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Review Article

A review on core shell nanoparticles: classes, synthesis, characterization of core shell nanoparticles

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ABSTRACT

Because of their remarkable capabilities in bioimaging, targeted medication and gene delivery, sensors, and other fields, nanoparticles have many fascinating uses in a variety of fields, and the biomedical field is no exception. Due to a number of benefits over simple nanoparticles, it has been determined that the core/shell class of nanoparticles holds the most promise for many medicinal applications. The evolution of biomedical research based on core/shell nanoparticles during the last 20 years or so is highlighted in this study. Five main categories-bioimaging, biosensor, targeted medication delivery, DNA/RNA interaction, and targeted gene delivery-are used to categorize applications of various core/shell nanoparticle kinds.

Keywords: Biomedical research, Biosensors, Nanoparticles, Targetted gene delivery

INTRODUCTION

The nanoparticles are the basic building block of nanotechnology. Particles of carbon, metal, metal oxides, or organic materials that range in size from 1 to 100 nanometers are known as nanoparticles.[1] In contrast to their counterparts at larger scales, the nanoparticles display distinct physical, chemical, and biological characteristics at the nanoscale. This phenomenon can be attributed to a number of factors, including improved mechanical strength, higher reactivity or stability in a chemical process, and a comparatively larger surface area to volume.[2] Because of these characteristics, nanoparticles are used in many different applications.

Aside from their substance, the nanoparticles vary in size, shape, and dimensions.[3] There are four types of nanoparticles: zero-dimensional, which has length, width, and height fixed at one point (like nano dots), one-dimensional, which can have only one parameter (like graphene), two-dimensional, which has length and width (like carbon nanotubes); and three-dimensional, which has all of the parameters (like gold nanoparticles).

The size, shape, and structure of the nanoparticles vary. They range in size from 1 nm to 100 nm and can be spherical, cylindrical, tubular, conical, hollow core, spiral, flat, etc., or irregular. Depending on surface differences, the surface may be uniform or uneven. Certain nanoparticles have single or many crystal solids that are either loose or clumped together, and they can be either crystalline or amorphous.[4]

STRUCTURE OF NANOPARTICLES

Nanoparticles may consist of many layers or be homogeneous. In the latter instance, the layers are frequently as the surface layer, which typically is composed of metal ions, polymers, surfactants, and a range of tiny molecules. The shell layer, which differs from the core layer in terms of composition. The nanoparticle's core layer, which is its central section.[5]

SYNTHESIS OF NANOPARTICLES

To synthesize nanoparticles (NPs) with precise size, shape, dimensions, and structure, a variety of techniques have been used. For the synthesis of NPs, there are two primary methods: top-down and bottom-up. Based on the operations and reaction circumstances, these techniques are further separated into various groups.

Top-down approach

In a top-down method, the bulk is broken down. Scheme 1: Diagrammatic depiction of material into nanosized particles using a top-down and bottom-up technique (Source: nanoscience.com). It's a damaging approach. To create the necessary structure with the right attributes, top-down procedures are easier and rely on either the division or removal of bulk material or the downsizing of bulk production processes. Among the most popular techniques for creating nanoparticles include mechanical milling, thermal breakdown, sputtering, laser ablation, and nanolithography.

Bottom-up approach

Another strategy that uses a build-up process is the bottom-up or constructive method, in which atoms are used to create clusters, which are then used to create nanoparticles. Typically, this method uses the reduction and sedimentation techniques. Because it may result in less waste, this method is thought to be more cost-effective. Sol-gel, spinning, green synthesis, chemical vapour deposition (CVD), pyrolysis, and biosynthesis are the most widely utilized examples of this technique.[6]

CLASSIFICATION OF NANOPARTICLES

Depending on their size, origin, pore size, structural arrangement, and possible toxicity, nanomaterials can be categorized into five groups.

Classification of nanomaterials based on origin

Nanomaterials are classified according to their origin into two groups: natural and manufactured nanoparticles.

Natural nanomaterials

Viruses, protein molecules, minerals like clay, natural colloids like milk and blood (liquid colloids), fog (aerosol type), gelatin (gel type), mineralized natural materials like shells, corals, and bones, insect wings and opals, spider silk, lotus leaves, gecko feet, volcanic ash, and ocean spray are just a few examples of the diversity of natural nanomaterials found in nature.

