Applications of Semi Conducting Nano Materials

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Abstract- Nanotechnology is going to revolutionize the world. Nano particles are of great scientific interest as they are effectively a bridge between bulk materials and atomic or molecular structures.

The often very high surface area to volume ratio of nano particles provides a tremendous driving force for diffusion, especially at elevated temperatures. Sintering is possible at lower temperatures and over shorter durations than for larger particles. This theoretically does not affect the density of the final product, though flow difficulties and the tendency of nano particles to agglomerate do complicate matters. The surface effects of nano particles also reduce the incipient melting temperature.

Thus When the size of semiconductor materials is reduced to nano scale, their physical and chemical properties change drastically, resulting in unique properties due to their large surface area or quantum size effect. Currently, semiconductor nano materials and devices are still in the research stage, but they are promising for applications in many fields, such as solar cells, nano scale electronic devices, light-emitting nano devices, laser technology, waveguide, chemicals and biosensors. Further development of nanotechnology will certainly lead to significant breakthroughs in the semiconductor industry.

Keywords: *Semiconductors, Nano materials, Solar Cells, Light Emitting Nano Devices*

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I. INTRODUCTION

A semiconductor is a material that has an electrical conductivity between a conductor and an insulator. In semiconductors, the highest occupied energy band, the valence band is completely filled with electrons and the empty next one is the conduction band. The resistivities of the semiconductor can be altered by up to 10 orders of magnitude, by doping or external biases. In the case of conductors, that have very low resistivities, the resistance is difficult to alter, and the highest occupied energy band is partially filled with electrons and the insulator has extremely high resistivities. It is difficult to alter the resistivity through doping or external fields and the bandgap between the valence band and the conduction band is large. In a metallic conductor, the current is carried by the flow of electrons. In semiconductors, current can be carried either by the flow of electrons or by the flow of positively-charged holes in the electron structure of the material. In the past 10 years, nano materials with diameters in the range of 1-20 nm, have become a major interdisciplinary area of research interest and their extremely small feature size has the potential for wide-ranging industrial, biomedical, and electronic applications. Surfaces and interfaces are very important for nano materials, but in the case of bulk materials, a relatively small percentage of atoms will be at or near a surface or interface. In nano materials, the small feature size ensures that many atoms, perhaps half or more in some cases, will be near the interfaces. Surface properties, such as energy levels, electronic structure, and reactivity can be quite different from interior states, and give rise to quite different material properties. Nano capsules and nano devices may present new possibilities for drug delivery, gene therapy, and medical diagnostics.. Carbon nano tubes have been shown to have unique properties, stiffness and strength, higher than any other material. Carbon nano tubes are reported to be thermally stable in vacuum up to 2800°C, to have a capacity to carry an electric current a thousand times better than copper wires, and to have twice the thermal conductivity of diamond. Carbon nano tubes are used as reinforcing particles in nano composites, but also have many other potential applications. They could be the basis for a new era of electronic devices, smaller and more powerful than bulk materials.

The nano computer was already made based on carbon nano tubes. Materials having sizes in the range of a nanometer scale have unique properties than bulk materials.

Recently there has been substantial interest in the preparation, characterization and application of semiconductor nano particles that play a major role in several new technologies. When the size of semiconductor materials is reduced to nano scale, their physical and chemical properties change drastically, resulting in unique properties due to their large surface area or quantum size effect. The conductivity of the semiconductor and its optical properties (absorption coefficient and refractive index) can be altered. Semiconductor nano materials and devices are still in the research stage, but they are promising for applications in many fields, such as solar cells, nano scale 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. Semiconductor devices include the various types of transistors, solar cells, many kinds of diodes including the light-emitting diode, the silicon controlled rectifier, and digital and analog integrated circuits. Some of the semiconductor nanomaterials such as Si, Si-Ge, GaAs, AlGaAs, InP, InGaAs, GaN, AlGaN, SiC, 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, air bags.

