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# Solar Cell Quantum Dots

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### Abstract

Quantum dots have offered an attractive option for photovoltaic. Multi junction solar cells made from quantum dots have been able to achieve around 7% conversion efficiency in the lab. While figures like this may not seem too impressive when compared to silicon solar cells, their promised theoretical conversion efficiency limit is an eye-popping 45%. This is possible because when a single photon is absorbed by a quantum dot, it produces more than one bound electron-hole pair, or exaction, thereby doubling normal conversion efficiency numbers seen in single-junction silicon cells. In this paper discuses about solar cell quantum dots and will be reviewed advantage and disadvantage Quantum dot solar cell.

### Keywords

Quantum Dot, Solar Cell, Nanostructures, Photovoltaic Material

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## 1. Introduction

The Earth receives an incredible supply of solar energy. The sun, an average star, is a fusion reactor that has been burning over 4 billion years. It provides enough energy in one minute to supply the world's energy needs for one year. In one day, it provides more energy than our current population would consume in 27 years. In fact, "The amount of solar radiation striking the earth over a three-day period is equivalent to the energy stored in all fossil energy sources. [1] Solar panels converts the sun's light in to usable solar energy using N-type and P-type semiconductor material. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the photovoltaic (PV) effect. Currently solar panels convert most of the visible light spectrum and about half of the ultraviolet and infrared light spectrum to usable solar energy. Solar energy technologies use the sun's energy and light to provide heat, light, hot water, electricity, and even cooling, for homes, businesses, and industry. There are a variety of technologies that have been developed to take advantage of solar energy. [2]

## 2. About Quantum Dots

Quantum dots are tiny particles or nanocrystals of a semiconducting material with diameters in the range of 2-10 nanometers (10-50 atoms). They were first discovered in 1980. [3] Quantum dots display unique electronic properties, intermediate between those of bulk semiconductors and discrete molecules, that are partly the result of the unusually high surface-to-volume ratios for these particles. [4-6] The most apparent result of this is fluorescence, wherein the nanocrystals can produce distinctive colors determined by the size of the particles. Due to their small size, the electrons in quantum dots are confined in a small space (quantum box), and when the radii of the semiconductor nanocrystal is smaller than the exciton Bohr radius (exciton Bohr radius is the average distance between the electron in the conduction band and the hole it leaves behind in the valence band), there is quantization of the energy levels according to Pauli's exclusion principle. [7-8] The discrete, quantized energy

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levels of quantum dots relate them more closely to atoms than bulk materials and have resulted in quantum dots being nicknamed 'artificial atoms'. Generally, as the size of the crystal decreases, the difference in energy between the highest valence band and the lowest conduction band increases. More energy is then needed to excite the dot, and concurrently, more energy is released when the crystal returns to its ground state, resulting in a color shift from red to blue in the emitted light. As a result of this phenomenon, quantum dots can emit any color of light from the same material simply by changing the dot size. Additionally, because of the high level of control possible over the size of the nanocrystals produced, quantum dots can be tuned during manufacturing to emit any color of light. [9] Typical methods include molecular beam epitaxial, ion implantation, and X-ray lithography. Quantum dots (QDs) are artificial clusters of semiconductive atoms that have the ability to confine the electrons motion due to their small size. One of the most important properties of Quantum Dots is the ability to tune their bandgap and therefore control their light absorbance and emission frequencies. This is done through the quantization of their energy levels. In this way it is possible for their optical and electrical properties to be adjusted according to their purpose of use. The latest advances in technology have shown that QDs can really make valuable contributions to a wide range of applications substituting for many of the bulk, expensive, and inefficient materials. [10]

## 3. Solar Cell Quantum Dots

The recent surge in the utilization of semiconductor nanostructures for solar energy conversion has led to the development of high-efficiency solar cells. Some of these recent advances are in the areas of synthesis of new semiconductor materials and the ability to tune the electronic properties through size, shape, and composition and to assemble quantum dots as hybrid assemblies.

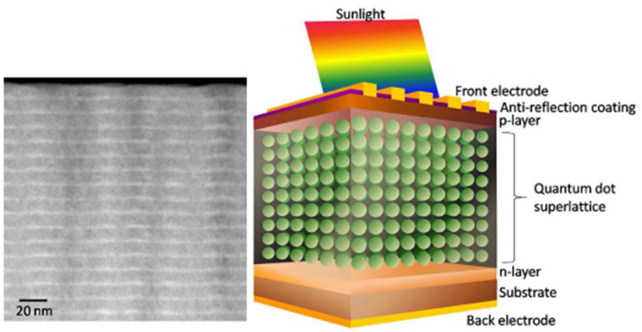


**Fig. 1.** TEM image of self-organized quantum dot super lattice (left) and schematic structure of quantum dot intermediate band solar cell (right).

