Review

Classification, Synthetic, and Characterization Approaches to Nanoparticles, and Their Applications in Various Fields of Nanotechnology: A Review

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Abstract: Nanoparticles typically have dimensions of less than 100 nm. Scientists around the world have recently become interested in nanotechnology because of its potential applications in a wide range of fields, including catalysis, gas sensing, renewable energy, electronics, medicine, diagnostics, medication delivery, cosmetics, the construction industry, and the food industry. The sizes and forms of nanoparticles (NPs) are the primary determinants of their properties. Nanoparticles' unique characteristics may be explored for use in electronics (transistors, LEDs, reusable catalysts), energy (oil recovery), medicine (imaging, tumor detection, drug administration), and more. For the aforementioned applications, the synthesis of nanoparticles with an appropriate size, structure, monodispersity, and morphology is essential. New procedures have been developed in nanotechnology that are safe for the environment and can be used to reliably create nanoparticles and nanomaterials. This research aims to illustrate top-down and bottom-up strategies for nanomaterial production, and numerous characterization methodologies, nanoparticle features, and sector-specific applications of nanotechnology.

Keywords: classification; synthetic; characterization; various fields of nanotechnology

1. Introduction

The field of nanotechnology has been increasingly popular during recent years. Nanoparticles are the core of nanotechnology. Nanoparticles are incredibly tiny particles with a size of less than 100 nm and can comprise carbon, metal, metal oxides, or organic substances [1]. The nanoparticles have distinct physical, chemical, and biological properties compared to their counterparts at larger sizes. Increased chemical reactivity or stability, a larger surface area relative to volume, greater mechanical strength, etc. all contribute to this effect. There are many uses for nanoparticles because of their specific properties. Nanoparticles differ from one another in size, shape, and dimension in addition to their material. Nanoparticles, such as nanodots and clusters, can have zero dimensions

if their three spatial dimensions are all inside the nanometric range. Nanotubes, nanorods, and nanowires all fall under the category of one-dimensional nanoparticles because their dimensions are in the nanometric range [2] or two-dimensional materials with at least one spatial dimension in the nanoscale range, such as graphitic carbon nitride [3] (g-C3N4) thin films or nanosheets and phosphorenes [4]. Whether it is nanosized grains in dense polycrystals or 3D porous nanostructures, the term three-dimensional means that the 0D, 1D, and 2D components are in compact, contact-forming surfaces [5,6]. Nanoparticles come in a wide variety of sizes, shapes, and compositions. Its sizes range from 1 to 100 nm and its shapes can be described as spherical, cylindrical, tubular, conical, hollow core, spiral, flat, etc. Surfaces can be smooth and homogeneous or uneven and wavy. Some nanoparticles have a crystalline or amorphous structure, with single- or multi-crystal solids that are dispersed or aggregated [7].

There are a variety of synthesis methods under development or improvement to enhance characteristics and lower manufacturing costs [8,9]. Process-specific nanoparticles are created by adapting several approaches in order to improve their optical, mechanical, physical, and chemical properties [10]. Due to the advancements in technology, scientists are now better able to characterize nanoparticles and find useful applications for them [11]. Today, nanoparticles can be found everywhere from kitchenware to electronics to renewable energy to aerospace. Nanotechnology has the promise of a bright and sustainable future.

Numerous types of nanoparticles such as metal oxide, perovskite, and composite nanoparticle have been synthesized with high efficiency in their properties. Hybrid semiconductor nanoparticles and heterojunction structures are emerging nanomaterials with enhanced photocatalytic properties. The hybrid system was first demonstrated for the colloidal CdSe nanorods with the deposition of Au metal. Using advanced synthetic techniques to control the morphology, size, position, and composition of various components. These HNPs have performed in photocatalytic water splitting via hydrogen generation through clean solar-to-fuel conversion. It plays a vital role in photocatalytic CO_2 reduction. The photocatalytic property of HNPs has important environmental applications such as water purification, waste treatment, and antibacterial activities [12].

Excessive consumption of personal care products and pharmaceuticals is drastically deteriorating the environment. Novel heterojunction structures are being designed as photocatalysts with high electron-hole segregation rates, low cost, and high redox power such as $Cd_{0.5}Zn_{0.5}$ nanorods/BiOCl microspheres. In this structure, $Cd_{0.5}Zn_{0.5}S$ has excellent photocatalytic potential, strong reducing power, broad solar light response, and abundant resources. However, its photocatalytic performance is undermined due to carrier reunion, weak oxidative activity, and photo corrosion. BiOCl has photocatalytic activities with properties such as eco-friendliness, facile defect engineering, strong physical stability, and unique photo/electric properties. However, it also has the problem of having a large band gap (3.2–3.4) and recombination of photogenerated electron/hole pairs. These problems are solved by the formation of heterojunction structures. The literature has confirmed that $Cd_{0.5}Zn_{0.5}S$ /BiOCl heterojunction shows a 2.8-fold and 9.6-fold increase in photo activity compared to the individual $Cd_{0.5}Zn_{0.5}S$ and BiOCl, respectively [13].

2. Classification of Nanoparticles

2.1. Organic Nanoparticles

This class of nanoparticles, organic nanoparticles (ONPs), are synthesized from organic molecules with a size of 100 nm or less [14]. Examples of this class are well-known organic nanoparticles or polymers, including ferritin, micelles, dendrimers, and liposomes. Micelles and liposomes are nanoparticles with a hollow interior known as a nanocapsule that are sensitive to heat and electromagnetic radiation (heat and light) [15]; they are also biodegradable and non-toxic. Because of their distinguishing features, they are preferable alternatives for medication delivery. The drug-carrying capacity, its stability, and delivery methods, either an entrapped drug or adsorbed drug system, affect their area of applications and their efficiency, despite the importance of the size, composition, surface shape, etc. [16].

Because of their efficiency and the fact that they may be injected into specific sections of the body (a process known as targeted drug delivery), organic nanoparticles find widespread application in the biomedical field, for example, in the drug delivery system [17].

2.2. Inorganic Nanoparticles

Nanoparticles that lack carbon atoms are known as inorganic nanoparticles. Inorganic nanoparticles are typically defined as those composed of metals or metal oxides.

2.2.1. Metal-Based Nanoparticles

Metal-based nanoparticles are synthesized to nanometric sizes using either destructive or constructive processes. The nanoparticles of nearly every metal are synthesizable 18. Metals such as aluminum (Al) [18], cadmium (Cd) [19], cobalt (Co) [20], copper (Cu) [21], gold (Au) [22], iron (Fe) [23], lead (Pb) [19], silver (Ag) [19,24], and zinc (Zn) [25] are frequently employed in nanoparticle synthesis. Metal nanoparticles, due to their quantum effects and enormous surface-to-volume ratio, have outstanding ultraviolet-visible sensitivity, electrical, catalytic, thermal, and antibacterial properties [26]. As a result of the lower particle size, there are many more atoms on the surface. The surface area to volume ratio of particles varies according to the shape and size of nanoparticles, which in turn affects properties such as the ultraviolet-visible sensitivity and conductivity. The electronic energy levels, electron affinities, electronic transitions, magnetic characteristics, phase transition temperature, melting point, and affinities to polymeric, biological, and organic substances are only some of the many properties that are influenced by changes in the surface area. Nanoparticles acquire their charge through a combination of the Coulomb charging effects and the quantum size mechanisms [27]. There is a wide spectrum of intriguing properties obtained when the Coulomb charge effect is combined with the quantum size, which are not seen in the same bulk material. Particles with sharp edges and spherical shapes are particularly susceptible to quantum phenomena. Nanoparticles are used in catalysis, sensing, and imaging according to their size-dependent effects.

2.2.2. Metal Oxide-Based Nanoparticles

Researchers have shown growing interest in metal oxides during the past few decades. Positive metallic ions and negative oxygen ions combine to form ionic compounds known as metal oxides. Ionic interactions are strong and stable because of the electrostatic interactions between the positive metal ions and the negative oxygen ions [28]. For instance, nanoparticles of iron (Fe) are readily converted to nanoparticles of iron oxide (Fe_2O_3) when exposed to oxygen at room temperature, greatly increasing its reactivity in comparison to iron nanoparticles. These oxide-based nanoparticles are synthesized to modify the properties of their metal-based counterparts. In order to take advantage of their enhanced reactivity and efficiency [29], metal oxide nanoparticles are often synthesized. Silicon dioxide (SiO_2), titanium oxide (TiO_2), zinc oxide (ZnO), and aluminum oxide (Al_2O_3) are among the most frequently synthesised oxides [30–34]. When compared to their metal analogues, these nanoparticles show remarkable qualities.

