

Review on Nanotechnology

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ABSTRACT

Many avenues are being explored to find alternative energy sources and to increase the efficiency of the resources we are already using. The field of efficiently utilizing solar radiation is one of the most promising today because of the large amount of sunlight available on this planet. Conventional solar power technology has two main drawbacks. The cost of manufacturing the components used in solar cells is high, and the efficiency of these devices is low. The use of nano technology is being investigated as a way to overcome these drawbacks. Nano particles have unique qualities which enable them to be tuned to absorb a wider range of wavelengths available in sunlight, thereby increasing efficiency. Their use lowers the cost of manufacture. This paper will explore the possibilities that nano particles offer to the field of solar energy.

1. INTRODUCTION

Traditional solar technology has relied on silicon as the semiconductor in solar cells. Its job is to absorb photons of light, thereby exciting electrons from the valence band to the conduction band and creating positively charged holes. Keeping these charge carriers separated and getting the electrons to flow and provide power is the basic idea behind getting usable energy from the sun.

One limitation to this type of a set up is the band gap of silicon. It cannot be changed easily in the bulk material. Only light that possesses energy equal to this band gap is utilized. Silicon absorbs light in the 500 – 1000 nm range. See Figure 1^[1]. Lower energy light passes through the cell unused. Higher energy light does excite electrons to the conduction band, but any energy beyond the band gap energy is lost as heat. If these excited electrons aren't captured and redirected, they will spontaneously recombine with the created holes, and the energy will be lost as heat or light.

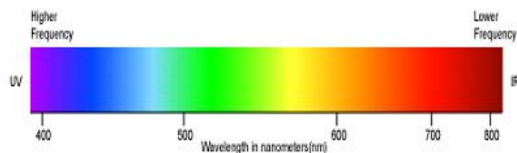


Figure 1:
Visible Light Spectrum

High quality silicon needed for these cells is expensive, as is the batch rather than continuous processing used in manufacturing these cells. Thin films made from less expensive cadmium telluride or cadmium sulfide make the cells more efficient, but vacuum deposition required in the manufacturing still keeps costs high.

2. QUANTUM DOTS OR NANOCRYSTALS

One area of research focuses on quantum dots or nanocrystals. They are made of materials from periodic groups II – VI, III – V, or IV – VI. They range in size from 2 – 10 nm in diameter. Electrons in bulk semiconductor material have energy levels that are so close together that they behave as if the levels were the same. This characteristic sets the band gap energy at a fixed amount. Quantum dots behave differently.

An exciton is defined as an excited electron-hole pair. The average distance between an excited electron and a hole is called the Exciton Bohr Radius.

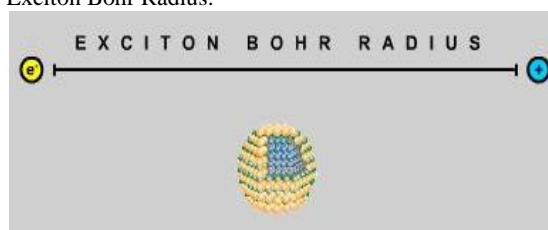


Figure 2. The Exciton Bohr Radius in relation to a quantum dot.^[1]

In bulk material, this radius is much smaller than the semiconductor crystal. But nanocrystal diameters are smaller than this Bohr radius. See Figure 2. Because of this, the “continuous band” of electron energy levels no longer can be viewed as continuous. The energy levels become discrete, and quantum confinement is seen to operate. The difference of a few atoms between two quantum dots alters the band gap boundaries. Small nanocrystals absorb shorter wavelengths or bluer light, whereas larger nanocrystals absorb longer wavelengths or redder light. Changing the shape of the dot also changes the band gap energy level as shown in Figure 3.

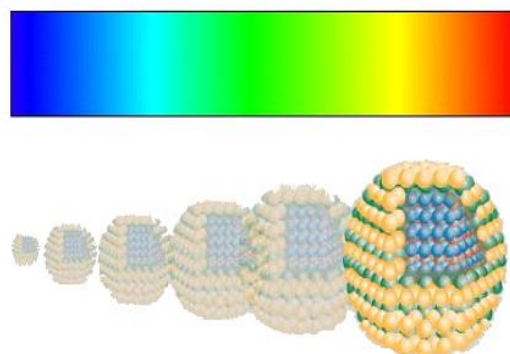


Figure 3. The relationship of size of quantum dot to the light absorbed.^[1]

Multiple excitons can be generated in quantum dot solar cells. If the irradiated energy is 2 – 4 times the band gap energy, two or

more excitons are generated in PbSe and PbS quantum dots. These particular quantum dots also absorb infrared radiation otherwise wasted by conventional cells. Tunable band gaps which increase the range of sunlight captured, and less expensive materials and processing are areas of active research. As exciting as these advances are, they represent only part of the challenge of efficient solar energy conversion. Once these electrons are excited, they must be prevented from recombining with holes, and they must be transported to electrodes.

