REVIEW ARTICLE

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Review of semiconductor nanoparticles:Optical and electronic properties

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Abstract

Our life has changed significantly due to recent milestone development in scientific world. Many of our activities are now directly or indirectly controlled by electronic devices. All these electronics devices are made from semiconductor materials. The demand of smaller and faster devices increases day by day due to the rapid progress in this field. This in turn allows us to model our environment with much more accuracy. Size quantization effects (quantum confinement) start playing a dominant role with the increasing miniaturization of the devices when their size reaches a few nanometers dimension and change the electronic and optical properties. Therefore, the aim of this review is to overview and highlights the optical andelectronics properties of semiconductor nanomaterials.

Keywords- Quantum confinement, Core shell, Band gap

Introduction

Semiconductor nanomaterials and devices have been extensively explored research area in past and are still in the research stage due to applications in many fields such as solar cells, nanoscale electronic devices, light-emitting diodes, laser technology, waveguide, chemical and biosensors, packaging films, super-absorbents, components of armor, parts of automobiles, and catalysts. Further development of nanotechnology will certainly lead to significant breakthroughs in the semiconductor industry. The semiconductor nano-materials such as Si, Si-Ge, GaAs, AlGaAs, InP, InGaAs, GaN, AlGaN, SiC, ZnO, ZnS, ZnSe, AlInGaP, CdSe, CdS, and HgCdTe etc., exhibit excellent application in computers, palm pilots, laptops, cell phones, pagers, CD players, TV remotes, mobile terminals, satellite dishes, fiber networks, traffic signals, car taillights, and air bags (Bailey and Nie,2003;Batu and Naoto,2014;Buda *et al.* 1992; Chestnoy *et al.,* 1986).

Semiconductor Nanoparticles

Semiconductor nanocrystals (NCs) are made from a variety of different compounds. They are referred to as II-VI, III-V or IV-VI semiconductor nanocrystals, based on the periodic tablewhich these elements are formed. For example, silicon and germanium are group IV, GaN, GaP, GaAs, InP and InAs are III-V, while those of ZnO, ZnS, CdS, CdSe and CdTe are II-VI semiconductors.

Classifications of Semiconductor Nanostructures

In nanocrystalline materials, the electrons are confined to regions having one, two or three dimensions, when the relative dimension is comparable with the de Broglie wavelength.Figure 1 shows the classification of nanomaterials.

1. Zero Dimensional (0D) Nanostructures

If size of the materials is reduced in x, y and z direction then the motion of electron is restricted in all direction, materials referred as quantum dots (Efros and Efros,1982). The zero dimensional shapes are regarded as the most basic and symmetric building blocks of the nanostructures, including cubes.

2. One Dimensional (1D) Nanostructures

If the motion of electron is restricted in x and y direction of materials, then these materials are known as one dimensional nanostructures such as nanorod, nanowire and nanotube . When the diameter of the nanorod, nanowire or nanotube becomes smaller, there is often a significant change in the properties with respect to crystalline solids or even two dimensional systems.

3. Two Dimensional (2D) Nanostructures

The family of 2D nanosystems encompasses all those systems that exhibit two dimensions exceeding the third one. However, the number and variety of inorganic nano objects belonging to this family is far lower with respect to 0D and 1D nanosystems. Indeed, nature tends to organize materials in a three dimensional way. 2D assemblies usually do not grow except under special and controlled experimental conditions.

4. Three Dimensional (3D) Nanosystems

Objects having either an overall size in the non-nanometric range (mainly in micrometer or millimeter range), but displaying nanometric features (such as nanosized confinement spaces) or resulting from the periodic arrangement and assembly of nanosized building blocks, can be classified as ‘3D nanosystems’. They exhibit different molecular and bul k pro pert ies.

