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# Quantum Dots Applications

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**Abstract:** A quantum dot is a particle of matter so small that the addition or removal of an electron changes its properties in some useful way. All atom s are, of course, quantum dots, but multi-molecular combinations can have this characteristic. Quantum dots typically have dimensions measured in nanometers, where one nanometer is 10 - 9 meter or a millionth of a millimeter. In this paper, we will discuss the quantum dot and their application.


**Keywords:** Quantum dots, Solar cells, Display, Sensor, Antibody, Fluorescence.

## 1. Introduction

A quantum dot gets its name because it's a tiny speck of matter so small that it's effectively concentrated into a single point. As a result, the particles inside it that carry electricity are trapped and have well-defined energy levels according to the laws of quantum theory, a bit like individual atoms. Tiny really does mean tiny: quantum dots are crystals a few nanometers wide, so they're typically a few dozen atoms across and contain anything from perhaps a hundred to a few thousand atoms. They're made from a semiconductor such as silicon. And although they're crystals, they behave more like individual atoms—hence the nickname artificial atoms. Quantum dots are precise crystals, so you make them in much the same way you'd make any other precise semiconductors crystals. Typical methods include molecular beam epitaxial, ion implantation, and X-ray lithography [1].

## 2. Quantum Dots Optical Properties

The optical properties of quantum dots are known to vary between different types and can be predicted by certain factors. The material that the quantum dot is constructed from plays a role in determining the intrinsic energy signature of the particle, but the most important factor that affects the optical properties is the size of the dots. Different sized quantum dots change the color emitted or absorbed by the crystal, due to the energy levels within the crystal.

**Energy Levels on Fluorescence Spectrum:** In the fluorescence spectrum, the color of the light differs according to the energy emitted by the crystal. Red light is associated with lower energy and blue light with higher energy. The band gap energy of a quantum dot is the difference in energy level between the dot's excited energy state and its resting state. The quantum dot can absorb fluorescent light at the frequency of its band gap to become excited, or emit the same frequency of light to return to its resting state [2].

**Effect of Size:** The size of a quantum dot is inversely proportional to the band gap energy level, and therefore alters the frequency light emitted and has an effect on the color. Smaller dots emit higher energy light that is bluer in color, whereas larger dots emit lower energy red light. It is also possible for larger quantum dots to posses several energy levels that are more closely aligned. This allows for the absorption of photons with different frequency levels, such as those on the red end of the light spectrum. Additionally, due to these additional energy levels electron-hole pairs can become trapped inside larger quantum dots. Over the long term, this causes larger quantum dots to have a longer lifespan that that of small quantum dots [3].

**Effect of Shape:** Recent research has also suggested that the shape of quantum dots may play a role in the band level energy of the dots and, as a result, affect the frequency of fluorescent light emitted or absorbed. However, there is insufficient evidence to support this hypothesis and the currently available information does not aid the construction of quantum dots to optimize their shape for specific optical properties [4].

**Effect of Structure:** The crystal lattice of the quantum dot semiconductor has an effect of the electronic wave function. As a result, a quantum dot has a specific energy spectrum equal to the band gap and a specific density of electronic state on the outside of the crystal. Quantum dots can also be synthesized with a protective shell to lengthen its lifespan and increase frequency of fluorescent emission. For example a quantum dot composed of cadmium serenade may have a thicker protective shell made of cadmium sulfide [5].

**Optimizing Optical Properties for Imaging:** The most important aspect of the quantum dot that affects the optical properties it displays is its size. The size of the dot can be manipulated in manufacturing processes to create a quantum dot suitable for the purposes of optical imaging. The shape and structure of the quantum dot should also be considered, as well as the material used in the construction process. However, as the size has a direct effect on the optical properties and the frequency of fluorescent light emitted or absorbed by the crystal, it should be given appropriate consideration [6].

## 3. Quantum Dots Solar Cells

High energy costs, dependence on foreign oil, unstable governments, the threat of global warming and increased greenhouse gases; we know the problems but we have not done enough to solve them. A quantum dot solar cell is a solar cell design that uses quantum dots as the absorbing photovoltaic material (Fig.1). It attempts to replace bulk materials such as silicon, copper indium gallium selenide (CIGS) or CdTe. Quantum Dot Solar cells can absorb energy 24/7. While common black silicon panels are best at absorbing visible light at the peak times of the day, QD Solar Cells can absorb power from the ultraviolet thru visible to the infrared lighting range to produce their power, day and night. The third generation of solar cells includes those based on semiconductor quantum dots. This sophisticated technology applies nanotechnology and quantum mechanics theory to enhance the performance of ordinary solar cells. Although a practical application of quantum dot solar cells has yet to be achieved, a large number of theoretical calculations and experimental studies have confirmed the potential for meeting the requirement for ultra-high conversion efficiency [7].

