Nanoparticle Enhanced Thin Film Solar Cells

Solar Cells

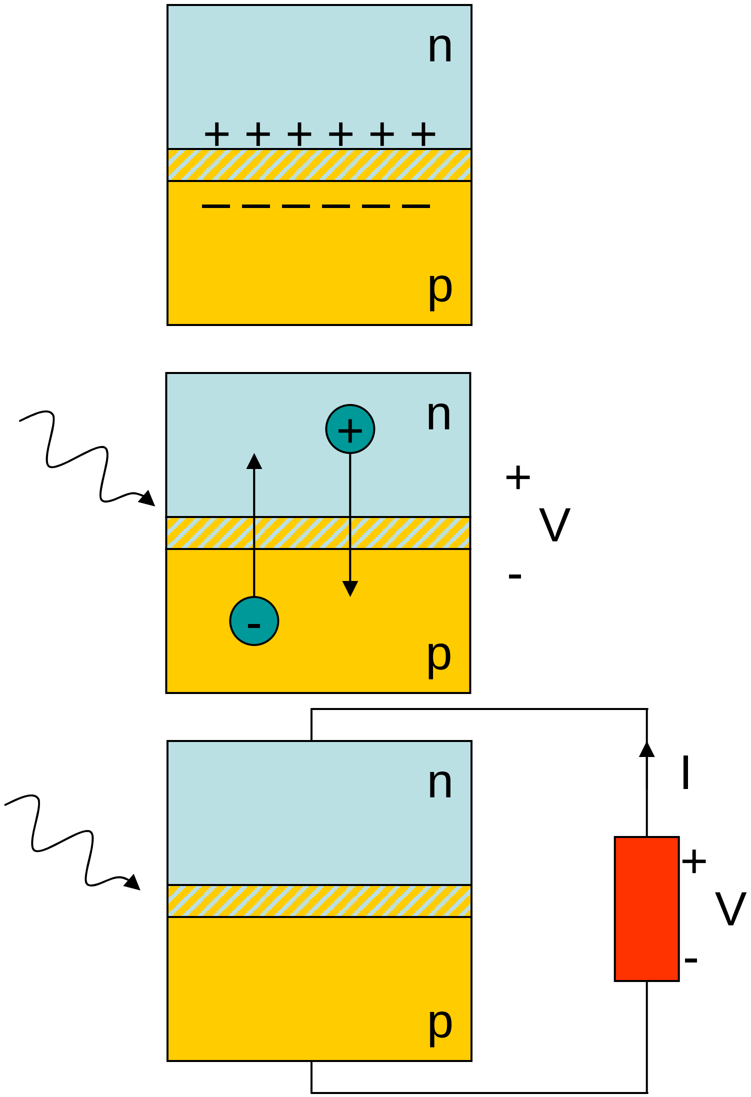
- Solar cells convert visible light to electricity.
- It is one of the “clean” sources of energy.
- In theory a 100 square mile area covered with solar panels would be sufficient for the energy needs of the US.
- Solar cells are based on the photovoltaic effect.

