

## Review: Quantum Dots and Application in Medical Science

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### Abstract

Quantum Dots are semiconductors with excitons confined in all three spatial dimensions. Quantum dots have replaced traditional organic dyes in biological and medicinal analysis and research work. These can be affectively used for in vitro imaging of single cell migration in real time. They are subject of interest in various fields like gene silencing, metastasis, stem cell therapeutics, lymphocyte immunology, cancer, embryogenesis etc. Investigations are also undergoing to know toxicity of Quantum dots before their use for human clinical trials. This review describes the latest application of Quantum dots in medical and biological research work.

**Keywords:** Quantum dots; nanocrystals; semiconductors;

### 1. Introduction

Quantum dots were discovered during research work in 1980s by Alexie Ekimov in glass matrix and Louis E Brus in colloidal solutions. These are semiconductors whose conductivity lies between that of bulk semiconductors and those of discrete molecules. In an unconfined (bulk) semiconductor, an electron-hole pair is typically bound within a characteristic length, which is called the exciton Bohr radius and is estimated by replacing the positively charged atomic core with the hole in the Bohr formula. If the electron and hole are constrained further, then properties of the semiconductor change. This effect is a form of quantum confinement, and it is a key feature in many emerging electronic structures. Their conductive properties can be altered by changing size and shape of individual crystals. The smaller the size of the crystal, means larger the band gap, the greater the difference in energy between the highest valence band and the lowest conduction band becomes, therefore more energy is needed to excite the dot, and concurrently, more energy is released when the crystal returns to its resting state.

As the crystal size grows smaller, resulting in a color shift from red to blue in the light emitted.

The main advantages in using quantum dots is that because of the high level of control possible over the size of the crystals produced, it is possible to have very precise control over the conductive properties of the material. Quantum dots (Q.dots) are particularly significant for optical applications due to their high extinction coefficient. The ability to tune the size of quantum dots is advantageous for many applications. For instance, larger quantum dots have a greater spectrum-shift towards red compared to smaller dots, and exhibit less pronounced quantum properties. Conversely, the smaller particles allow one to take advantage of more subtle quantum effects. Being zero dimensional, quantum dots have a sharper density of states than higher-dimensional structures. As a result, they have superior transport and optical properties.

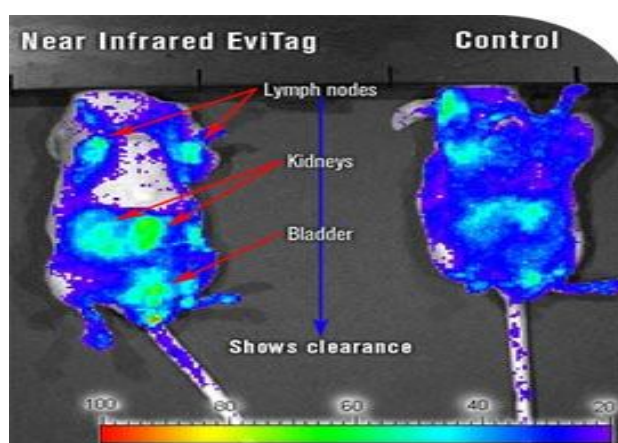
## 2. Quantum Dot

### 2.1 Production methods of Quantum dots

There are several ways to confine excitons in semiconductors, resulting in different methods to produce quantum dots. Dots are grown by advanced epitaxial techniques in nanocrystals produced by chemical methods or by ion implantation, or in nanodevices made by state-of-the-art lithographic techniques. Quantum dots are made through various processes like Colloidal synthesis, Fabrication, Viral assembly, Electrochemical assembly, Bulk-manufacture, Cadmium-free quantum dots.

### 2.2 Application of Quantum Dots.

The new generations of quantum dots have far-reaching potential for the study of intracellular processes at the single-molecule level, high-resolution cellular imaging, long-term in vivo observation of cell trafficking, tumor targeting, and diagnostics.



**Fig. 1:** Mice cell detection using quantum dots.

Quantum dots have been found to be superior to traditional organic dyes on several counts, one of the most immediately obvious being brightness (owing to the high extinction co-efficient combined with a comparable quantum yield to fluorescent dyes ) as well as their stability (allowing much less photo bleaching). Quantum dots are 20 times brighter and 100 times more stable than traditional fluorescent reporters. The extraordinary photo stability of quantum dot probes is the real-time tracking of molecules and cells over extended periods of time. Researchers were able to observe quantum dots in lymph nodes of mice for more than 4 months.

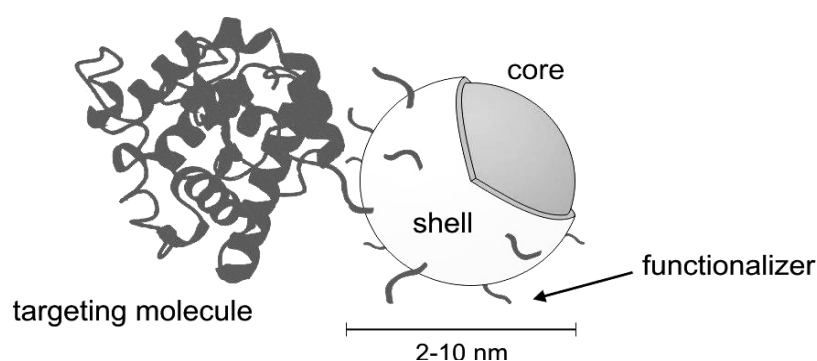
Semiconductor quantum dots have also been employed for in vitro imaging of pre-labeled cells. Quantum dots are dramatically better than existing methods for delivering a gene-silencing tool, known as siRNA, into cells.

