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Review Article

A REVIEW ON QUANTUM DOTS (QDS)

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ABSTRACT

Recently, the drugs in nanometer size range have found to increase the performance of various dosage forms. Quantum dots (QDs) have gained attention and interest of scientists due to their targeting and imaging potential in nano based drug delivery, in pharmaceutical and biomedical (cell biology) applications. They are artificial semiconductor nanocrystals that have tunable and efficient photo luminescence with narrow emission spectra and high light stability making them excellent probes for bioimaging applications. QDs absorb white light and can produce different colors determined by the size of the particles and band Gap. Nowadays, quantum dots are used for labeling live biological material *in vitro* and *in vivo* in animals (other than humans) for research purposes and also useful for immunoassay studies. In the present article, we have discussed various aspects of QDs, highlighting their pharmaceutical and biomedical applications and current challenges in introducing QDs into clinical practice.

Keywords: Nanotechnology, Quantum dots, Fluorescence, Particle size, Diagnosis.

1. INTRODUCTION

Nanotechnology deals with the study of smaller structures with a size range between 1 to 100 nm. It covers various fields like biophysics, molecular biology, and bioengineering, electronics and sub specialties of medicine such as cardiology, endocrinology, ophthalmology, oncology, immunology etc. It also deals with emerging new technologies for development of effective, stable and promising drug delivery system. Pharmaceutical Nanotechnology applies the methods and principles of nano science and nano medicine to pharmacy for the development of new drug delivery systems which can overcome the drawbacks of conventional drug delivery systems. Pharmaceutical nanotechnology helps to fight against various diseases by detecting the antigen associated with diseases and also by detecting the microorganisms and viruses causing the diseases [1, 2]. Quantum Dots (QDs) are a central topic in nanotechnology. It has been around since the 1980s when scientists were exploring the technology as a way to build nano-scale computing applications where light is used to process information. Recently, Quantum Dot technology is being used in medicine. They are man-made semiconductor nanocrystalline materials that have emerged as indispensable tool in biomedical research, especially for quantitative, multiplexed and long-term efficient fluorescence imaging as well as detection. "*Quantum*" is a Latin word which means minimum amount of any physical entity involved in an interaction. QDs have optical and electronic properties that differ from larger particles due to quantum mechanics. If ultraviolet light is emitted to Quantum Dots, an electron in the quantum dot can be excited to a state of higher energy. The excited electron can drop back into the valence band releasing its energy by the emission of light (luminescence). The color of that light depends on the energy difference between the conductance band and the valence band [3].

1.1. Discovery of Quantum Dots

Quantum dot was discovered by the Russian Physicist, Alexei Ekimov. At the end of the 1970s, Alexei Ekimov synthesized nanocrystals of copper chloride and then of cadmium selenide in a molten glassmatrix. He then observed fluorescence and color transitions. These observations were published in 1980. Another Russian physicist, Alexander Efros published the first theory aiming at explaining the behavior of these very small crystals by the confinement of their electrons in 1982. Influenced by Alexei Ekimov, the American chemist Louis Brus, Bell Labs tried and successfully produced nano crystalline material, but in a liquid form, to obtain a colloidal suspension. In that way, in 1983 he obtained the first colloidal Quantum Dots of cadmium sulphide, which is easier to handle and published his results [4].

2. PROPERTIES OF QUANTUM DOTS [5-7]

- Quantum dot is zero dimensional material. All dimensions are below the 100 nm that is within the nanoscale. They have sharper density.
- Particle size range is between 2 to 10 nm.
- Band gap energy is inversely proportional to the size of quantum dot. Band gap energy ∝1/Size of Quantum dots. Smaller is the size of the quantum dot larger is the band gap and vice versa.
- They are offered in both organic and aqueous formulations.
- Quantum dots show color glow when it is illuminated by UV radiation. As quantum dots increase in size, the emission color will have a red spectral shift and decrease in size shows blue color. Color irradiation depends on the size of the quantum dot and band gap.
- It is 10-20 times brighter as compared to conventional dyes.
- Quantum dot gives better contrast with electron microscope.
- QDs possess luminescence properties.
- QD emits the wavelength which is fall in between UV and IR electromagnetic radiation.
- Thermal stability is high (depending on the shell)

2.1. Conduction Band

It is a high energy level band having high energy state and partially filled by the electrons. Conduction band is above the Fermi level (Fig.1). When the atom is excited, electrons move into the conduction band and the current flows due to such electrons.

2.2. Valence Band

It is the energy band formed by a series of energy levels containing valence electrons. It has low energy state and always filled by the electrons. Valence band is below of Fermi level. When the atom is excited, electrons will move out of the conduction band. The highest energy level which can be occupied by an electron in the valence band at 0 K is called the Fermi level.

