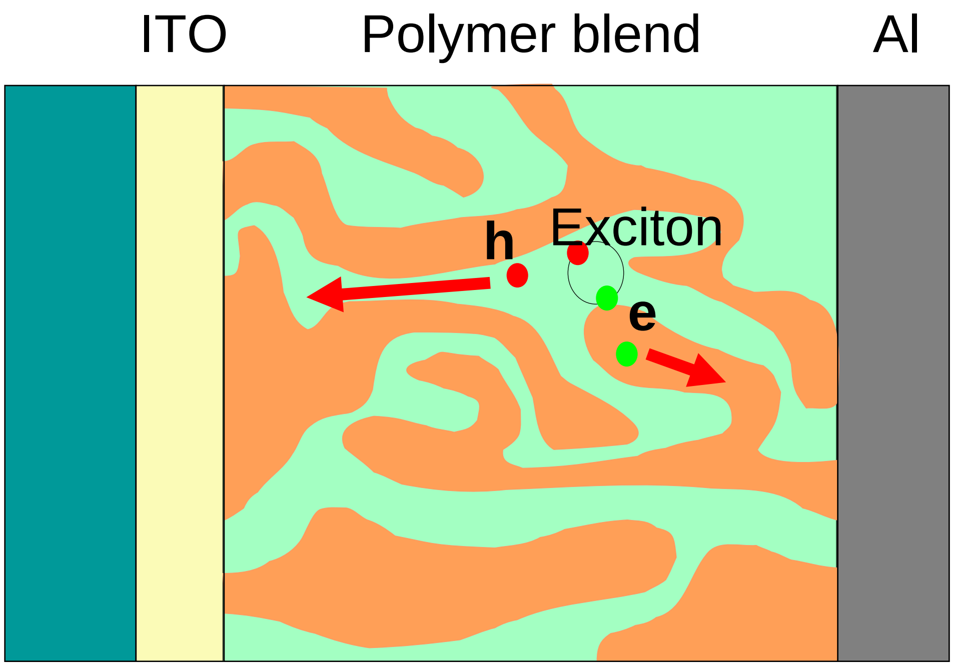
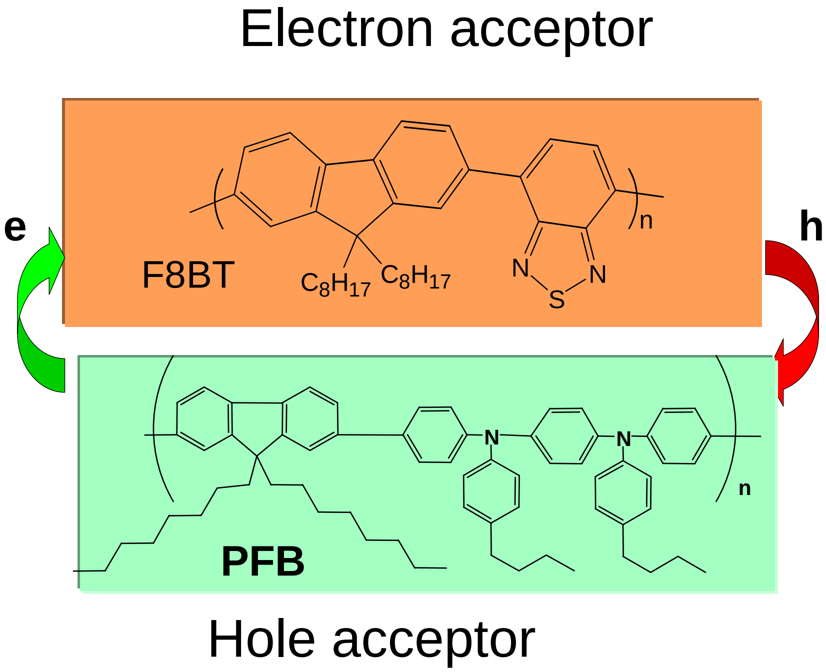
- Nanostructured solar cells
- Beyond the Shockley-Queisser limit

‘Dispersed Interface’ Photovoltaics

‘mixed’ polymers generally phase-separate due to low entropy of mixing – spinodal decomposition