Photovoltaic Effect

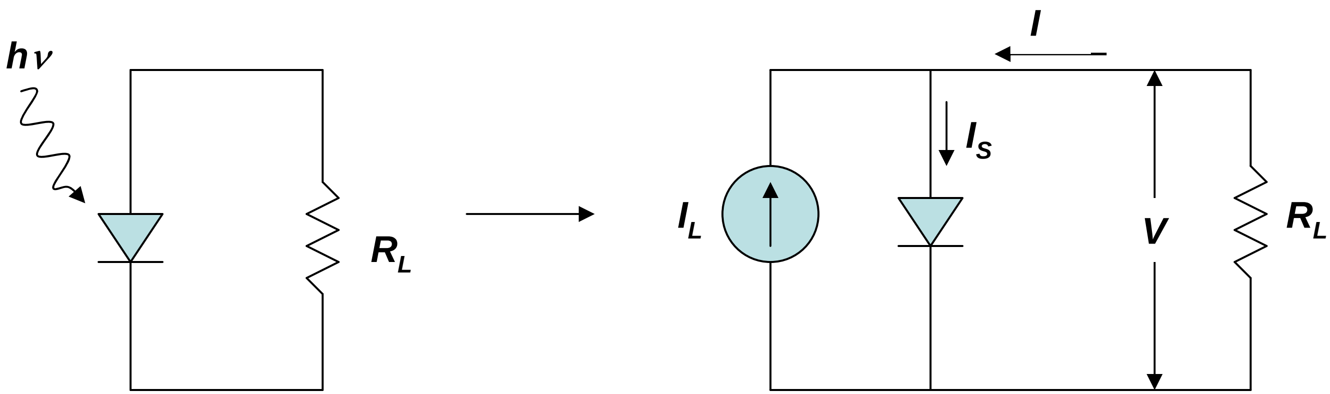
- Discovered in 1839 as a light induced current between two metal electrodes.
- When photons are absorbed in a material, some electrons gain enough energy to become free and contribute to current.
- If the light is incident on a p-n junction, the absorbed photon creates an electron-hole pair.

p-n Junction Solar Cells

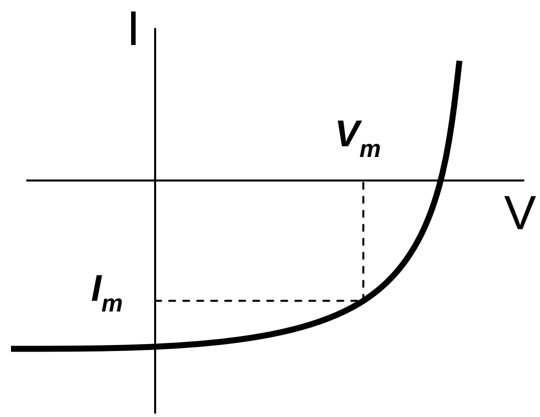
- Most commonly made of crystalline silicon by diffusing an n-type layer into a p-type substrate (or vice versa).
- When a p-n junction is formed, near the junction, the extra electrons from the n-side are attracted to the extra holes from the p-side.
- As the two sides rush towards each other, a neutral depletion layer is formed with a built-in electric field that opposes any further charge movement.
- When light is incident on the junction, each absorbed photon creates an electron-hole pair.
- The electrons and holes are separated by the built-in electric field at the junction. The electrons move to the n-side and the holes to the p-side and create a potential difference.
- If the device is connected to an external load, a current will flow.



Current – Voltage Characteristics



Since the solar cell is essentially a diode, it has the I-V characteristics of one

