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Review Article

A comprehensive review on various techniques used for synthesizing nanoparticles

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ABSTRACT

Nature is still the main focus of scientific and technological research, particularly in nanotechnology and because of its remarkable properties; nanotechnology has acquired much interest in recent years. This review focuses on up-to-date overview of classification of nanoparticles, characterization, methods of preparation, characterization and application of nanoparticles. Initial section of the review gives insight on various techniques for the synthesis nanoparticles, encompassing both bottom-up and top-down approaches. Different methods for the synthesis of nanoparticles are discussed in details. Highlighting the importance of controlling shape, size, and composition to develop nanoparticles and enhance the properties of nanoparticles. These properties include enhanced surface area, unique optical, electronic, and magnetic characteristics, as well as improved mechanical properties. Understanding these attributes is essential for harnessing nanoparticles in different applications effectively. Broad spectrum of applications for nanoparticles is also discussed. Additionally, nanoparticles have found applications in catalysis, environmental remediation, and antimicrobial coatings, contributing to sustainable development and environmental protection. Overall, nanoparticles represent a progressive area of research with tremendous potential for innovation and societal impact. Our evaluation will serve as a solid reference, assisting the scientific community to comprehend the discussed topic better by showing the role of each technique in a comparable manner. As the field of nanoparticles is constantly evolving, this review incorporates the latest research, developments, and advancements up to the time of its publication. A comprehensive understanding of their properties,

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synthesis and applications is decisive for realizing the full potential of nanoparticles in various scientific and industrial domains.

1. Introduction

Material researchers have spent the last 50 years, investigating in great details how to use nanoparticles and nanostructured materials in various fields sectors. Exploiting the special characteristics of materials at the nanoscale is known as nanotechnology. Nanotechnology has taken front stage and has received massive attention over time, when technological advancements are discussed. Nanotechnologies have had a substantial impact on practically all areas of society and industries because they provide better built, longer-lasting, safer, cleaner, and smarter products for medicine, daily life, agriculture, communications and other industries. The term "Nanotechnology" has been incorporated into many disciplines, and it is rapidly evolving by producing nanoproducts with novel size-related physicochemical properties that distinguish them from larger matter. The primary goal of nanotechnology is to process, separate, consolidate, and deform materials with a single atom or molecule [1]. Medicine, food, cosmetics, natural health, biomedical sciences, mechanics, optoelectronics, substance enterprises, energy science, nonlinear optical devices, single electron transistors, catalysis, space industries, chemical industries, gadgets, light producers, and photoelectrochemical applications are just a few of the fields where nanotechnology is gaining traction [2]. Nanotechnology has numerous applications, are shown in Fig. 1.

At the nanoscale, nanotechnology is related to the physical, chemical, biological, and engineering sciences [3,4]. Tools based on nanotechnology may be capable of identifying disease in very low amounts of tissue or cells [5]. Nanotechnology can potentially aid tissue reproduction and repair [6]. Medieval stained glass is one of history's most well-known or well-documented examples of nanotechnology [7]. Nanotechnology's rapid advancement gives effective methods to apply this interesting technology in broad applications, such as biofuel synthesis. The use of various types of nanoparticles, particularly metallic ones, in Biofuel production, like biohydrogen, biodiesel, bioethanol, and biogas, can enhance production efficiency and performance [8].

Nanoparticles are thought to be the foundation of nanotechnology. Methods for producing nanoparticles are constantly being researched and developed. Nature contains several types of nanoparticles, each with remarkable applications in their own field. Nanoparticles include both nanocapsules and nanospheres. Nanospheres are a matrix system with uniform drug distribution, whereas nano capsules are a system with the drug surrounded by a special polymeric membrane. Nanoparticles are the smallest microscopic or ultrafine particles; Sizes range from 1 to 100 nm [9]. The imperial properties of nanoparticles have already been utilized in a broad spectrum of potential uses, including biomedical devices, renewable energies, medicine, environmental remediation, antimicrobials, and biological sensor production [10–12].

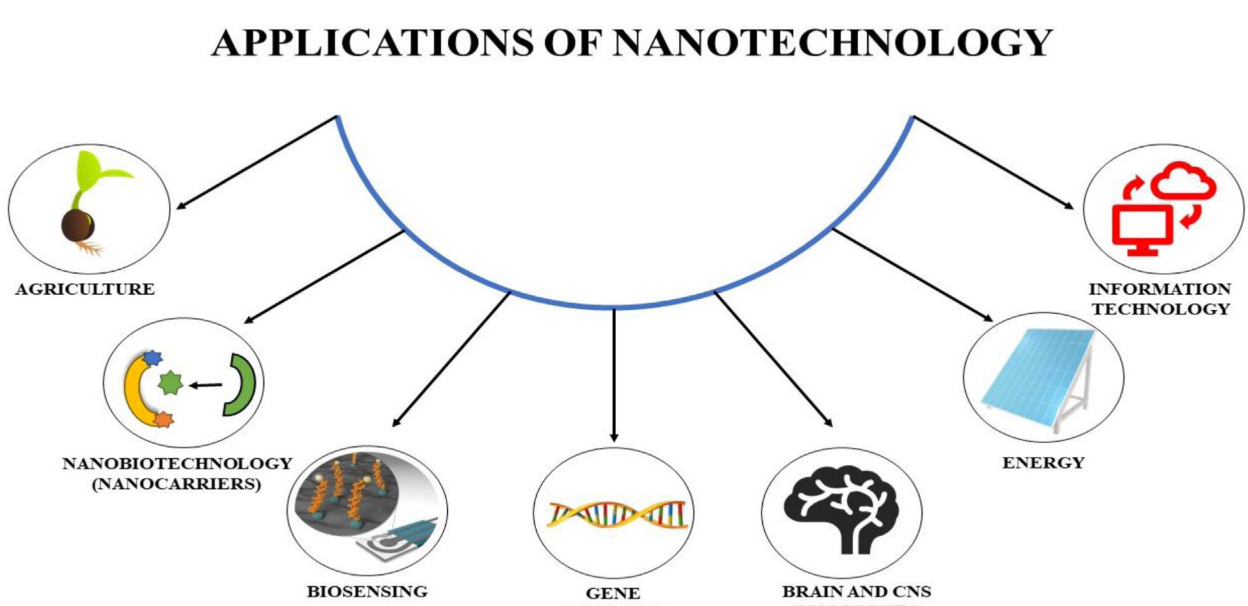

Fig. 1 – Different applications of nanotechnology.

Table 1 – Classification of nanomaterials in different dimensions.

NANOMATERIAL	CLASSIFICATION	SIZE (DIAMETRES)	REFERENCES
Zero Dimension	Fullerenes	0.5–1 nm	[13]
	Quantum dots	2–10 nm	[14]
	Atomic clusters	1–10 nm	[15]
One Dimension	Nanotubes	1–100 nm	[16]
	Fibres and filaments	<50 nm	[17]
Two Dimension	Nano discs	10–100 nm	[18]
	Nano lasers	<10 nm	[19]
Three Dimension	Clusters	1–10 nm	[20]
	Crystallites	1–100 nm	[21]

2. Classification of nanomaterials

In Table 1, the classification of nanomaterials is based on the number of dimensions. Nanostructures materials are classified as (0D) zero dimensional (1D) one-dimensional (2D) two-dimensional and (3D) three dimensional nanomaterials.

3. Nanoparticles synthesis

Nanotechnology is fundamentally altering how materials are synthesized and devices are manufactured. Nanomaterial synthesis is an essential part of nanotechnology and nanoscience. During synthesis of nanomaterials, a number of controlling factors are involved in the nucleation and subsequent production of stabilized nanoparticles. These factors include temperature, reactant concentrations, reaction time, and pH. According to studies, adjusting the pH of the reaction medium tends to generate variations in the shape and size of synthesized nanoparticles. Particularly, higher pH values tend to produce smaller particles and lower acidic pH values likely to produce larger particles [22,23]. In Reaction Time, the production of nanoparticles is depending critically on the reaction time [24]. It produced fast colour change in the specific instance within 2 min. The reaction medium was rapidly reduced and nanoparticles appeared within 2 min. In Temperature, the production of nanoparticles is significantly influenced by temperature. Although reaction temperature is a key element in all synthesizes, it has been discovered that temperature also plays a important role in defining the yield, size and shape of the synthesized nanoparticles [25,26]. Nanoparticle synthesis to improve control over particle size distribution, quality, purity, quantity and morphology. While using cost-effective and environmentally friendly processes has always been a source of difficulty for scholars [27]. Nanoparticles come in a variety of shapes, including hexagonal, circular, triangular and chain-like structures [28,29].

Traditionally, there are two methods for creating nanoparticles which can be classified based on their assembly *i.e.*, Top-down and Bottom-up approach [30] which are schematically shown in Fig. 2.

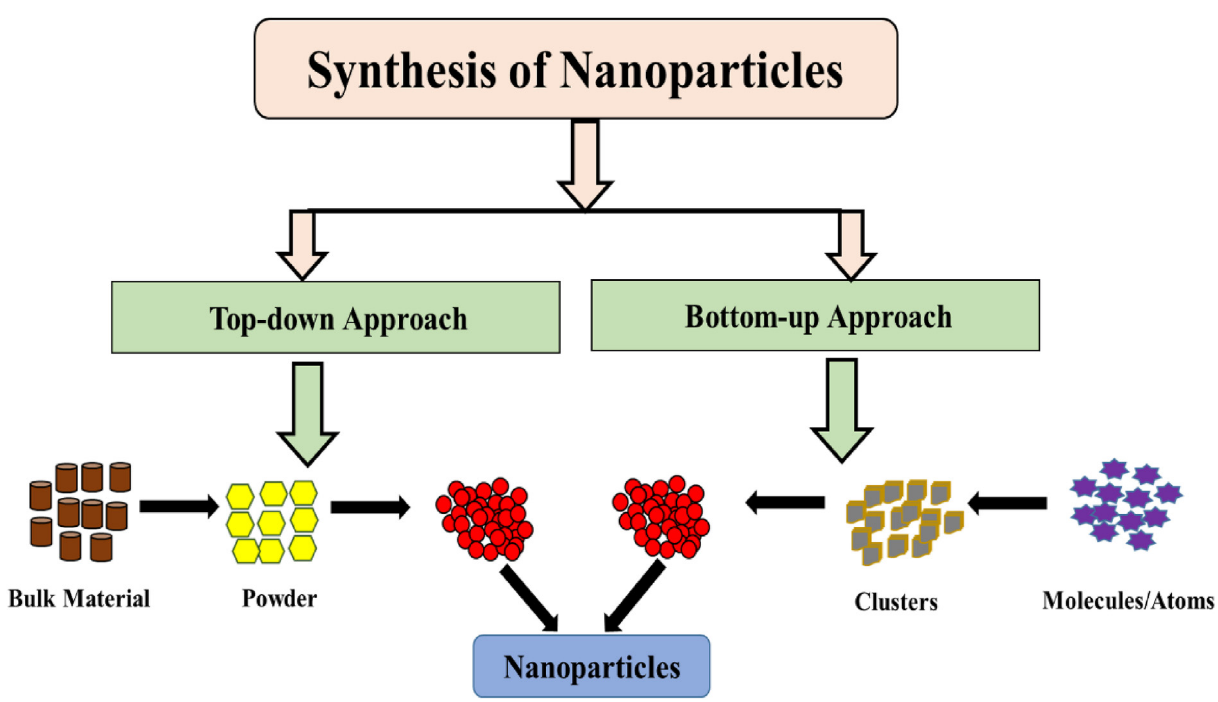

Fig. 2 – Schematic representation of 'top-down approach' and 'bottom-up approach' for synthesis of nanoparticles.

