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A Review of Classification of Nanomaterials with its Properties and Applications

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Abstract- Nanotechnology is a known field of research since last century. Different major advances have occurred in the field of nanotechnology since the concept of "nanotechnology" was first introduced by Nobel laureate Richard P. Feynman in his well-known 1959 lecture "There's Sufficiently of Room at the Bottom" (Feynman, 1960). Using nanotechnology, researchers have been able to create new materials at the nanoscale.Nanomaterials are essential building blocks in nanoscience& nanotechnology. The field with the earliest beginning & most significant successes is the exploration of nanomaterials& nanostructures. The nanostructure science & technology has grown rapidly in the last several years, encompassing an open range of disciplines. A wide range of novel functions & materials might be generated, as well as a new generation of products could be created.

Keywords - Nanomaterial's, Nanostructures, Properties of Nanomaterial's, Nanotechnology

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INTRODUCTION

Nanomaterials are essential building blocks in nanoscience& nanotechnology. A nanostructure science & technology has grown rapidly in the last several years, encompassing a open range of disciplines. Anextensive range of novel functions & materials might be generated, as well as a new generation of products could be created. In the short term, it has already had a significanteffect on the market, and this is only expected to grow.

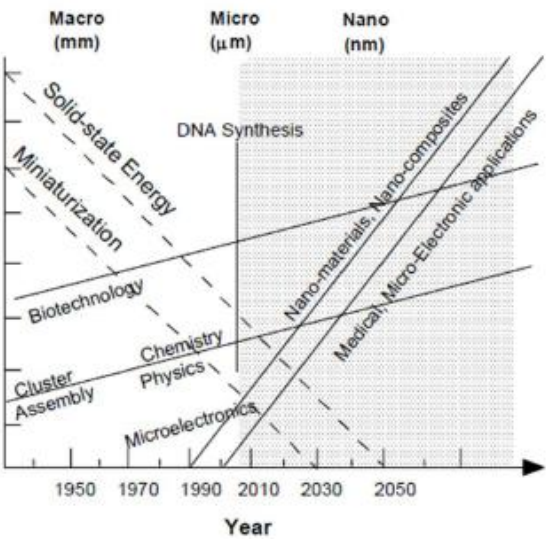

Figure 1: Evolution of science & technology

The term "nanomaterials" refers to a group substances whose small dimension <100 NMs. A nanometer is a million of a millimetre lesser than the diameter of a human hair. The unusual optical, magnetic, electrical, & other features that emerge at such a small scale intrigue scientists. In electronics, medicine, or other sectors, these emergent features hold considerable promise.

Figure 2: Nanomaterials

Engineered nanoparticles (EN) are of special importance, as they have been created for, and are already being employed, a broad range of commercial applications. Sunscreens, cosmetics, sporting goods, stain-resistant clothes, tyres, electronics, & slew of other commonplace objects contain them, and they're also employed in medical diagnostics, imaging, and drug administration.

To take use of their nanometer-level design and new features, nanomaterials are resources that have been engineered at the molecular level. Due to increased surface area & novel quantum phenomena, materials at the nanoscale can exhibit unique features. In comparison to traditional materials, nanomaterials get a substantially higher surface area to volume ratio that lead to better compound reactivity or alter their strength. At the nanoscale, quantum effect could play a significantly larger role in defining the property and features of materials, resulting in unique optical, electrical, & magnetic capabilities. "

ADVANCES IN NANOMATERIALS

The origins of nanomaterials can be traced back to the early meteorites that emerged after the Big Bang. Nanostructures like seashells, skeleton, or others were later developed by nature. The usage of fire by premature humans created nanoscaled smoke particles. The either sides, nanomaterials have a far longer scientific history. Michael Faraday's 1857 production of colloidal gold particles is one of the earliest scientific reports. Over the past 70 years, nanostructured catalysts have also been studied. The early 1940s saw the outline of precipitated & fumed silica nanoparticles as an alternative to ultrafine carbon black in rubber reinforcements in the U.S& Germany.

