QUANTUM PHENOMENA IN ZERO DIMENSIONS: QUANTUM DOTS

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***Abstract*— Quantum phenomena in zero dimensions: quantum dots because of many interesting and important applications currently in use by this nanotechnology. The usefulness and application of quantum dots technologically continues to expand and research is striving to bring their benefits to more and more technologically applied fields. SMALLER…smaller…smaller - In the semiconductor industry, this mantra translates to faster…… faster…..faster. The question is, how small can we go? At Lawrence Livermore National Laboratory, the answer may be: as small as quantum dots. Quantum dot has some attractive advantages: long-term photostability, higher fluorescent outcome, narrower fluorescence emission, sensitivity to the electric and magnetic field.**

Keywords: Quantum dot, Photostability, Band Gap, Exciton, etc.

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I. INTRODUCTION (QUANTUM DOT)

An object that confines electrons in all three dimensions. Here grouping of atoms is so small that the addition or removal of an electron will change its properties in a significant way.

Quantum dots are semiconductors on nanometer scale that contain a tiny droplet of free electron. Also known as Mesoscopic or artificial atoms.[1]

Typical dimensions ranging from 2-10 nanometers (10-50 atoms) in diameter .They can have anything from a single electron to a collection of several thousands. Their size, shape and the number of electron can be precisely controlled. Just as in an atom, the energy levels are quantized due to confinement of electrons. They have properties that are between those of bulk semiconductors and those of discrete molecules. In Biochemistry - QD's are known as redox groups while in nanotechnology these are called quantum bits or qubits. Requisite absorption and resultant emission wavelength dependent on dot size.

II. QUANTUM DOTS BACKGROUND

In 1970's, first low dimensional structures QW (Quantum Wells) were developed. 1D (quantum wires) and 0D (quantum dots) were subsequently developed (Fig 2). In Quantum Wells - Density of states is continuous and in Quantum Dots - Density of states is discrete. They are interesting both from a fundamental point of view and for their potential applications which include transistors that control currents at the single electron level, highly efficient low power lasers and even circuit elements for quantum computers.

Features of Quantum Dots

As semiconductors derive their great importance from the fact that their electrical conductivity can be altered via an external stimulus voltage, photon flux, etc.

The usefulness of Quantum Dots comes from their peak emission frequency's extreme sensitivity to both the dots size and composition.

Bands and Band gaps

The electrons in bulk (much bigger than 10 nm) semiconductor material have a range of energies. One electron with a different energy than a second electron is described as being in a different energy level, and it is established that only two electrons can fit in any given level. In bulk, energy levels are very close together, described as continuous, meaning that there is almost no energy difference between them. Some energy levels are simply off limits to electrons; this region of forbidden electron energies is called the band gap, and it is different for each bulk material. Electrons occupying energy levels below the band gap are described as being in the valence band. Electrons occupying energy levels above the band gap are described as being in the conduction band.

Electrons and Holes

In natural bulk semiconductor material, an extremely small percentage of electrons occupy the conduction band the overwhelming majority of electrons occupy the valence band, filling it almost completely. The only way for an electron in the valence band to jump to the conduction band is to acquire enough energy to cross the band gap. Most electrons in bulk simply do not have enough energy to do so. Applying a stimulus such as heat, voltage, or photon flux can induce some electrons to jump the forbidden gap to the conduction band. The valence location they vacate is referred to as a hole since it leaves a temporary "hole" in the valence band electron structure.

Bulk Semiconductors - A Fixed Range of Energies

Electrons in natural semiconductor bulk that have been raised into the conduction band will stay there only momentarily before falling back across the band gap to their natural, valence energy levels. As the electron falls back down across the band gap, electromagnetic radiation with a wavelength corresponding to the energy it loses in the transition is emitted. Great majority of electrons, when falling from the conduction band back to the valence band, tend to jump from near the bottom of the conduction band to the top of the valence band- in other words, they travel from one edge of the band gap to the other. Because the band gap of the bulk is fixed, this transition results in fixed emission frequencies. Quantum dots offer the unnatural ability to tune the band gap and hence the emission wavelength.

III. QUANTUM CONFINEMENT IN EMICONDUCTORS-QUANTUM DOTS

Quantum Dots are made of semiconductor material. The electrons have a range of energies. Concepts of energy levels, band gap, conduction band and valence band still apply. But there is a major difference related to Exciton Bohr Radius which is different for each material. (EXCITON BOHR RADIUS-Excitons have an average physical separation between the electron and hole) as shown in fig 4. In bulk, the dimensions of the semiconductor crystals are much larger than excitons Bohr Radius allowing the exciton to extend to its natural limit.

