

1. Introduction

In recent years nanotechnology has become one of the most important and exiting forefront fields in physics, chemistry, biology and engineering and technology. Nano means 10^{-9} m. A nanometer (nm) is one thousand millionth of a meter. Atoms are extremely small and the diameter of a single atom varies from 0.1 to 0.5 nm depending on the type of the element. For example, one carbon atom is approximately 0.15nm in diameter and a water molecule is almost 0.3nm across. A red blood cell is approximately 7,000 nm wide and human hair is 80,000 nm wide.

2. Origin of Nano technology

While the word nano technology is relatively new, the existence of nanostructures and nanodevices is not new. Such structures existed on the earth as life itself. Though it is not known when humans began to use nanosized materials, the first known, Roman glassmakers were fabricated glasses containing nanosized metals.

When the material size of the object is reduced to nanoscale, then it exhibits different properties than the same material in bulk form.

Nanoscience

Nano science deals with the study of properties of materials at nano scales where properties differ significantly than those at larger scale.

Nanotechnology

Nanotechnology deals with the design, characterization, production and applications of nanostructures and nanodevices and nanosystems.

3. Nano materials

All materials are composed of grains. The visibility of grains depends on their size. Convectional materials have grains varying in size from hundreds of microns to millimeters. The materials processing grains size ranging from 1 to 100 nm, known as nano materials. Nano materials can be produced in different dimensionalities.

One dimensional nano material: Surface coatings and thin films

Two dimensional nano materials: nano tubes nano wires, biopolymers

Three dimensional nano materials: nano particles, precipitates, colloids, quantum dots, nano crystalline materials, fullerenes or carbon nano-60.

4. Basic principles of nano materials

When the material size of the object is reduced to nanoscale, then it exhibits different properties than the same material in bulk form. The factors that differentiates the nanomaterials form bulk material is

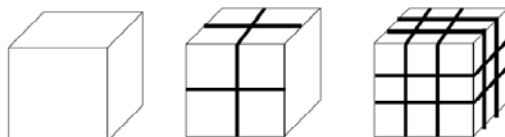
1. Increase in surface area to volume ratio
2. Quantum confinement effect

Increase in surface area to volume ratio:

The ratio of surface area to volume ratio is large for nano materials.

Example 1: To understand this let us consider a spherical material of radius 'r'. Then its surface area to volume ratio is $\frac{3}{r}$. Due to decrease of r, the ratio increases predominantly.

Example 2: For one cubic volume, the surface ratio is $6m^2$. When it is divided into eight cubes its surface area becomes $12m^2$. When it is divided into 27 cubes its surface area becomes $18m^2$. Thus, when the given volume is divided into smaller pieces the surface area increases.



Due to increase of surface of surface area, more number of atoms will appear at the surface of compared to those inside. For example, a nano material of size 10nm has 20% of its atoms on its surface and 3nm has 50% of its atoms. This makes the nanomaterials more chemically reactive and affects the properties of nano materials.

Quantum confinement effect:

According to band theory, the solid atoms have energy bands and isolated atoms possess discrete energy levels. Nano materials are the intermediate state to solids and atoms. When the material size is reduced to nanoscale, the energy levels of electrons change. This effect is called quantum confinement effect. This affects the optical, electrical and magnetic properties of nanomaterials.

5. Fabrication methods of nanomaterials

The nanomaterials can be synthesized in two ways, namely

Bottom –up approach and

Top-down approach

Bottom-up approach:

In this method, the nanomaterials are synthesized by assembling the atoms and molecules together.

Examples: Ball milling and Sol-gel method.

Top-down approach:

In this method, the nanomaterials are synthesized by dis-assembling the solids into finer pieces until the particles are in the order of nanometers.

Examples: plasma arching, chemical vapour deposition method

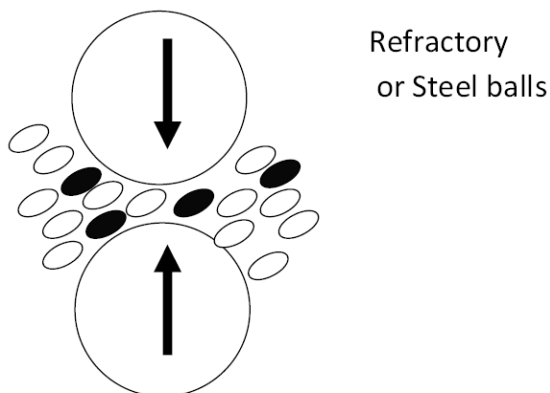
Ball milling method

This method is a very popular, simple inexpensive and scalable method. This is also called crushing method. Ball method is to prepare a wide range of elemental and oxide powders. This method is to produce nanocrystalline or amorphous materials.