2.3. Band gap

The ‘band gap’ of a semiconductor is the minimum energy needed to excite an electron that is stuck in its bound state into a free state where it can participate in conduction [8].

Band gap is very critical parameter in many electronic and optical application. If light is emitted to semiconductors, some electons acquire energy to jump from valence band to conduction band, since higher energy level is not favorable, after a while they may want to come back to the valence band they release diference energy between the valence band and conduction band. Returning electrons from conduction band to valence band relase photons with amount of energy ual to the band gap. According to quantum mechanics energy of photons relates to the wavelength (color) of photons as shown in fig. 2.

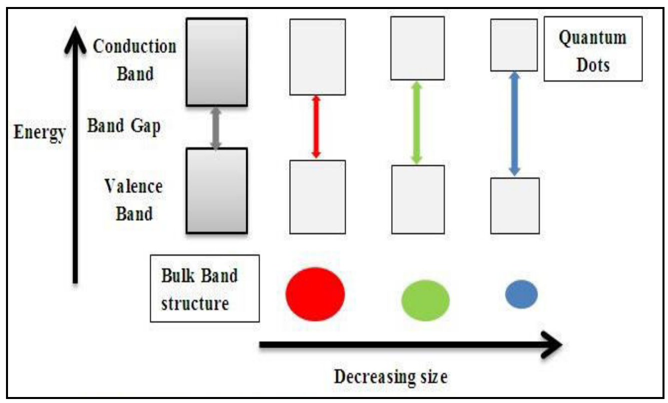

Fig. 1: Valence Band, Conduction Band and Band Gap.

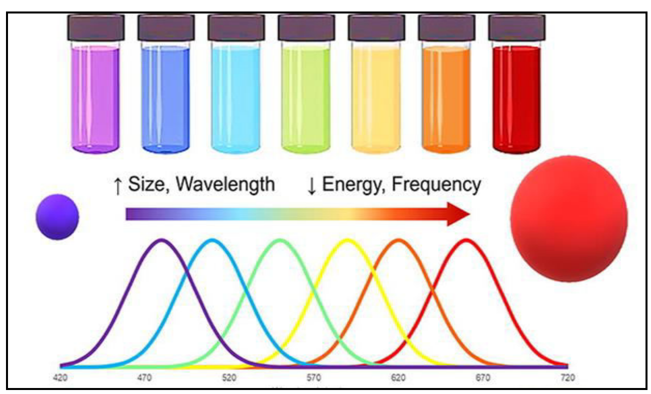

Fig. 2: Quantum Dots with gradually stepping emission from violet to deep red [10]

This means emitted colors depends on the band gap. Various size of Quantum Dots results in quantum confinement and hence different Band Gap. Different Band Gap of Qunatum Dots results indifferent color emitting [9].

3. STRUCTURE OF QUANTUM DOTS

QDs are generally composed of core, shell and surface coating parts which gain high luminescence, stability and surface activation. Typical QDs are core core- shell structures.

Core is composed of monolayers of semiconductor material such as CdSe, CdTe, and fluorescence emission as well as excitation wavelength as shown in fig. 3. At first, coating part is hydrophobic. Nowadays hydrophilic polymers or molecules are used for coating. Shell surrounds and stabilizes the core. It is effective on the decay kinetics, fluorescence and photostability of quantum dots. Slight red shift is observed due to tunneling of charge carrier into the shell. Organic capping determines its biological functionality, solubility and stability. Amphiphilic polymers enhance the water solubility of quantum dots and allow incorporating ionizable functional groups.

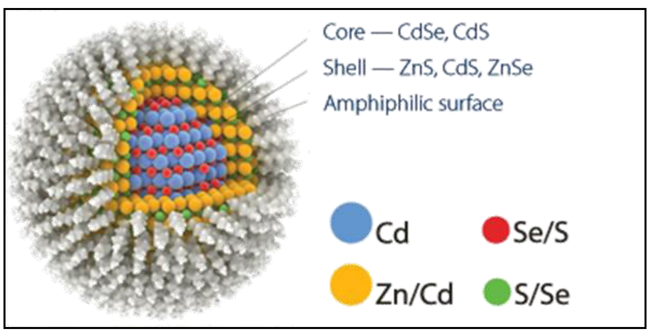

Fig. 3: Structure of Quantum Dot [11]

4. TYPES OF QUANTUM DOTS

QDs are composed of II-VI groups (e.g., CdSe, CdTe, CdS, and ZnS) or III-V elements (e.g., InAs)

4.1. Group 13 and Group 15 elements semiconducting QDs

It consists of any one element from group 13 and any one from group 15. Group 13 elements are B, Al, Ga and Group 15 elements are As, Sb, Bi.

