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ADVANCEMENTS IN THE FIELD OF QUANTUM DOTS

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ABSTRACT

Quantum dots are defined as very small semiconductor crystals of size varying from nanometer scale to a few micron i.e. so small that they are considered dimensionless and are capable of showing many chemical properties by virtue of which they tend to be lead at one minute and gold at the second minute.

Quantum dots house the electrons just the way the electrons would have been present in an atom, by applying a voltage. And therefore they are very judiciously given the name of being called as the artificial atoms. This application of voltage may also lead to the modification of the chemical nature of the material anytime it is desired, resulting in lead at one minute to gold at the other minute. But this method is quite beyond our reach.

A quantum dot is basically a semiconductor of very tiny size and this special phenomenon of quantum dot, causes the band of energies to change into discrete energy levels. Band gaps and the related energy depend on the relationship between the size of the crystal and the exciton radius. The height and energy between different energy levels varies inversely with the size of the quantum dot. The smaller the quantum dot, the higher is the energy possessed by it.

There are many applications of the quantum dots e.g. they are very wisely applied to:

Light emitting diodes: LEDs eg. White LEDs, Photovoltaic devices: solar cells, Memory elements, Biology : biosensors, imaging, Lasers, Quantum computation, Flat-panel displays, Photodetectors, Life sciences and so on and so forth.

The nanometer sized particles are able to display any chosen colour in the entire ultraviolet visible spectrum through a small change in their size or composition.

KEYWORDS: Artificial atoms, Colloidal Synthesis, Lithography, Epitaxy, Multiple Exciton Generation, Metamaterials.

1.INTRODUCTION

Quantum dots house the electrons just the way the electrons would have been present in an atom, by applying a voltage. And therefore they are termed as the artificial atoms. This applied voltage may also lead to the modification of the chemical nature of the material anytime it is desired, which results in a very rare behavior of the material showing lead at one minute and gold at the other minute. But this method is quite beyond our reach.

A quantum dot is basically a semiconductor of very tiny size and this special phenomenon of quantum dot, causes the band of energies to turn to discrete energy levels. Band gaps and the related energy are dependent on the relationship between the size of the crystal and the exciton radius. The height and energy between different energy levels varies inversely with the size of the quantum dot. The smaller the quantum dot, the higher is the energy possessed by it.

The nanometer sized particles are able to display any chosen colour in the entire ultraviolet visible spectrum through a small change in their size or composition.

Smaller sized quantum dots give rise to higher energy which results in smaller wavelength. This smaller wavelength will affect the colour of the dot i.e. for the more wavelength the colour will be red and with decrease in wavelength the colour will gradually change towards blue.

For a CdSe quantum dot, 5nm sized dot will show red colour whereas 1.5nm dot will show violet colour.

Dots could also constitute materials which are capable of absorbing and emitting lights at any wavelength their designer set them in or could serve as more efficient and better tuned semiconductor lasers.

2. The three major fabrication methods for quantum dots are:

2.1 COLLOIDAL SYNTHESIS

By growing the quantum dots in a beaker which may be made up of nearly any semiconductor and many a metals eg cobalt, gold, nickel etc.

2.2 LITHOGRAPHY

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By growing the quantum dots in a semiconductor heterostructure which refers to a plane of one semiconductor sandwiched between two other semiconductors. If this sandwiched layer is very thin i.e. about 10 nanometers or less, then the electrons can no longer move vertically and thus are confined to a particular dimension. This is called the quantum well.

When a thin slice of this material is taken to create a narrow strip then it results in a quantum wire, as it gets trapped in a 2 dimensional area.

Rotating this to 90 degrees and repeating the procedure results in the confinement of the electron in a 3 dimension which is called the quantum dot.

According to quantum mechanics and Heisenberg's uncertainty principle, the more confined an electron is, the more uncertain is its momenta; and hence, the wider the range of momentum is, the higher is the energy possessed by the electron i.e. may be infinite in case the electron is confined to an infinitely thin layer.

The electrons confined in an electron wire are free only in one dimension, those confined in a plane are have no freedom in the 3rd dimension, and those confined in a quantum dot are not free in any dimension.

2.3 EPITAXY:

Self-assembled dots can also be grown by depositing a semiconductor with larger lattice constant on a semiconductor with smaller lattice constant eg. Germanium on Silicon. These self-assembled dots are then used to make quantum dot lasers.

Hence, the quantum dots are actually formed when very thin semiconductor films buckle due to stress of having lattice structure slightly different in size from those on which the films are grown.

3. APPLICATION

Dots promise a wide range of properties in electronic and optical applications. Some of the applications include the following fields:

- ✓ Photovoltaic devices: solar cells
- ✓ Biology : biosensors, imaging
- ✓ Light emitting diodes: LEDs eg. White LEDs
- ✓ Quantum computation
- ✓ Flat-panel displays
- ✓ Memory elements
- ✓ Photodetectors
- ✓ Lasers
- ✓ Life sciences.

Out of the numerous applications of quantum dots, one of the major application is in the field of solar cells.