Artificial nanomaterials

Examples of artificial nanomaterials that are purposefully created using exacting mechanical and manufacturing processes are carbon nanotubes and semiconductor nanoparticles like quantum dots (QDs). Depending on their structural composition, nanomaterials are classified as metal-based materials, dendrimers, or composites.

Classification of nanomaterials based on structural configurational and composition

Nanoparticles can be broadly classified into four types based on their structural composition: inorganic, carbon-based, organic/dendrimers, and composite.

Organic nanomaterials

Organic molecules are transformed into organic nanomaterials at the nanoscale. Liposomes, ferritin, dendrimers, and micelles are a few types of organic nanoparticles or polymers. Nano capsule micelles and liposomes are non-toxic biodegradable nanoparticles with hollow interiors that are light, heat, and electromagnetic radiation sensitive. A dendrimer's surface is covered in many chain ends that have the ability to carry out particular chemical reactions. Dendrimers are employed in opt electrochemical systems, light harvesting, molecular recognition, and nano sensing. Moreover, three-dimensional (3D) dendrimers may be helpful for drug delivery since they have interior holes that can accommodate extra molecules.

Inorganic nano materials

They are referred to as inorganic nanoparticles since they do not include carbon atoms. Metal-based or metal oxide-based nanomaterials are the usual categories for inorganic nanoparticles.

Metal-based nanoparticles

Destructive or constructive methods can be used to create metal-based nanoparticles. Metals that are commonly utilized in the synthesis of nanoparticles include aluminum (Al), cadmium (Cd), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), silver (Ag), and zinc (Zn). In addition to their electrical, catalytic, thermal, and antibacterial qualities, metal nanoparticles have exceptional UV-visible sensitivity due to their quantum effects and large surface-to-volume ratio. Due to their exceptional optical characteristics, metal nanoparticles are employed in many different research domains.

Metal oxide nanoparticles

Positive metallic ions and negative oxygen ions make up metal oxide nanoparticles, also referred to as metal oxide nanomaterials. Silicon dioxide (SiO2), titanium oxide (TiO2), zinc oxide (ZnO), and aluminum oxide (Al2O3) are examples of commonly manufactured metal oxide nanoparticles. In contrast to their metal counterparts, these nanoparticles have exceptional characteristics.

Lipid-based nanomaterial

The majority of lipid-based nanoparticles have spherical shapes and range in diameter from 10 to 100 nm. It is composed of a matrix of soluble lipophilic molecules and a solid lipid core. In the biomedical domain, lipid-based nanoparticles can be used as RNA release therapy for cancer treatment and as medication carriers.

Carbon based nano materials

Five primary components make up carbon-based nanomaterials: carbon nanotubes, graphene, fullerenes, carbon nanofiber, and carbon black. Bucky balls are fullerenes, which are spherical or ellipsoidal structures made of carbon nanomaterials. Fullerenes are spherical compounds that develop from 28 to 1500 carbon atoms and have diameters of up to 8.2 nm for single layers and 4 to 36 nm for multi-layered fullerenes.

Composites nanomaterials

Combinations Nanoparticles mixed with bulk-type materials, nanoparticles mixed with larger-scale materials, and nanoparticles mixed with other nanoparticles are all considered nanomaterials. In items ranging from packaging materials to auto parts, nanomaterials are already being employed to enhance mechanical, thermal, and flame-retardant qualities.

CLASSIFICATION BASED ON PORE DIMENSIONS

According to the length of their diameter dimensions, nanomaterials are divided into three categories: macroporous, mesoporous, and microporous. In the intended sense, the size of molecules is determined by the diameter of the pores, which also gives information on the qualities of diffusion and interaction. During the diffusion process, there will be more molecule-to-molecule interaction and less molecule-to-wall interaction if the guest molecules are smaller than the pore size. Applications that depend on this parameter, such as adsorption and diffusion, can benefit from them.

Micro porous materials

Materials with pores that are less than 2 nm in diameter are referred to be micro porous materials. They might only contain linear molecules or tiny molecules like gasses. Their interaction characteristics are high and their diffusion kinetics are slow. Microporous materials include Na-Y and naturally occurring clay minerals. They are utilized in gas storage materials, membrane filters, and gas purification systems.

Mesoporous materials

The holes of mesoporous materials are sufficiently enough in diameter to accommodate some large molecules that are larger than 2 nm but smaller than 50 nm. Mesoporous materials, such as MCM-41, MCM-48, SBA-15, and carbon mesoporous materials, can be employed as liquid or vapor adsorbing systems or as nanoreactors for polymerization.