Inorganic & organic nanophase engineering is quickly expanding, allowing for manipulation of mechanical, catalytic, electric, magnetic, optical, & electronic properties in a wide range of materials. When it comes to creating nanophase or cluster-assembled materials, the development of small clusters that are then fused together into a bulk-like material is the most common method. When used in macroscale semiconductor processes, nanophasesilicon that differ from regular silicon in physical & electrical properties can develop new devices. With quantize semiconductor "colloids," ordinary glass become an extremely high-performance optical medium that could be used in the development of optical computers.

CLASSIFICATION OF NANOMATERIALS

The least 1-dimension of a nanomaterial must be 100 nm or smaller. Surface films, strands, &fibres are examples of nanoscale materials, while strands and fibres are examples of nanoscale materials in two dimensions (eg. particles). A variety of shapes & sizes has found in their single, combined, or agglomerated forms. Nanotubes, dendrimers, quantum dots, & fullerenes are among the most common forms of nanomaterials. Because of small size & unique chemical properties, nanomaterials are useful in the field of nanotechnology. 0D, 1D, 2D & 3-D nanostructures are all types of nanostructures, as per Siegel.

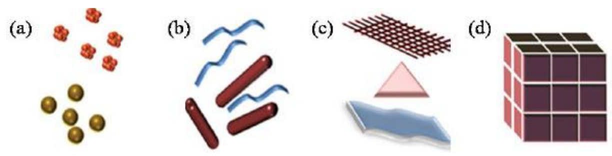

Figure 3: Classification of nanomaterials (a) 0D spheres & clusters, (b) 1D nanofibers, wires & rods (c) 2D Films, plates & networks (d) 3D nanomaterials

The word "nanomaterial" states to materials with a grain size of less than 50 nm or dimensionality of less than 50 nm. These materials could be manufactured with assorted modulation dimensions as outlined by Richard: zero (atomic clusters & filament assemblies), one (multilayers) & 2 or three (ultrafine-grained overlayers or buried layers) as seen in above figure.

PROPERTIES OF NANOMATERIALS

In contrast to the vast differences between the properties of atoms or bulk materials, nanomaterials have properties that are fundamentally distinct from those of microstructured materials. A substantial fraction of surface atoms, a high surface energy, unique detention, or reduced imperfection are all a result of the materials' nanoscale size. This is not the case with bulk materials. For example, nanoparticles have an extraordinarily large surface area to volume ratio, which results in increased surface-dependent characteristics. Mechanical, optical, electrical, & magnetic qualities have all been the subject of recent, in-depth research for application.

Mechanical property

Nanostructures obviously show various mechanical properties. For example, single walled & multi walled carbon nanotubes exhibit high mechanical strength & elastic limits that lead to excellent mechanical flexibility (Varadan et al 2010). Nanocrystalline ceramics has pressed & sintered into different shapes at extensively low temperatures whereas ceramics are hard to machine even at maximum temperatures. As grain size is decreased, the fatigue life of nanomaterials is enlarged by an average of 200-300% over conventional materials and superplasticity is observed at lower temperatures at higher strain rates.

Optical property

The transition between the energy level in semiconductors and metals demonstrate large change in optical properties like color, as a function of particle size. For example, colloidal solutions of gold NPs have a deep red color and the color becomes deep yellow as the particle size increases. If the size of nanoparticle is made small enough, light emitted from the particle is highly polarized along their longitudinal directions (Varadan et al 2010).

Electrical property

Due to multiple different mechanisms such grain boundary scattering, ballistic conduction, coulomb charging, tunnel & wide of band gaps, the influence of nanomaterial size on electrical conductivity is complicated & difficult to interpret. In addition, reduced impurity, structural defects & dislocations would affect the electrical conductivity of nanomaterials. The coulomb blockade effects in nanomaterials results in conduction processes which involve single electrons, and hence small amount of energy is required to operate a switch, a transistor or a memory element (Varadan et al 2010).