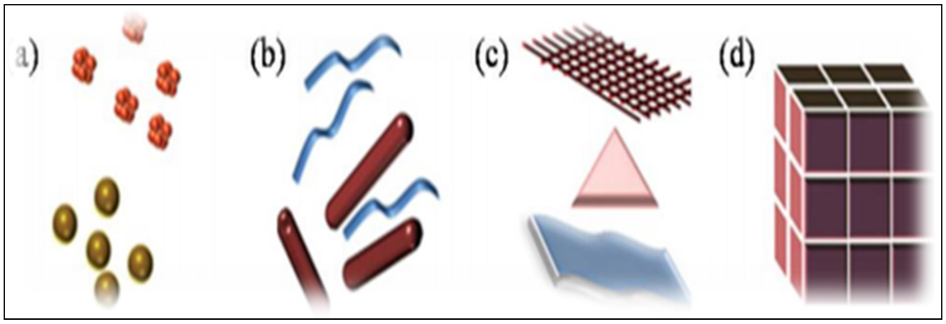

Figure 1: Classification of nanomaterials (a) 0D spheres and clusters (b) 1D nanofibres, wires and rods (c) nano films, sheets (d) 3D nanomaterials.

Core-Shell Nanostructures

The optical properties of the NCs are controlled by surface engineering. One important strategy is the over growth of NCs with a shell of a second semiconductor, resulting in a core-shell (CS) system. This method has been successfully applied to improve the florescence quantum yield and the stability against photo-oxidation by the proper choice of the core and shell materials, to tune the emission wavelength in a large spectral window (Nozic, 2001; Peng *et al.* 2000, Peng *et al.* 1997).

Quantum Confinement Effects

The tuning of fundamental properties such as optical and vibrational properties of nanostructured semiconductor material is possible when the size of the nanostructured semiconductor material approaches the exciton Bohr radius, due to the confinement of charge carriers and phonons within the nanoparticles. This is called quantum confinement effect (Schaller and Climov, 2004; Steigerwald,1990). One of the most important consequences of the spatial confinement effect is an increase in the energy of the band -to-band excitation peaks (blue shift), as the radius R of a microcrystalline semiconductor is reduced in relation with the Bohr radius.

Nanoparticles Synthesis Methods

Amongst the available synthetic methods employed for the development of nanosized systems, there are two main general approaches: “bottom-up” and “top-down”. The former applies to the creation of organic and inorganic structures, atom-by-atom or molecule-by-molecule. It implies the use of atoms or molecules as building blocks, to design and assemble nano arrangements of atoms in a functional form to give macroscopic systems.

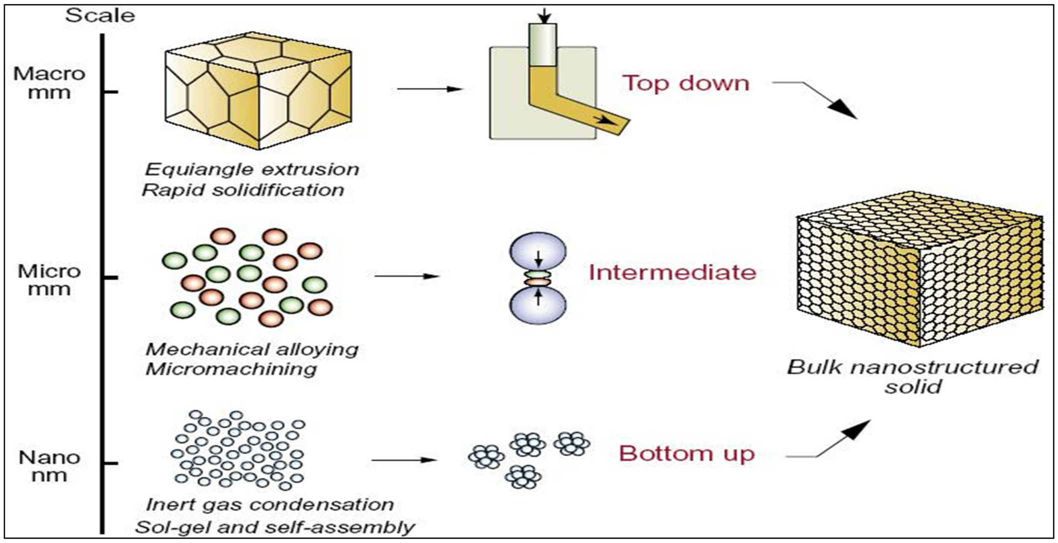

Figure-2

The preparation of nanoparticles can be achieved through different approaches (Henglein, 1989, Hines and Guyot, 1996, Iigima, 1991), either chemical or physical, including gaseous, liquid and solid media. While physical methods generally tend to approach the synthesis of nanostructures by decreasing the size of the constituents of the bulk material (top-down approach), chemical methods tend to attempt to control the clustering of atoms/molecules at the nanoscale range (bottom-up approach) as shown in Figure -2.