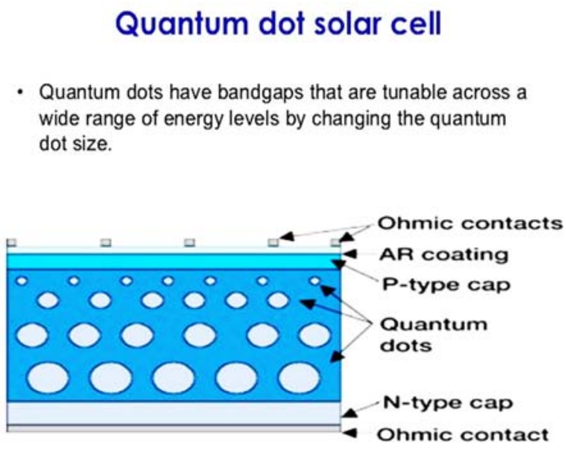


**Fig. 1.** Quantum dot solar cell. Quantum dots have bandgaps that are tunable across a wide range of energy levels by changing the quantum dot size. (www.slideshare.net).

## 4. Quantum Dots Display

A quantum dot display is an experimental type of display technology. Quantum dots (QD) or semiconductor nanocrystals could provide an alternative for commercial applications such as display technology. QD LED or QLED is considered as a next generation display technology after OLED-Displays. QLED means Quantum dot light emitting diodes and are a form of light emitting technology and consist of nano-scale crystals that can provide an alternative for applications such as display technology (Fig.2). The structure of a QLED is very similar to the OLED technology. But the difference is that the light emitting centers are cadmium selenide (CdSe) nanocrystals, or quantum dots. A layer of cadmium-selenium quantum dots is sandwiched between layers of electron-transporting and hole-transporting organic materials. An applied electric field causes electrons and holes to move into the quantum dot layer, where they are captured in the quantum dot and recombine, emitting photons. The spectrum of photon emission is narrow, characterized by its full width at half the maximum value. There are two major fabrication techniques for QD-LED, called phase separation and contact-printing. QLEDs are a reliable, energy efficient, tunable color solution for display and lighting applications that reduce manufacturing costs, while employing ultra-thin, transparent or flexible materials [8].

**QLEDs advantages:**

1. Pure color — Will deliver 30-40% luminance efficiency advantage over organic light emitting diodes (OLEDs) at the same color point.
2. Low power consumption — QLEDs have the potential to be more than twice as power efficient as OLEDs at the same color purity.

3. Low-cost manufacture — the ability to print large-area QLEDs on ultra-thin flexible substrates will reduce luminaries manufacturing cost.

4. Ultrathin, transparent, flexible form factors — QLEDs will enable designers to develop new display and lighting forms not possible with existing technologies.