Magnetic property

The coercivity and saturation magnetization values that measure the strength of magnet enhance by decrease in grain size. Because of their enormous surface area, magnets built of nanocrystalline yttrium-samarium-cobalt grains have strange magnetic characteristics. Ferromagnetic particles become unstable when the particle size reduces below a certain size, since the surface energy provides a sufficient energy for domains to spontaneously switch polarization directions. As a result ferromagnetic becomes super paramagnetics.

APPLICATIONS OF NANOMATERIALS

Nanotechnology provides the connections between the sciences to develop anconsiderate of the correlation among the emerging interdisciplinary fields. As nanomaterials possess single and beneficial chemical, physical & mechanical property, will offer better products for home, communication, medicine, transportation, agriculture and industry in general. Some of the existing applications of nanomaterials are briefly shown below.

Nanomaterials in automobiles

The engine cylinders are layered with nanocrystalline ceramics, include zirconia & alumina for complete & proficient combustion of the fuel, thereby reduce environment pollution. Aircraft components made of nanomaterials are stronger & operate at higher temperatures and so aircraft can fly faster using the same amount of aviation fuel. Polymer nanocomposites are utilized for body panels and it can improve the engine efficiency also. Nanoparticles are also presently utilized as fuel additives to lower consumption in commercial vehicles and reduce toxic emissions.

Nanomaterials in medicine

Nanomaterials size is comparable the most biological molecules & structures, thus they is used for biomedical research & usage both in vivo & in vitro. One of the attractive applications is nanorobots or nanobots for improved therapy and diagnostics. Nanogold particles are used as specific staining agents in biological electron microscopy.

Advanced nanotechnology based tissue engineering can lead to life extension. Colloidal nanoparticles linked with protein and peptides provide the key to assemble new materials for developing homogeneous bioassays. Nanocrystalline silicon carbide (SiC) is a candidate material for synthetic heart valves primarily due to its low weight, high strength, wear resistance, and corrosion resistance. Nanocomposites have utilized as intelligent materials for 'artificial noses' or sensors of biological material.

Other applications

Nanocrystalline zinc selenide, zinc sulphide, cadmium sulphide & lead telluride improve the resolution of monitors. The utilize of anophosphors would diminish the cost of making high resolution televisions. Carbon nanotubes are also the candidates of this purpose. Resonant MRI is a medical diagnostic technique that uses MRI to detect abnormalities in the body. Nanomagnets for removal of soil contaminants and nanosensors for new pesticides and insecticides are in use. Nanomaterials, with their enhanced chemical activity, could be utilized as catalysts to reduce pollution from fossil fuels & coal. Viruses of dimensions 10 - 100nm are removed by ultrafiltration. Dissolved salts and color producing organic compounds are removed by reverse osmosis and nanofiltration. Food spoilages can be detected by nanosensors that are located directly into the packaging material.

LOW DIMENSIONAL SEMICONDUCTOR SYSTEMS

Low Dimensional Semiconductor Systems (LDSS) (Davies 1998, Delerue et al 2004) that revolutionize the semiconductor physics for the past three decades find their importance as the technology grows and moves towards miniaturization. In LDSS, electrons are kept to move in two, one and zero dimensions. Most of these structures are really heterostructures where the composition of semiconductors can be changed in nanometer scale. Structures of these sizes are also called as mesoscopic because the confinement length is intermediate between the microscopic lattice constant and the macroscopic extension of the bulk material.

Two Dimensional Structures

Structures in which electrons are confined in one spatial dimension & free to move in other two dimensions are conventionally called as two dimensional structures and are known as Quantum wells (QW). The energy levels in this system are widely separated, because of this the electrons will appear to be frozen in the ground state and no motion is possible in this confined dimension. The result is a two dimensional (2D) electron gas. Quantum wells are classified into two types. In type I, the lowest electron & hole states are confined in the well material and in type II they are confined in different parts of structures (e.g. Holes in the well and electrons in the barrier as in GaAs/AlAs). Other types of quantum wells are also possible (Bastard et al 1991).

