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Study of the Methods Used to Manufacture Nanomaterials

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Abstract:

The interdisciplinary topic of nanomaterial manufacturing encompasses engineering, chemistry, biology, physics, and materials science. It is certain that new materials with specific qualities will be produced as a result of collaboration between scientists from other fields. In order to design products that are directly transferred into the industrial sector and to stay informed about future issues and demands, the success of nanomanufacturing hinges on the close collaboration between academics and industry. There are two approaches to producing a material at a nanoscale: the top-down approach begins with a tangible size of the material being studied and gradually reduces it to the nanoscale. This involves the use of light drilling, cutting, scraping, and grinding processes. The smallest scale that can be obtained with these procedures is within 100 nanometers, and research is still ongoing to acquire smaller sizes than that. These techniques have been used to attain minuscule electronic substances, such as computer chips and others. The other method works from the bottom up, or bottom-up, starting with single molecules as the smallest unit and building up to a larger structure. These methods are typically chemical in nature, and they are distinguished by their ability to produce products that are small (one nanometer in size), reduce material waste, and increase bonding strength among the resulting nanoparticles.

Introduction

American theoretical physicist Richard Feynman initially introduced the concept of nanotechnology in his 1959 speech "There's Plenty of Room at the Bottom." Products are created for a variety of purposes, including improved and new ones[1]. The word "nanotechnology" has been in use since

1974. The definition was given by Taniguchi [2]. Moreover, a definition of nano science and nanotechnology was published in 2000 by the US National Nanotechnology Initiative (NNI) [3]. Nanotechnology (nm) is the most accurate metric measurement unit currently in use. It depicts nanostructures that are around 80,000 times smaller than the diameter of a hair and lengths of one billionth of a metre. The unification of nanoscience has opened up a plethora of scientific potential.

This process of material production has unexpected consequences and is meant to be used in all areas of cognition, such as advanced technology, biology, chemistry, and physics [4]. The manufacturing revolution powered by nanotechnology will propel ideas beyond the conventional and industrial to almost unthinkable heights when contrasted to the current state of affairs. Vasileios Markakis, Costas A. Charitidis, Pantelitsa Georgiou, Malamatenia A. Koklioti, and Aikaterini-Flora Trompeta conducted study in 2014. Engineering, chemistry, biology, physics, and materials science are all included in the multidisciplinary field of nanomaterial fabrication. Collaboration between experts from different domains will undoubtedly result in the production of novel materials with unique properties. Success in nanomanufacturing depends on tight cooperation between academia and industry to design products that can be directly implemented in the industrial sector and to stay informed about difficulties and requests that may arise in the future. It is critical to select an appropriate procedure that combines the synthesis of nanomaterials with the required properties and low contamination levels with the technique's scalability. Their industrial implementation is severely hampered by the absence of specific provisions in EU legislation, a suitable regulatory framework, and guidance on safety criteria. The lack of an appropriate framework for patent registration and legislation pertaining to intellectual property rights further impede the process of bringing a product into the industrial world. High-quality nanomaterials have a growing number of industrial applications, making them promising future resources with a broad range of possible applications. Without a doubt, the existing gap between fundamental research on nanomaterials and practical applications will decrease in the next ten years. In 2019, Nada M. Čitakovid conducted study on physical properties. Due to their unique physical characteristics and the plethora of potential everyday uses, nanoparticle materials have garnered increased attention over the past ten years. It's been demonstrated that there is a change in the physical properties (magnetic, mechanical, optical, melting temperature, material conductivity, etc.) of materials when compared to bulk materials. For some physical elements, differences could range widely and perhaps approach several orders of magnitude. Because they hold enormous promise for the generation of innovative materials with a wide range of scientific and technological uses, materials built of nanoparticles are the focus of extensive research. The manufacturing of materials based on nanoparticles is expected to increase in the near future, and these materials are expected to play a significant role in technology, medicine, and other fields. This study aims to investigate material manufacturing processes. The trajectory of science and technology in the future It provides scientists with essential knowledge that they can utilise to treat a variety of diseases, including cancer. Computer processors, solar collectors, and pharmaceuticals are some of the other industries that benefit from it. As so, it might fit in smaller sizes and more effectively on computers. Scientists predict that this technology will change the appearance of Earth [5-8].

