

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

## A Study on Quantum Dot and its Applications

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**ABSTRACT:** Quantum Dots(QD) are semiconductor nanocrystals with diameters in the range of 2-10 nanometers. The electronic properties of the quantum dots fall between those of bulk semiconductors and those of discrete molecules of comparable size, and optoelectronic properties such as band gap, can be tuned as a function of particle size(QD) for a given composition. Generally, as the size of the QD decreases, the difference in energy between the valence band and the conduction band increases. Thus 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 colour shift from red to blue in the emitted light. As a result of this phenomenon, quantum dots can emit any colour of light from the same material simply by changing the dot size. The easily tuneable band gap of quantum dots makes them especially suited for optical applications, including LEDs, displays and photovoltaic cells. In the seminar we shall further discuss on applications, advantages and disadvantages of QDs.

**KEYWORDS:** Quantum Dot, Semiconductor Quantum Dots

### I. INTRODUCTION

Quantum dots (QD) are semiconductor devices that tightly confine electrons or holes in all three spatial dimensions. They can be made via several possible routes including colloidal synthesis, plasma synthesis, or mechanical fabrication. The term “quantum dot” was coined by Mark Reed in 1988, however they were first discovered in a glass matrix by Alexey Ekimov in 1981 and in colloidal solutions by Louis E. Brus in 1985. The electronic properties of the quantum dots fall between those of bulk semiconductors and those of discrete molecules of comparable size, and electronic properties such as band gap, can be tuned as a function of particle size and shape for a given composition. For example, the photoluminescence of a QD can be manipulated to specific wavelengths by controlling particle diameter. Larger QDs (radius of 5-6 nm, for example) emit longer wavelengths resulting in emission colors such as orange or red. Smaller QDs (radius of 2-3 nm, for example) emit shorter wavelengths resulting in colors like blue and green, although the specific colors and sizes vary depending on the exact composition of the QD Units

Because of the high tunability of properties, QDs are of interest in many research applications such as transistors, solar cells, LEDs, and diode lasers. For example, the ability of QDs to precisely convert and tune a spectrum makes them ideal for LCD displays. Previous LCD displays can waste energy converting red-green poor, blue-yellow rich white light into a more balanced lighting. By using QDs, only the necessary colors for ideal images are contained in the screen. The result is a screen that is brighter, clearer, and more energy-efficient. The first commercial application of quantum dots was the Sony XBR X900A series of flat panel televisions released in 2013. QDs are also being researched as possible qubits for quantum computing. Beyond electronic applications, QDs are also being investigated in the medical field for medical imaging

### II. QUANTUM CONFINEMENT

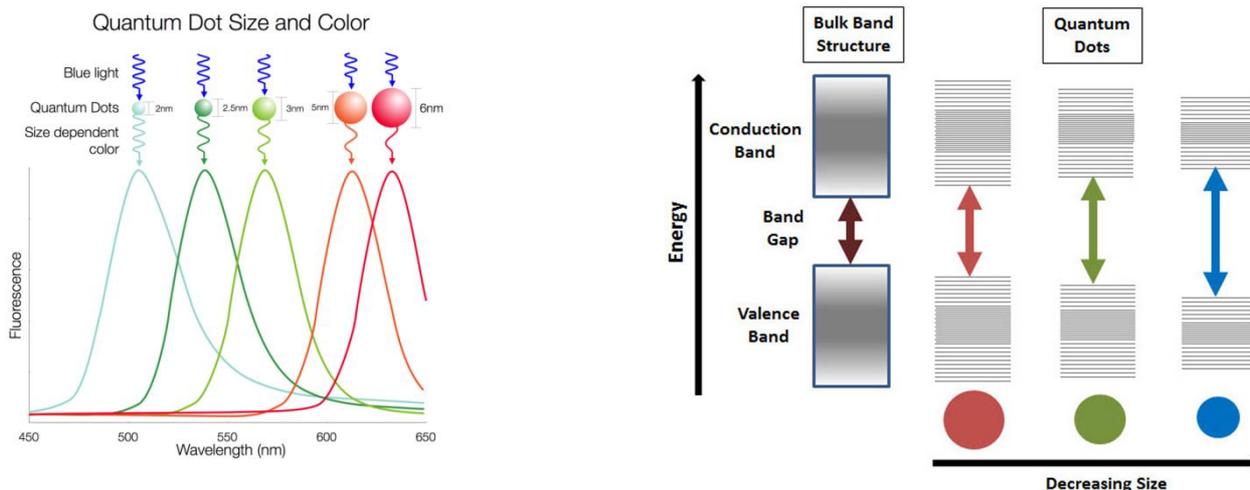
The quantum confinement effect is essentially due to changes in the atomic structure as a result of direct influence of ultra-small length scale on the energy band structure. The length scale corresponds to the regime of quantum confinement ranges from 1 to 25 nm for typical semiconductor groups of IV, III-V and II-VI. In which the spatial extent of the electronic wave function is comparable with the particle size. As a result of these “geometrical” constraints, electrons “feel” the presence of the particle boundaries and respond to changes in particle size by adjusting

