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Application of Quantum Dots in light emitting technology

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Abstract : *This article reviews the present state of research involving semiconductor quantum dots, which gives a brief review of the theory behind their unique features, and an introduction explaining the significance of quantum dot research. The distinctive properties exhibited by the quantum dots have given the access to a wide gamut of applications. The characteristic moving of the band gap energy with quantum dot size, as predicted from the density of states for low-dimensional structures, allows practical measurements to determine the extent to which the phenomena of quantum confinement effects play a role in the resulting properties. The Quantum Dot technology is currently being applied comprehensively in various fields. Quantum dots are basically nanocrystals that glow with bright, rich colors when stimulated by an electric current. Quantum dots house the electrons just the way the electrons would have been present in an atom, by applying a voltage. And hence they are very judiciously named as "the artificial atoms". QD-LEDS are expected to find applications in television and mobile displays, general light sources, and lasers. Comments are made on the past research, present progress and the future prospects of quantum dots applications.*

Keywords: *Electroluminescence, Light Emitting Diodes, Nanotechnology, Quantum Dot, QDLED.*

I. Introduction

Nano material is the materials of the nano-range (10^{-9} m). Nano materials are of interest since they bridge the gap between the macro and micro levels and thus open up entirely new avenues for various applications in Electronics, Optics, and Biology and so on QDs are basically nanoparticles (nano crystals) of a semiconductor material. Examine into semiconductor colloids started way back in the early 1960s. Quantum dot research has been progressively increasing since then, as there is considerably growing number of peer-reviewed technical papers. In the late „90s, technical industries began vending quantum dot based products, such as Quantum Dot Corporation. The idea of using quantum dot as a light source first developed in 1990s. Early „90s applications included, imaging using Quantum dot infrared photo sensor. In early 2000s, scientists began to understand the ability of growing quantum dot as the next initiation light source and display technology. At first the initial targets were biotechnology applications, such as biological component and cellular imaging, quantum dots are being considered by producers for the use in light-emitting diodes (LEDs), lasers and telecom devices such as optical amplifiers and waveguides. The properties of quantum dots differ considerably from their large counterparts, mainly because of two fundamental factors. Firstly, the particles in nano-dimension consist of larger surface to volume ratio which gives unique properties to nano particles compared with bulk solids. Moreover, Quantum dots (QDs) have an adjustable band-gap due to quantum confinement [1]. Quantum confinement generally leads to widening of the band-gap with a decrease in the size of quantum dots. This confinement results in properties that are not seen in huge form of materials. Quantum dots are interesting because they are highly fluorescent, have adjustable band gap, high quantum yield, biocompatible. Recent progress in semiconductor nanotechnology depicts that these features have advantages for the application in many quantum instrument, such as QD diodes as well as quantum computing processes[2].

II. The Fabrication methods for Quantum Dots

The Quantum Dots can be synthesized by the following three methods. A succinct description of these methods is as follows.

2.1 Colloidal Synthesis : In this method the Quantum Dots are synthesized by growing the nanomaterials in a beaker which formed of nearly any semiconductor and many a metals eg. Cobalt, gold and nickel etc. The method relies on the rapid injection of the semiconductor materials into specifically designed solvents that can match up with the surface of the precipitated particles[3].

2.2 Lithography : In this method the Quantum Dots are synthesized by growing the nanomaterial‟s in a semiconductor heterostructure which refers to a single plane of one semiconductor packed in between two other semiconductors. Since, this sandwiched layer is very thin i.e. about 10 nm or less, then the electrons can no longer shift vertically and thus are limited to a specific dimension. This is called the quantum well. When a thin portion of this material is taken to make a narrow strip then it

results in a quantum wire, as it gets surrounded in a 2 dimensional area. Turning this to 90 degrees and repeating the procedure results in the confinement of the electron in a 3 dimension called as the quantum dot[3].

2.3 Epitaxy : In this method of Quantum Dot synthesis, self-assembled dots can also be produce by setting down a semiconductor having a larger lattice constant, on a semiconductor having a smaller lattice constant e.g. Germanium. These self-gathered dots are then used to make quantum dot lasers. Thus, the quantum dots are truly formed when very thin semiconductor films clips due to stress of having lattice structure slightly different in proportion from those on which the films are grown[3].

