Introduction to Nanotechnology

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Abstract

Nanoscience and Nanotechnology are very vast and very old sciences that people know from the very beginning. Life started with the big bang, where all atomic and molecular phenomena happened, which falls under nanoscience. It is right to say nanoscience as the science of God. Knowingly or unknowingly, we come across many events in our daily life that are influenced by nano science and technology. Our "Rishis" used "Bhasma" for medication, which is a classic example of nanotechnology. 0D, 1D, 2D, and 3D nanoparticles are described and explained in detail. In this chapter, structural, optical, chemical, electronic, mechanical, thermal, and magnetic properties of nanoparticles in general are also discussed.

Key words

Nanoscience · Nanotechnology · Atomic · Size

1.1 Introduction

The term nanotechnology is made up of two words; in which, Greek word "nano" means billionth and the second word is technology. Nanotechnology considers the objects that are of the size below 100 nm. As an outcome, nanotechnology or nanoscale technology (Ghazi et al. 2018; Wang et al. 2017; Ghaffari et al. 2012; Gleiter 2009; Bhushan 2016; Nouailhat 2010) is generally considered to be at a size below 100 nm (a nanometer is one billionth of a meter, 10^{-9} m). Nanotechnology, in

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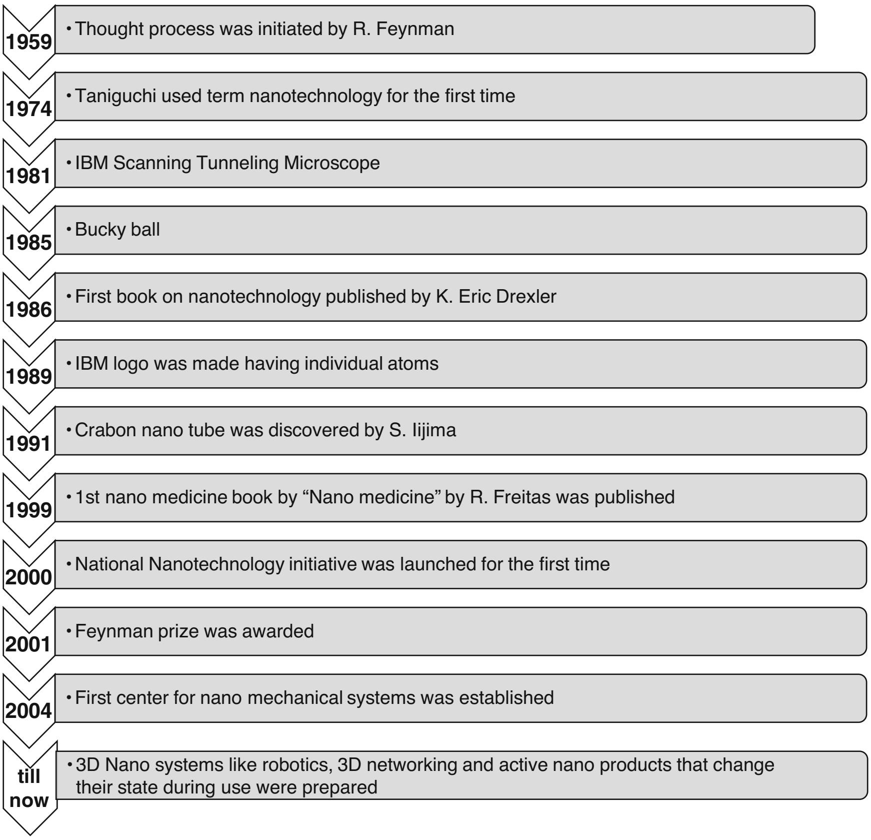
short, is called as "nanotech," and it is defined as the study of controlling matter on an atomic and molecular scale. In general, nanotechnology is the name of the science which deals with structures of the size 100 nm or smaller in at least one dimension, and also it involves developing materials or devices within that size (Baer et al. 2003; Whitesides 2005). The range of nanotechnology is very wide, from the smallest particles which cannot be seen by the naked eye to the food we eat and clothes we wear. The definition of nanotechnology can be stated as:

- The development in the field of research and technology at various levels such as atomic, molecular, or macromolecular levels, having a length scale of approximately 1–100 nm.
- Creation and use of devices and structures with novel properties due to small size.
- Controlling or manipulating matter at atomic scale.

Nanotechnology is becoming very popular with time. Firstly, Michael Faraday in 1857 mentioned during a lecture on the optical properties of gold noticeable that "a mere variation in size of the particles gave rise to a variety of resultant colors." The invention of atomic force microscopy (AFM) in 1986 and first electron transistor in 1987 and then creation of carbon nanotube in 1991 depict the growth in the field of nanotechnology. Here some of the historical contents of nanotechnology development are listed in the flowchart below.



Nanoparticles in the range 1–100 nanometer are the fundamental components of nanotechnology and made up of metal, carbon, organic matter, or metal oxides. The physical, chemical, and biological properties of nanoparticles are unique at nanoscale in comparison with their respective bulk counterparts. This is due to larger surface area to the volume ratio, high reactivity or chemical stability, increased mechanical strength, etc. (Sui et al. 1996). Due to these properties, nanoparticles are used in many applications. The nanoparticles are different in terms of dimensions, shapes, and sizes. The classification of nanoparticles on the basis of dimensions can be done as zero dimensional, one dimensional, two dimensional, and three dimensional. In case of a zero-dimensional nanomaterial, the length, breadth, and height are fixed at a single point like nanodots. In case of one-dimensional nanomaterial, it can possess only one parameter, for example, carbon nanotubes, and for two dimensional, it has length and breadth in nanoscale, for example, graphene. For three-dimensional nanomaterial, it has all the parameters such as length, breadth, and height of nanorange, for example, gold nanoparticles. The shape, size, and structure of nanoparticles are different as it may be cylindrical, spherical, conical, tubular, hollow core, spiral, flat, etc. The surface may have variation or it may be uniform. Nanoparticles are classified into crystalline or amorphous based on whether the single or multicrystal solids are loose or agglomerated (Rashad et al. 2009).