3.1. *Top-down approach*

A collection of fabrication technologies is referred to a top-down approach that begins with a bulk block material that is the same as the base substrate. This route takes the bulk material and reduces it in size by using Crushing, milling, or grinding are physical processes used to break up large particles [31]. Top-down approaches are typically simpler, relying on bulk material elimination or bulk fabrication technique miniaturization to create the desired structure with the desired properties. This synthesis method is an improvement on those used to create micron-sized particles. The flaws in the surface structure are the most significant matter with the top-down approach. For the fabrication of many man-made materials, the top-down approach is currently dominant in industry [32,33]. Top-down approaches have primarily focused on attrition methods as well as more complex methods involving microfluidics and lithography [34]. The semiconductor industry is a good example, where photolithography, a lithography-based process, is used to imprint features of MOSFETs (metal oxide semiconductor field effect transistors) onto a silicon wafer [35]. Top-down approaches use larger initial structures that can be controlled externally during nanostructure processing, ball milling and plastic deformation are two examples [36]. The most major problem with the top-down approach is flaws in the surface structure. For instance, lithographic nanowires have a rough surface and may include several contaminants and structural flaws [37].

3.2. *Bottom-up approach*

Bottom-up approaches include material component miniaturization, followed by a self-assembly process that results in the formation of nanostructures [38]. The synthesis of nano-sized materials is of great interest due to their distinct properties that differ from bulk materials [39]. The bottom-up approach means building a material from the ground-up: molecule for molecule, atom for atom, or cluster for cluster [40]. The alternative method referred to is more economical and has the potential to produce less waste. The bottom-up approach involves constructing a material from the smallest units, such as atoms, molecules, or clusters, and is frequently employed in the production of nanoscale materials. The process allows for the creation of uniform shapes, sizes, and distributions in many nanoscale materials.

This approach is employed in the continuous synthesis of inorganic nanoparticles, which involves using a wet chemical technique. By rapidly mixing two precursor solutions, it is possible to achieve a narrow particle size distribution for various inorganic nanoparticles, including zinc oxide, magnetite, and brushite [41]. Titanium dioxide (TiO2) nanoparticles were synthesized using a bottom-up hydrolytic sol–gel synthesis andevaluated using green metrics using two different approaches, namely Life Cycle Assessment (LCA) methodology andEnvironmental Assessment Tool for Organic Syntheses (EATOS) software [42]. The bottom-up approach's main concern is surface layer adhesion to the base substrate. Bottom-up techniques is well-known for the preparation of

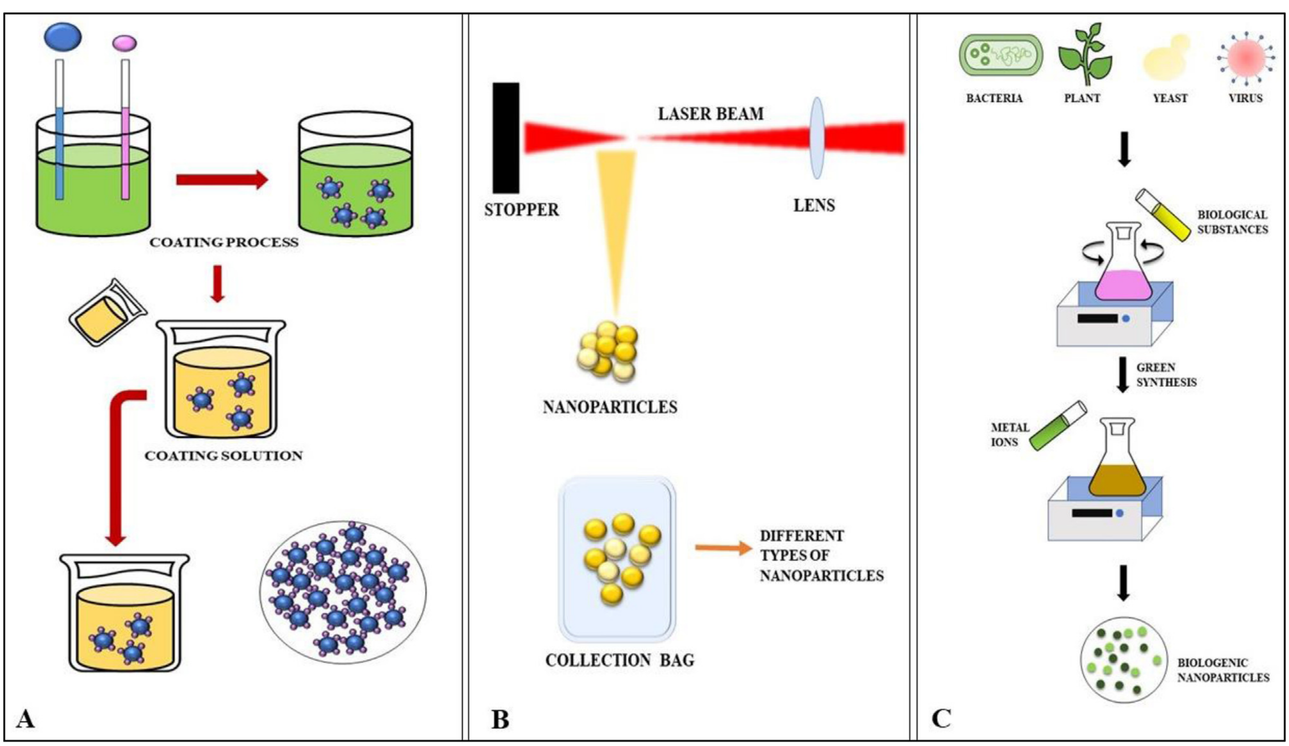

Fig. 3 – Methods of synthesis of Nanoparticles (A) Chemical synthesis by the means of reduction/precipitation reactions (B) Physical synthesis of nanoparticles, and (C) Biological synthesis utilizing microorganisms or plant extracts as reducing agents.

luminescent nanoparticles [43]. Bottom-up nanofabrication pushes the limits of miniaturization, provides virtually limitless opportunities for the fabrication and design of functional nanostructured materials, and it has the potential to be considerably more cost-effective than top-down nanofabrication [44].

4. Different methods for synthesis of nanoparticles

Various chemical, physical and biological techniques are presently accessible to create various varieties of nanoparticles [45–48] as depicted in Fig. 3.

Though chemical and physical methods are more commonly used for nanoparticles synthesis, their applications are limited due to the use of toxic compounds and yields [49,50]. Because of the simplicity and versatility of the procedures, the development of environmentally safe biogenetic production methods is becoming more popular [51]. Nanoparticles distinctive physical, chemical and biological properties make them ideal for a variety of applications in various industries and biomedical sectors [52]. Various techniques are involved for the synthesis of nanoparticles as shown in Fig. 4.

4.1. *Physical methods of nanoparticles synthesis*

Nanoparticles have traditionally been produced using physical methods, which utilize thermal energy, high-energy radiation and mechanical pressure, to cause material condensation, evaporation, abrasion, or melting. Physical methods are superior to chemical approaches in terms of solvent contamination absence in thin films and nanoparticle distribution homogeneity. Physical methods employ a top-down approach, are solvent-free, and yield consistent monodisperse nanoparticles. Laser ablation, laser pyrolysis, physical vapor deposition, high-energy ball milling, and inert gas condensation are among the physical methods commonly used to generate nanoparticles.

4.1.1. *Inert gas condensation (IGC)*

This technique can be applied to create a variety of nanomaterials, including intermetallic compounds, semiconductors, ceramics, composites, and alloys, in addition to metallic and metallic oxide nanoparticles. This method provides a variety of nanoparticles sizes. A variety of factors, including chamber pressure, inert gas injected into the chamber, and temperature, can be used to regulate the prepared nanoparticles' size [53]. The inverse gas chromatography (IGC) method was used to create size-controlled copper nanoparticles [54,55]. The IGC method was used to synthesize silver nanoparticles and the inert gas pressure and evaporation temperature had a strong influence on crystallinity, size distribution, and morphology. It was discovered that inert gas condensation is a highly efficient method for producing high-quality silver and platinum nanoparticles [56]. Using an inert gas condensation method, metallic dielectric multi-core-shell nanoparticles were created [57]. Inert gas condensation (IGC) is an adaptable method for producing ultrafine nanoparticles [58].