2.3. Carbon-Based Nanoparticles

Carbon has played a pivotal role in the development of human civilization on Earth. When combined with other materials, it creates bonds that are unrivaled in strength. Different methods of synthesis have led to the development of a wide variety of carbon-based nanomaterials during the past few decades. As a result of their unusual shape and varied qualities, they have found application in many multiple sectors. Nanomaterials based on carbon have several potential uses, including storing and producing energy, treating water and wastewater, and biological applications. There are a number of allotropic shapes that carbon can take. Diamond, graphite, and buckminsterfullerene are all examples of allotropes. Graphite possesses the highest thermodynamic stability among them all. Because of its high conductivity, it can be used in a variety of electronic applications,

including batteries, electrodes, solar panels, etc. Graphite is made up of stacked sheets of graphene. Graphene is a new type of carbon that consists of a single layer of atoms arranged in a honeycomb arrangement on a two-dimensional sheet. It is quite useful as a building block in the creation of other forms of carbon nanoparticles [35] due to its high strength. Carbon nanotubes are another novel form of carbon (CNTs). Although CNTs, fullerenes, and graphene are all synthesised in different ways, their physical properties and chemical properties are connected. The development of derivatives and composites based on fullerenes is the most far-fetched because they are the oldest known. Despite this, CNTs and graphene have vast potential for further study and show promise as viable alternatives in a wide range of fields. Activated carbon has been shown to be an excellent adsorbent in a wide variety of applications, including adsorption, separation, catalytic processes, and many more [36].

2.3.1. Fullerenes

Buckminster fullerene, one of the most notable and widely applied fullerenes, is C60. The cage-like arrangement of its 60 carbon atoms (each with 3 bonds) gives it a shape resembling that of a soccer ball [36]. In the C60 construction, 20 hexagons and 12 pentagons are used. Resonance stabilization and icosahedral symmetry are two properties that are well-established for this structure. Due to its distinctive set of physicochemical features, it finds application in the field of material science. C60-based nanostructures, including nanorods, nanotubes, and nanosheets, have recently found wide use in many fields of nanoscience and nanotechnology. C60 is versatile and can be used to speed up the reactions of a wide range of compounds in many different ways [37]. Because of its unique qualities, it can be integrated into systems to improve specific behaviors. C60 can undergo molecular manipulation and the synthesis of polymeric material for use in environmental applications through covalent, endohedral, and supramolecular transformations.

2.3.2. Graphene and Graphene Oxide (GO)

The fabrication of polymer-based nanocomposites has found graphene to be a useful addition in polymers [35]. The outstanding mechanical, electrical, and molecular barrier qualities are responsible for this. However, there are challenges associated with pure graphene, including its complex bottom-up synthesis, limited solubility, and agglomeration issues. In this way, graphene oxide and other structurally related compounds can be made from carbon sources using a straightforward top-down approach. Since they may be readily synthesized, they are suitable alternatives to graphene. Their great solubility and efficient surface modification are both made possible by the diffusion of functionalized oxygen groups on their structure. Additionally, GO functions well as a filler in nanocomposite polymers. This is because it disperses well in polymer matrices and has excellent properties. A tight structure is formed by sp2 carbon atoms that block the passage of gas molecules. As a result, it finds widespread application as a packaging material, shield for delicate electronics, and corrosion-resistant material [38]. Due to its unique hydrophilic, electrical, and thermal properties, GO is used in the development of stimuli-responsive materials.

2.3.3. Carbon Nanotubes (CNTs)

Carbon nanotubes (CNTs) are a highly adaptable form of the carbon allotrope. It is designed and built from rolled-up sheets of graphene and has a structure that is both cylindrical and tubular and long. Multi-walled carbon nanotubes (MWCNTs) are created by many concentrically interlocked nanotubes while single-walled carbon nanotubes (SWCNTs) are made up of a single layer of carbon atoms. SWCNTs have a maximum diameter of 3 nm, but MWCNTs can be larger than 100 nm. The mechanical strength of MWCNTs is greater than that of SWCNTs because of the presence of multiple layers of carbon atoms. In comparison to common metals such as iron and steel, CNTs have been found to have significantly greater tensile strength and Young's modulus [39]. SWCNTs are well-suited for use as sensors due to their remarkable twisting properties. Because of their

great durability, MWCNTs find application in composites research. Mechanical, electrical, chemical, and biological applications of CNTs have been reported [40]. Electrochemical and energy storage applications, and vacuum microelectronics and electron field emission systems, heavily rely on CNTs. Because of their uniform shape and pinpoint accuracy, they are superior in the electrical industry. Hydrogen is also stored in CNTs. Because of their exceptional absorption capacity, they are ideal for this use. Carbon nanotubes (CNTs) are frequently employed as filler and reinforcement material in mechanical composites for the purpose of lowering the overall weight [41].

2.3.4. Carbon Nanofiber (CNFs)

Carbon nanofibers (CNFs) are nanofibers with a hollow core made of either a single layer of graphite or two layers of graphite layered in parallel or at an angle to the fiber axis of [42] degrees. The adjacent layers are piled in a variety of configurations, such as parallel, cup-stacked, and bamboo-like. In the case of [43] CNFs, graphene layers are layered in the form of cones, cups, or plates to form spherical nanostructures. CNTs are cylindrical carbon nanotubes (CNFs), which are generated when CNFs containing graphene are rolled up. Since CNTs have smaller diameters, lower densities, and better mechanical qualities (due to fewer microstructural defects) [44], CNFs have received less attention. In contrast to CNTs, however, CNFs are ideal replacements because of their inexpensive cost and wide availability [44]. The development mechanism of carbon fibers and the parameters that regulate their shape is of critical importance [45] due to their widespread industrial uses. Furthermore, CNFs can be investigated and tested for the purpose of applying the information learned to costly CNTs [46] because of their inexpensive synthesis cost. MWNTs have a fabrication cost that is two to three times greater than CNFs while SWNTs are much more costly to fabricate. Research into new methods of fabrication should lead to additional reductions in the already low cost of fabrication [46]. CNFs have found more uses due to their unique properties. Scientists now routinely employ CNFs in the fabrication of composite materials that vastly outperform state-of-the-art materials [47]. Due to their unique electrical, thermal, and mechanical qualities, CNFs have attracted a lot of interest. These CNFs are used in electrical applications because they require less loading to obtain the required electrical conductivities. The structure of CNFs is determined by the synthesis method (catalysts, feedstock, etc.) and the post-treatment methods [48–50], both of which influence CNFs' characteristics.

2.3.5. Activated Carbon or Charcoal

Activated carbon, often known as charcoal, is a type of carbon that has been processed so that the pores are extremely small and the volume is very low. The purpose of its synthesis is to provide a wide surface area for adsorption or chemical reactions. Therefore, activated carbon is widely employed as an adsorbent in water purification operations to remove foulants. It is commonly used in the extraction of minerals from water and the purification of colors and gases. The problem is that the efficiency of the removal is low. Nanoporous activated carbon is a functional kind of activated carbon that is used to obtain the required efficiency [51]. Nanoporous structures are mostly made of carbon. There is also some hydrogen and oxygen but in lower concentrations. Nitrogen, sulphur, phosphorus, and inorganic materials may also be present, depending on the precursor, production method, and post-synthesis processing. When examining the nanoporous surface, oxygen groups are most obvious. Nanoporous activated carbon is used extensively because of its high-quality pore shape (micropores or (micro + mesopores)) and heteroatoms (including oxygen, nitrogen, and sulphur) [52].

