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QUANTUM DOTS AND THEIR MULTIMODAL APPLICATIONS: AN OVERVIEW

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ABSTRACT:- Semiconducting quantum dots, whose particle size is in the nanometer range, have very unusual properties. The quantum dots have band gaps that depend in complicated ways on a number of factors described in the article. The relationships between processing, structure, properties, and performance are examined for semiconducting quantum dots. Various methods for synthesizing these quantum dots and the resulting properties are discussed. Quantum states and confinement of their excitons can shift their optical absorption and emission energies. Such effects are important for tuning their luminescence, which is excited by photons (photoluminescence) or an electric field (electroluminescence). In this article, the decoupling of quantum effects in excitation and emission is described, as well as the use of quantum dots as sensitizers in luminescent materials. In addition, multimodal applications of quantum dots are discussed, including electroluminescent devices, solar cells, and biological imaging.

KEYWORDS:- Quantum dots, Semiconducting nanomaterials, Electroluminescence, Photoluminescence, biological imaging.

INTRODUCTION:- Nanostructured materials are interesting because they can bridge the gap between bulk and molecular level and lead to completely new applications, especially in electronics, optoelectronics and biology. If the optical and electronic properties of a solid vary markedly according to particle size and 100 nm variation, it can be called a nanostructure and is classified as two-dimensional, e.g., thin films or quantum holes,one-dimensional.e.g., quantum wires or zero-dimensional or dots. In the last two decades, much attention has been paid to the optoelectronic properties of nanostructured semiconductors or quantum dots, since many of the essential properties are size-dependent in the nanometer range. The Quantum dots is zero-dimensional with respect to the bulk, and the finite number of electrons results in discrete quantized energies in the density of states for unaggregated zero-dimensional structures. Although it is zero-dimensional with respect to mass, it is considered a box in quantum mechanics; the size of the box is important and will be discussed later). Sometimes the presence of one electronic charge in Quantum dots repels the addition of another charge and leads to a stair-like I-V curve and DOS. The step size of the stairs is proportional to the inverse of the radius of the Qdots. The limits of when a material has bulk, Qdots, or atomic properties depend on the composition and crystal structure of the compound or solid element. A huge number of basic features can be realized when resizing with standard composition, and some of them are discussed. Quantum dots can be broadly classified as either elemental or composite systems. In this review, we highlight nanostructured materials based on compound semiconductors and multimodal applications based on their optoelectronic and optical properties. The process of synthesizing PbS Quantum dots was developed more than 2000 years ago using cheap natural materials such as PbO, Ca (OH)2 and water. The Romans and Greeks used these materials as cosmetics to dye their hair. In recent history, Qdot size control of silicate glasses are one of the oldest and most widely used glass color control techniques. In the early 20th century, CdS and CdSe were combined with silicate glasses to produce a reddish-yellow color. In 1932, Rocksby used X-ray diffraction (XRD) to determine that the colors were caused by CdS and CdSe precipitates. In the past, glasses doped with semiconductor particles were also used as filters in optics. In 1981, Ekinov and Onushchenko reported a blue shift of the optical spectrum of nanometer sized CuCl in silicate glass. In 1982, Efros and Efros hypothesized that quantum size effects (size changes in optical and optoelectronic properties) could be used to control glass color by changing the size or stoichiometry of CdSxSe1-x. In 1991, the color change of colloidal solutions of semiconductors was discussed by Rosetti et al.. During this period, several different synthesis methods were developed. During the last two decades, experimental and theoretical studies of these nanoparticles have increased significantly to investigate many fundamental Qdot properties and have been attracted by commercialization efforts. In this review, we briefly discuss the structure, properties, usage and performance of Quantum dots in multimodal applications

QD size:- Each 10 nm contains nearly 3 million Quantum dots when aligned or equaled to the width of a human thumb. Accordin to the small size of the QD, the electron in the QD is confined to the quantum box (small space) even if its radius is smaller than the Bohr radius of the excitation, which means that there is a gap between the electron and the. a hole the electron-hole pair is followed by a large distribution of energy levels. As a result, it takes more energy to enter the excited state and more energy is added to return to the resting state. In general, as the QD size decreases, the energy gap between the highest valence band and the lowest conduction band increases. Therefore, the piercing requires more energy, which is released when those crystals return to their ground state, because the color of the emitted light changes from a longer wavelength (red color) to a shorter wavelength (blue color).