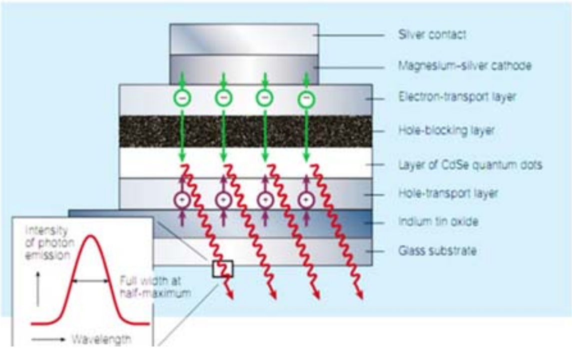


**Fig. 2.** QD LED structure (http://www.qled-info.com).

## 5. Quantum Dots Sensors

Findings - This shows that QDs are being exploited in a range of experimental sensors for detecting physical variables, notably radiant/electromagnetic quantities and temperature; chemical compounds, such as metals and many species of clinical interest; and a variety of gases and vapours (Fig.3). Prospects also exist to develop improved sources and detectors for use in optical gas sensors. Semiconductor QDs are attracting growing interest from the sensor research community and the greatest short-term prospects probably lie with advanced IR image sensors and FPAs, together with THz detectors. In the longer term, the technology has prospects to yield families of sensitive and selective chemical sensors and although its role in gas detection is less clear, some significant developments have been reported. As this technology is investigated further and matures, it is expected to play a key role in future generations of photonic nanosensors. Enzymes are essential in the human body, and the disorder of enzymatic activities has been associated with many different diseases and stages of disease. Luminescent semiconductor nanocrystals, also known as quantum dots (QDs), have garnered great attention in molecular diagnostics. Owing to their superior optical properties, tunable and narrow emissions, stable brightness and long lifetime, QD-based enzyme activity measurement has demonstrated improved detection sensitivity, which is considered particularly valuable for early disease diagnosis. Recent studies have also shown that QD-based nanosensors are capable of probing multiple enzyme activities simultaneously. This review highlights the current development of QD-based nanosensors for enzyme detection. The enzyme-QD hybrid system, equipped with unique electronic, optical and catalytic properties, is envisioned as a potential solution in addressing challenges in diagnostics and therapeutics [9].

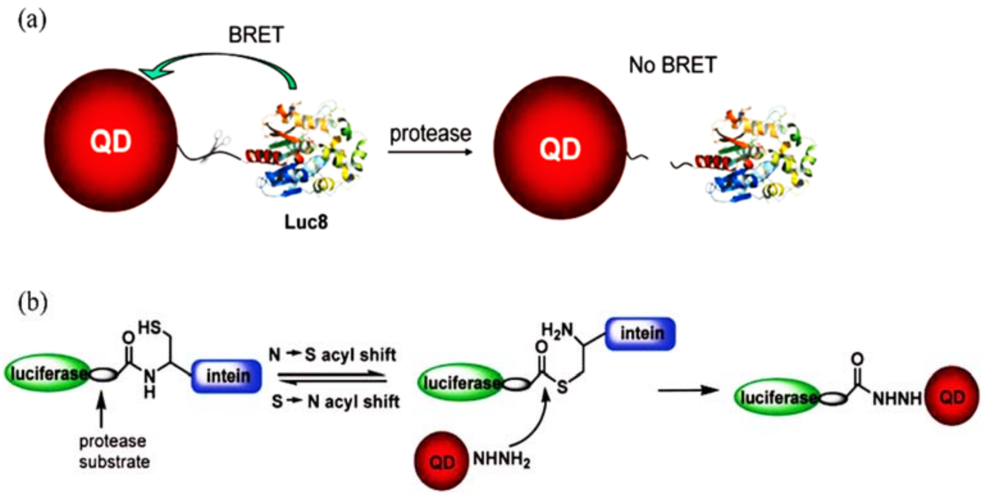


**Fig. 3.** Semiconductor Quantum Dots in Chemical Sensors and Biosensors (www.mdpi.com).

Quantum dots are nanometer-scale semiconductor crystals with unique optical properties that are advantageous for the development of novel chemical sensors and biosensors. The surface chemistry of luminescent quantum dots has encouraged the development of multiple probes based on linked recognition molecules such as peptides, nucleic acids or small-molecule ligands.

## 6. Quantum Dots Battery

On average, it usually takes about 2-3 hours to charge a smartphone from completely drained to 100%. Because so many of us are constantly on the go and rely so heavily on our phones throughout the day, battery life becomes increasingly important. A new device by startup called Store Dot could revolutionize battery charges by bringing a phone from dead to full in about 30 seconds. The secret to Store Dot's technology is quantum dots, which are about 60 times smaller than a single HIV vision. The "dots" are actually peptides that have been altered to have certain properties, like optical or the ability to generate charge when strained. Only two peptides are connected and they have a crystalline structure that aids in their stability and ability to hold a charge, which should last through thousands of charge cycles. Traditional batteries use an electrolyte to generate electrons, but Store Dot has made a battery that uses a quantum dot nanocrystal solution instead. The resulting battery is about five times more powerful. It could also be used to make a batter equal in power, though considerably smaller. Currently, Store Dot's charger is about the size of the phone, though a couple inches thicker, but the company is working on scaling it down for a commercial release in late 2016. The charger is expected to cost about $30. The prototype was built for the Samsung Galaxy 4, though they plan to make chargers for other brands as well.

