

Review Article

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Applications of nanotechnology and nanoproduction techniques

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Abstract: A wide variety of materials having at least one dimension between 1 and 100 nm make up the remarkable class of materials known as nanomaterials (NMs). By rationally designing nanoparticles, very large surface areas may be attained. It is possible to create NMs with exceptional mechanical, optical, electrical, and magnetic properties that differ significantly from their traditional materials. A brief history of NMs and how they have been used to spur advancements in nanotechnology development is covered in this overview. Throughout the review, the special properties of NMs are emphasized. There is a discussion of several techniques for synthesizing NMs, including top-down and bottom-up strategies. The characteristics, uses, and methods of manufacture of nanoparticles are succinctly and simply summarized in this study.

Keywords: nanomaterials, nanomaterials applications, reinforcement, nanomaterial composites, nanomaterial production

1 Introduction

A billionth of anything, 10^{-9} m, is referred to as a “nano.” The primary distinction between bulk materials (BMs) and nanomaterials (NMs) is that the former have sizes above 100 nm in all dimensions, while the latter have sizes in the 1–100 nm range in at least one dimension. The two main categories of particles are BMs and NMs. Table 1 lists the properties of both types of particles, making it simple to identify and differentiate between NMs and BMs. In addition, Table 2 lists the special mechanical, optical, electrical, and magnetic features of NMs. There are five major areas within nanotechnology that have been identified [1,2]: (a) molecular nanotechnology; (b) NMs and nanopowders; (c)

nanoelectronics; (d) nanooptics and nanophotonics; and (e) nanobiomimetics. The notion of nanotechnology was first put out at the California Institute of Technology (Caltech) during the annual conference of the American Physical Society, which Richard Feynman, the 1959 Nobel Prize winner, helped to establish. “There is plenty of room at the bottom,” Feynman said in his well-known address, “the principles, as far as I can see.” In 1981, Eric Drexler, a student of Dr. Feynman, published the first scientific research on nanotechnology [1–4]. Nanocrystalline, nanostructured, and nanosized materials are terms that are frequently used to describe substances with crystallites or particle sizes less than 100 nm [5,6]. Some unexpected changes in physical and mechanical properties occur as a substance shrinks in size to the nanoscale. The variety of goods incorporating such nanoparticles and their potential uses keep expanding, as new applications for materials with these special features are discovered [7,8]. The processes involved in creating NMs and their many uses have been covered in a number of studies. In this study, the distinction between conventional and NMs was reported, as well as the modifications in properties that take place when a material reaches the nanoscale. Examples from research and experiments on the processes involved in creating and using NMs for industrial purposes were also provided.

2 History and development of nanotechnology

The Romans, in the fourth century AD, were the first to employ nanoparticles and structures. Dichroic glass, which describes two forms of glass that change color depending on the lighting, is one of the most fascinating instances of nanotechnology in antiquity [3]. Michael Faraday examined the distinct optical and electrical characteristics of colloidal suspensions of “Ruby” gold in 1857. The concepts of nanotechnology were first proposed by 1959 Nobel Prize winner Richard Feynman, who contributed significantly to its establishment. The term “nanotechnology”

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Table 1: General properties of NMs and bulk materials (BMs)

NMs	Bulk materials (BMs)
Chemical compounds or materials with at least one dimension in the nanoscale range of 1–100 nm are referred to as NMs	Particles that are larger than 100 nm in all dimensions are considered BMs
Not visible with a standard microscope or the human eye	Observable with a basic microscope or the naked eye
Higher surface-to-volume ratios produce superior results in solar cells, gas sensors, and catalysis, among other applications	Low surface atom or molecular fraction, which determines their characteristics
Metal nanoparticles have unique scattering properties	Metal bulk has normal scattering properties
Differentiating the size of the particle allows for the “tuning” of NM’s distinct chemical and physical characteristics	Their chemical and physical properties cannot be adjusted

was originally used in 1974 by Japanese physicist Norio Taniguchi. He described how complex machinery made of individual atoms is put together to form nanostructures [1–4]. Scientists Heinrich Rohrer and Gerd Binnig invented the scanning tunneling microscope (STM), a significant advancement in nanotechnology, at the IBM Zurich Research Laboratory in 1981. STM uses a pointed tip that approaches the conductive surface of the material so closely that the atoms’ electron wave functions overlap with the surface atom wave functions to determine the surface properties [2]. Around the close of the 20th century, two main approaches were put up to explain several choices for synthesizing nanostructures: the top-down and bottom-up procedures. The aim of the top-down approach is to reduce BM to the size of nanoparticles. Alternatively, the bottom-up method constructs nanostructures molecule by molecule or atom by atom by employing physical and chemical methods [1–4]. In the United States, President George W. Bush signed the 21st Century Nanotechnology Research and Development Act, establishing the National Technology Initiative and emphasizing the importance of nanotechnology research. Interestingly, the researchers also discovered how to make nanoparticles in accordance with the specifications of several scientific fields, including biology, chemistry, computer science, materials science, physics, and engineering. Because of their fascinating properties, carbon nanotubes (CNTs) are being extensively studied as conductive materials in the fields of biology and electronics. These days, nanotechnology is a fast-growing discipline having applications in optics, biology, medicine, electronics, and catalysis, among other areas. To put the theory of nanoscience into real-world applications, a number of scientists have acknowledged and capitalized on the ability to view, measure, assemble, regulate, and synthesize materials at the nanoscale scale. Because nanoparticles can easily cross the blood-brain barrier, nanotechnology may one day help medical professionals treat conditions like dementia and cancer that affect the brain [9,10]. In addition, nanotechnology additives will have the potential to demonstrate self-

sense properties that help materials to self-heal when damaged, which could be useful in the aviation industry [11].