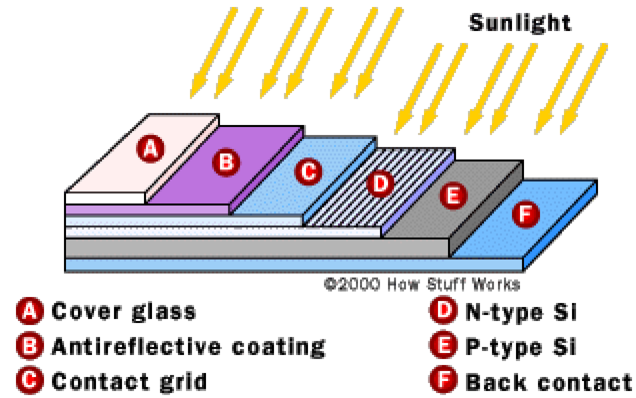


$$P_m = I_m V_m$$

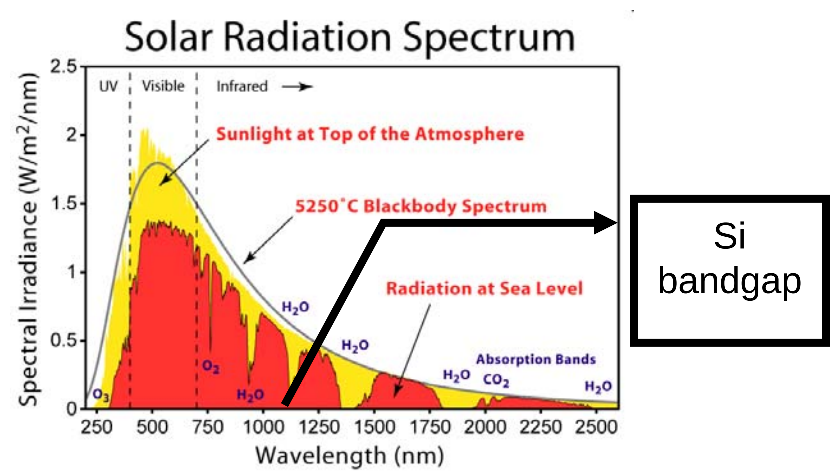
Overall solar cell efficiency: $$\eta = \frac{P_m}{EA_c}$$,where E is solar irradiance in W/m^2 under standard conditions and A_c is the surface area of the solar cell in m^2.

Efficiency in p-n Junction Cells

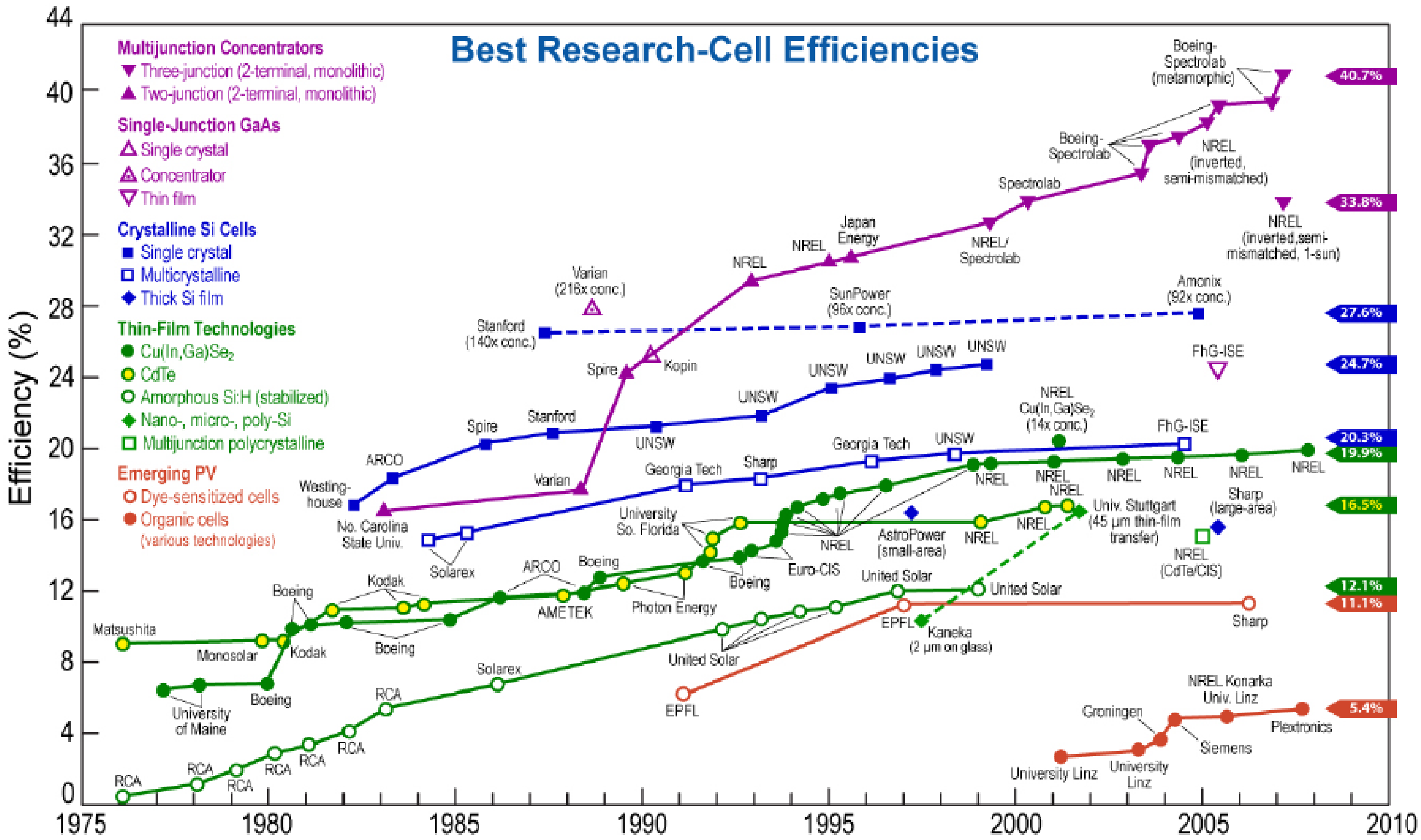
- Practical efficiencies are around 15%.
- Solar cell efficiency is affected by many factors:
  - Reflectance of the surface
  - Band gap of the cell material vs. incident photon energy
  - Collection efficiency of free electrons
  - Internal device resistance