II. INTRODUCTIONS TO NANO SCIENCE AND NANOTECHNOLOGY

In the past few decades, nano science and nanotechnology have been making significant progress and their effect on every field has been truly acknowledged in the world. The study of nano materials and nanostructures is a field with the earliest start that has obtained rich achievements. Nano materials and nanostructures play the most important supporting role for applications of nano science and nanotechnology in the field of fabrication, such as information & techniques, energy sources, environment, health and medical treatments.

The study of nano materials and nanostructures is an important source for establishing new principles, new techniques and new methods, thereby potentially leading to breakthroughs in great scientific problems. At the same time, the nano material market is also a native power for the development of nano materials. It will stimulate and promote the development of nano materials and nanostructures. Recently there has been substantial interest in the preparation and characterization of materials consisting of particles with dimensions in the semiconductor nano crystalline materials .One factor driving the current interest in nano particle research is the perceived need for further miniaturization of both optical and electronic devices. There are practical constraints associated with current technologies; lithographic methods cannot at present be used with a resolution much less than ca. 200 nm. Most semiconducting materials such as the II/VI or III/VI compound
semiconductors, show quantum confinement behavior in the 1-20 nm size range, a smaller size than can be achieved, using present lithographic methods.

III. SEMI CONDUCTOR NANO PARTICLES AND THEIR CLASSIFICATION

Semiconductor nano crystals (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 table groups into which 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.

In nanocrystalline materials, the electrons are confined to regions having one, two or three dimensions (Figure 1) when the relative dimension is comparable with the de Broglie wavelength. For a semiconductor like CdSe, the de Broglie wavelength of free electron is around 10 nm. The nanostructures of semiconductor crystals having the zdirection below this critical value (thin film, layer structure, quantum well) are defined as 2D nanostructures. When the dimension both in the x and z direction is below this critical value (linear chain structure, quantum wire) the nanostructures are defined as 1D and when the y direction is also below this threshold (cluster, colloid, nanocrystal, quantum dot) it is referred to as 0D.

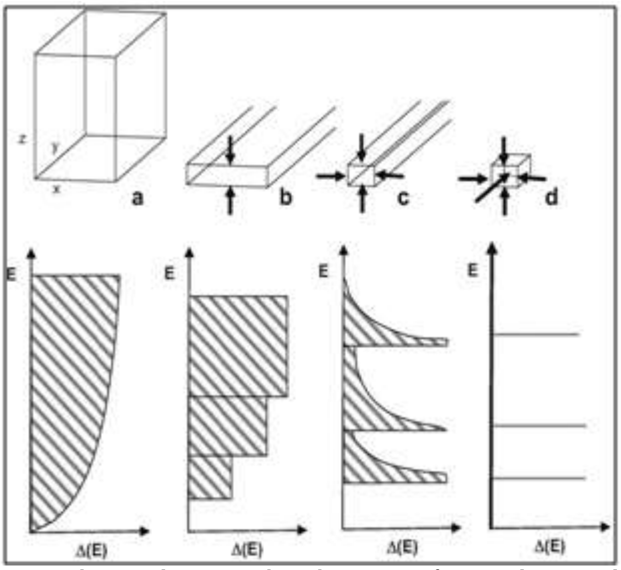

Figure 1. Schematic drawing to show the concept of system dimensionality: (a) bulk semiconductors (3D); (b) thin film, layer structure, quantum well (2D); (c) linear chain structure, quantum wire (1D); (d) cluster, colloid, nanocrystal, quantum dot (0D). In the bottom, the corresponding density of states[Δ(E)] versus energy (E) diagram (for ideal cases)

a) Zero Dimensional (0D) Nanostructures

In the early stages of research on nano-building block synthesis, zero dimensional shapes were regarded as the most basic and symmetric, including spheres and cubes. Several semiconductor nano crystals have been grown from the ageing processes of ionic precursors inside organic micelles. However, nanocrystals obtained by this method have relatively poor crystallinity or polydispersity in their size. As an alternative way to solve these problems, a thermal decomposition method of organometallic precursors under hot organic solution was adopted.