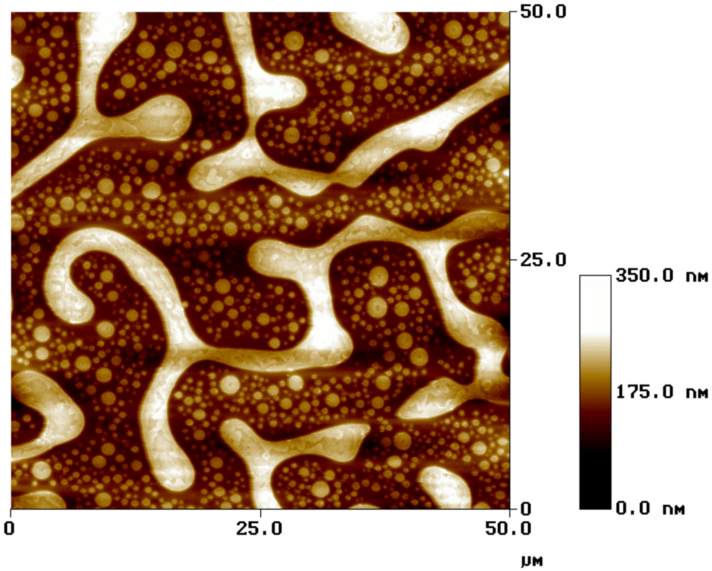
Halls et al. Nature **376**, 498 (1995),
Yu et al. Science **270**, 1789 (1995)



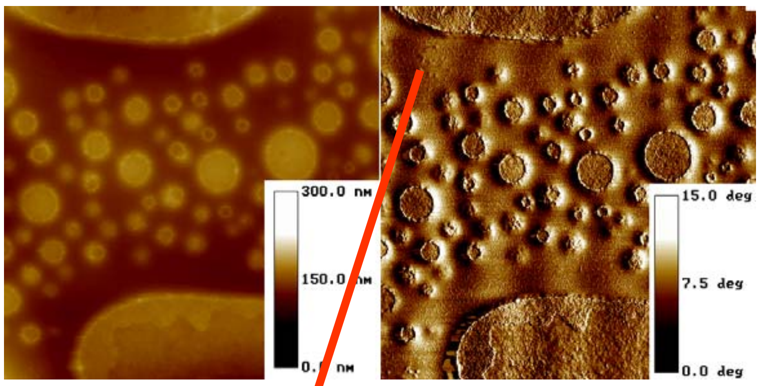


Fine structure in F8BT-PFB blends:

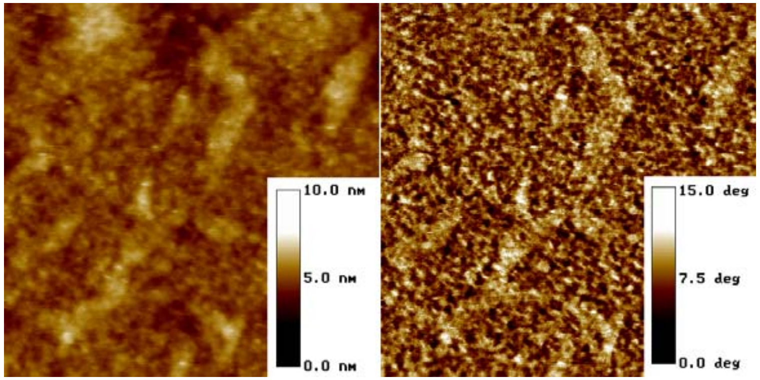
High Resolution Atomic Force Microscopy



50 μm



10 μm

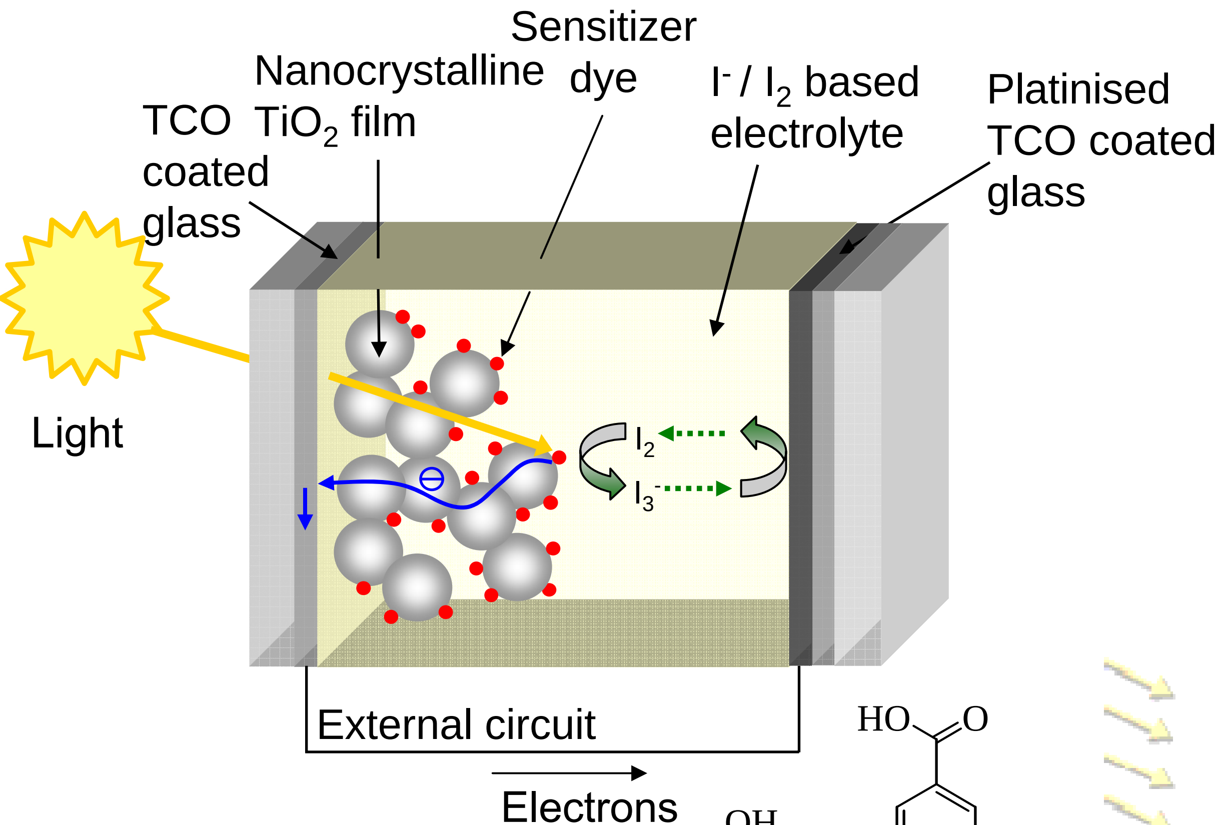


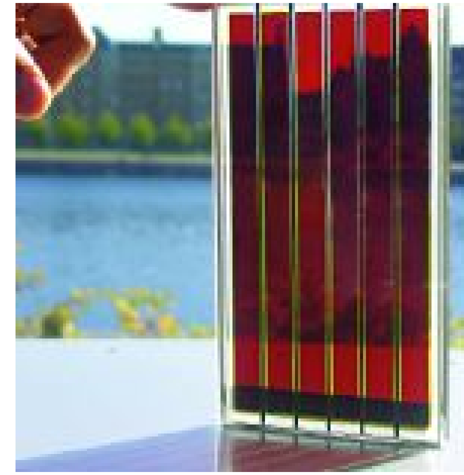
0.5 μm

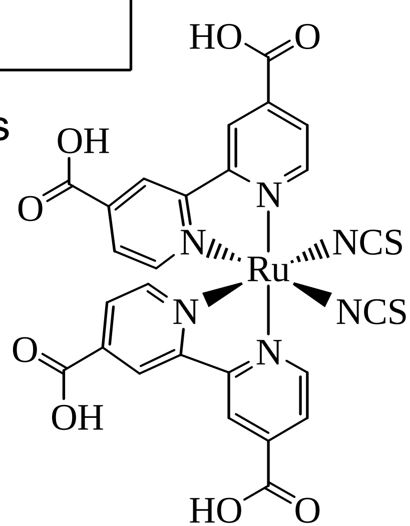
Structure on many length scales

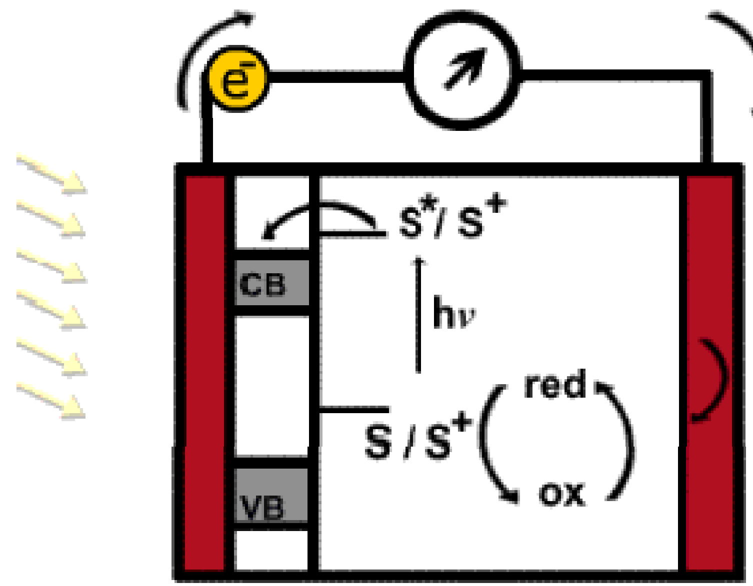
Sub-20nm structure most important for device operation

Dye-sensitised solar cells







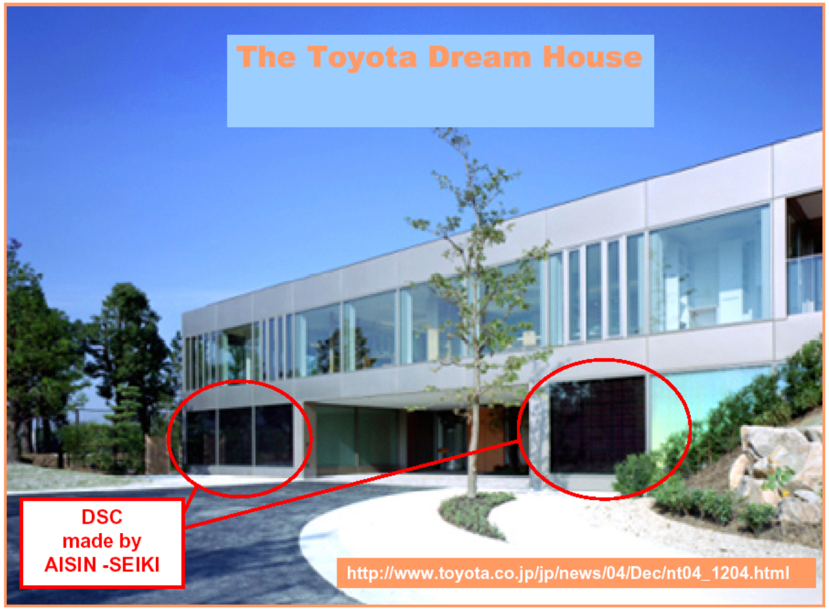


Dye = $Ru(dcbpy)_2(NCS)_2$
Carboxylates result in self-assembly as monolayer on TiO_2 film.

Current DSSC Status:

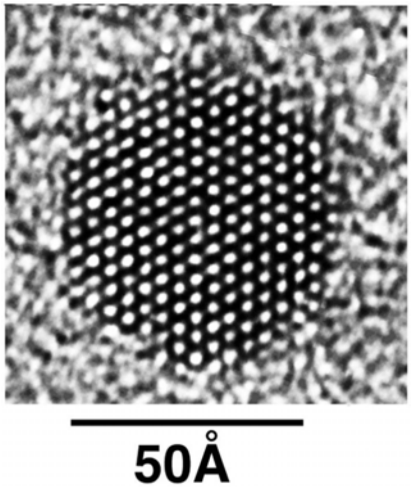
- Best lab device efficiency 12 %
- Stable devices 5-8 %
- Trade off between efficiency, stability and processability
  - Replacing liquid electrolyte with less volatile materials (polymer electrolytes, molecular hole semiconductors, ionic liquids)
  - Interface engineering: redox cascades, barrier layers etc.
- Review: Grätzel, M. *Nature* **2001**, *414*, 338-344 plus MRS Bulletin Jan 2005

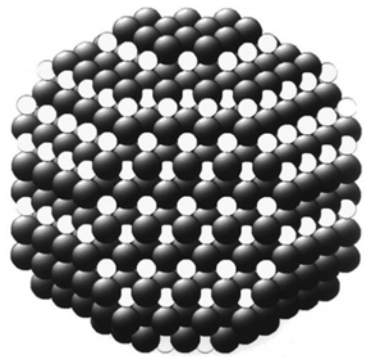
Fabrication on metal foils for consumer products
First factory (30 MW_p/yr) on line early 2007
in Cardiff, UK
http://www.g24i.com/