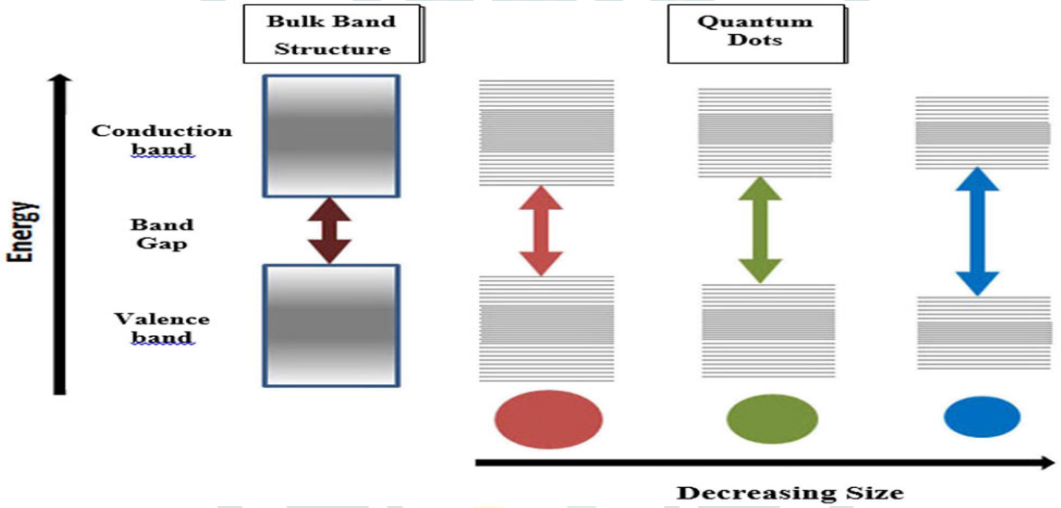

FIGURE 1 SPLITTING OF ENERGY LEVELS IN QUANTUM DOTS

Splitting of energy levels in Quantum dots due to the quantum confinement effect, and semiconductor bandgap increases with decrease in size of the nanocrystal

QD size effect:-The QD size effect (QDE) appeared when the diameter of the nanocrystalline semiconductor approaches the Bohr diameter of the excitation, resulting in the appearance of the electronic properties of the QD. CdS, one of the famous Quantum dots, was studied 30 years ago; Quantum dots are formed when their nanodiameter is ≤6 nm (3000–4000 atoms) or less near the diameter of the extension. In general, a large percentage of the atoms in Quantum dots have a small-scale system located at or near the surface. 15% of the cadmium sulfide atoms in a 5 nm quantum dot are on the surface. The existence of a large interface between the nanocrystal and the surrounding medium influenced their properties. Nanocrystals have surface imperfections and electron-hole traps that are detected by optical excitation. Therefore, the presence of these trapped electrons and holes caused changes in the optical properties of the nanocrystals.

Color-changing phenomena:-Quantum dots can emit light of any color from the same nanocrystalline semiconductor simply by changing its size. This suggests a great potential control over QD size,which can be tuned to emit light of any color during synthesis processes. Therefore, larger dots emit at longer wavelengths, such as red, while smaller dots emit at shorter wavelengths, such as green. QD (radio wavelength) tuning has the same behavior as guitar strings, in that the guitar string produces a higher pitch and the extension lowers the pitch. Meanwhile, the band gap varies in size, while the band gap is the energy required to move an electron from the valence band to the conduction band and when it is in the visible wavelength spectrum, resulting in changes in the emitted color. Also, the magnetic memory (coercive force) required to reverse the internal field of the quantum dot depended on its size.

