NANOSCIENCE AND NANOTECHNOLOGY

Abstract

The study on elementary associations between the substantial properties and different types of phenomena of production as well as determination of material's dimensions in the nanometer scale (1 to 100 nm) are referred to as Nanoscience. The Nanoscience has a typical dimension span, which lies between subnanometer to quite a few hundred nanometers. The Nanometer scaled materials may possess substantial properties uniquely different from that of massiveness material. Thus materials in this dimension range exhibit their unique physical and chemical properties. An alteration from atoms or molecules to massiveness form also takes place in this dimension range. When the materials are restricted to the nanometer range, they may lose their all properties. Nanotechnology is latest but investigation on nanoscaled size materials is not new at all. Nanotechnology is the designing, production and applications of the nanomaterials and nanostructures. It also includes the elementary perceptive of the substantial properties and phenomena of production of nanostructures and nanomaterials. A rapid development of Nanoscience and Nanotechnology will not be possible unless it is not supported by a strong background of theoretical study in the same area of experimental field.

Keywords: Nanomaterials, Nanoscale, Physical Properties, NEMS, MEMS, Ab-initio study.

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I. INTRODUCTION

In Nanoscience, we deal with very small structures or small-sized materials. The study of elementary associations between the physical properties and different types of phenomena of creation as well as determination of material's size in the nanometer range are also attributed as Nanoscience. The Nanoscience has a distinctive dimension span, which lies between sub-nanometer to quite a few hundred nanometers. A nanometer is equal to one billionth of a meter (i.e. 1 nm = $l0^{-9}$ m). The micrometer scaled materials mostly have physical properties identical as that of bulk, however, nanometer scaled materials may possess physical properties particularly unusual from that of bulk. Thus materials show their unique physical properties in nanometer scaled size range. An alteration from atomic or molecular range to massiveness structure also performs in this dimension range. When bulk materials are restricted to the nanometer scale, they may drop their substantial properties (like electronic, optical, magnetic, etc). For example, a bulk semiconductor material becomes an insulator or conductor when its size is concentrated to nanometer scale. Even though bulk gold does not show signs of catalytic property but nanosized gold becomes an exceptional low temperature catalyst.

Generally, Nanotechnology is the designing, production and use of the nanostructures and nanomaterials. It also exhibits the elementary understanding of the substantial properties and phenomena of production of nanostructures and nanomaterials. The capacity to control and production of materials at the nanoscaled size with exceptional reproducibility is crucial for the progression of modern industry.

Nanotechnology is latest but investigation on nanoscaled size materials is not new at all. "There is a plenty of room at the bottom, I would like to explain a field, in which little has been done, but in which an massive amount can be done in principle. What I would like to talk about is the difficulty of manipulating and controlling belongings on a small scale. . . ": this well-known statement of legendary Richard Feynman [1] given in 1959 at the annual meeting of the American Physical Society (APS) with enormous forethought has been sensitized in less than half a century by regular efforts and important assistance from the scientific society across the world. The learning of natural systems and the manufacturing of numerous materials such as metallic quantum dots, colloidal dispersions and catalysts have been in the nanometer scale for a long time. At present time, investigation on nanostructures is not only among the most vigorous area in Nanotechnology but it is also being step by step inserted into our everyday life.

II. NANOMATERIALS AND NANOSTRUCTURES

Nanostructures correspond to a bridge amid molecules and bulk systems. Usually, nanostructures are visualised to be a number of atoms or molecules bonded mutually within a radius not as much hundred nanometer. Nanostructures can be considered over nanometer length scale among zero to two dimensions. Thus, nanostructured materials are those with minimum one dimension laying in nanometer size range. These nanostructured materials can be separated into zero dimensional (Nanoclusters), one dimensional (Nanotubes and Nanowires) and two dimensional (Slim film) based on their shapes.

A nanocluster is a non-periodic three dimensional structure and is an intermediate state of matter linking molecule and bulk, whose electronic, optical, vibrational, magnetic, thermal and other properties may be interesting. The small nanocluster is analogous to a molecule and it has discrete energy levels. However, about the small sized nanoclusters the two fundamental facts are attributable as a replacement for that its substantial properties are extremely strange from those of the massiveness material. The primary fact is that the excitons are constrained in a dimension to the size of the nanocluster size causing in a solidity of the bulk exciton and analogous to blue shift in their first excited state with diminishing size. This property is acknowledged as the quantum confinement effect [2]. According to the scientific point of view, the effect of quantum confinement has produced a huge interest due to the exceptional capability to alter the optical properties by varying particle size. The second significant fact of the quantum-confined nanoclusters is that their surface to volume fraction is to a great extent of larger than those of the massiveness material and thus the character of the surface influences additional on the substantial properties of these nanoclusters.

In 1985, R. Buckminister Fuller has discovered a soccer ball like molecule having sixty carbon atoms (C_{60}). It has twelve pentagonal and twenty hexagonal faces arranged symmetrically to form a molecular ball. The C_{60} molecule has been named fullerene following the architecture and originator of it. Originally, the molecule was called buckminsterfullerene, but this name is a bit unwieldy, so it has been reduced to fullerene. In fact, a soccer ball has the similar geometric design as fullerene. As C_{60} is soluble in Benzene, single crystal of it can be developed by using slow evaporation technique from Benzene solution.