4. GRATZEL CELLS

In the early 1990's, Professor Gratzel developed a solar cell utilizing a dye that absorbs light. This arrangement is shown in Figure 4.

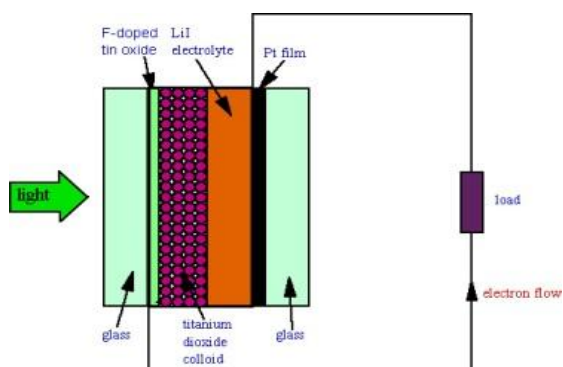


Figure 4. Basic Gratzel cell composition.[2]

Nanoparticles of titanium dioxide, widely available and less expensive than silicon, are used in these cells. TiO_2 has a wide band gap and is able to conduct electrons efficiently once they are in the conduction band. Its band gap is too wide to absorb much sunlight, but when the TiO_2 particles are coated with a metalorganic ruthenium-based dye, the dye absorbs light, becomes oxidized (loses electrons), and injects these electrons into the TiO_2 . These diffuse to the electrode while the holes pass to the LiI electrolyte. The electrons pass through an external load, doing work, then flow to the counter electrode. Here the electrons are carried by iodine ions to regenerate the dye through reduction (gain of electrons). Figure 5 shows this regeneration cycle.

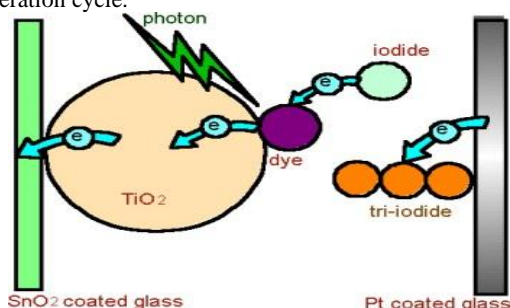


Figure 5. Mechanism of light absorption, electron injection and subsequent transport.[2]

Gratzel cells demonstrate 10% power conversion efficiencies which are comparable to those achieved by current silicon devices.^[7] However, the dyes are sensitive to heat and light. Research is being done to replace the dye molecules with semiconducting InP, CdSe, CdS, and PbS nanocrystals. These absorb light over a broader range than the organic dyes. Nanocrystals prepared with protective shells are more stable than organic dyes and will not photo-bleach or degrade as easily as the dyes do from heat and UV light.

5. CONJUGATED POLYMERS

Conjugated polymers, polymers with "alternating single and double carbon – carbon bonds along the polymer backbone",^[3] are being utilized in photovoltaic cells. The bonding between the carbons is sp-2 hybridized, leaving one unhybridized p-z orbital which comes out of the plane of the polymer. A delocalized electron cloud results from the pi-orbitals as shown in Figure 6. Single and double carbon-carbon bonds have different lengths, and consequently have different energies. Because the bonds alternate along the backbone, they create an energy gap and act as semiconductors.

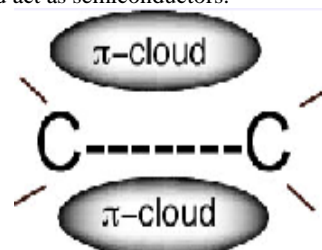


Figure 6. A carbon-carbon bond showing the delocalized electron cloud from the unhybridized p-z orbital.[3]

Hybridization of 3s and 3p orbitals gives four identical hybrid orbitals. Neighboring atoms overlap to form bonding and anti-bonding orbitals. The bonding orbitals overlap, becoming the valence band. The anti-bonding orbitals overlap, becoming the conduction band.^[3] These polymers are less expensive to make than inorganic photovoltaics and are being explored for use in solar cells. Here in Figure 7 is one such arrangement using PPV (poly (2-methoxy-5-(3',7'-dimethyl octoxy)-p-phenylene vinylene) as the electron donor and PCBM (1-(3(methoxy carbonyl) propyl-1-phenyl [6,6] methono-fullerene) as the electron acceptor.