However if the size of a semi conductor crystal becomes small enough that it approaches the size of the materials exciton bohr radius than the electron energy levels can no longer be treated as continuous - they must be treated as discrete, meaning that there is a small and finite separation between energy levels. This situation of discrete energy levels is called quantum confinement, and under these conditions, the semi of the conductor material ceases to resemble bulk, and instead can be called a quantum dot. This has large repercussions in the absorptive and emissive behavior semiconductor material.

Quantum dot is a brand new development from the nano particle science. Now the most useful quantum dot is semiconductor QDs, such as ZnS-capped CdSe nanocrystals. [6]

A Figure 5 is a sketch map for the structure of the semiconductor QDs. The typical QD is comprised by two main parts. The middle part is a single crystal, which is the heart of the structure. The diameter of it is about few nanometers and the size and the shape can be controlled by appropriate growing environment [2]

A TUNABLE RANGE OF ENERGIES: -

Because quantum dots electron energy levels are discrete rather than continuous, the addition or separation of just a few atoms to the quantum dot has the effect of altering the boundaries of the band gap. Changing the geometry of the surface of the quantum dot also changes the band gap energy. The band gap in a quantum dot will always be energetically larger; therefore we refer to the radiation from quantum dots to be blue shifted reflecting the fact that electron must fall a greater in terms of energy and thus produce radiation of a shorter and therefore "bluer" wavelength. (Higher energy-lower wavelength- blue shifted).

IV. SIZE DEPENDENT CONTROL OF BAND GAP IN QUANTUM DOTS

As with bulk, electrons tend to make transitions near the edges of the band gap. Because the band gap of the bulk is fixed the transition results in fixed emission frequencies. However with quantum dots, the size of the band gap is controlled simply by adjusting the size of the dot. Because the emissions frequency of a dot is dependent on the band gap, it is therefore possible to control the output wavelength of a dot with extreme precision. In effect it is possible for Evident Technologies to tune the band gap of a dot, and therefore specify its "color" output depending on the needs of the customer (Fig 6).[3][4][5]

In Bulk— fixed band gap — fixed emission frequencies

In Quantum dots – size of the band gap varies as the size of the dot

Decreasing energy →
Increasing wavelength

V. APPLICATIONS

The tunable band gap of Quantum dots with unique optical and electronic properties and a broad range of emission frequencies make it important for future applications and can create opportunities in a range of global markets [7].

a) SOLAR CELLS AND PHOTO VOLTAIC

Quantum Dots regarded as a new direction for PHOTO VOLTAIC SOLAR POWER and have the potential to change the world. Traditional solar cells are made of semiconductors and expensive to produce electricity. When sunlight hits material in the solar cell, the material kicks off an electron and charge is the electricity while QD's produce 3 electron for every photon of sunlight that hits the dots, thus increasing conversion efficiency to as high as 65%. Another interesting thing - QD do not require big bulk solar panels to work. Researchers are combining the dots with liquid polymers i.e. they can sprayed onto any surface i.e. anything painted can act as a solar cell. Think about that in the near future we will be able to go solar by just repainting our house. Hybrid cars will be revolutionized and so our mobile phones. The scope of this breakthrough is as breathless as it is unlimited.[8][9]

b) QUANTUM COMPUTERS

Quantum Dots could form basis of new computers i.e. quantum Computers which could be faster and provide more memory then conventional technology. In conventional computers information is represented as a series of ones and zeros or binary digits called "bits". Computers based on quantum physics would have "Quantum bits or Qubits" that exist in both on and off states, thus processing information much faster than conventional one. For quantum computations to work, information will have to be exchanged between pairs of qubits. Unlike conventional computers circuit in which electrical currents is used to carry information and perform computations quantum dot based quantum computers would rely on the manipulation of the electron spin. With improvements in quantum dots ordering and positioning, it is possible for us to hope in the near future to address and store information optically in a single quantum dots, thus opening the possibility of ultrahigh density memory devices.[11]

c) OTHER APPLICATIONS

- Optical and Optoelectronic devices,
- Semiconductors with QDs as Material for Cascade Lasers Cascade L
- Semiconductors with QDs as Material for IR Photodetectors -
- Color Coded Quantum Dots for Fast DNA Testing.

VI. CONCLUSIONS

Quantum Dots are amazing little wonders that allow us to tune them and attach them how we wish. We can use them for detections of almost anything we might want to find. Their switch behavior will be useful in data transmission. Plus there are quiet a few methods to their production. In the years to come they have a great potential to become as integrated in to our lives as electricity, light, and radio waves have done.