3 Classification of nanostructured materials

The term “nanostructured materials” refers to a class of substances whose crystallite and/or particle sizes are less than 100 nm. Nanostructured materials come in many different varieties. As illustrated in Figure 1, they are categorized based on the dimensionality of the nanostructure, with classes ranging from zero-dimensional (0D) atom clusters to three-dimensional equated grain formations.

The categories of materials with nanostructures are [12,13]:

1. 0D NMs such as – nanocrystals (1–30 nm), nanoclusters (up to 50 units), and nanoparticles which have all three length scales L_x , L_y , L_z .
2. One-dimensional (1D) NMs (one of the dimensions is outside the range of the nanoscopic) such as nanofibers, nanotubes, nanorods, and nanowires. Most nanostructures have a diameter between 1 and 100 nm with short lengths.
3. Two-dimensional NMs (two dimensions are out of the nanoscopic) such as nanosheets, nanocoatings, and thin films fall within this category.
4. Three-dimensional (3D) nanocrystalline structures or nanophase materials.

4 General properties of NMs and BMs

It is well recognized that the primary distinctions between bulk and NMs are their respective uses, sizes, and susceptibilities to visual perception. The key distinctions between

Table 2: Changes in mechanical and physical properties by nanoscale

Property	Properties changed as a result of materials' nanoscale
Mechanical	Grain boundary or hard nanoparticles have demonstrated better mechanical properties in nanostructured materials (manufactured <i>via</i> nanopowder consolidation) and nanoparticle-reinforced matrix composites. A common material will become somewhat more refined when nanoparticles are added, creating an intragranular structure that strengthens the grain boundary and enhances the mechanical characteristics of the materials there. A few factors influencing the mechanical performance of NMs, including grain size, production method, and nanoparticle selection [14–17] The following are some examples of experiential research for improving the mechanical properties of NMs: when hard nano-TiC particles were added up to 20 weight percent, the mechanical characteristics (hardness, impact, creep, and tensile strength) of the epoxy-nano-TiC composites improved because the TiC powder was well dispersed with little agglomeration and air bubbles. Nonetheless, agglomeration, the lack of an epoxy matrix between the TiC particles, and air bubbles caused a drop in the mechanical property values for poxy-30 weight percent nano-TiC composites [18]. Adding 3% nano-oil palm empty fruit string filler to kenaf epoxy composites can considerably improve their tensile strength, elongation at break, and impact strength [19]. Due to the many grain boundaries, materials with copper nanoparticles smaller than 50 nm are very hard and lack the malleability and ductility of bulk copper [20]. Metal matrix nanocomposites have higher fracture toughness and fracture strength due to grain refinement, and leading to the improvement of mechanical properties of the nanocomposite. Al25wt% nano-TiC composites have a high hardness due to small reinforcement particles, which allow for a greater surface area in contact with the aluminum particles. Large reinforcement particles, on the other hand, have a limited region of contact and impede the diffusion process. Comparing composites reinforced with bigger particles at the same weight %, those reinforced with smaller TiC particles had more barriers per unit area [16,17,21]. Concrete's splitting tensile strength, bending strength, and compressive strength may all be increased by adding 3 weight percent nano-SiO₂ [22]. When a portion of the cement is replaced with nano-SiO₂, its high activity facilitates the hydration process of the concrete, reducing the nano-SiO₂'s setting time [23]. Because of their large surface area and ability to create strong networks within the asphalt binder, NMs improve resistance to permanent deformation and give the binder a stronger texture [24]
Optical	The dynamic optical properties of nanoparticles can differ greatly from those of the same BM, including absorption, transmission, reflection, and light emission. Changes in these attributes are seen at the nanoscale. The shift in optical characteristics at the nanoscale level is made possible by the fact that electrons in nanoparticles are less free to move than in BMs due to their small size. The restricted mobility of electrons in nanoparticles causes them to react to light differently than in BMs. For example: • The color of bulk gold is yellow, but the color of nanosize gold is red • The color of bulk silicon is gray, but the color of nanosized silicon is red [25] • in bulk and scatters visible light and inhibits ultraviolet radiation, Even though the particle size of nanoscale zinc oxide is far smaller than that of visible light, it does not scatter light. It seems translucent as a result [26]
Electrical	The mobility of the charge carriers is the primary issue of NMs' electrical characteristics. There is no way around the quantum-size effect and quantum confinement effect when a material's dimensions are down to the nanoscale range. Certain voltages have the ability to convert certain conductive metal nanoparticles into nonconductive materials due to the quantization of electron energy. When materials are reduced in size to a few nanometers, they can lose their conductivity, such as copper, while insulating materials, like silicon dioxide, gain conductivity, and lose their insulating qualities [27]. The dielectric characteristics, resistivity, and electrical transport of NMs are primarily controlled by increased interfacial atoms or ions, sinking a significant number of defects along the grain boundaries, grain size, and doping impurities [28]. Because of the rise in band gap energy that occurs with a decrease in particle size, particularly for semiconductor nanoparticles, the electrical conductivity of NMs is often lower than that of BMs [29]. For instance, even though gold nanoparticles are metallic, they become insulators once the energy bands stop overlapping in the 2–4 nm range [30]. The fundamental factor influencing electrical conductivity is the distance between neighboring energy levels. Particle size has a major impact on the electrical structure of the nanoparticles [31]. The conductivity of nanowires rises sharply in comparison to BMs as their diameter falls below 20 nm because of enhanced surface scattering for electrons and phonons, larger surface areas, and a very high density of electronic states [32]. Depending on their size, crystal structure, and chemical makeup, CNTs can exhibit a broad spectrum of electrical characteristics, from metallic to superconducting, insulating, and semiconducting [33]
Magnetic	The capacity of a ferromagnetic material to resist an external magnetic field without demagnetizing is known as coercivity. Higher magnetic nanocomposites, characterized by a drop in coercivity below a certain size leading to superparamagnetic behavior and an increase in coercivity till a critical size, have a variety of uses, from data storage to diagnostic applications like clinical imaging. A magnetic field is used to manipulate these nanoparticles. When ferrite nanoparticles are smaller than 128 nm in size, for example, they become superparamagnetic and do not aggregate. By altering the surface of ferrite nanoparticles with surfactants, phosphoric acid derivatives, or silicon, one can boost their stability in a solution. But in other circumstances, nanoparticles' magnetic characteristics might also be detrimental. For instance, ferroelectric materials smaller than 10 nm have the ability to change the direction of their magnetization with thermal energy at normal temperature, which makes them inappropriate for use in memory storage [34]