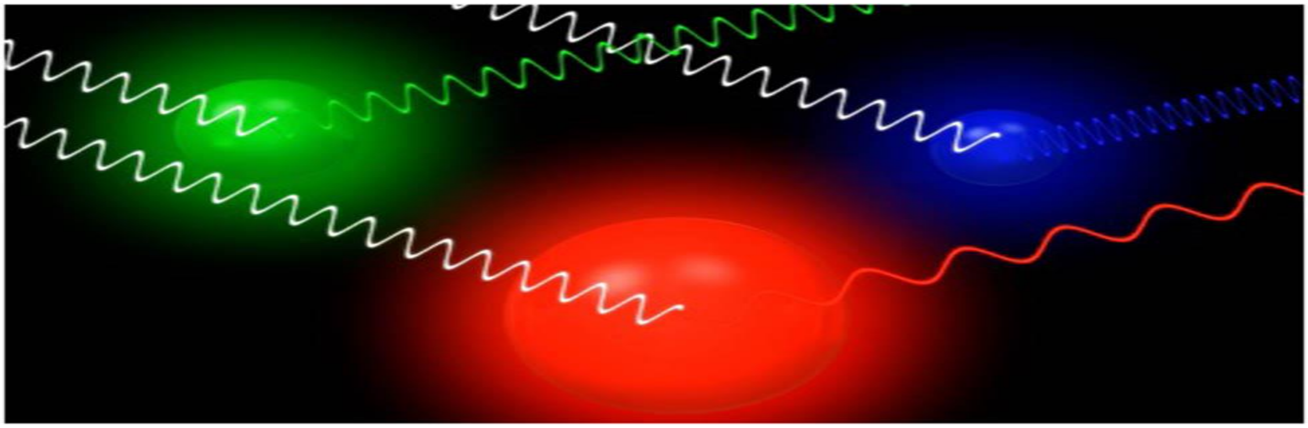

FIGURE 2 ***COLOR-CHANGING PHENOMENA***

QD TYPES:-

A)Core-type Quantum dots :- Quantum dots can be single-component materials with a uniform internal composition, such as selenides or sulfides (chalcogenides). Electroluminescence and optical core-type QD properties can be tuned by any simple change in QD size.

B)Core–shell Quantum dots (CSQuantum dots):- Quantum dots with small regions of one material embedded in another bandgap material are called CS Quantum dots. Quantum dots with CdSe in the core and ZnS in the shell are available with high quantum yields ≥ 80%. The QD shells improve the quantum yield and make them more suitable for their synthesis conditions for various applications. CS Quantum dots are used to improve the efficiency and brightness of semiconductor nanocrystals, and they grow shells of other semiconductor material with a larger gap around them. Thus, the electroluminescent properties of Quantum dots are due to exciton decay (recombination of electron-hole pairs) by radiative processes. It can also occur through non-radiative processes, leading to a decrease in the fluorescence quantum yield.

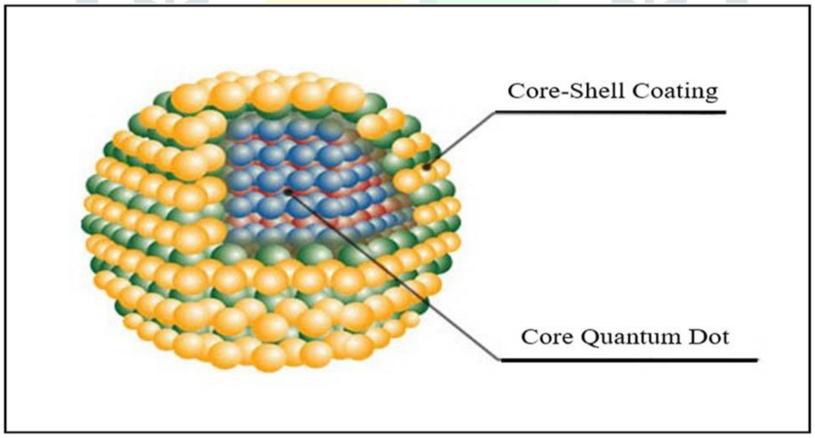

FIGURE 3 CORE-SHELL QUANTUM DOTS

C)Alloyed Quantum dots :-Doped Quantum dots formed by two nanocrystalline semiconductors have different band gap energies with characteristic features distinctly different from those of their parent semiconductors. This is also supported by the fact that doped Quantum dots exhibit novel tunable properties that have been clearly shown to exhibit distinct quantum confinement.Doped Quantum dots have homogeneous and gradient internal structures, whose composition and internal structure only change without changing the size of the nanocrystals, because it is possible to tune the electrical and optical properties in the form of CDs x Se1-x / doped Quantum dots . ZnS (6 nm diameter) emitting light at different wavelengths according to the changing composition