Macro porous materials

Materials that have pores large enough (more than 50 nm) to hold very large molecules, including polyaromatic systems or tiny biological molecules, are said to be macro porous. Macro porous materials include porous glasses, porous gels, and carbon microtubes. These materials are mostly employed as sensing materials, scaffolds to graft functional groups like catalytic centers, and matrices to store functional molecules.

Applications of nanomaterials

Applications for nanomaterials are numerous and include chemical and cosmetic fields like nanoscale chemicals and compounds, paints, and coatings, as well as nanomedicine disciplines like tissue engineering, medical devices, and nanodrugs. The fields of nanoparticles, carbon nanotubes, biopolymers, paints, and coatings, food sciences, including processing, nutraceutical foods, and nanocapsules; environment and energy, including fuel cells, photovoltaics, and water and air purification filters; military and energy, including biosensors, weapons, and sensory enhancement; electronics semiconductors, including chips, memory storage, photonic, and optoelectronics; and scientific tools, including atomic force, microscopic and scanning tunneling microscopes.[7]

Core-shell nanoparticles consist of a core composed of one substance covered with another. Compared to simple nanoparticles, core-shell nanoparticles offer significant advantages in biological applications. These advantages include less cytotoxicity, increased dispersibility, bio- and cyto-compatibility, improved conjugation with other bioactive molecules, increased thermal and chemical stability, and more.

In more detail, when the target nanoparticles are poisonous, which could seriously harm the host's organs and tissues. The nanoparticles become substantially less poisonous and biocompatible when a harmless substance is coated on top of the core. In certain cases, the shell layer enhances the properties of the core material in addition to acting as a benign layer. The shell of other materials enhances the optical characteristics and photo stability of semiconductor core/shell nanoparticles.

Nanoparticles' hydrophilicity is crucial for their dispersion in aqueous biological systems. The enhancement of bio-dispersivity, biocompatibility, and cytocompatibility renders it a valuable substitute for traditional drug delivery methods. Researchers are drawn to this class of materials in large part because of their simplicity of synthesis. When the core material is hydrophobic, the issue of dispersibility and bio- and cytocompatibility can be resolved by coating the core surface with a hydrophilic substance in the form of core/shell nanoparticles. (iii) For many bio-applications, the conjugation of biomolecules onto particle surfaces is crucial. The coating of an appropriate biocompatible material helps to resolve the issue of the material of interest being difficult to conjugate with a certain type of biomolecule. iv) Coating core particles with an inert substance usually improves their stability when the core materials are prone to heat or chemical changes when exposed to the environment. In this instance, core/shell nanoparticles show greater promise than single nanoparticles for biological purposes.[8] Because of its potential in fields like medication delivery, biomedical imaging treatment, tumor therapy, and microfluidic devices, core-shell particles have gained importance in the last ten years.

One because nanoparticles had better qualities than bulk materials, researchers looked at them in the early studies. Researchers created unstable semiconductor particles in the 1980s that were more efficient than the permitted particles.[2,3] Researchers created new, unstable semiconductor particles with increased efficiency in the 1990s.[4] But creating nanoparticles is still a difficult process that calls for a variety of methods, and there is a greater need for cutting-edge materials than ever before.[5] The development of architectures for these various core-shell nanocomposites has benefited from improvements in characterisation techniques.[6] The full understanding of some theoretical models, like the classic particle-in-the-box model, for which classical physics rules have not been able to explain, depends on nanomaterials with overlapping and distinct chemical and physical properties. Furthermore, the combination of these materials at the nanoscale has facilitated the development of novel technologies across numerous scientific domains, opening up new avenues for the use of micro-strategies in the creation of biological systems and devices.[9]

