Fundamentals of nanotechnology

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What is the Plasmons of the surface?

When a metal particle is exposed to light, the oscillating electromagnetic field of the light induces a collective coherent oscillation of the free electrons (conduction band electrons) of the metal. This electron oscillation around the particle surface causes a charge separation with respect to the ionic lattice, forming a dipole oscillation along the direction of the electric field of the light. The amplitude of the oscillation reaches maximum at a specific frequency, called surface plasmon resonance (SPR). The SPR induces a strong absorption of the incident light and thus can be measured using a UV–Vis absorption spectrometer.

The SPR band is much stronger for plasmonc nanoparticles (noble metal, especially Au and Ag) than other metals.
The SPR band intensity and wavelength depends on the factors affecting the electron charge density on the particle surface such as :-

-the metal type,
-particle size,
-shape,
-structure,
-composition and
-the dielectric constant of the surrounding medium.

From this reason, it can be easily understand the different in the colour of gold metal(for example) when the gold particles become in nanoscale.

Magnetic Properties

The magnetic properties of nanoparticles are determined by many factors, including:-

-The chemical composition,

-The type and the degree of defectiveness of the crystal lattice,

-The particle size and shape,

-The morphology,

-The interaction of the particle with the surrounding matrix and the neighbouring particles.

By changing the nanoparticle size, shape, composition and structure, one can control to an extent the magnetic characteristics of the material based on them. However, these factors cannot always be controlled during the synthesis of nanoparticles nearly equal in size and chemical composition; therefore, the properties of nano- materials of the same type can be markedly different.

When the size of the magnet is reduced, the number of the surface atoms becomes an important fraction of the total number of atoms, also the surface area/volume ratio become important, so surface effects becomes important, and quantum effect start to prevail. When the size of these domains reaches to nanoscale, these materials show new properties due to quantum confinement.

Bulk gold and Pt are non-magnetic, but at the nano-size they are magnetic. Surface atoms are not only different to bulk atoms, but they can also be modified by interaction with other chemical species, that is, by capping the nanoparticles. This phenomenon opens the possibility to modify the physical properties of the nanoparticles by capping them with appropriate molecules. Actually, it should be possible that non-ferromagnetic bulk materials exhibit ferromagnetic-like behavior when prepared in nano range. One can obtain magnetic nanoparticles of Pd, Pt and the surprising case of Au (that is diamagnetic in bulk) from non-magnetic bulk materials. In the case of Pd and Pt, the ferromagnetism arises from the structural changes associated with size effects.

The main applications at which nanomaterials can be used depending on its magnetic properties are, Ultrahigh density magnetic storage devices, Magnetic random access memory (MRAM), Ferrofluids, Spintronics, Magnetic semiconductors, Nanogranular magnetic materials, etc.

Electrical properties

The properties like conductivity or resistivity are come under category of electrical properties. These properties are observed to change at nanoscale level like optical properties. The examples of the change in electrical properties in nanomaterials are:

Electrical properties

1. Conductivity of a bulk or large material does not depend upon dimensions like diameter or area of cross section and twist in the conducting wire etc. However it is found that in case of carbon nanotubes conductivity changes with change in area of cross section.
2. It is also observed that conductivity also changes when some shear force (in simple terms twist) is given to nanotube.
3. Conductivity of a multiwalled carbon nanotube is different than that of single nanotube of same dimensions.

Electrical properties

4. The carbon nanotubes can act as conductor or semiconductor in behaviour but we all know that large carbon (graphite) is good conductor of electricity.

In electrically conducting carbon nanotubes, only one electron wave mode is observed which transport the electrical current. As the lengths and orientations of the carbon nanotubes are different, they touch the surface of the mercury at different times,which provides two sets of information:

Electrical properties

(i) the influence of carbon nanotube length on 1.24 Introduction to Nanomaterials the resistance; and
(ii) the resistances of the different nanotubes. As the nanotubes have different lengths, then with increasing protrusion of the fiber bundle an increasing number of carbon nanotubes will touch the surface of the mercury droplet and contribute to the electrical current transport.