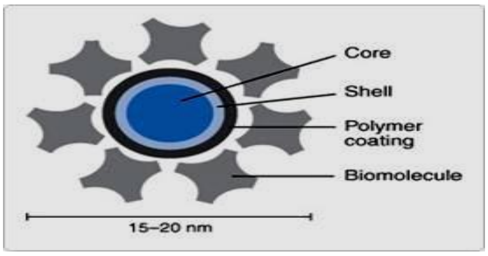

Fig 1.Generalized representation of a Quantum Dot

III. QDs in light emitting technology

QDs engross all wavelengths higher in energy than their band gap and convert them into a single color, i.e. they have wide absorption spectra, but thin emission spectra. This feature gives them advantages over organic fluorophores as their excitation wavelength could be anywhere within a wide range. The thin emission spectra of QDs and the switch ability of such results in an extremely wide color range, and thus QD displays have the ability for improved color saturation as compared to OLED displays. A Quantum dot is a zero dimensional relative to the bulk, and the limited number of electrons end in discrete quantized energies in the densities of states (DOS) for non-aggregated zero dimensional structures [4]. The absorption spectra of such particles are very broad extending from the ultraviolet range to a cutoff wavelength in the visible region of the spectrum. This opens the doors for a large number of applications of the Quantum dots in display related devices. Adjusting the dimensions of a quantum dot will allow it to discharge light in the visible part of the spectrum. What is important, however, is that the different quantum dots will also absorb the same color they emit. The Quantum dots ensure that the quality of the light generated is quite flawless and efficient. Since we are considering the nanoscale, the conductivity of the concerned materials is high which reduces the energy required for the emission phenomena.

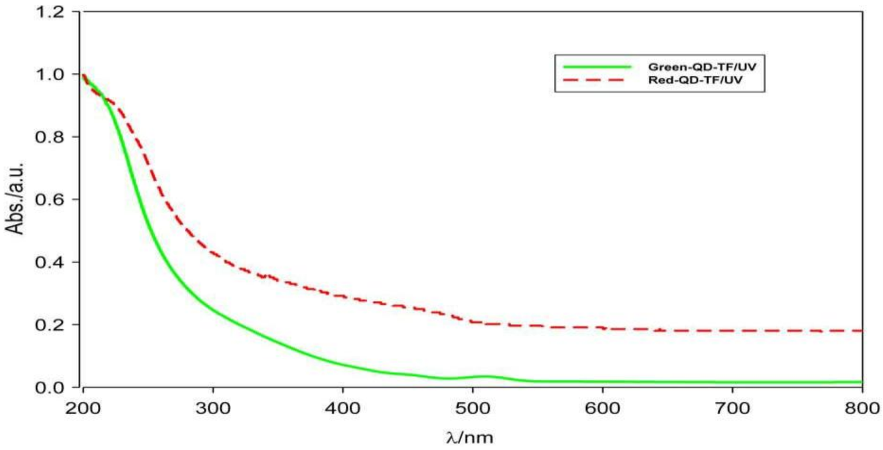

Fig 2. Absorption spectra of red and green QDs

The emission and absorption spectra conforming to the energy band gap of the quantum dot is governed by the quantum captivity principles in an infinite square well potential. The band gap increases with a decrease in the size of the quantum | Volume 2 | Issue 2 | | Feb. 2016| 13 | www.ijltem.com International Journal of Latest Technology in Engineering & Management (IJLTEM) dot. The dots have the ability to absorb and emit at any desired wavelength. Thus, as seen the above representation we find that the smaller the quantum dot, the higher the energy band gap. They can produce the white light by intermixing red, green and blue dots homogenously which is difficult to achieve with the traditional LED-phosphor setup [5]. The absorbance and photoluminescence bands of quantum dots also allow them to act as wavelength conversion substance for light emitting diodes. The QD emission is typically narrower than that of inorganic phosphorus presently used as wavelength conversion substance. Quantum dots absorb light from wavelengths tinier than their absorbance edge and then discharge light at their luminescence peak wavelength.