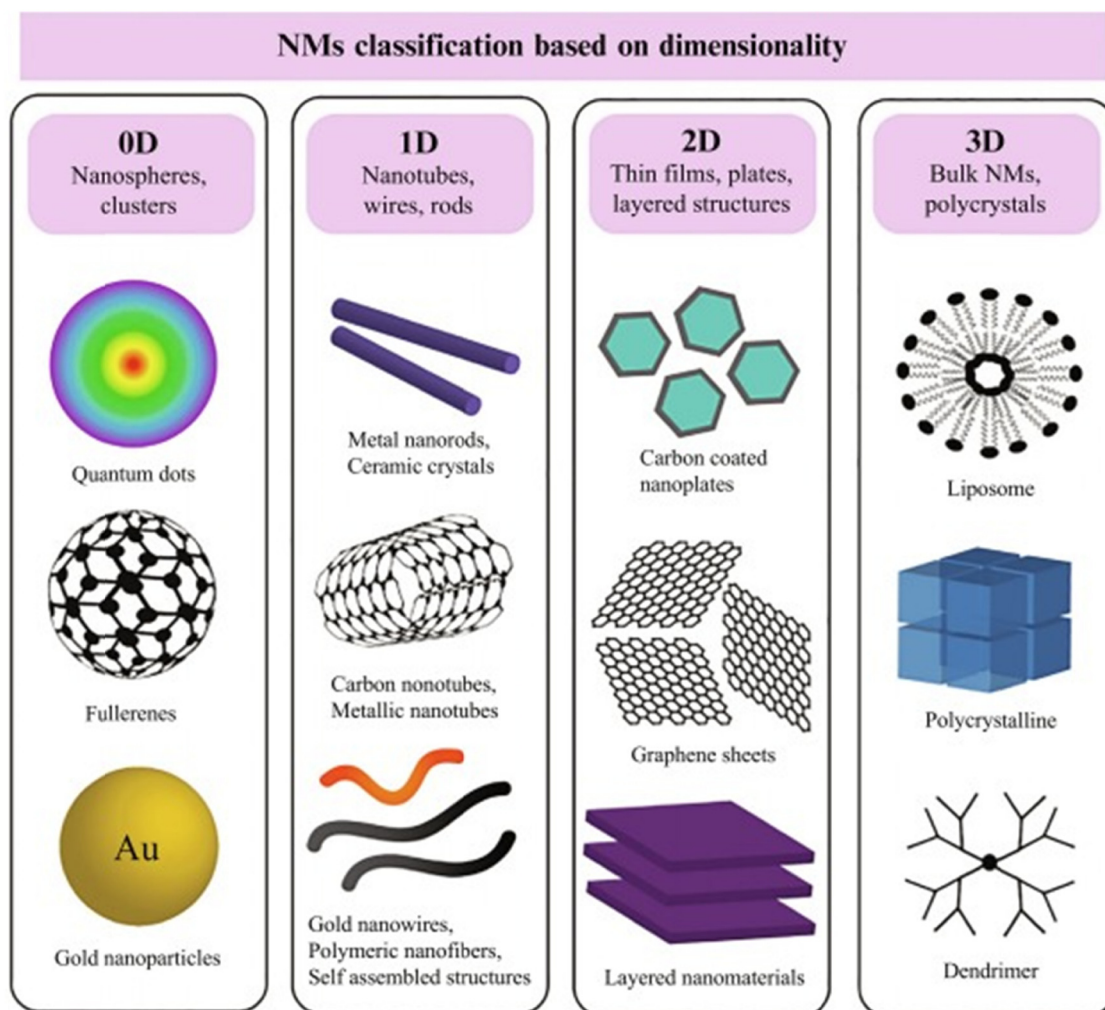


Figure 1: Diagram of the four different forms of nanocrystalline materials.

nanoparticles and BMs are displayed in the following table. Additionally, molecules or atoms in their NM state differ from similar BMs in their chemical and physical characteristics [1–6].