Optical and Electronic Properties Semiconducting Nanoparticles

1. Optical Property

It is well known that the band gaps of different semiconductors such as III-nitrides, II-VI group, IV group elements can be tuned by varying the composition in their alloys which make thesesystems prominent for various applications like in optoelectronic devices, to use them for aspectral range starting from deep infrared to distant ultraviolet region. Quantum confinement hasa great impact on the optical properties of semiconductor nanoparticles (Tang and Giersig, 2002). Figure-3 shows photoluminescence spectra of quantum dot of different sizes and different composition. The potential candidature of semiconductor nanoparticles as light absorbers in solar-cell devices of third generation has attracted number of researchers. For example PbSe, PbS, Cd, Se, PbTe, InAs and Si Nanoparticles shows much efficient multiple-exciton generation *i.e.* the chance of producing multiple electron-hole pairs from a single, high-energy photon, which thus increased the solar cell power (Tang and Giersig, 2002) For the solar energy conversion the semiconductor Nanoparticles requires a good match between the NC absorption spectrum and the solar spectrum. Few experiments found that the lack of a large overlap between absorption and emission spectra in CdSe NC can improve the efficiency of light-emitting diodes (LEDs) due to the reduction in re-absorption (Woggon,1997). A recent report has highlighted the unique role of strain in colloidal (core) shell quantum dot heterostructures (Yoffe, 2002). Thus, if the materials composing the heterostructure are reasonably deformable, strain can be tolerated and shared across the entire nanoparticle without the introduction of quenching defects.