DIFFERENT SHAPED OF CORE SHELL NANOPARTICLE

Not only may symmetrical (spherical) nanoparticles be created thanks to advancements in novel synthesis processes, but also a wide range of other shapes, including cubes, 7-, 14 prisms, 15, 16 hexagons, 7, 8, 17, 20, octahedrons, 11, 12, disks, 21 wires, 22, 29, rods, 22, 30, 37 tubes, 22, 38, 41, and more. It is important to remember that the majority of research on variously shaped nanoparticles is actually quite new. According to several very recent publications, it is also extremely possible to create different-shaped core/shell nanoparticles, much like with simple nonspherical nanoparticles. 42, 46 Nanoparticle characteristics are related to their real shape in addition to their size. For instance, the blocking temperature, magnetic saturation, and permanent magnetization of magnetic nanocrystals are all influenced by particle size, but due to surface anisotropy effects, the coercivity of the nanocrystals is entirely dependent on the form of the particles.[9] The fundamental understanding of magnetism and its practical applications, including high-density information storage, could be greatly aided by variously formed magnetic nanocrystals.[9] Significant shape dependence also exists for several physical and chemical characteristics of nanoparticles, including catalytic activity and selectivity, electrical optical properties and melting point55. Furthermore, the particle shape also affects other characteristics including the sensitivity to surface-enhanced Raman scattering (SERS) and the plasmon resonance characteristics of gold or silver particles.

Classes of core shell nanoparticles

Nanoparticles can be classified as simple, core/shell, or composite nanoparticles based on one or more materials. While composite and core/shell particles are built of two or more components, as their names suggest, simple nanoparticles are often constructed of just one material. A core (inner material) and a shell (outer layer material) are the two main components of core/shell type nanoparticles. These can include, among other things, inorganic/inorganic, inorganic/organic, organic/inorganic, and organic/organic materials in close contact. The final use and application have a significant influence on the core/shell nanoparticle's shell material selection. A schematic representation of the many classes of core/shell nanoparticles may be seen in The most prevalent are concentrated spherical core/shell nanoparticles. where a shell made of a different material entirely envelops a basic spherical core particle. By employing an appropriate procedure, it is also conceivable to create a movable core particle inside a uniformed hollow shell particle following a bilayer coating of the core material and simply removing the first layer.[10]

Synthesis of core–shell micro/nanoparticles

The preparation/synthesis of core materials and the synthesis/deposition of shell layers are the two general phases involved in creating core–shell micro/nanoparticles. Solid phase reaction, liquid phase reaction, gas phase reaction, and mechanical mixing are the four categories into which the synthesis methods of nanoparticles can be categorized based on the various principles.

Materials that require phase change to acquire particular properties by calcination at high temperatures something that wet chemistry approaches cannot accomplish throughout the synthesis process are typically synthesized using the solid phase reaction method. As a result, inorganic core-shell nanoparticle production typically employs this technique.

Monodisperse single crystal Co (Fe) Pt@C nanoparticles with an L10 structure were created using a one-step solid phase synthesis method; as seen in figure 1, the metal salts were distributed, dried, and broken down on the carbon-coated copper grid, after which a cluster formation process took place (I, II, III). Single crystal core–shell nanoparticles (IV, V) were then created by the clusters' grains aggregating and recrystallizing.[11] In contrast to a conventional two-step synthesis process that involves the solution phase synthesis of fcc (face-centered cubic)-Co (Fe) Pt nanoparticles, the produced particles demonstrated ferromagnetic characteristics with coercivity up to 12.2 kOe at ambient temperature. Figure shows a schematic illustration of how L10-CoPt@C nanostructures are formed.[11]

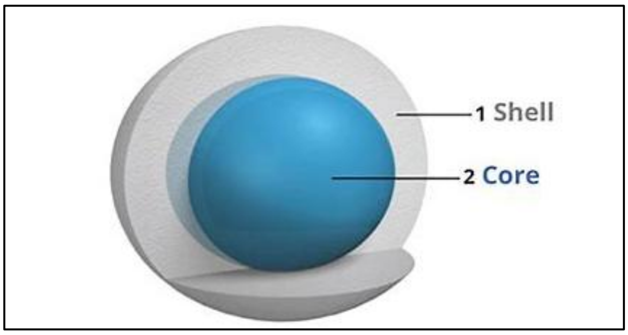

Figure 1: Structure of coreshell nanoparticle.

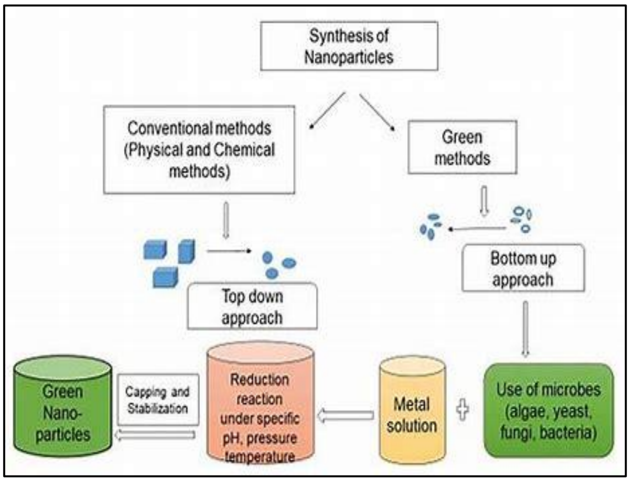

Figure 2: Synthesis methods.