FIGURE 4 ALLOYED QUANTUM DOTS

Properties of Quantum Dots:-

Since quantum dots are essentially semiconductors, they are also known as semiconductor nanocrystals. Because they are significantly smaller than bulk semiconductors and slightly larger than individual atoms, Quantum dots have properties that appear to be somewhere between bulk materials and individual atoms. Because of their unique size, quantum effects dominate the properties of quantum dots. Electrons exist in distinct energy levels in a bulk semiconductor. The lower energy level is called the valence band, while the higher energy level is called the conduction band. The energy difference between the two groups is called the band gap. An electron can jump from the valence band to the conduction band by absorbing energy, such as light or heat. When an electron leaves the valence band, it leaves a hole behind. A hole and an electron together form an exciton. The average distance between an electron and a hole is called the Bohr radius of the excitation. When the semiconductor size is smaller than the Bohr radius, it becomes a quantum dot and experiences quantum confinement. Confinement here refers to the fact that the random motion of electrons is restricted or confined in a QD. This leads to distinct energy levels. As we decrease the particle size, the energy levels become more discrete and in turn increases the band gap. This increase in bandwidth also results in better gap energy. Therefore, the size of the crystal can determine the energy of the bandgap, which in turn determines the energy of the emitted photon. Quantum dots have a large absorption spectrum, i.e. they can be excited in a wide range of wavelengths; Furthermore, since their size controls the energy of the released photon, the user can limit the emission spectrum as narrow as possible. Compact Quantum dots in blue have a larger bandwidth, while red Quantum dots have a smaller bandwidth.

Synthesis:-

Several ways have been used to synthesize Quantum dots, but in general, top-down processing methods and top-down approaches have been used in QD synthesis techniques. Top-down processing methods include molecular beam epitaxy (MBE), ion implantation, e-beam lithography, and x-ray lithography. Using an alternative bottom-up approach, colloidal Quantum dots are prepared by self-assembly in solution after chemical reduction. Several different self-assembly techniques (from bottom to top) have been used to synthesize Quantum dots and can be broadly divided into wet-chemical and vapor-phase methods: (a) wet-chemical methods mostly follow conventional deposition methods. Homogeneous nucleation occurs when atoms or molecules of a solute coalesce and reach a critical size without the aid of an existing solid interface. Wet chemical methods typically include microemulsion, sol-gel, competitive reaction chemistry, hot solution dissolution, sonication or microwave, and electrochemistry. (b) Vapor-phase methods to produce Quantum dots start with processes where layers are grown atom by atom in the process. As a result, the self-assembly of Quantum dots on the substrate occurs without a pattern. Self-assembly of MBE-grown material nanostructures, sputtering, liquid metal ion sources, or gaseous monomer aggregation are generally classified as vapor-phase methods.

A)Top-Down Synthesis Processes :-In the bottom-up approach, the semiconductor is diluted to form Qdots. Typically, electron radio lithography, reactive ion etching, and/or wet chemical etching are used to achieve ~30 nm diameter Qdots. Controlled shapes and sizes with desired packing geometries can be achieved through systematic experiments of the quantum confinement effect. Alternatively, focused ions or a laser beam have also been used to produce zero-dimensional arrays of dots. The main disadvantages of these processes are the introduction of impurities in the Quantum dots and structural defects through patterning. Known for more than 20 years, etching plays a very important role in these nanomanufacturing processes. In dry etching, a reactive gas species is introduced into the etching chamber and a radio frequency voltage is used to create a plasma that breaks the gas molecules into more reactive fragments. These high kinetic energy species hit the surface and form a volatile reaction product to etch the patterned sample. When the energetic species are ions, the etching process is called reactive ion etching (RIE). Selective etching of the substrate is achieved with an overlay pattern. Fabrication of GaAs/AlGaAs quantum structures as small as 40 nm by RIE with a mixture of boron trichloride and argon has been reported. This RIE process has been used to produce densely packed arrays for laser testing of Qdot semiconductors. Arrays of closely packed ZnTe Quantum dots with dot spacings ranging from 180 nm to 360 nm were fabricated by RIE using CH4 and H2.