There are numerous synthesis techniques that are developed to improve the properties of nanomaterials and to reduce the cost of production. The modification in some methods is done to improve their optical, mechanical, physical, and chemical properties (Chandamma et al. 2017; Gao et al. 2013; Yadav et al. 2016). The characterizations are improved due to vast development in the instrumentation. The use of nanoparticles is in every field like in cooking vessel, electronics to renewable energy, and aerospace industry. So, it can be said that nanotechnology is the key for a clean and sustainable future. The nanostructured materials and nanosystems can be invented by discovering new materials and processes at the nanoscale and the advancement of novel theoretical and experimental techniques. There are much current and expected advancement in nanoscale science and nanotechnology in terms of its applications in agriculture, medicine, energy, electronics, etc. The developments in the domain of nanotechnology are increasing day by day, and it plays a very important role in creating new products, substituting present production equipments, and reformulating novel materials to improve the performance and reduce the consumption of energy and is also used for remediation of environment (Melo et al. 2015; Mallesh and Srinivas 2019). Although it is beneficial for the environment that consumption of matter and energy is decreased, a more sustainable route can be offered by nanotechnology to remediate the problems. Nanotechnology can be used to develop solutions to environmental problems, measures to address both the ensuing problems from interactions of material and energy with the environment and the risks associated with nanotechnology (Harris and Šepelák 2018).

Nanotechnology can be stated as the complex interdisciplinary science that includes (Ghazi et al. 2018; Mehta 2017; Thakur and Hsu 2011; Thakur et al. 2014; Sawant et al. 2016; Manikandan et al. 2018) the study of nanophysics, nanochemistry, nanomaterial science, nanoelectronics, nanobionics, and nanometrology. This is illustrated as under:

- Nanophysics including spintronics, quantum physics, and photonics is destined for assembling and fabricating nanostructures artificially and doing research about the external size effects.
- Nanochemistry including sol-gel, nanocolloid, and quantum chemistry is destined for the nanoparticle synthesis and doing research about their intrinsic size effects.
- Nanomaterial science including nanoceramic compounds, nanotribology, nanopowder technology, nanosintering, etc. is about developing and producing nanostructured materials and nanocomposites having unique properties.
- Nanobionics is the branch of nanotechnology that is about developing nanobiochips, nanobiorobots, etc.
- Nanoelectronics is the development of nanomotors, nanodevices, ultra-large integrated circuits (ULCI), micro-optoelectronic-mechanical systems (MEMS, MOEMS), nanorobots, etc.
- Nanometrology is building and developing special nanotools, information, instrumentations, and computational systems.

1.2 Classification of Nanoparticles

The classification of nanoparticles can be done in accordance with organic, inorganic, and carbon based as shown in Fig. 1.1. Some organic nanoparticles or polymers are micelles, dendrimers, ferritin, liposomes, etc. The features of these nanoparticles are listed as:

- Biodegradable.
- Nontoxic.
- Some particles among them like micelles and liposomes have a hollow core (Fig. 1.2), known as nanocapsules.
- Sensitive to thermal and electromagnetic radiation such as heat and light.

These features make these materials capable for application in drug delivery. The drug carrying capacity, delivery systems, its stability, and entrapped or adsorbed drug system decide the field of applications and their efficiency apart from their normal characteristics like the surface morphology, size, composition, etc. The use of these organic nanoparticles is in the field of biomedicines. In case of drug delivery systems, these are efficiently injected on particular parts of the body called as targeted drug delivery.

The particles that are not made up of carbon are called inorganic nanoparticles. Inorganic nanoparticles are metal- and metal oxide-based nanoparticles. Metal-based nanoparticles are the nanoparticles that are prepared from metals to nanometric sizes by using either destructive or constructive methods. It is possible to synthesize almost all the metals into their nanoparticles (Sivakumar et al. 2011). The metals

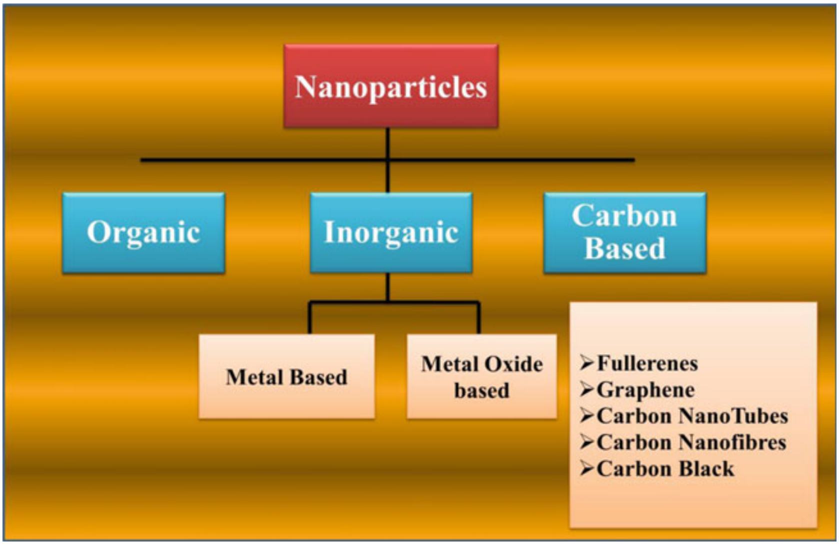


Fig. 1.1 Classification of nanoparticles according to organic, inorganic, and carbon based