A quantum dot solar cell is a solar cell design that uses quantum dots as the absorbing photovoltaic material. It attempts to replace bulk materials such as silicon, copper indium gallium selenide (CIGS) or CdTe. Quantum dots have band gaps that are tunable across a wide range of energy levels by changing the dots' size. In bulk materials the bandgap is fixed by the choice of material. This property makes quantum dots attractive for multi junction solar cells, where a variety of materials are used to improve efficiency by harvesting multiple portions of the solar spectrum. [11-12]

Quantum dots are semiconducting particles that have been reduced below the size of the Exciton Bohr radius and due to quantum mechanics considerations, the electron energies that can exist within them become finite, much alike energies in an atom. Quantum dots have been referred to as "artificial atoms". These energy levels are tuneable by changing their size, which in turn defines the bandgap. The dots can be grown over a range of sizes, allowing them to express a variety of bandgaps without changing the underlying material or construction techniques. [13] In typical wet chemistry preparations, the tuning is accomplished by varying the synthesis duration or temperature. The ability to tune the bandgap makes quantum dots desirable for solar cells. Single junction implementations using lead sulfide (PbS) CQDs have bandgaps that can be tuned into the far infrared, frequencies that are typically difficult to achieve with traditional. Half of the solar energy reaching the Earth is in the infrared, most in the near infrared region. A quantum dot solar cell makes infrared energy as accessible as any other. [14]

Moreover, CQDs offer easy synthesis and preparation. While suspended in a colloidal liquid form they can be easily handled throughout production, with a fume hood as the most complex equipment needed. CQDs are typically synthesized in small batches, but can be mass-produced. The dots can be distributed on a substrate by spin coating, either by hand or in an automated process. Large-scale production could use spray-on or roll-printing systems, dramatically reducing module construction costs.

The establishment of low-cost and high-performance solar cells for sustainable energy sources to replace fossil fuels has become an urgent subject to scientists around the world. Because traditional photovoltaic devices (i.e. the p-n junction silicon crystalline solar cells) suffer from high costs of manufacturing and installation, now the focus is on the next generation of solar cells with high efficiency at economically viable costs. As a cost-effective alternative to silicon-based photovoltaics, semiconductor quantum dot (QD)-sensitized solar cells (QDSCs) have attracted considerable attention recently and have shown promising developments for the next generation of solar cells. QDSCs can be regarded as a derivative of dye-sensitized solar cells (DSCs), which were first reported by O'Regan and Gra¨tzel in 1991 (8). In DSCs, the sensitizer commonly uses organic dyes of ruthenium polypyridine complexes. [15]

In a conventional solar cell, light is absorbed by a semiconductor, which has a higher resistance than metal. The semiconductor is doped in order to increase its conductivity. One side of the semiconductor is p-type doped by adding an atom with a valence one lower than the host atoms. This atom takes away a weakly bound outer electron from a host atom and creates a "hole". Adding many of these atoms creates an abundance of holes, and since the holes are actually atoms missing electrons, the p-doped semiconductor has a positive charge. The other side is n-type doped; an atom with a valence one higher than the host atoms is added to the semiconductor, providing an extra electron, and therefore giving the n-doped semiconductor a negative charge. In order to appreciate the potential of quantum dots in solar cell technology, it is important to first be aware of the limitations of conventional solar cells. Crystalline materials such as silicon, cadmium telluride, and copper indium gallium selenide arbsorb photons with energies correspondent to their band gaps, since a specific wavelength of light provides the required amount of energy for an electron to jump from the valence band to the conduction band. Electrons that are excited into higher levels in the conduction band relax by giving off phonons, thus heating up the solar cell without generating electricity. This heating also damages the cell and reduces its performance. Photons that do not provide enough energy for an electron to jump the band gap simply pass through the solar cell. [16]