4.1.2. *Laser ablation*

The laser ablation (LA) technique is also known as pulse laser deposition (PLD), which involves laser beam ablation to remove material from a solid surface. In the laser ablation process, a high-powered laser beam is employed to evaporate particles from a solid source [59,60]. PLD (Physical vapour deposition) is an another and different vacuum-based PVD (Physical vapour deposition) process that removes material from the target using laser energy. The high-powered laser pulses cause melting, evaporation, and ionization on the target's surfaces. It should be noted that the nucleation process is

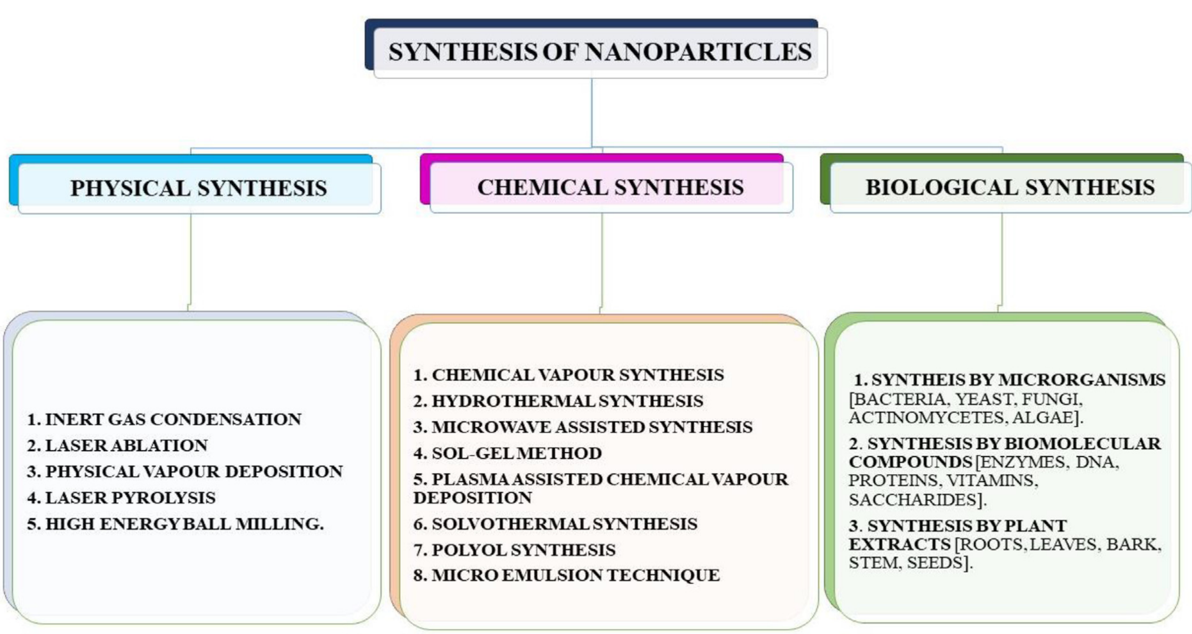

Fig. 4 – Varioustechniques for synthesis of Nanoparticles.

significantly influenced by electron and ion species for which, the outcome was electrically charged laser ablation particles [61,62]. In2005, PLD, Ni-NPs were created and confirmed using atomic force microscopy (AFM) [63,64]. The LA technique was used to create colloidal zinc metallic NPs [65]. The researchers used pulse laser deposition to create photo luminescent lead sulphide (PbS) nanoparticles in an amorphous SiO2 matrix on a Si substrate. SAG (Spark ablation in gas) was used to create the silver nanoparticles which were then in situ loaded onto a carbon fiber using nitrogen flow. The effect of the carrier gas flow rate and deposition period on the particle size and the dispersibility of the as-prepared Ag nanoparticles on the carbon fiber via SAG, as well as how well the samples performed in hydrogen evolution reaction in acidic conditions were investigated [66].

PLD was used in another study to deposit Surface enhanced Raman scattering using Ag nanoparticles on nickel hydroxide nanosheet arrays [67]. The wavelength of the laser influences the particles synthesized by laser ablation. However, it is still challenging to reproduce the striking shift in size distribution caused by the nucleation and development of laser-vaporized materials [68]. The drawbacks to this technique include its massive price and low yield, additionally to the challenge of controlling the morphology of the nanomaterials produced. This method can also be used to create carbon nanotubes.

4.1.3. *Physical vapors deposition (PVD)*

Physical vapors deposition is vaporization, thin film coating process that involves atomic level material transfer, i.e., metals and alloys can be transferred from one source to another in the vapors state. It is “physical,” because PVD (physical vapors deposition) is a form of “green engineering” that generates little pollution during the process [69]. Physical vapors deposition is referring to a group of procedures used in the formation of nanoparticles and fabrication of thin material layers [70]. Physical vapors deposition coatings are frequently used to improve metal hardness, oxidation resistance, and wear resistance. Sputtering is the most commonly used physical vapors deposition technique for nanoparticle synthesis. Sputtering is a PVD method that uses vacuum to deposit thin films and nanoparticles [71]. In 2012, Asanithi et al. the process situations for DC (Direct current) magnetron sputtering of uniformly sized silver nanoparticles were optimized. Bouchat et al. [72] have accustomed to create a diverse variety of nanoparticles including non-metallic and metallic Ichida et al. [73], germanium nanoparticles and quantum dots were created using the sputtering method for use in the electronic and optoelectronic industries. PVD process temperature is relatively low [74].

4.1.4. *Laser pyrolysis*

Laser pyrolysis is an effective method for producing inexpensive and magnetic nanoparticles. Laser pyrolysis is a vapors phase synthesis technique [75,76]. The technique works by decomposing a high-power CO2 laser, that is utilized to excite gaseous or liquid reactants and then quenches them. In a series of reactors, a salt solution is sprayed in this process, whereas the solvent evaporates, the droplet's solute concentration rises. This process produces particles that are dried and converted at a high temperature. Laser pyrolysis enables large scale production scalability, but it necessitates sophisticated and costly equipment [77]. Laser pyrolysis has also created molybdenum disulphide, silicon carbide, and silicon nanoparticles [78]. Using laser pyrolysis, TiO/SiO2 nanoparticles was synthesized [79]. According to the literature, nitrides, oxides, carbides, metals, and composite nanoparticles have the potential to be produced by this process [80]. Using tetraethyl orthosilicate, silane, and titanium isopropoxide as precursor materials, and the laser pyrolysis process, a variety of ceramic nanoparticles, including silicon dioxide and titanium dioxide, have been synthesized for cultural heritage protection and energy applications [81]. Laser pyrolysis method sis able to synthesize NPs from a diverse array of ternary composites, oxide and non-oxide [82].

4.1.5. *High energy ball milling (HEBM)*

The first nanomaterials were created using a simple method known as ball milling. Milling method (wet or dry), ball-to-powder weight ratio, milling speed, milling duration, high energy ball mill type, and milling atmosphere. The amount of energy transferred during the process between the balls and the material is influenced by milling media, which affects the morphological and physical properties of the nanomaterials [83]. In 2017 Muñoz et al. studied chemical as well as structural properties of Fe nanoparticles produced by this method were studied [84]. In aqueous media, Phosphate ester was used as a surfactant and Carbon black was used as a precursor, to produce graphite nanoparticles with sizes between the range from 1 to 30 nm using high-energy surfactant-aided ball milling [85]. ZnO-NPs of 30 nm size were produced using HEBM from ZnO microcrystalline powder [86]. Dodecyl dimethylbetaine (BS-12) was used in the surfactant assisted HEBM method to prepare pure nanoparticles of Calcium Carbonate from cockle shells [87]. In two ways, HEBM was used to produce FePt nanoparticles. The first involved mixing and milling elemental powders, whereas the second involved milling, while in the presence of surfactants oleyl amine and oleic acid, as well as hexane as a solvent [88]. In 2013, Kar et al., to produce uniform Lithium niobate nanoparticles, various milling parameters were optimized [89]. Recently, researchers established (high-energy ball milling) HEBM as a high-powered method for producing nitrogen-doped carbon NPs on a large scale for catalytic applications [90]. Chen and colleagues used microwave-assisted high energy ball milling to prepare pure and well-crystallized cobalt ferrite nanoparticles in 2014 [91]. Using a high energy ball milling process, fumed silica nanoparticles were combined with poly (methyl methacrylate), PMMA [92].

4.2. *Chemical methods of nanoparticles synthesis*

The chemical method, which uses inorganic and organic reducing agents, for synthesis of nanoparticles. Reducing agents reduce ions, resulting in metal formation and agglomeration into oligomeric clusters. Metallic colloidal particles are formed as a result of these clusters [93–95]. It is critical to utilize protective agents during the preparation of metal nanoparticles in order to stabilize dispersive nanoparticles. Nanoparticles surfaces can absorb or bind protective agents, preventing agglomeration [96]. Polyethylene glycol (PEG), polymethylmethacrylate (PMMA) Polyvinyl pyrrolidone (PVP), and Poly (methacrylic acid) (PMAA) have all been widely used as protective agents. The protective agent prevents the nanoparticles from clumping together [96]., Chemical methods used to create nanoparticles include microwave assisted synthesis, Hydrothermal synthesis, polyol synthesis, micro emulsion technique, salvo thermal synthesis, Sol–gel method, plasma and chemical vapors synthesis. These methods are classified as bottom-up nanoparticle synthesis.

4.2.1. *Chemical vapors synthesis*

CVS is referred to as chemical vapors precipitation (CVP), chemical vapors condensation (CVC), chemical vapors deposition (CVD), and chemical vapor's reaction (CVR). Using chemical reactions that occur at extremely high temperatures, this method serves to deposit solid films from the vapors phase. Precursor content, reaction rate, and temperature, all have a big impact on how well the materials get deposited [97]in the semiconductor industry, this method is frequently used to produce high-performance and pure, thin films. Thin films contain ultrafine particles produced by the CVD process under certain conditions. The substrate is typically exposed to volatile precursors in a CVD process. Three different states in which the precursors exist, i.e., solid, gas and liquid via synthesis method and are produced as vapors in the reactor under conditions that necessitate particle nucleation [98,99]. In 2004, Cao et al., and Gracia et al. This method was used to create nanoparticles, and it was discovered that the surface had more defects. Metal organic precursors undergo chemical vapors deposition (CVD) produce Ni/NiO nanostructures (MOCVD). MOCVD has several advantages over alternative methods, including the fact that the process is considerably simple, the equipment is inexpensive, and particle formation can be controlled by a number of the process variables and parameters such as high-temperature reactor, precursor concentration, or reactor residence time [100]. Despite being influenced by nanometric bilayer islands and the use of nanoparticles in CVD, the lateral size of MoS_2 monolayers improves, enabling them to reach and grow to a typical size of 20 m [101].

4.2.2. *Hydrothermal synthesis*

A promising method for producing hydrophobic or hydrophilic magnetic nanoparticles with controlled size and shape has recently been proposed: hydrothermal synthesis [102]. It is possible to accomplish this in two ways: continuous hydrothermal systems and batch hydrothermal systems. At 150 °C, the hydrothermal technique was used to create nanoparticles less than 10 nm wide [103,104]. Hydrothermal synthesis of nanoparticles of diverse materials is a simple and quick procedure. The hydrothermal technique can be used to regulate particle size, surface chemistry, composition, particle morphology and crystalline phase by adjusting the reaction temperature, pressure, solvent properties, aging time, additives and solution composition [105]. The hydrothermal synthesis can be performed below or above the water's supercritical point. To regulate both pressure and temperature during the reaction, a suitable reactor or sealed reaction vessel is required. This method of synthesis can yield monodisperse particles with high crystallinity; however, it may be difficult to scale in some cases. The benefit of using this technique is that it enables the low-cost synthesis of a large number of NPs. Hydrothermal synthesis is a simple and quick method for producing nanoparticles of different materials such as ZnO, CdS, $FeWO_4$, $CoFe_2O_4$, Zr, Ag and others [106–109]. Hydrothermal or electrochemical treatments have also been used to produce inorganic nanoparticles [110–113]. A flow-type apparatus was used to perform synthesis of CeO_2 and AlO (OH)hydrothermally [114]. TiO_2 nanoparticles created by in situ method using MXene as a starting precursor in a one-step hydrothermal process. During the hydrothermal method, MXene is controlled oxidized, forming TiO_2 on the MXene sheets' edges [115].