Prototype building integrated DSSC
Toyota, Japan

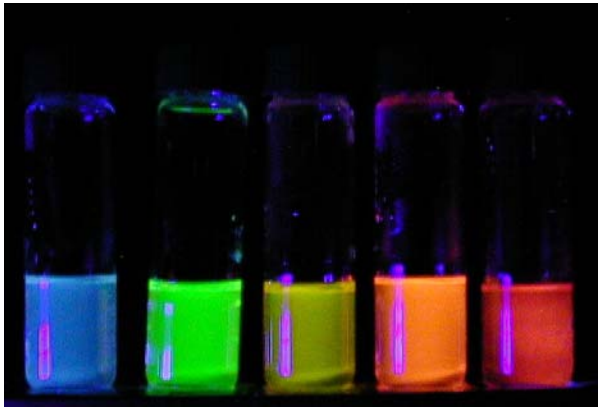
Inorganic Semiconductor Nanoparticles





Luminescence

(CdSe with ZnS shells)



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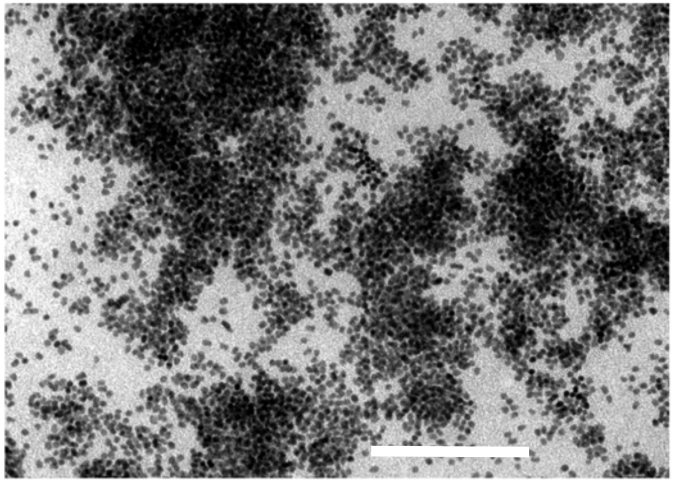
Increasing diameter

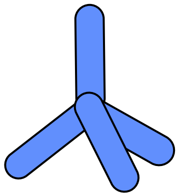
- Quantum confinement
- Particle-in-a-box