4.2. Group 12 and Group 16 elements semi-conducting QDs

It consists of any one element from group 12 and any one element from group 16. Group 12 elements are Zn, Cd (Transition elements) and Group 16 elements are S, Se, Te.

4.3. Group 14 elements semiconducting QDs

It consists of elements from Group 14 (Si).

5. SYNTHESIS OF QUANTUM DOTS

A large number of synthetic methods have been developed for the synthesis of traditional quantum dots, i.e. metal-based quantum dots which come under two classes, that is top-down approach and bottom-up approach. In top-down method, the bulk material is finely powdered to particles with the size range in nanometers that include sonication, physical vapor deposition, ball milling, etc. In the case of bottom-up method, the quantum dots are formulated using a chemical reaction of various metal ions using specific types of techniques that involves hydrothermal synthesis, solvothermal techniques, microemulsion, thermal decomposition, etc.

5.1. Colloidal synthesis of Quantum Dots [12, 13]

It is one of the cost-effective methods for the synthesis of Quantum Dots. It involves heating precursor solutions to form nucleated monomers which cool slowly, in order to toughen it under high temperatures and result in nanocrystal growth. Typical Quantum dots are made of binary compounds such as lead sulfide, lead selenide, cadmium selenide, cadmium sulfide, cadmium telluride, indium arsenide, and indium phosphide. Colloidal Quantum Dots are formulated by self-assembly in the solution following a chemical reduction which involves following procedure

(i) Immerse semiconductor microcrystals in glass dielectric matrices. (ii) Take a silicate glass with 1% semiconducting phase (CdS, CuCl, CdSe, or CuBr) (iii) Heat for several hours at high temperature (iv) formation of crystals.

Disadvantage of the process involves size variations & size dispersion.

5.2. Plasma Synthesis of Quantum Dots [13]

This method is used to formulate powder-based quantum dots, through non- thermal gas-phase processes. This is a novel approach to produce nanocrystals such as QDs, which conventionally use high-temperature synthesis methods, relies instead upon energetic surface reactions. Synthesis of QDs by this method could improve doping processes for quantum dots, enabling further functionalities.

6. APPLICATIONS OF QUANTUM DOTS [11, 14-17]

Quantum dots are used for:

- Various biochemical and biomedical research
- Multi-color imaging of biological objects (viruses, organelles, cells, tissue) *in vitro* and *in vivo*
- *In situ* diagnosis of cancer markers, lymph node cancer as shown in fig. 4
- Multi-channel optical coding, such as flow cytometry and high-performance analysis of proteins and nucleic acids
- Study of the spatial and temporal distribution of biomolecules using confocal microscopy
- Surface Enhanced Raman Spectroscopy
- Radio-Opaque and Paramagnetic Properties
- Immunoassay studies.

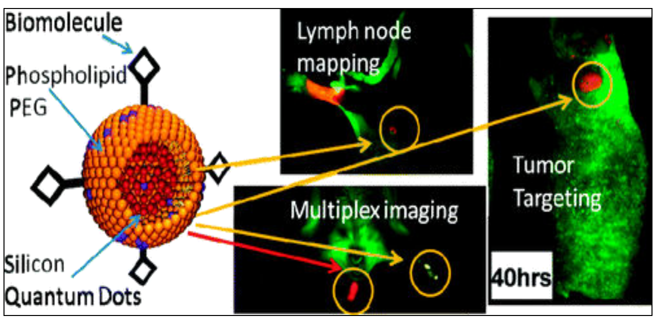

Fig. 4: Diagnosis of cancer using Quantum Dots [18]

7. CHALLENGES IN THE USE OF QUANTUM DOTS [15, 19, 20]

There are many drawbacks in the use of Quantum Dots:

- Highly toxic
- Require stable polymer shell
- Degradation of QDs into the living organisms
- It is hard to control Particle size
- Shells can alter the optical properties.

8. CONCLUSION

Pharmaceutical nanotechnology has a new scope of study with excellent opportunities in different areas of diagnosis and treatment of various diseases. It is developed as a new area of interest having a great potential as carrier for many potent drugs and diagnostics. It has played a very important role to overcome several limitations of conventional dosage forms for like tablets, capsules etc. Quantum Dots have emerged as useful tool in medicine and diagnosis. They possess unique photo-physical properties suitable for addressing the needs of personalized medicine. They have extraordinary luminescence emission properties depending on their particle size and band gap. Quantum dots have proven powerful imaging agents capable of detecting a wide range of diseases such as cancer. They are used for imaging of various biological objects. But these nanoparticles are usually made with toxic metals such as cadmium that can cause toxicity which is one of the major problems for their use. However research is going on to overcome all these challenges.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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