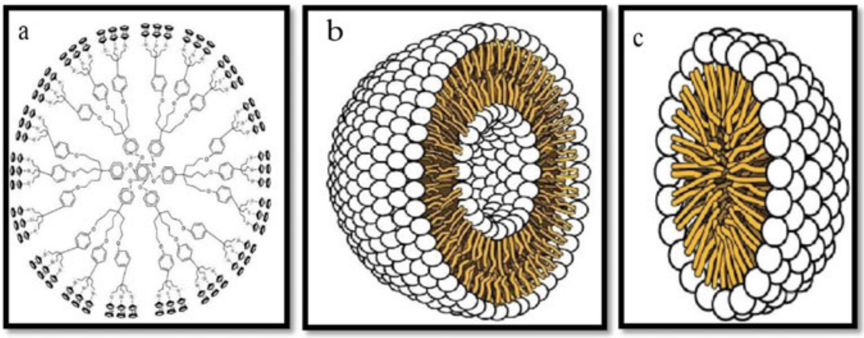


Fig. 1.2 Organic nanoparticles: (**a**) Dendrimers; (**b**) liposomes; (**c**) micelles

that are commonly used for the synthesis of nanoparticles are cobalt (Co), aluminum (Al), copper (Cu), cadmium (Cd), iron (Fe), gold (Au), silver (Ag), lead (Pb), and zinc (Zn). The nanoparticles have properties like sizes as low as 10–100 nm, high surface area to volume ratio, surface charge, pore size, surface charge density, color, shapes like spherical and cylindrical, crystalline and amorphous structures, and sensitivity and reactivity to environmental factors like heat, air, sunlight, moisture, etc. The metal oxide-based nanoparticles have modified properties in comparison to their respective metal-based nanoparticles, for example, in the presence of oxygen, iron nanoparticles oxidize to iron oxide (Fe_2O_3) at room temperature due to which its reactivity gets increased compared to iron nanoparticles. Due to increased reactivity

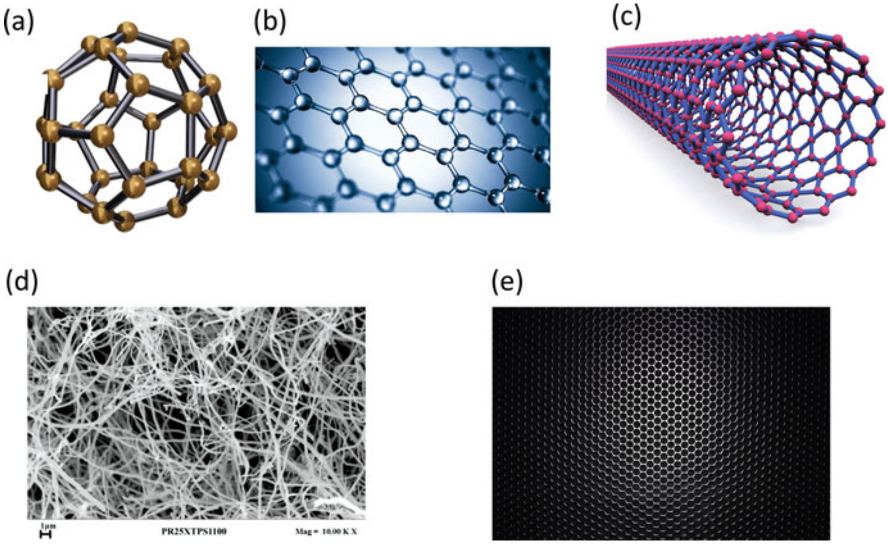


Fig. 1.3 Carbon-based nanoparticles: (**a**) fullerenes; (**b**) graphene; (**c**) carbon nanotubes; (**d**) carbon nanofibers; and (**e**) carbon black

and efficiency, metal oxide nanoparticles are synthesized (Baer et al. 2003). Some commonly synthesized are aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), silicon dioxide (SiO_2), cerium oxide (CeO_2), titanium oxide (TiO_2), magnetite (Fe_3O_4), and zinc oxide (ZnO).

The nanoparticles which are completely made of carbon are known as carbon based nanoparticles (Whitesides 2005). These materials can be classified into graphene, fullerenes, carbon nanofibers, carbon nanotubes (CNT), carbon black, and activated carbon in nanosize and are illustrated in Fig. 1.3. Fullerene (C_{60}) is spherical in shape and is a carbon molecule that is made up of carbon atoms that are held together by sp^2 hybridization. About 28–1500 carbon atoms build the spherical structure having diameters up to 8.2 nm for single-layered and 4–36 nm for multi-layered fullerenes. Graphene is called as an allotrope of carbon. Graphene shape is hexagonal having honeycomb lattice that is made up of carbon atoms in a 2D planar surface. Graphene sheet has a thickness of 1 nm. A Carbon nanotube (CNT) is a graphene nanofoil having a honeycomb lattice made up of carbon atoms wound into hollow cylinders to build nanotubes with diameters of measurement 0.7 nm for single-layered and 100 nm for multilayered carbon nanotubes and length in the range of a few micrometers to several millimeters. The ends can be open or closed by a half fullerene molecule. The particles have high interaction such that the bound inaggregates and around 500 nm agglomerates are formed.

In simple words, nanotechnology may be defined as a branch of science which deals with materials or structures in nanoscale range varying from subnanometer to several nanometers. This field is quite similar to quantum mechanics and is a new

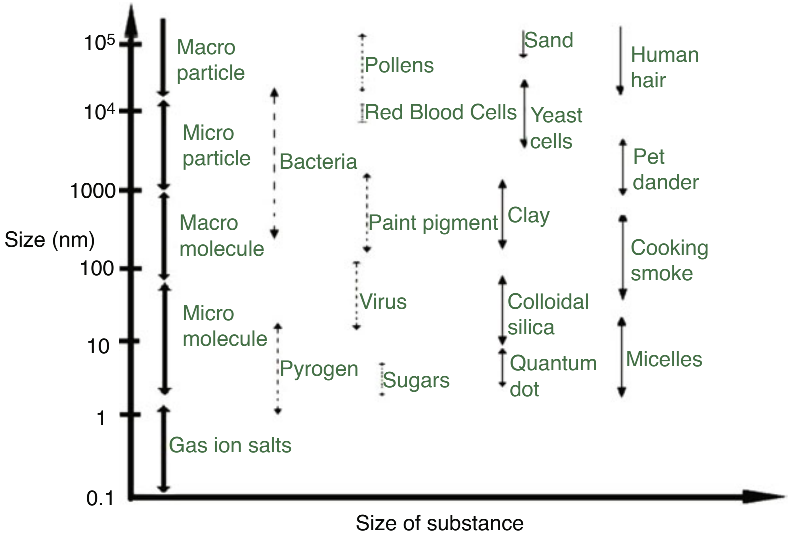


Fig. 1.4 Zero-dimensional representation of nanostructures with their typical ranges of dimensions

scientific domain. The zero-dimensional representation of nanomaterials having typical ranges of dimensions is shown in Fig. 1.4. In the nanometer scale, the synthesized materials or structures have some new physical properties from which some properties are known. For example, by varying the dimension of material, band gap of the semiconductor can be tuned. Still, there are certain properties which are not in the knowledge till now. These new physical properties are capable of satisfying human beings and also proved to bring new advancements in the field of science and technology.