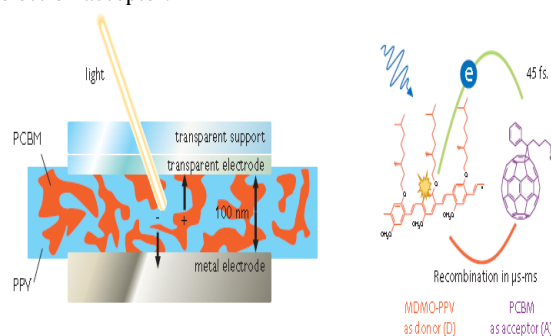


Figure 7. A polymer solar cell on the left, and the photovoltaic process of the cell on the right.[4]

An improved fullerene (C70) that shows better absorption in the visible spectrum has been made. Its structure along with its isomers is shown in Figure 8.

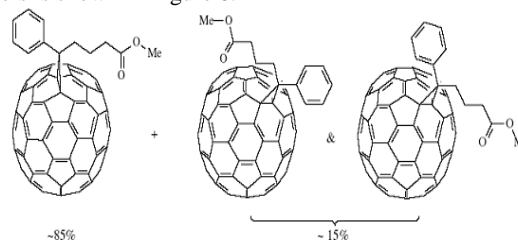


Figure 8. The improved fullerene (C70) and its isomers.[5]

The graph in Figure 9 shows the broader absorption range achieved with the C70 fullerene. Its line on the graph is the solid one.

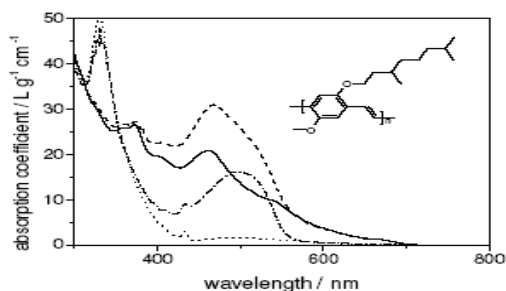


Figure 9. Graph showing the improved range of absorption of the C70 fullerene.[5]

Use of polymers as electron donors to replace dyes in the Grazel cells is also being investigated. MEV-PPV (poly (2-methoxy-5(2-ethyl) hexoxy-phenylene-vinylene) is layered with titanium dioxide (TiO_2) film. The TiO_2 layer has particles 80 nm wide with 20 nm pore diameters between them.[6] The polymer flows into these pores, enhancing the interface between the electron donor (the polymer) and the electron acceptor (TiO_2). This shortens the exciton diffusion length and overcomes the degradation of the ruthenium-based dyes. The mechanism of electron transfer from the polymer to the TiO_2 nanoparticle occurs because of a lowering of electron energy upon transfer as illustrated in Figure 10.

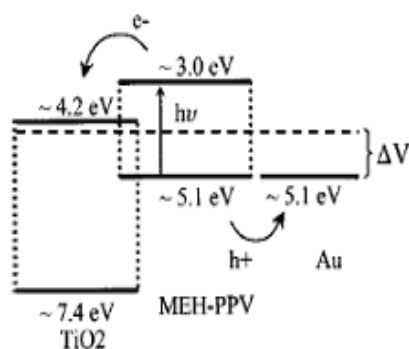


Figure 10. Diagram showing the alignment of energy levels at the TiO_2 /MEH-PPV interface. An electron in the polymer (MEH-PPV) lowers its energy by transferring to a TiO_2 nanoparticle.[6]

6. SUMMARY AND CONCLUSION

In an attempt to find a cheaper, more durable and more efficient way of harnessing energy from the sun, researchers have turned to nanocrystals for some answers. Traditional silicon solar cells are expensive to make, and bulk silicon has a band gap that is not easily changed. This limits the range of sunlight that these devices can utilize. Band gaps in quantum dots can be altered by changing the size of the dots. Grazel cells have the same power conversion efficiencies as silicon cells, but they utilize dyes which photo-degrade. Using nanocrystals and conducting polymers to replace the dyes offers some hope of providing more durable devices. All-organic devices made from conducting polymers are less expensive than traditional solar cells but present challenges of low electron mobility, electron traps and degradation from UV light. Polymer and inorganic nanocrystal devices overcome the low electron mobilities and electron traps, but still photo-degrade. All inorganic nanocrystal-nanocrystal devices have high electron mobilities, few electron traps, and are not sensitive to photo-oxidation. These look to be the most stable devices developed to date. While much work remains to be done to develop efficient and inexpensive solar cells, the progress achieved thus far is very promising.

7. REFERENCES

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