Overview Of Nanoscience And Nanotechnology

Nanoscience is an interdisciplinary field that seeks to bring about grown-up nanotechnology. Connection between different fields such as physics, biology, engineering, chemistry, computer science and other, nanoscience is expanding very quickly [1].

On December 29, 1959, Richard Feynman has given the ideas on 'nano-technology' in his talk "ThereHYPERLINK "http://en.wikipedia.org/wiki/There's_Plenty_of_Room_at_the_Bottom"'HYPERLINK "http://en.wikipedia.org/wiki/There's_Plenty_of_Room_at_the_Bottom"s HYPERLINK "http://en.wikipedia.org/wiki/There's_Plenty_of_Room_at_the_Bottom"plenty of Room at the Bottom". He described a procedure by which the ability to control atoms and molecules might be developed, using certain set of tools to the needed scale [2].

Nanotechnology is the design, classification, fabrication, and function of structures, devices, and systems by controlled exploitation of size and shape at the nanometer scale-length. One nanometer is equal to the one billionth of a meter. The properties of the materials significantly change at nanoscale level. The two important factors [3] that are responsible for these characteristic changes are

First, Surface to volume ratio of nonmaterial is larger as compared to the same mass of material produced in bulk form. Therefore chemically reactivity of the materials increases and affects their strength or electrical properties.

Second, at nanoscale quantum mechanical effects begin to govern due to which there is change in the optical, electrical and magnetic properties of the materials. [3].

Fabrication of nanomaterials entails two main approaches "top-down" and "bottom-up". The role of both the approaches is very important in nano technology. In top down approach successive cutting of a bulk material is done to get nano sized materials. This approach leads to the bulk fabrication of the nano structures. Where as the bottom up approach deals with the fabrication of the materials from the atomic level. Nano materials with less defects, more uniform chemical composition are fabricated with the help of Bottom up approach [4].

1.2 Nano Materials

Materials science-based approach to nanotechnology is developed by nanomaterials. It studies materials with morphological aspects on the nanoscale, and particularly those which have unique properties originating from their nanoscale dimensions. Nanoscale is generally defined as less than a micron in at least one dimension [5].

1.2.1 Nanoscale in One Dimensions

In recent years significant attention has been generated by one dimensional nanomaterials such as tubes and wires among the scientific community. Particularly, the novel electrical and mechanical properties of these materials are the subject of intense research.

1.2.1.1 Carbon Nanotubes

Carbon nanotubes were discovered by Iijima in 1991. The nanotubes appeared to be made up of a perfect network of hexagonal graphite, rolled up to form a hollow tube. The range of the diameter of the nanotube is from one to hundred nanometers where as the range of its length is from one to a few micrometers. Carbon nanotubes exhibit the unusual photochemical, electronic, thermal and mechanical properties. The electrical conductivity of Single walled carbon nanotubes is similar as of copper and thermal conductivity is similar as of diamond [6].

Carbon nanotube

1.2.1.2 Nanowires

Nanowires are ultrafine wires, formed by self-assembly. These wires can be made from a wide range of materials. Semiconductor nanowires have shown incredible optical, electronic and magnetic characteristics. For example, silica nanowires can bend light around very tight corners. Nanowires have prospective applications in high-density data storage, either as magnetic read heads or as storage media, and electronic and optoelectronic nano devices [7].

Nanowires

1.2.2 Nanoscale in Two Dimension

Two-dimensional nanomaterials, such as thin films, layers and surfaces have been developed and used for decades in different fields. Many devices based on thin films for their function, and control of film thicknesses approaching the atomic level is routine. In chemistry monolayers are also characteristically made and used. From the atomic level the formation and properties of these layers are reasonably well understood. Advances are being made in the control of the composition and smoothness of surfaces, and the development of thin films. Engineered surfaces with modified properties such as large surface area or specific reactivity are used in many applications such as in fuel cells and catalysts. Surfaces with improved properties have different applications throughout the chemicals and energy sectors [8].

1.2.3 Nanoscale in Three Dimensions

Three Dimensional nanomaterials like nanoparticles, Fullerenes, quantum dots have got significant interest.

1.2.3.1 Nanoparticles

Nanoparticles are usually defined as the particles having size less than 100 nm. Metals, semiconductors, or oxides Nanoparticles or nanocrystals show particular mechanical, optical, magnetic, electrical, and other properties. Nanoparticles are of great interest as they play a role of a bridge between bulk materials and atomic or molecular structures. Relative to bulk materials nanoparticles exhibit a number of special properties. For example, the bending of bulk copper into wires and ribbons occurs with movement of copper atoms at about the 50 nm scale. Nanoparticles show astonishing optical properties as they are small enough to confine their electrons and produce quantum effects. For example the color of gold nanoparticles appears deep red to black in solution. Nanoparticles have very high surface area to volume ratio which provides a remarkable driving force for diffusion. The surface effects of nanoparticles also reduce the melting temperature [9].