1.2.1 Classification of Nanomaterials on the Basis of Size

On the basis of size, the classification of nanoparticles can be done into zero, one, two, and three dimensional as shown in Fig. 1.5. The materials which have structures in the range 1–100 nm are called nanostructured materials. The size and nature of the nanostructures define the properties of the nanostructured materials. Large changes in the material properties in comparison with a non-nanostructured material can be observed, if the characteristic length scale of the microstructure is comparable to the associated lengths to fundamental physical phenomena. A great variety of nanostructures can be produced using crystallites of nanometer size of elements like sodium chloride and gold, depending on the chemical composition of the mixture, the crystallographic orientation, and the possibility to have nonequilibrium structures that have certain property advantages. Nanostructured materials can be made by using nanoparticles as building blocks. The nature of nanostructured material can vary, and these may be nanocrystallites, fullerenes, nanofibers, nanotubes, etc. Nanomaterials are the simplest building blocks of nanostructured

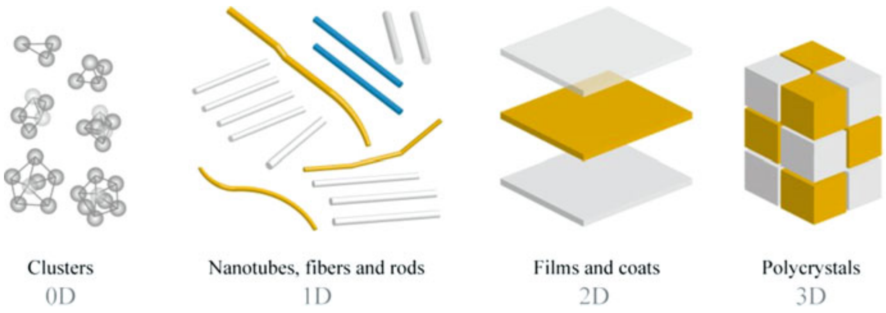


Fig. 1.5 Nanostructured materials

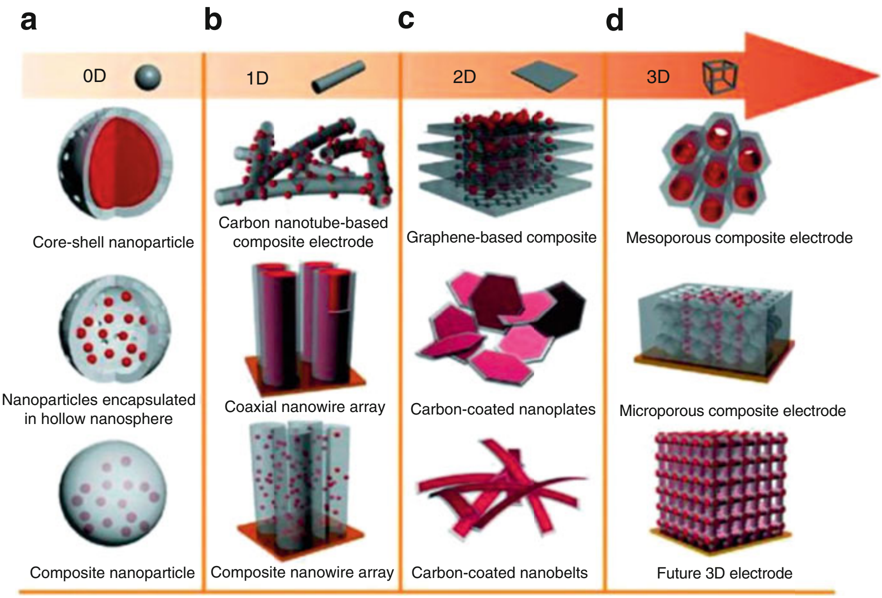


Fig. 1.6 Different types of (**a**) 0D (**b**) 1D (**c**) 2D, and (**d**) 3D nanostructured materials

nanomaterials, and it is possible to use more complicated elementary structures to make nanocomposites. Nanoparticles are the very simple objects which can be used to make nanomaterials. However, it is not an easy task to self-assemble nanoparticles according to a given template. There are only few examples such as sulfides or selenides combining with success soft templates, oriented attachment resulting in 1D structures, and self-alignment of nanoparticles by dipolar interactions. Different techniques like electron lithography can be used to design hard nanotemplates. Nanoparticles having controlled size and shape can be synthesized using soft nanotemplates, for example, mesophases and micellar systems. Different types of 0D, 1D, 2D, and 3D nanostructured materials are shown in Fig. 1.6.

Various types of nanostructures can be differentiated on the basis of dimensionality. The word "nano" is originated from a Greek word "nanos," which means dwarf. This word "nano" is meant for a number 10^{-9}, i.e., one billionth of a unit.

A significant progress has been made in the field of zero-dimensional nanostructured materials in the past 10 years. The zero-dimensional nanostructured materials can be synthesized using a variety of physical and chemical methods. Recently, zero-dimensional nanostructures like quantum dots, core-shell quantum dots, hollow spheres, heterogeneous particle arrays, onions, and nanolenses have been prepared by several research groups. Also, these materials like quantum dots have been extensively studied in single-electron transistors (Nayak et al. 2011), light-emitting diodes (Harzali et al. 2018), lasers (Zhang et al. 2009), and solar cells (Saeedi Afshar et al. 2018).