# 4. Quantum Dot Solar Cell Advantages

Quantum dots hold promise for low-cost solar cells because they can be made using simple, inexpensive chemical reactions. Scientists have calculated that quantum dots could be used to make thin-film photovoltaics that are at least as efficient as conventional silicon cells, and possibly more efficient. The higher possible efficiency is because nanocrystals made of certain semiconductors can emit more than one electron for every photon absorbed. Plus, tweaking their size and shape changes the colors of light they absorb. The next generation of solar cells being researched is focused on efficiency and low cost with quantum dots being the primary point of interest. Quantum dots are the main focus for next generation research because of their unique quantum properties and ability to cover both goals of the next generation of solar cells. The quantum dots are cost-effective in two respects. First, they can be produced rather inexpensively and second, they produce more energy. They can be mass produced through high-throughput roll-to-roll manufacturing, which ends up lowering the cost of quantum dots [17]. Through multiple electron generation, more electricity can be produced for every photon of light, which leads to the contribution of cost-effectiveness [18]. Quantum dots are not only cost-effective, but due to their unique quantum properties, they are also versatile, highly-efficient in conducting an electrical current, and are an ethical option for the next generation of solar cells. A key advantage of the nanowire-quantum dot cells is that they could be made on large areas. "One of the main benefits of quantum dots is that they're grown in and deposited from solution. This translates to fabrication of large-area films, which is necessary for making solar panels. Zinc oxide nanowires are also grown in an aqueous solution process. Scalability should be one of the primary practical advantages of this type of solar cell." Solar cells made from quantum dots could be low-cost, flexible, and easy to make. But the efficiency with which they convert light into electricity remains too low for practical use. Researchers Institute of Technology now shows that incorporating nanowires into quantum dot solar cells increases the cells' efficiency by 35%. [19] Solar-cell technology has advanced rapidly, as hundreds of groups around the world pursue more than two dozen approaches using different materials, technologies, and approaches to improve efficiency and reduce costs. Now a team at MIT has set a new record for the most efficient quantum-dot cells a type of solar cell that is seen as especially promising because of its inherently low cost, versatility, and lightweight. [20]

*Generally the benefits of these solar cells are:*

Tunable band edge offers the possibility to harvest light energy over a wide range of visible-IR light with selectivity

**Fig. 2.** Tunable band edge.

Hot carrier injection from higher excited state (minimizing energy loss during thermalization of excited state)

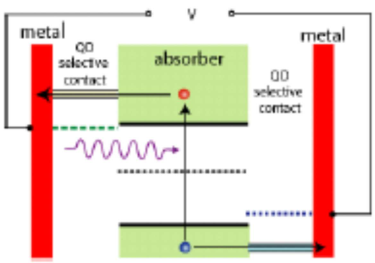


**Fig. 3.** Hot carrier injection from higher excited state.

Multiple carrier generation solar cells. Utilization of high energy photon to multiple electron-hole pairs

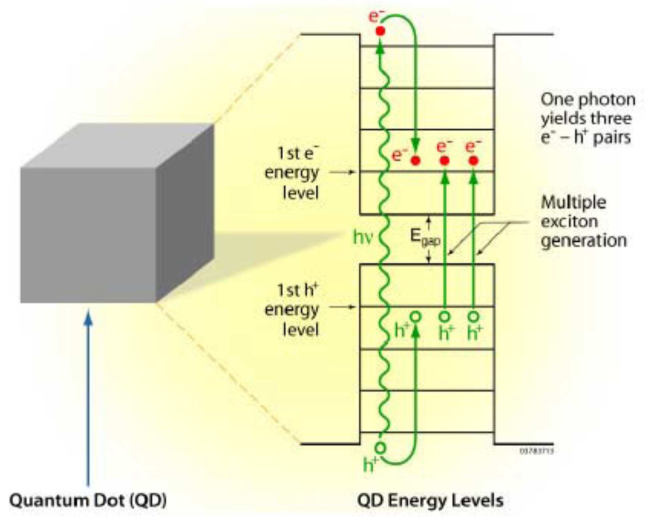


**Fig. 4.** Multiple carrier generation solar cells.

## 5. Conclusion

Quantum dot solar cells have a lot of potential in operation of energy efficiently and with low cost. Quantum dots have many specification that make them better suited for solar cells than bulk materials such as crystalline silicon, including an easy and inexpensive fabrication process, and tunable bandgaps. By stacking quantum dots of different sizes in gradient multi layer nanofilms, solar cells are capable of absorbing all of the sun's spectrum. Multi-layer quantum dot solar cells can provide a clean, renewable and sustainable energy source and so have a hopeful future in energy operation of technology.