b) Quasi One Dimensional (1D) Nanostructures

The term quasi one dimensional nanostructures is used, because the dimensions are often larger than the indicated threshold, although elongation along one main axis still exists. When the diameter of the nano rod, nano wire or nano tube becomes smaller, there is often a significant change in the properties with respect to crystalline solids or even two dimensional systems. A bismuth nano wire is an excellent example, which transforms into a semiconductor, as the wire diameter becomes smaller. By controlling the growth variables such as temperature, the choice of capping molecules, precursor concentrations, crystalline phases of the nuclei and the choice of the regime between kinetically controlled and thermodynamically controlled growth, various nano-building blocks with multi-dimensionalities have been produced. To generate one dimensional nanocrystals, researchers have explored the 'one step in situ synthesis' of 1D nanorods, utilizing methods similar to those for the well studied spherical nanocrystals. For example, the use of binary capping molecules such as TOPO and hexylphosphonic acid (HPA) was effective for the generation of shape anisotropy in CdSe along with the intrinsic hexagonal structure nature.

c) **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

All 2D flat nanocrystals possess an overall size in the order of 10 nm. Such a size limitation is pursued, in order to prevent the growth along only one specific direction, leading to a 1D system. The synthesis of two dimensional nanocrystals is achieved by the self-assembly of solutions and the constituting elements of these systems are usually metals. Discoidal nanocrystals are typical flat building blocks. They are typically obtained by surfactant assisted synthesis, or anisotropic crystal growth passing through colloidal systems.

d) **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 bulk properties. In particular, 3D nanocrystals superstructures are prepared by assembling basic nanosized building blocks such as; 0D spheres 1D rods and 2D plates, to have bigger sized structures of innovative shapes. On the contrary, nanoporous materials are made with a 'complementary' approach, since a system of nanosized void pores is obtained within a continuous bulk material. Simpler nanosystems can otherwise be used as 'artificial atoms' to build three-dimensional superstructures, such as superlattices in which a given nanoparticle is in a predictable and periodic lattice point. , 0D nanosystems (and mainly nanoparticles) are the best choice, since they can easily lead to the highly ordered 3D closely packed patterns, kept together by chemical interparticle interactions. Superlattices of CdSe nanocrystals can be obtained, using a selective evaporation technique from a solution of octane & octanol containing spherical CdSe nanocrystals. Such superstructures display a face centered cubic packing of CdSe nanocrystals. They exhibit novel optical properties which are different from those of diluted CdSe nanospheres in solution.

IV. QUANTUM CONFINEMENT EFFECTS

The confinement of an electron and hole in nanocrystals significantly depends on the material properties, namely, on the Bohr radius aB. These effects take place in bigger nanocrystals and depend on the material properties, namely, on the Bohr radius aB = 2.34 nm and aB of about 10 nm, which would have Cd related compounds such as CdTe, CdZnTe and CdTeSe. 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. Theoretically, the regimes of quantum confinement differ in their main electron-hole interaction energy, i.e., the Coulomb term and the confinement energy of the electron and hole and kinetic energy.

a) *Weak Confinement Regime*

To observe this regime, the radius R of a crystallite should be greater than the bulk exciton Bohr radius aB. In this region of weak confinement, the dominant energy is the Coulomb term and there already occurs a size quantization of the exciton motion. The exciton energy states are shifted to higher energies by confinement and the shift in energy ΔE is proportional to 1/R2. The shift 'ΔE' of the exciton ground state is given approximately by,

$$\Delta E \approx \frac{\hbar^2 \pi^2}{2MR^2}$$

where, M is the mass of the exciton and it is given by

M = $m_e^* + m_h^*$, with m_e^* and m_h^* being the effective masses of the electron and hole respectively.

b)The moderate confinement regime

The moderate confinement regime occurs when R≈ aB and ah < R < ae, where, ah and ae are the hole and electron Bohr radii, respectively. In II-VI semiconductors, this region is well observable in small QDs. Its characteristic feature is the well restricted motion of a photo excited hole.

c)Strong Confinement Regime

In the strong confinement regime the size of a QD can be decreased in such a way that R<< aB and R << ah and ae

The electrons and holes can now be thought of as confinement independent particles. So excitons are not formed and the separate size quantization of an electron and hole is the dominant factor. The optical spectra consist also of a series of lines due to the transition between sub-bands. This factor was confirmed experimentally and the simple model gives the shift in energy as a function of crystallite size as,

$$\Delta E \approx \frac{\hbar^2 \pi^2}{2\mu R^2}$$

in which the exciton mass M is replaced by the reduced exciton mass μ, where,

$$\frac{1}{\mu} = \frac{1}{m_e^*} + \frac{1}{m_h^*}$$

The electrons and holes in QDs are treated as independent particles and for the excited state there exists a ladder of discrete energy levels, as in molecular systems.