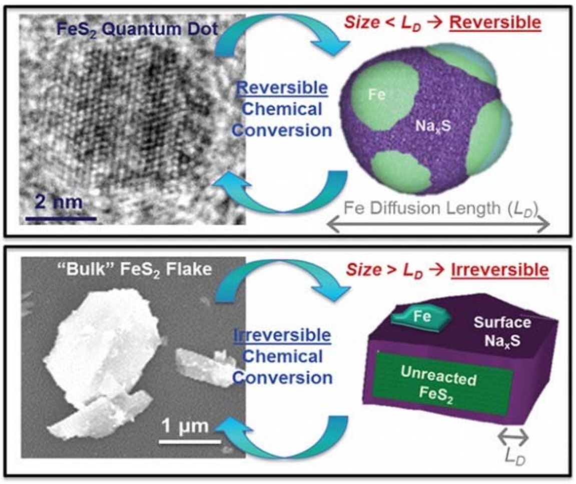


**Fig. 4.** Putting bulk iron pyrite in a battery works poorly because the iron must move to the surface so that sodium-sulfur material (or lithium-sulfur material) can form and store energy. Iron pyrite quantum dots, by contrast, have iron close to the surface due to their small size, and this energy storage process can occur reversibly over many cycles. The diffusion length (LD) represents the distance iron atoms have to move through the iron pyrite to reach the surface. (http://news.vanderbilt.edu/).

If you add quantum dots – nanocrystals 10,000 times smaller than the width of a human hair to a smartphone battery it will charge in 30 seconds, but the effect only lasts for a few recharge cycles.

## 7. Quantum Dots Antibody

One of the key questions in biology understands how cells move, interact, and evolve in living organisms. Tremendous efforts have been made to answer these questions in vitro, which have yielded a molecular-level understanding of cellular events. However, an increasing number of studies indicate that cellular activities need to be understood in the context of their natural environments. Single-cell labeling methods in use currently involve immunohistochemistry, genetic manipulation, or irradiation of mice, none of which reflect the native microenvironments. Labeling of cell surface receptors in living cells can be achieved using antibody-conjugated semiconductor quantum dots (QDs). The inherent photostable property of QDs can be exploited for understanding the arrangement and distribution of receptors in the plasma membrane. Multiplexed, phenotypic, intravital cytometric imaging requires novel fluorophore conjugates that have an appropriate size for long circulation and diffusion and show virtually no nonspecific binding to cells/serum while binding to cells of interest with high specificity. In addition, these conjugates must be stable and maintain a high quantum yield in the in vivo environments. Here, we show that this can be achieved using compact (~15 nm in hydrodynamic diameter) and biocompatible quantum dot (QD) -Ab conjugates. This in vivo cytometric technique may be useful in a wide range of structural and functional imaging to study the interactions between cells and between a cell and its environment in intact and diseased tissues [11, 12].

## 8. Quantum dots for Cancer Diagnosis

Cancer is a major public health problem in the world, and one in four deaths in the United States is due to cancer, with an estimated 1479350 new cancer cases and 562340 deaths from cancer expected in 2009. Although progress has been made in reducing incidence and mortality rates and improving survival, cancer still accounts for more deaths than heart disease in persons younger than 85 years of age. One major challenge is how to diagnose cancer in early stage when curative treatment is possible. New technologies are required to dramatically improve the early detection and treatment of cancer, and fluorescent molecules can play a big role in this field. Nanotechnology is an emerging field that may have potentials to make paradigm changes in the detection, treatment, and prevention of cancer. The development of biocompatible nanoparticles for molecular targeted diagnosis and treatment is an area of considerable interest. The basic rationale is that nanoparticles have unique structural and functional properties different from those of discrete molecules or bulk materials. One of the most exciting advances in label technology is the development of quantum dots (QDs), a heterogeneous class of engineered nanoparticles with unique optical and chemical properties making them important nanoparticles with numerous potential applications ranging from medicine to energy. Used as in vitro and in vivo fluorophores, QDs are intensely studied in molecular, cellular, and in vivo imaging due to their novel optical and electronic properties. To be different from those reviews focusing on the basic mechanisms and development of QDs, this review focuses on recent application of QDs in cancer diagnosis, including early detection of primary tumor such as ovarian cancer, breast cancer, prostate cancer, and pancreatic cancer, as well as regional lymph nodes and distant metastases [13]. Quantum dots (QDs) are semiconductor nanocrystals that emit fluorescence on excitation with a light source. They have excellent optical properties, including high brightness, resistance to photobleaching and tunable wavelength. Recent developments in surface modification of QDs enable their potential application in cancer imaging. QDs with near-infrared emission could be applied to sentinel lymph-node mapping to aid biopsy and surgery. Conjugation of QDs with biomolecules, including peptides and antibodies, could be used to target tumors in vivo [14].