In materials science, many nanoparticles have very different mechanical properties from those of conventional materials and also there is an improvement of the surfaces by adding new friction, wear or adhesion properties.

In medicine, the origin of diseases on the nanometer scale has lead to improvements in drug design and targeting. There is also a greater understanding of the functioning of different molecules in biology. Nanoparticles are also being used for analytical and instrumental applications, tissue engineering and imaging.

A wide variety of nanoscale materials and coatings are already in use in different consumer products such as sunscreens and cosmetics, fibers and textiles, dyes, and paints.

The smallest components of a computer chip are on a nanoscale. The constant drive towards miniaturization in electronic engineering has led to devices that are well within the nanometer range. Data storage devices based on nanostructures provide smaller, faster, and lower consumption systems.

Optical devices have also benefited from this trend and new types of microscopes have been invented, that can produce images of atomic and molecular processes at surfaces [10].

1.2.3.2 Fullerenes

A new class of carbon materials has been discovered in the mid-1980s called fullerene or carbon 60 (C60). It is the allotropic form of carbon. It is a spherical molecule having diameter about 1nm and consisting of sixty carbon atoms. These carbon atoms are arranged as twenty hexagons and twelve pentagons. Fullerenes has a number of applications such as miniature ‘ball bearings’ to lubricate surfaces, drug delivery vehicles and in electronic circuits [11].

Fullerene

1.2.3.3 Dendrimers

Dendrimers are branched, generally spherical large molecules. A dendrimer is symmetric, and frequently adopts a spherical three-dimensional morphology. The functional groups on the molecular surface are responsible for the properties of dendrimers [12]. These are polymeric molecules, formed through a nanoscale self-assembly process. Dendrimers have different types, of which the smallest is several nanometres in size.

Dendrimers are used in many applications such as coatings and inks. Dendrimers can be active as nanoscale carrier molecules and are used in drug delivery. As dendrimers can trap metal ions so that Environmental clean-up could be assisted by dendrimers which could then be filtered out of water with ultra-filtration techniques [11].

1.2.3.4 Nanocomposites

Nanocomposites are materials in which nanosized particles are incorporated into a matrix of standard material. In nanocomposite materials many properties like mechanical strength, toughness and electrical or thermal conductivity are significantly improved. Some nanocomposite materials are thousand times tougher than the bulk component materials. Nanocomposites, such as nanosized clays, are already being added to different products including auto parts to packaging materials to increase the mechanical and thermal properties.

Nanocomposites are currently being used in many applications including solid polymer electrolyes for batteries, thin-film capacitors for computer chips, automotive engine parts and fuel tanks, gas barriers and food packaging [13].

1.2.3.5 Quantum Dots

In the early 1980s nanoparticles of semiconductors (quantum dots) were initially created. Quantum effects come into play when semiconductor particles are made small enough so that the energies limit at which electrons and holes can exist in the particles. As energy is related to wavelength, therefore the optical properties of the particle can be finely tuned depending on its size. Thus simply by controlling the size, particles can be made to emit or absorb specific wavelengths of light.

monolayer-protected, high-quality, monodispersed, crystalline quantum dots have been created. These quantum dots with size 2nm are suitably treated and processed as a typical chemical reagent [11].

1.3 Applications of nanotechnology

1.3.1 Drug delivery

Drug delivery is related to deliver certain drugs to specific cells using nanoparticles. By depositing the active agent in the effected region only, the overall drug consumption and side-effects can be lowered significantly. By doing so no higher dose is needed than required. Human sufferings can also be reduced through this approach. For example the use of co-polymers, which form micelles for drug encapsulation and hold small drug molecules transporting them to the desired region. The important applications include cancer treatment with iron nanoparticles or gold shells. There is an overall benefit to the public health system because a targeted medicine reduces the treatment expenses. Nanotechnology is also opening up new opportunities in implantable delivery systems that are often preferable to the use of injectable drugs. This rapid rise may cause difficulties with toxicity, and drug efficiency can diminish as the drug concentration falls below the targeted range.

1.3.2 Medicine

Nanomaterials have various applications in the field of medicine because of their unique properties. To describe this newly developed field terms such as biomedical nanotechnology, nanomedicine, and nanobiotechnology are used. Nanomaterials can be useful for biomedical research and applications as the size of nanomaterials is similar to that of most biological molecules. Thus biology has led to the development of diagnostic devices, analytical tools, drug delivery vehicles, and physical therapy applications [14].

