NANOTECHNOLOGY

Important properties of any material; such as the electrical, optical, thermal and mechanical properties are determined by the way in which molecules and atoms assemble on the nanoscale into larger structures. In nanometer size structures these properties often differ from the macro scale, because of quantum mechanical effects.

- ✓ *Nanomaterials are materials of which at least one dimension is between 1 and 100 nanometers.*

Nanoscience refers to the study, manipulation and engineering of matter, particles and structures on the nanometer scale.

- ☞ It is an interdisciplinary field of science combining physics, materials science, chemistry, and related disciplines.
- ☞ Important properties of materials, such as the electrical, optical, thermal and mechanical properties, are determined by the way molecules and atoms assemble on the nanoscale into larger structures. In nanometer size structures these properties often differ from the macroscale, because of quantum mechanical effects.

Nanotechnology is the application of nanoscience leading to the use of new nanomaterials and nanosize components in useful products.

- ☞ The design, characterization, production, and application of structures, devices, and systems by controlled manipulation of size and shape at the nanometer scale

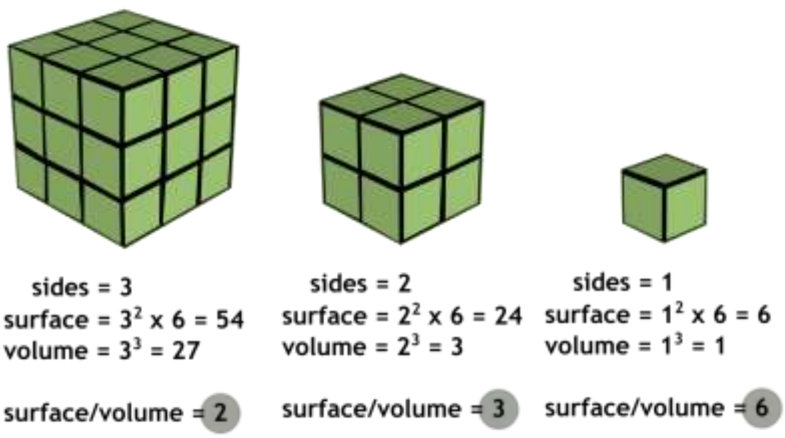
SIGNIFICANCE OF NANOSCALE

Two important factors that changes the properties in nanoscale are surface to volume ratio and quantum effects

1. Surface to Volume Ratio

A cube of dimension 3x3x3 have a surface to volume ratio of 2 whereas a cube of dimension 1x1x1 have a surface to volume ratio of 6. When the size of the particle is reduced, its surface to volume ratio increases.

When we move into nano scale this change is very large .For ex: If we divide a $1cm^3$ volume into $1nm^3$ parts the total surface area increases from $6cm^2$ to $60000000cm^2$.



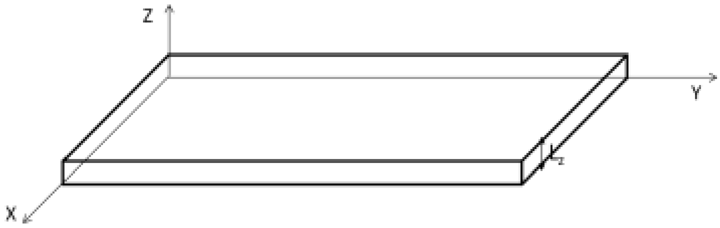
2. Quantum Confinement

A quantum confined structure is one in which the motion of the carriers are confined in one or more directions by potential barriers. Particle behaves as free particle when the confining dimension is large compared to the wavelength of the particle. When the confining dimension decreases and reaches a certain limit (comparable to de Broglie Wavelength), the energy levels becomes discrete.

Based on the number of dimensions of restriction, nanostructures are classified into three; nanosheet, nanowire and quantum dot.