3. Synthesis of Nanoparticles

This study seeks to investigate the processes involved in the fabrication of nanomaterials using a variety of methods. Nanomaterials can be synthesized in two distinct ways, as depicted in Figure 1.
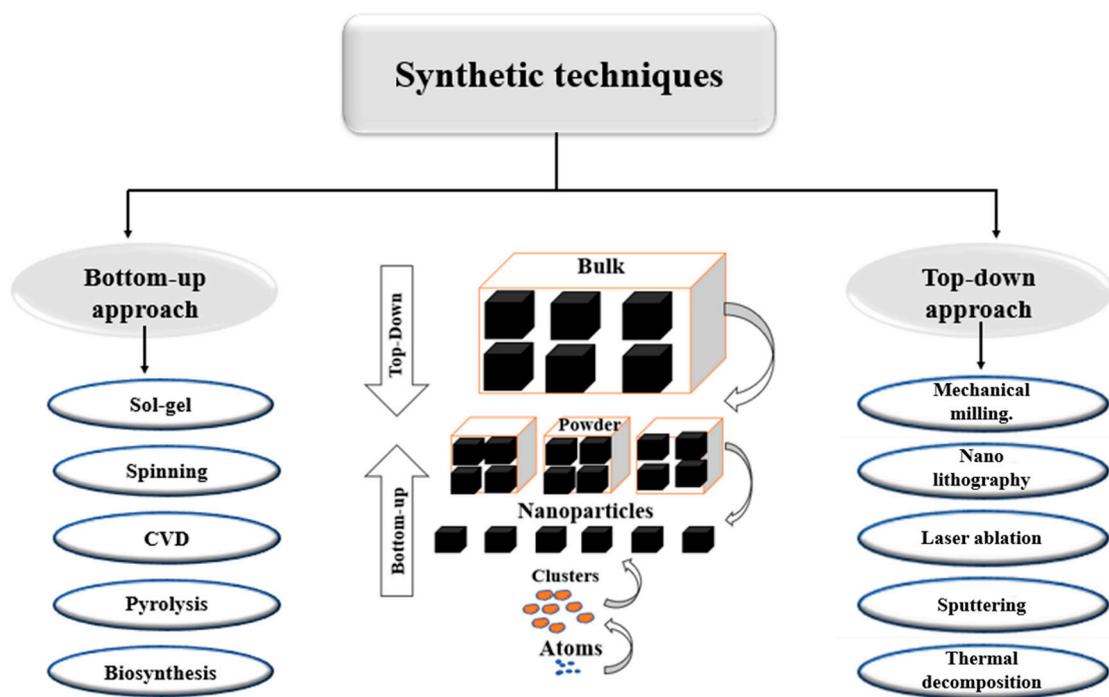
Figure 1. Bottom-up and top-down synthetic approaches to nanoparticles.

3.1. Bottom-Up Method

The bottom-up, or self-assembly, method of nanofabrication involves the utilization of chemical or physical forces acting at the nanoscale to combine building blocks into functional structures. In bottom-up synthesis, materials are synthesized from the atomic to the cluster to the nanoparticle level. Biological systems are the inspiration for bottom-up techniques since they use chemical forces to build everything necessary for existence. Scientists aim to mimic nature by creating atomic clusters that can self-assemble into increasingly complex shapes. Sol–gel, spinning, chemical vapor deposition (CVD), pyrolysis, and biosynthesis are the bottom-up processes that are utilized most frequently in the fabrication of nanoparticles.

3.1.1. Sol–Gel Method

The sol–gel technique is a highly adaptable soft chemical process that is extensively utilized in the synthesis of metal oxides, ceramics, and glasses. Ultrafine or spherical powders, thin film coatings, ceramic fibers, and microporous inorganic membranes are only some of the additional ceramics and glasses that may be available commercially [53,54].

Primitives for the sol–gel process typically include metal alkoxides or organometallic inorganic salts. This process involves a chain reaction of hydrolysis and polycondensation that results in a colloidal suspension or a sol from the precursor. The molecules in a system go from a homogenous liquid (or "sol") to a solid (or "gel") state during the sol–gel process, which occurs at room temperature and pressure [55–57]. After preparing the gel, the nanopowder of metal oxide is obtained by drying and calcining the gel at various temperatures. The shape, morphology, and textural qualities of the resulting materials can be adjusted with the sol–gel process.

The sol–gel approach offers many benefits over high-temperature methods, including the ability to create metastable materials, increased product purity and compositional homogeneity, and lower operating temperatures. Additionally, the shape of the particles is affected by this process as the molecular precursor is chemically transformed into the final oxidic network. The sol–gel approach has previously been reported by multiple research groups for the synthesis of nanoscale iron oxide and alumina.

One of the numerous benefits of this procedure is that it can be used to create metal and ceramic nanomaterial at temperatures between 70 degrees Celsius and 320 degrees Celsius, greatly expanding the spectrum of materials that may be processed [58–61], achieving atomic-level homogeneity in the final product, molecular-scale compositional control, and porosity to obtain high-surface-area materials. High-purity reagents also allow for the synthesis of materials with complicated compositions, leading to more pure end products. Thicknesses of more than a micron are challenging to achieve with physical deposition techniques, but the sol–gel process makes this possible. Coatings can be applied over intricate geometries, and complex composition materials can be synthesised. Hydrolysis and polycondensation methods are frequently employed to produce sols from inorganic metal salts or metal–organic compounds. A variety of ceramic materials can be fashioned through additional processing of the sol. Spin-coating and dip-coating are two methods for creating thin films. Sol forms a moist gel when poured into a mold [62,63]. Due to volumetric shrinkage, a solid and stiff structure is achieved [64] after drying the gel. It is worth noting that a nanosized porosity [65,66] can be achieved by carefully manipulating the drying conditions of the gel. One of the benefits of nanoporosity is that it has a much higher specific surface area than regular porosity [67,68]. Hydrogen, for instance, can be trapped and stored in the porosity of a nanoporous carbon material [69–72].

The main drawbacks of adopting the metal alkoxide-based sol–gel technique are its susceptibility to moisture and the lack of commercially available precursors that are acceptable, especially for mixed-metal oxides. It is common for the different hydrolysis susceptibilities of the individual components to cause problems in the sol–gel synthesis of mixed oxides from alkoxide mixtures. Additionally, the advantages of improved homogeneity may be lost during the hydrolysis of the alkoxides, which may ultimately result in component segregation and mixed phases in the final product [73].

3.1.2. Spinning Method

A spinning disc reactor is the equipment that is used to carry out the spinning method of nanoparticle synthesis (SDR). A disc rotates inside a chamber/reactor whose physical properties, such as temperature, can be adjusted. Nitrogen or other inert gases are commonly used to purge the reactor of oxygen and prevent chemical reactions from taking place [74].

Streams of liquid reagents are directed at the disc's center, where it is rapidly rotated (between 300 and 3000 rpm) to create a film of fluid (1 to 200 nm). High heat and mass transmission are caused by the fluid layer's thickness and the vast contact area between the layer and the disc's surface. As a result, the drag forces that are created between the moving fluid and the disc surface make it possible for the reagents in the liquid streams that are flowing down the disc surface to micromix in a manner that is both highly effective and very quick. Nanoparticles, which have a diameter of 100 nm or less, require a manufacturing process that encourages nucleation while stifling particle development and clumping. When the concentration of the limiting reagent is highest, the nucleation rate is highest, the supersaturation is highest, and the reaction rate is highest. Micromixing, or the thorough mixing of the fluid streams entering the reactor, is necessary to achieve equilibrium between the chemicals. Micromixing often occurs in less than one millisecond.

To intensify the mixing of liquid streams passing over its surface, the spinning disc reactor (SDR) is the more adaptable and basic piece of machinery. A commercially viable quantity of the solid product can be made when the process is run in a continuous mode. It is easier to scale up from a lab scale of operation and has a higher level of safety than conventional stirred tank reactors [75]. Materials with a water-like viscosity can normally be processed at a rate of roughly 150 kg/h in SDR with a 500-mm diameter.

The fluid streams may enter the disc at its center or travel its circumference. The optimal feeding point criterion for a solid production process strikes a balance between the desired maximum local mixing and residence time. The disc's temperature can be controlled by a heating coil placed underneath it or by a thermostatic fluid stream moving

through the disc plate. Most of the time, the rate of rotation is variable and under close supervision [76]. The disc is round and can be smooth or grooved, depending on the material used. The latter scenario involves the creation of waves and ripples within the disc's liquid layer to induce turbulence. Some installations use a vertical SDR with a horizontally rotating shaft to facilitate slurry removal. Two coaxially rotating discs [77] form a novel energy dissipation apparatus with increased novelty and efficiency (DSDR). The top disc can spin in both a clockwise and anticlockwise direction. The effectiveness of DSDR in precipitation-based barium sulphate synthesis was studied. The new machinery has several benefits, one of which is the reduction in particle size and the consequent smaller particle size dispersion.

