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4. Nanomaterials: Introduction and their Properties

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Abstract:

Nanomaterials are natural products and may be generated through by-products of combustion reactions, or may be produced during engineering assignments for specific purposes. The chemical and physical properties of these nanomaterials are different to their counterparts of bulk mater. Nanomaterials sometimes may be produced by chance in the form of by-product of mechanical and industrial activities such as vehicle engine exhausts, smelting, welding fumes, combustion proceedings from domestic solid fuel heating and cooking. This chapter gives brief introducing from general information about nanomaterials, nanotechnology and later narrowing down to the concrete aspects of topic by placing emphasis on properties. This also deduces a short introduction of significance of nanomaterials properties in context of optical, thermal and sensing applications. Brief understanding of structure and properties of nanomaterials are also discussed. Nanotechnology includes controlling the size of materials at very small size that may be of 100 nanometers or lesser and also involves the manufacturing of instruments or materials in nanometer range. Nanotechnology is used globally in every field of engineering and science. Functionalized nanomaterials can promote the openings for engineering of structures to achieve modified properties.

Keywords:

Nanomaterials, properties, size, structure and applications.

4.1 Introduction:

Nobel laureate - Richard Smalley remarked as that future world would be magnificent due to the discovery of small atomic level things which will transform the human living style [1]. Nanoscience and technology will develop the new man made materials with changing their nature in coming years [2]. Physicist Richard P. Feynman suggested first time about 'nanotechnology' and advised that manufactured amenities and things would be with molecule features in coming era [3]. Feynman deduced an approach, such that a group with accurate apparatus can fabricate other small scale groups. In 1980s, Dr. K. Eric Drexler deeply elaborated the fundamental ideas, importance of nanotechnology and Nano devices through their speeches and books [4, 5].

It is well expressed about nanometer that this length scale is an amazing point where smaller fabricated device meets the natural atoms and molecules [6]. The size of nanomaterials remains bigger comparatively single atoms while lesser from bulk solids. As a comparison, other typical sizes of everyday objects and organisms [7] are shown in Figure 1.1.

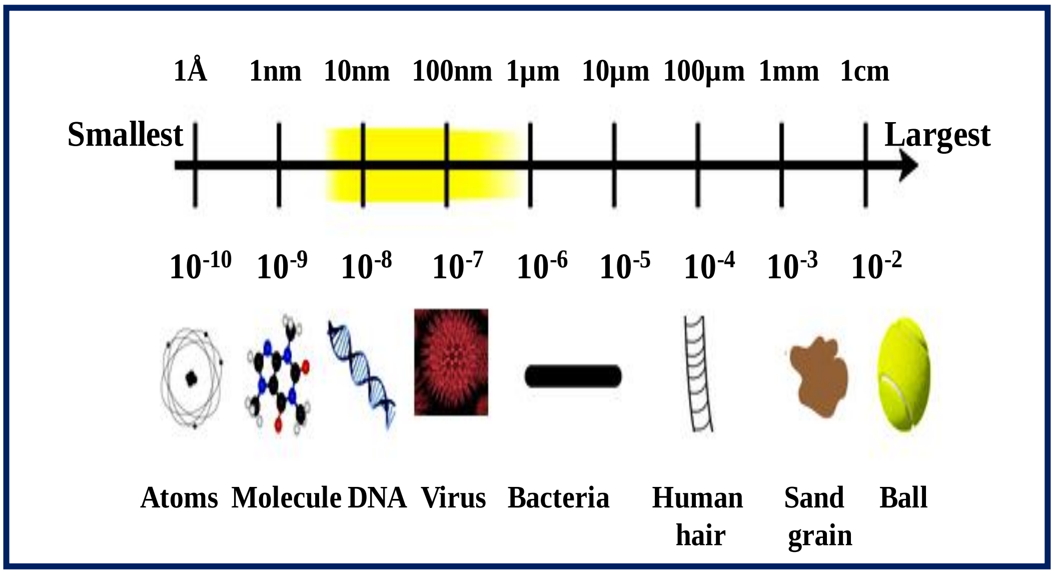

Figure 4.1: Size Regimes for Different Materials in Context To Nanometer

When size of materials decreases the physical, mechanical, chemical, thermal, optical and electronic features significantly changes. This is due to increasing dominance of atoms on the surface over that of those in the interior of the particle leading to alteration in their properties.