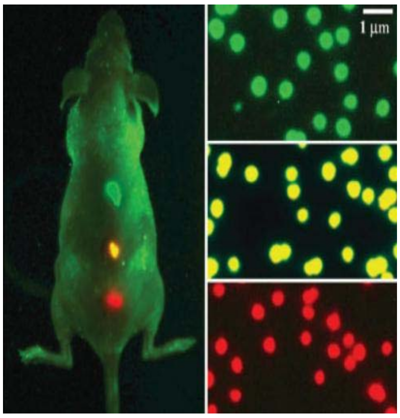


**Fig. 5.** Multicolor quantum dot (QD) capability of QD imaging in live animals. (triplehelixblog.com).

## 9. Quantum Dots Fluorescence

Quantum dots are tiny particles or nanocrystals of a semiconducting material with diameters in the range of 2-10 nanometers (10-50 atoms). They were first discovered in 1980 [15]. Quantum dots display unique electronic properties, intermediate between those of bulk semiconductors and discrete molecules, that are partly the result of the unusually high surface-to-volume ratios for these particles. The most apparent result of this is fluorescence, wherein the nanocrystals can produce distinctive colors determined by the size of the particles. The luminescent properties of quantum dots arise from recombination of electron-hole pairs (exciton decay) through radiative pathways. However, the exciton decay can also occur through nonradiative methods, reducing the fluorescence quantum yield. [16] One of the methods used to improve efficiency and brightness of semiconductor nanocrystals is growing shells of another higher band gap semiconducting material around them. These quantum dots with small regions of one material embedded in another with a wider band gap are known as core-shell quantum dots (CSQDs) or core-shell semiconducting nanocrystals (CSSNCs). For example, quantum dots with CdSe in the core and ZnS in the shellavailable from Aldrich Materials Science exhibit greater than 80 % quantum yield. Coating quantum dots with shells improves quantum yield by passivizing nonradiative recombination sites and also makes them more robust to processing conditions for various applications. This method has been widely explored as a way to adjust the photophysical properties of quantum dots. The small size of quantum dots allow them to go anywhere in the body making them suitable for different bio-medical applications like medical imaging, biosensors, etc. At present, fluorescence based biosensors depend on organic dyes with a broad spectral width, which limits their effectiveness to a small number of colors and shorter lifetimes to tag the agents. On the other hand, quantum dots can emit the whole spectrum, are brighter and have little degradation over time thus proving them superior to traditional organic dyes used in biomedical applications [17, 18].

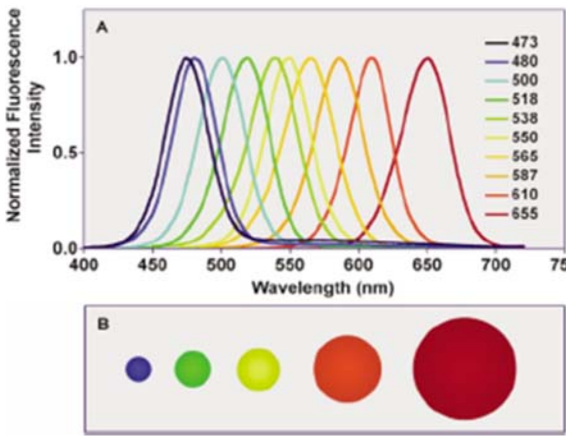


**Fig. 6.** Fluorescence spectra of CdSe quantum dots (www.intechopen.com).

## 10. Quantum Dots Laser

A quantum dot laser is a semiconductor laser that uses quantum dots as the active laser medium in its light emitting region (Fig. 7). Due to the tight confinement of charge carriers in quantum dots, they exhibit an electronic structure similar to atoms. A quantum dot laser is a semiconductor laser that uses quantum dots as the active laser medium in its light emitting region. Due to the tight confinement of charge carriers in quantum dots, they exhibit an electronic structure similar to atoms. Lasers fabricated from such an active media exhibit device performance that is closer to gas lasers, and avoid some of the negative aspects of device performance associated with traditional semiconductor lasers based on bulk or quantum well active media. Improvements in modulation bandwidth, lasing threshold, relative intensity noise, line width enhancement factor and temperature insensitivity have all been observed. The quantum dot active region may also be engineered to operate at different wavelengths by varying dot size and composition. This allows quantum dot lasers to be fabricated to operate at wavelengths previously not possible using semiconductor laser technology. Recently, devices based on quantum dot active media are finding commercial application in medicine (laser scalpel, optical coherence tomography), display technologies (projection, laser TV), spectroscopy and telecommunications. A 10 Gbit/s quantum dot laser that is insensitive to temperature fluctuation for use in optical data communications and optical networks has been developed using this technology. The laser is capable of high-speed operation at 1.3 μm wavelengths, at temperatures from 20 °C to 70 °C. It works in optical data transmission systems, optical LANs and metro-access systems. In comparison to the performance of conventional strained quantum-well lasers of the past, the new quantum dot laser achieves significantly higher stability of temperature.