Typical c-Si Solar Cell Structure

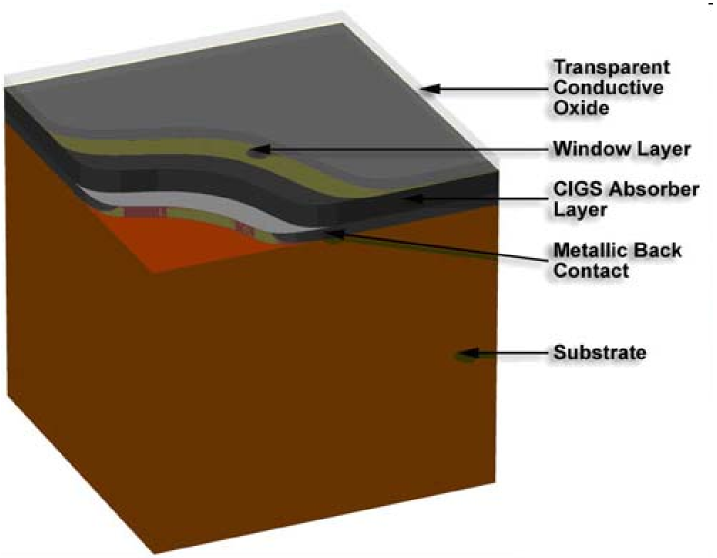


Comparison of Efficiencies



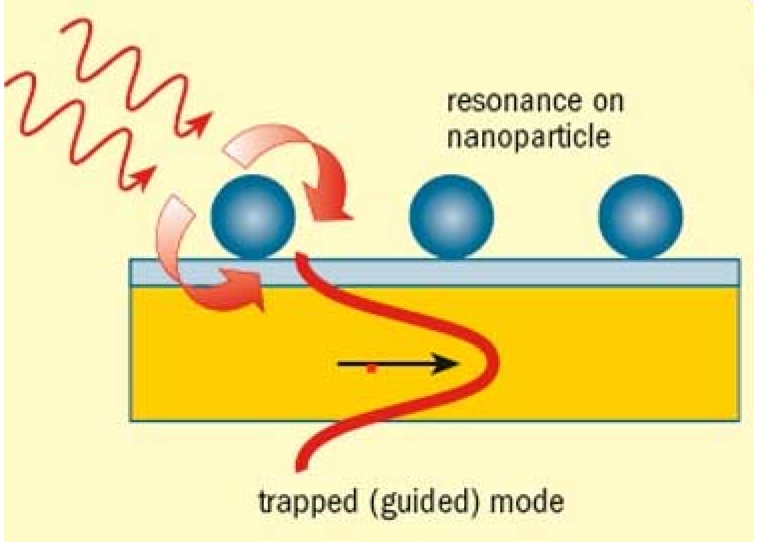
Thin Film Solar Cells

- While many technical difficulties with crystalline cells can be overcome or mitigated, cost is still a major factor.
- Thin film solar cells can be cheaper to manufacture.
- The main materials used in thin film solar cells are amorphous Silicon, CdTe and CIS/CGIS.
- Thicknesses are ~1 micron.
- Efficiencies are < 10%.