3.1.3. Chemical Vapor Deposition (CVD) Method

A chemical process, chemical vapor deposition, involves the reaction of volatile precursors in the gas phase to generate a solid molecule that is deposited on surfaces [78]. Chemical processes that occur on or near a hot surface (heterogeneous) and gas-phase reactions (homogeneous) work together to deposit powders or films. Most CVD reactions are endothermic, meaning that energy must be added to the reacting system in the form of activation energy. The main drawback of the chemical vapor deposition process is the potential for chemical dangers caused by the explosive, poisonous, and corrosive precursor gases. The difficulty in the deposition of multi-component materials is another disadvantage of this technique [79].

The chemical vapor deposition (CVD) method is divided into subcategories based on the energy source used to commence the process, such as thermally activated CVD [80], plasma-enhanced CVD [81], and photo-initiated CVD [78].

Thermally Activated CVD

Conventional chemical vapor deposition (CVD) processes [82], such as thermally activated CVD (TACVD), use inorganic chemical precursors and rely on the use of heat to kick off the chemical reactions. A common practice is to increase the temperature in the gas phase in order to generate reactive species and speed up the kinetics [78]. These systems typically supply temperatures between 800 and 2000 °C. TACVD's primary benefit is its ease of use and rapid growth rate at low pressure (normal pressure). This method, which is well-suited to a high-volume continuous growth process [83], is now frequently utilized in the industry for surface coatings. Although there are benefits to using thermal sources, there are also drawbacks to consider. The temperature-sensitive substrates may be destroyed by excess heat, for instance, and this would severely restrict the available precursors [84]. Furthermore, there is significant wasted energy due to the inefficient gas heating precursor process. Thus, to permit deposition at lower temperatures, many alternate kinds of energy input were created.

Plasma Enhanced CVD

Plasma-enhanced chemical-vapor deposition (PECVD) [85] is one method for lowering growth temperatures. Glow discharge chemical vapor deposition is yet another name for physical evaporation chemical vapor deposition (PECVD). Instead of using heat energy, electron energy (plasma) is used to kickstart processes, resulting in the formation of chemically active ions and radicals that can take part in heterogeneous reactions and thus make low-temperature, rapid deposition possible [86,87].

Plasma-enhanced deposition, in contrast to TACVD, can take place at low temperatures, even near ambient temperatures. This paves the way for the deposition of substrates such as aluminum, organic polymers, metals, and metal alloys that are sensitive to temperature [88]. In addition, PECVD is regarded as the most potent CVD method because of the high energy transferred to the relevant species. Various materials, both those with typical properties and those with unusual ones, have been deposited using PECVD techniques, and this technique has been utilized to create inorganic and organic compounds and polymers.

However, as a result of its high energy input, it frequently catalyzes reactions too rapidly, leading to undesirable side effects and higher complexity of the final results [89].

The liquid-phase plasma (LPP) technique is another way to create nanoparticles. Because this nonequilibrium plasma can produce quick reactions due to the reactive chemical species, i.e., radicals, it is a new practical and easy way to make metal nanoparticles. Solvent and process gas are the only elements that affect LPP. In addition, high-energy radicals and a number of reactive species are formed in this case of LPP, leading to the direct synthesis of a number of NPs, including metal, alloy, oxide, silicon, carbonaceous, and composites [90].

The use of liquid-phase plasma for the production of inorganic nanomaterials is less frequent. Liquid-phase plasma is exceptional in the synthesis of various types of nanomaterials, particularly nanocomposite materials, because it produces a variety of active compounds that are also numerous and have a higher density of radicals and electrons [90]. Because of this, it has attracted increasing attention in recent years and has been used in the production of many different nanomaterials, including metal nanoparticles and layered double hydroxides (LDHs). The production of nanoparticles and nanostructures is reasonably low cost, especially when compared to solid-phase synthesis techniques. Experimental procedures in liquid-phase synthesis are straightforward with a high mass yield. Traditional benchtop chemistry is used with common reagents and equipment. Surface functionalization can be accomplished in situ with respect to the application field [91,92]. Another advantage of plasma technology is the synthesis of toxic free nanomaterials, which can be used in biological applications and in the field of medicine. Due to this distinguishing property, this technique is receiving significant attention [93].

Due to the numerous applications of nanotechnology, a precise and particular particle size and form are needed. However, the plasma is easily influenced by ambient conditions and the production of bubbles during the electrical breakdown of liquid, making it difficult to control the nanoparticle size with this method. This means that without carefully regulating the gas bubble forms, it would be hard to control the size and shape of nanoparticles, particularly in the case of the in-liquid plasma process [90].

Photo-Induced CVD

Photo-induced CVD (PICVD) [94,95] refers to a CVD procedure that uses photons with very high energy. Arc lamps, carbon dioxide lasers, Nd-YAG lasers, excimer lasers, argon ion lasers [96], and ultraviolet (UV) or vacuum ultraviolet (VUV) lights [97] are some of the many types of light sources used in PICVD. The interaction of light radiation with precursor molecules in the gas phase or on the growth surface [95] constitutes the process known as photo-induced chemical vapor deposition (CVD). Ultraviolet or visible photons from an excimer lamp can disrupt the chemical bonds in precursor molecules but only if the molecules absorb enough energy to do so. Coating by PICVD occurs as a result of the interaction of the light, precursor, and substrate light absorbed and energized by reactant molecules, intramolecular energy transfer, single or multiple photon dissociation, surface adsorption and desorption, surface diffusion, surface nucleation, and film growth kinetics. The gas source, light source, and film deposition conditions affect the PICVD reaction processes and development patterns. It is possible to operate the PICVD process at either atmospheric or decreased pressure (for example, 0.01–1 atm), drastically lowering the system [98] cost. In addition to the benefits associated with gas-phase coating methods, PICVD has additional potential benefits, such as the ability to be accomplished at room temperature, which can effectively prevent and eliminate the adverse impact of migration of impurities, self-doped gas miscellaneous, reaction system contamination, and radiation damage to the substrate in the high-temperature and plasma process [78].

3.1.4. Pyrolysis Method

One type of thermochemical process in which the substance is broken down into smaller components involves heating the material to very high temperatures in the absence of oxygen. This technique is the standard method used for mass producing nanoparticles

in the industry. One of the first steps is to use fire to char a predecessor. The liquid or gaseous precursor is injected into the furnace at high pressure through a narrow opening and burned [99]. In order to extract the nanoparticles, the combustion or by-product gases are first air categorized. For rapid evaporation, some furnaces use lasers and plasma instead of flame [100]. Pyrolysis has a high yield and is a simple, efficient, cost-effective, continuous process. However, it is challenging to achieve the required size of the nanoparticles using this method because as soon as the NPs leave the hot chamber, they attempt to aggregate and form NP chains. This is the fundamental drawback of the pyrolysis approach for synthesizing nanoparticles [101].

3.1.5. Biosynthesis Method

Nanoparticles that are safe for humans and the environment can be synthesized using biosynthesis. The synthesis of nanoparticles using biological systems is fast, practical, and environmentally beneficial [102]. Furthermore, NPs' toxicity and size characteristics can be adjusted to suit the application. Many studies have investigated the feasibility of synthesizing NPs by employing microorganisms such as bacteria, actinobacteria, fungus, yeast, microalgae, and viruses [103–105]. Microorganisms have cells that are naturally adaptable to a wide range of environments, proliferate rapidly, and require little maintenance. Exopolysaccharides, nanocellulose, and nanowires are just a few examples of the unique nanomaterials that bacteria and microalgae have the ability to produce [106–108].

Compared to the use of chemicals and physical processes, the production of NPs using biological sources (such as bacteria, actinobacteria, yeast, fungi, algae, and viruses) is safer [109–111]. Bacteria are favored for NP production because they can easily be cultivated in artificial circumstances and maintain a steady growth rate despite the low nutrient content of the fabricated NPs. Microorganisms have the ability to convert inorganic elements into NPs via their extracellular or intracellular routes [104,111], and they can adapt to increasing concentrations of metals. Microbes take in metal ions from the medium they are growing in and reduce them enzymatically to the elemental form [112].

