Engineering properties and applications of Nanomaterials- A Review

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Abstract: Nanomaterials, with dimensions on the nanometer scale, exhibit unique and tunable properties that have revolutionized various engineering applications. This abstract provides an overview of the engineering properties and applications of nanomaterials and their significance in diverse fields. The engineering properties of nanomaterials, shaped by their nanoscale dimensions, open avenues for innovation across various disciplines. The diverse applications discussed underscore the transformative impact of nanomaterials on technology, promising a future where their unique properties are harnessed for the benefit of society.

Keywords: Nanomaterials, Metals, Quantum dots, Bucky balls/nanotubes, Carbon Based Materials, Fullerenes Carbon Nanotubes

I. INTRODUCTION

Material science is a branch of science, which makes it possible to study the behavior of all types of materials in a well-defined and systematic manner, right from the structure of matter. It correlates the properties of matter with its structure. Material is synonymous with substance, and is anything made of matter. The progress of civilization right from "Stone –Age" to "Present Era" changed the physical meaning of a material. For Stone Age humans, different types of stones were the materials subject of interest, while it changed to metals (Copper and Iron) in the Metal Age and today is the "Age of Plastics". However, now the field has further broadened to include every class of materials, including ceramics, polymers, semiconductors, magnetic materials, composites, glasses, medical implant materials, biological materials and nanomaterials (materiomics).

Materials play key role in the technologies that provide protection, communication, information, construction, mechanization, agriculture, and health. Materials exhibit different types of properties both at microscopic and macroscopic levels, depending on their nature, source, size, and shape. Therefore, Materials science is the study of the structural and functional properties of materials. Since the numerous properties of materials cannot be explained within the context of any single discipline. Materials science is a multi-disciplinary subject that is embodied with the concepts of solid-state physics, metallurgy, ceramics, and chemistry. With a basic understanding of the origins of properties, materials can be selected or designed for an enormous variety of applications, from structural steels to computer microchips. Materials science is therefore important to many engineering fields, including electronics, aerospace, telecommunications, and information processing, nuclear power, and energy conversion.

Over a period of several years, the field of "material science" has undergone a lot of changes because of remarkable improvements in technologies. Materials are manipulated from bulk to nano materials. The idea of nanotechnology appeared for the first time about more than six decades ago. Richard Feynman (Well known Physicist and Nobel Laureate in Physics, 1965) in his famous talk state that "*There's Plenty of Room at the Bottom*", at the American Physical Society meeting at Caltech on December 29, 1959. In his talk, he has expressed his views that it is possible to manipulate a process and arrange the atoms the way we want according to the principles of Physics. In later years, this classical talk has become an Invitation to Enter a New Field of Physics. It has become stimulus to think about nanotechnology. The term ***nano*** originated from the Greek word "nanos" which means 'dwarf' or extremely small. It is one billionth of a meter. Therefore, *nanoscience or nanotechnology* is a branch of science and technology that deals with materials having at least one spatial dimension in the size range of 1 to 100 nanometers (nm). Their defining characteristic is a very small feature size in the range of 1-100. One nanometer spans 3-5 atoms lined up in a row. It is of interest to note that diameter of a human hair is about five (5) orders of magnitude larger than a nanoscale particle. Nanomaterials can be metals, ceramics, polymeric materials, or composite materials. Now scientists are talking about the activity of atoms or molecules of chemical compounds instead of their equivalents or molarities. Nanomaterials are not simply another step in miniaturization, but a different arena entirely. At this size, they are still metallic, but smaller ones turn into insulators. Their equilibrium structure changes to icosahedral symmetry, or planar, or hollow depending on the size. Emil Roduner, in his tutorial-review clearly demonstrated how size matters and nanomaterials are different from materials [1]. It has also provided excellent bibliography on this subject. The difference in the behavior of materials from normal to nano has been attributed to a change in the bonding pattern

Property	Gold (Au)	Gold Nano
Color	Yellow	Red
Electrical Conductivity	Conductive	Loses conductivity at 1-3 nm
Magnetism	Non-magnetic	Becomes magnetic at 3 nm
Chemical Reactivity	Chemically inert	Explosive and catalytic

Nanoparticle Classifications

Nanoparticles fall into three major types Viz., Naturally occurring, Incidental and Engineered

Naturally Occurring Nanoparticles: Certain man-made activities and natural phenomenons are known to generate nano particles spontaneously that include Sea spray, Mineral composites, volcanic ash, Viruses.