Some nanoclusters through a challenging amount of valence electrons demonstrate evidence of exceptional steadiness in opposition to dissociation relative to other nanoclusters. These nanoclusters are referred to as magic number nanoclusters, whose exceptional stability may be conferred by either electronic or structural considerations. The Spherical model (Jellium model) indicates that nanoclusters with valence electrons of 2, 8, 20, 40… have superior solidity as the closure electronic shells, which are known as electronic magic number. The sequence 1, 13, 55, 147, 309, 561,…. also represents a number of atoms in a nanostructure having higher stability, which are known as structural magic number.

The procedures of the production of nanostructures underlying nanoscience and nanotechnology have two different approaches: one is the bottom-up approach, in other words, the miniaturization of the bulk material as articulated by Feynman and the other is the approach of the self-assembly of atomic or molecular components to produce nanostructures. There are numerous other ways for production and processing techniques for example top to down and also bottom to up approach, forced and spontaneous process. Top to down approach method of production of nanostructures is in common an addition form of lithography. The concept and perform of a bottom-up approach method in chemistry and material sciences are not latest. Synthesis of huge polymer molecules is a distinctive bottom to up approach method, in which each constructing blocks or monomers are collected to produce a large molecule or polymerized into massiveness material. Crystal growth is also another bottom-up approach method, where growth species either atoms or ions or molecules orderly assemble into preferred crystal structure on the developed surface by self-assembly. Thus, the nanostructures can be built by assembling individual atoms or subdividing bulk material.

Nanostructures have been drawing a grand deal of research concern due to their distinctive physical properties, characteristics of neither the molecular nor bulk phase and thus have potential to develop the broad area of Nanotechnology. The substantial and chemical properties of nanostructures can vary considerably from those of the massiveness materials of the same composition. The distinctiveness of the structural, characteristics, energetics and chemistry of nanostructures establishes the foundation of Nanoscience. A nanostructure of an appropriate property can be used in the fabrication of Nano Electro Mechanical Systems (NEMS) and Micro Electro Mechanical Systems (MEMS). The present day research activity involves the study of the physical properties like the structural, electronic, optical, vibrational, magnetic and thermodynamical ones of the nanostructures like nanoclusters, nanotubes, nanowires, thin films and their nanocomposites of the different types of materials like metals, semiconductors and insulators. This field also covers diversity of interests in various disciplines like physics, chemistry and material science.

III. SEMICONDUCTING COMPOUNDS

Among II-VI semiconducting compound materials, Zinc Oxide (ZnO), Zinc Sulfide (ZnS) and Zinc Selenide (ZnSe) are distinguished direct band gap semiconductors and promising multi-functional materials for producing electronic, optical, mechanical and photonic devices. These semiconductors have almost similar elementary physical properties. Due to possessing large energy band gap of 3.37 eV for Zinc Oxide, 3.65 eV for Zinc Sulfide, and 2.80 eV for Zinc Selenide correspondingly at room temperature, these semiconducting materials and their compound or multiple structures in nanoscaled range are exceptional materal for ultraviolet light lasers(UV Lasers) and light detectors operating in the 320 to 400 nm wavelength range.

ZnO material represents a remarkable focus of study. It possesses a huge excitation binding energy of 60 meV and it is an appropriate material for optoelectronic devices of short wavelength. The high excitation binding energy in a ZnO bulk material can ensure efficient excitation emission at room temperature and such room temperature luminescence of Ultra-voilet range has indeed been found in thin films and disordered nanoparticles. In addition, ZnO is transparent to visible light and can be prepare extremely conductive by doping. Moreover, the non-central symmetry in Wurtzite and due to developed polarity create this material inherently piezoelectric, which, in combination with its vast electromechanical coupling, results in strong pyroelectric and piezoelectric properties functional in actuators, piezoelectric sensors and nanogenerators. On the other hand, ZnO is also a biocompatible material having high isoelectric point (IEP) of amount 9.5, which makes it appropriate for adsorption of proteins with low IEPs, because the protein immobilization is mostly forced by electrostatic interactions. Furthermore, ZnO nanostructures have distinctive advantages together with low toxicity, high particular surface area, electrochemical activity, high conductivity and chemical stability. Therefore, it is a remising material for biosensor applications and can be directly used for biomedical applications with no coating [9-11]. Synthesis of Zinc Oxide slim films have been an energetic field for the reason that of their applications as catalysts, transducers and sensors from the time when the year 1960s,. Over the previous few years, the synthesis of Zinc Oxide nanomaterials has been of increasing curiosity due to their potential applications in nanoscale devices. ZnO possesses the most remarkable and rich configurations of nanostructures such that one material can form its electrical and optical properties which depend understandingly on both the morphology and its dimension. ZnO develops best on Gallium Nitride (GaN) substrates because of the high-quality lattice match but can also be build up on silicon substrate for more frequent usages. Many nanostructures like nanoarrays, nanorods, nanotubes, nanowires, nanobelts or nanoribbons, nanorings, nanohelices, nanobows, nanotips, nanoflowers, nanobullets, nanosheets, nanonails or nanopencils, nanosprings, nanoporous structures, nanoplatelets, nanobridges, nanowalls, hierarchical nanostructures, etc. of Zinc Oxide have been synthesized and also explored by a diversity of techniques.