4.2.3. *Microwave assisted synthesis*

Numerous Nanoparticles have been produced using microwave radiations. Microwave radiation has been used to create many nanomaterials. Microwave techniques eliminate the need for long periods of high temperature calcination and enable fast, reproducible nanomaterial synthesis. The effects of "microwave dielectric heating" on the effective heating of materials underpin microwave-enhanced chemistry. This concept is reliant on a material's ability to absorb and convert microwave energy into heat. Recent research has shown that microwave heating can be extremely useful in a variety of organic synthetic methods. Microwave heating is efficient and precise, and without interaction between both the reaction vessel and energy source is required [116]. In 2005, Corradi et al. Microwave radiation was used to create colloidal TiO_2 nanoparticle suspensions in 5 min. A non-quantum mechanical effect that results in sample volumetric heating is microwave dielectric heating [117]. CuS are nanoparticles that can be produced using microwave-assisted synthesis and have highly photocatalytic activity in natural sunlight for the degradation of 4-chlorophenol, methylene blue and methyl orange [118]. A novel microwave-assisted method for producing zinc oxide (ZnO) nanoparticles was developed, utilising PVA (polyvinyl alcohol) and ascorbic acid as capping and stabilising agents. The antimicrobial and anti-biofilm activity of ZnO nanoparticles synthesized was tested and found to be excellent against gram-negative and gram-positive bacteria [119]. Silver nanoparticles were created by microwave irradiating silver salts, typically silver nitrate [120]. In 2022, Xin et al. elucidated the microwave-assisted synthesis of Pt NPs is first clarified, and the results show that precursor reduction is essential for assessing the crystallinity of Pt NPs core-state [121].

4.2.4. *Sol–gel method*

The sol–gel technique is used to create metal oxides from a solution of chemicals that acts as a precursor to a combined polymer network or discrete particles. In material chemistry, sol–gel is a technique for producing small particles. The precursor sol can be positioned onto the substrate to create a film, which is then set into the preferred shape container, or it may be utilized to create powder. It is primarily used in the metal oxides' synthesis. This gel is made up of discrete polymers or particles. Chlorides and metal alkoxides are the most commonly used precursors. For the formation of colloids, these precursors have been hydrolyzed and poly-condensed. The two main reactions in sol–gel are the hydrolysis of the alcoholic group and its condensation. Using the appropriate casting container, the obtained precursor sol can be given the desired shape. It can also be deposited on a substrate via dip or spin coating to form a film, or it can be used to create microsphere or nanosphere powder. Sol–gel synthesis includes the steps of mixing, casting, gelation, aging, drying, and densification [122,123]. Fe3O4 nanoparticles were efficiently created using sol–gel techniques and annealed under vacuum at various temperatures [124]. The morphology particles were having, discovered to be almost spherical using the sol–gel method [125].

4.2.5. *Plasma assisted chemical vapors deposition (PECVD)*

This is a popular deposition process via chemical vapors process for thin film deposition. Plasma-assisted thin film deposition is commonly used in the fabrication of microelectronic circuits [126]. In 2010, Shimada et al. chemical vapors deposition was aided by microwave plasma and used to create gallium nitride nanoparticles (MPECVD) [127]. Carbon nanoparticles and Hydrogenated silicon nanoparticles were synthesized using microwave plasma enhanced chemical vapors deposition (MPECVD) and (radio) frequency plasma enhanced chemical vapors deposition (RFPECVD)respectively [128,129]. The research teams and their workmates used the PECVD technique to produce carbon nanoparticles-based tough and rigid films by tuning the self-bias, bringing various doping approaches, and employing metal (or carbon) bilayer and multilayer designs [130,131]. In 2012, Yun et al. used the PECVD process to create a silica NP array on a flexible polymer substrate [132]. However, as the power increased the reactivity of the plasma and the chemical reactions increased, resulting in the leading development of more nuclei and the disappearance of species which are not reactive. Coagulation growth can be prevented under these conditions, and small-sized NPs can form. A TiO2-CNT-Ag (titanium dioxide-Carbon nanotubes) composite ternary film was effectively synthesized using the chemical vapors deposition method by plasma enhancement [133].

4.2.6. *Solvothermal synthesis*

Solvothermal synthesis has been discovered to be a versatile method for producing an extensive range and narrow size distribution of nanoparticles. The Solvothermal method, like the hydrothermal method, can be used with solvents other than water. The solvothermal method, which allows for more control over shape, size and crystallinity distributions as opposed to the hydrothermal technique, has been used to create nanoparticles and nanorods with and without surfactants [134]. Using a solvothermal method, CuFe2O4 nanoparticles (NPs) were created with Tri-ethylene glycol was used as a reductant, stabilizer and solvent [135]. A reductive solvothermal process was used to create MgMn2O4 spinel nanoparticles. Spinel oxide is a promising cathode material because of its high theoretical energy density and relatively high Mg-ion diffusivity [136]. Pure nickel nanoparticles were also synthesized at low temperature using an easy solvothermal route [137].

4.2.7. *Polyol synthesis*

Polyol synthesis, also known as thermal decomposition, was initially developed to produce noble metal particles before being expanded to produce magnetic nanoparticles [138]. The polyol process is a metal-containing compound synthesis method that uses a reaction medium, polyethylene glycol assists as a solvent, complexing agent and reducing agent [139]. A polyol solution dissolves the metal precursor, heated to almost freezing points (temperature). Furthermore, at the high temperatures used in the reactions described here, the polyol serves as a reducing agent for the reduction of metal. The polyol method can also be used to mass-produce nanoparticles [140]. The polyol technique was also used to create magnetic nanoparticles of magnetite, Fe3O4, and other materials at low temperatures [141,142]. Metal oxide NPs, metal hybrid NPs, metal-based NPs, and Magnetic NPs were all created using this method [143,144]. In 2019, Mahamuniet et al. synthesized facile polyol-mediated synthesis and checked their pathogenic micro-organisms antimicrobial activities. Antibacterial activity was inversely proportional to nanoparticle size. Various CuInS2 (CIS) nanostructures were created using polyols used as the solvent and also as the reductant [145].

4.2.8. *Micro emulsion technique*

The "micro emulsion" term was first introduced by Schulman et al. [146]. The micro-emulsion technique was used to create inorganic nanoparticles [147]. Using the reduction strategy and the microemulsion technique, metal NPs were easily prepared. Composite NPs, metal salt NPs, semi-conducting metal sulphites NPs, magnetic nanoparticles, metal nanoparticles, and metal oxide NPs are among the inorganic nanomaterials synthesized [148]. Micro emulsions are macroscopically homogeneous, optically transparent, isotropic, and thermally stable dispersions. Depending on the surfactant used, a micro emulsion system is made up of mono-dispersed water-in-oilor oil-in-water droplets (spherical). Martinez-Rodriguez et al. have reported the rapid, simple, and production of Pt cubic nanoparticles [149]. Zinc oxide nanoparticles synthesized, using a microemulsion approach in a W/S ratio of 5, revealing the wurtzite structure of ZnO nanoparticles [150]. This method can produce well-crystallized nanoparticles; however, its versatility in terms of nanoparticles nature, shape and size is limited [151]. SDS (Sodium dodecyl) surfactants and Tween-80 were used to make silica-coated and magnetite NPs in water-in-oil micro-emulsions [152]. The microemulsion method was used to create stable SiO2 NPs of various sizes [153]. Using a combo of the reverse microemulsion technique and the calcination technique, BiVO4 nanoparticles were created [154].

4.3. *Biological methods of nanoparticles synthesis*

Even though physical and chemical methods are efficient in creating well-defined nanoparticles, they have some drawbacks, including a long synthesis time, higher production costs, difficulty in purification, as well as the discharge of dangerous and hazardous by-products [155]. Chemical synthesis techniques can also contribute in the appearance of

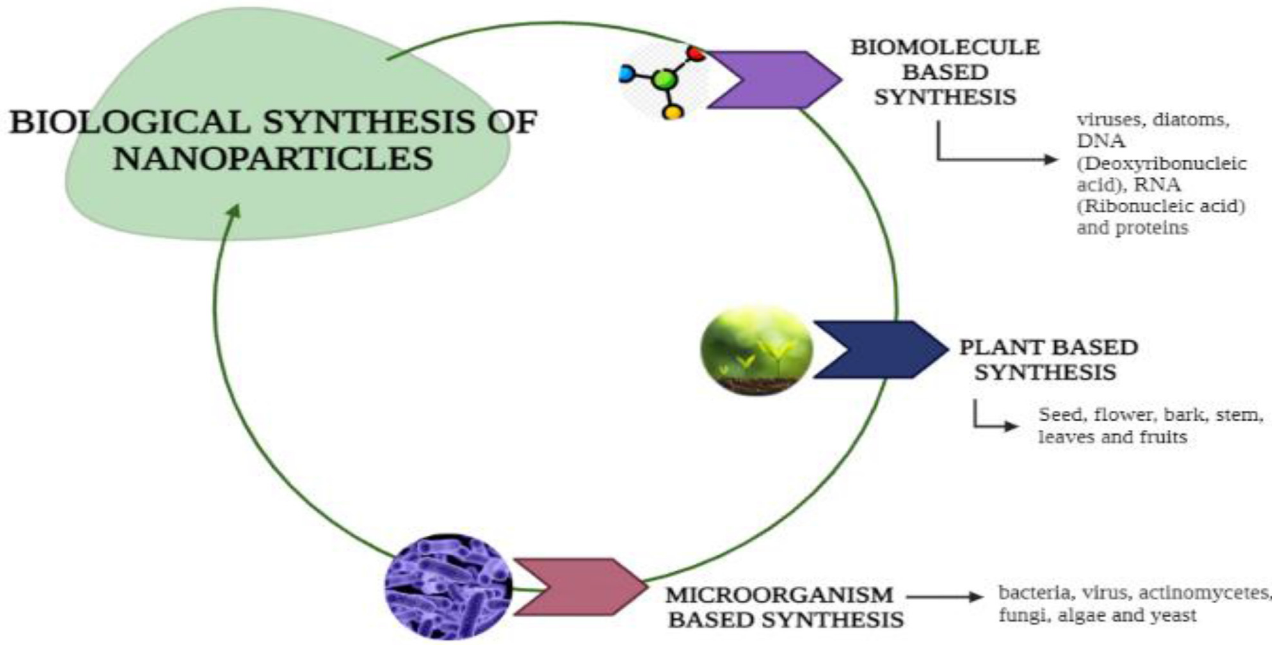

Fig. 5 – Different biological synthesis of nanoparticles.

hazardous chemical species that have been adsorbed, which can have negative consequences in medical applications [156]. Green synthesis methods have advantages over traditional methods that use chemical agents which are toxic for the environment. Nanoparticles synthesized by the means of biological entities both intracellularly and extracellularly. A living system's ability to remodel inorganic metal ions into nanoparticles using its inherent organic chemistry processes has revealed a previously unknown area of biochemical analysis. The combination of nanotechnology and biology results in nanobiotechnology, which is an advanced field comprising living entities of both eukaryotic and prokaryotic origin [157]. Nanoparticles biosynthesis technique follows bottom-up method which involves primary reaction (oxidation/reduction) [158]. To create metal and metal-oxide nanoparticles, these methods use biological systems such as fungi, actinomycetes, bacteria, viruses, yeast, biomolecules, different plant-based extracts, and so on as shown in Fig. 5. Biological methods of nanoparticle synthesis can be generally categorized into different categories: I) Biomolecules based synthesis, II) Microorganisms based synthesis, and III) Plants based synthesis.