Electrical properties

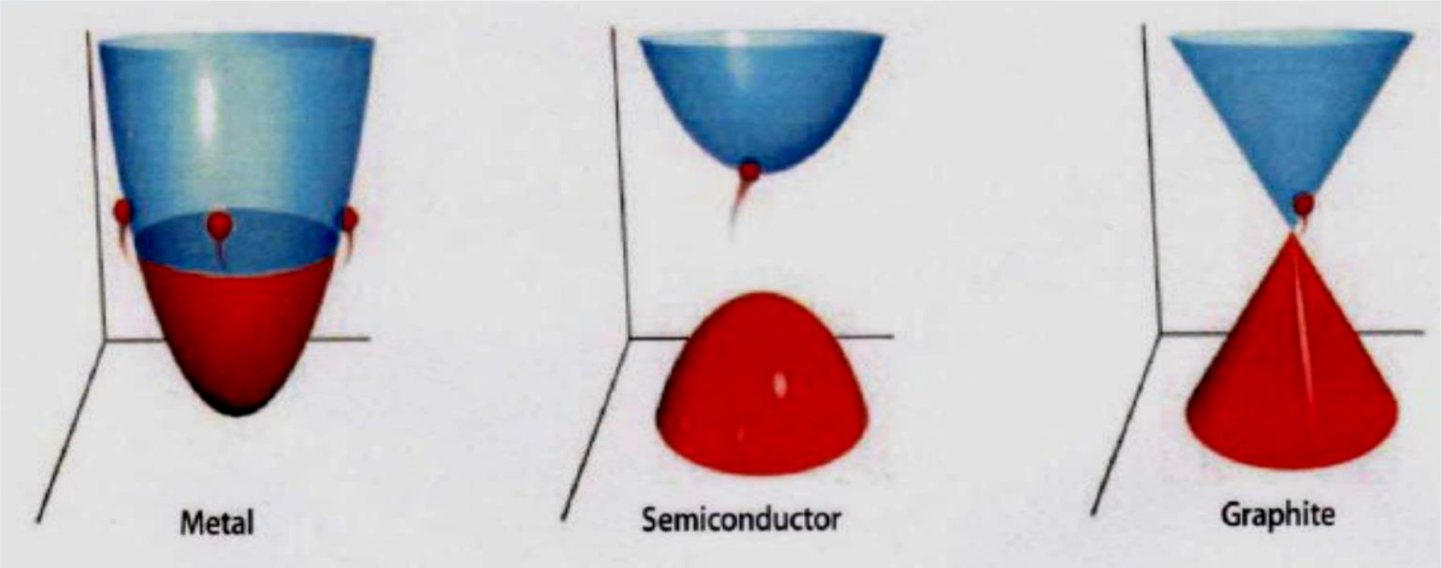

Figure 1 Electrical behavior of naotubes.

Electrical properties

There are three categories of materials based on their electrical properties:
(a) conductors;
(b) semiconductors; and
(c) insulators.

The energy separation between the valence band and the conduction band is called Eg (band gap).

The ability to fill the conduction band with electrons and the energy of the band gap determine whether a material is a conductor, a semiconductor or an insulator. In conducting materials like metals, the valence band and the conducting band overlap, so the value of Eg is small:

thermal energy is enough to stimulate electrons to move to the conduction band. In semiconductors, the band gap is a few electron volts. If an applied voltage exceeds the band gap energy, electrons jump from the valence band to the conduction band, thereby forming **electron-hole pairs** called **excitons**. Insulators have large bandgaps that require an enormous amount of voltage to overcome the threshold. This is why these materials do not conduct electricity (**Figure 2**).

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Electrical properties

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Figure 2: Schematic illustration of the valence and conduction bands in materials based on their electrical properties: insulator, semiconductor and conductor

Quantum confinement and its effect on material electrical properties

Quantum confinement causes the energy of the band gap to increase as illustrated in **Figure 3**. Furthermore, at very small dimensions when the energy levels are quantified, the band overlap present in metals disappears and is actually transformed into a band gap. **This explains why some metals become semiconductors as their size is decreased**.