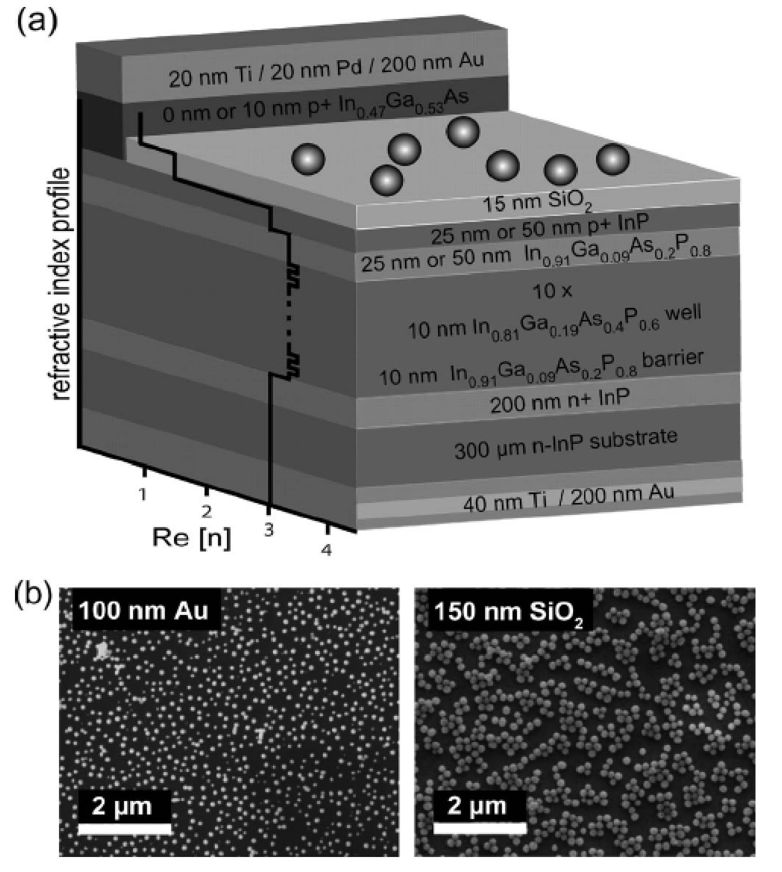
Enhanced Light Scattering with Nanoparticles

- One issue with thin film cells is the reduced absorption of sunlight due to the small thickness of the film.
- One group in Australia (ANU) is using silver nanoparticles to enhance absorption. (Opt. Exp. **16**, 21793 (2008)
- A thin (~100nm) film of silver is deposited on the oxidized surface of a thin silicon film solar cell by vacuum evaporation.
- Subsequent heating at 200 °C creates silver nanoparticles through bubbling.
- The silver nanoparticles can scatter visible light very efficiently and create a trapped mode for the incident light.



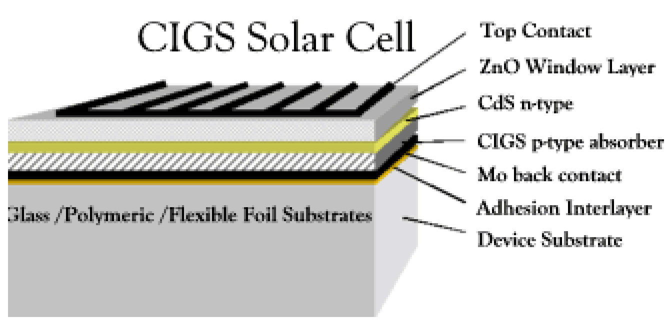
Nanoparticles and Quantum Wells

- Another approach is to combine a quantum well (QW) with nanoparticles. (APPLIED PHYSICS LETTERS **93**, 091107 2008)
- A quantum well is created when a lower band gap material is sandwiched between two higher gap barriers.
- The lower band gap increases light absorption but also traps the carriers.
- Using the nanoparticles enhanced scattering property, fewer QWs can be used.