5 Changes in properties by nanoscale

Nanomaterials have different surface effects compared to micromaterials or BMs, mainly due to three reasons; (a) dispersed NMs have a very large surface area and high particle number per mass unit, (b) the fraction of atoms at the surface in NMs is increased, and (c) the atoms situated at the surface in NMs have fewer direct neighbors. As a consequence of each of these differences, the mechanical and physical properties of NMs change compared to

their larger-dimension counterparts (as demonstrated in Table 2).

6 Applications of nanotechnology in industry

Nanotechnology helps address future societal by various applications in the fields of industries, medicine, agriculture, biotechnology, and electronics. The following industry key applications depend on the unique change in properties:

6.1 Metals

Nanoparticulate metals can have surface hardness up to five times higher than that of conventional microcrystalline

metals when they are compressed into solid forms. Bulk nanocrystalline component preparation still has challenges, such as strong grain growth after sintering. Furthermore, metals' properties may be dramatically changed by adding ceramic nanoparticles, such as carbides, into them [16,17].

6.2 Ceramics

The compression of nanoscale ceramic particles into solid pieces with many grain boundaries leads to improvements in most other properties and increases in hardness and wear resistance. These new materials have the potential to replace metals in many different applications [35].

6.3 Polymers

Due to their improved barrier, strength, and conductive properties, as well as their reduced weight, ability to speed up part production and replace more expensive materials, ability to replace metals with flame-resistant plastics, and many other properties, polymer materials (layered silicate or nanofibers CNT-polymer nanocomposites [PNCs]) are expected to be used in a wide range of applications. An alternative to traditionally filled polymers or mixes of polymers is PNCs, also known as polymer nanostructured materials. PNCs gain from the special effects of incorporating inorganic materials of nanoscale sizes into a polymer matrix, as opposed to conventional systems where the reinforcement is on the order of microns [35,36].

6.4 Cutting tools

Compared to typical cutting tools made or coated from large particles, cutting tools created or coated with nanoparticles (nanocrystalline and carbide powders) offer a variety of advantages, such as high hardness, resistance to wear and corrosion, and great endurance [37,38].

6.5 Porous sensors

Semiconductor nanoparticle-based porous sensing aggregates may be produced with low-load compression. Because more of the gas to be detected (such as sulfur dioxide) is adsorbed

per unit mass than is often the case with crushed powders, the electrical changes are more pronounced. Thus, using nanoparticles in sensor technologies offers a number of advantages [31,38].

6.6 Computer chips

It is clear that we need more compact, high-performing technology. A microprocessor's operating speed increases dramatically when its size is significantly reduced [39]. These parts might be radically reduced in size to allow for considerably faster computations by enabling the microprocessors that house them to operate at much higher rates. The cleanest nanoparticles with the highest thermal conductivity levels are used to create computer chips, and the end product is of the finest standard. These chips last longer on the shelf and are more powerful [40].

6.7 Phosphors for high-definition TV

Reducing the phosphor pixels as much as possible is necessary to increase screen resolution. Lead telluride, zinc sulfide, and nanocrystalline zinc selenide made from sol-gel are a few examples of this screen. The cost of these screens was greatly lowered with the development of nanophosphors [39–41].

6.8 Storage applications

The path to advancement in memory technology includes cost reduction and the creation of memory systems that are quicker, more energy-efficient, smaller, and capable of holding more data. Theoretically, all of these advantages can be achieved by shrinking the size of the fundamental storage cell; therefore, it makes sense to assume that nanotechnology will someday play a crucial role [39–41].

6.9 High power magnets

The magnetic strength of a substance is measured using saturation and coercively magnetization data. When the granules' specific surface area and grain size both decrease, these values increase. Magnets composed of nanocrystalline

yttrium-samarium-cobalt grains have very interesting magnetic properties because of their incredibly large surface area. Ship motors, ultrasensitive analytical instruments, quieter submarines, automobile alternators, land-based power generators, and magnetic resonance imaging for medical diagnosis are among the common applications [37].

6.10 Batteries

An important technology in contemporary civilization is the storage of electrical energy at high charge and discharge rates. Watches, toys, electric vehicles, computers, laptops, and other electronic devices all utilize batteries. These batteries need to be recharged regularly because of their limited storage capacity [42]. The shelf life of conventional batteries is among their key determining factors. As a result of their foam-like structure and the high surface area that nanoparticles provide, NMs can be used to extend the storage capacity and longevity of batteries [43]. In contrast to traditional batteries, for example, Ni-MH batteries made of nanocrystalline nickel and metal hydrides need to be recharged less frequently and have superior mechanical, chemical, and physical properties. Utilizing nanotechnology, Toshiba has created special electrode materials to increase the capacity of these batteries [44].

6.11 Automobiles

There may be a loss of fuel and an increase in pollutants as a result of incomplete combustion of gasoline in engines. Therefore, using NMs to create spark plugs helps to improve their durability and corrosion resistance, as well as their lifespan and performance, which leads to perfect combustion [45,46]. Nanomaterials have been included in automobile paint and car glass to promote safety, but other uses of

NMs in cars are confined to producing particular parts that need improvement in some properties [46].