These properties of nanomaterials have evoked tremendous interest in the area of nanotechnology [8]. One nanometer is 10^{-9} m on the length scale and denotes about single molecule size [9]. The hair size (in wide) of human-being may be 60,000-80,000 nm so we guess that one nanometer is very small size.

4.2 Classification of Nanomaterials:

Nanomaterials are defined as particles (rods, crystals or spheres) having size in 1 and 100 nm range, at least in one dimension. Nanomaterials can be categorized based on its geometrical form and dimensionality of constituent elements [10], are shown in Figure 1.2.

- 0-D nanomaterials are in nanoscale ranges like nanoparticles.
- 1-D nanomaterials are above nanoscale ranges materials including nano-wires and nano-rods.
- 2-D nanomaterials are also above nanoscale ranges materials such as nano-sheets and nano-films.
- 3-D nanomaterials are not limited in the nanoscale includes bulk nanostructure materials or layers.

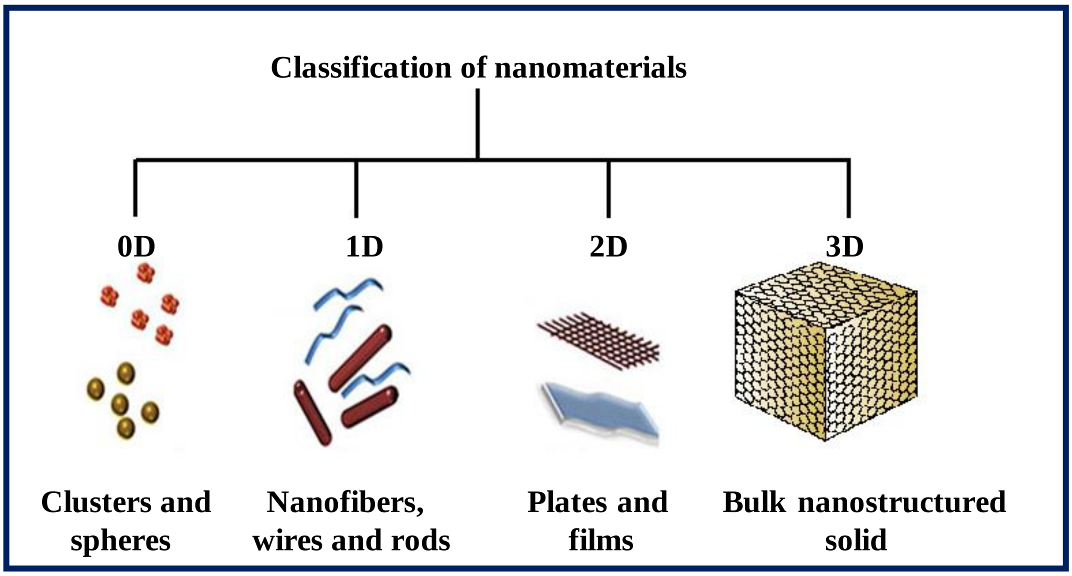

Figure 4.2: Different Forms of Nanomaterials on Dimension Basis

4.3 Categories of Nanomaterials:

Nanomaterials are further divided into four categories:

4.3.1 Carbon Structured Nanomaterials:

This type of nanomaterials is composition of carbon containing hollow spheres, cylindrical, ellipsoids or tubes configuration. Cylindrical carbon structures are known as nanotubes and ellipsoidal and spherical configured materials are referred to the fullerenes. Carbon based nanomaterials are stronger and lighter materials with beneficial uses in electronics area, improved films and coatings [11].

4.3.2 Metallic Nanomaterials:

Nano metals, oxides and quantum dots are included in these nanomaterials. Quantum dot crystal is formed of many atoms within the size of nanometer range. The size variation of quantum dots effects on the optical characteristic [12].

4.3.3 Dendrimers:

Nano sized polymers are the dendrimers which are made of bifurcate components. Dendrimer has number of chain-endings on their surfaces which are responsible for performing as particular role. Dendrimers possesses inner hollow chambers so that outer components may be settled in it. Thus, catalysis reaction is also completed with the help of these properties [13].

4.3.4 Nanocomposites:

Nanocomposites are combination of one, two or more components which contain superior features of every component individually. The nanocomposites may applied for investigation of physical, optical, electrical, thermal, barrier and flame retardant properties [14].

4.4 Approaches for Fabrication of Nanomaterials:

Nanomaterials are synthesized from two main approaches: top-down and bottom-up approach, expressed in Figure 1.3 [15]. In top-down approach, bulk molecule breaks down into its smaller parts by mechanical procedures. Bottom-up approach is subjecting molecule of precursor to various chemical routes and form different nanomaterials. Contamination and size control is the drawback of a top-down approach. Bottom-up approach minimizes some of these limitations.

