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Revealing The Concept & Fundamental of Quantum Dots

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ABSTRACT

This article reviews the current state of research involving semiconductor quantum dots, provides a brief review of the theory behind their unique properties, and an introduction explaining the importance of quantum dot research. The characteristic shifting of the band gap energy with quantum dot size, as predicted from the density of states for low-dimensional structures, allows experimental measurements to determine the extent to which quantum confinement effects play a role in the resulting properties. Quantum dots are very tiny crystals that glow with bright, rich colors when stimulated by an electric current. QD-LEDS are expected to find applications in television and computer screens, general light sources, and lasers. Finally, some of the more exciting applications for quantum dots currently being researched for use in the field of optoelectronics are reviewed, including quantum dot infrared photo-detectors, quantum dot lasers, and quantum dot solar cells and Qd TV (quantum dot TV). Comments are made on the current progress and the future prospects of quantum dot research and device applications.

Keywords: *QD(quantum dot), Band Gap, Fabrication, Nanocrystal Structure*

I. INTRODUCTION

Quantum dots are tiny particles, or “nanoparticles”, of a semiconductor material, traditionally chalcogenides (A chalcogenide is a chemical compound consisting of at least one chalcogen ion and at least one more electropositive element. Although all group 16 elements of the periodic table are defined as chalcogens, the term is more commonly reserved for sulfides, selenides, and tellurides, rather than oxides.) 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). The diameter of a QD is so small; it is actually smaller than the excited electron-hole Bohr radius. How many atoms are included in the quantum dot determines their size and the size of the quantum dot determines the color of light emitted. The idea of using quantum dot as a light source first developed in 1990s. Early applications included, imaging using QD infrared photodetectors and light emitting diodes and single color light emitting devices. Starting from early 2000, scientists started to realize the potential of developing quantum dot as the next generation light source and display technology. Initially targeted at biotechnology applications, such as biological reagents and cellular imaging, quantum dots are being eyed by producers for eventual use in light-emitting diodes (LEDs), lasers, and telecommunication devices such as optical amplifiers and waveguides. The strong commercial interest has renewed fundamental research and directed it to achieving better control of quantum dot self-assembly in hopes of one day using these unique materials for quantum computing. Double quantum dots have been suggested as an ideal model system for studying interactions between localized impurity spins in addition to the Kondo effect. We demonstrate a Kondo effect in a series-coupled double quantum dot. When the many body molecular states are formed, we observe a splitting of the Kondo resonance peak in the differential conductance. The occurrence of the Kondo resonance and its magnetic field dependence agree with a simple interpretation of the spin status of a double quantum dot

II. CHARACTERSTICS

A. *Band Gap*

Quantum dots are fluorophore nanocrystals whose excitation and emission is fundamentally different than traditional organic fluorophores. Instead of electronic transitions from one valence orbital to another, quantum-dot fluorescence involves exciting an electron from the bulk valence band of the semiconductor material across an energy gap, making it a conduction electron and leaving behind a hole. The electron–hole pair (also known as an exciton) is quantum-confined by the small size of the nanocrystal (smaller than the exciton Bohr radius). When the electron–hole pair eventually recombines, a characteristic photon is emitted. Minute changes to the size of the confining crystal alter the energy bandgap, thus

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determining the color of the fluorescence photon. In general, the smaller quantum dot, the larger the bandgap energy for a given material, and thus, the shorter the wavelength of the emitted fluorescence. Of the many types of quantum dots that can be made from various semiconductor materials, CdSe/ZnS quantum dots are presently the most common commercially available as secondary antibody conjugates.

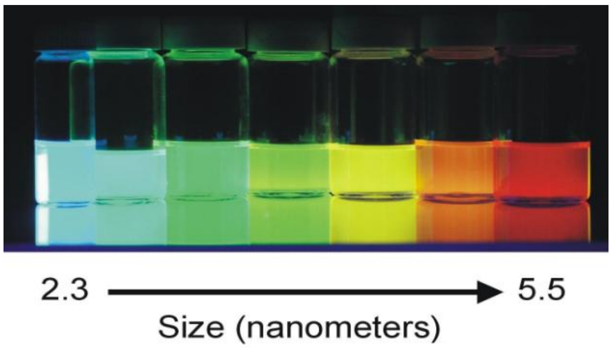

Figure 1

They are composed of a core of cadmium selenide ranging from about 10 to 50 atoms in diameter and about 100 to 100,000 atoms in total, and as mentioned, the size of the core determines the fluorescence emission spectra. They have a thin zinc sulfide passivating layer that improves the fluorescence quantum efficiency and stability of the quantum dots and an organic polymer coating to make them water soluble and enabling bioconjugation to targeting molecules such as anti-IgG (immunoglobulin G) secondary antibodies, Fab fragments, peptides, or streptavidin.