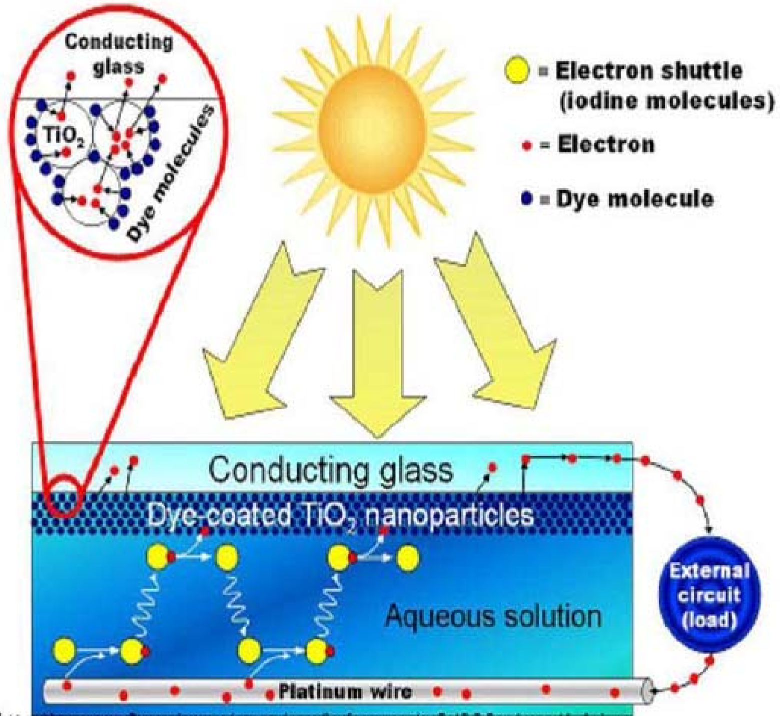
Low Cost CIGS Manufacturing

- A company called ISET has patented a low-cost, non-vacuum approach to the deposition of the CIGS absorber layer.
- This patented process uses water-based inks made from tiny nanoparticles of copper, indium and gallium oxides as precursor materials.
- The proprietary ink formulation allows us to fix the composition of precursor oxides <u>molecularly</u> and thus by gas-solid processing, they accurately and uniformly control the composition of the semiconductor over large areas.



Dye Sensitized Solar Cells

- A photon is absorbed by the dye and excites an electron in the dye.
- The electron is then "injected" into the wires or particles.
- Travels to the electrode, which is connected to an external circuit.
- The dye is regenerated by the electrolyte.



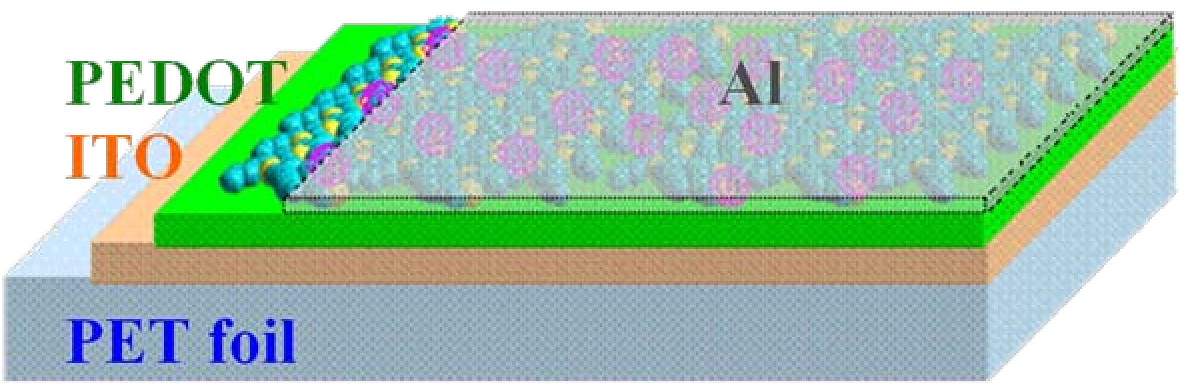
http://www.nsf.gov/news/mmg/media/images/pr04095solarcell_h.jpg