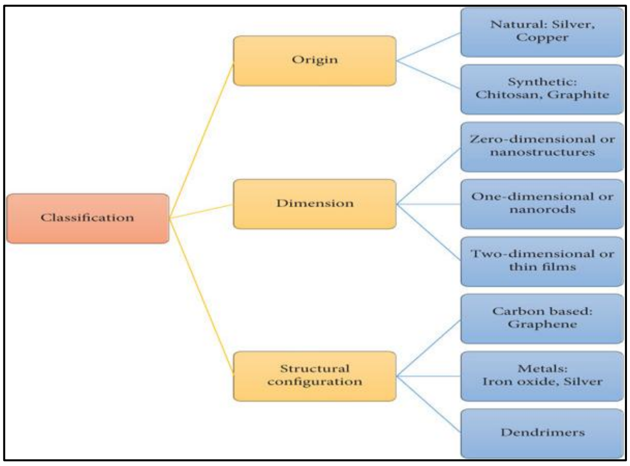

Figure 3: Classification.

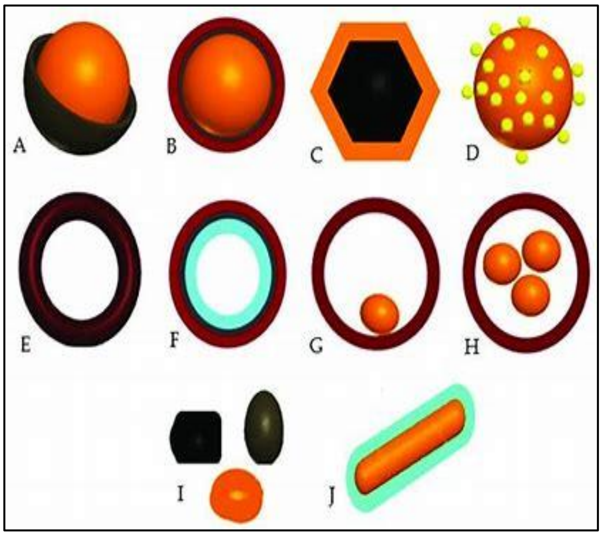

Figure 4: Shapes of core shell nano particles.

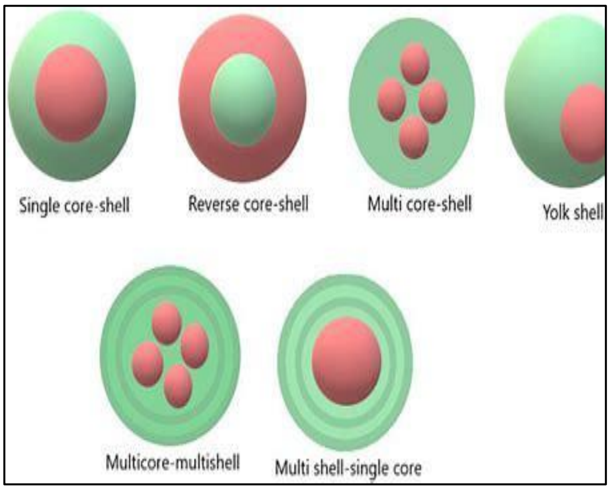

Figure 5: Classes of core shell nanoparticles.

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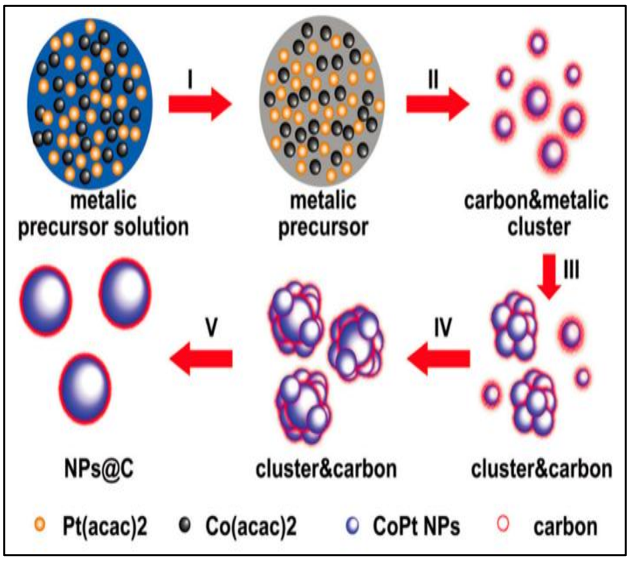

Figure 6: Synthesis of core shell nanoparticles.