B. *Q-Dot Nanocrystal Structure*

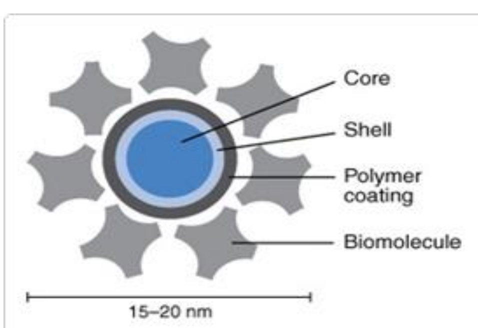

Figure 2

Fundamentally, Q dot nano-crystals are fluorophores—substances that absorb photons of light, then re-emit photons at a different wavelength. However, they exhibit some important differences as compared to traditional fluorophores such as organic fluorescent dyes and naturally fluorescent proteins, ends there. Qdot nanocrystals are nanometer-scale (roughly protein-sized) atom clusters, containing from a few hundred to a few thousand atoms of a semiconductor material (cadmium mixed with selenium or tellurium), which has been coated with an additional semiconductor shell (zinc sulfide) to improve the optical properties of the material. These particles fluoresce in a completely different way than do traditional fluorophores.

C. *FORMATION OF QUANTOM DOT*

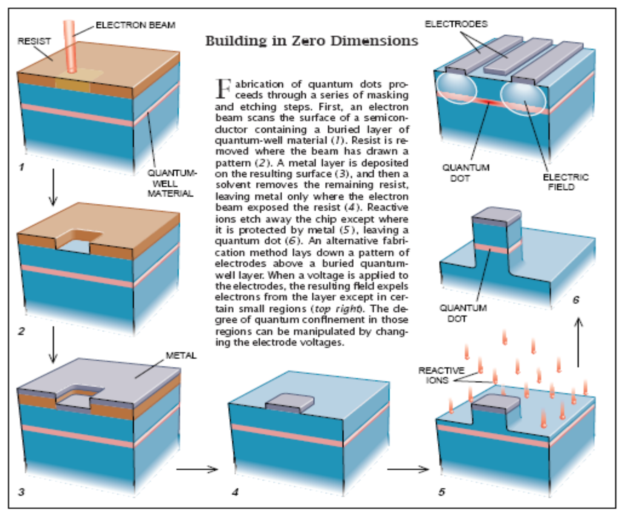

Figure 3

D. *EFFICIENCY IMPROVEMENT OF QUANTUM DOT*

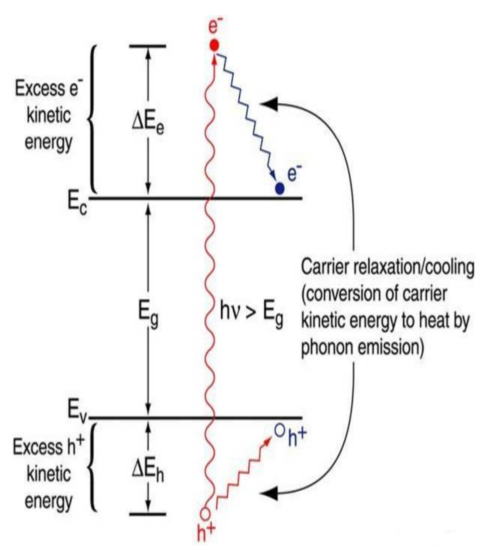

Figure 4
Thermalization losses in solar cells

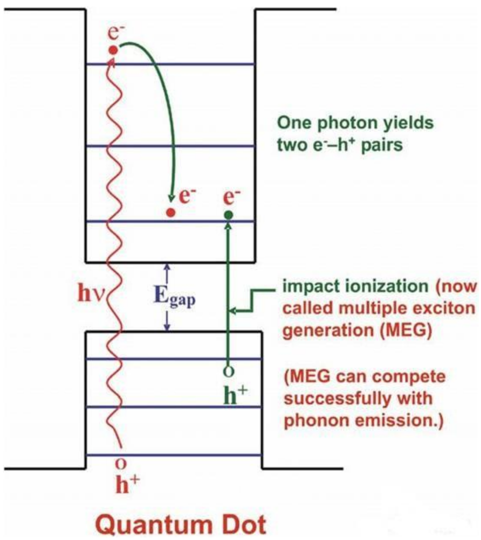

Figure 5

Limitation of solar cell is also related with recombination of electron-hole pair. Recombination is part of a process to restore equilibrium to a semiconductor that has been perturbed, or disturbed out of equilibrium. Perturbations can be in the form of an applied electric field, a change in temperature or exposure to light. Recombination occurs when there is an excess of carriers and they are destroyed, by recombining. When electron-hole pairs are destroyed, a negatively charged electron is attracted to a positively charged hole, and as they get together, their charges are canceled and the electron is part of a bond once again. Auger recombination is a type of band-to-band recombination that occurs when two carriers collide. The collision transfers the energy released from the recombining carrier to the surviving carrier. In other words, one carrier loses energy and the other gains it. The one that loses it is recombined, and the one that gains it goes to a higher energy level. Eventually, this highly energized carrier "thermalizes" - loses energy in small steps through heat producing collisions with the semiconductor lattice, until it eventually recombines or gains energy once more. And larger hole effective mass leads to rapid thermalization.