Incidental Nanoparticles: Cooking smoke, Diesel exhaust, Welding fumes, Industrial effluents, and Sandblasting are the few sources of forming "Incidental nanoparticles"

Engineered Nanoparticles: Engineered nanoparticles are the manufactured particles, depending on the needs with nanoscale dimensions. Examples include Metals, Quantum dots, Bucky balls/nanotubes, Sunscreen pigments, and Nanocapsules. Most of the current nanomaterials could be organized into: Carbon Based Materials (Fullerenes and Carbon Nanotubes), Metal Based Materials (Semiconductors and Quantum dots), Dendrimers, and Composites.

04Synthetic strategies of nano materials

There are two approaches for synthesis of nano materials and the fabrication of nano structures viz., "Top down". and "Bottom up" Top down approach refers to slicing or successive cutting of a bulk material to get nano-sized particle. Bottom up approach refers to the buildup of a material from the bottom: atom-by-atom, molecule -by- molecule or cluster -by- cluster. Both approaches play very important role in modern industry and most likely in nano technology as well. There are advantages and disadvantages in both approaches.

Attrition or Milling is a typical top down method in making nano particles, where as the colloidal dispersion is a good example of bottom up approach in the synthesis of nano particles.

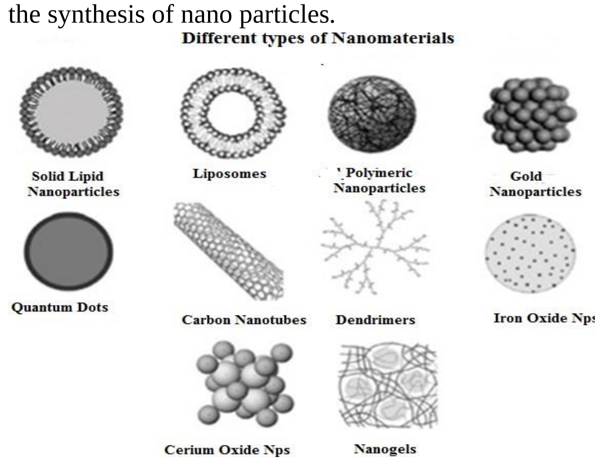

Figure.1.02. Different types of nanomaterials

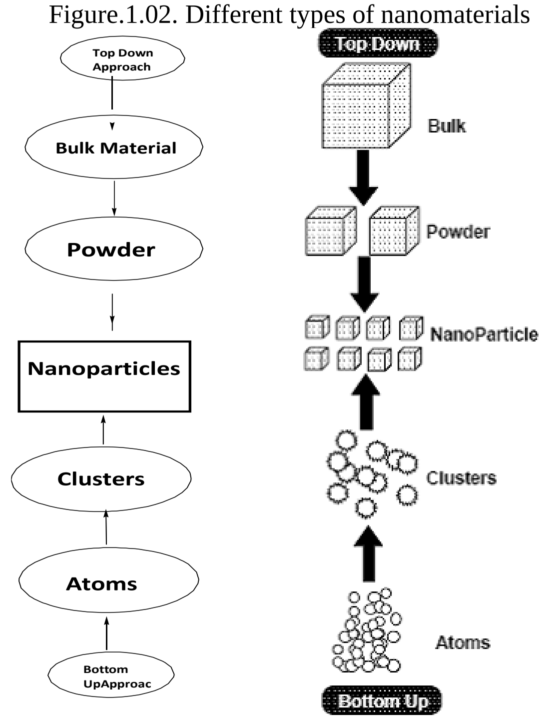

Figure.1.03.Schematic representation of the building up of Nanostructures

The top-down method by which an external force is applied to a solid that leads to its break-up into smaller particles. The method includes the following techniques.

1. High-energy ball milling: Nanoscale powders are produced by milling bulk materials [13].
2. Arc discharge: Alternating current (AC) or direct current (DC) arcs are used to evaporate materials [14].
3. Wire explosion: Used to produce conducting nanomaterials such as metals. A sudden high current pulse is supplied resulting in explosion [15].
4. Laser ablation: High-energy laser to induce evaporation [16].
5. Inert-gas condensation: particle growth is achieved by condensing evaporated atoms in matrix [17].
6. Ion sputtering: Impact using high energy ions (usually rare gases) cause evaporation [18].