IV. Electroluminescence in QDs

Electroluminescence is the experience whereby light is emitted from a material following the application of an electric field to it. The process can be described by an equivalent mechanism to that of Photoluminescence where instead of exciting the molecule over the absorption of radiation, the molecule is excited electrically. The molecule then eases to its ground state radiatively and Electroluminescence results. The energy levels of organic molecules are frequently described as the lowest vacant molecular orbital (LUMO), or the excited state, and the highest engaged molecular orbital (HOMO), or the ground state with the gap between the two levels the energy bandgap (Eg).

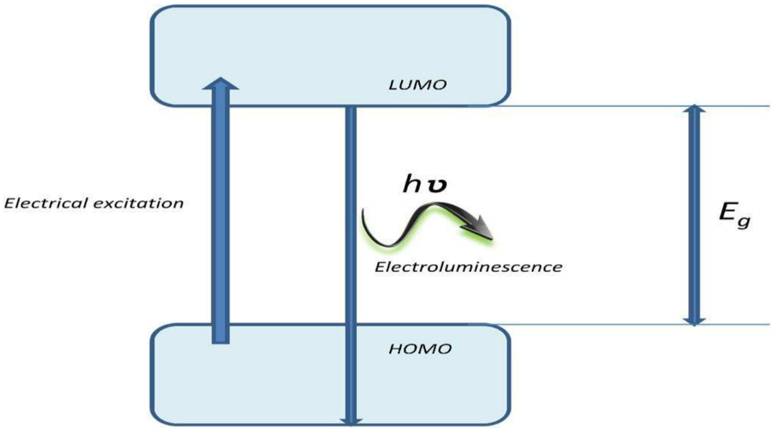

Fig 3. Representative diagram showing the phenomena of electroluminescence

Major breakthroughs in harnessing electroluminescence have been made possible through the development of wide band gap light emitting diodes (LEDs) in the 1960s, the progress of evaporated organic films in the 1980s and most recently through the progress in solution-process able quantum dots. CdSe/ZnS systems have been studied most as long as the EL is concerned, although, Cd is environmentally limited owing to its toxicological properties and its feasibility as a commercial material is consequently questionable. Semiconductor nanoparticles covered with another layer of semiconductor have proved to be of great importance to improve the luminescence from these core shell assemblies. The choice of shell material is important for localization of the electron–hole pair. There are type-I nanostructures such as CdSe@CdS or CdSe@ZnS in which the conduction band of the shell material (which is a higher band-gap material) is at higher energy than the core and valence band of the shell is at lower energy than that of the core [6].

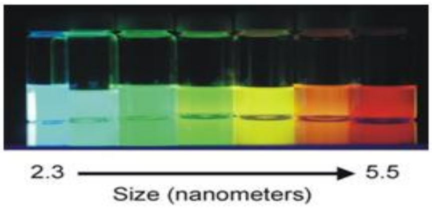

Fig 4. Change in emitted color with change in Quantum dot radius (in nm)

A bulk semiconductor has a nearly constant supply of energy states above its band gap, quantum dots theoretically have discrete energy, levels like atoms do, and the spacing among the electron and hole energy levels increases as the quantum dots are made smaller. Persuasively the distribution of energy states in an assembly of quantum dots is primarily determined by the size distribution of the quantum dots.

Fig 4. Electroluminescence from a GaN heterostructure LED with CdSe-ZnS core-shell quantum dot.