2.1 Nanosheet/ Quantum Well

In Nanosheet confinement is in one dimension only and carriers are allowed to freely move in two directions. So nanosheet is a two-dimensional nanostructure with thickness up to 100 nm. Wave function and energy values of the particle are



$$\mathbf{\Psi_n(x,y,z) = \sqrt{\frac{2}{L_z}} \sin\left(\frac{n_z \pi z}{L_z}\right) \; e^{ik_x x} \;\; e^{ik_y y}}$$

$$\mathbf{E_n = \frac{n_z^2 \pi^2 \hbar^2}{2mL_z^2} + \frac{\hbar^2 k_x^2}{2m} + \frac{\hbar^2 k_y^2}{2m}}$$

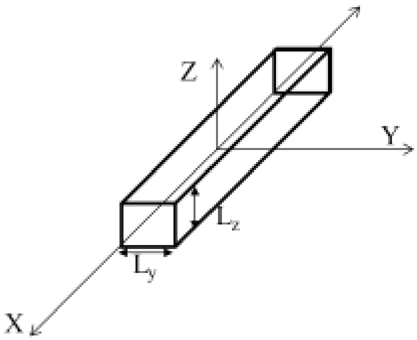
A typical example of a nanosheet is graphene, the thinnest two-dimensional material (0.34 nm) in the world. It consists of a single layer of carbon atoms with hexagonal lattices.

2.2 Nanowire/ Quantum wire

In nanowire, confinement is in two dimensions and carriers are allowed to move freely in one direction only.

Particles can move freely along x and y direction. Movement is restricted in Y-direction by a small distance Ly and in Z-direction by a small distance Lz. Ex: Motion of careers in carbon nanotube

Wave function and energy values of the particle are



$$\boldsymbol{\Psi_n(x,y,z) = \sqrt{\frac{2}{L_y}} \sqrt{\frac{2}{L_z}} \; sin\left(\frac{n_y \pi y}{L_y}\right) \; sin\left(\frac{n_z \pi z}{L_z}\right) e^{ik_x x}}$$

$$\boldsymbol{E_n = \frac{n_y^2 \pi^2 \hbar^2}{2mL_y^2} + \frac{n_z^2 \pi^2 \hbar^2}{2mL_z^2} + \frac{\hbar^2 k_x^2}{2m}}$$

$$\boldsymbol{E_n = \frac{\pi^2 \hbar^2}{2m}\left(\frac{n_y^2}{L_Y^2} + \frac{n_Z^2}{L_Z^2}\right) + \frac{\hbar^2 k_x^2}{2m}}$$

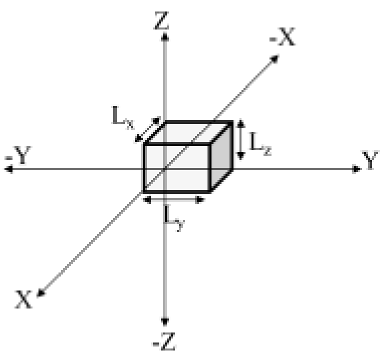
Nanowires are used in applications including: small electronic circuits, memory devices, transistors, biomolecular nanosensors, MEMS, etc.

2.3 Nanocrystal/ Quantum dot

In quantum dot, confinement is in all three dimensions and carriers are not allowed to freely move in any direction.

Movement is restricted in X-direction by a small distance L_x, movement is restricted in Y-direction by a small distance L_y and in Z-direction by a small distance L_z .

Wave function and energy values of the particle are



$$\boldsymbol{\Psi_n(x,y,z) = \sqrt{\frac{2}{L_x}} \sqrt{\frac{2}{L_y}} \sqrt{\frac{2}{L_z}} \; sin\left(\frac{n_x \pi x}{L_x}\right) sin\left(\frac{n_y \pi y}{L_y}\right) sin\left(\frac{n_z \pi z}{L_z}\right)}$$

$$E_n = \frac{\pi^2 \hbar^2}{2m}\left(\frac{n_X^2}{L_X^2} + \frac{n_y^2}{L_Y^2} + \frac{n_Z^2}{L_Z^2}\right)$$

Unique properties of quantum dots are used for a wide-ranging number of applications in areas such as catalysis, electronics, photonics, information storage, imaging, medicine, or sensing.

Quantum dots, because they are both photo-active (photoluminescent) and electro-active (electroluminescent) and have unique physical properties, will be at the core of next-generation displays. Compared to organic luminescent materials used in organic light emitting diodes (OLEDs), QD-based materials have purer colors, longer lifetime, lower manufacturing cost, and lower power consumption. Another key advantage is that, because QDs can be deposited on virtually any substrate resulting in printable, flexible and even rollable – quantum dot displays of all sizes.