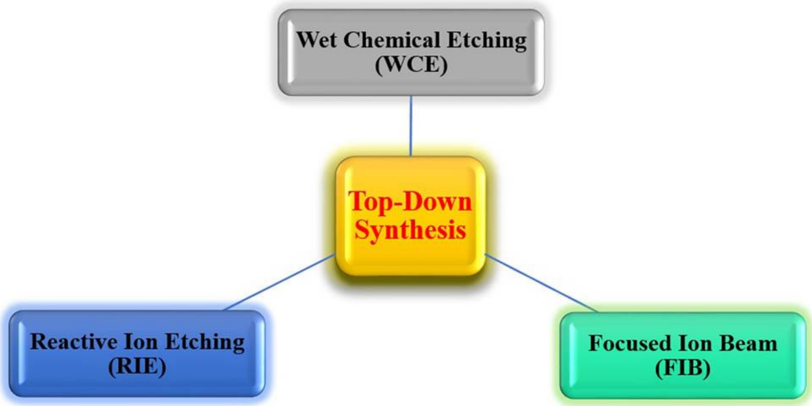

FIGURE 5 SYNTHESIS OF QUANTUM DOTS

B)Bottom-up Approach:-Several different self-assembly techniques have been used to synthesize Quantum dots and can be broadly divided into wet-chemical and vapor-phase methods. Microemulsion, sol-gel, competitive reaction chemistry, hot solution degradation, and electrochemistry are usually placed in the category (1) of wet chemical methods. The self-assembly of nanostructures in a material grown by molecular beam epitaxy (MBE), sputtering, liquid metal ion sources, or gaseous monomer aggregation is generally classified as (2) vapor phase methods.