V. Oleds

An organic light- emitting diode (OLED) is basically a LED in which the emissive electroluminescent layer is a film of organic compound which discharge light in response to an electric current. This layer of organic semiconductor is placed among two electrodes typically; at least one of these electrodes is transparent. The layer of organic semiconductor material is molded between two electrodes, where at least one of the layers is transparent. Materials with self- luminous feature that eliminates the need of a back light, these result in a thin and compact display. A typical OLED is made of a layer of organic materials situated between two electrodes, the anode and cathode, all deposited on a substrate. The organic particles are electrically conductive as a result of delocalization of pi electrons caused by conjugation over part or entire molecule. These materials have conductivity levels ranging from insulators to conductors, and are therefore considered organic semiconductors. However multilayer OLEDs can be fabricated with two or more layers in order to improve device efficiency. OLEDs are used to create digital displays in devices such as television screens, computer monitors and portable systems such as mobile phones, gaming consoles and PDAs. A major area of research is the development of white OLED devices for use in solid-state lighting instrument [6].

VI. Qdleds

QLEDs or QDLED is considered as a next generation display technology after OLED-displays. The structure of a QDLED is analogous to that of an OLED. An applied electric field causes electrons and holes to move into the Quantum dot layer, where they are captured in the Quantum dot layer, emitting photons. QDLEDs are basically a genuine example of electroluminescence. They provide the hard-to-reach blue end of the spectrum, and are the key for opening any number of exciting technological developments in the fields of full-color, flat-panel displays; ultrahigh-density optical memories and data storage, backlighting and so on. The so-called quantum confinement phenomenon occurs as the size of the semiconductor becomes analogous to or smaller than the excitation Bohr radius, and where the electron and hole are confined by the limitations of the material. It leads to discrete energy levels, known as “confinement states”, as expected by a particle in a box (Schrödinger's) equation [7]:

$$E = \frac{n^2 h^2}{8mL^2}$$

Where n = the quantum number;
h = Planck‟s constant; m = the electronic mass, L =the width of the box.

The electron-hole pairs present in the nanocrystals are also called as excitons. The nanocrystal is supplied the voltage by the electric source and the excitons emit the photons. In QD-LEDs like LEDs there are two types of recombination, radiative and non-radiative. If the recombination (electrons and holes) is radiative, photons are emitted, and the wavelength of photon is independent to the charge moving layers and only depends on the QDs. According to doping of QDs, the radiative recombination can be either of one monomolecular or bimolecular.

Monomolecular recombination occurs in doped quantum dots and the rate of recombination on is directly proportional to minority carrier concentration. If the quantum dots are undoped, the recombination percentage depends on both of the carriers, so this kind of recombination is bimolecular the middle layer which is the emitting layer (the nano dot layer) is quite different from the one found in the OLEDs. QDs are composed of nanoparticles with range of diameters from 5–20nm. When charge carriers (electrons and holes) are confined to such tiny particles, the larger band gap of the surrounding substance creates a barrier. When the charge carriers (electron–hole pairs) eventually recombine, a characteristic photon is emitted. The discrete energy levels that arise as a result of this barrier subsequently dictate the material properties.

