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THEORETICAL CONCEPT OF SEMICONDUCTOR NANOPARTICLES AND THEIR APPLICATIONS

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Abstract:

Investigating the properties of nanostructured materials has attracted the great attention in the field of physical science, biotechnology, material science etc. These materials possess extraordinary physical, chemical, catalytic, electronic and optical properties. Due to aforementioned interesting properties, these materials furnish broad scope of utilizations in an assortment of fields such as electronics, photonics, detecting etc. Reduction in the size of semiconductor materials causes the remarkable change in physical as well as chemical properties. The current scenario of scientific community is still doing innovative researches on semiconductor nano materials to make them more applicable in many fields like laser technology, light-emitting nano devices etc. Moreover, the emergence of nanotechnology has caused significant breakthroughs in the field of semiconductor industry.

Key Words: Semiconductor, Nanoparticles, Nanomaterials, Electronics, Photonics, Material Science

Introduction:

The emergence of semiconductor NPs is considered as a significant breakthrough in the field of material science. Semiconductor NPs exhibit a wealth of quantum phenomena and also furnish specific size dependent material properties. These types of materials show the intermediate properties between metals and nonmetals. Hence numerous applications of semiconductor NPs have been reported in the literature [1-2]. Drastic change in the electronic and optical properties has been observed when the particle size of semiconductor NPs is changed. The modifications in properties are noticed due to the three-dimensional (3D) quantum confinement of electrons and holes when the size of the particle approaches the Bohr radius of an exciton. Actually semiconductor NPs are regarded to have wide band gaps and hence tuning in band gap causes a remarkable changes in their properties [3]. Therefore, semiconductor NPs have shown significant applications in the field of electronic devices, photo catalysis and photo-optics. Because of their appropriate band gap and band edge positions, semiconductor NPs possesses immense potential in water-splitting applications [4].

Recently, semiconductor NPs with reduced dimensions have been demonstrated to possess electronic as well as optical properties which alter with size of the particles, and hence making them promising candidates for applications involving tenability of optical and/or electronic properties [5-7]. The isothermal equation of states (EOS) is directly responsible for thermo elastic properties of nanomaterials. A relationship between thermo dynamical variables at different pressure is easily established by EOS of a system. Therefore, the study of thermo elastic properties of InP (Indium phosphide), InAs (Indium arsenide) and InSb (Indium antimonide) using different EOSs is highly desirable. In this regard, many theoretical researchers have developed different isothermal equation of state for calculation of pressure, bulk modulus, pressure derivative of bulk modulus, Grüneisen Parameter, etc. at different compressions. Notably, the Grüneisen parameter is considered as a dimensionless quantity which is associated to the anharmonicity of lattice vibrations.

In recent years, several effective approaches have been done in the preparation, characterization and application of semiconductor nanoparticles that demonstrate a significant role in several innovative novel technologies. When the reduction in size of semiconductor materials is done to nanoscale, drastic changes in their physical and chemical properties are noticed and hence because of their large surface area or quantum size effect, specific properties of semiconductor nanoparticles are resulted. The conductivity of the semiconductor and its optical properties (absorption coefficient and refractive index) can be altered. Several innovative researches are being done for semiconductor nanomaterials and devices. Semiconductor nanomaterials are extensively explored in many fields like light-emitting diodes, solar cells, nano scale electronic devices, wave guide, laser technology, chemical and biosensors, packaging films, super absorbents, parts of automobiles, components of armor and catalysts. Moreover, development in the field of nanotechnology will certainly enhances the semiconductor industry such as kinds of diodes including the light-emitting diode, the silicon controlled rectifier, and digital and analog integrated circuits. Many semiconductor nanomaterials like Si, Si-Ge, GaAs, AlGaAs, InP, InGaAs, GaN, AlGaN, SiC, ZnS, ZnSe, AlInGaP, CdSe, CdS, and HgCdTe etc., possess excel level of applications in cell phones, laptops, palm pilots, computers, pagers, CD players, mobile terminals, TV remotes, fiber networks, satellite dishes, traffic signals, car taillights, and air bags. The aim of the present article is to overview and highlights the synthetic methods as well as applications of semiconductor nanoparticles. Most of the semi conducting materials like II-VI or III-VI compound semiconductors demonstrate quantum confinement property in the 1-20 nm size range. Here we wish to discuss the recent research and applications of semiconductor nanoparticles.

Due to surface effects and quantum size effects, most of the physical properties like structural, optical, magnetic, thermal, dielectric, etc. are affected by size reduction. The extremely small dimensions of semi conductor nanoparticles possess unique properties, which are basically different from, and often superior to those of their traditional counterpart. Recently, several interesting researches have been reported regarding the study of size effect in semiconductors of reduced dimension (in nanometer scale) due to their applications in catalysis, optoelectronic devices, resonant tunneling devices, single electron devices, magnetic sensors, memory devices, etc. [8-9] Optical spectroscopy is considered as one of the most appropriate technique to monitor the size-evolution of the electronic structure.