6.12 Aerospace components

Aerospace component makers work to make their products stronger, harder, and longer lasting due to the hazards associated with flying. The fatigue strength, which declines with age, is one of the essential qualities required of airplane components. The lifespan of the airplane is significantly extended by using stronger materials for the component construction [47]. A decrease in the material's grain size results in an increase in fatigue strength. Nanomaterials offer a considerable reduction in grain size compared to traditional materials, which results in an average 200–300% improvement in fatigue life [48]. Additionally, faster and more efficient flying is achievable with the same amount of aviation fuel since components manufactured from NMs are more resilient and able to function at higher temperatures. As the parts of a spaceship operate at significantly greater temperatures and faster speeds, the material must be resistant to elevated temperatures. Such components include thrusters, vectoring nozzles, and rocket engines [49]. Nanomaterials are the ideal choice for spaceship applications. In addition to all industrial applications, there are so many medical, agriculture, and biotechnology applications using nanotechnology [50].

7 Nanomaterials production techniques

A number of well-established methods exist for synthesizing NMs from diverse starting materials. All these methods adhere to the two fundamental techniques of “top-down” and “bottom-up” (as shown in Figure 2) [50]. The “bottom-

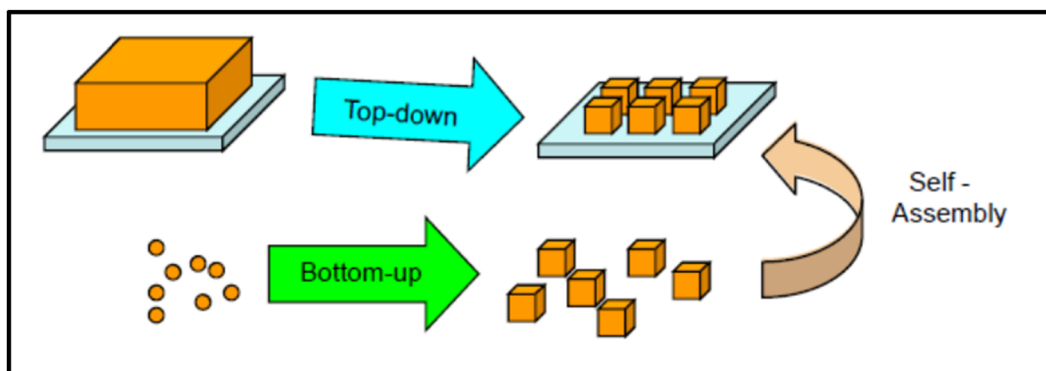


Figure 2: “Top-down” and “bottom-up” strategies for synthesizing NMs.

up” strategy is typically the antithesis of the “top-down” strategy. The processes utilized to develop mechanical and physical particles based on the reduction of larger materials into smaller ones to make NMs are referred to as “top-down” [51]. This procedure frequently makes use of specialized mills of various types for this purpose. Creating larger nanostructures using the bottom-up strategy begins with rearranging atoms.

The required characteristics and the chemical composition of the nanoparticles dictate which process is best. It requires in-depth understanding of the short-range forces of attraction, such as electrostatic and van der Waals forces, as well as other interactions between atoms or molecules. The following are a few instances of prominent and typical approaches (top-down and bottom-up) [50,51]. Depending on their crystal structure, manufacturing process, and material composition, many nanostructures can have quite varied morphologies. The synthesis techniques now in use enable the creation of nanoparticles in a range of sizes and forms, including spheres, cubes, octahedrons, rods, tubes, needles, and more. The variety of morphological forms that may be created at the nanoscale using organic molecules is practically limitless [52]. Using self-assembling duplex DNA as building blocks, for instance, modern biotechnologies enable the controlled manufacture of three-dimensional structures with sizes ranging from 10 to 100 nm. Nanoscale “DNA origami” – polygon frameworks, gears, bridges, bottles, *etc.* – was made using one of these methods [53]. Because morphology variation is a reflection of the result of surface (interface) development (transformation) throughout the material-making process, it is an efficient means of influencing the functionality of NMs that also influences their biocompatibility. Particularly for nanoparticles, morphological variety is crucial since these materials often have a high number of surface atoms that control their chemical and physical characteristics [54].

7.1 Bottom-up approaches

7.1.1 Vapor techniques

7.1.1.1 Aerosol processes

When an aerosol is atomized, it can form small droplets that solidify when the solvent is subsequently evaporated. Alternatively, an aerosol can be transformed into a particle by nucleation and growth through condensation and coagulation, respectively, to create nanoparticles using aerosol-based methods. It is possible to atomize various liquids or solid *via* nebulization or electrohydrodynamic atomization

and to prepare air for particles, one can use actuated plasma, flame, furnace, or spark discharge processes [55]. Aerosol-assisted chemical vapor deposition and physical vapor deposition methods will be discussed in detail. The aerosol method has been more and more popular recently since it is easy to use, has excellent control over the size and form of the particles, is inexpensive, adaptable, and produces clean particles with little environmental impact [56].

7.1.1.2 Atomic or molecular condensation (gas condensation) vapor condensation (vapor deposition) technique

Figure 1 displays a typical experimental setup. Within a horizontal tube furnace, the synthesis takes place in an alumina or quartz tube. An alumina boat laden with high-purity oxide particles is placed in the middle of the furnace, which has the maximum temperature. Usually, the substrates are positioned downstream, after the carrier gas, to gather the necessary nanostructures. Poly-crystalline alumina, single-crystal alumina (sapphire), or silicon wafer can be used as the substrates. O-rings are used to seal the stainless steel caps on both ends of the tube. A suitable temperature gradient in the tube is achieved by cooling water flowing within the cover caps. The system is first pushed down to around 10–2 Torr for the experiments. The tube is then heated to the reaction temperature at a predetermined heating rate by turning on the furnace. The tube pressure is then brought back to 200–500 Torr by adding an inert gas, such as argon or nitrogen, to the system at a steady flow rate (various source materials and final deposited nanostructures need different pressures). To evaporate the source material and attain a suitable level of deposition, the reaction temperature and pressure are maintained for a predetermined amount of time. It is possible to evaporate source materials under low pressure and high temperatures. The inner tube then transports the gas and the vapor to the lower temperature zone, where the vapor eventually supersaturates. The nucleation and development of nanostructures will take place once it reaches the substrate. When the furnace is switched off, the growth comes to an end. After that, inert gas is pumped into the system to bring it down to ambient temperature. The goal of the procedure is to vaporize the target materials quickly with a heat source and then swiftly condense them. Depending on the response, evaporation processes may be separated into physical and chemical (applying reaction gases instead of the carrier gas) processes as shown Figure 3 [57,58].