The biological method for the synthesis of nanoparticles is green and free of toxicity, but the problem associated with this problem is that there are many other compounds in plant extractions and it takes a lot of time to remove all the impurity and there is still a chance of undesired particles to be present in the final product [113].

3.2. Top-Down Methods

The top-down, or destructive, approach involves breaking a material down to its atomic building blocks. Structures with a long-range order and linkages at the macroscopic level are strong candidates for top-down techniques. Using this method, large portions of material can be broken down into smaller, nano-sized pieces. While top-down methods are more accessible, they fall short when trying to produce particles with complex shapes or sizes. A major drawback of this method is the challenge it presents in producing particles with the right size and form. Common techniques for synthesizing nanoparticles include mechanical milling, nanolithography, laser ablation, sputtering, and thermal decomposition.

3.2.1. Mechanical Milling Method

Mechanical methods are the most cost-effective for mass-producing nanomaterials [114]. Grinding materials with a ball mill is perhaps the easiest method. The balls and milling chamber of the ball milling technique are what give this technique its name. A ball mill is essentially a stainless steel container with a large number of small iron, hardened steel, silicon carbide, or tungsten carbide balls designed to rotate within it [115]. A powdered substance is placed into the metal jar. By adopting a ball milling process, this powder will be reduced to nanoscale dimensions. Mechanical attrition, in which the kinetic energy of the grinding medium is transferred to the material being reduced, is the mechanism by which nanomaterials are synthesized in a ball mill [116]. Mechanical milling

is the most widely utilized top-down method for creating a wide variety of nanoparticles. With this method, a wide range of NPs and metal alloys can be manufactured. A quantity of the powdered substance is poured into the milling vial, and the friction and interaction between the vial and the balls produces heat and pressure, which can lead to a drastic phase transition at high temperatures [117]. It is used to make things such as particle sizes smaller in various materials. The crystallite size, particle size reduction, mechanical dislocation, surface modification, and the likely formation of metastable phases are all significantly affected by ball milling powder samples. Some reactions can be triggered that normally would not happen at room temperature.

The limitation of the ball milling method is that the resultant microstructures (nanostructures/nanoparticles) are very sensitive to the grinding environment and may be unintentionally contaminated by the milling media and environment. Long-term milling is necessary to prepare particles that are smaller (20 nm or smaller). The noise pollution and environmental disruption caused by the ball milling method is another drawback [118].

3.2.2. Nanolithography Method

Nanolithography, which scientists are currently studying, is used to produce structures on the nanometric scale, often with at least one dimension in the 1 to 100 nm range. In order to create patterns on the nanoscale, nanolithography is an extremely useful and powerful technique. Nanolithography is a multi-step procedure that can be used to build well-defined 2D metal arrays on surfaces with a fine regulated shape, size, and spacing. Multiple nanolithographic techniques exist, such as optical, electron-beam, multiphoton, nanoimprint, and scanning probe lithography [119]. As a rule, lithography entails printing a desired shape or structure onto a light-sensitive material and then selectively removing a section of the material to obtain the desired shape and structure. The ability of nanolithography to mass produce uniformly sized and shaped nanoparticles is its primary benefit. Complex equipment is needed, which increases the price, and there are other costs to consider [120].

3.2.3. Laser Ablation Method

Nanoparticles can be synthesised using a variety of solvents and laser ablation synthesis in solution (LASiS). Laser irradiation of a metal immersed in a liquid solution forms nanoparticles by condensing a plasma plume [121].

Nanoparticles (NPs) can be easily synthesised using laser ablation since it is a direct and fast method for producing a wide variety of NPs, including metal, semiconductor, polymer, and NPs of complicated many-element metal and semiconductor alloys. There is no need to use dangerous or explosive chemical precursors, the chemical reaction time is short, and neither high temperatures nor pressures are required. Ultrapure colloidal solutions free of reaction by-products are produced when NPs are synthesized in water. These characteristics of NPs [122] facilitate their biological and biochemical use in living organisms. In order to synthesize metal-based nanoparticles, this top-down approach is a reliable alternative to the traditional chemical reduction of metals. Because it enables the stable synthesis of nanoparticles in organic solvents and water without the use of stabilizing agents or chemicals, LASiS is regarded as a "green" research method. However, this method has some disadvantages. Long-term laser ablation causes a high concentration of nanoparticles to grow in the colloidal solution, blocking the laser's path and absorbing laser energy into the nanoparticles themselves rather than the target surface. Overall, this lowers the rate of ablation [123].

3.2.4. Sputtering Method

Sputtering is the process by which atoms are ejected from the surface of a substance (the target) via the bombardment of energetic particles [124]. Atoms on a cathode/target are sputtered when they are accelerated away from the cathode/target by the impact of

bombarding ions, which is a momentum transfer process. When atoms are sputtered, they travel until they hit a substrate, where they are deposited and create the desired layer.

Nanoparticles can be deposited on a surface via sputtering, which involves the ejection of particles from the surface in response to collisions with ions [125]. When using sputtering, a thin coating of nanoparticles is deposited and then annealed. The nanoparticles' size and form depend on factors such as the layer thickness, annealing temperature and time, substrate [126], etc. Pure metals and semiconductor elements and alloys and compounds, including oxides, nitrides, sulphides, and carbides, can all be sputtered.

The disadvantages of the sputtering method are that the sputtering gas composition (He, Ne, Ar, Kr, and Xe) has an effect on the surface morphology, composition, texture, and optical properties of the nanocrystalline metal oxide coating. Furthermore, compared to thermal evaporation, sputtering rates are modest, and the majority of the energy is transformed into heat when impacted on the target, which must be eliminated [127–129].

3.2.5. Thermal Decomposition Method

The synthesis of stable monodispersed nanoparticles via thermal breakdown is a novel approach. This synthesis method is also one of the most practical methods for producing monodispersed metal nanoparticles. More importantly, it solves the biggest problem in nanotechnology research: how to precisely regulate the size and form of nanomaterials (a challenge that has been estimated as being worthy at least) [130]. The synthesis time, temperature, reactant concentrations, stabilizer/capping agent (surfactant) concentrations, and surfactant type are other variables to consider when aiming for a precisely regulated nanometric size [131]. Solvent-free thermal decomposition, as described by Palacious-Hernández et al. and Kino et al., is a simple and moderate process that does not require raw materials [130,131]. Similarly, Tran et al. noted that unlike biological methods, thermal breakdown allowed for simultaneous production of a huge number of nanoparticles [132].

Because heat can break chemical bonds, thermal breakdown is endothermic chemical decomposition [133]. The decomposition temperature is the precise heat at which an element undergoes chemical breakdown. The production of nanoparticles involves breaking down the metal at very precise temperatures, triggering a chemical reaction that leads to the formation of byproducts.

There are some limitations to the thermal decomposition approach. A large number of metal compositions and combinations are simply difficult to deposit. There are only a few processing variables available for controlling the film properties. The source material could be inadequate [134].

4. Properties of Nanoparticles

In general, the characteristics of nanoparticles can be divided into two categories: chemical and physical.

4.1. Physical Properties

The optical properties of a nanoparticle include its color; its ability to transmit, absorb, and reflect light; and its ability to absorb and reflect ultraviolet light in solution or after being coated onto a surface are examples of the optical qualities that make up its physical makeup. In addition to this, it covers the mechanical properties of the material, such as its elasticity, ductility, tensile strength, and flexibility, all of which are important factors in the use of the material. The hydrophilicity, hydrophobicity, suspension, diffusion, and settling qualities are some of the other properties that have found their way into many commonplace items. Nanoparticles' conductivity, semiconductivity, and resistivity, among other magnetic and electrical properties, have opened the way for their use in thermal conductivity applications in state-of-the-art electronics. These applications are for sustainable energy.

4.2. Chemical Properties

The applications of this substance are determined by its chemical properties, which include the reactivity of the nanoparticles with the target, and their stability and sensitivity to elements such as moisture, environment, heat, and light. Nanoparticles are suitable for use in biological and environmental applications due to their antibacterial, antifungal, disinfecting, and toxic characteristics. The flammability, corrosiveness, anticorrosiveness, oxidative potential, and reduction potential of the nanoparticles all play a role in determining their individual applications.