The research on one dimensonal ZnO nostructures has speedily extended in previous numerous years. The one dimensional ZnO nanostructures have been emerging lone primary nanomaterials in the field of nanotechnology jointly with silicon nanowires and carbon nanotubes. The number of published research papers and the mixed fields based on ZnO nanostructures are as mammoth as those for quantum computation technique, darkmatters, carbon nanotubes and semiconductor slim layers.

In nature, ZnS usually found as white and yellow colored crystal or powder. Both Zinc Wurtzite and Zinc Blende structures of ZnS are covalently bonded solids. Zinc Sulfide is one of the majority vital materials in the electronic and production industries with an extensive range of major potential applications. Ernest Rutherford and others have used Zinc Sulfide material recently in nuclear physics as a scintillation detector due to its excellent property of providing visible light leading excitation by electron beams or X-rays. Bulk ZnS with accumulation of a small amount i.e. parts per million (ppm) of appropriate activator has been utilized as phosphor material for cathode ray tubes with X-ray screens in dark situation. Metal ion doped Zinc Sulfide is one of the newest research topic e.g., it yields an orange-red color at 590 nm with manganese (Mn) doping and copper (Cu) doped ZnS is used in Electro-luminescent (EL) panels. ZnS:Mn is one of the best material for an alternating current thin-film Electro-luminescent (ACTFEL) device, which is a thin film stack, characteristically consisting of a phosphor sheet doped with a luminescent impurity. A number of fresh applications including Nonlinear optical devices, light-emitting diodes (LEDs, with doping), infrared windows, field emitters, sensors, lasers and flat panel displays have later been discovered [3-5]. Recently the research on one dimensional ZnS nanostructures has become of emergent attention due to their possible applications for understanding basic substantial concepts and for nano range optoelectronic devices.

Similar to ZnO and ZnS, ZnSe is one more semiconducting material that has been extensively studied. Among II-VI compound, Zinc Selenide based semiconductors have a particular significance and have been intensively studied ever since 1970s. ZnSe material is particularly attractive due to the ability of emitting light from the blue to the Ultra-voilet spectral range of electromagnetic radiation. The ZnSe based photonic devices such as the blue-green laser diode, blue-ultraviolet photodetector, saturable-absorber Q switch and modulated waveguide [6-8] have been observed recently. The ZnSe Quantum Dots (QDs) and ZnSe-based nanostructures such as ZnSe/ZnS core/shell semiconductor Quantum Dots have been the focus of intense exploration in recent years. There are a large number of experimental studies covering the synthesis and properties of the core/shell structure.

IV. THEORETICAL STUDY

It is quite obvious that a rapid development of nanoscience and nanotechnology will not be possible unless it is not supported by a strong background of theoretical study in the same area. We may have a promising class of new but unknown materials. As an example, the nanocomposites may have entirely new properties different from the properties of the individual compounds. These efforts have been intensified by the recent success in understanding the physics and the applications of the quantum confined two dimensional electron gas structures.

Theoretical exploration of nanostructures is of essential importance since it provides one to both examine elementary physics and to optimize nanostructured devices. The benefit of theoretical studies is that the systems are well defined and their unique properties away from those that are experimentally offered can also be examined. Thus, relatively replacing experiment, theory provides a useful corresponding approach to explore the physical and chemical properties of nanoparticles.

Theoretical attempts have been made to understand the various exotic properties of the nanostructures and nanocomposites seen in the experiments. In order to have a clear physical understanding of the nanostructures, first - principle study (i.e. ab initio study) for the stability and the various physical properties (like electronic, optical, vibrational and magnetic) of these nanostructures are very much awaited. Obviously, one needs to develop parameter free first-principle methods to obtain reliable and quantitative outputs of all the features observed in experiments.

At present, the experimental research on the semiconducting quantum dots (QDs) is concentrated either on the synthesis of mono - dispersed size nanostructures or fabricating embedded QDs in hetero-structures. The sever limit imposed by the non-availability of mono - dispersed size nanocrystals has kept the practical applications of QDs many years away. As a replacement for modulating the excitonic properties of the host electrons or holes by quantum -confinement a new advance has been adopted where the host - exciton is replaced by a localized impurity in the QDs. Several distinctive devices and novel applications of this approach are in offing.

The present day research makes the focus on the variety of nanostructures for example quantum dots, nanowires, nanotubes and slim layers of metals, semiconductors and insulators. An example is of porous silicon, which is the quantum wires of nanosizes of 20 - 30 Å and has been seen to yield visible light from red to violet and even ultraviolet. The quantum dots and nanowires so far have not been successfully used in photonics because of the occurrence of the dominating surface related non-radioactive recombination in the strongly confinement limit.

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