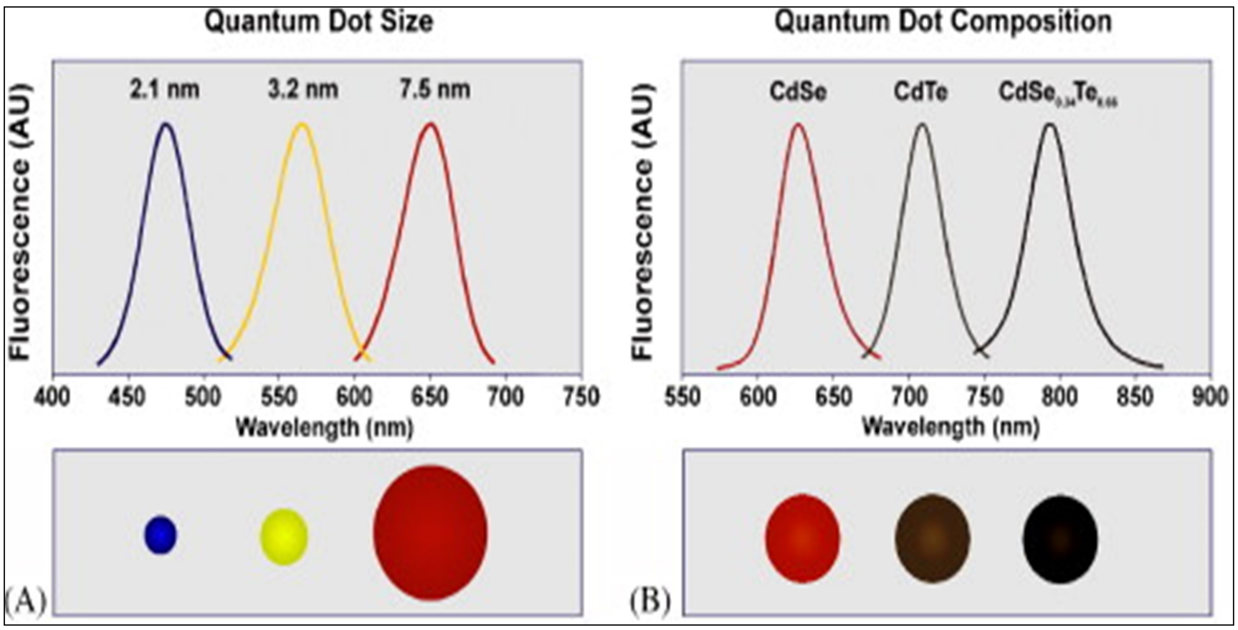

Figure-3 Shell quantum dot heterostructures

2. Electronic Properties

Electronic structures in nano regimes are extremely enviable for the future potential electronic devices. On the other hand, nano structures are still a challenge, where different experimental as well as theoretical approaches have been employed to understand the variation of electronic structures of nanoparticles as a function of its size. The study of quantum confinement phenomena in semiconductor nanopartiles is the subject of intense research which in fact determines their electronic behavior. A theoretical approach effective mass approximation (EMA) (Yoffe, 2002) is employed firstly to understand quantum confinement effects on the electronic band gap as a function of size of nanoparticles. To date numerous theoretical methods have been developed such as firstprinciples, semi-empirical pseudo-potential and tight binding (TB) method to see the effect of size on the electronic band structure of various nanoparticles.1989 Lippens and Lannoo have used semi-empirical TB approach with sp3s* orbital basis to compute the variation in the energy gap of semiconductor nanoparticles as a function of size. Figure 4 shows the variation of energy gap as a function of the number of unit cells in the NC of different shapes, indicates that the energy gap slightly depends on the arrangements of the atoms in the NC.

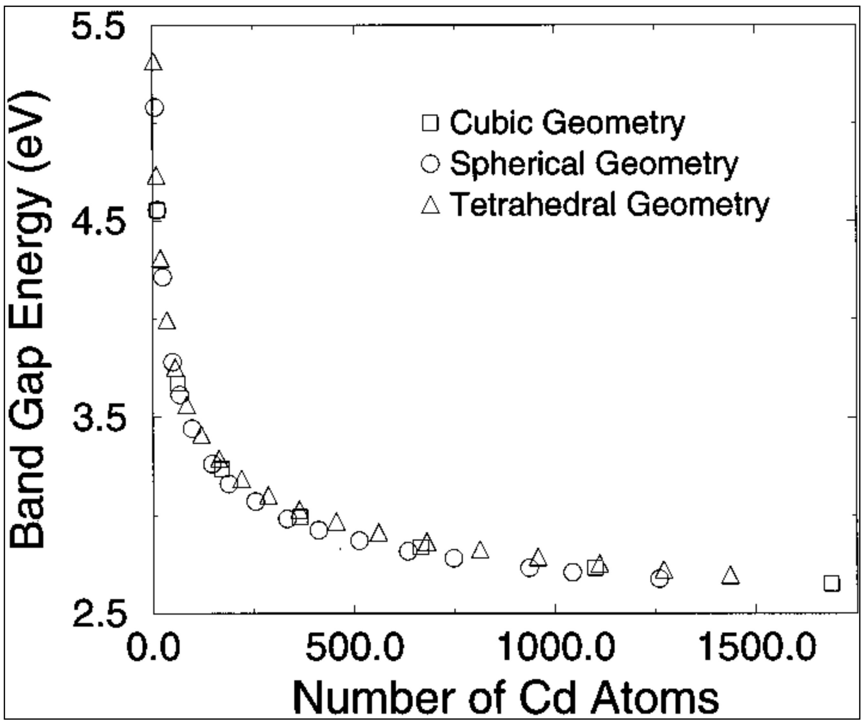

Figure-4 Variation of energy gap as a function of the number

The most important consequence of the quantum confinement effect is the size dependence of the band gap for nanocrystalline semiconductors. By confining the exciton of a semiconductor, the band gap may be tuned to a precise energy depending on the dimensionality and degree of confinement. Quantum dots have attracted broad attention due to their wide optical tunability and utility for bio-labeling, whereas elongated structures have been shown to emit linearly polarized light with a wide energy separation between the absorption and emission maxima (Stokes shift), which can reduce light reabsorption for light emission applications.

Conclusions

The basic of semiconductor, nanoscience, and synthesis of nanostructures is discussed. The fundamental of core-shell structure and few results are reviewed. Semiconductor nanomaterials are found to be advancedmaterials for various applications, which have been discussed at length. The unique physical and chemical properties of semiconductor nanomaterial make it suitable for application in emerging technologies, such as nanoelectronics, nanophotonics, energy conversion, non-linear optics, miniaturized sensors and imaging devices, solar cells, detectors, photography and biomedicine.

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