Physical vapor condensation (PVC) is used to create nanoparticles if their composition matches that of the

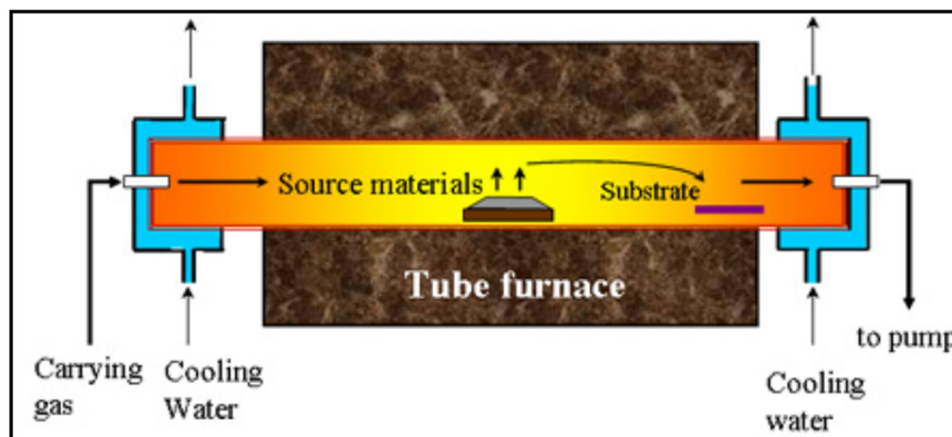


Figure 3: Vapor condensation (vapor deposition) technique.

target materials [59]. However, chemical vapor condensation (CVC), which occurs when vapor and other components are combined to form a vapor, is typically used to create nanoparticles that are different in composition from the target materials [60]. While the PVC approach produces a nanomaterial from a single source, the CVC process produces distinct components of the material once its composition is created. Making Fe or FeN nanoparticles, which are known to have great magnetic properties and corrosion resistance in addition to outstanding mechanical properties, is a perfect application for CVC techniques [61]. During the CVC process, the employment of the precursor Fe (CO) and the carrier gas NH provides the ability to alter the phase of these nanoparticles (Fe and FeN). Studying variations in the composition and phases of the resulting nanoparticles throughout the CVC process with the precursor decomposition temperature is the main goal of this work. A BM needs to be heated to a high enough temperature inside of a vacuum chamber (far beyond the melting point but less than the boiling point) to be vaporized and atomized and then guided to a chamber with either an inert or reactive gas environment. Nanoparticles were originally generated through nucleation, which was induced by the interaction of the metal atoms with the gas molecules, which resulted in their fast cooling. When a solution is added with oxygen, a reactive gas, metal nanoparticles are created. Consideration should be given to rapid oxidation, which might result in overheating and particle sintering. In general, gas evaporation typically results in materials and aggregates with a wide particle size range [62]. Nanoparticles such as iron, iron oxide, aluminum, TiO_2 , and Sb_2O_3 have been synthesized by vapor condensation which is based on the evaporation of a solid metal followed by rapid condensation to form nanosized particles to deposit the evaporation product on the hard surface. Nanosized powders can then be used as

fillers for composite materials or consolidated into BM [63–65]. The advantage of this method is the low level of contaminations and the ability to produce the desired final size by using suitable temperature, gas environment, and evaporation rate [66]. One of the most significant advantages of the vapor condensation process, which may be used to manufacture films and coatings, is its adaptability and simplicity of usage. Other advantages include the purity of the products and the density of the steam produced. This technique also makes it possible to quickly accelerate and guide high-density steam to the metal that has to be coated. Despite the advantages of this technology, its biggest disadvantages are its high manufacturing costs and the potential for interactions between heating source materials and metal vapors.

7.1.1.3 Arc discharge generation

Metals can also be vaporized by using an electric arc as a source of energy. Two electrodes made of the metal that will be vaporized in this process are charged with an inert gas. The application of a strong current approaches the breakdown voltage. The arc that forms between the two electrodes transfers a little amount of metal from one to the other. This procedure is relatively reproducible; however, it produces very little in the way of metal nanoparticles. You can make metal oxides or other compounds by using oxygen or another reactive gas [67]. Electrical discharge is a widely utilized technique because it produces significant evaporation rates due to its high temperatures.

7.1.1.4 Laser ablation techniques

Laser ablation technique is schematized in Figure 4 [68]. It consists of focusing on the surface of a material (gas or

liquid) using a laser beam, which causes its vaporization at the irradiated point. The impact between the evaporated part and the surrounding molecules results in the formation of a laser-induced plasma plume, which is subsequently confined in a specific region to disperse the nanoparticles so that the coagulation phenomenon is correctly controlled in the final stages of the process. In the ablation chamber, there are interactions among the target material, particle concentration, and experimental media (argon, water, and ambient air). However, due to the high concentration of evaporated material in the column, agglomerates may form there. This method is not commonly used because of its low throughput and high operating costs, especially on a large scale [68].