4.3.1. *Biological synthesis of nanoparticles using biomolecules*

Biomolecules are sophisticated nanostructures, programmed by sequence information and adapted by evolution. Viruses, diatoms, DNA, RNA, and proteins are all powerful tools that are used as blueprint (template) for the synthesis of nanoparticles are shown in Fig. 6. Actin filaments have advantage because it serves as a template for nanowire formation [159]. DNA is regarded as admirable biomolecular template and a promising candidate with a strong affinity for transition metal ions. The amino acid functional groups found in molecular enzyme that could function as reducing agent for metal nanoparticles synthesis, while the remaining polypeptide chain may help to stabilize the nanoparticles [160].

Many biological complexes are functioning as actual systems and equipment for nanotechnology [161]. Additionally, DNA can be used for peptide fibers and protein for the nanoparticle's synthesis [162,163]. Different researcher reported that DNA used as templates or organic scaffolds to synthesis a wide range of nanoparticles and nanoparticles assemblies [164–167]. Because of their biocompatibility, water solubility, and potential applications, lipid bilayer nanomaterials that are being modified such as carbon nanotubes, semiconductor quantum dots, silica nanoparticles and researchers' focus is on noble metal synthesized nanoparticles.R describe straightforward and method for creating with controllable utilising Using double-stranded DNA (dsDNA) as a template, researchers present an easy and universal process for producing metal-graphene oxide (GO) heterostructures with controlled nanoparticle size and shape [168]. DNA-directed silver (Ag) nanoparticles (NPs) were successfully synthesized and these composites decrease *Xanthomonas perforans* cell viability in culture and on plants [169]. A multifunctional and biocompatible nanoplatform called DNA aptamer-conjugated magnetic graphene oxide (Apt@MGO) was created by researchers in order to selectively and quickly eradicate MRSA (Methicillin-resistant *Staphylococcus aureus*). According to an in vitro study, Apt@MGO is a targeted, biocompatible, and light-activated photothermal agent that effectively and quickly kills MRSA in the aggregated condition when exposed to NIR light [170].

4.3.2. *Biological synthesis of nanoparticles using microorganisms*

Microbes are small organisms that include bacteria, fungi, and viruses. Some microorganisms can survive on metal ions and grow in a variety of environments due to their resistance

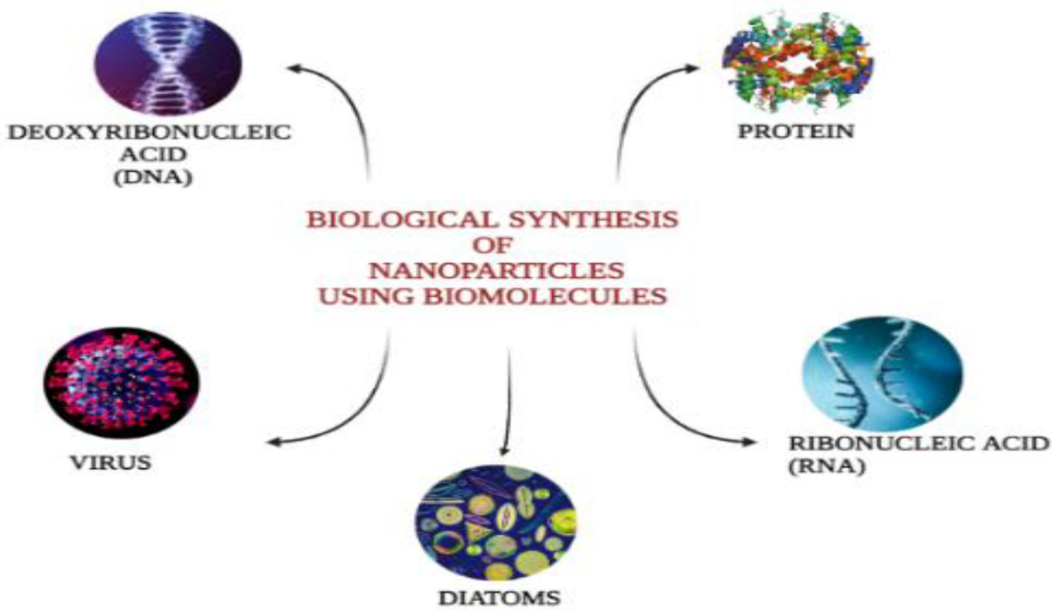

Fig. 6 – Biomolecules mediated synthesis of nanoparticles.

to that metal. A green chemistry method that combines nanotechnology and microbial biotechnology is called microbial nanoparticles synthesis. Biosynthesis of tellurium, platinum, alloy of gold-silver, silver, zirconia, titanium, palladium, silica, quantum dots, uraninite, magnetite and gold nanoparticles has been discovered by bacteria, actinomycetes, fungi, yeasts, and viruses [171]. In fact, microbial NP synthesis has combined several disciplines, including biotechnology, microbiology, and nanotechnology, to form a new field known as nanobiotechnology [172]. Metal nanoparticles synthesis in bacteria is dependent on the localization of the cell's reductive components. Extracellular nanoparticles production has broader applications in optoelectronics, bioimaging, sensor technology and electronics than intracellular accumulation [173]. Bacteria, viruses, fungi, algae, yeast and actinomycetes, are all commonly used as bioreactors in the synthesis of nanoparticles [174,175]. as shown in Fig. 7.

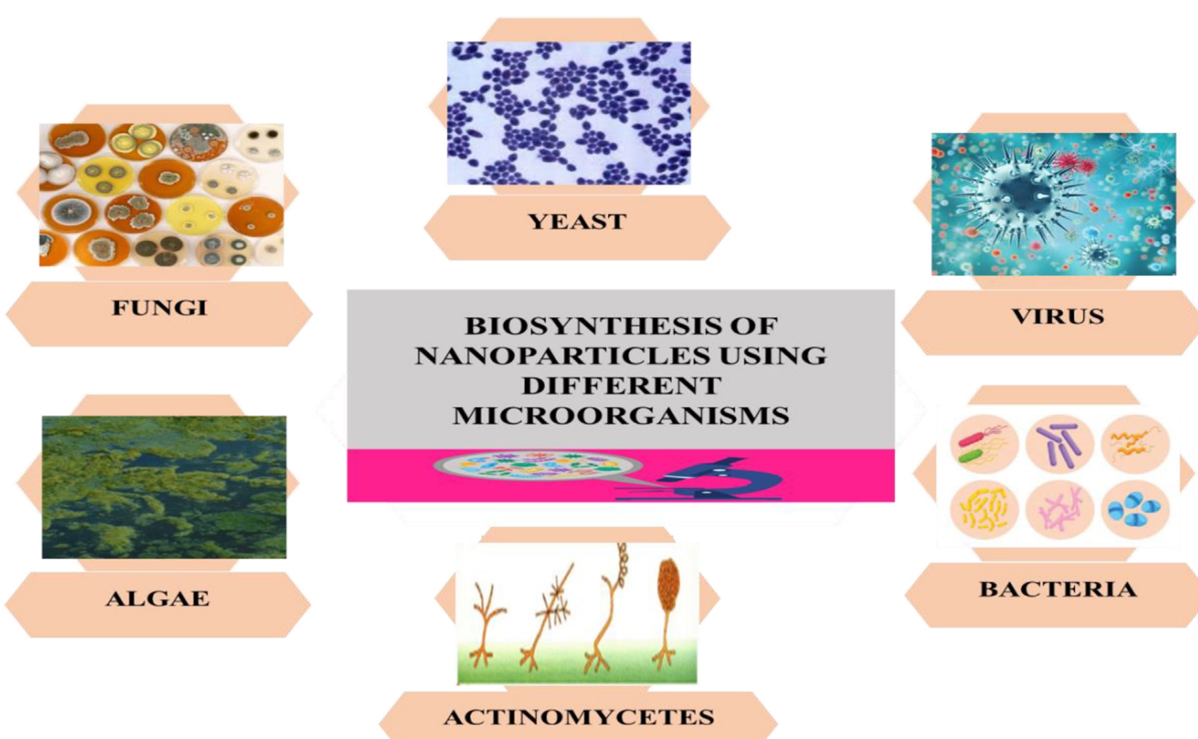

Fig. 7 – Variety of microorganisms used for synthesis of nanoparticles.

4.3.2.1. *Bacteria*. Bacteria are included in unicellular organisms growing very quickly in warm, moist environments. Many bacteria are capable of producing nanoparticles such as silver NPs, zinc oxide NPs, gold NPs, magnesium NPs, arsenic NPs, iron oxide NPs, and so on. To reduce interacting metal ions, bacteria use a variety of anionic functional groups, reducing sugars, proteins, enzymes, and other bacterial biomass components. Nanoparticles are manufactured using gram-positive bacteria as well as gram-negative bacteria. Gram-positive bacteria enclose in a cell wall is rich in anionic functional groups, and cell wall consists of peptidoglycan, and various acids including lipoteichoic and teichoic, different polysaccharides, andvarious proteins serving as a site for subsequent reduction and cation biosorption. The use of cultural supernatants in the synthesis of metallic nanoparticles of Ag of *Enterobacter cloacae*, *Escherichia coli* and Klebsiella pneumonia [176]. The metal ions majority shows toxic behavior towards bacteria, to overcome the hazardous nature of the ions bacteria developed a defense system to counteract such toxicity and ion reduction is such one mechanism [177]. Vaidyanathan et al. synthesize nanoparticles using *Bacillus licheniformis*, which secretes NADPH and NADPH-dependent enzymes and one such example is nitrate reductase, which successfully transform Ag^{+} to Ag^{0} [178].Ag-NPs produced non-enzymatically using bacterial bio-matrix as a reducing and capping agent was described [179].Silver nanoparticles synthesized from the *Saccharomyces cerevisiae*, *Bacillus subtilis*, *E. coli* and study their the antimicrobial effects against different pathogens and anticancer activity on MCF-7 cell line [180]. Bacteria are an extremely important tool for nanoparticles synthesis due to their diversity and excellent ability for adaptability toward extreme environmental conditions [181]. In the literature, various research in regard of NPs synthesized biologically using bacteria have been reported, including elementary compounds and substances [182–184]. Therefore, using bacteria as nano-factories might offer a novel approach to metal or metalloid ion removal and fabrication of the materials with unique characteristics [185].