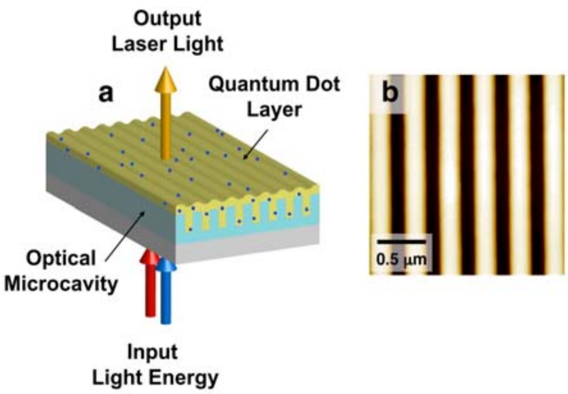


**Fig. 7.** A schematic of a quantum dot lasing device (www.kurzweilai.net).

## 11. Conclusions

Quantum dots (QDs) are artificial clusters of semiconductive atoms that have the ability to confine the electrons motion due to their small size. One of the most important properties of Quantum Dots is the ability to tune their bandgap and therefore control their light absorbance and emission frequencies. This is done through the quantization of their energy levels. In this way it is possible for their optical and electrical properties to be adjusted according to their purpose of use. The latest advances in technology have shown that QDs can really make valuable contributions to a wide range of applications substituting for many of the bulk, expensive, and inefficient materials.

### 11.1. Quantum Dot Advantage

1. Quantum Dot formations absorb photons of light and then re-emit longer wavelength photons for a period of time. The high level of control possible over the size of the dot produced provides very precise control over the wavelength of the re-emitted photon. That means that the color of the light emitted from the QD can actually be manipulated without significant cost or the use of high-end technology. Following this 2-procedure, a full range of QDs can be manufactured, each with a narrow distinct emission spectrum.
2. Another great benefit is the fact that they only require a small amount of energy in order to be excited and this can be achieved by a single blue or ultraviolet wavelength beam, regardless of the QD size. Both attributes reduce the costs dramatically.
3. The high photostability and brightness of QDs make them suitable for high sensitivity applications like fluorescent tagging and live-cell imaging. Their fluorescence properties and their high resistance to metabolic degradation enable a wider range of experiments to be performed ignoring possible time barriers.
4. QDs can be used in various forms, e.g. as small crystals in liquid solutions, as quantum dust, and in bead form. All these existing forms make their range of applications even wider.
5. Another great aspect of QD manufacturing is that there are multiple methods to develop them easily and cost effectively. These methods include lithographic techniques, epitaxial techniques, and colloidal synthesis.

### 11.2. Quantum Dot Advantage

1. A potential drawback when used in biological applications is the fact that due to their large physical size, they cannot diffuse across cellular membranes. The delivery process may actually be dangerous for the cell and even result in destroying it. In other cases a QD may be toxic for the cell and inappropriate for any biological application.
2. Their quite extended lifetime may be a hindrance to certain applications that require QDs to biodegrade immediately after the experiment has been performed. In certain cases however it is possible to remove the QDs by simply washing the cells with appropriate solutions.
3. Additionally, Quantum Dots may blink and become invisible. Certain drawbacks on the QD surface may lead to quantum yield deterioration, meaning that the ratio of the emitted to the absorbed energy is rather low. Their low transmittance may stay undetectable or may demand high-sensitivity detection systems.
4. In display and monitor industry, QDs are expected to be used in a new LED (light-emitting diode) variation, the QD-LEDs. However, the manufacturing of blue emitting QDs is a difficult process. It requires smaller sizes than the rest of the color emitting dots and an amplified emission compared to the other colors, so that the human eye can detect the same signal.

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