7.1.1.5 Plasma technique

Plasma spray synthesis and microwave plasma process are the two types of plasma processes. The plasma zone produces electric-charged particles that are used in the microwave plasma process. The advantages of the charged particles therefore result in a decrease in agglomeration and coagulation [69]. Reactants can ionize and dissociate at reaction temperatures lower than chemical vapor deposition, which is why the particles still have electrical charges on them. The approach has the ability to produce unagglomerated particles, a restricted particle size range, and quick production rates [70]. A technique known as plasma spray synthesis may be used outside to create nanoparticles. The incredibly high flow velocity of the produced nanoparticles makes collection challenging. The method has several benefits, including ease of use, affordability, and the ability to produce large quantities. Utilization of the method is constrained by the requirements for safe and efficient particle collection [71].

7.1.2 Liquid phase techniques

7.1.2.1 Sol-gel

The sol-gel technique is a more chemical (wet chemical) procedure for producing various nanostructures, especially metal oxide nanoparticles. The word “sol” describes organic or liquid solvents containing dispersions of finely divided solid particles, with sizes ranging from 1 to 100 nm. This process involves heating the material while stirring it until it gels, after dissolving it in water or alcohol [72]. The hydrolysis/alcoholysis process results in a wet or moist gel, which needs to be dried in accordance with its intended use and desired qualities. For example, burning alcohol is used to complete the drying process if the solution contains alcohol. After being created, the gels are crushed, dried, and then calcined. The low reaction temperature and accessibility of sol-gel technology allow for fine control of the chemical composition. The sol-gel approach is feasible due to its low reaction temperature, which also permits effective chemical composition control of the final products [73]. Ceramics may be produced using the sol-gel method for a number of uses, including as a bridge layer between thin metal oxide coatings and as a molding material. Sol-gel materials find extensive uses in optical, electrical, energy, surface engineering, biosensors, and a variety of separation methods, such as chromatography. The sol-gel procedure is a popular and useful way to produce nanoparticles with different chemical compositions [72,74].

7.1.2.2 Solvothermal technique

Solvothermal synthesis is a method of producing NMs at extremely high temperatures and pressures, usually between 1 and 10,000 atm. The process is typically carried out at a temperature that is equivalent to or greater than the boiling point

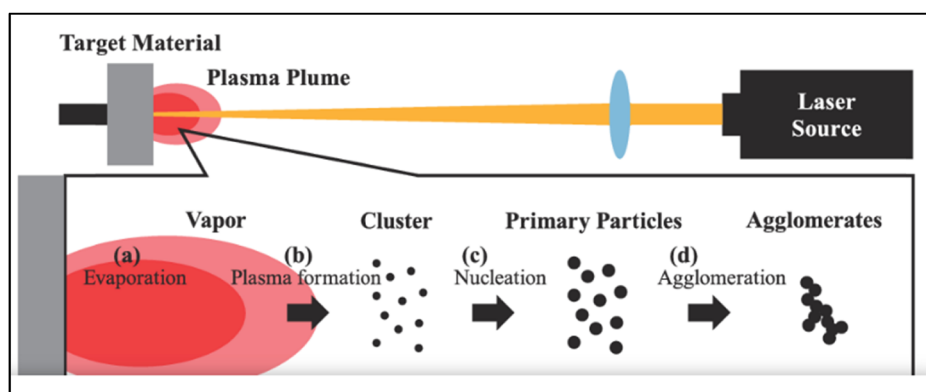


Figure 4: Laser ablation technique.

of the reaction medium in a sealed vessel (such as an autoclave) [75]. Reaction containers must be chemically inert. The reaction solution is heated over the boiling point of the solvent in the enclosed autoclave, resulting in high pressure. In such a situation, the solvent becomes a supercritical fluid, or a fluid in which the gaseous and liquid phases coexist. The autoclave is cooled to room temperature to extract the desired product when the reaction is finished. Solvent-related impurities are eliminated in the next step. When using water as the solvent and usually operating below the supercritical temperature of water (374°C), the technique is known as hydrothermal synthesis. Nanoparticles have been produced using this process in a range of shapes, such as spheres, rods, tetrapods, and others. These forms may be produced by varying the reaction temperature, precursor concentration, and reaction time [76].

7.1.2.3 Sonochemical technique

Strong ultrasonic radiation is used in sonochemistry, a scientific field that studies chemical interactions between molecules. The primary mechanism underlying the sonochemical reaction is acoustic cavitation, which is the growth, expansion, and collapse of bubbles in a liquid subjected to ultrasound. Even though cavitation is expected to be avoided when designing reactors because it can cause erosion damage, acoustic cavitation is essential to sonochemical processing since it can be regulated and restricted to only the reaction and not the reactor [61]. This process has been widely employed to generate nanosized materials with peculiar features because of the particular circumstances (very high temperatures (5,000 K), pressures (>20 MPa), and cooling speeds (>109 K s⁻¹) [51]. The inexpensive cost of sonochemical research is without a doubt its greatest advantage [77].