4.3.2.2. *Fungus*. Several fungi have been used as novel and use as the tools for the extracellular and intracellular are reassuring for nanoparticles development. The fungal-mediated green chemistry method to NPs synthesis has several benefits, which include economic viability, higher bioaccumulation, and a method for synthesis are easily scalable due to easy downstream processing and biomass handling. Fungi, as opposed to bacteria, can produce more nanoparticles due to increased protein secretion, which directly translates to increased nanoparticles productivity [186]. Most fungi have a wide range of growth for sodium chloride, pH and temperature, making changes in culture conditions to produce homogeneous nanoparticles possible [187].

Additionally, numerous investigations have shown that extracellular myco-synthesis nanoparticles of silver via Ag + ion reduction using genus Aspergillus which include a variety of species, such as *Aspergillus niger* [188], *Aspergillus flavus* [189], Aspergillusterreus [190] and A. Fumigatus [191]. The synthesis of Ag nanoparticles biologically via; *Aspergillus terreus* has also been reported, and the proposed mechanism is an NADH [nicotinamide adenine dinucleotide (NAD) + hydrogen (H)] dependent enzyme catalyzed extracellular reaction process [192,193]. A number of other reports on the biosynthesis of Ag NPs using diverse species of fungus are available which also include Bryophilous rhizoctoni, *A. flavus*, Pleurotusostreatus, etc. [194,195] It has been reported that the Metallic nanoparticles are produced by various Fusarium species for intra and extracellular silver nanoparticles [196,197]. In order to create metallic nanoparticles, some filamentous fungi such as Penicillium were also studied. For this reason, various studies have been performed using species of Penicillium such as, *Penicillium brevicompactum* [198], *Penicillium fellutanum* [199], Penicillium sp. [200], *Penicillium citrinum* [201], and *Penicillium nalgiovense* [202]. Fungi can generate a substantial number of extracellular enzymes including glucanases, chitinases, glycosyl hydrolases, xylanases, Mannanases, cellulases and proteases under the right conditions [203]. *Fusarium solani*, an endophytic fungus used for the synthesis of gold nanoparticles which was isolated from the *Chonemorpha fragrans* plant, [204]. The synthesized gold nanoparticles showed cytotoxic activity against different cancer cells [205].

4.3.2.3. *Yeast*. Single-celled eukaryotes belonging to fungus kingdom. For biomineralization, Yeast cells serve as template, primary mechanism for the NPs formation such as Au NPs using thermomonospora fusca, thermomonospora curvata and thermomonospora chromogena species [206,207]. Yarrowialipolytica was also used for the production of gold NPs [208]. Researchers showed the relevance of Hanensulaanomala species to reduce gold salt-generating AuNPs [209]. It has also been reported that yeast can be used to make PbS and Cd nanoparticles using *Candida glabrata* and Rhodosporidiumdiobovatum sp., [210]. BDU-XR1 yeast strain isolated from yogurt (spontaneous)synthesize Ag-NPs in Azerbaijan [211]. Depending on the preparation methods, Ag-NPs were produced inside the cells and in cell wall [212,213]. Transcriptome analysis using RNAseq in yeast cells treated with spherical citrate-coated silver NPsrevealed several differentially expressed genes. Fourier-transform infrared analysis of biosynthesized Ag-NPs revealed notable peaks corresponding to the Ag-NPs' binding to active biomolecules like, alcohols, aromatic amines and carboxylic acids [214]. In 2020, Shu et al., yeast extract was utilized as capping and reducing agent to produce well-dispersed Ag nanoparticles of uniform spherical shape [215].

4.3.2.4. *Actinomycetes*. Actinomycetes are microorganisms that resemble fungi and bacteria in some ways. The thermomonospora sp. is used for biosynthesis of Au-nanoparticles [216,217]. Au-nanoparticles were synthesized intracellularly by using alkali tolerant rhodoscoccus sp. The cytoplasmic membrane contained more nanoparticles than the cell wall, according to the research. Actinomycetes have gotten a lot of attention because they are underutilized and could be a good candidate for metal nanoparticle synthesis [218]. Due to their saprophytic behavior and actinomycetes are recognized as superior groups among commercially significant microbial species [219,220]. Actinobacteria have successfully reported the biological synthesis of metallic nanoparticles, and as a result, actinomycetes have been considered for NP synthesis [221,222].

4.3.2.5. *Algae*. A diverse group of plants that is being researched for its potential applications in nanotechnology. In 2019, Sharma et al. reported Platinum nanoparticles (PtNPs) derived from S. myriocystum and employed as biosensors to measure level of adrenaline in human body [223]. Hormone-based drug i.e., Adrenaline is used to treat asthma, allergies and also heart attacks. Gracilaria edulis was used for the synthesis of silver and zinc oxide nanoparticles [224,225]. Brown algae used for the biological synthesis of TiO2NPs and ZnO-NPs [226]. Another study used S. *muticum* to synthesize ZnONPs [227]. Ag-NPs derived from the Ulva latica (green algae) and Hypnea musciformis (the red algae) have shown inhibition of growth in fungal strains such as *A. niger*, Candida parasitosis and *Candida albicans* [228]. Likewise, Au-NPs and Ag-NPs were synthesized from Neodesmuspupukensis and tested for antifungal activity [229]. When compared to cyanobacterial extract, the Ag-NPs synthesized from Microchaeta demonstrated superior de-colorization capability counter-to dyes like 'methyl red azo' [230]. In a recent study, it was discovered that Chlorella ellipsoidea-mediated bio-matrix-loaded Ag-NPs had high photocatalytic activity for the destruction of the harmful pollutant colors methylene orange and blue [231].

4.3.3. *Biological synthesis of nanoparticles using plants*

A diverse array of phytochemical constituents is present in plants and are thus used in the pharmaceutical industry, indirectly or either directly [232]. Plants are having various applications else than acting as medicines like, food supplements, nutraceuticals etc. [233]. The medicinal properties of plants are known since human civilization started. The findings of medical efficacy of plants have already been tried by ethnopharmacologists, botanists, microbiologists and natural-product chemists [234]. Plants, in particular, secretes bio-molecules which are functionally active, reducing metal ions, making biological nanoparticle synthesis biocompatible [235]. Plants contain a phytochemicals and various different metabolites [236]. Plants are used to make nanoparticles because they are spontaneous, inexpensive and have a single step biosynthesis process [237,238]. A number of plants and their different parts are used for the bio-synthesis of nanoparticles as shown in Fig. 8. Many different plant extracts have been employed as precursors in the creation of nanoparticles (NPs) with potential applications. Certain plants have been identified as hyperaccumulators because they accumulate in higher concentrations of metals than other source [239]. Quinines, organic acids and flavones, are the primary water-soluble phytochemicals responsible for immediate reduction.Tannic acid, a polyphenolic compound present in different plants, can be used as a functional stabilization of nanoparticles, especially for gold nanoparticles [240].Researcher synthesized silver nanoparticles using ellagic acid rich-berry extracts and investigate their antimicrobial properties towards model dental pathogens *C. albicans and Enterococcus faecalis with* potential mechanisms [241].Recently, research on the synthesis of ZnONPs has utilised plants like *Zanthoxylum armatum* [242]. In 2020, Chauhan et al. studied cannabis sativa for its uses as a reducing and stabilizing agent in the synthesis of nanoparticles [243]. The use of anthocyanin rich-red cabbage extract (RCE) with its antimicrobial and antioxidant capabilities for the synthesis of stable iron oxide (Fe_3O_4) NPs. The

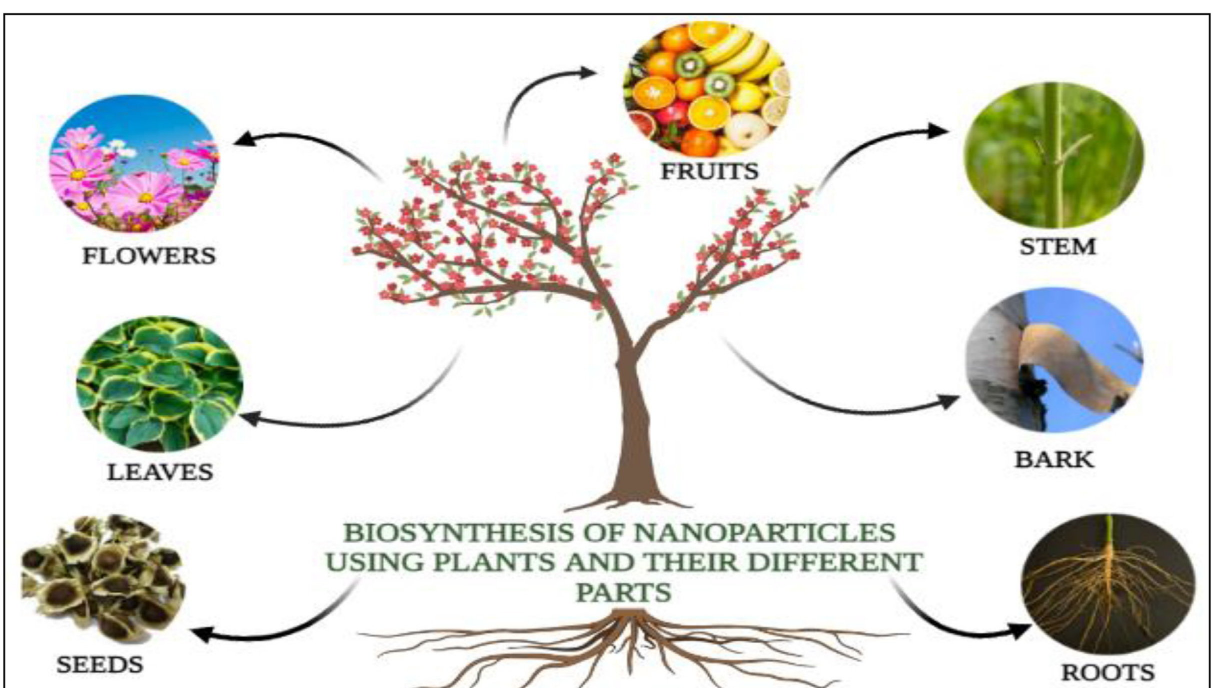

Fig. 8 – Plant mediated synthesis of nanoparticles.