Due to the importance in research and having a variety of potential applications, in one-dimensional nanostructured materials, the interest of researchers is increasing in these materials. A large number of novel phenomena can be explored at the nanoscale using one-dimensional nanostructured materials. Also, these materials are useful in investigating the size and dependence on dimensions of functional properties. They are also used to play the role of interconnects and as a key unit in fabrication of optoelectronic, electronic, and EEDs having nanoscale dimensions. After useful work, significant attention has been attained by one-dimensional nanostructured materials like nanotubes. There is a great impact of one-dimensional nanostructured materials in nanodevices, nanoelectronics, alternative energy resources, nanosystems, nanocomposite materials, and national security. One-dimensional nanostructured materials include hierarchical nanostructures, nanotubes, nanowires, nanoribbons, nanorods, and nanobelts (Amer 2017; Sertkol et al. 2010).

The two-dimensional nanostructured materials have two dimensions outside of the nanoscale range. Also, these nanomaterials have many low-dimensional characteristics that are different from their bulk counterparts. Some unique shape-dependent properties are exhibited by these two-dimensional nanostructured material geometries. Also, these materials are the key components for synthesizing nanodevices (Chithra et al. 2017; Rafiq et al. 2015). The mechanism for the growth of nanostructures, investigation, and developing applications in the field of nanoreactors, sensors, photocatalysts, and nanocontainers can be easily understandable by fabricating two-dimensional nanostructured materials (Narang and Pubby 2021). Two-dimensional nanostructured materials include nanoprisms, junctions (continuous islands), branched structures, nanodisks, nanoplates, nanosheets, and nanowalls.

Due to many superior properties and large specific surface area over the bulk materials, researchers are taking great interest in three-dimensional nanostructured materials, and these materials are being synthesized from the past 10 years (Ling et al. 2010; Costa et al. 2008; Pei and Wang 2018). As it is a well-known fact that the behavior of nanostructured materials is strongly affected by size, shape, morphology, and dimensionality which are the key factors for the applications and ultimate performance of the nanomaterials. Hence, three-dimensional nanostructured materials having controlled structure and morphology are being synthesized by the researchers. The range of applications of these materials is very wide, for example, in the area of electrode material for batteries, catalysis, and magnetic material. Due to supply enough absorption sites for all involved molecules in a small space and higher surface area, the three-dimensional nanostructured materials are attracting intensive interest by researchers. Also, better transport of the molecules is possible due to porosity of these materials in three dimensions. Some examples of three-dimensional nanomaterials are nanocones, nanoballs, nanopillers, nanocoils, and nanoflowers.

1.3 Properties of Nanomaterials

1.3.1 Structural Properties

The changes in the spacing between interatoms can lead to an increase in the surface area and surface energy with a decrease in particle size. This is because of the compressive strain caused by the internal pressure by the small radius of curvature in the nanoparticle. It is evident that interatomic spacing increases with a decrease in particle size for semiconductors and metal oxides. One more effect is the stability of metastable structures in small clusters and nanoparticles, and due to this there is loss in all traces of the usual bulk atomic arrangement. Metallic nanoparticles, for example, gold, adopt polyhedral shapes like multiply twinned icosahedra, cube octahedra, and multiply twinned decahedra. These nanoparticles may be considered as multiply twinned crystalline particles (MTPs) in which understanding of shapes in terms of surface energies of various crystallographic planes, the growth rates along various crystallographic directions, and the energy required for the formation of defects such as twin boundaries can be made possible. But it is evident that these particles are crystalloids or quasiperiodic crystals. The growth of nanocluster, up to a size where they will switch into a more regular crystalline packing, is possible by these icosahedral and decahedral quasicrystals. Crystalline solids are different from amorphous solids because they possess long-range periodic order and the patterns and symmetries correspond to 230 space groups. Such long-range periodic order is not possessed by quasiperiodic crystals, and more differently five-fold symmetry is exhibited by them, which is forbidden in the 230 space group. In the hexagonal close packed and cubic close packed structures, that is exhibited by many metals in which each atom is coordinated by 12 neighboring atoms. These all coordinating atoms are in contact, but these are not evenly distributed around the central atom. Each atom situated at the apex of icosahedra is in contact only with the central atom in the alternative arrangement. The body of the material gains shape and point group symmetry of regular icosahedra by relaxing the rigid atmospheric model, allowing the central atom to decrease in diameter by 10%, and bringing the coordinating atoms in contact. This symmetry indicates the presence of 20 threefold, 12 fivefold, and 30 twofold axes of symmetry. This geometry depicts a quasiperiodic crystal nucleus which may grow in the form of pentagonal dodecahedra or icosahedra.

These are dual solids having identical symmetry in which the apices of one are replaced by the faces of the other. There is difficulty in understanding the characteristics that are related to size instability of quasiperiodic crystals. The process of multiple twinning is a frequently observed process, and such crystals are differentiated from quasiperiodic crystals by their electron diffraction patterns. Here, the five triangular faces of the fivefold symmetric icosahedra can be mimicked by five twin-related tetrahedra (with a close-packed crystalline structure) through relatively small atomic movements.

1.3.2 Optical Properties

The optical properties are greatly affected by reducing the dimension of materials. There are two groups when the size dependence is classified. One is because of the increase in energy level spacing as the system becomes more confined, and the other is because of surface plasmon resonance. The band gap increases with decrease in size due to quantum size effect in the semiconductor nanoparticles in which the interband transition shifts to higher frequencies. In a semiconductor, there is a rapid increase in energy separation (the energy difference between the completely filled valence band and the empty conduction band) with a decreasing size, and this energy separation is of the order of a few electron volts. A blue shift in the band gap is produced by quantum confinement and also in the appearance of discrete subbands attributed to quantization along the direction of confinement. The optical properties of the nano semiconductors can be modified by varying the size and keeping the same chemical composition. The variation in the nanoparticle size can lead to luminescent emission from the semiconductor nanostructures. The nature of electronic density of states and carrier confinement of semiconductor nanostructures make it more efficient for devices that are operating at lower threshold currents than lasers. The size-dependent emission spectra of quantum dots, quantum wells, and quantum wires make the lasing media attractive. The quantum dot lasers show less dependence on temperature than conventional semiconductor lasers. The same quantum size effect is also known in metal nanoparticles. However, in order to observe the localization of the energy levels, there is requirement of very small size so that the level spacing exceeds the thermal energy (~26 MeV). An in-phase oscillation is caused by surface plasmon resonance which is the coherent collective excitation of all the free electrons within the conduction band. A surface plasmon resonance is generated when the size of a metal nanocrystal is smaller than the wavelength of incident radiation. Biomedicine, photocatalysis, optical detectors, imaging, lasers, sensors and solar cells are some of the prominent applications based on the optical properties of the nanomaterials.