Most solar cells are made up of a sandwich of two crystal layers: one that is slightly negatively charged and one that is slightly positive. The negatively charged crystal layer has extra electrons, and when a photon with enough energy strikes the material, it emits an electron on the positively charged layer, increasing its energy and leaving behind a "hole." The electron-hole pairing is called an exciton. If the photon doesn't have enough energy, the electron stays put. If the photon has too much energy, the charge flows using only the energy it needs, and the remainder warms up the device.

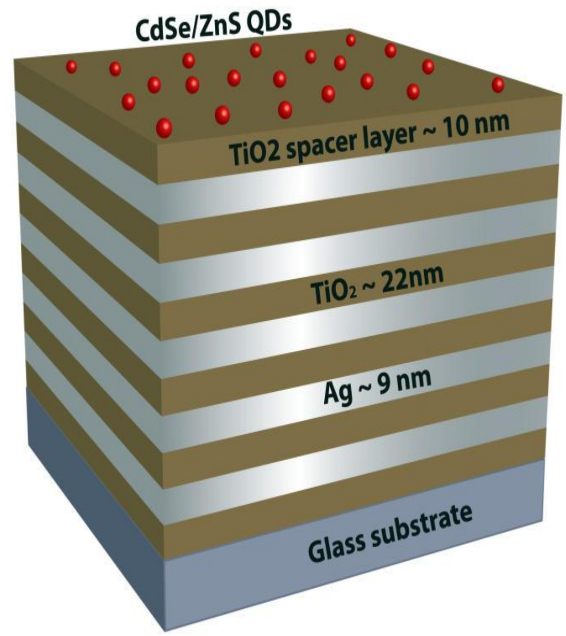
MEG, abbreviated name for Multiple Exciton Generation, is one of the technologies of "third-generation" solar technology. Using these advances, solar panels can possess the advantages of being thinner, lighter, cheaper, more flexible and fundamentally more efficient than current devices on the market. As a result, solar energy will be more cost-effective and will form a greater share of the world's energy supply. The small size of quantum dots allows them to contain charges and more efficiently convert light to electricity. When a photon that has at least double the energy that is needed to move an electron strikes the lead selenide quantum dots, it can excite two or more electrons instead of letting the extra energy go to waste, generating more current than a conventional solar cell.

By this way, the energy can be saved in case of a quantum dot solar cell which is not possible in case of traditional solar cells.

Since the quantum dot band gap is tunable, so Quantum dots can generate multiple exciton (electron-hole pairs) after collision with one photon. So, the generation of electricity increases and the maximum theoritical efficiency can be raised to a range as high as 63.2%.

4. BOOSTING THE EFFICIENCY

Besides cost, another limitation of solar cell has always been its efficiency. It indicates towards producing such material which can be optimized to generate electricity with maximum efficiency. This can be done using 'metamaterials' which shows properties not found in the nature and are capable of changing the properties of light dramatically.



Metamaterials consists of layers of silver and titanium oxide and the tiny components called quantum dots. As we have discussed, the metamaterials have the capability of changing the properties of light dramatically. The light becomes "hyperbolic," which increases the output of light from the quantum dots. Such materials could easily enhance the efficiency of the solar cells. "Altering the topology of the surface by using metamaterials provides a fundamentally new route to manipulating light," said Evgenii Narimanov, a Purdue University associate professor of electrical and computer engineering. Researchers are working to perfect the metamaterials, which might be capable of ultra-efficient transmission of light, with potential applications including advanced solar cells and quantum computing.

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5. ADVANTAGES

1) Quantum dots may be able to increase the efficiency and reduce the cost of today's typical silicon photovoltaic cells.

2)1-D architectures are useful for designing next generation solar cells.

3) Quantum dots may result in a 7-fold increase in final output according to the experiments being done since 2006. The experiments show that quantum dots of lead selenide can produce as many as seven excitons from one high energy photon of sunlight (7.8 times the bandgap energy). This compares favorably to today's photovoltaic cells which can only manage one exciton per high-energy photon, with high kinetic energy carriers losing their energy as heat.

4) Quantum dot photovoltaics are theoretically very cheaper to manufacture.

6. REFERENCE

1) Mark A. Reed, M. A., January 1993, SCIENTIFIC AMERICAN, *Quantum Dots*, Available from: www.eng.yale.edu/reedlab/publications/58%20QDotsSciAm1993.pdf
2) Holister, P., Vas, C. R., and Harper, T., October 2003, Technology White Papers nr. 13, *Quantum Dots*, Available from: http://images.iop.org/dl/nano/wp/quantum_dots_WP.pdf
3) Gunjan Mishra, *Quantum Dots*, Available from: http://wolfweb.unr.edu/homepage/bruch/Phys461/6.pdf
4) Brittany Webb, *Quantum Dots*, Available from: ion.chem.usu.edu/~tapaskar/Britt-Quantum%20Dots.pdf
5) http://www.evidenttech.com/search
6) http://www.sciencedaily.com/releases/2012/05/120524143529.htm
7) http://www.scientificamerican.com/article.cfm?id=quantum-dots-and-more-use
8) Kamat, P., October 2008, Workshop on Nanoscience for Solar Energy Conversion, *Quantum Dot Solar Cells: Semiconductor Nanocrystals As Light Harvester,* Available from:portal.ictp.it/energynet/material/Kamat.pdf
9) http://www.wikipedia.org