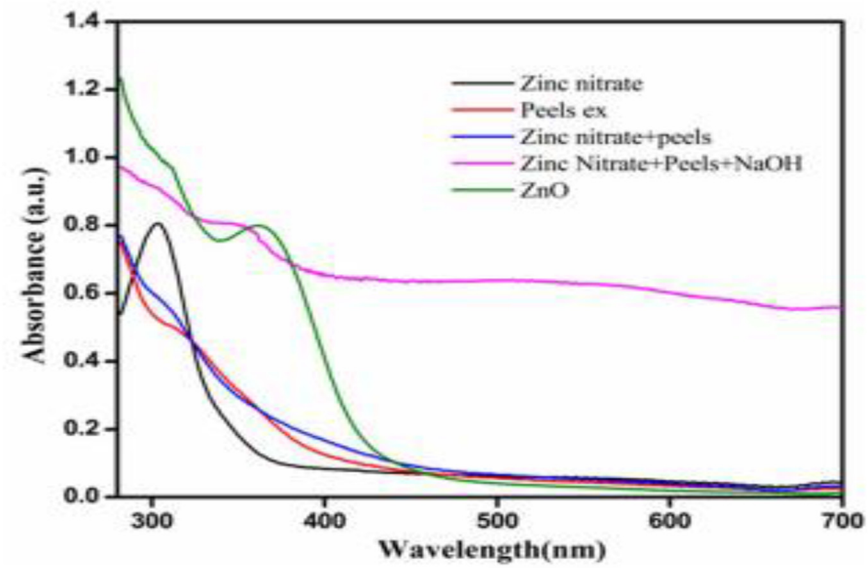

Fig. 9 – UV–vis absorption spectra of Zinc oxide Nanoparticles [252].

Fe_3O_4 NPs displayed antimicrobial and antioxidant properties along with greater stability [244].

Copper oxide nanoparticles (CuO-NPs) created while using two methods: green synthesis (CuO(G)-NPs) and microwave irradiation (CuO(M)-NPs) using *Z. armatum* plant extract [245]. The silver doped zinc oxide nanoparticles (AgZnO) were fabricated using the seed extract of *Moringa oleifera* [246]. *Cannabis sativa* was also used in a green route for the synthesis of Cu, Mg, and Ag doping nanoparticles [247]. Aqueous extracts of three different Sideritis species; *S. brevidens* (SB), Sideritisargyrea (SA) and *S. lycia* (SL) were used to create silver nanoparticles (AgNPs). The cholinesterase (BChE: butyrylcholinesterase and AChE: acetylcholinesterase) and tyrosinase activities were also checked [248]. Utilizing plants for the synthesis of nanoparticles has the benefit of being convenient, handled easily, and contain variety of metabolites that may abet in reduction. Many natural biomolecules in plants play crucial role in the bio-reduction, formation, capping and stabilization of NPs [249,250].

5. Characterization techniques for synthesized nanoparticles

The expansion of nanotechnology in numerous research fields has necessitated the use of analytical techniques for nanoparticles analysis and characterization. Nanoparticle characterization is a critical step in understanding the reaction mechanism and its applications. UV–V is spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), Brunauer–Emmett–Teller (BET), Transmission electron microscopy (TEM) are all generally used techniques for characterization of nanoparticles. Such techniques are useful for determining nanoparticles shape, size, crystallinity, and surface area [251]. The following analytical tools that are used to characterized synthesized nanomaterials are described in detailed.

5.1. *Ultraviolet–visible spectroscopy analysis*

UV-V is spectroscopy (UV–Vis) is relatively simple and inexpensive characterization technique that is frequently used for the study of nanomaterials. It measures the intensity of light reflection intensity from a sample and contrasts it w the light reflection intensity from a reference material. The optical absorbance spectra are measured to indicate NPs production as seen in Fig. 9. UV-V is spectroscopy provides the information about transmission and absorption properties of the sample. NPs have optical properties that are sensitive to concentration, shape, size, agglomeration state and refractive index close the NP surface. UV-V is spectroscopy an important tool to characterize, investigates and identifies, these materials as well as assess the stability of NP colloidal solutions. In Fig. 9, The conversion of Zn (NO_3)2 to ZnO was confirmed by the UV–V is spectra. During ZnO synthesis, the maximum wavelength of 300 nm of Zn (NO_3)2 shifts from 340 to 370 nm.

5.2. *X-ray diffraction (XRD) analysis*

X-ray diffraction (XRD) is one of the most often applied techniques for the characterizing NPs. It also provide chemical information for elemental analysis as well as for phase analysis. X-ray diffraction (XRD) is an imperative technique for analyzing a wide range of materials, including fluids, powders and crystals [253]. The crystalline nature of nanoparticles was confirmed by X-ray crystallography, as shown in Fig. 10. XRD is highly useful for stress measurements and texture analysis, in addition to chemical characterization. The phase, structural analysis and grain size of the synthesized nanoparticles were analyzed using this technique.

5.3. *Brunauer–Emmett–Teller (BET) analysis*

Since it is widely available in high purity and interacts significantly with the majority of materials, nitrogen is

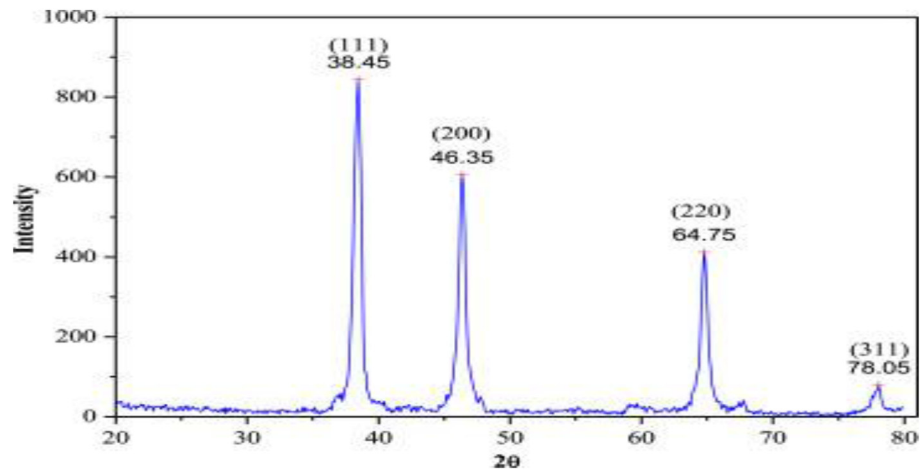

Fig. 10 – XRD pattern of the Ag nanoparticles [248].

typically used in BET surface area analysis. Due to the normally poor contact between gaseous and solid phases, the surface is chilled with liquid nitrogen in order to produce detectable amounts of adsorption. The BET method was also used to estimate the surface areas of metal–organic frameworks (MOFs), which are crystalline complexes of metal ions coordinated to organic molecules. The result for BET in Fig. 11, suggests that ZnO has a porous structure, as shown by the isotherm of N2 adsorption and desorption.

5.4. *Field emission scanning electron microscopy (FESEM) analysis*

The morphology of the prepared sample was evaluated utilizing SEM technique. The SEM approach, which is based on electron scanning concept and give all the information that is currently known about the NPs at the nanoscale level. In this method beam of electrons from the electron gun is made to incident on the sample holder. While electron gun is placed at top of the instrument and vacuum is created in the chamber to direct the electron beam to the sample incident. In the instrument, lenses and electromagnetic field control the path of the electron beam. When an accelerated electron beam incident on the sample, some of the incident is back scattered, some transmitted through sample and some gives secondary electrons. The detector tracks these back scattered and secondary electrons. Finally, through the computer, morphology of the sample can be recorded. The flower-like grains are developed with less agglomeration, as shown for the FESEM images of Ag-doped ZnO as shown in Fig. 12.

5.5. **Fourier transform infrared spectroscopy *(FTIR)***

FTIR is a technique based on the measurement of the electromagnetic radiation absorption at wavelengths between the mid-infrared regions (4000–400 cm^{-1}). It is a method for

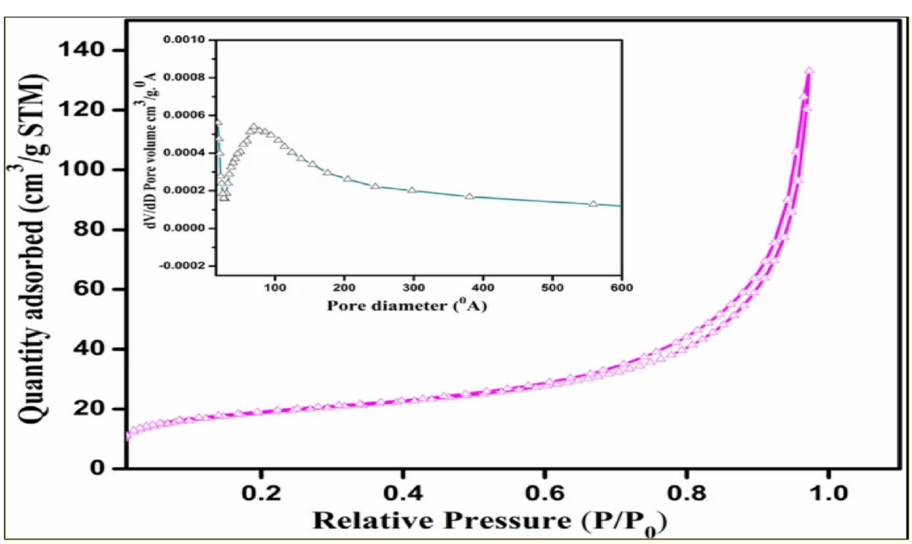

Fig. 11 – BET analysis of ZnO nanoparticles [252].