Bottom-up approach refers to the buildup of a material from the bottom: atom-by-atom, molecule-by-molecule, or cluster-by-cluster. Several methods are under this category:

05Applications of nanomaterials

One of the stimulating features of nanotechnology is its potential use in almost any field. The discovery of nanoparticles with varied size, shape and composition has stretched the limits of technology in ways that scientists would never have dreamt of a century ago. Nature makes and chemistry re-shapes; huge varieties of nanoparticles have emerged in our daily life, in every field from drugs and electronics to paints and beauty care, and they are now emerging in the field of catalysis.

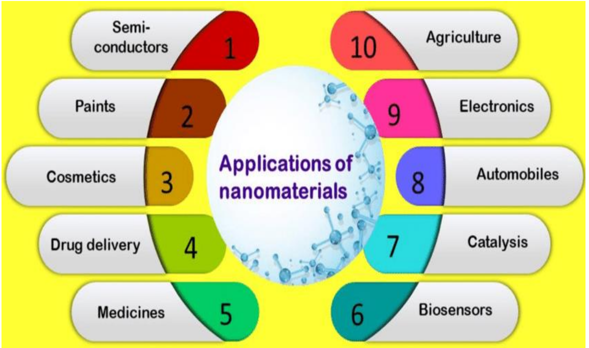

Figure.1.04. Applications of nanomaterials

Nanomaterial Catalysis:

Ertl has classified various aspects of the dynamics of surface reactions and catalysis into five categories in terms of time and length scales.

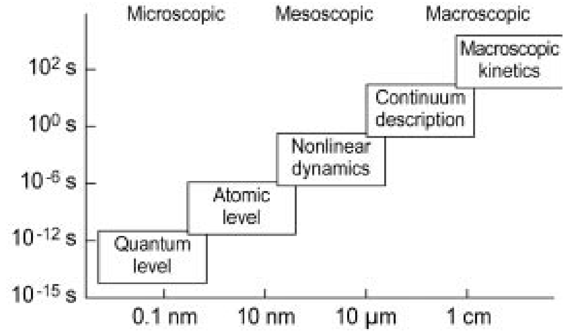

Figure.1.06. Classification based on time and length scales

Nanomaterial catalysis has emerged as a field at the interface between homogeneous and heterogeneous catalysis and offers unique solutions to the demanding requirements for catalyst improvement. Heterogeneous catalysis represents one of the oldest commercial applications of nanoscience and nanoparticles of metals, semiconductors, oxides, and other compounds have been widely used for important chemical reactions. The nanocatalysts display the benefits of both homogenous and heterogeneous catalysts, such as high efficiency and selectivity, stability and easy recovery/recycling. Nanomaterial-based catalysts usually break up into metal nanoparticles in order to speed up the catalytic process. Metal nanoparticles have a higher surface area which facilitates more catalytic reactions to take place at the same time. This action shows the increased catalytic activity of nanoparticles over bulk materials. Nanocatalysts can also be easily separated and recycled with more retention of catalytic activity than their bulk counterparts. These catalysts can play two different roles in catalytic processes: they can be the site of catalysis or they can act as a support for catalytic processes. They are typically used under mild conditions to prevent decomposition of the nanoparticles at extreme conditions.

Functionalized nanoparticles

Functionalized metal nanoparticles are more stable in solution compared to non- functionalized metal nanoparticles[33]. In liquid solutions, the metal nanoparticles are close enough together to be affected by van der Waals force. If there isn't anything to oppose these forces, then the nanoparticles will aggregate, which will lead to a decrease in catalytic activity by lowering the surface area.[33] For organometallic functionalized nanoparticles, ligands are coordinated to the metal center to prevent aggregation. Using different ligands alters the properties and sizes of the nanoparticle catalysts. Nanoparticles can also be functionalized with polymers or oligomers to sterically stabilize the nanoparticles by providing a protective layer that prevents the nanoparticles from interacting with each other. Alloys of two metals, called bimetallic nanoparticles, are used to create synergistic effects on catalysis between the two metals.[34]

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