VII. REFRENCES

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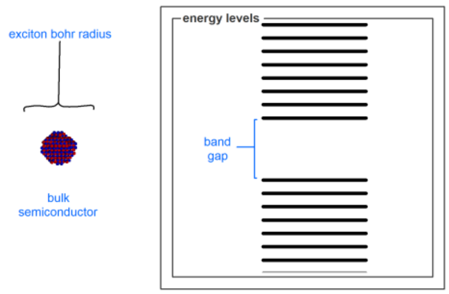
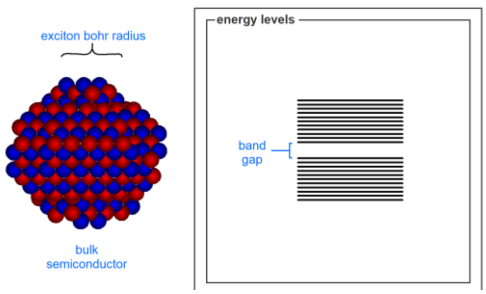
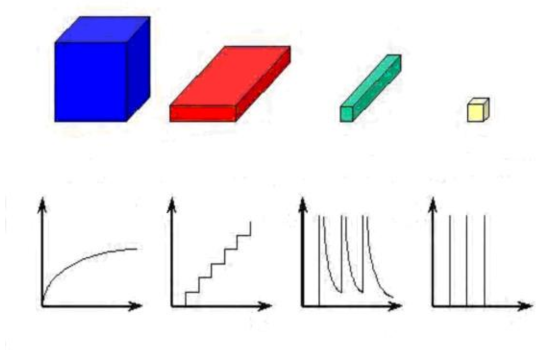


(a)



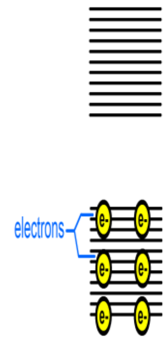
(b)

(c)
Fig 1 Energy band gap in quantum dots (a): Discrete energy levels (b) continuous energy levels (c) energy spectrum

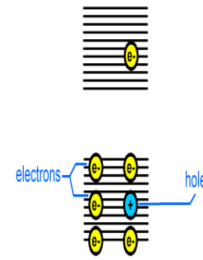


a) *b)* *c)* *d)*

Fig 2: The density of states (DOS) in selected semiconductor crystals. The DOS of (a) bulk semiconductor, (b) quantum well, and (c) quantum wires, (d) quantum dots.



(a)



(b)

Fig 3 (a) Energy band gap (b) Electron hole pair formation

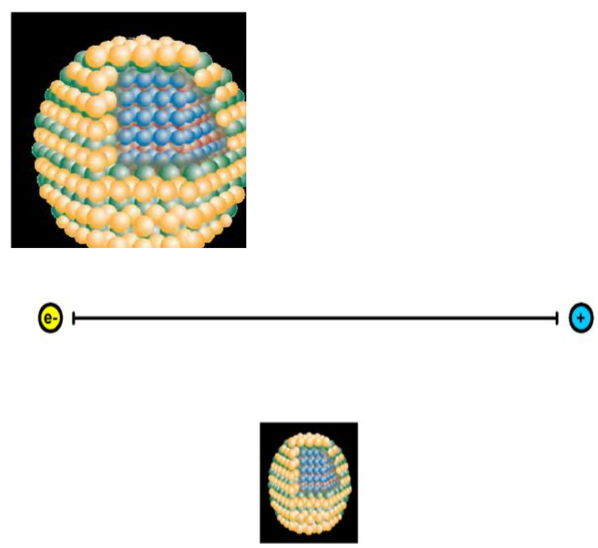


Fig: 4: Exciton Bohr Radius

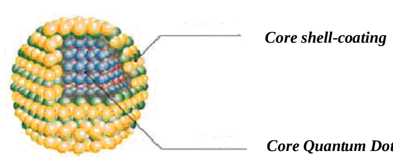


Fig 5: Structure of Quantum

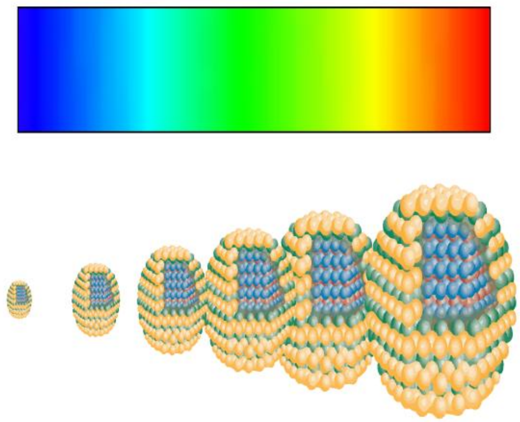


Fig 6: Size of band gap varies as the size of the dot