1.3.3 Chemical Properties

Chemical reactivity of the materials has a link with the size effects. Nanoscale structures, for example, nanolayers and nanoparticles, have potentially different crystallographic structures and very high surface area to volume ratios that causes a radical alteration in chemical reactivity. Nanoparticles generally show new chemistry which are different from their particular large counterparts; for example, in the form of micron-sized particles, there are many new medicines which are insoluble in water, but in a nanostructure form, they get dissolved easily. Hence, it is important to chemically identify the nanomaterials and characterize them. A few of the chemical properties that are essential for characterizing nanomaterials are composition, structure, chemical bonding, reactivity, stability, melting and boiling points.

1.3.4 Electronic Properties

The changes in electronic properties during decrease in the system length scale are mainly related to the increasing influence of the electrons' wavelike property, i.e., quantum mechanical effects and lack of scattering centers. The discrete nature of the energy states becomes apparent when the size of the system becomes comparable with the de Broglie wavelength of the electrons. But to observe a fully discrete energy spectrum, the system should be confined in all three dimensions. Below a critical length scale, conducting materials behave as insulators due to overlapping of the energy bands. Due to their intrinsic wavelike nature, quantum mechanical tunneling of electrons is possible between two closely adjacent nanostructures. Resonant tunneling occurs when a voltage is applied between two nanostructures due to which discrete energy levels are aligned in the density of state causing an increase in the tunneling current. The impurities, scattering with phonons, and scattering at rough surfaces determine the electronic transport in macroscopic systems. There is diffusive transport and path of every electron relates a random walk. In inelastic scattering, when system has dimensions smaller than the electron mean free path, electrons travel through the system without phase randomization of wave functions. This gives rise to additional localization phenomena related to phase interference. If due to small system, all scattering centers are to be eliminated completely, and if boundary reflections are purely specular due to smooth sample boundaries, then the electron transport is purely ballistic, and the sample acts as a waveguide for the electron wave function. Conduction in highly confined structures like quantum dots is very sensitive to the presence of other charge carriers and thus to the charge state of the dot. The conduction processes involving single electrons are caused by these Coulomb blockade effects due to which very substantial amount of energy is required by them to operate a transistor, switch, or memory element. Different types of components for information processing applications, electronic, and optoelectronic can be produced by utilizing all these phenomenas.

1.3.5 Mechanical Properties

The mechanical properties of the nanomaterials (hardness, fracture toughness, scratch resistance, elastic modulus, fatigue strength, etc.) are different from the bulk materials because of the nanometer size. This modification may result in an enhancement of mechanical properties of nanomaterials that often results from structural perfection of the materials. The small size either renders them free of internal structural imperfections such as dislocations, impurity precipitates, and micro twins. It is not possible to cause mechanical failure due to few defects or impurities. The highly energetic imperfections within the nano dimension will migrate to the surface to relax themselves under annealing, thereby causing purification of the material and leaving perfect material structures inside the nanomaterial. Moreover, the external surface of nanomaterials are free of defects in comparison to the bulk materials, causing enhancement in the mechanical properties of nanomaterials.

1.3.6 Thermal Properties

There is low progress in study of the thermal properties of nanomaterials due to the difficulties encountered in measuring experimentally and controlling the thermal transport in nanoscale dimensions. The introduction of atomic force microscopy (AFM) to measure the thermal transport of nanostructures within nanometer scale with high spatial resolution has provided a promising way to probe the thermal properties of nanostructures. The availability of the definition of temperature is in question when the dimensions go down into nanoscale. Phonons carry the thermal energy in nonmetallic material system which has a wide variation in mean free path and frequency. Generally, at room temperature, the phonons that carry heat have large mean free path and wave vectors in nanoscale range. Due to this, the nanostructure dimensions are comparable to the wavelength and mean free path of phonons. However, average energy of a material system defines the temperature. In case of macroscopic systems, a local temperature in each region within the materials is defined by the dimension, and there is variation in this local temperature from region to region, so that thermal transport properties based on certain temperature distributions can be investigated. But in case of nanomaterial systems, a local temperature sometimes can’t be defined by just the dimensions because dimensions are too small to define. Also, the concept of temperature defined in equilibrium conditions is difficult or problematic to use for theoretical analysis of thermal transport in nanoscale. In nanomaterial systems, various factors like the large interfaces, the special shape, and the small size do modification in the thermal properties of the nanomaterials, rendering them a quite different behavior in comparison to the macroscopic materials. The size of the nanomaterials become comparable to the mean free path and wavelength of the phonons. When the dimension goes down to nanoscale, there is a significant change in phonon transport within the material due to the phonon confinement and quantization of phonon transport, which results in modified thermal properties. The thermal properties are also affected by the special structure of nanomaterials. For example, carbon nanotubes due to their tubular structures have extremely high thermal conductivity in axial directions, leaving high anisotropy during the heat transport in the materials. The thermal properties of nanomaterials are also determined by interfaces. The thermal properties of nanomaterials have another promising application in the use of nanofluid to enhance the thermal transport. The nanofluids consist of nanomaterials of size in the range 1–100 nm which are suspended in a liquid generally referred to as the solid-liquid composite materials. The increase in thermal conductivity in comparison to liquids not containing nanomaterials is an important feature of nanofluids.