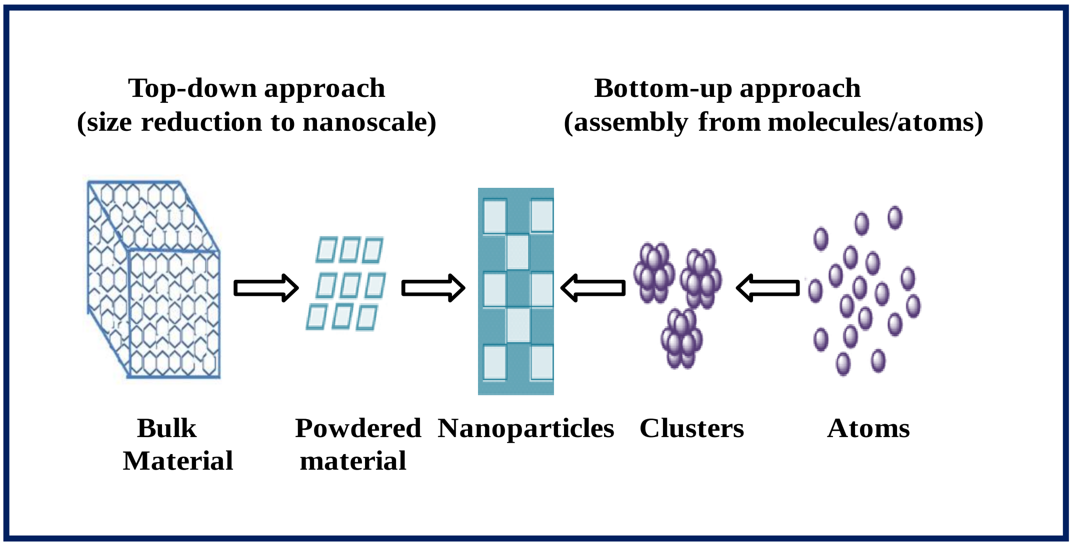

Figure 4.3: Approaches for Synthesis of Nanostructures

Bottom-up approach produces nanostructures with few defects, chemical composition with strong homogeneous and higher long and short ranges in order. While top-down approach involves internal stress with surface defects and contaminations. Nanostructures have been synthesized through various technologies and methods. The said approaches can be categorized in various groups.

They are synthesized weather from vapour, liquid or solid phase such that (i) vapour phase growth, involve laser reaction pyrolysis for synthesis of nanoparticle and atomic layer deposition (ALD), (ii) liquid phase growth, incorporate colloidal procedure for the preparation of nanoparticles and self-assembled monolayers, (iii) solid phase growth, include phase segregation to form nanoparticles in glass matrix and (iv) hybrid growth, contain vapour-liquid-solid (VLS) nanowires growth.

4.5 Shapes of Nanomaterials:

Metal particles are particularly interesting nanoscale system because of the ease with which they can be synthesized and modified chemically [16]. Nano sized metallic particles are unique and can considerably change physical, chemical, and biological properties due to their surface-to-volume ratio; therefore, these nanoparticles have been exploited for various purposes. These properties significantly depend on the size, shape and surface chemistry of the nanomaterials. Preparation and characterization of novel nanostructures (cubes, disks, plates, prisms, triangles, wires, rods and macroporous) of noble metals have come a long way of various investigations in the laboratories [17–21]. In recent years, new methods have been developed to synthesize non-spherical nanoparticles (Figure 1.4) like oval, cubic, rod, pyramid, etc. [22, 23].