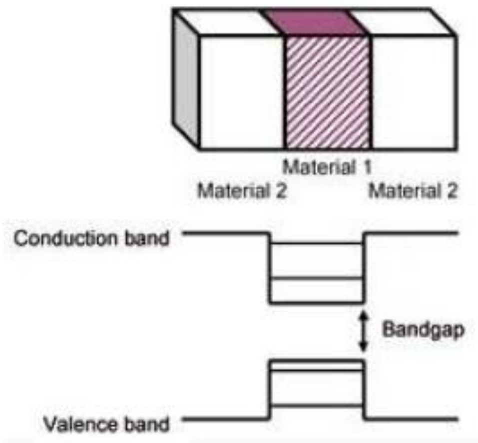

Figure 4: Formation and band diagram of quantum well

As quantum wells are essentially two dimensions thick, the density of states of their electrons is more pronounced than in bulk materials (Fig. 5). In light of this, they find extensive application in diode lasers, especially blue lasers. In order to create HEMTs (High Electron Mobility Transistors) that are utilized in low noise electronics quantum wells are used. Quantum wells are also the foundation of several infrared photo detectors that find usage in infrared imaging. At low temperatures, these systems exhibit several intriguing behaviors. The Quantum Hall Effect is one such characteristic, and it manifests itself in extremely strong magnetic fields. Two-dimensional hole gas (2DHG) is produced by acceptor dopants in a manner analogous to that of electron gas.

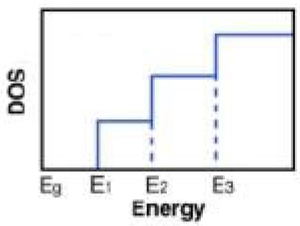

Figure 5: Energy versus density of states in a quantum well

One Dimensional Structures

Electrons can be trapped in a two dimensional potential well and made to move in one dimension only that leads to a Quantum Wire (1D). Highly conducting one dimensional materials based on polymers are now known, which are highly anisotropic crystals of organic salts. Nanotubes, nanofibres are well known quantum wires, since they have high aspect ratio and ballistic conduction. Density of states versus energy for one dimensional electron gas is shown in Fig 6.

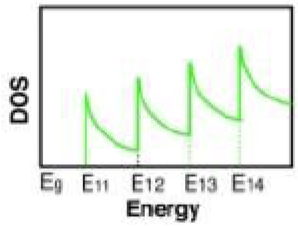

Figure 6: Energy versus density of states in a quantum wire

Quantum wires can be doped and used to construct devices, especially light emitting diodes (LED). The introduction of carriers in one dimensional quantum structures leads to strong quenching of low energy peaks in the absorption spectrum, or a blue shift of the absorption edge, caused by band (and phase space) filling that quenches both the excitonic and band-to-band absorption. This effect and its subsequent refractive index change can be exploited for constructing an efficient optical modulator extremely controlled by the injection of carriers. The quantum confined stark effect (QCSE) describes, even at room temperature, the large energy shifts of the quantized energy levels in a semiconductor quantum heterostructure in the existence of an electric field.

Zero Dimensional Structures

Individual zero dimensional structures (quantum dots) can be created from two dimensional electron or hole gases present in remotely doped quantum wells or semiconductor heterostructures. The sample surface is coated with a thin layer of resin and such quantum dots are mainly of interest for experiments and applications involving electron or hole transport. Density of states versus energy for a QD is shown in the Fig 7.