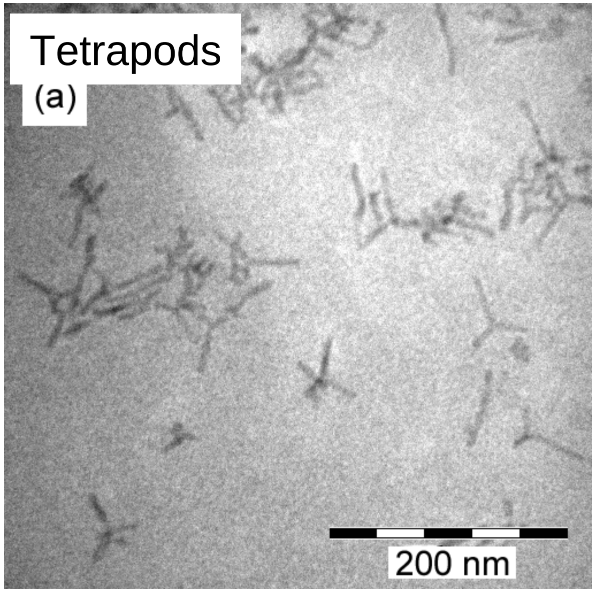


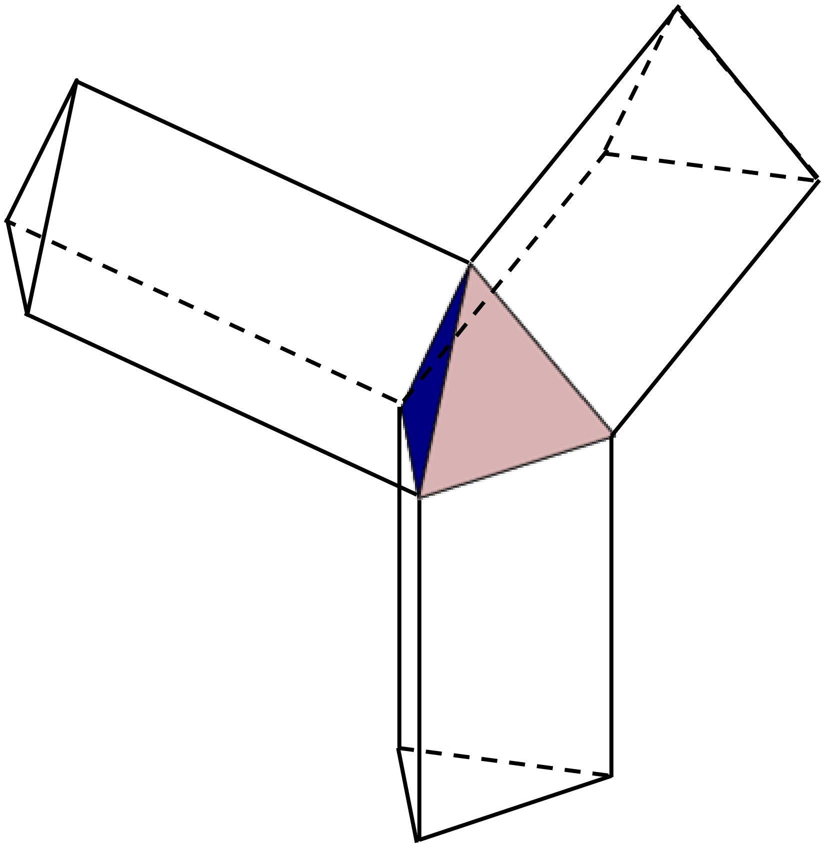
100 nm

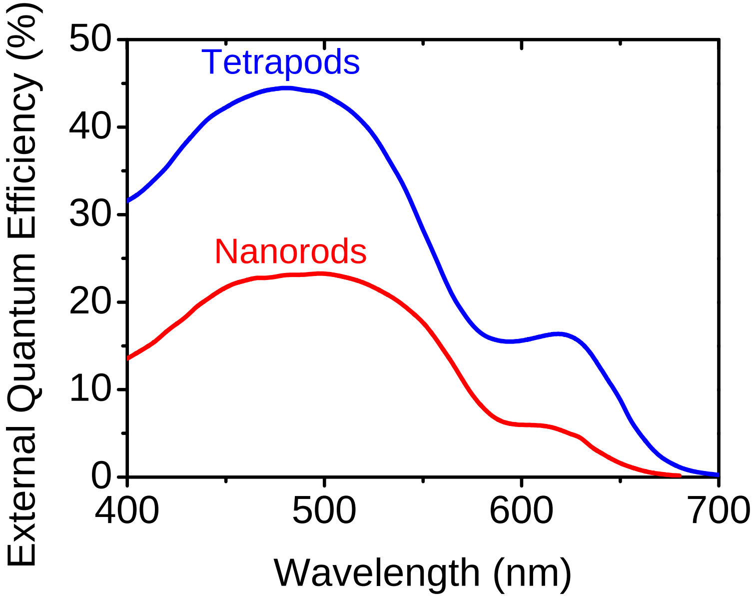
- Use as electron acceptor in polymer solar cell