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their energy. This phenomenon is known as the quantum-size effect. Quantization effects become most important when the particle dimension of a semiconductor near to and below the bulk semiconductor Bohr exciton radius which makes materials properties size dependent. In general, the Bohr radius of a particle is defined as  $a = \epsilon m a_0 / m^*$  where  $\epsilon$  is the dielectric constant of the material,  $m^*$  is the mass of the particle,  $m$  is the rest mass of the electron, and  $a_0$  is the Bohr radius of the hydrogen atom. When the particle size approaches Bohr exciton radius, the quantum confinement effect causes increasing of the excitonic transition energy and blue shift in the absorption and luminescence band gap energy. In addition, quantum confinement leads to a collapse of the continuous energy bands of a bulk material into discrete, atomic like energy levels. The discrete structure of energy states leads to a discrete absorption spectrum, which is in contrast to the continuous absorption spectrum of a bulk semiconductor. A quantum confined structure is one in which the motion of the carriers (electron and hole) are confined in one or more directions by potential barriers. Based on the confinement direction, a quantum confined structure will be classified into three categories as quantum well, quantum wire and quantum dots. Based on the quantum effect as the size of the QD decreases, the difference in energy between the valence band and the conduction band increases. Thus 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 colour shift from red to blue in the emitted light.



### III. APPLICATIONS

#### Quantum dot displays

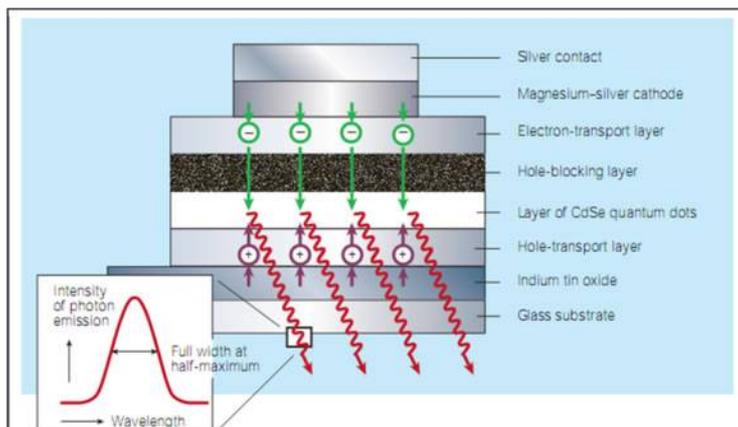
QD LED or QLED is considered as a next generation display technology after OLED\_Displays. QLED means Quantum dot light emitting diodes and are a form of light emitting technology and consist of nano-scale crystals that can provide an alternative for applications such as display technology. The structure of a QLED is very similar to the OLED technology. But the difference is that the light emitting centres are cadmium selenide (CdSe) nanocrystals, or quantum dots. A layer of cadmium-selenium quantum dots is sandwiched between layers of electron-transporting and hole-transporting organic materials. An applied electric field causes electrons and holes to move into the quantum dot layer, where they are captured in the quantum dot and recombine, emitting photons. The spectrum of photon emission is narrow, characterized by its full width at half the maximum value.