When the balls are allowed to rotate with particular rpm inside of a drum the necessary energy is transferred to the powder which in turn reduces the powder grain-sized structure to ultrafine or nano range particles. Depending

on the material either refractory balls or steel balls or plastic balls are used. The energy transferred to the poser from the balls depends on many factors such as rotational speed of the balls, number of balls, milling time and the milling medium.

Generally, a hard material will be selected to synthesize softer material. Commonly α –alumina and zirconica balls are used to synthesize the nanomaterials.



Chemical vapour deposition:

In chemical vapour deposition is a well known process in which a solid is deposited on a cooled surface via chemical reaction from vapor or gas phase. The basic steps involved in this process are (i) Generation of vapour by boiling or subliming a source material (ii) Transformation of the vapour from the source to the substrate and (iii) Condensation of vapour on the cool substrate.

In this method, the atoms or molecules are in gaseous state allowed to react homogeneously or heterogeneously depending on the applications. This method is an excellent method which is used to control the particle size, shape and chemical compositions.

This method is used to produce the nano powders of oxides and carbides of metals. Production of pure metal powders is also possible using this method.

Sol-gel method

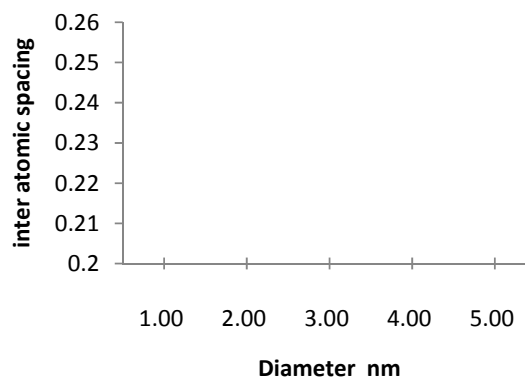
The sol-gel process is a wet technique i.e., chemical solution deposition technique used for the production of high purity and homogeneous nanomaterials. In solutions the molecules of nanometer size are dispersed and move around randomly and hence the solution is clear. In colloids the molecules of size ranging from $20\mu\text{m}$ to $100\mu\text{m}$ are suspended in a solvent. When mixed with a liquid is called as sol. A suspension that keeps its shape is called a gel. Thus the colloids are suspensions of colloids in liquids that keep their shape. The formation of sol-gels involves hydrolysis, condensation growth of particles and formation of networks.

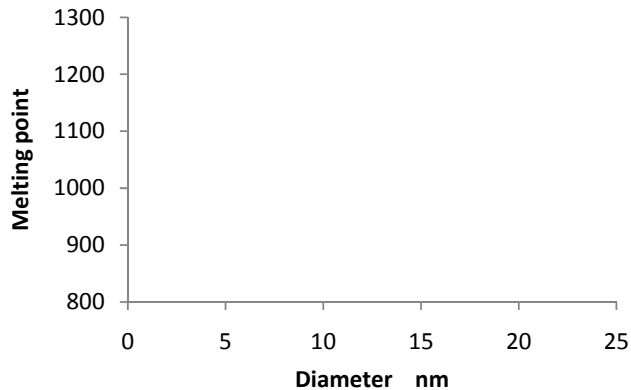
Plasma arching method:

Plasma is an ionized gas. To produce plasma, high potential difference is applied across the electrodes. An arc passes from one electrode to another. The gas yields up its electrons and positive ions at anode. Positively charged ions pass to other electrode (cathode) pick up electrons and are deposited to form nano particles. Using this plasma arching method, very thin films of the order of atomic dimensions can be deposited on the surface of an electrode. This deposition is carried in vacuum or in an inert gas. By using carbon electrodes, carbon nanotubes can be formed on the surface of the cathode.