5. Characterization

The potential and use of nanoparticles are both determined by the qualities that make it distinct. Figure 2 depicts an overview of the characterization techniques.
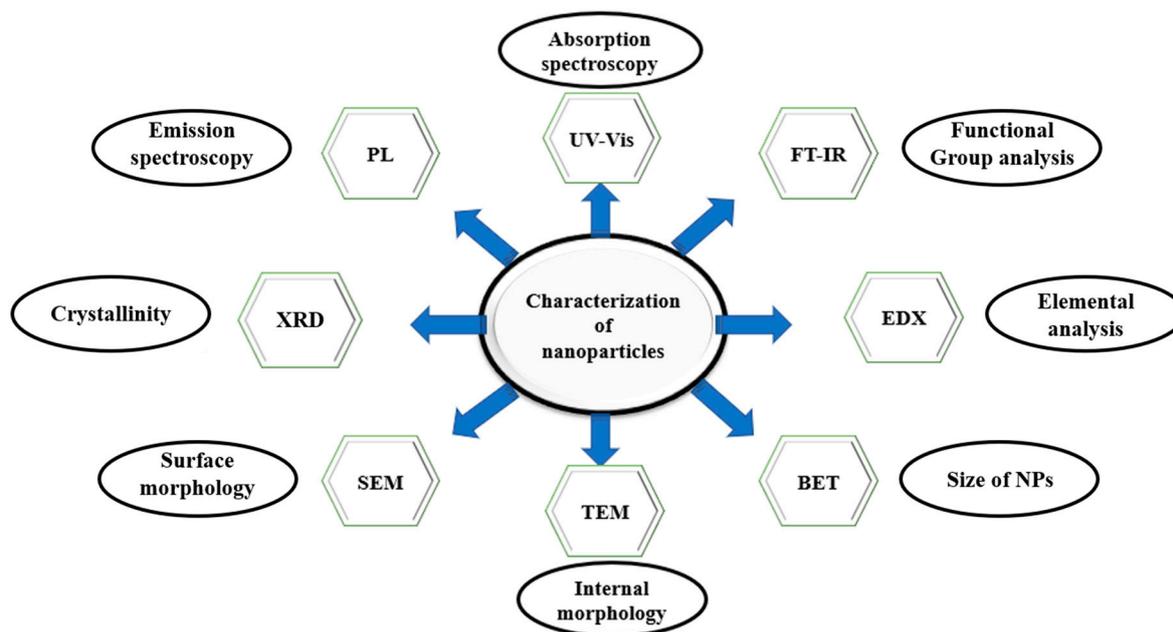

Figure 2. Overview of characterization techniques.

5.1. Size of Nanoparticles

Particle size is one of the most fundamental and fundamentally significant measurements for the characterization of nanoparticles. This factor determines the size of the particle, how it is distributed, and whether the particle is on the micro- or nanoscale. Electron microscopy is a technique that is utilized to measure the particle size and distribution most of the time. Images captured with a scanning electron microscope (SEM) or transmission electron microscope (TEM) are used for particle and cluster size analysis while laser diffraction techniques are utilized for the evaluation of solid-phase bulk samples [135]. Photon correlation spectroscopy and centrifugation are the two methods that are used to measure the particles found in the liquid phase. When dealing with particles that are in a gaseous phase, it is difficult and sometimes even irreverent to use imaging techniques. As a result, a scanning mobility particle sizer (SMPS) is utilized because it is superior to other measurement techniques in terms of speed and precision.

5.2. Surface Area of Nanoparticles

The surface area is another important feature to consider when attempting to characterize nanoparticles. The ratio of the surface area to the volume of a nanoparticle has a significant impact on the performance and attributes of the nanoparticle. BET analysis is the method that is most frequently utilized in order to estimate the surface area [136]. Although a straightforward titration is sufficient for determining the surface area of par-

ticles found in the liquid phase, this technique is laborious and time-consuming. As a result, nuclear magnetic resonance spectroscopy (also known as NMR) is utilized. For the purpose of measuring the surface area of nanoparticles while they are in the gaseous phase, a differential mobility analyzer (DMA) and a modified SMPS are utilized.

5.3. Composition of Nanoparticles

Nanoparticles' purity and performance are directly correlated to the chemical or elemental composition of the particles. It is possible that the presence of increased secondary or unwanted elements in the nanoparticle will cause the efficiency of the nanoparticle to decrease, in addition to leading to secondary reactions and contamination during the process. The X-ray photoelectron spectroscopy (XPS) technique is often utilized in order to carry out measurements of the composition [137,138]. In some methods, the particles are first subjected to chemical digestion, and then they are subjected to a wet chemical examination, which may include mass spectrometry, atomic emission spectroscopy, and ion chromatography. The particles that are in the gaseous phase can be collected either through filtering or electrostatically, and spectrometric or wet chemical techniques are utilized for the analysis [139].

5.4. Surface Morphology of Nanoparticles

Nanoparticles can take on a wide variety of shapes, and their surfaces can be patterned in a variety of ways, both of which are important for utilizing their properties. There are many different shapes, some of which are spherical, flat, cylindrical, tubular, conical, and irregular. The surfaces of these shapes can be crystalline or amorphous, and they can be uniform or have irregularities. Imaging methods using electron microscopy, such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM) [140,141], are typically used to determine the surface. When it comes to imaging using electron microscopy, the particles in the liquid phase are captured either electrostatically or through filtering while the particles in the gaseous phase are deposited on a surface for subsequent analysis.

5.5. Surface Charge of Nanoparticles

The interactions that a nanoparticle has with a target are determined by either its surface charge or its overall charge. Measurement of the surface charges and the dispersion stability of a substance in a solution is one of the most common applications for a zeta potentiometer [142]. To determine the charge of nanoparticles while they are in the gaseous phase, a differential mobility analyzer (DMA) is utilized.

5.6. Crystallography of Nanoparticles

Crystallography is the scientific study of the arrangement of atoms and molecules within crystals and other materials. To identify the structural organization of nanoparticles, crystallography can be performed using powder X-ray, electron, or neutron diffraction [143].

5.7. Concentration of Nanoparticles

It is necessary to quantify the number of nanoparticles that are dispersed throughout the gaseous phase in order to calculate the concentration of air or gas that will be needed for the operation. Performance can be measured in terms of its effectiveness by considering factors such as the concentration, size, and distribution of nanoparticles in a given volume of air or gas. In most cases, a condensation particle counter is utilized in order to carry out the measurements of concentration (CPC).

6. Applications

Nanoparticles are excellent prospects for a wide variety of applications across a range of fields due to their singular dimensions (size, shape, and structure) and their distinct biological, physical, and chemical properties. The applications of nanoparticles and various fields of nanotechnologies are shown in Figure 3.
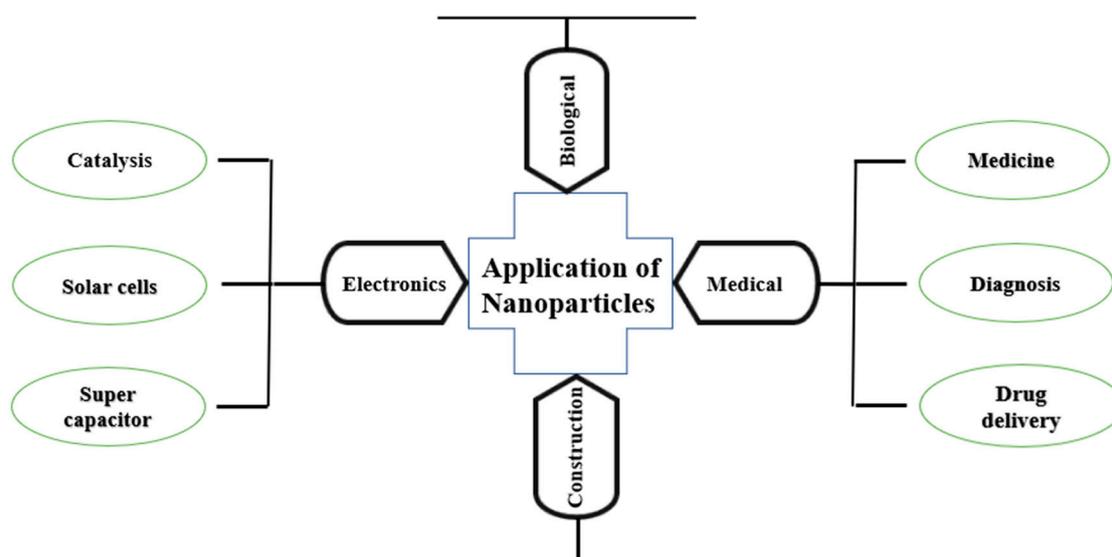
Figure 3. Application of nanoparticles and different fields of nanotechnology.