There are two major fabrication techniques for QD-LED, called phase separation and contact-printing. QLEDs are a reliable, energy efficient, tuneable colour solution for display and lighting applications that reduce manufacturing costs, while employing ultra-thin, transparent or flexible materials.

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### QLEDs advantages:

Pure colour — Will deliver 30-40% luminance efficiency advantage over organic light emitting diodes (OLEDs) at the same colour point.

Low power consumption — QLEDs have the potential to be more than twice as power efficient as OLEDs at the same colour purity.

Low-cost manufacture — The ability to print large-area QLEDs on ultra-thin flexible substrates will reduce luminaire manufacturing cost.

Ultrathin, transparent, flexible form factors — QLEDs will enable designers to develop new display and lighting forms not possible with existing technologies.

Category		LCD TV	QD TV	OLED TV
Definition	Response speed	1~5 ms	1~5 ms	Less than 0.001 ms
	Contrast ratio	5000:01:00	5000:01:00	infinite
	Viewing angle (Brightness/contrast)	50°/20°	50°/20°	Free
	Color accuracy	Less than 100%	More than 125%	108%
Display method	Display images as the light from the backlight goes through the LCD and color filter	Similar to LCD, uses QD film or tube in front of the backlight to express colors	Display images as the OLED particles self-emits light, without the need for a backlight	

### Quantum dot solar cells

High energy costs, dependence on foreign oil, unstable governments, the threat of global warming and increased greenhouse gases; we know the problems but we have not done enough to solve them...until now.

Quantum Dot Solar cells can absorb energy 24/7. While common black silicon panels are best at absorbing visible light at the peak times of the day, QD Solar Cells can absorb power from the ultraviolet, visible to the infrared lighting range to produce their power, day and night. The typical silicon wafer solar panel is power rated using sunlight at zenith

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(climax or high point) which provides a radiance of just over 1 kilowatt per square meter at sea level. This peak energy is a combination of 527 watts of infrared radiation (IR), 445 watts of visible light, and 32 watts of ultraviolet radiation (UV). The wafer type silicon solar cells available today can only process visible sunlight. That means over half of the energy available from IR and the remainder in the UV are not being absorbed so they can be converted to electricity. Instead these IR and UV light waves become detrimental thermo energy which further limits the absorption of silicon solar panels. 56% of the available energy to be converted to electricity is LOST using today's solar cells.

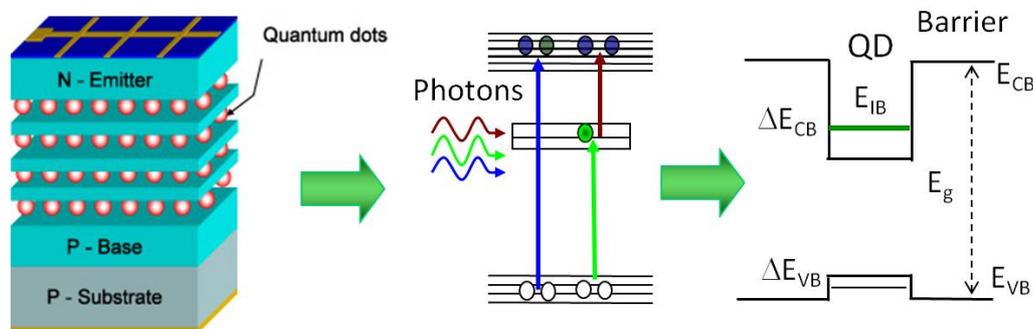
Qd solar cell is aimed to develop ultra high efficiency solar cells based on self assembled quantum dot (QD) nanostructures. Ideally quantum dot cells are combined with these traditional thin-film semiconductor cell designs, or applied using a mixture of nanocrystalline quantum dots optimized for different wavelengths. III-(As, Sb) quantum dots are incorporated into the i-region of a p-i-n junction for multi-photon absorption. Based on theoretical predictions, these QD solar cells have potential for efficiencies greater than 50%.