6. Properties of nanomaterials**Physical properties****Inter atomic distance:**

When the material size is reduced to nanoscale, surface area to volume ratio increases. Due to increase of surface of surface area, more number of atoms will appear at the surface of compared to those inside. So Interatomic spacing decreases with size. The variation of nearest neighboring distance in copper with decrease of particle is shown in figure.

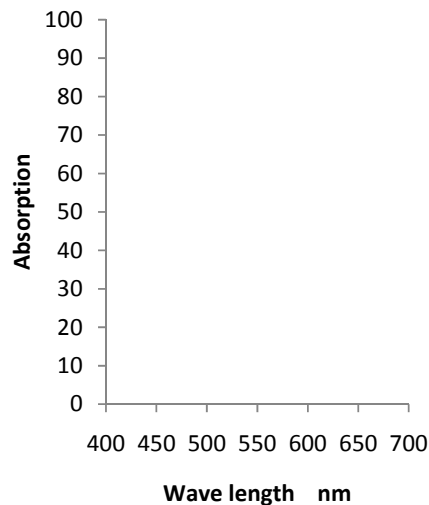


Thermal properties

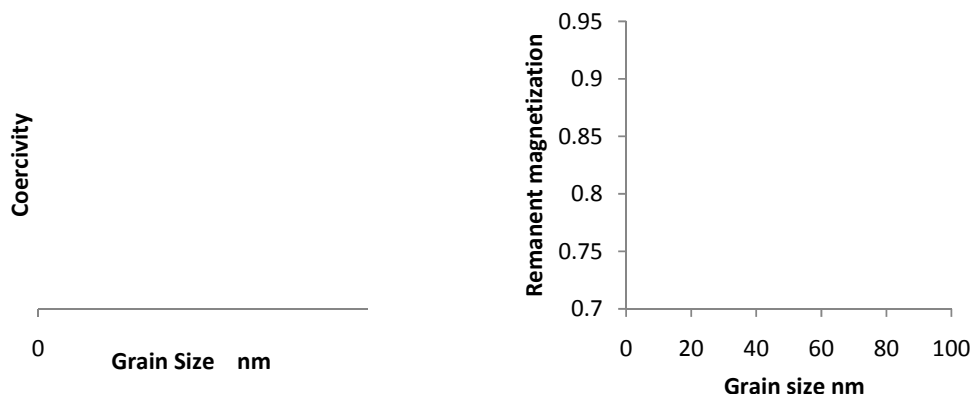
Thermal properties nano materials are different from that of bulk materials. The Debye Temperature and ferroelectric phase transition temperature are lower for nano materials. The melting point of nano gold decreases from 1200 K to 800K as the size of particle decreases from 300\AA to 200\AA . The variation of melting point in gold with decrease of particle is shown in figure.

Optical properties:

Different sized nano particles scatters different of light incident on it and hence they appear with different colours. For example nano gold does not act as bulk gold. The nano particles of gold appear as orange, purple, red or greenish in colour depending on their grain size. The bulk copper is opaque where as nanoparticle copper is transparent. The optical absorption spectrum of gold as a function of particle size is shown in figure.

**Magnetic properties:**

The magnetic properties of nano materials are different from that of bulk materials. In explaining the magnetic behavior of nanomaterials, we use single domains unlike large number of domains in bulk materials. The coercivity values of single domain is vary large. The variation of remanet magnetization and coercivity as a function of grain size is shown in figure.



For example, Fe, Co, and Ni are ferromagnetic in bulk but they exhibit super paramagnetism. Na, K, and Rh are paramagnetic in bulk but they exhibit ferro-magnetic. Cr is anti ferromagnetic in bulk but they exhibit super paramagnetic.

Mechanical properties

The mechanical properties such as hardness, toughness, elastic modulus, young's modulus etc., of nano materials are different from that of bulk materials. In metals and alloys, the hardness and toughness are increased by reducing the size of the nano particles. In ceramics, ductility and super plasticity are increased on reducing grain size. Hardness increases 4 to 6 times as one goes from bulk Cu to nanocrystalline and it is 7 to 8 times for Ni.