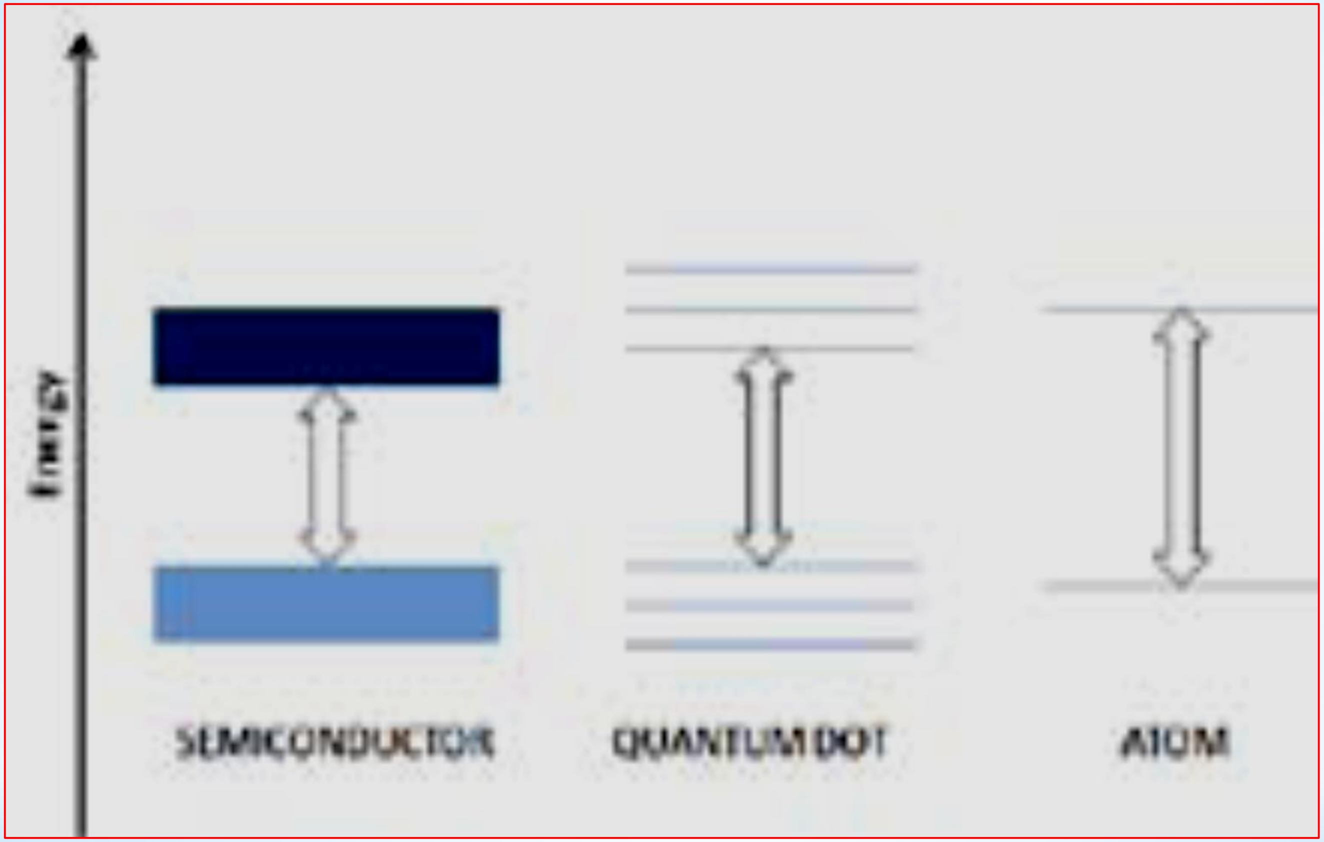

Figure 3: The image compares the energy of the band gap (arrow) in a bulk semiconductor, a quantum dot and an atom. As more energy states are lost due to the shrinking size, the energy band gap increases.

The increase in band gap energy due to quantum confinement means that more energy will be needed in order to be absorbed by the band gap of the material. Higher energy means shorter wavelength (blue shift). The same applies to the wavelength of the fluorescent light emitted from the nano-sized material, which will be higher, so the same blue shift will occur.

Thus, a **method of tuning the optical absorption and emission properties of a nano-sized semiconductor** over a range of wavelengths **by controlling its crystallite size** is provided. The optical properties of nano-sized metals and semiconductors (quantum dots) are described in the section of this chapter on optical properties.