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Nanomaterials and Nanotechnology

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In this article, the concept of nanoparticles and nanomaterials has been introduced. An attempt has been made to review the different types of nanomaterials (fullerenes, quantum dots and nanotubes) along with their applications in different fields.

Key Words: Nanotechnology, Materials science.

INTRODUCTION

Over the past few decades' scientists were busy in the miniaturization of the electronic instruments. In this effort they found nanomaterials. *Nano* is a Greek word meaning dwarf or extremely small: one nanometer = 10^{-9} m. Nanomaterials are solids with very small size, in the range of 1-100 nm and the technology involved in producing these materials and then making different nanomachines from them is called nanotechnology.

Nanoparticles

Nanoparticles are considered to be a cluster of atoms (molecules) bonded together within a diameter of 100 nm and are denoted as A_n where A is the symbol of the element and n is the number of atoms (molecules) in it, e.g., Al_{12} denotes a nanoparticle of Al metal with 12 atoms in it. In a crystal there are, in 1nm, 3-5 atoms lined up in a row. So a cube of a crystal with 1 nm edge contains 25-125 atoms while a spherical nanoparticle with 1 nm diameter contains 12-65 atoms. Nanoparticles may be both magnetic and non-magnetic in nature. The most interesting aspect is that a nanoparticle of a paramagnetic material may exhibit finite and large magnetic moment. For example, Rh is a paramagnetic metal but it has been found that a nanoparticle Rh_n shows significant increase in net magnetic moment for $n < 20$. It shows that one can prepare magnetic nanoparticles from non-magnetic materials, which is a very important finding.

Nanomaterials

Three types of nanomaterials have been fabricated and are being used: Quantum wells (QWs), quantum wires (QWs) and quantum dots (QDs). QWs are used in tunneling experiments; QWs and QDs are used in fabricating electronic devices etc. We have been able to have a precise control over shape and size of a QD, which will allow us to have a control over the number of electrons in it. QDs are also called artificial atoms due to the similarity of its electron states with an atom.

Structure of nanoparticles

A parameter P_S is defined which gives the ratio of surface S to volume V of a solid, *i.e.*,

$$P_S = S/V$$

For infinite dimensional solids, $P_S = 0$. As the size of the material becomes finite P_S becomes finite therefore, surface effects become significant. For large nanoparticles structure is the same as that of the bulk material but with some different lattice parameter, *e.g.*, Al nanoparticle with 80 nm size possesses fcc structure (X-ray diffraction). In very small nanoparticles, P_S approaches 1 and most of the atoms lie on their surface. So the surface energy is very large and these would prefer to assume spherical shape. The experimental determination of small clusters is difficult. But in the theoretical determination of the structure of a nanoparticle one can use either the density functional approach or the computer simulation methods. In Al_{13} there are three possible arrangements of atoms (Fig.1). The density functional theory has predicted icosahedral structure for Al_{13}. There are a number of methods to synthesize nanoparticles: Some of them are Laser Beam Methods, Pulsed Laser Beam Method, Chemical Methods, Self-assembly Methods like Molecular Beam Epitaxy technique, etc.

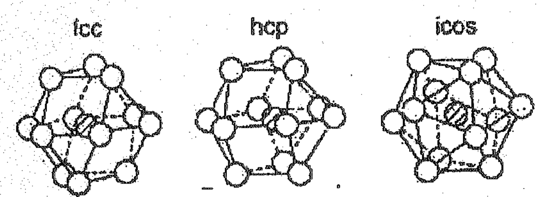

Fig. 1 : Three possible structures of Al_{13}

Bulk nanostructured materials

Solid having a nanoparticle as their basic unit of structure (in place of atoms or molecules) are called nanostructured materials (NSMs). These are of two types.

1. **Crystalline nanostructured materials:** In these solids nanoparticles form a periodic three-dimensional array and hence exhibit some symmetry. At present, we are not able to fabricate crystalline NSMs, which is the main problem in Nanotechonogy. The following difficulties were experienced :

i. Synthesis of nanoparticles of a particular size.
ii. Technique to place nanoparticles on a periodic lattice.

Once these difficulties are overcomed, we shall be able to fabricate a number of crystalline NSMs from a single element, which may possess entirely different properties from the parent element. So there is immense scope of the subject. Scientists believe to have a break through by 2020.

2. Amorphous nanostructured materials: These solids the nanoparticles are randomly oriented and exhibit no symmetry. They are being manufactured using different methods.

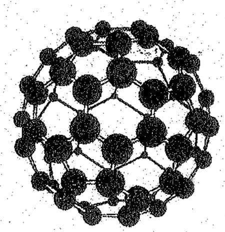

Fig. 2 : Structure of C_{60} molecule

Carbon nanoparticles

Carbon is one of the most abundant element on the earth and exists in a number of different solid forms: diamond, graphite, coal and soot. In 1985, Kroto and coworkers produced clusters of carbon atoms in the laboratory namely C_{60} and C_{70} molecules called Buckyballs or fullerenes. NMR experiments have established that C_{60} molecules possess a truncated icosahedral structure, which is like a cage (spherical shape) (Fig. 2). C_{60} molecule is very hard, harder than diamond. C_{70} molecule is obtained from C_{60} molecule by adding 10 carbon atoms around the equatorial plane of C_{60} molecule. The shape of C_{70} molecule is not spherical but like a rugby ball. C_{60} and C_{70} molecules can be produced by passing an arc between two graphite rods at high pressures. Alkali doped C_{60} solid exhibits metallic character with high T_c values ($\approx 33^\circ$K).

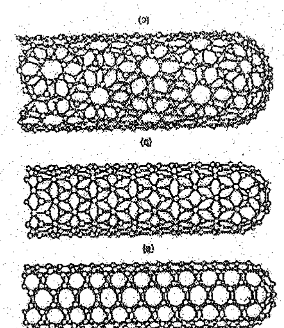

Fig. 3 : Structure of carbon nanotubes (a) Arm chair, (b) Zigzag (c) Chiral

Carbon nanotubes

Carbon nanotubes form another interesting class of carbon nanomaterials. These can be imagined as rolled sheets of graphite (about different axes) with closed ends of the tube. There are three types of nanotubes: armchair structure, chiral structure and zigzag structure. The different types of structures of nanotubes are shown in Fig. 3. Further nanotubes can be categorized as single-walled and multi-walled nanotubes and it is very difficult to produce the former.

Applications

Nanomatetials and nanotechnology hold the promise of exciting applications in basic sciences, biosciences, medicine, environment, electronics and a host of other related fields.

Quantum dots: can be used to produce tiny lasers and can be used in pharmaceuticals and biosciences. These can be used to verify quantum laws in a laboratory.

Nanotubes: Carbon nanotubes have higher strength and are thermally stable. These behave like wave-guides. These can be used in fuel cells and as sensitive sensors. Metallic nanotubes can be used in electronic circuits. Nanoscale transistors can be made from carbon nanotubes ($1/500^{th}$ of conventional transistor). This discovery will revolutionize the electronics industry and will be the ultimate reduction in electronic components.

Nanocomposites of polymers are very strong, hard and thermally very stable. These are being used in car industry for many other purposes.

Health hazard

Recent study has shown that Buckyballs become toxic, when something is put inside it. Nanoparticles are so small in size that these can directly penetrate our skin and can cause threat to the life of all the living animals and the human beings. Therefore, there is a need explore about the toxicity of the nanoparticles of various elements and materials.

Nanoscience is still in its infancy and nanotechnology is presently more of a concept than reality. Recently, very simple machines have been reported in literature[4]. But, the concept of nanotechnology has great potential in future.

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