Fundamental Concept of Semiconductor Nanoparticles:

In bulk crystalline ZnS: Mn, at room temperature, the partially spin-forbidden $Mn^{2+4}T_1 \rightarrow {}^6A_1$ transition shows a lifetime of 1.8 ms. In ZnS: Mn having the size of3nm, two lifetimes τ_1=3.7ns,τ_2=20.5ns are possible. In ZnS: Cuλ_{em}=480nm, τ_1=2.9ns, τ_2=20.5ns, two different recombination centers may be involved in nanoparticles firstly the recombination centers lying on surface and secondly the recombination centers lying inside the bulk. For interpretation of these observations, it is suggested that the hybridization of s-p electron state of host with the d-electron state of Mn^{2+}, is caused to a remarkable extent by the spatial overlap of these states owing to the confinement. The expression for luminescence efficiency ηcan be written as:

$$\eta = \frac{\alpha_r}{\alpha_r + \alpha_{nr}} \tag{1}$$

Where, α_r and α_{nr} stands for radiative and non-radiative rates, respectively.

It is observed that the radiative recombination usually occurs at the surface. Therefore, α_{nr} certainly depend on the number of surface atoms per units volume and the expression for α_{nr} can be written as:

$$\alpha_{nr} \propto \frac{4\pi R^2}{\frac{4}{3}\pi R^3} \qquad \propto \therefore \frac{1}{R} \tag{2}$$

α_r depends on the number of Mn^{2+} at Zn^{2+} sites. In case of a single Mn^{2+} ion within a nano-crystal may written as:

$$\alpha_r \propto R^{-3} \tag{3}$$

Thus from Equations (1), (2) and (3) we get:

$$\eta = \frac{\frac{C_1}{R^3}}{\frac{C_1}{R^3} + \frac{C_2}{R}} \qquad = \frac{1}{(1 + \frac{C_2}{C_1} R^2)}$$

$$\eta = \frac{1}{(1 + \beta R^2)} \tag{4}$$

Where, $\beta = \frac{C_2}{C_1}$

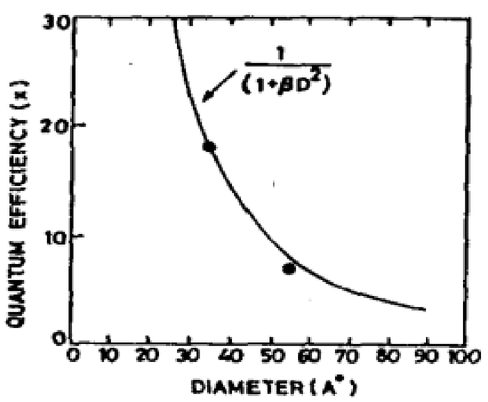

Figure 1: Variation of luminescence quantum efficiency of ZnS: Mn^{2+} nanocrystals as a function of the radius

Figure 1 depicts the size dependence of the luminescence efficiency of ZnS: Mn nanoparticles. The dependency of η or R of equation (4) is seen clearly. To synthesize then anocrystalline Zns, a reaction was performed between diethylzinc and hydrogen sulfide using toluene as solvent [8]. Usually, doping of bulk ZnS is done by thermal diffusion at high temperatures [>1100°C].However, since sintering of nano crystallitsis done at extremely low temperatures, doping must be done during precipitation. Doping of the ZnS: Manganese chloride is done by reaction with ethyl magnesium chloride to obtain diethyl manganese using tetrahydrofuran as solvent. Coating with the surfactant methacrylic acid is employed for the proper separation of the particles.

Application of Semiconductor:

Semiconductor nanomaterials possess interesting physical and chemical properties in comparison to their conventional bulk counterparts and molecular materials. The most interesting properties of these materials are as follows: narrow and intensive emission spectra, high chemical and photo bleaching stability, processability, continuous absorption bands, and surface functionality. With the emergence "nanochemistry", numerous research publications regarding the synthesis of semiconductor nanoparticlesare published [10]. For example, significant change in optical properties of semiconductor nanomaterials is observed due to the spatial quantum confinement effect. The very high dispersity (high surface-to-volume ratio) causes the change in both physical and chemical properties of the semiconductor followed by a significant influence on their optical and surface properties. Consequently, the scientific community is doing extensive researches on semiconductor nanomaterials for about 20 years. Therefore significant interest in research and applications of semiconductor nanomaterials is noticed in diverse disciplines like solid state physics, materials science, physical chemistry, inorganic chemistry, colloid chemistry, medical sciences, and recently biological sciences, engineering, and interdisciplinary fields. Among the several specific properties of nanomaterials, the movement of electrons and holes in semiconductor nanomaterials is basically driven by the well-known quantum confinement, and the transport properties related to phonons. Additionally, photons are significantly affected due to the size and geometry of the materials [11-12]. The new and unique properties of semiconductor nanomaterials have drawn sincere attention of researchers. The novel applications are observed in the field of emerging technologies like nanophotonics, nanoelectronics, catalysis, energy conversion, miniaturized sensors and imaging devices, non-linear optics, solar cells, detectors, photography biomedicine etc.

Conclusions:

The basic concept, preparation and unique physical and chemical properties of semiconductor nanomaterials are incorporated. Some important applications of semiconductor nanomaterials have been discussed in this article. The unique properties of semiconductor nanomaterial make them appropriate for exploration in emerging technologies, like energy conversion, nanophotonics, nanoelectronics, non-linear optics, miniaturized sensors and imaging devices, detectors and photography etc.

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