AN ELABORATION OF QUANTUM DOTS AND ITS APPLICATIONS

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ABSTRACT

Being a semiconductor of very tiny size, quantum dots cause the band of energies to change into discrete energy levels. Band gaps and their related energy depend on the relationship between the size of the crystal and the exciton radius. The height and the energy between different energy levels varies inversely with the size of the quantum dot. The smaller the quantum dot, the higher is the energy it possesses. Quantum dots are defined as very small semiconductor crystals of size varying from nanometer scale to a few micron i.e. they are 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 generally 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 named as the artificial atoms. This application of voltage may 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 in the present scenario. The applications of the quantum dots are quite vast e.g. they are very effectively 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 when a small change in their size or composition is done.

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

I. INTRODUCTION

Quantum dots, otherwise known as the artificial atoms, house the electrons just the way the electrons would have been present in an atom, by applying a voltage. 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 till now.

Being a semiconductor of very small size, quantum dot causes the band of energies to turn to discrete energy levels. Band gaps and related energy depend on the relationship between the size of the crystal and the exciton radius. The height and the 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[3] are able to display any chosen colour in the entire ultraviolet visible spectrum through a minor change of their own size or composition.

Fig.1 Quantum dots arranged by size, emitting light of different colours

Smaller sized quantum dots give rise to the higher energy which results in smaller wavelength[4]. This smaller wavelength will affect colour of the dot i.e. for more wavelength the colour will be red and with decrease in wavelength the colour will gradually change towards blue.
For a CdSe quantum dot, a dot sized 5nm will show red colour whereas 1.5nm sized dot will show violet colour. Dots could also constitute of the 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.
Here we are going to highlight the field of quantum dots with the help of its fabrication process, its applications, the ways to boost energy using quantum dot, and some of the paths which can be covered in the near future so as to obtain new applications through quantum dots.

II. FABRICATION METHODS

2.1 LITHOGRAPHY:

By growing 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 not move vertically and thus are confined to a particular dimension[2]. This is called the quantum well.
When 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 confines the electron in a 3 dimension which is called the quantum dot.
According to quantum mechanics and the Heisenberg's uncertainty principle[1], 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 have no freedom in the 3^{rd} dimension, and those confined in a quantum dot are not free in any dimension.

2.2 COLLOIDAL SYNTHESIS:

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

2.3 EPITAXY:

Self-assembled dots are also 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 used to make quantum dot lasers.

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

III. APPLICATION

Dots provide a wide range of properties in electronic and optical applications[4]. Some of the applications include the following fields:

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

Out of these 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 positively charged. The negatively charged crystal layer has many 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 known as an exciton. If the photon has insufficient energy, the electron stays put. If the photon has more than enough 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 the "third-generation" solar technology. Using these advancements, 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 of this, solar energy will be more cost-effective and will form a greater share of the world's energy supply. The smaller size of quantum dots allows them to contain charges and more efficiently convert light to electricity. When a photon having 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 the quantum dot solar cell which is not possible in case of traditional solar cells.

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

IV. WAYS OF BOOSTING THE EFFICIENCY

Besides cost, another limitation of the solar cell has always been its efficiency. It indicates 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 properties of light dramatically.

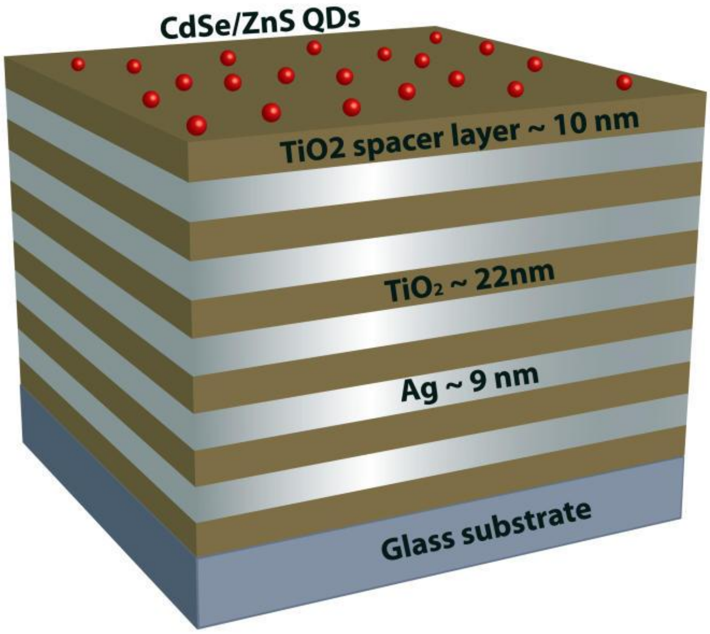

Fig.2 Nano-structured metamaterial [12].

Metamaterials consist of layers of silver and titanium oxide and the tiny components called quantum dots. As we have already discussed, the metamaterials have the capability of changing the properties of light dramatically. The light hence becomes "hyperbolic," which increases the output of light from the quantum dots. Such materials could easily enhance the efficiency of solar cells.

"Altering the topology of the surface by using metamaterials provides fundamentally new route to manipulating light," said Evgenii Narimanov, a Purdue University associate professor of electrical and computer engineering. Researchers are working to make the metamaterials perfect, which might be capable of ultra-efficient transmission of light, with potential applications including advanced solar cells and quantum computing.

V. BOONS PROVIDED BY QUANTUM DOTS

1) Quantum dots may result in a 7-fold increase in final output according to the experiments being done from 2006. The experiments show that the 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 present photovoltaic cells which can only manage one exciton per high-energy photon, with high kinetic energy carriers losing their energy as heat.
2) One dimensional architectures are useful for designing next generation solar cells.
3) Quantum dots may be able to increase the efficiency and reduce the cost of present day's typical silicon photovoltaic cells.
4) Quantum dot photo-voltaic would be theoretically cheaper to manufacture.

VI. FUTURE PROSPECTIVE

There are many possibilities of quantum dots in the future e.g.

i) Anti-counterfeiting capabilities:
This is the unique ability[10] of quantum dot, which is not possible iusing the semi-conductors. It can be used to control absorbtion and emission spectra to produce unique validation signatures.

ii) Counter espionage/ defense applications:
This is a protection against friendly-fire events, where quantum dots are integrated with dust so that they can track the enemy particles.

ACKNOWLEDGEMENTS

The authors would like to raise the vote of thanks to KIIT University for providing a learning atmosphere to accomplish the needs of this paper & also Professor Biswajit Ghosh whose guidance is immense in the preparation of the paper in each step.

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