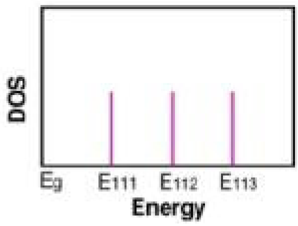

Figure 7: Energy versus density of states in a quantum dot

Due to their finer density of states, quantum dots outperform high-dimensional objects in terms of transport or optical characteristics. This means that quantum dots has found in devices as diverse as diode lasers, white light emitting diodes, amplifiers, & biological sensors. Quantum dots are also employed in solid state quantum computing. Quantum computing could be achievable with enough entangled quantum dots (qubits) and some sort of operation-carrying out mechanism.These low dimensional semiconductor systems exhibit many novel phenomena like quantum size effect, quantum Hall effect, hydrogenic system in one and two dimensions, semiconductor - metal - insulator transitions in lower dimension and Bloch oscillators. Hence the conventional semiconductor devices are being replaced slowly by these nano level systems. At present, the nanostructures and nanomaterials dominate almost all the fields of Sciences like physics, chemistry, biology and also Engineering and Technology as there is a marvelous potential in these materials.

LITERATURE REVIEW

Salata, (2004) Nanotechnology is getting developed at several levels: materials, devices and systems. The nanomaterials level is the most advanced at present, both in scientific knowledge and in commercial applications.

Rana and Kalaichelvan, (2013) Nanoparticles are less than a few 100 nm. This reduction in size brings about significant changes in their physical properties with respect to those observed in bulk materials. They can be metallic, mineral, polymer-based or a combination of materials.

Salata, (2004) Most of these changes are related to the appearance of quantum effects as the size decreases, and are the origin of phenomena such as the superparamagnetism, Coulomb blockade, surface plasmon resonance, etc. The increase in the surface area to volume ratio is also a consequence of the reduction in size. It leads to the appearance of surface effects related to the high number of surface atoms, as well as to a high specific area, which are important from the practical point of view.

Shrivastava, (2002) As the atoms and molecules located at the particle surface become significant in the nanometer order, the melting point of the material decreases from that of the bulk material because they tend to move easier at the lower temperature. The reduction of the melting point of ultrafine particles is regarded as one of the unique features of the nanoparticles related with aggregation and grain growth of the nanoparticles or improvement of sintering performance of ceramic materials. Hence, melting point of nanomaterials differs from their corresponding bulk materials as an end result of their free surface and size. Several examples could be found to illustrate the melting point depression as function of the particle size.

Matsui, (2005) When the materials are reduced to the nanolevel, electromagnetic forces become predominant in these nanoparticles. The mass of the nanoscale object is so small, that the gravity becomes negligible and electromagnetic forces overtake the gravitational force. The nanoparticles are raw materials for a number of electronic devices. The electromagnetic properties play a great role for the improvement of the product performance. The minimum particles size to keep the ferroelectric property differs depending upon the kind and composition of the materials. As for the magnetic property, ferromagnetic fine particles have a single magnetic domain structure as they become very small as in the order less than about 1 μm and show super-paramagnetic property, when they get further finer. In this case, although the individual particles are ferromagnetic with the single magnetic domain structure, the particles collectively behave as paramagnetic. It is magnetized as a whole in the same direction of the external magnetic field but the magnetization disappears by the thermal fluctuation, when the external magnetic field is taken away. The time for disappearing of magnetization depends upon the particle size, like, the magnetization of the material responds with the external magnetic field as a paramagnetic when the particles are small enough but it decreases gradually as the particle size becomes larger. Gold which is a stable substance as bulk shows unique catalytic characteristics as nanoparticles

CONCLUSION

These materials' extraordinary mechanical, electrical, optical, & magnetic properties have sparked a lot of curiosity recently.Nanotechnology produced materials of many types at nanoscale level. Materials with at least one dimension that is less than 100 nm are included in the NPs' broad class. These materials has 0D, 1D, 2D, or 3D, depending on the shape as a whole. Nanophase ceramics are of tremendous interest & more flexible at elevated heat than coarse-grained ceramics.Many different non-linear optical characteristics are known to appear in nanostructured semiconductors. Quantum confinement phenomena in semiconductor Q-particles can result in unique features, such as luminescence in si powders &si germanium quantum dots.

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