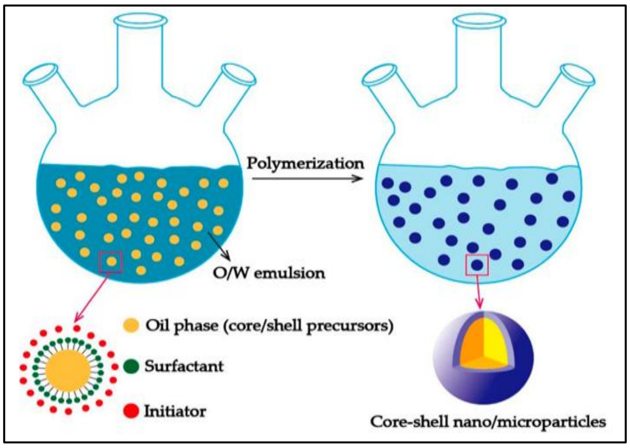

Figure 7: Liquid phase reaction.

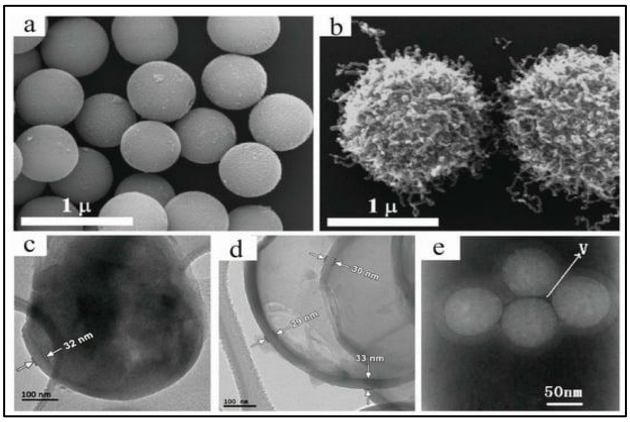

Figure 8: (a-e) Gas phase synthesis.

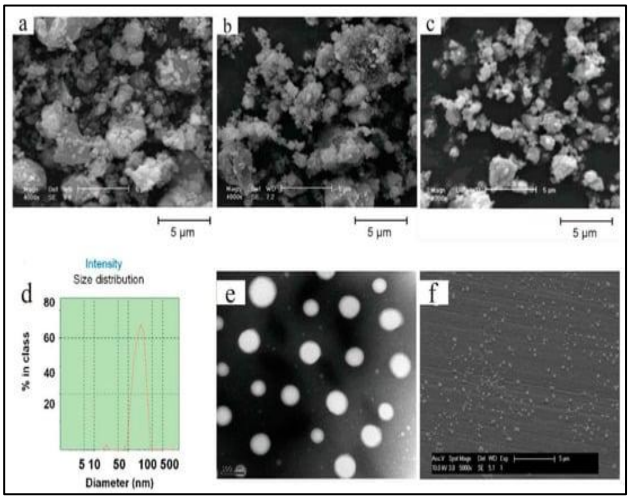

Figure 9: (a-f) Morphology of coreshell nanoparticles.

Liquid phased reaction

In order to deposit modifiers or a coating on the surface of pre-formed particles, chemical reactions conducted in a wet environment are referred to as the liquid phase reaction method.[12] The liquid phase reaction approach, which is commonly used in both industry and the laboratory to manufacture core-shell nanoparticles, has the advantages of low reaction temperatures and easy equipment when compared to other methods. The sol–gel, hydrolysis, electrochemical, hydrothermal, and emulsion polymerization techniques are among the frequently employed liquid phase reaction techniques.

The first step in the sol-gel process is to create a low-viscosity solution by dispersing the raw ingredients into the solvent. As a result, gel formation and doping at high molecular levels are simple processes. Nevertheless, it is impossible to overlook certain issues with the sol-gel approach. The entire sol–gel process often takes a few days or even weeks, and the gels may have a large number of micropores, which will cause samples to shrink as a result of gases and organic chemicals leaving during the drying phase.