2. The theoretical section

Europe's manufacturing sector is currently facing increased pressure from increasingly competitive economies. China and other formerly developed economies are posing a threat to Europe's hegemony, especially in the high-technology sector [9–12]. will be necessary in order to generally approve nanomaterials (NMs) to enter the industrial sector. One of the most promising industries in the manufacturing segment is NM manufacturing. The nanomanufacturing economy is growing these days [13]. There are projections that NMs' sales will surpass 14 billion euros by 2015, notwithstanding the fact that precise forecasts cannot be produced beyond 2020. NMs are often not visible in the final product, even if they are introduced early in the value chain. Therefore, the majority of industrial sectors ought to regard nanotechnology as a new field of study with unquantifiable financial benefits before the end of this decade. Considering this, it is ridiculous that there aren't more companies in Europe that are devoted to producing NMs alone. European nanomaterials manufacturing does not prioritise carbon-based nanomaterials such as fullerenes, carbon nanotubes (CNTs), and carbon nanofibres (CNFs). Most manufacturers who include nanomaterials into their operations do so sparingly. The scientific community concentrated its research efforts on creating new NM production processes in order to raise the interest of the industrial sector in NM production. The majority of commodities requiring fabricated nanostructures are produced today using top-down traditional technologies, and the enormous facilities needed for large-scale manufacturing have a substantial environmental impact [14–16]. Regretfully, the majority of suggested methods are either ineffective for large-scale production or fail to successfully maintain the desired characteristics of the created NMs. Another major issue that scientists address is the necessity of equipping these cutting-edge manufacturing techniques with in situ monitoring of the entire process in order to generate high-quality goods. One possible solution that can lessen the chance of a product failure is online process monitoring, which offers ongoing feedback on the product's quality. Therefore, extensive collaboration between the scientific community and end users is crucial to overcoming these obstacles. [17].

2.2. Methods for Synthesis of Nanoparticles

2.2.1. Procedures based on aerosols In the industrial context, aerosol-based techniques are a common means of generating nanoparticles [18, 19]. An aerosol is a system of liquid or solid particles suspended in air or another gaseous medium. Molecules as small as 100 nm can be considered particles. Aerosols were in use for a very long period before the basic science and engineering behind them were fully understood. For example, paints and plastics were made with pigments like titania and carbon black particles, which were also used to strengthen car tyres. Another illustration is the process of flame pyrolysis, which forms fume silica and titania from the corresponding tetrachlorides. Additionally, optical fibres are created via a process akin to this [20]. Spraying is used to dry wet materials and apply coatings. When the precursor chemicals are sprayed onto a heated surface or into a hot atmosphere, they cause a precursor pyrolysis, which formats the particles. Oxford University developed a room-temperature electrospraying technique for semiconductor and metal nanoparticle production [21]. Using a spray gun deposition technique, catalyst precursors such iron chlorides (III) were deposited to facilitate the production of CNTs. These catalyst deposition methods are inexpensive, simple to apply, and effective on a wide range of substrates. They are also appropriate for large surfaces [22].

2.2. 2. Gas condensation, often known as atomic or molecular condensation Since it was first explained in 1930, the gas-phase condensation process is without a doubt the original theory for producing metal nanoparticles [23]. The metal to be evaporated, a pumping system, a vacuum chamber with a heating element, and apparatus for gathering powder are the main parts of the gas condensation system. When a bulk material is heated in a vacuum chamber to a temperature that is sufficiently high—far above the melting point but below the boiling point—a stream of vaporised and atomized materials is created. The stream of evaporated and atomized material is subsequently directed towards a chamber that contains a gas environment, either inert or reactive. The ideal gas pressure is one that is both high enough to promote particle formation and low enough to permit spherical particle formation. The metal atoms' contact with the gas molecules causes them to cool quickly, which leads to the nucleation and subsequent formation of nanoparticles. Reactive gas, like oxygen, when added to a solution, produces metal nanoparticles. Rapid oxidation should be monitored since it may lead to particle overheating and sintering. The resulting materials often have a broad particle size distribution and agglomerate because the formation of particles during gas evaporation is basically random [24, 25].

2.2.3. Production of arc discharge The process of creating energy with an electric arc is another way to vaporise metals. The charging of two metal electrodes in the presence of an inert gas is the basis of this technique. High current is delivered until the breakdown voltage is reached. The arc that forms between the electrodes causes a small amount of metal to vapourize from one to the other. This method is reasonably reproducible, despite producing very little metal nanoparticles. Metaloxides and other compounds can be made with oxygen or another reactive gas [26]. Even though it's a well-known method, industrial processing depends on managing the arc's extraordinarily high temperature process, which produces enormous evaporation rates. High concentrations of the vaporised metal in the carrier gas can also result in the production of large particles [27].