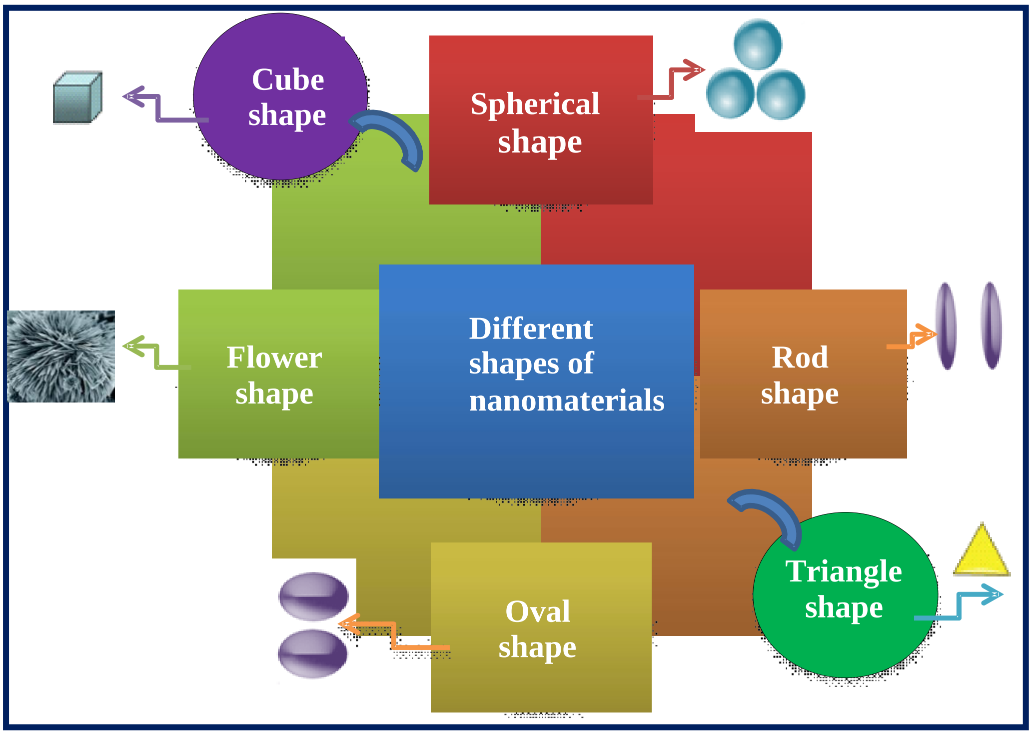

Figure 4.4: Representation About Different Shapes of Nanomaterials

4.6 Applications of Nanotechnology:

Unrivalled options are developing for re-engineered existing materials within 100 nm ranges like nanodots, crystalline materials, fibers (nanorods, nanotubes) and films which provide a better choice to fabricate further new nanodevices and materials [24]. Nanotechnology assigns various applications in optical, communication, electronics, biological systems and novel materials [25]. The applications of nanoparticles are depended on various factors like physical properties of material, size and surface area. Figure 1.5 shows an overview of various applications of nanotechnology.

As the sizes of the materials exist in nanoscale range, the surface atoms increase strongly along with increase in surface volume (S/V) ratio so that the material behaves like more chemically reactive. The performance of nanomaterials with quantum confinement, surface plasmon resonance (SPR) and super paramagnetism properties will improve day by day. So that, low cost and featured nanopowders, nanoparticles, and nanocomposites would be developed having broad applications.