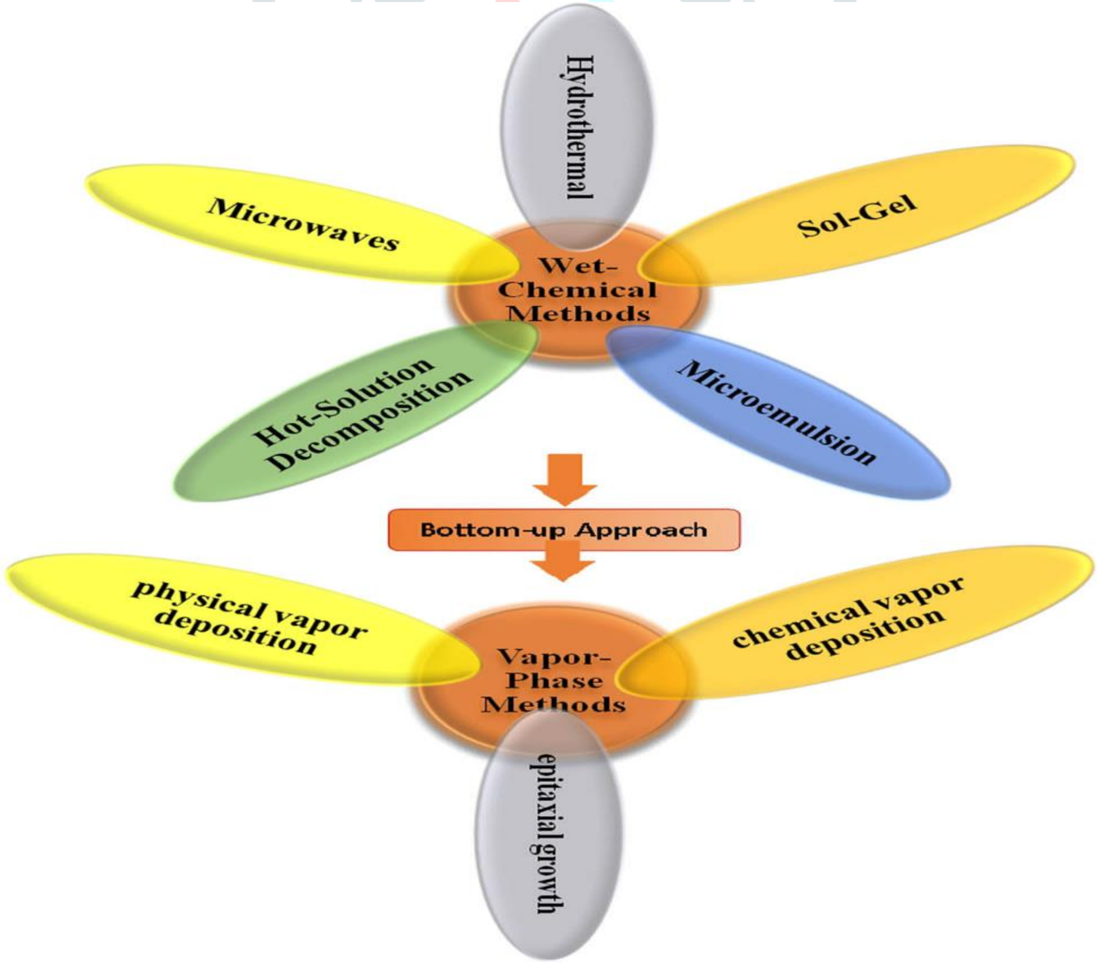

FIGURE 6 *APPROACHES OF QUANTUM DOTS*

Wet-Chemical Methods:-Wet chemical methods basically follow conventional deposition methods by carefully monitoring the parameters of the individual solution or solution mixture. The deposition process always involves both nucleation and limited nanoparticle growth. Nucleation can be classified as homogeneous, heterogeneous or secondary nucleation. Homogeneous nucleation occurs when atoms or molecules of a solute coalesce and reach a critical size without the aid of an existing solid interface. Quantum dots of desired size, shape and composition can be achieved by varying factors such as temperature, electrostatic double layer thickness, stabilizers or micelle formation, preconcentrations, anionic and cationic species to solvent ratio. Some common synthetic processes are briefly discussed below.

Sol-Gel Process:-Sol-gel techniques have been used for many years to synthesize nanoparticles, including Qdots. In a typical technique, a salt (nanoparticles dispersed in a Brownian motion solvent) is prepared using a metal precursor (usually alkoxides, acetates, or nitrates) in an acidic solution. or mainstream media. The three main steps in this process are hydrolysis, condensation (sol formation) and growth (gel formation). Briefly, the metal precursor hydrolyzes in the environment and condenses to form salts, followed by polymerization to form a network (gel). This method was used to synthesize II-VI and IV-VI Q-points such as CdS, ZnO, PbS. For example, ZnO Quantum dots are prepared by mixing solutions of Zn acetate in alcohol and sodium hydroxide followed by controlled aging in air. The process is simple, cost-effective and scalable. The main disadvantages of the sol-gel process are the wide size distribution and high error content. Therefore, this synthetic technique is used sparingly.

Other Synthesis Processes:-Sound waves or microwaves are passed through a mixture of precursors in water to grow Qdots. These waves provide the energy to separate the parent and water molecules, resulting in the growth of Qdots. It has been reported that ultrasonic waves are used to synthesize 1–5 nm Quantum dots by forming, growing, and bursting bubbles in a liquid. Such acoustic cavitation creates a localized hot spot through adiabatic compression of the gas within the collapsing bubble, enabling reactions that form Q-spots. In one approach, metal ion acetate precursors were dispersed in solution, selenurea was added, and sonicated under argon for one hour. The temperature of the solution increased to 80 °C during the time required to produce the Qdots.

***Toxicity Of Quantum dots : -* Quantum dots** are diverse materials that differ from their common chemical counterparts, leading to the most important research projects to assess QD toxicity, which is a major challenge. Many studies show that the cytotoxicity of cite is not only due to the released cd2 ions, but also due to the intracellular distribution of QD into cells and related nanoscale properties. A recent case study observed a genotoxic response to cited Quantum dots in human breast cancer cells. in some in vitro studies, QD toxicity may be due to their physical and chemical properties (size, concentration, shape, charge, composition, surface functional groups, mechanical stability, surface charges, and photolytic stability) and environment. Assessing their potential toxicity is difficult because these factors include properties such as qd size, concentration, chemical composition, charge, and cleavable ligands, as well as their oxidative, mechanical, and photocatalytic stability. in addition, the application of toxicity of Quantum dots to the cell nucleus was investigated, where Quantum dots were found to induce DNA mutation, which prevents the further reproduction process to generate new cells that can carry the same diseases. in the future, Quantum dots will be used to identify different types of cancer cells and the molecular mechanisms of diseases, and they will also find their role in new drug processing mechanisms and the discovery of new biochemical analysis methods. Thus, Quantum dots can one day be safely used as fluorescent probes for biological imaging, monitoring targeted drug delivery, and monitoring changes in the functional and structural properties of their intracellular components.

QD APPLICATIONS:

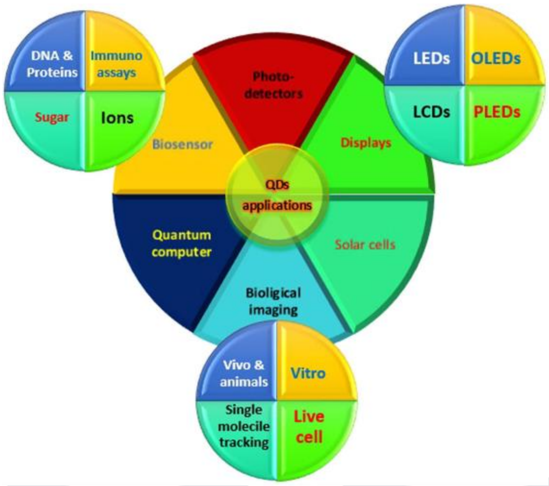

FIGURE 7 QUANTUM DOTS APPLICATION

Photodetectors:-Advanced integrated circuits using quantum dot photodetectors (QDPs) through substrate integration fabricated from their single crystal semiconductor or solution processed. QDPs are used in surveillance, machine vision, spectroscopic instruments, and industrial controls