In a conventional solar cell, light is absorbed by a semiconductor, producing an electron-hole (e-h) pair; the pair may be bound and is referred to as an exciton. This pair is separated by an internal electric field present in p-n junctions or Schottky diodes and the resulting flow of electrons and holes creates electric current. The internal electric field is created by doping one part of semiconductor interface with atoms that act as electron donors (n-type doping) and another with electron acceptors (p-type doping) that results in a p-n junction. Generation of an e-h pair requires that the photons have energy exceeding the bandgap of the material. Effectively, photons with energies lower than the bandgap do not get absorbed, while those that are higher can quickly thermalize to the band edges, reducing output. The former limitation reduces current, while the thermalization reduces the voltage. As a result, semiconductor cells suffer a trade-off between voltage and current (which can be in part alleviated by using multiple junction implementations). The detailed balance calculation shows that this efficiency can not exceed 31% if one uses a single material for a solar cell.

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. 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.

Moreover, CQDs offer easy synthesis and preparation. While suspended in a colloidal liquid form they can be easily handled throughout production, with a fumehood 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.



## Quantum computing

Quantum computing studies theoretical computation systems (quantum computers) that make direct use of quantum-mechanical phenomena, such as superposition and entanglement, to perform operations on data. Quantum computers are different from digital electronic computers based on transistors. Whereas digital computers require data to be encoded

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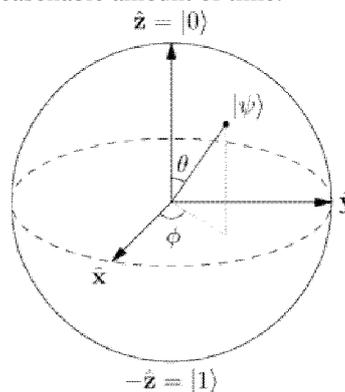
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into binary digits (bits), each of which is always in one of two definite states (0 or 1), quantum computation uses quantum bits (qubits), which can be in superpositions of states. A quantum Turing machine is a theoretical model of such a computer, and is also known as the universal quantum computer. Quantum computers share theoretical similarities with non-deterministic and probabilistic computers. The field of quantum computing was initiated by the work of Paul Benioff and Yuri Manin in 1980, Richard Feynman in 1982, and David Deutsch in 1985. A quantum computer with spins as quantum bits was also formulated for use as a quantum space-time in 1968.

As of 2016, the development of actual quantum computers is still in its infancy, but experiments have been carried out in which quantum computational operations were executed on a very small number of quantum bits. Both practical and theoretical research continues, and many national governments and military agencies are funding quantum computing research in an effort to develop quantum computers for civilian, business, trade, and national security purposes, such as cryptanalysis.

Large-scale quantum computers would be able to solve certain problems much more quickly than any classical computers that use even the best currently known algorithms, like integer factorization using Shor's algorithm or the simulation of quantum many-body systems. There exist quantum algorithms, such as Simon's algorithm, that run faster than any possible probabilistic classical algorithm. Given sufficient computational resources, in theory a classical computer could be made to simulate any quantum algorithm, as quantum computation does not violate the Church-Turing thesis. Quantum computers, on the other hand, may be able to efficiently solve problems that no classical computer would be able to solve within a reasonable amount of time.



The Bloch sphere is a representation of a qubit, the fundamental building block of quantum computers.

## Biological Applications

- Cellular Imaging
- Real-time tracking of molecules and cells over extended periods of time
- Can detect tumor
- Observing Component of cell

## IV. ADVANTAGES

1. Cost effective
2. Can be used in various forms
3. High resistance to metabolic degradation
4. Require a small amount of energy in order to be excited

## V. DISADVANTAGES

1. QDs may be toxic for the cell and inappropriate for any biological application.
2. They cannot diffuse across cellular membranes
3. Quantum Dots may blink and become invisible.
4. the manufacturing of blue emitting QDs is a difficult process.

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## VI. CONCLUSION

Despite any disadvantages, the versatility and flexibility of QDs have proven to be valuable assets, capable of outweighing any negative aspects. This great advantage alone makes them excellent candidates for the production line and particularly significant for future developments

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