**Table 1:** Distinct properties of Quantum dots.

Sl. No	Property of Q. dots
1.	Extremely high brightness when excited.
2.	Highly resistant to photo bleaching.
3.	Emission spectra can be tuned by the size (called “size quantisation effect”), composition of their cores and shells.
4.	Broad excitation and narrow and symmetric emission spectra, which make it feasible to perform (simultaneous detection of multiple signals using a single excitation source.

First attempts have been made to use quantum dots for tumor targeting under in vivo conditions. There exist two basic targeting schemes: active targeting and passive targeting. In active targeting, quantum dots are functionalized with tumor-specific binding sites to selectively bind to tumor cells.

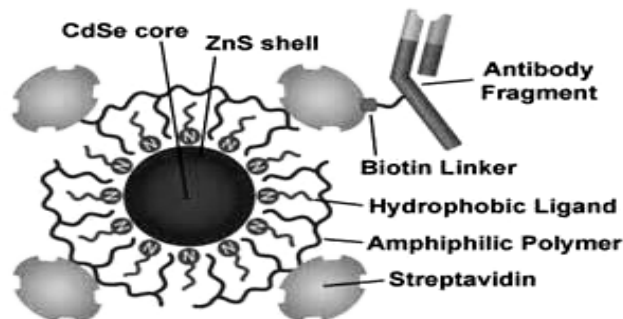
In Passive targeting utilizes the enhanced permeation and retention of tumor cells for the delivery of quantum dot probes. Fast-growing tumor cells typically have more permeable membranes than healthy cells, allowing the leakage of small nanoparticles into the cell body



**Fig. 2:** A core-shell quantum dot bound to a biomolecule.

Another area of studies is quantum dots acting as the inorganic fluorophore for intra-operative detection of tumors using fluorescence spectroscopy. Q. dots are mostly synthesized in non-polar organic solvents. If they are to be solubilized in aqueous buffers, their hydrophobic surface ligands must be replaced by amphiphilic ones. To functionalize Q. Dots with biomolecules, amphiphilic polymers are engineered to carry chemically reactive groups, such as amines and carboxylic acids. Biomolecules, such as peptides, antibodies, DNA or siRNA, can react with these functional groups to form covalent linkages mediated by various coupling reagents. In addition, biomolecules can be conjugated with Q. Dots through noncovalent affinity binding, such as the interactions of biotin/avidin, or nickel nitrilotriacetic acid (Ni-NTA)/histidine-tagged peptides.

Traditionally chalcogenides (selenides or sulfides) of metals like cadmium or zinc (CdSe or ZnS, for example), which range from 2 to 10 nanometers in diameter (about the width of 50 atoms) are used to make Q. dots. For biomedical purposes, in which fluorescence in the visible region is usually required, both core and shell are composed of elements from the II B and VI A groups of the Periodic Table. The major examples are CdSe/ZnS, CdTe/CdS and ZnSe/ZnS Q. Dots. Most Q. Dots crystallizes either in the cubic zinc blend or in the hexagonal wurtzite type structure. The majority of QDs are binary semiconductor crystals, which are composed of two types of atoms. Cadmium selenide (Cd/Se) Q. Dots are the most well studied and widely used. A Cd/Se Q. Dots consists of a Cd/Se core, capped with a ZnS shell.



**Fig. 3:** A Quantum dot biological imaging probe of Zinc and Cadmium compounds.

Biomedical applications of quantum dots include microscopy and multiplexed histology, flow-cytometry, drug delivery, photodynamic therapy, in vivo whole animal and clinical imaging (e.g., angiography), tissue mapping and demarcation, e.g., sentinel lymph node), real time detection of intracellular events, signaling, and bio-sensing, tracking cell migration (e.g., stem cells), low cost but sensitive point-of-care detection (e.g., lateral flow), and environment and bio-defense.

**Table 2:** Various biomedical applications of Q. dots in recent time.

Sl. No	Biomedical Application of QDs
1	Quantum dots as fluorophores for imaging and detection purposes by non-specific labeling
2	Quantum dots for intracellular delivery
3	Internalization of quantum dots by live cells
4	Quantum dots as probes in other bioassays. Quantum dot fluorescence dyes have 15 -20nm fluorescence lifetime which will enable them to study the signal noise ratio effectively

### 3. Conclusion

The new generations of Quantum dots have more potential than traditional chemical dye probes for the study of intracellular processes in human beings at the single molecule level, high-resolution cellular imaging, long-term in vivo observation of cell trafficking, tumor targeting, and diagnostics. Research is going on in the areas like DNA moments, labeling of proteins, tagging of nucleic acid. Thus research and development of Q. dots as new bioimaging probe in medicine opens new frontiers in treatment of critical diseases.

### 4. Acknowledgement

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