2.2.4. Procedure for laser ablation The feeding mechanism for the metal target and the high-power laser beam with the optical focusing system are the two main parts of the laser ablation technique (Figure 2.1). When the laser beam is focussed at the target surface, it expands into the gas environment above the target, ejecting a supersonic jet of evaporated material known as a plume perpendicular to the target surface. The carrier gas transports the produced particles to the product collector. The production of extremely crystalline materials and the use of metals and metal oxides as precursors are the main advantages of this technique. The concentration and distribution of particle sizes

2.2.5. Vapour deposition of chemicals To create a thin solid coating onto a substrate, chemical vapour deposition (CVD) involves initiating chemical reactions between the substrate surface and a gaseous precursor [20]. The process temperature can be considerably lowered in comparison to the thermal CVD method by the use of plasma (PECVD: Plasma Enhanced Chemical Vapour Deposition) or higher temperatures (thermal CVD). This method's inexpensive setup costs, high production yield, and flexibility of scaling up make it a popular choice for materials processing [21]. Chemical vapour deposition has emerged as a cutting-edge production technique in numerous industries, including the ceramic and semiconductor sectors [28]. A typical industrial CVD system consists of an exhaust gas treatment system (e.g., NaOH and liquid N2 traps before by-products are released into the atmosphere), an energy system, a gas delivery system, a reaction chamber or reactor, a loading/unloading system (transport of substrates) and a process automatic control system. The gases are introduced into a reaction chamber that is set up to function at a high temperature between 500 and 1200 ˚C. Additionally, inert gases like nitrogen and argon are frequently employed as carrier gases. When the heated substrate and the gases enter the reactor, they react and deposit a solid layer onto the substrate's surface. The two most important operating factors for this process are the temperature and pressure system [29]. Figure 2.2 shows a CVD system at laboratory scale. When it comes to scaling up, CVD is the only approach that shows promise when compared to arc discharge and laser aided procedures, and it is frequently employed for the manufacturing of CNTs [30].

2.2. 6. The process of plasma There are two types of plasma processes: spray synthesis and microwave plasma process. Particles carrying electric charges originate in the plasma zone and are a part of the microwave plasma process. The advantages of the charged particles therefore allow for a reduction in agglomeration and coagulation [19, 20]. Lower reaction temperatures than chemical vapour deposition are possible because the reactants are ionised and dissociated, but the particle electrical charges are retained. The method's narrow particle size distribution, high production rates, and capacity to produce unagglomerated particles are its advantages [21]. One technique for producing nanoparticles that can be employed even in an open environment is plasma spray synthesis. The collection of the generated nanoparticles is difficult due to the extraordinarily high flow velocity of the particles. The method's simplicity, affordability, and potential for mass production are its advantages.

2.2. 7. Sol-gel

An established industrial approach for producing colloidal nanoparticles from liquid phase is the sol-gel method. In recent years, it has undergone additional development in order to produce cutting-edge nanomaterials and coatings [26, 27]. The Sol-gel process is a chemical technique that relies on condensation or hydrolysis processes (Figure 2.3). Nanosized particles precipitate when the reactants are added in the right amounts. Numerous benefits of sol-gel methods include low processing temperatures, adaptability, and simplicity in shaping and embedding. Alkoxides are frequently utilised as precursors for the synthesis of oxides because they are readily available and the M-OR bond's high liability, which makes in situ tailoring during processing easy. By using this technique, the possibility of nanoparticle release upon solution drying is reduced [28].

Solvothermal technique (2.2. 8) The procedure of starting chemical reactions between a gaseous precursor and a substrate surface in order to deposit a thin solid coating on the substrate is known as the "solvothermal method" [20]. By using higher temperatures (thermal CVD) or plasma (PECVD: Plasma Enhanced Chemical Vapour Deposition), the process temperature can be lowered significantly when compared to the thermal CVD approach. This approach is well-liked for materials processing because of its low setup costs, high production yield, and adaptability to scaling up [21]. In many areas, including semiconductor and ceramics, chemical vapour deposition has become a state-of-the-art production method [28]. An energy system, a gas delivery system, a reaction chamber or reactor, a loading/unloading system (transport of substrates), an exhaust gas treatment system (e.g., NaOH and liquid N2 traps before by-products are released into the atmosphere), and a process automatic control system make up a typical industrial CVD system. A reaction chamber that is designed to operate at a high temperature of 500–1200 ˚C is filled with the gases. Furthermore, inert gases such as argon and nitrogen are commonly used as carrier gases. A solid layer is deposited on the surface of the substrate as a result of a reaction that occurs when the heated substrate and the gases enter the reactor. The temperature and pressure system are the two most crucial operating parameters for this process [29]. A laboratory-scale CVD setup is depicted in Figure 2.2. Compared to arc discharge and laser assisted processes, CVD is the only method that exhibits promise in terms of scaling up, and it is widely used in the production of CNTs [30].