## 6. Discussion

Unique properties of quantum dots offer new opportunities to develop low-cost and high efficiency solar cells. Solar energy no carbon dioxide emissions, unlimited supply and available to all. This renewable source is one of the answers to energy independence, but has been previously expensive to implement. Now, with advanced automated tetra pod quantum dot manufacturing, both cost and efficiency concerns are addressed. Solar cells quantum dots can absorb all wavelengths of visible sunlight plus the UV and Infrared. Using proprietary technologies, manufacture very low cost solar cells utilizing Quantum Dot Technology for less than the cost of conventional solar cells. third generation quantum dot solar cells do not require custom made, expensive, nor complex, processing equipment, and we do not use costly silicon or rare earth elements such as indium. Quantum Dot Solar Cells have extremely high potential efficiency; having demonstrated the production of multiple exactions from a single electron. Quantum Materials' Solar cells will come to market competitively priced with the opportunity to reduce prices even further as economies of scale come into effect. Additionally we believe our quantum dot manufacturing capability and print based cell manufacturing process will enable the rapid deployment of additional manufacturing sites across the globe.

## References

[1] http://www.renewableenergyworld.com

[2] Chuang, Chia-Hao M., et al. "Improved performance and stability in quantum dot solar cells through band alignment engineering." *Nature materials* 13.8 (2014): 796.

[3] Ekimov, A. I., and A. A. Onushchenko. "Quantum size effect in three-dimensional microscopic semiconductor crystals." *ZhETF Pisma Redaktsiiu* 34 (1981): 363.

[4] El-Sayed, Mostafa A. "Small is different: shape-, size-, and composition-dependent properties of some colloidal semiconductor nanocrystals." *Accounts of chemical research* 37.5 (2004): 326-333.

[5] Ashoori, R. C. "Electrons in artificial atoms." *Nature* 379 (1996): 413-419.

[6] Collier, C. P., T. Vossmeyer, and J. R. Heath. "Nanocrystal superlattices." *Annual Review of Physical Chemistry* 49.1 (1998): 371-404.

[7] Reimann, Stephanie M., and Matti Manninen. "Electronic structure of quantum dots." *Reviews of Modern Physics* 74.4 (2002): 1283.

[8] Bawendi, Moungi G., Michael L. Steigerwald, and Louis E. Brus. "The quantum mechanics of larger semiconductor clusters ("quantum dots")." *Annual Review of Physical Chemistry* 41.1 (1990): 477-496.

[9] Yoffe, A. D. "Semiconductor quantum dots and related systems: electronic, optical, luminescence and related properties of low dimensional systems." *Advances in Physics* 50.1 (2001): 1-208.

[10] Bagher, Askari Mohammad. "Quantum Dots Applications." *Sensors & Transducers* 198.3 (2016): 37.

[11] Ip, Alexander H., et al. "Hybrid passivated colloidal quantum dot solids." *Nature nanotechnology* 7.9 (2012): 577-582.

[12] Baskoutas, Sotirios, and Andreas F. Terzis. "Size-dependent band gap of colloidal quantum dots." *Journal of applied physics* 99.1 (2006): 013708.

[13] H Sargent, E. "Infrared quantum dots." *Advanced Materials* 17.5 (2005): 515-522.

[14] Ward, Amanda, and Penny Hausher. "Quantum Dots: The Future of Highly-Efficient Solar Cells."

[15] Tian, Jianjun, and Guozhong Cao. "Semiconductor quantum dot-sensitized solar cells." *Nano reviews* 4 (2013).

[16] Sargent, Edward H. "Colloidal quantum dot solar cells." *Nature photonics* 6.3 (2012): 133-135.

[17] Ho, M. "Quantum dots and ultra-efficient solar cells?." *ISIS Press Release Jan* 19 (2006): 4.

[18] Jean, Joel, et al. "ZnO nanowire arrays for enhanced photocurrent in PbS quantum dot solar cells." *Advanced materials* 25.20 (2013): 2790-2796.

[19] Nanowires Boost Efficiency of Quantum Dot Solar Cells by Prachi Patel, Materials Research Society | Published: 18 April 2013.

[20] Improving a new breed of solar cells, Quantum-dot photovoltaics set new record for efficiency in such devices, could unlock new uses. David L. Chandler | MIT News Office, May 27, 2014.