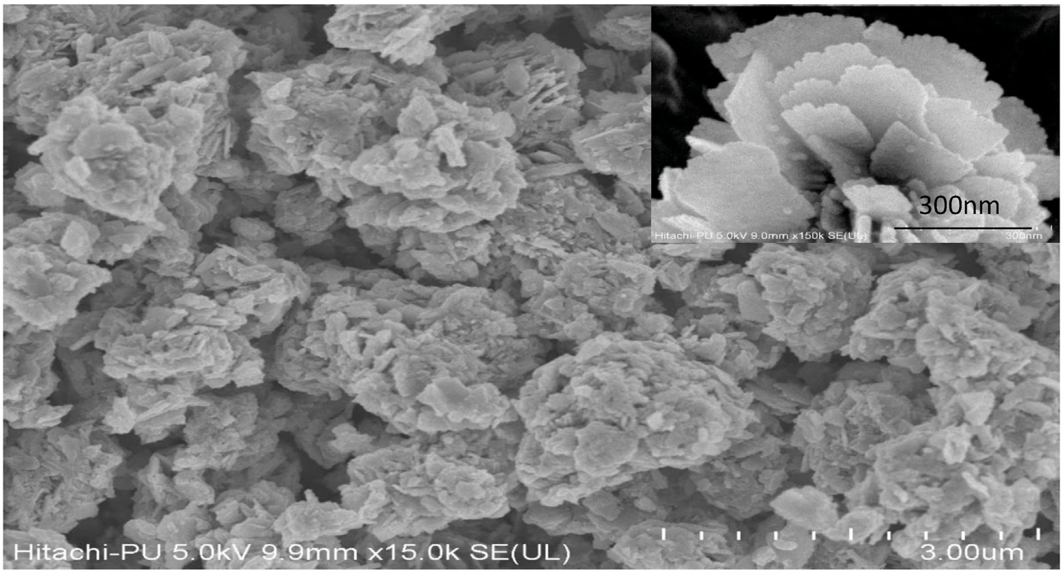

Fig. 12 – FESEM image of annealed zinc oxide nanoparticles [246].

obtaining an infrared spectrum of a solid, liquid, or gas's absorption or emission. A molecule's dipole moment is altered as it absorbs IR light, making it IR active. A recorded spectrum reveals the location of bands related to the type and strength of a bond as well as specific functional groups, offering details on the interactions and molecular structures. In Fig. 13, FTIR spectrum shows absorption bands at 3422, 2921, 2856, 1743, 1631, 1450, 1377, 1240, 1043 and 596 cm^{-1} indicating the presence of capping agent with the nanoparticles [248]. The observed intense bands were compared with standard values to identify the functional groups.

5.6. *Transmission electron microscopy (TEM) analysis*

TEM instrument is commonly used for the analysis of nanoparticles. Because TEM is based on electron transmittance principle, it may provide information on the bulk material at magnifications ranging from extremely low to high. This technique is used to study the various morphologies of nanoparticles. Size, particle shape and grain size are precisely measured by TEM. In TEM, filament is the electron source of the instrument; electrons are emitted either by thermionic filament or field emission filament. The electron produced from the filament is accelerated by electrode or cathode to attain high energy. Electromagnetic lens is the one that gives the images of the samples. Crystal plane, miller indices and interatomic distance were studied through HRTEM (High resolution transmission electron microscopy) technique. In TEM, SAED pattern gives details about the nature of the sample *i.e.,* amorphous and crystalline. The concentric ring says about the amorphous nature of the sample and systematically arranged dots which tells about the crystallinity of the sample. Fig. 14 provides some TEM micrographs with SAED pattern showing morphologies of

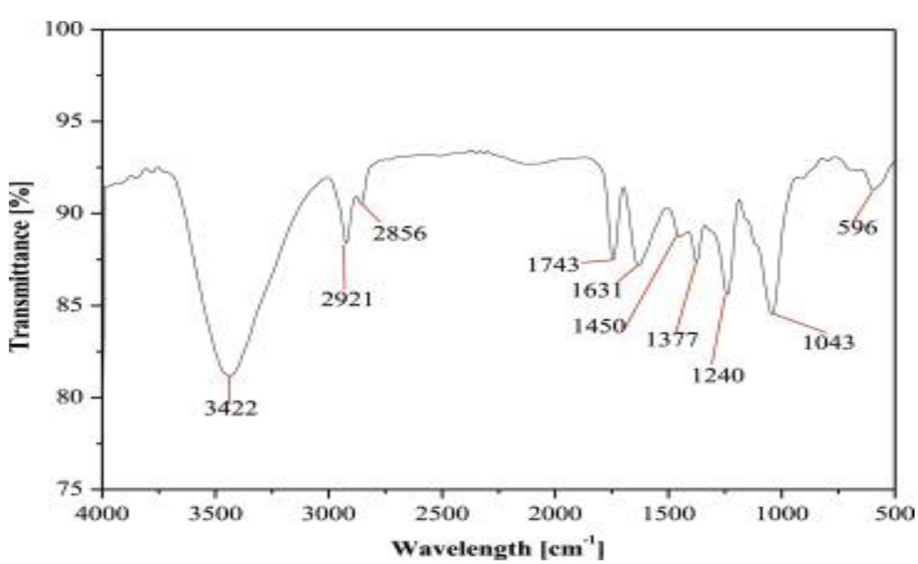

Fig. 13 – FT-IR spectrum of biosynthesized ZnO NPs [248].

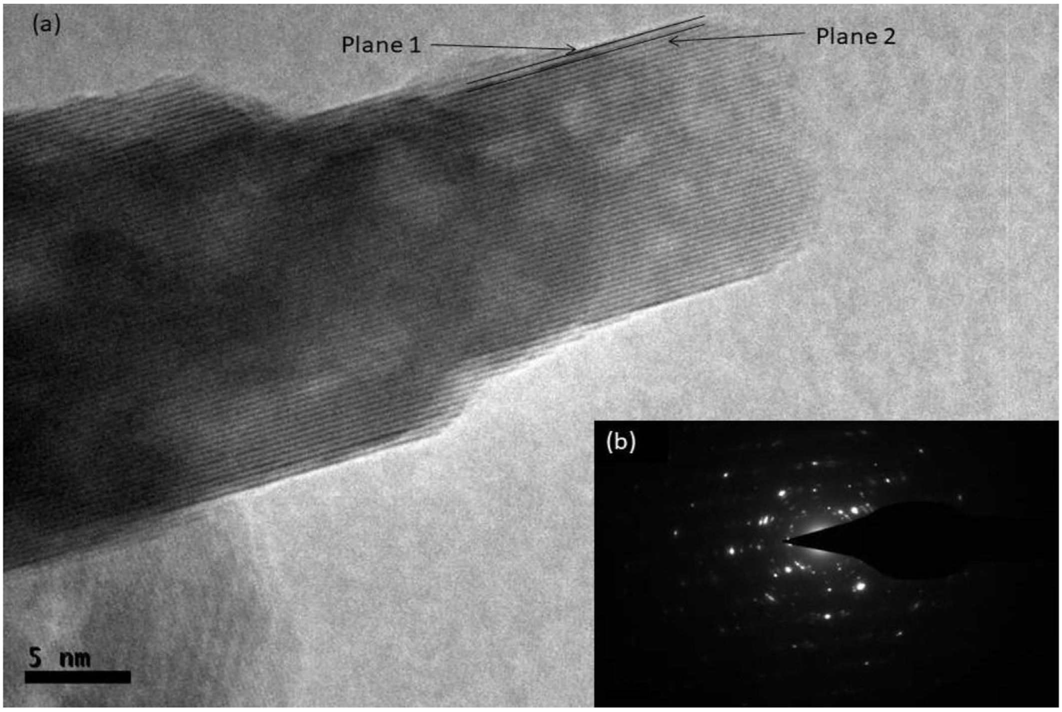

Fig. 14 – TEM micrograph with SAED pattern for Ag doped ZnO nanoparticles [246].

Table 2 – Applications of different types of Nanoparticles.

NANOPARTICLES	SIZE	STRUCTURAL PROPERTIES	APPLICATIONS	REFERENCES
Carbon nanotubes	2–100 nm	Single-wall carbon nanotubes (SWCNTs) and multi-wall CNTs (MWCNTs)	Drug delivery and Anti-cancer, energy related devices, high thermal conductivity, corrosion resistance etc.	[254]
Nano capsules	100–500 nm	Shell and core combinations.	Controlled drug delivery, biocompatibility, high loading capacity.	[255]
Dendrimers	1–15 nm	Highly branched ends and central core.	Cardiovascular therapy, Anti-inflammatory therapy, anti-bacterial therapy, imaging diagnostics etc.	[256]
Liposomes	100–200 nm	Lipid bi-layer globules	Hydrophobic and Hydrophilic drug delivery	[257]
Polymeric nanoparticles	1–1000 nm	Polymers as chitosan, PLGA	Biocompatibility, biodegradability and non-toxicity, Tissue regeneration, anti-microbial properties, etc.	[258]
Nanosphere	100–150 nm	Spherical shaped.	Tissue regeneration and drug delivery, Anti-Alzheimer activity, neurodegenerative disease, etc.	[259]

NPs. This TEM image gives the side view of the sample and confirms that the flower-like structure is being developed by small thin films. The SAED pattern in clearly shows that the nanostructures formed are crystalline.

6. Applications of different types of nanoparticles

The fields of application for nanoparticles are wide ranging as shown in Table 2. They are very important in the creation of different materials. A few of the many potential advantages of nanoparticles are improved catalytic activity, electrical conductivity, increased strength, and durability. There are several products using nanotechnology available on market right now. Additionally, sunscreens and cosmetics contain nanoparticles. They serve as drug delivery agents in the treatment of cancer.Nanoparticles are promising in regenerative medicine, for example in tissue cultures.

7. Conclusion

Recent studies have given a great deal of attention to nanotechnologies and nanomaterials. Nanomaterials are quite interesting since they have a lot of potential to develop novel and innovative products across many areas. Nanoparticles have better features because of their small size, such as a larger surface area, high reactivity, stability, strength, sensitivity, etc. Due to their unique and intriguing characteristics above their bulk counterparts, nanoparticles having one or more dimensions of the order of 100 nm or less have attracted significant interest and are used in a variety of applications. Nanoparticles are particularly prone to severe oxidation when being stored until use because of their small sizes. Both top-down and bottom-up strategies are used in the synthesis of nanoparticles. For academic research and commercial business purposes, the nanoparticles are produced using a several techniques that can be divided into three primary categories; biological, physical and chemical processes. In this review, we covered the preparation of nanoparticles using different techniques. The ability to produce particles with various chemical compositions, Monodispersed, sizes and shapes is necessary for the use of nanoparticles. Compared to physical and chemical processes, which not only cost more money but also produce toxic byproducts that harm the environment. The role of several approaches for the characterization of nanoscale materials was also discussed in this review. Researchers will benefit from a better understanding of the health and safety implications of nanoparticles as well as the ability to develop safer nanomaterial.

Declaration of Competing Interest

“The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper”.

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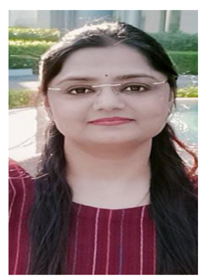

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