2.2. 9. For the synthesis of fine oxides and powders, hydrothermal synthesis is appropriate. The pressure is higher than the ambient pressure and the operating temperatures are typically lower than 100 C. Because of recent advances in reactor design, hydrothermal synthesis is an enabling and supporting technology that is ready to demonstrate its worth at the industrial level. The process of continuous hydrothermal synthesis involves combining a metal salt solution with superheated or supercritical water to create nanoparticulate material. That is, the two distinct fluids are continually mixed together instead of slowly heating the entire contents of a batch vessel [4]. The continuous hydrothermal reactor system with its inlets, mixing zone, and formulation phases is displayed in Figure 2. 4. To be more precise, the superheated fluid flows down an inner nozzle pipe (A) and up against a cold metal salt flow (B). At the interface between the two fluids, nanoparticles develop, and the slurry of nanoparticles is carried by the buoyancy of the heated flow [17, 25].

10. Sonochemical technique 2.2 The study field known as sonochemistry examines how the application of intense ultrasonic radiation causes molecules to conduct chemical reactions [6]. The process of sonochemical development, growth, and collapse of bubbles in a liquid under ultrasonically irradiation is known as acoustic cavitation. Acoustic cavitation, despite its potential for harm, is essential to sonochemical processing because it can regulate and restrict its effects to the reaction rather than the reactor [7]. Since the special conditions (very high temperatures (5000 K), pressures (>20 MPa), and cooling rates (>109 Ks 1)) allow for the formation of smaller particles and different shapes of products than other methods, this method has been widely used to produce nanosized materials with unusual properties [38].

The main advantage in conducting sonochemical experiments is that it is very inexpensive.

2.2.11 Milling and mechanochemical processing both result in mechanical attrition. The industrial technique of mechanical attrition (MA) has been used since 1970 to convert powder particles into new alloys and phase combinations. The large-scale manufacture of nanocrystalline powders is made possible by this technique's ability to overcome the quantitative limits on the preparation of nanocrystalline materials. Furthermore, it offers multiple choices for forming different combinations of atomic bonding in nanostructured powders, including metal/metal, metal/semiconductor, and metal/ceramic, as well as crystalline/crystalline or crystalline/amorphous structures. The ability of the mechanical milling process to function at low temperatures, which permits the freshly formed grains to develop extremely slowly, is one important advantage [8]. With this method, complex materials with particular grain or interface-boundary patterns can be produced. Since it is sometimes difficult to distinguish a glassy structure from a nano-crystalline structure, research has focused on nanocrystalline nanomaterials, which have grain or interphase barriers between the nanophase domains [9]. Two different processes for making nanopowders have been devised using mechanical milling. In the first, a single phase powder is ground by controlling the equilibrium point between cold welding and fracture. Particles larger than 100 nm cannot be welded in this way at extremely low temperatures [8]. The average grain size decreases from 50–100 nm to 2–20 nm as a result. This decrease in average grain size, which is around 103–104, is due to the creation and self-organization of large-angle grain boundaries between the powder particles. The process of producing microstructures differs greatly from other synthesis processes, despite the finished microstructure being somewhat similar.The powder particles' internal structure is continually refined to nanoscale sizes due to the considerable plastic deformation caused by mechanical attrition [3]. During the process, temperatures rise to above 100 to 200 degrees Celsius[4]. Mechanical milling is quite prone to contamination, even if air control can be used to regulate chemical reactions between the environment and the milled particles[39].This led to the development of the second technique, called mechanochemical processing (MCP), which is a novel and affordable means of creating a variety of nanopowders. mechanical.In MCP, a conventional ball mill can be used as a chemical reactor with a low temperature. The active powder mixture's reaction kinetics are accelerated by the ball mill due to the intimate mixing and nanoscale grain structure refining. This is the actual milling process that happens. To make sure the reaction is finished, temperature heat treatment is usually used after the reaction. In order to lower process costs and industrialise products, a variety of precursors can be employed, such as oxides, carbonates, sulphates, chlorides, fluorides, hydroxides, and others [8]. Numerous ball mills, such as planetary mills, shaker mills, tumbler mills, vibratory mills, and attrition, have been developed for mechanical attrition [4]. Shaking or violent agitation are components of the method. The powder is added to a closed container containing coated steel or tungsten carbide balls that have been hardened. The powder's typical particle diameter should be 50, and the mass ratio between the powder and the ball should be 5:10. High density materials, such as steel or tungsten, are ideal for milling since a ball's kinetic energy is determined by its mass and velocity [30].

Conclusion

Unlike the case of making ordinary materials, the physical and chemical composition of the raw materials employed in the manufacturing process have a significant impact on the attributes of the final nano-material. Depending on their size, they can be seen under a microscope and be either visible or undetectable to the unaided eye. The size of the particles in these materials ranges from hundreds of micrometres to centimetres, whereas the particles in nanomaterials have a size between one and one hundred nanometers.

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