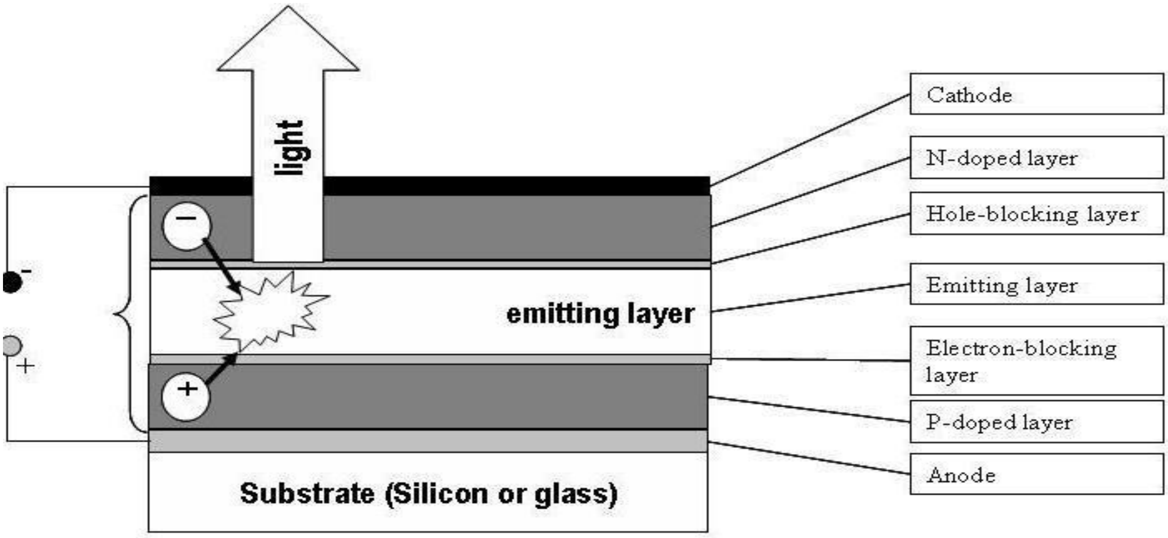

Fig 5. Emission of light in a

QDLED : Of the many types of quantum dots that can be made from various semiconductor materials, CdSe/ZnS quantum dots are currently the most public commercially available as secondary antibody conjugates This effect (size quantization) gives QDs several appealing properties, including high quantum efficiency, a broad absorption band, narrow emission linewidth, and a controllable emission peak. Similarly the energy of the emitted photons can be altered accordingly. Also the emitted light can be obtained in the desired color using a color filter. The spectrum of the photon emission is narrow, characterized by its full size at half the maximum value. By changing the size and the color of the materials used as Quantum dots we can tune the wavelength of the emitted light. Size quantization effects bring a wide color gamut, improved light proficiency, and a tunable emission wavelength [8].

VII. Advantages

Quantum Light Emitting Diodes (QDLEDs) are superior to standard LEDs and OLEDs, in the same ways the quantum dots are superior to bulk semiconductors. Quantum Dots have certain features of interest which set them apart from other nanomaterials. Some advantages of QDLEDs over other Light Emitting Technologies are as follows:

1. Traditional incandescent bulbs may be replaced using QDLED technology, since QDLEDs can provide a low-heat, full-spectrum source of light. They deliver 30-40% luminance efficiency advantage over OLEDs.
2. Quantum Dots are less affected by temperature fluctuations, which increase the life of the QDLEDs. They have the ability to be more than twice as power capable as OLEDs at the same color purity.
3. The tunability of QDs gives them the capacity to discharge nearly any frequency of light - a traditional LED lacks this ability. Small changes to the size or configuration of a quantum dot allow the energy levels, and the bandgap, to be fine-tuned to specific, desired energies.

The ability to print large area QDLEDs on ultra-thin flexible substrates will decrease the manufacturing and production cost.

5. The experiments have revealed that even small variations in the quantum dot film thickness lead to a dramatic deviation in QD LED performance.
6. QDLEDs are still in the initial stage development, yielding only 10,000 hours at low brightness, but in theory is a more stable light-emitting material than organic dyes.
7. They produce a high quality white light and are much more inexpensive comparative to the contemporary Lighting technology.

Similarly they have a higher performance as well as longer life compared to their predecessors [9].

VIII. Conclusion

QDLEDs emit red, green, and blue color light that are highly color saturated, efficient and which can be striped laterally for max color display applications by means of micro-contact printing of single layers of nanocrystals. In the future, we can expect many new products and processes based on nanostructured materials and semiconductor quantum dots. As assembly, synthesis, and deposition techniques improve, semiconductor quantum dots will be effectively incorporated into more and more electronic devices to improve performance and enable higher efficiency. Despite the advantages of QDLEDs and using them in optoelectronic instruments like thin film displays, which cause the improvement in color saturation in this kind of displays, there are some problems limiting the applicability of QDLEDs which can be listed as follows:

1. Efficient non-radiative Forster resonant energy transfer (FRET) of excitons within the inhomogeneous size distribution of QDs to non-luminescent sites, where they have nonradiative recombine, cause self-quenching phenomenon.

2. Satisfying in photoluminescence (PL) of QDs by the neighboring conductive metal oxides because of carrier imbalance (due to a large hole or electron injection obstacle between the p or n type metal oxides and the QDs).
The biggest challenge facing QDLEDs, despite having a very high efficiency, is the reliability.

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