7.2 Top-down approaches

7.2.1 Solid phase techniques mechanical attrition (high energy ball milling)

With this method, each particle that has to be reduced to a nanosize is forcefully milling in tiny, closed cylinders using steel or ceramic balls. Final grain size is frequently influenced by the ball-to-powder ratio of the ball mill utilized, as well as milling duration, temperature, environment, and milling speed. High energy milling process involves mechanochemical and mechanical activation and by this technique, at least theoretically can synthesize all kinds of materials. The mechanochemical process involves chemical reaction

and phase transformation due to the application of mechanical energy (ball milling) [78–80]. Carbides of Ti have been synthesized directly from mixtures of titanium oxide and graphite as well as ferrotitanium and graphite through mechanical activation and heat treatment. In the proposed technique, the synthesis of TiC was achieved at a temperature much lower than those used in the conventional carbothermic reductions due to the mechanical activation process and reducing the powder to nanosize [81,82]. X-ray diffraction method was used to characterize the powders in their as-milled state. Many reports are available on the formation of nanopowders by mechanical alloying from raw materials [83,84]. A major disadvantage of mechanical alloying and mechanical activation is the possibility of contamination from the milling media and agglomeration due to the large forces and energies involved in the milling process. However, This can be minimized by limiting the milling time. The technique holds tremendous potential for the inexpensive synthesis of a variety of ceramic and metallic nanopowders [85,86]. The main factors that affect the MA process are types of mill, milling tools, milling environmental, milling temperature, milling time, and milling atmosphere [87]. There are various types of mills (attrition mill, horizontal mill, 1D vibratory mill (shaker mill), planetary mill, and 3D vibratory mill) (Figure 5). Various types of

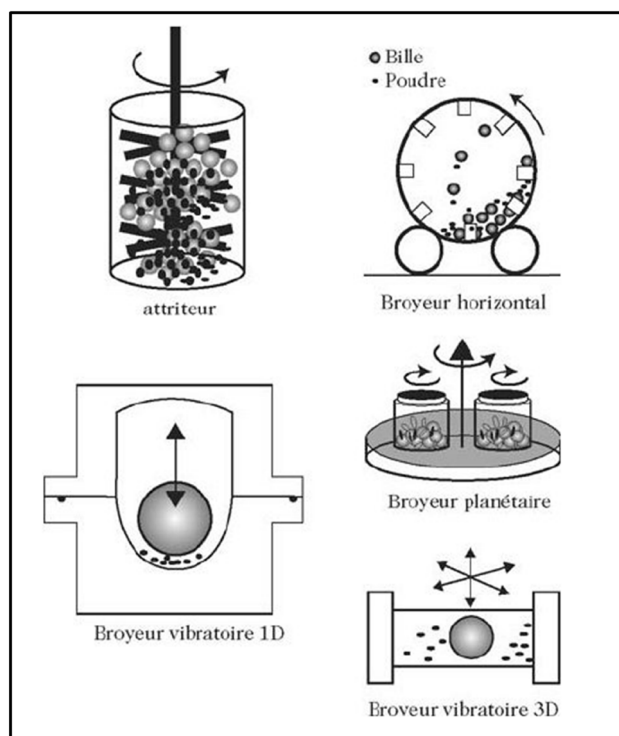


Figure 5: Different types of ball mill: attrition mill, horizontal mill, planetary mill, and the 1D and 3D vibratory mills.

mills differ in their capacity, speed of operation, and ability to control the operation by varying milling temperature and the extent of minimizing the contamination of the powders. The high-energy ball mills most commonly used in research laboratories comprise one or more containers in which the powder and balls are placed.

During milling the component powders are (a) both ductile, (b) ductile/brittle, or (c) both brittle. Accordingly, they exhibit different morphologies during milling. A thorough study of the characteristics, applications, and fabrication processes of nanoparticles often results in the improvement of industrial products via the selection of the most appropriate characteristics, applications, and manufacturing procedures [88]. The required NMs may now be produced by a variety of synthetic techniques, including mechanical milling, physical processing, and wet chemical processes. Different nanocomposites have been synthesized using physical and chemical processes; however, these approaches remain limited since they need complex setups, have low nanoparticle productivity and high operating costs, generate huge amounts of chemical waste, and significantly increase the risk of contamination. Due to these shortcomings, researchers have focused on developing more convenient fabrication techniques for selective applications.

8 Conclusions

For a very long time, humans have used NMs without realizing it. Scholars first encountered the idea of contemporary nanotechnology because of Feynman's well-known lecture, "There's Plenty of Room at the Bottom." Since then, there has been significant advancement in nanotechnology, and the subject is always growing into new areas. Materials of any size between 1 and 100 nm are typically referred to as NMs. Nanomaterials are synthesized using two primary methods (both top-down and bottom-up methods). Unique mechanical, optical, electrical, and magnetic features that set them apart from more conventional materials have been demonstrated by NMs. The family of NMs has been thoroughly studied for a wide range of applications because of its large surface areas, quick charge transfer capabilities, and strong mechanical characteristics. As a result of well-organized nanostructures, more attention is presently being paid to creating NMs with regulated morphologies and nanoscale dimensions in order to accomplish the desired results. A deeper comprehension of the issues facing contemporary society and the quick advancement of nanotechnology can help resolve future problems. Based on the current state of research and development in NM field, In the future,

nanotechnology additives will have the potential to demonstrate self-sense properties that help materials to self-heal when damaged, which could be useful in the aviation industry. Despite its many beneficial applications and capabilities to develop modern industries, Nanotechnology faces several challenges, including cost, acceptability and compatibility concerns, and information gaps about the advantages of employing NMs.

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