Emulsion polymerization is another popular technique for creating core-shell micro/nanoparticles, in addition to the sol-gel approach. As illustrated in Figure, the most widely used kind of emulsion polymerization is an O/W (oil in water) emulsion, which typically begins in the water including core materials, monomers, initiators, and surfactants. Oil in water (O/W) emulsion polymerization is shown schematically.

Gas phase reaction

In order to create core-shell nanoparticles, the gas phase reaction method, which primarily consists of physical vapor deposition (PVD) and chemical vapor deposition (CVD), is utilized to deposit the shell materials in the gas phase supersaturated system on the target particle surfaces.

The basic idea behind PVD is that the material sources are physically transformed into gaseous atoms, molecules, or partially ionized into ions under vacuum conditions. The resulting material is then transported by low-pressure gas or plasma to deposit on the surfaces of core materials that serve specific purposes. Cathodic arc deposition, electron beam physical vapor deposition, evaporative deposition, pulsed laser deposition, and sputter deposition are the primary techniques used in the PVD process. Rh-Au core-shell nanoparticles were effectively produced on the surface of TiO2 (110) by PVD of Rh and then exposing Au at a high sample temperature (500 K).[13] It shown that bimetallic nanoparticles may be created using the same "seeding and growing" technique that was utilized to manufacture monometallic particles in a narrow size distribution.[14]

Target core-shell particles are created by the chemical interactions of gases or steams on the surfaces of core materials, which is the primary function of CVD. Atomic-layer CVD (ALCVD), combustion CVD (CCVD), hot filament CVD (HFCVD), hybrid physical–chemical vapor deposition (HPCVD), rapid thermal CVD (RTCVD), photo-initiated CVD (PICVD), and plasma technique are the several types of CVD. The reaction source materials required for film formation are typically readily available, and the CVD process may create a wide range of thin films (carbides, nitrides, borides, silicides, and oxides) at deposition temperatures significantly lowerthan melting or decomposition temperatures.

Images of (a) SiO2/IO microspheres and (b) "Medusa-like" SiO2/IO/carbon nanofibers and tube particles were captured by a scanning electron microscope (SEM).[15] Oictures of the 1 µm Li2S@C core-shell particles taken with a transmission electron microscope (TEM) (c) prior to and (d) following the dissolution of Li2S.[16] (e) TEM micrographs of four cores over-coating with SiC/SiO2 nanoparticles with a single shell structure.[17]

Although thin films and core-shell particles are frequently prepared using PVD and CVD, there are currently very few reports of the tribological uses of core-shell particles produced using those techniques. As a result, they merit the interest of researchers.

Mechanical mixing

Through convection and diffusion, two or more particles with favorable adhesion or adsorption characteristics at a specific temperature can be uniformly adsorbed on the surfaces of the modified particles using the mechanical mixing method. The surface modification or recombination is then completed when the particles are closely merged to cover the target particles' surfaces under the influence of external forces (aerodynamic force, gravity, and mechanical force).[18] By ball milling combinations of Al and MoO powders to create a quick combustion reaction, Heidarpour and colleagues.[19] created Mo@Al2O3 nanocomposites. Figure 5a–c shows the SEM images of the final products.

In addition to ball milling, mechanical mixing and high-pressure homogenization were used to create temperature-sensitive and core-shell structured gel nanocarriers (NCs) for paclitaxel (PTX) using 12-hydroxystearic acid as an organic gelator (Figure 5).[20] Compared to conventional nanocarriers, the PTX-loaded gel NCs were more effective at suppressing tumor growth without endangering other organs and exhibited superior in vivo biocompatibility.

Morphology of powder particles (stoichiometric composition) following milling periods of (a) 90, (b) 120, and (c) 240 minutes Heidarpour et al characterization of the gel nanocarriers (NCs). (e) TEM and (f) SEM pictures of the gel NCs; (d) particle size and size distribution.[19,20]

The characteristics of coated particles can be somewhat enhanced by the mechanical mixing approach. The weak bonding interactions between the core and shell materials make it difficult for this approach to evenly cover the particle surfaces fully; as a result, it is now infrequently employed for the manufacture of core–shell micro/nanoparticles.[21]

CHARACTERIZATION OF CORE/SHELL NANOPARTICLES

The presence of shell material on the core surface makes it crucial to characterize core/shell nanoparticles; therefore, an appropriate characterisation method is always needed for both the core and the shell. One technique might not be enough, however the majority of characterization methods are the same as those used for single particles. Measurements of size, shell thickness, elemental and surface analysis, optical characteristics, and thermal stability are among the most important characterization methods for core/shell nanoparticles.