1.3.7 Magnetic Properties

Magnetic nanoparticles have a wide range of applications, such as ferrofluids, refrigeration, bioprocessing, and color imaging, as well as high storage density magnetic memory media. The large surface area to volume ratio results in a substantial proportion of atoms (those at the surface which have a different local environment) having a different magnetic coupling with neighbouring atoms, leading to differing magnetic properties. When the particle size decreases below a certain value, ferromagnetic particles become unstable as domains are spontaneously switched in polarization directions by gaining surface energy; due to which, ferromagnetic becomes paramagnetic. However, this ferromagnetic which is nanometer-sized ferromagnetic turned to paramagnetic has a different behavior than the conventional paramagnetic and is known as superparamagnetic. While multiple magnetic domains are formed by bulk ferromagnetic materials, only one domain is formed by small magnetic nanoparticles exhibiting a phenomenon known as superparamagnetism. The overall magnetic coercivity in this case is then lowered, and there is random distribution of magnetizations of the various particles due to thermal fluctuations and only get aligned in the presence of an applied magnetic field. The nanoscale multilayers show giant magnetoresistance (GMR) which consist of a strong ferromagnet (e.g., Fe, Co) and a weaker magnetic or nonmagnetic buffer (e.g., Cr, Cu).

1.4 Conclusions

Enormous progress is made by nanotechnology in the past decades. In summary, the requirements of nanotechnology are the fabrication of matter on the scale of atoms and molecules, prediction, and measurement. Hopefully, there is revolutionary impact of the atomic scale nanotechnology in the way of doing, designing, and producing things in the future. Nanotechnology can be defined as an atomic or molecular approach using which physically, chemically, and biologically stable structures can be built of one atom, or one molecule, at a time. Nanomaterials can be classified as organic, inorganic and carbon based. According to their size 0D, 1D, and 2D nanostructures are defined. Due to large surface to volume ratio and size in nanometer range, these materials exhibit unique physical, chemical, optical, thermal and magnetic properties. The results of developments and investigations in nanotechnological fields are entering into all areas of our lives, like aerospace, agriculture, materials science, energy, medicine, defense, and environmental science. There are some active research areas which include nanodevices, nanolithography, nanopowders, nanorobotics, nanostructured catalysts, nanocomputers, nanoporous materials and molecular nanotechnology, nanolayers, molecular manufacturing, medicines and nanobiology (e.g., prediction, prevention, and treatment of diseases), and some organic nanostructures. Researchers have come to know from many years that current technologies are depending on processes which take place at the nanoscale. Some instances of these technologies are adsorption, lithography, catalysis, plastics, drug design, composites, and ion exchange.

References

Amer MA (2017) Structural , elastic and magnetic studies of the as-synthesized co 1 À x Sr x Fe 2 O 4 nanoparticles. J Alloys Compd 690:293–303. https://doi.org/10.1016/j.jallcom.2016.08.135

Baer DR, Burrows PE, El-Azab AA (2003) Enhancing coating functionality using nanoscience and nanotechnology. Prog Org Coat 47:342–356. https://doi.org/10.1016/S0300-9440(03)00127-9

Bhushan B (2016) Introduction to nanotechnology: history, status, and importance of nanoscience and nanotechnology education. https://doi.org/10.1007/978-3-319-31833-2_1

Chandamma N, Manohara BM, Ujjinappa BS, Shankarmurthy GJ, Santhosh Kumar MV (2017) Structural and electrical properties of zinc doped nickel ferrites nanoparticles prepared via facile combustion technique. J Alloys Compd 702:479–488. https://doi.org/10.1016/j.jallcom.2016.12.392

Chithra M, Anumol CN, Sahu B, Sahoo SC (2017) Structural and magnetic properties of ZnXCo1−XFe2O4 nanoparticles: nonsaturation of magnetization. J Magn Magn Mater 424:174–184. https://doi.org/10.1016/j.jmmm.2016.10.064

Costa ACFM, Diniz APA, de Melo AGB, Kiminami RHGA, Cornejo DR, Costa AA, Gama L (2008) Ni-Zn-Sm nanopowder ferrites: morphological aspects and magnetic properties. J Magn Magn Mater 320:742–749. https://doi.org/10.1016/j.jmmm.2007.08.011

Gao P, Hua X, Degirmenci V, Rooney D, Khraisheh M, Pollard R, Bowman RM, Rebrov EV (2013) Structural and magnetic properties of Ni1-xZnxFe 2O4 (x=0, 0.5 and 1) nanopowders prepared by sol-gel method. J Magn Magn Mater 348:44–50. https://doi.org/10.1016/j.jmmm.2013.07.060

Ghaffari M, Huang H, Tan OK, Shannon M (2012) CrystEngComm Band gap measurement of SrFeO 3 2 d by ultraviolet photoelectron spectroscopy and photovoltage method. https://doi.org/10.1039/c2ce25751c

Ghazi N, Mahmoudi Chenari H, Ghodsi FE (2018) Rietveld refinement, morphology analysis, optical and magnetic properties of magnesium-zinc ferrite nanofibers. J Magn Magn Mater 468:132–140. https://doi.org/10.1016/j.jmmm.2018.07.084

Gleiter H (2009) Nanoscience and nanotechnology: the key to new studies in areas of science outside of nanoscience and nanotechnology. MRS Bull 34:456–464. https://doi.org/10.1557/mrs2009.122

Harris VG, Šepelák V (2018) Mechanochemically processed zinc ferrite nanoparticles: evolution of structure and impact of induced cation inversion. J Magn Magn Mater 465:603–610. https://doi.org/10.1016/j.jmmm.2018.05.100

Harzali H, Marzouki A, Saida F, Megriche A, Mgaidi A (2018) Structural, magnetic and optical properties of nanosized Ni0.4Cu0.2Zn0.4R0.05Fe1.95O4 (R = Eu3+, Sm3+, Gd3+ and Pr3+) ferrites synthesized by co-precipitation method with ultrasound irradiation. J Magn Magn Mater 460:89–94. https://doi.org/10.1016/j.jmmm.2018.03.062