Nanocrystal shape control









- Best power conversion efficiencies ~ 3%

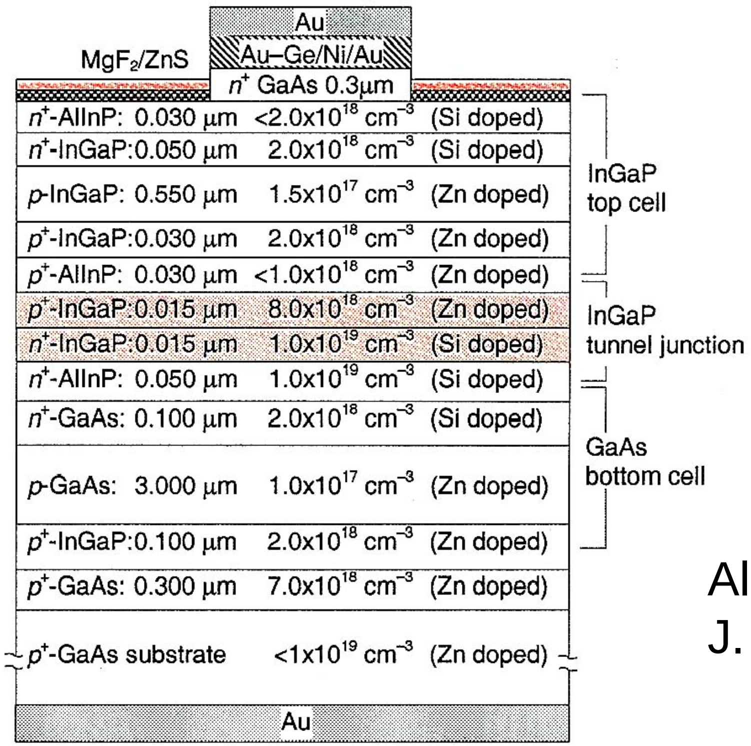
B. Sun *et al.* J. Appl. Phys. **97** 014914 (2005)

Beyond the Shockley-Queisser Limit:

Tandem cells:

Use stack of cells, grading band-gap from highest at incident light surface (with highest V_{oc}) to lowest at back of cell. Practical structures require diodes to be wired in series, so balancing photocurrents from these tandem cells is necessary.

Best results with III-V semiconductors, with demonstrated efficiencies above 33%



Lattice-matched III-V semiconductor growth reduces defects at boundaries.

Example: 2-cell stack [Takamoto et al, Appl. Phys. Lett. **70**, 381 (1997)]

$In_{0.5}Ga_{0.5}P$ top cell – band gap near 1.9 eV

GaAs bottom cell – band gap 1.45 eV

Note: expensive to make – ok for space satellites….

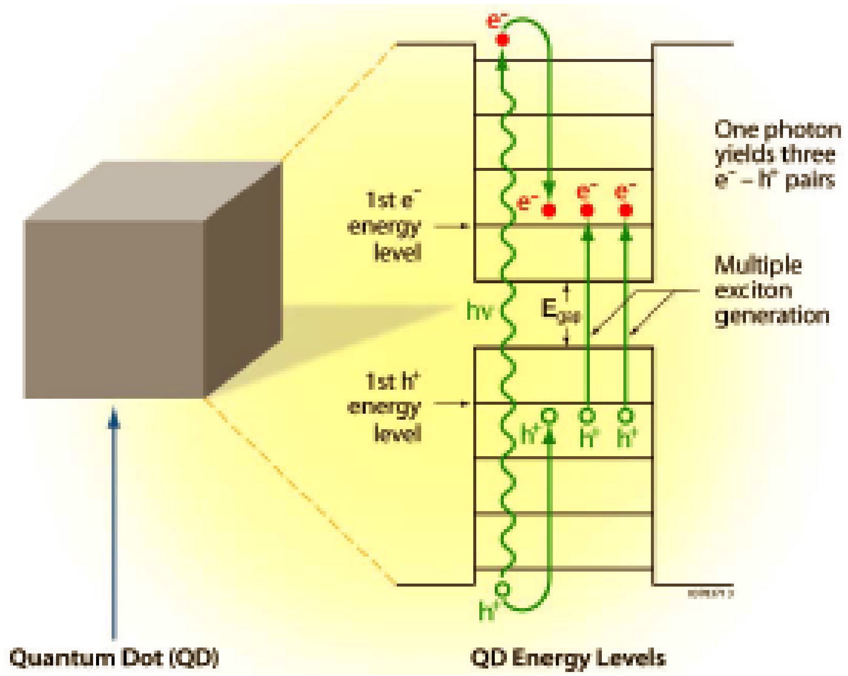
Also possible (easier?) with organics – see J. Y. Kim *et al.*, Science 317 222 (2007)

Beyond the Shockley-Queisser Limit:

Multiple charge pair generation:

One photon to produce multiple e-h pairs? Very inefficient in bulk materials, due to energy and momentum conservation. Possible in nanoparticles, where k conservation is relaxed?

Multiple exciton generation in quantum dots: Evidence for multiple exciton generation in nanocrystals of e.g. PbS



Schaller and Klimov, Phys. Rev. Lett. **92**, 186601 (2004)

Not yet proven that the extra carriers can be extracted in a solar cell