6.1. Catalysis

6.1.1. Dye Degradation

The removal of water pollutants that are present in water bodies, such as cationic dyes, acid dyes, azo dyes, and other contaminants of a similar kind, is essential for the treatment of wastewater and its potential future applications. These contaminants contribute to the contamination of water and have a harmful impact on aquatic life. NPs can either function as a catalyst or adsorb contaminants over their high surface area [144] due to the fact that they have a high surface area but a smaller size. It has been demonstrated that both Ag and AuNPs are capable of producing satisfactory levels of catalytic activity when it comes to the elimination of organic dyes. These nanoparticles speed up the rate of reaction while also reducing the amount of time necessary to remove the dye [145,146]. The use of platinum nanoparticles in automotive catalytic converters is one of the most important applications because these nanoparticles, which have a larger surface area, reduce the quantity of platinum that is needed, which in turn significantly lowers the cost of the converters while significantly improving their overall performance. Nanoparticles are used in a number of chemical reactions, including the reduction of nickel oxide to the metal nickel (Ni).

The primary technical issue for scientists in the application of photocatalysis in environmental remediation is always efficiency. The improved photocatalytic efficiency is primarily dependent on material improvement. However, the development of photocatalysts has surpassed the design of photoreactors, which severely restricts the use of photocatalysis technology in environmental remediation. A photoreactor, a device that brings photons, photocatalysts, and reactants into contact, is required for the implementation of many photocatalysts in industrially feasible applications. Nanoparticle separation, mass transfer limitation, and photonic efficiency have always been issues that limit photoreactors' high photocatalytic efficiency [147].

Photocatalysis is an environmentally friendly treatment due to its ability to achieve complete mineralization and zero end wastes. To be commercialized, a photocatalyst must be efficient to completely degrade the pollutant, reusable, and thermostable, i.e., not easily destroyed by temperature increases, and, most importantly, it should be cost effective. The synthesis of such a catalyst that absorbs a broad spectrum of sunlight for electron hole pair generation and prevention of the charge recombination increases the demands for a photocatalyst on the commercial level. Along with improving the catalyst efficiency, there is a need to develop photoreactors that do not limit the photocatalyst efficiency [147,148].

6.1.2. Nitrogen Fixation

The foundation of the modern economy is fossil fuels. Fossil fuels, on the other hand, are not renewable and will pollute the environment by producing massive volumes of CO_2 and other harmful gases. The widespread usage of fossil fuels since the Industrial Revolution has exposed humanity to two significant issues: energy shortages and environmental damage [149]. Furthermore, plants, animals, and other forms of life on Earth require the element nitrogen to survive. N_2 takes up more than 78% of the atmosphere, yet because of its inherent inertness, it is very difficult to use [150]. The best energy source to address and solve this issue is NH_3, which can be produced using the photocatalytic or electrocatalytic synthesis of atmospheric nitrogen into ammonia, which emits less CO_2 than fossil fuel [151]. The prerequisite for an effective nitrogen reduction reaction process is typically the adsorption of gas-phase N_2 onto the surface of the catalysts, and nanomaterials as catalysts play a vital role in this conversion or reduction of N_2 into NH_3 due to their high surface area.

6.1.3. CH_4 Conversion

The conversion of CH_4 into lower olefins, acetic acid (CH_3COOH), CH_3OH, aromatics, CO, and CO_2 is another method for producing clean energy [152]. Due to the rising demand for these compounds and the recent discovery of significant deposits and resources of CH_4, technologies for the effective conversion of CH_4 to higher value-added chemicals, such as fuels, olefins, and aromatics, are being sought [153]. However, CH_4 is the least reactive alkane as it has the strongest C-H bond (439 kJ/mol) and the lowest polarizability and electron affinity [154]. As a result, C-H bonds typically need to be activated at high temperatures and pressures, which significantly increases the capital expenditure and creates operational risks and environmental issues. Because it uses photon energy rather than heat energy to drive CH_4 oxidation, photocatalysis is a promising method [155].

6.2. Oil Recovery

Researchers in the upstream petroleum industry are interested in the applications of nanoparticles for oil recovery due to their high surface-area-to-volume ratio and their improved chemical reactivity. Since the very first day of production, nanoparticles have been investigated as potential additives to water flooding. In addition, nanoparticles have also been investigated as potential later-stage water flooding additives (secondary and tertiary recoveries). Nanoparticles were investigated at the laboratory scale for enhanced oil recovery (EOR) applications as performance improvers for polymer [156] and surfactant [157] flooding processes, wettability modifiers [158], emulsion stabilizers [159], etc. In the field of EOR applications, silica nanoparticles have received the most attention among the many kinds of nanoparticles.

6.3. Electronics

Nanoparticles are becoming more prevalent in display technology as a result of the increased demand in recent years for displays that are both huge in size and brighter than ever before. These displays are typically found in computer monitors and televisions. Nanocrystalline lead telluride, cadmium sulphide, zinc selenide, and sulphide are some examples of the materials that are utilised in the production of light-emitting diodes (LEDs) in current displays [160]. The rise of portable consumer devices, such as mobile phones and laptop computers, has resulted in an increasing demand for batteries that are small and lightweight despite having a high capacity for their given size. Nanoparticles are the superior option when it comes to the selection of materials for use as separator plates in batteries. Because of their foam-like (aerogel) structure, aerogel batteries are capable of storing a significantly greater amount of energy than conventional batteries. Batteries that are constructed using nanocrystalline nickel and metal hydrides have a larger surface area, which means that they require less charging over their lifespan [161].

6.4. Gas Sensor

Gases that are combustible, explosive, poisonous, or otherwise dangerous pose a significant risk to both human and environmental health and safety in everyday production and existence. As a result, there is an immediate demand for high-performance equipment that can detect these noxious gases. Due to their ability to transform a predetermined gas volume proportion into electrical signals, gas sensors serve a pivotal role in the identification of many different gases. They are advantageous due to being cheap, quick to react, sensitive, and selective. Additionally, the gas sensor device can be used in electronic interfaces without any additional wiring or calibration. For this reason, gas sensors have found widespread application in a variety of disciplines, including environmental tracking, air quality tracking, vehicle exhaust tracking, medical diagnostics, and food and cosmetics tracking.

Over the past few decades, scientists have perfected the process of creating gas sensors that are based on nanomaterials. Different types of gas sensors, such as semiconductors, polymers, contact combustion, and solid electrolytes [162,163], can be distinguished by their underlying operating principle. Semiconductor gas sensors have grown into one of the largest and most commonly used sensors in the world due to their ability to detect a wide variety of gases, high sensitivity, low cost, and straightforward manufacture [163]. Semiconductor gas sensors are classified as either resistive or non-resistive depending on the method used to detect the gas, with the former detecting the gas concentration by a change in the semiconductor's resistance value when exposed to the gas. Currently, resistive semiconductor-type gas sensors [163–165] are fabricated using gas-sensitive materials such as semiconductor metal oxides, conductive polymers, and carbon materials.

Metal oxides such as zinc oxide (ZnO), indium oxide (In_2O_3), tin oxide (SnO_2), and tungsten oxide (WO_3) have been proven to be the ideal choices for the fabrication of resistive gas sensors because of their benefits of simple manufacturing, low cost, easy mobility, and high sensitivity [166,167]. However, their rapid advancement has been limited by factors such as a high operating temperature, high power, and low selectivity [168,169]. Due to their distinct single-atom layer structure, high specific surface area, and numerous surface-active locations, two-dimensional (2D) nanomaterials, such as graphene, transition metal chalcogenides, layered metal oxides, black phosphorus, and others, have demonstrated significant potential in gas sensors [170,171].