Biosensors:-Many recent biosensors rely on the unique optical properties of Quantum dots in various fields, such as zinc sulfide Quantum dots used to detect food toxins. Many QD-based sensors are used for pesticide monitoring. Phosphorgraphene Quantum dots (N,P-GQuantum dots) are used to detect NO2− in nitrogen in living cells, which has carcinogenic effects because it is often used as a food additive or preservative. Therefore, it can easily interact with proteins and then form carcinogenic N-nitrosamines, increasing the possibility of deformities and cancer.

Biological imaging:- Biological research is considered one of the main branches of QD applications, where Quantum dots are used as tracers that are injected into the tissues of targeted living cells. QD applications can be designed for advanced cancer therapy because they can target a specific organ, such as the liver, instead of traditional chemotherapy. Quantum dots can also be used for early detection of cancer cells with a very accurate diagnosis

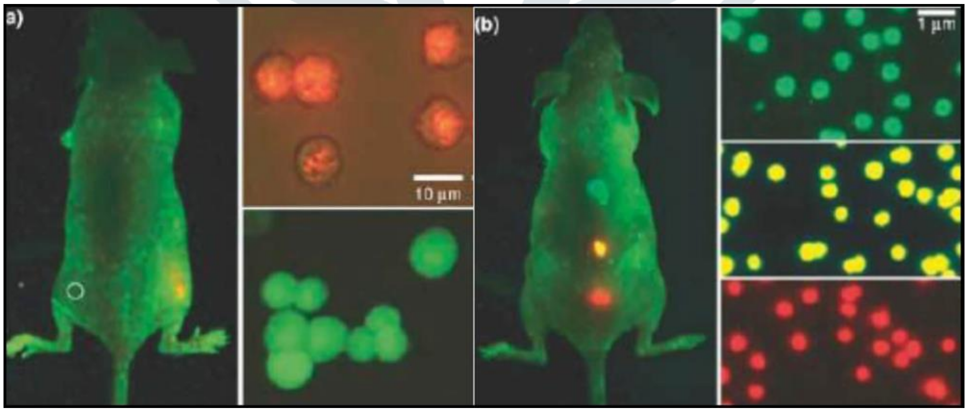

FIGURE 8 QUANTUM DOTS BIOLOGIC IMAGING

Solar cells:- QD-sensitized solar cells (QUANTUM DOTS SCs) represent the third generation of solar cells with an efficiency of approximately 60%, while the maximum efficiency of conventional solar cells is 33% [50,51]. Quantum dots have several distinct properties that make them inexpensive and very efficient in solar cell applications:

- Choosing a synthesis-based solution and production process helps to choose a suitable substrate, which leads to a reduction in the production costs of solar cells.
- High crystallization of solar cells can occur at low temperatures, which leads to a decrease in their energy consumption.
- Improve visible absorption with a wide adjustable bandwidth for visible light collection.
- The high efficiency of QUANTUM DOTS SC can mean the generation of multiple carriers during the manufacturing process. Organic-inorganic hybrid solar cells combine organic polymers and inorganic nanoparticles with the aim of combining the advantages of both groups of materials.

Future Prospects:- applications until now, cancer has been the specter of death in the world, so the early diagnosis and treatment of cancer is at the forefront of cancer qd research. in addition to detecting cancers such as leukemia, ovarian cancer, prostate cancer, breast cancer, and pancreatic cancer, these tests include. future research should look for less toxic quantum dots, such as quantum dots with unique optical properties, and include many applications such as various Bio applications (biosensing and bioimaging), solar cells Leds and photocatalysis.

Conclusion:-Future applications of qd materials exceed all expectations related to their enhanced photophysical and chemical properties. The quantum size effect is the key to the variety of qd properties, which makes quantum dots suitable for various recent applications. in the future, qd materials can be specially applied in qd solar cells, biosensors, bioimaging, quantum computers, li-fi, light detectors, and photocatalysis.

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