III. QUANTUM DOT APPLICATION

a. Biomedical Applications of Quantum Dots May 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)
- Environment and bio-defense

b. Quantum Dot LED

Quantum-dot LEDs, particularly those that provide the hard-to-reach blue end of the spectrum, appear to be key to opening any number of exciting technological advances in the fields of full-color, flat-panel displays; ultrahigh-density optical memories and data storage; backlighting; and chemical and biological sensing. "We have also explored the use of quantum dots for blue lasers," notes Lee. "In 1999, we demonstrated that lasing may be possible with these quantum dots, opening the door to a new class of blue lasers that have intriguing applications for both the private sector and the missions of the Department of Energy."

c. Photovoltaic Cell

1) *First Generation:-*
   - *Single crystal Silicon Wafer*
   - High Carrier Mobility
2) *Second Generation:-*
   - *Thin Film Technology*
   - Less Expensive
3) *Third Generation:-*
   - *Nanocrystals Solar Cells*
   - Enhance Electrical Performances of the Second Generation While Maintaining Low Production Costs.

d. Photodetector Devices

Quantum dot photo detectors can be fabricated either via solution-processing, or from conventional single-crystalline semiconductors. Conventional single-crystalline semiconductor QDPs are precluded from integration with flexible organic electronics due to the incompatibility of their growth conditions with the process windows required by organic semiconductors. On the other hand, solution-processed QDPs can be readily integrated with an almost infinite variety of substrates, and also post processed atop other integrated circuits. Such colloidal QDPs have potential applications in surveillance, machine vision, industrial inspection, spectroscopy, and fluorescent biomedical imaging.

e. Computing

Quantum dot technology is one of the most promising candidates for use in solid-state quantum computation. By applying small voltages to the leads, the flow of electrons through the quantum dot can be controlled and thereby precise measurements of the spin and other properties therein can be made. With several entangled quantum dots, or qubits, plus a way of performing operations, quantum calculations and the computers that would perform them might be possible.

f. Other Application Of Quantum Dot

- Solid-state lighting which makes use of second generation quantum dots to dispense with the need for either incandescent bulbs or compact fluorescent lamps can deliver high quality white light at a fraction of the energy consumption and with unrivalled efficiency, resulting in domestic and commercial lighting products which can literally "last a lifetime".
- In the drive to deliver the one-dollar-per-watt efficiency goal for PV cells, CIGS nanoparticles provide an ingenious solution. The photo generated excitons of these nanoparticles can be harnessed, providing a source of energy. Solar cells composed of CIGS nanoparticles are a fraction of the cost of traditional solar cells to manufacture, they are physically robust and flexible, and operate at high efficiency even in low light conditions.
- Gold Q-dots has very well defined excitation and emission spectrum. And due to the high electron density and the strong electron-electron coupling, the gold Q-dots exhibit quite good characteristic change corresponding to the nanocluster size and geometry.

IV. FUTURE ASPECTS

Progress with the development of new nanomaterials continues at a rapid pace, and certainly many new types of commercially available quantum dots and enhanced multifunctional nanoscale probes are to be expected. Aside from an expansion of the repertoire of colors, smaller bioconjugates as well as enhanced surface chemistries should allow for even greater penetration into cells and tissues. More distinct-shaped (pyramid, rod, dot, oblate, square) quantum dots from a wide range of semiconductor materials have already been demonstrated, and their availability as secondary antibody or direct primary antibody conjugates will allow for easier multiprotein discrimination by electron microscopy. Furthermore, as methods for delivering quantum dots into living cells continue to evolve and improve, sophisticated correlated live-cell and electron-microscopic imaging of single molecules will be possible. Q-dots can give us a higher signal than the conventional organic dyes. Then we can set up a shout time scan to gain enough signals for the camera system to image. This gives us a chance to test the precise fast moving tracks, which cannot be done before due to the weak signals.

V. CONCLUSION

QD-LEDs emits red, green, and blue color light that are highly color saturated, efficient and which can be patterned laterally for full color display applications by means of micro-contact printing of single layers of nanocrystals. The use of micro-contact printing of nanocrystals to fabricate LEDs has tremendous potential for flat panel display technology. However, phase separation of QDs from organics could still have niche roles in QD-LED fabrication where cost is of extreme importance, and lateral patterning is not necessary, for example in the construction of white light emitting QD-LEDs for general lighting application. In this case, the development of a highly soluble, high bandgap molecular organic semiconductor remains. The completion of a toolkit of easily processed, highly emissive, stable QD materials has allowed QD-LEDs to reach technological significance.

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