Enhanced Light Absorption with Nanoparticles

- Because c-Si has a band gap in the NIR, most of the energy of the visible and UV photons are wasted as heat when the photon is absorbed.
- Depositing thin layers with different band gaps will improve efficiency but increase cost.
- Creating nanocrystalline layers of porous silicon is a convenient way of achieving this goal.
- When crystals are confined to nanometer size, the band gap of the material becomes wider.
- Porous silicon can be created by electrochemical etching of a c-Si surface and produce ~2 nm size particles with band gaps in the visible or near UV. (IEEE Photonics Technology Letters **16**, 1927-1929 (2004))

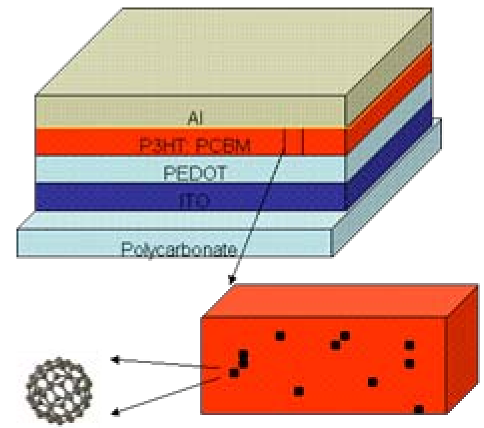
Organic Photovoltaics

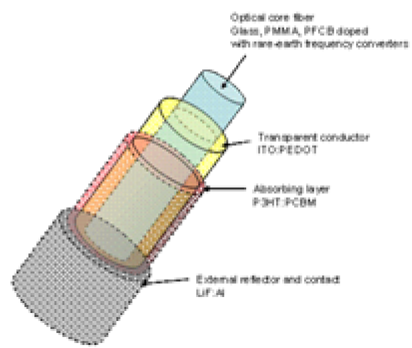
- Unlike p-n junction devices, solar cells made out of organic molecules are made out of electron donor and acceptor materials.
- When an electron-hole pair is created in a polymer chain, it is strongly bound.
- In order to create a current, this pair has to be dissociated. The acceptor material is for this purpose.

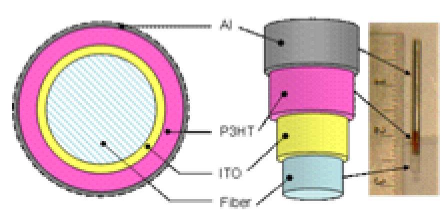


Enhancing Organics PVs with Nanoparticles

- Nanoparticles can be more efficient as acceptors.
- The process, called charge transfer, can increase efficiency.
- WFU Nanotech is very active in this area.







Another Polymer Example

- Using an aluminum oxide template consisting of nanometer sized honeycomb array the polymer P3HT is drawn through the openings through vacuum and capillary forces.
- The structure is then backfilled with C60 which acts as the electron acceptor.
- The aluminum oxide allows the P3HT chains to align themselves in a stacked array which increases conductivity.
- The honeycomb structure increases the surface area which helps with electron transfer.
- While reported efficencies are low (~1 %) the method is cheap and scalable.
- Ref: Adv. Funct. Mater. 2010, 20, 540–545.