As a result, the most often employed characterization methods include thermogravimetric analysis (TGA), X-ray photoelectron spectroscopy (XPS), photoluminescence (PL), scanning electron microscopy (SEM), transmission electron microscopy (TEM), dynamic light scattering (DLS), and UVvis spectroscopy. Analysis can be categorized as explained in the following categories based on various instruments and characterization approaches.

Microscopic analysis

However, because core/shell nanoparticles can only produce a surface, it is challenging to differentiate between core and shell materials. However, SEM can be employed for elemental analysis of the shell surface when coupled with energy-dispersive X-ray spectroscopy (EDX). Field-emission SEM (FESEM), which may reach a significantly greater magnification than standard SEM, has shown value most lately. FESEM photos at high magnification can reveal whether the shell surface is rough or smooth. Heterogeneous nucleation allows the shell material molecules to grow directly onto the core surface, resulting in smooth surfaces.

Spectroscopic analysis

Because optical characteristics are typically quite sensitive to surface modifications of nanocrystals, they can provide some indirect insight into how the shell materials are coated on the core surface. One popular spectroscopic method for analyzing various kinds of nanoparticles is UV-vis spectroscopy. Specifically, those that provide an absorbance spectrum in the UV-vis area and have the ability to absorb energy in this region. In When characterizing core/shell nanoparticles, the individual spectra of the core, shell, and core/shell material are compared using UV-vis. Photoluminescence or fluorescence spectroscopy is another useful method for characterizing such were the ingredients of the pure shell. On the other hand, the shell material coating on the core surface is primarily indirectly supported by UV or PL spectroscopy. In order to uncover surface information, such as (i) elemental composition, (ii) chemical status, (iii) empirical formula, (iv) electronic state or binding modes of surface ligands, and (v) depth analysis or atomic composition with depth, X-ray photoelectron spectroscopy (XPS) is another crucial spectroscopic technique.

Scattering analysis

One of the main methods for characterizing nanoparticles in their colloidal or powdered form is light, electron, or neutron scattering from materials. Another important method for directly measuring particle size in nanoparticle solutions is dynamic light scattering (DLS), also known as photon correlation spectroscopy or quasi-elastic light scattering. The thickness of the shell can be determined by measuring the particle sizes both before and after coating. be quantified. Measuring the ζ potential of the core particles in the solution provides indirect indication of the degree of core surface alteration. This technique provides the particles' hydrodynamic diameter.

Characterization of synthetic crystalline materials is another common application for powder X-ray diffraction. Its primary purpose is identification of unidentified substances as well as to describe the crystalline size (grain size), preferred orientation, and crystallographic structure of polycrystalline or powder solid samples. The Scherrer equation explains the impact of finite crystallite sizes as indicated by the broadening and intensity change of the peaks in X-ray diffraction. It serves as an indirect indicator of the existence of a comprehensive, homogeneous covering for core/shell nanoparticles. The coating on the shell materials causes the core material's diffraction peak intensity to drop, and once it is thick enough, the peak vanishes entirely.

According to certain research, the amorphous nature of the shell material and inadequate shell thickness may be the cause of low-intensity diffraction peaks of the core material that emerge after the coating. The same analytical goal is served by the independent employment of wide-angle X-ray scattering (WAXS) and small-angle X-ray scattering (SAXS). The primary benefits of SAXS are that the sample can be solid, liquid, or even a combination of solid and liquid of the same or different material. The operating angle 2θ is in the range of 0.110.[22]

CONCLUSION

Nanotechnology is improving our everyday lives by enhancing the performance and efficiency of everyday objects. It provides a clean environment by providing safer air and water, and clean renewable energy for a sustainable future. Nanotechnology has gained a wide attention where more investment is made for the research and development by top institutions, industries and organisations. Nanotechnology has established to be an advanced field of science where extensive research is carried out to implement the technology. It is being tested for various new applications to increase the efficiency and performance of the object or process and subsequently reduce the cost so that it is accessible for everyone. The nanotechnology has a great future due to its efficiency and environmental friendly property.

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