V. APPLICATION OF SEMICONDUCTOR NANO MATERIALS

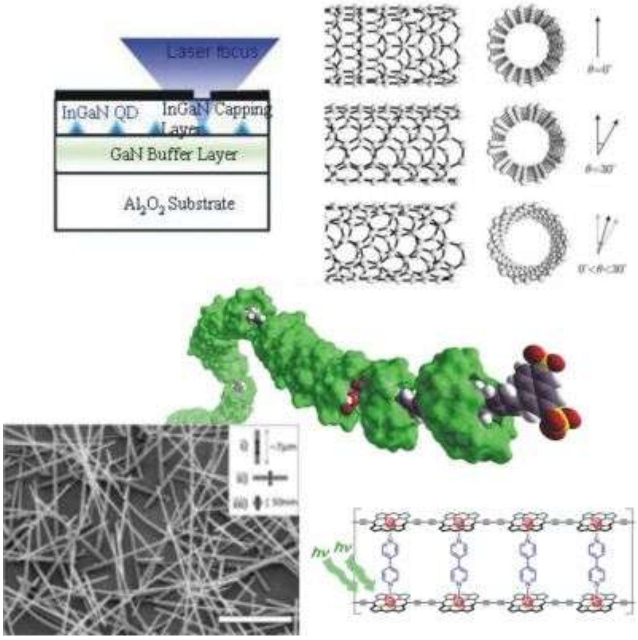

FIGURE 2. Semiconducting nano-materials

a)Semiconductor Nano materials for Hydrogen Production

Hydrogen is a promising alternative fuel, since it is completely pollution-free and can readily be produced from renewable energy resources, thus eliminating the net production of greenhouse gases There is increasing environmental pollution, caused by combustion engines, and additional problems associated with large-scale mining, transportation, processing and usage of fossil fuel. Photo catalysis is expected to make a great contribution to both environmental treatment (emission cleaning and water purification) and renewable energy. Hydrogen (H_2) is widely considered to be the future clean energy carrier in many applications, such as environmentally friendly vehicles, domestic heating, and stationary power generation. Photo catalytic hydrogen production from water in one of the promising techniques due to the following advantages:

- It is based on photon (or solar) energy, which is a clean, perpetual source of energy, and mainly water, which is a renewable resource.
- It is an environmentally safe technology without undesirable by-products and pollutants.
- The photochemical conversion of solar energy into a storable form of energy, i.e. hydrogen, allows one to deal with the intermittent character and seasonal variation of the solar influx.

Photo catalyst materials play a crucial role in H_2 production. Nano structured photo catalysts are expected to be a future trend, since nano sized photo catalysts have shown much better performance than their bulk counterparts. Many of semiconductor nano materials have been used to produce H2. Semiconductors such as TiO_2, ZnO, ZrO_2, V_2O_5, WO_3, Fe_2O_3, SnO_2, CdSe, GaAs, GaP and metal sulphides (CdS and ZnS) are employed as photocatalysts. Among the semiconductors, titanium dioxide (TiO_2) is one of the most important and widely used photocatalysts, because of its suitable flat band potential, high chemical stability, nontoxicity, corrosion resistance, abundance, cheapness, and high photocatalytic activity.

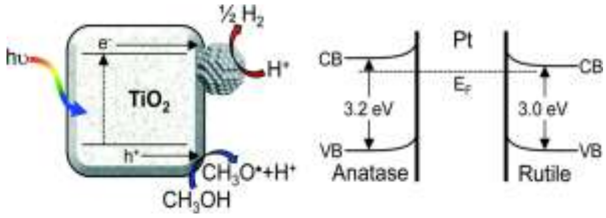

Figure 3 Schematic of photocatalytic hydrogen production via exciton creation and charge separation between highly dispersed platinum nanoparticles and titania.