Ling W, Zhang H, He Y, Wu Y, Yang K, Li Y, Li S (2010) Low temperature fired Ni-cu-Zn ferrite with bi 4 Ti 3 O 12. J Magn Magn Mater 322:819–823. https://doi.org/10.1016/j.jmmm.2009.11.010

Mallesh S, Srinivas V (2019) A comprehensive study on thermal stability and magnetic properties of MnZn-ferrite nanoparticles. J Magn Magn Mater 475:290–303. https://doi.org/10.1016/j.jmmm.2018.11.052

Manikandan V, Denardin JC, Vigniselvan S, Mane RS (2018) Structural, dielectric and enhanced soft magnetic properties of lithium (Li) substituted nickel ferrite (NiFe2O4)nanoparticles. J Magn Magn Mater 465:634–639. https://doi.org/10.1016/j.jmmm.2018.06.059

Mehta RV (2017) Synthesis of magnetic nanoparticles and their dispersions with special reference to applications in biomedicine and biotechnology. Mater Sci Eng C 79:901–916. https://doi.org/10.1016/j.msec.2017.05.135

Melo RS, Silva FC, Moura KRM, De Menezes AS, Sinfrônio FSM (2015) Magnetic ferrites synthesised using the microwave-hydrothermal method. J Magn Magn Mater 381:109–115. https://doi.org/10.1016/j.jmmm.2014.12.040

Narang SB, Pubby K (2021) Nickel spinel ferrites: a review. J Magn Magn Mater 519:167163. https://doi.org/10.1016/j.jmmm.2020.167163

Nayak RR, Pradhan N, Behera D, Pradhan KM, Mishra S, Sukla LB, Mishra BK (2011) Green synthesis of silver nanoparticle by Penicillium purpurogenum NPMF: the process and optimization. J Nanopart Res 13:3129–3137. https://doi.org/10.1007/s11051-010-0208-8

Nouailhat A (2010) An introduction to nanoscience and nanotechnology. Nanotechnology:1–206. https://doi.org/10.1002/9780470610954

Pei J, Wang Z (2018) Effect of bi-co co-doping on the microstructure and magnetic properties of NiMgCuZn ferrites. J Magn Magn Mater 465:598–602. https://doi.org/10.1016/j.jmmm.2018.06.045

Rafiq MA, Khan MA, Asghar M, Ilyas SZ, Shakir I, Shahid M, Warsi MF (2015) Influence of Co2+ on structural and electromagnetic properties of Mg–Zn nanocrystals synthesized via co-precipitation route. Ceram Int 41:10501–10505. https://doi.org/10.1016/j.ceramint.2015.04.141

Rashad MM, Hessien MM, El-midany A, Ibrahim IA (2009) Journal of magnetism and magnetic materials effect of synthesis conditions on the preparation of YIG powders via co- precipitation method. J Magn Magn Mater 321:3752–3757. https://doi.org/10.1016/j.jmmm.2009.07.033

Saeedi Afshar SR, Hasheminiasari M, Masoudpanah SM (2018) Structural, magnetic and microwave absorption properties of SrFe12O19/Ni0.6Zn0.4Fe2O4 composites prepared by one-pot solution combustion method. J Magn Magn Mater 466:1–6. https://doi.org/10.1016/j.jmmm.2018.06.061

Sawant VJ, Bamane SR, Shejwal RV, Patil SB (2016) Comparison of drug delivery potentials of surface functionalized cobalt and zinc ferrite nanohybrids for curcumin in to MCF-7 breast cancer cells. J Magn Magn Mater 417:222–229. https://doi.org/10.1016/j.jmmm.2016.05.061

Sertkol M, Köseoğlu Y, Baykal A, Kavas H, Toprak MS (2010) Synthesis and magnetic characterization of Zn0.7Ni0.3Fe2O4 nanoparticles via microwave-assisted combustion route. J Magn Magn Mater 322:866–871. https://doi.org/10.1016/j.jmmm.2009.11.018

Sivakumar P, Ramesh R, Ramanand A, Ponnusamy S, Muthamizhchelvan C (2011) Preparation and properties of nickel ferrite (NiFe2O 4) nanoparticles via sol-gel auto-combustion method. Mater Res Bull 46:2204–2207. https://doi.org/10.1016/j.materresbull.2011.09.010

Sui X, Scherge M, Kryder MH, Snyder JE, Harris VG, Koon NC (1996) Barium ferrite thin-film recording media. J Magn Magn Mater 155:132–139. https://doi.org/10.1016/0304-8853(95)00722-9

Thakur A, Hsu J (2011) Novel magnetodielectric nanomaterials with matching permeability and permittivity for the very-high-frequency applications. Scr Mater 64:205–208. https://doi.org/10.1016/j.scriptamat.2010.09.045

Thakur A, Thakur P, Hsu JH (2014) Structural, magnetic and electromagnetic characterization of In3+ substituted Mn-Zn nanoferrites. Z Phys Chem 228(6–7):663–672. https://doi.org/10.1515/zpch-2014-0477

Wang HG, Liu W, Jia N, Zhang M, Guo M (2017) Facile synthesis of metal-doped Ni-Zn ferrite from treated Zn-containing electric arc furnace dust. Ceram Int 43:1980–1987. https://doi.org/10.1016/j.ceramint.2016.10.164

Whitesides GM (2005) Nanoscience, nanotechnology, and chemistry. Small 1:172–179. https://doi.org/10.1002/smll.200400130

Yadav RS, Havlica J, Masilko J, Kalina L, Wasserbauer J, Hajdúchová M, Enev V, Kuřitka I, Kožáková Z (2016) Impact of Nd^{3+} in $CoFe_2O_4$ spinel ferrite nanoparticles on cation distribution, structural and magnetic properties. J Magn Magn Mater 399:109–117. https://doi.org/10.1016/j.jmmm.2015.09.055

Zhang E, Yin D, Xu L, Yang L, Yang K (2009) Microstructure, mechanical and corrosion properties and biocompatibility of Mg-Zn-Mn alloys for biomedical application. Mater Sci Eng C 29:987–993. https://doi.org/10.1016/j.msec.2008.08.024