1.3.3 Energy

The different projects of nanotechnology related to energy are storage, energy saving, conversion, and controlling the processing rates. The renewable energy sources are also beneficial. Energy consumption can be reduced by better insulation systems and by the use of stronger and lighter materials in the transportation sector. For illumination nanotechnological approaches like light emitting diodes or quantum caged atoms could lead to a strong reduction of energy consumption.

solar cells have different semiconductor layers stacked together to absorb light at different energies but they still only be able to use 40 percent of the Sun's energy. The efficiencies of commercially available solar cells is much lower (15-20%). By designing specific catalysts with larger surface area nanotechnology could improve combustion. At the University of Toronto, scientists have developed a spray-on nanoparticle substance that instantly transforms a surface into a solar collector [14].

1.3.4 Agriculture and the Environment

For better germination and soil management many projects around the world are exploring the use of nanoparticles. A method of producing ammonia using buckyballs has been discovered by the researchers at Kyoto University Japan. The ammonia is a key component of fertilizers. The Russian Academy of Sciences reports that by spraying a solution of iron nanoparticles on to fields the germination of tomato seeds can be improved.

Many methods have been developed to apply nanotechnology and particularly nanoparticles to cleaning up soils contaminated with heavy metals. Dr. Wei-Xang Zhang has reported a nano clean-up technique of injecting nano-scale iron into a polluted place. The particles flow along with the groundwater and decontaminate while traveling, which is much less expensive than digging out the soil to treat it. For six to eight weeks, the nano-scale iron will remain active in the soil, after this time it dissolves in the groundwater and becomes indistinguishable from naturally occurring iron [15].

1.3.5 Electronics

Nanotechnology has played a very important role in the field of electronics. Because of contamination of particles and poor heat dissipation many of the miniaturized products in this field perform very poorly. Nanomaterials are very important to produce long lasting and strong interconnections. The novel production of nanotechnology is the super capacitors. Due to the large surface areas these super capacitors have a quite large capacitance as compared to the normal capacitors.

For a wide variety of applications nanomaterials are also used in many other fields. Aerogels are used for the insulation of homes and offices so that heating and cooling bills can be reduced significantly. Nanomaterials are used for the production of harder and tougher cutting tools that give many industrial benefits like low production cost and higher productivity. One of the most important productions that uses nanotechnology is the high energy density batteries [16].

1.3.6 Food

Many nanoparticles are developed that transport vitamins and other nutrients in food that beverages the food without affecting the taste and appearance. Actually these nanoparticles encapsulate the nutrients and bring them into the bloodstream through the stomach.

Silicate nanoparticles are used to provide a barrier to gasses or moisture in a plastic film used for packaging. This might reduce the possibility of food spoiling or drying out. Clay nanocomposites are also being used to provide an impermeable barrier to gasses such as oxygen or carbon dioxide in lightweight bottles, cartons and packaging films. By embedding silver nanoparticles in the plastic, storage bins are produced. These silver nanoparticles kill bacteria from the material so that health risks are minimized from harmful bacteria. Research is also being performed to produce nanocapsules containing nutrients. These nanocapsules would be released into the body when nanosensors detect a vitamin deficiency in our body that [17].

1.3.7 Chemical Sensors

Nanotechnology helps to detect very small amounts of chemical vapors by the sensors. In nanotechnology-based sensors a variety of detecting elements like carbon nanotubes, zinc oxide nanowires or palladium nanoparticles are used. The electrical properties of the sensing elements can be changed by a few gas molecules because of the small size of nanoparticles, nanowires, or nanotubes. This allows the detection of a very low concentration of chemical vapors. An evident application is to use these sensors throughout an airport or other security systems to check for vapors given off by explosive devices.

In industrial plants that use chemicals in manufacturing, these sensors can also be useful to detect the release of chemical vapors. This technology should also make possible economical set of connections of air quality monitoring stations to develop the tracking of air pollution sources [18].

1.4 Zinc oxide

The formula of Zinc oxide is ZnO. It is an inorganic compound. It appears as a white powder. It is insoluble in water and alcohol but is soluble in most acids, such as hydrochloric acid. As a mineral Zinc oxide is present in the Earth's crust as zincite. The bonding in ZnO is largely ionic.

In materials science, Zinc oxide is commonly called as II-VI semiconductor since zinc and oxygen are the elements of 2nd and 6th groups of the periodic table, respectively. Zinc oxide has a number of encouraging properties such as good transparency, wide band gap, high electron mobility , strong room-temperature luminescence etc. Zinc oxide is an amphoteric oxide. The melting point of ZnO is 1975°C [19].