In order to enhance the photocatalytic efficiency of semi-conductors, Serpone et al. proposed an interparticle electron transfer process, by coupling two semi-conductors with different redox energy levels to increase the charge separation for the corresponding conduction and valence bands and absorb visible light. The semiconductor photocatalyst TiO2 and ZnO were coupled with another semiconductor nanomaterial such as CdS, SnO_2, WO_3, Bi_2S_3, Cu_2O, Bi_2O_3, Fe_2O_3,CdSe, ZrO_2, $ZnMn_2O_4$,and In_2O_3.

b)Silicon Semiconductor Nanomaterials and Devices

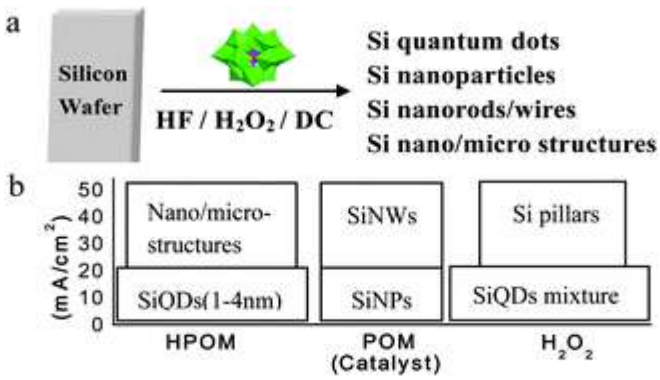

Figure 4 Small sized Silicon Nano Particles

The development of silicon based materials and devices will influence the future development of current microelectronics and information technology to a certain extent, which has an important strategic significance. Besides the widely used crystalline silicon wafers, silicon nanostructures have been considered as the basic components for future nano/microelectronic devices. With the size of silicon based complementary metal oxide semiconductors (CMOS) circuit reducing gradually down to 10 nm or even smaller, a series of severed challenges appear, such as how to deal with device manufacturing limits, dramatic increase in cost, and the working mechanism changes of new devices. These lead to the 'bottle-neck' of the future development in the silicon based microelectronics industry, while silicon based nanotechnology can provide a solution with lower cost and higher efficiency.

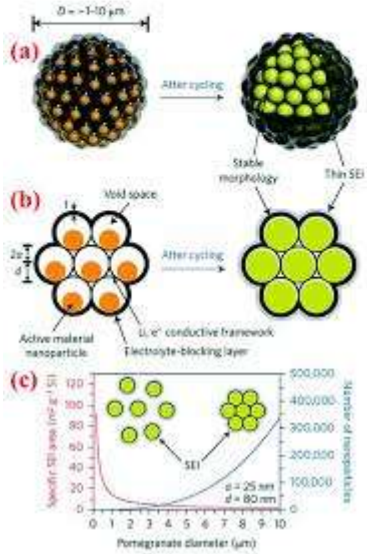

Figure 5. Schematic drawing to show the concept of system dimensionality: (a) bulk semiconductors (3D); (b) thin film

Silicon as a potential anode material for Li-ion batteries: where size, geometry and structure matter - Nanoscale

The size effect of silicon nanostructures leads to a lot of novel properties. One typical example is the size-tunable highly-luminescent silicon nanostructures due to the quantum effect. By using these novel properties scientists have recently developed several silicon based novel devices like highly sensitive biological and chemical sensors, high-efficiency solar cells and light-emitting diodes. Therefore, silicon nanostructures show wide application prospects in many fields. Our aim is to build an internationally advanced scientific center for nano technologically research and to create a competitive technology innovative environment for nanotechnology applications.

VI. CONCLUSIONS

Semiconductor nano materials are advanced materials for various applications, which have been discussed at length. The unique physical and chemical properties of semiconductor nano material make it suitable for application in emerging technologies, such as nano electronics, nano photonics, energy conversion, non-linear optics, miniaturized sensors and imaging devices, solar cells, detectors, photography and biomedicine.

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