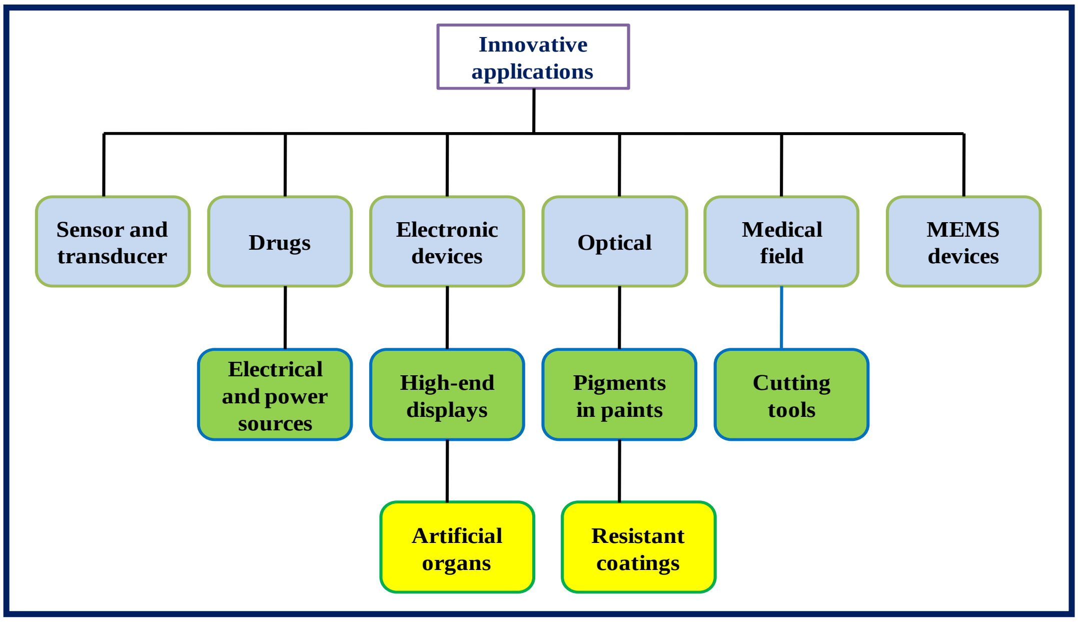

Figure 4.5: Applications of Nanotechnology in Various Areas

These nanomaterials will also apply in chemical and energy conversion procedures as highly selective and efficient catalysts. The nanomaterials functionalized catalysis may provide an importance in photo-conversion devices, bioconversion (energy), bio-processing (food and agriculture), fuel cell devices, waste and pollution control systems.

4.7 Some Properties of Nanomaterials:

Nanomaterials have been widely used due to the numerous applications for human being. The nanomaterials are within 100 nm ranges and possess 20 - 15,000 molecules. These nanoparticles contain different specific physical, chemical and biological valuable characteristic than own bulk substance.

4.7.1 Optical Properties:

The nanomaterials bands deduce a collective oscillation of conduction band electrons. The electrons match the sizes of silver nanoparticles are too smaller than the wavelength of incident light. Such, the constant electric field of incident light and the electrons generates an electromagnetic field which behaves as a surface plasmon resonance (SPR) [26]. The absorption/scattering effects may be modified with adjusting the parameters like size, shape and refractive index for nanoparticles. As such, small nanoparticle absorbs light having peak about 400-420 nm, whereas bigger sized nanoparticle has enhanced scattering with broad band and shifts towards higher wavelength. Moreover, the changes in optical characteristics also possible by delocalization of particles aggregation and the conduction electrons [27]. These small sized silver nanoparticles can easily observe using conventional microscope due to its high scattering cross section. When silver nanoparticles irradiated from white source, produce bright blue color which is due to the SPR [28].

4.7.2 Thermal Properties:

Thermal behaviour is one of the significant properties of metal nanostructures. The thermal properties of nanomaterials are commonly determined by Thermogravimetric analysis (TGA) technique and theoretically it can be derived by Gibbs–Thomson. Thermal properties depend upon the size of nanoparticles due to the large S/V ratio while it is ignorable in case of bulk material. Previous studies stated that the melting point is found at low temperature for small sized nanoparticles [29]. The lower thermal conductivity value of nanoparticles suggests the existence of a stabilizer agent which capped the nanoparticles properly and prevents from further growth [30].

4.7.3 Electrical Properties:

Some nanomaterials with their unique electrical properties can be utilized in electronic devices. The electrical conductance of nanoparticles varying in size from 4 to 12 nm that were grown in glass-ceramic was examined [31]. The study found that the presence of these type of nanoparticles in ECAs decreased the resistivity. The above findings prove that nanomaterials have the potential to be exploited in electrical devices. The zeta potential (ζ) defines the electrical potential in colloidal dispersions to indicate the potential stability of nanoparticles [32]. A large negative or positive zeta potential of nanoparticles suggest that they tend to repel each other and there is no tendency to flocculate or vice versa.

4.7.4 Sensing Properties:

Nanomaterials show good sensing activity. Every sensing system has its merits and demerits and possesses an important role in the applicable area. For detection of volatile organic vapors, the performance of gas sensing depends on the S/V ratio of the materials. Nanomaterials have better sensing capacity than bulk or thin film sensors. A gas sensor can gather information about composition and concentration of any gas throughout the environment [33].

In the context of toxic gases, their concentrations may serve as biomarkers of disease in skin, blood, breathe and faces. To detect these gases for prevention form health problems, gas sensor has been developed. The sensing and determination of toxic gases are very important issue with great effect on the atmosphere, industries and medical area [34]. Gas detection in dense concentrations is easy to sensing due to its sharp odour. The quantification determination of some gas concentration is not possible by the human nose. Furthermore, it is possible to detect these type of gases at low concentration (<ppb in air) by sensing.

4.8 Summary:

In brief, this chapter has delivered the development in the recent years in synthesis approaches, properties, improvement with modifications and applications of nanomaterials. The complications came across by these materials in terms of crystal phases and nonstoichiometric compositions are cultivated. This chapter provides synthesis approaches and important characteristics of nanomaterials. The applications of nanomaterials in optical, electrical, sensing and thermal areas are discussed.

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