6.5. Cosmetics and Sunscreens

Traditional sunscreen that offers protection from ultraviolet (UV) rays is not stable over the long term when it is used. Numerous benefits can be gained from the use of sunscreen that contains nanoparticles, such as titanium dioxide. Some sunscreens make use of titanium oxide and zinc oxide nanoparticles due to the UV protection that these nanoparticles provide. Titanium oxide and zinc oxide nanoparticles are both transparent to visible light, and they also absorb and reflect UV rays. Some lipsticks employ iron oxide nanoparticles as a pigment [172].

6.6. Medicine and Drug Delivery

In 1995, the United States Food and Drug Administration granted clinical permission for the use of the first nanoparticle-based drug, liposomal doxorubicin (Doxil®), for the treatment of cancer. This event marked the introduction of nanomedicines to the market [173]. More than 1500 different nanomedicine products have been tested in clinical settings as a result of the rapid expansion of nanomedicine research [174]. Liposomes, albumin nanoparticles, polymer micelles, and magnetic nanoparticles are a few types of nanoparticles that have been developed and approved for use as medical devices or nanocarriers for therapeutic and diagnostic substances [175].

The use of nanoparticles in the administration of drugs is one way that the area of medicine has benefited from nanotechnology [172,176]. Using nanoparticles, the medication can be transported to the desired cellular location [177,178]. Administration of the drug

in the desired location at the required dosage brings about a significant reduction in both the overall intake of the drug and its adverse effects. This approach lowers both the costs and the adverse consequences. With the assistance of nanotechnology, the process of tissue engineering, which involves the reproduction and repair of damaged tissue, can be carried out. Tissue engineering has the potential to take on the role of more conventional medical procedures, such as artificial implants and organ transplants. One such instance is the formation of carbon nanotube scaffolds for the growth of bones [179].

6.7. Diagnosis

Many different NPs are employed in the detection and treatment of various cancers. Such NPs are useful for precisely imaging tumors and/or delivering medications (theragnostic method) with minimal side effects. Some examples of nanodevices synthesised for use in oncology applications include quantum dots (QDs), carbon nanotubes (CNTs), paramagnetic nanoparticles (NPs), liposomes, gold nanoparticles (GNPs), MRI contrast agents for intraoperative imaging, and cutting-edge NP-based techniques for highly specific detection of DNA and protein [180–183].

Due in part to these innovations, NP probes for molecular and cellular imaging, tailored NP drugs for cancer therapy, and integrated nanodevices for early cancer detection have all been developed in recent years. As a result of these breakthroughs, personalized therapy, in which a patient's cancer is diagnosed and treated based on their unique molecular profile of genetic and protein indicators, is a promising area of research. Biocompatibility, in vivo kinetics, tumor-targeting efficacy, acute and chronic toxicity, escape from the reticuloendothelial system, cost-effectiveness, and other limitations have hampered progress in the preclinical and clinical stages of developing in vivo nanodevice applications [184,185].

New developments are required in the area of nanotechnology. Therefore, this field is defined by its persistent development and change considering these constraints. These initiatives have led to the diagnostic or therapeutic use of nanowires [186], nanocantilevers [187], quantum dots [188–190], nanoshells [191], dendrimers [192–194], liposomes [194,195], nanopyramids [196–198], and nanogels [199,200] in cancer research.

6.8. Food

Because nanoscale structures have exhibited unique capabilities that improve the sensory, physical, chemical, biological, antibacterial, nutritional, and healthy aspects of food products, food nanotechnology has been growing quickly over the past two decades. In particular, food scientists are adapting frameworks from other fields. Condensed matter physics, colloidal and polymer sciences, materials science and engineering, and pharmaceutics are a few examples of fields that could potentially provide solutions for the food industry. The utilization of nanotechnology enhances the food industry by enhancing harvesting, processing, preservation, and packaging. When used in the packaging of food, a nanocomposite coating can directly introduce antimicrobial chemicals onto the coated film surface [201]. Nanodrops, an additive used in the canola oil production business, are one such example. Their purpose is to facilitate the transmission of vitamins and minerals present in the food.

6.9. Construction

In the building industry, nanotechnology has led to faster, cheaper, and safer procedures. Improvements in the mechanical characteristics and durability are two outcomes of the incorporation of nanosilica (SiO_2) into conventional concrete [1,202]. The addition of hematite (Fe_2O_3) nanoparticles to concrete increases its strength [203]. There is no substitute for steel as a building material because of its accessibility and versatility. The utilization of nanotechnology in steel, for instance, results in nanosized steel, offering stronger steel cables for use in bridge construction [1]. Glass is also a crucial component of building materials. Glass for building purposes is a hot topic of study due to the potential benefits of incorporating nanotechnology. Titanium dioxide (TiO_2) nanoparticles are used to coat

glazing due to their sterilizing and anti-fouling qualities and their ability to catalyze a robust chemical reaction that breaks down volatile organic compounds (VOCs) and organic contaminants [204]. Nanotechnology-based window coverings are more effective in keeping outside light and heat out. By incorporating nanoparticles into paints, self-healing properties, resistance to corrosion, and insulation can be achieved. Because of their hydrophobic properties, these paints can be used to cover metal pipes to prevent corrosion caused by salt water. Paints benefit from nanoparticle inclusion since they are lighter and have better characteristics. When applied to large objects such as airplanes, for instance, the objects are lighter overall and require less paint, which is good for the environment and the company's bottom line.

6.10. Renewable Energy and Environmental Remediation

Nowadays, nanoparticles are widely used, from environmental cleanup to performance enhancement in the renewable energy sector, due to their distinctive physical and chemical features [205]. Some other research work [206–215] has been carried out on different geometric surfaces with nanomaterial features and variable boundary constraints. Nature provides its own nanoparticles, some of which have been shown to be environmentally therapeutic. Nanoparticles have been employed in environmental remediation, also known as nanoremediation, to treat or disinfect air, water, and soil for more than a decade. The need to pump groundwater out for treatment and the need to excavate to reach the intended destination are both avoided with nanoremediation's in situ treatment. After being injected at the target site, the nanoparticles travel with the groundwater flow to the receiving aquifer, where they immobilize the contaminants and purify the water. Redox reactions are the primary mechanism at play in decontamination. Nanoparticles are used to cleanse, purify, and desalinate seawater and other surface waters. Heavy metals, viruses, and organic pollutants are likely contaminants. The effectiveness of the removal is a requirement for chemicals, which may sometimes result in unwanted byproducts of the reaction, as has been demonstrated. Since oil can travel great distances, spills are a significant global concern. Traditional cleaning methods are labor-intensive and time-consuming, exacerbating the problem by increasing the likelihood of more contamination. The use of nanoparticles in the cleanup of oil spills is another proven application of this technology. Nanoparticles are mostly employed in the purification of sewage and sludge from industrial and municipal sources. Nanoparticles are being used instead of traditional chemicals because they are cheaper, more effective, and lesser amounts are required for treatment. The food and dairy industries have benefited greatly from the implementation of nanofiltration, a relatively new membrane filtration technique for water purification. There is an increasing worry about soil contamination. Nanoparticles are injected into contaminated soil at strategic spots to remove or treat contaminants such as heavy metals or hazardous byproducts of the industry. Gaseous processes can benefit from the increased surface area of some nanoparticles, which have been utilized as nanocatalysts. The most common application is in industrial stacks, where pollutants are reduced to safe levels or eliminated entirely.

The potential of nanoparticles as a source of renewable energy is the subject of intensive study. The efficiency of solar cells has increased noticeably as a result of advances such as coatings that absorb more light and UV and reflect less of it. Due to the hydrophobic nature of certain nanoparticles, self-cleaning solar cells are now a practical reality. Due to their high thermal conductivity and heat absorption capability, some nanoparticles are employed to coat boilers and solar concentrators to increase their thermal efficiency.

7. Conclusions

Nanotechnology strengthens the functionality and efficiency of commonplace items, which in turn improves our daily life. Cleaner air and water, and renewable energy sources ensure a brighter future for everyone. The leading institutions, corporations, and organizations are increasingly investing in nanotechnology research and development.

Nanotechnology has proven to be a cutting-edge scientific topic, with many researchers devoting their time to the development of new applications for this technology. This technology is undergoing testing for a variety of new applications, with the goals of improving the object's or process's efficiency and performance, and decreasing the cost to increase its availability. As a result of its efficiency and low impact on the environment, nanotechnology has great promise for the future.

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