Chemical properties

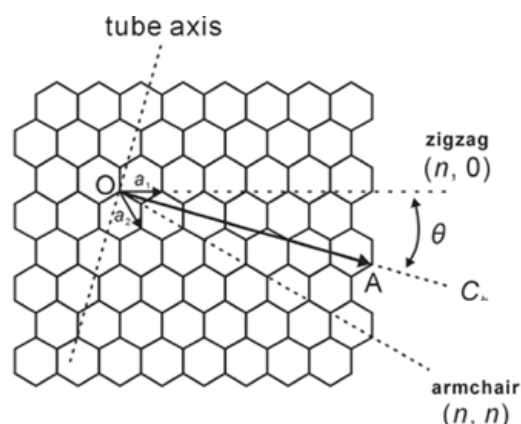
Nanocrystalline materials are strong, hard, erosion and corrosion resistant. They are chemically active and have the following chemical properties.

1. In electrochemical reactions, the rate of increase in mass transport increases as the particle size decreases.
2. The equilibrium vapour pressure, chemical potentials and solubilities of nanoparticles are greater than that for the same bulk material.
3. Most of the metals do not absorb hydrogen. But the hydrogen absorption increases with the decrease of cluster size in Ni, Pt and Pd metals.

7. Carbon nanotubes:

Carbon nanotubes were first observed by Sumino Iijima in 1991. Carbon exists in a large number of allotropic forms. These include diamond, graphite and fullerenes (such as C_{60} , C_{70} etc.).

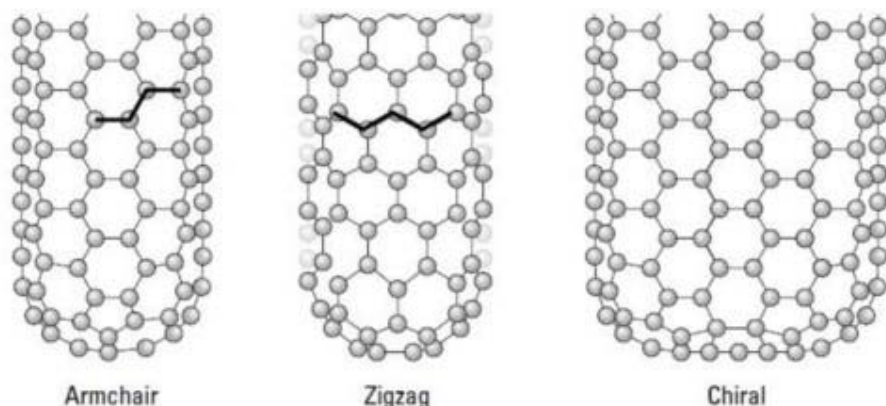
Carbon nanotubes are obtained by rolling the graphite sheet into tubes with the bonds at the ends of the sheet. These bonds are used to close the tube. Generally, the length of carbon nanotubes varies from several micrometers to millimeter and the diameter will vary from 1 to 20 nm.



A tube may contain one cylindrical wall of graphite or a number of concentric cylindrical walls. A carbon nanotube consisting of one cylindrical graphite is called single walled nanotube. Otherwise they are known as multi walled nanotubes.

Depending on how sheet is rolled, they are classified into three types. The three types of carbon nanotubes are

- 1) Zigzag
- 2) Chiral
- 3) Armchair



8. Properties of carbon nanotubes

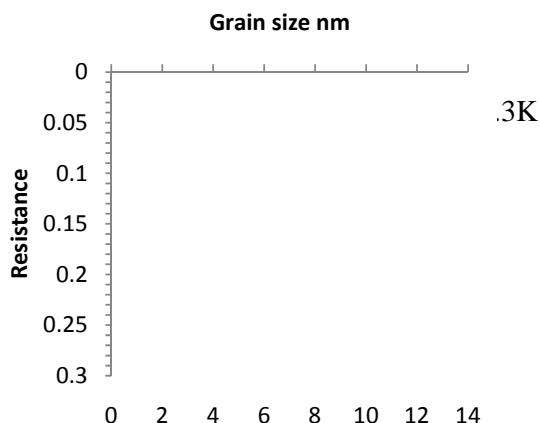
Electrical conductivity

Generally the carbon nanotubes produced both in metallic and semiconducting in their electrical behavior. Conductivity of multi walled nanotube is more complex. The conductivity and resistivity of ropes of single walled carbon nanotubes has been measured by placing the electrodes at different parts of the carbon nanotubes. The resistivity of single walled carbon nanotube ropes was of the order of 10^{-4} ohm-cm at 27° . This means that the conductivity of single walled nanotube ropes are most conductive carbon fibers of known.