The direct band gap of ZnO is 3.2 eV at room temperature and high exciton binding energy 60 meV. The excitonic transitions even at room temperature are possible because of high exciton binding energy. Semiconductor compounds are very important owing to their novel optical and transport properties.

Research has been going on to modify the properties of ZnO to use it for different applications. For example, to use as UV detectors and emitters the band gap of ZnO is modified. Therefore, It is a prospective candidate for optoelectronic applications in the short wavelength range (green, blue, UV), information storage and sensors. If the size is in the nanometer range then the optical and electronic properties of semiconductors can be further altered. Nanoparticles of ZnO attract a growing interest due to their potential use in new nanodevices [20].

Zinc oxide nanoparticles are mostly studied because of their applied features such as in solar energy conversion, luminescence, photo-catalysis, coatings, transparent UV protection films, and chemical sensors [21]. Zinc oxide has also handy uses in gas sensing devices, surface acoustic wave devices, and piezoelectric devices [22].

1.4.1 Crystal structusre

Zinc oxide crystallizes in three forms, hexagonal wurtzite, cubic zincblende and the hardly ever cubic rocksalt. The most stable and common structure is the hexagonal wurtzite. The zinc and oxide centers are tetrahedral. At relatively high pressures about 10 GPa the rocksalt (NaCl-type) structure is observed [19]. The hexagonal wurtzite structure of Zinc oxide is shown in figure below. The lattice constants are a = 3.25 Å and c = 5.2 Å.

Zinc Oxide Hexagonal Wurtzite Structure

1.4.2 Properties of Zinc Oxide

Zinc oxide has a large bandgap, due to which it has advantages of higher breakdown voltages, capability to maintain large electric fields, lower electronic noise, and high temperature and high power operation. For ceramics its different properties such as high heat capacity and heat conductivity, low thermal expansion and high melting temperature, are useful.

The refractive index and thermal conductivity of zinc oxide is high. It also has binding, antibacterial and UV-protection properties. ZnO has the highest piezoelectric tensor among the tetrahedrally bonded semiconductors. This property makes it important material for many piezoelectric applications. ZnO has nHYPERLINK "http://en.wikipedia.org/wiki/N-type_semiconductor"-type character. Appropriate n-type doping is easily done by substituting Zn with group-III elements such as Al, Ga, In [19].

1.4.3 Uses of ZnO

For material science applications, zinc oxide is added into a variety of materials and products such as plastics, pigments, foods, lubricants, ceramics, glass, cement, rubber, ointments, batteries etc.

For concrete manufacturing zinc oxide is widely used because addition of ZnO enhances the processing time and the resistance of concrete against water.

Zinc oxide is used in paints that keep their flexibility and adherence on the surfaces for several years. It is also used for paper coatings [19].

Zinc oxide has been normally used in piezoelectric transducers, gas sensors, photonic crystals, photodiodes, transparent conductive films, and solar cell windows [23].

Strength and stability of the plastic films can be improved as zinc oxide nanoparticles are incorporated into plastic packaging to block UV rays and provide anti bacterial protection [17].

Zinc oxide has also been used for spintronics applications if it is doped with magnetic ions like Mn, Fe, Co.

The zinc oxide nanorods can be used as field emitters, as pointed tips of ZnOnanorods result in a strong enhancement of an electric field.

Aluminium doped ZnO layers are used as transparent electrodes [19].

Aluminium doped ZnO have many potential applications in optical devices, photonic crystals, light-emitting diodes and laser diodes [24].

1.5 Motivation of the Thesis

In material science nanoparticles have potential applications in different fields because of their unique properties. Nanocrystals or nanoparticles made of metals, semiconductors, or oxides are of great interest for their electrical, optical and chemical properties. Nanoparticles are of great scientific interest as they are effectively play the role of a bridge between bulk materials and atomic or molecular structures. A bulk material should have constant physical properties regardless of its size, but at the nano scale this is often not the case. Nanoparticles can contribute stronger, lighter, cleaner and smarter surfaces and systems. ZnO has been normally used in piezoelectric transducers, gas sensors, photonic crystals, photodiodes, transparent conductive films, and solar cell windows. ZnO has also been used for spintronics applications if it is doped with magnetic ions like Mn, Fe, Co. Aluminium doped ZnO layers are used as transparent electrodes. Aluminium doped ZnO nanoparticles have many prospective applications in optical devices, photonic crystals, light-emitting diodes and laser diodes.