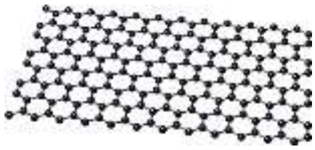
PROPERTIES OF NANOMATERIALS

The main reasons behind the difference in properties of nanomaterials in comparison with their bulk atructre are;
(i) Large fraction of surface atoms,
(ii) Large surface energy,
(iii) Spatial confinement, and
(iv) Reduced imperfections.

Mechanical Properties

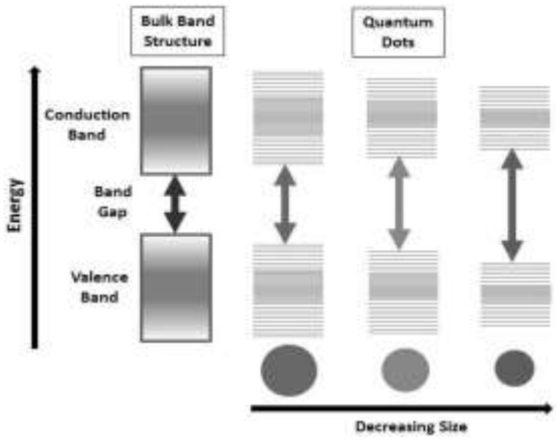
The mechanical properties of nanomaterials increase with decrease in size, because smaller the size, lesser is the probability of finding imperfections such as dislocations and vacancies.

Strength of material improves significantly as the particle size decrease due to perfect defect free surface. Hardness of material also increases as particle size is decreased. Youngs' modulus and fracture toughness of material also increases as particle size is decreased.



For example: Graphene is a single layer of graphite. Its crystalline structure is two-dimensional. Graphene is believed to be the strongest material yet discovered. It is stronger than diamond and is about 300 times stronger than steel.

Electrical Properties



Electrical conductivity changes in both ways; may increase or decrease depending on the material. Electrical conductivity may increase due to better ordering in structure.

When bulk material is reduced in size, continuous energy levels can become discrete and the band gap will increase. This means a conductor may become semiconductor and semiconductor may become insulators.

Optical Properties

1. When bulk material is reduced in size, energy levels become discrete resulting in discrete absorption and emission spectra.

2. Surface plasmon resonance (SPR) is the resonance effect due to the interaction of conduction electrons of metal nanoparticles with incident photons. The value of SPR depends on free electron density and dielectric medium surrounding the nanoparticle. SPR effect occurs in noble metal nanoparticles, which gives rise to sharp and intense absorption band in visible range. Plasmon band red shifts with increasing particle size. The increase of both absorption wavelength (color of nanoparticle) and peak width with increasing particle size. Eg: Spherical shape gold nanoparticle gives red color, flat gold nanoparticles give blue color.

APPLICATIONS

Electrical/Electronics

- Flexible, bendable, foldable, rollable, and stretchable electronics
- Improve efficiency of solar cells.
- Develop compact fuel cells.
- Super capacitors
- Develop compact sensors
- Smaller, faster, and better transistors.
- Ultra-high definition displays and televisions using quantum dots.
- Nanoparticle copper suspensions have been developed as a safer, cheaper, and more reliable alternative to lead-based solder.

General

- Nanoscale additives to or surface treatments of fabrics can provide lightweight can help them resist wrinkling, staining, and bacterial growth.
- Nanoscale titanium dioxide and zinc oxide have been used for years in sunscreen to provide protection from the sun while appearing invisible on the skin.
- Nanoscale additives in polymer composite materials are being used in baseball bats, tennis rackets, bicycles, motorcycle helmets, automobile parts, luggage, and power tool housings, making them lightweight, stiff, durable, and resilient
- Clear nanoscale films on eyeglasses, computer and camera displays, windows, and other surfaces can make them water- and residue-repellent, antireflective, self-cleaning, resistant to ultraviolet or infrared light, antifog, antimicrobial, scratch-resistant, or electrically conductive.

Defense

- Lifetime of material coatings increased from hours to years.
- High Power Microwave devices with reduced weight, shape and power consumption

Medical

- Nanoparticle are used to deliver drug to specific cells such as cancer cells.
- Nanoparticles are used for anti bacterial treatments.
- Nanoparticles are used as fluorescent biological labels.
- Nanoparticles are used for bone tissue engineering.
- Nanoparticles can be used in tumor destruction via heating
- Nanopartices are used to enhance contrast in MRI, probing of DNA in stem cell research, etc.