Magnetic property

The carbon nanotube displays the magneto-resistive effects at lower temperature i.e., the resistance of the carbon nanotube is changed by the application of dc magnetic field. The variation of resistance in carbon nanotube at 2.3K and 0.36k w.r.t magnetic field is shown in figure.

The observed magneto- resistance effect is negative. This is due to the decrease in resistance with increase in magnetic field.



Highly absorbent

The carbon nanotubes have large surface area and high absorbance. So the carbon nanotubes are used in the air, gas and water filtration.

Mechanical properties

The strength of the sp^2 carbon-carbon bonds gives carbon nanotubes amazing mechanical properties. The stiffness of the material is measured in terms of its Young's modulus. The Young's modulus value of single walled nanotube is about 1Tera Pascal, which is approximately 5 times greater than steel. The tensile strength or breaking strain of nanotube is about 150GPa, which is approximately 150 times greater than steel.

Vibration properties

Similar to carbon dioxide molecule, Carbon nanotubes have two normal modes of vibration (a set of vibrational motions known as normal mode of vibrations). The different modes of vibrational motion are determined from the symmetry of the molecule. In the first mode the diameter of the carbon nanotube moves in and out at the frequency of 165 cm^{-1} . In the second mode the carbon nanotube crushing in one direction and expansion takes place in the perpendicular direction. Thus, it oscillates between sphere and ellipse at a frequency of 17 cm^{-1} . The frequency of the vibration modes depends on the diameter of the nanotube.

9. Applications of nano tubes**Field emission**

When a small electric field is applied parallel to the axis of a nanotube, electrons are emitted at a very high rate from the ends of the tube. This is called field emission. The electron emission of carbon nanotubes is used in electronic industries like flat panel displays.

Electronics

The single walled carbon nanotube can be act as a transistor. Pairs of carbon nanotubes show as logic structures. A single nanotube with natural junction acts as a rectifying diode.

Hydrogen storage

Carbon nanotubes can store hydrogen and also helium, oxides and metals like copper.

Mechanical machines

Carbon nanotubes can act as a axels in nanomachines.

Space elevators

Like graphite, carbon nanotubes with stand high temperature, so they are used for thermal protection of spacecraft during re-entry of into the atmosphere. Carbon nanotubes have high Young's modulus, so they with stands aeronautical strains.

Hospitals

Carbon nanotubes are thin, so they can penetrate the skin with out pain. Blood can be drawn from the patients through nanostraws to know glucose levels and to inject insulin whenever required.

10. Applications of nanomaterials

Nano materials posses unique and beneficial, physical, chemical and mechanical properties, they can be used for a wide verity of applications.

Material technology

- Nanocrystalline aerogel are light weight and porous, so they are used for insulation in offices homes, etc.,

- Cutting tools made of nanocrystalline materials are much harder, much more wear- resistance, and last longer.
- Nanocrystalline material sensors are used for smoke detectors, ice detectors on aircraft wings, etc.,.
- Nanocrystalline materials are used for high energy density storage batteries.
- Nanosized titanium dioxide and zinc dioxide are used in sunscreens to absorb and reflect ultraviolet rays.
- Nanocoating of highly activated titanium dioxide acts as water repellent and antibacterial.
- The hardness of metals can be predominately enhanced by using nanoparticles.
- Nanoparticles in paints change colour in response to change in temperature or chemical environment, and reduce the infrared absorption and heat loss.
- Nanocrystalline ceramics are used in automotive industry as high strength springs, ball bearings and valve lifters.

Information technology

- Nanoscale fabricated magnetic materials are used in data storage
- Nano computer chips reduce the size of the computer.
- Nanocrystalline starting light emitting phosphors are used for flat panel displays.
- Nanoparticles are used for information storage.
- Nanophotonic crystals are used in chemical optical computers.

Biomedicals

- Biosensitive nanomaterials are used for tagging of DNA and DNA chips.
- In the medical field, nanomaterials are used for disease diagnosis, drug delivery and molecular imaging.
- Nanocrystalline silicon carbide is used for artificial heart valves due to its low weight and high strength.

Energy storage

- Nanoparticles are used for hydrogen storage.
- Nanoparticles are used in magnetic refrigeration.
- Metal nanoparticles are useful in fabrication of ionic batteries.