INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Nano Material: Synthesis And Application

Prapti Kharat*, Ishwari Kachare, Ankita Joshi, Nikita Jori, Madhavi Joshi

Pravara Rural Education Society Institute of pharmacy, Loni.

ARTICLE INFO
Published: 07 Aug 2025
Keywords:
nanotechnology nano material, synthesis method, nanoparticles, particles size, properties and application
DOI:
10.5281/zenodo.16759604

ABSTRACT

The recent past in the technological development evidenced that evolution in Nanotechnology and nanoscience is the key factor. Nanotechnology is multidisciplinary science which deals with physics, chemistry, materials science and other engineering sciences. The applications of Nanotechnology are spreading in almost all the branches of science and technology In this review various methods of preparing nanomaterials including Gas Condensation, Vacuum Deposition and Vaporization, Chemical Vapor Deposition (CVD) and Chemical Vapor Condensation (CVC), Mechanical Attrition, Chemical Precipitation Sol-Gel Techniques, Electrodeposition are discussed Nanomaterials research takes a materials science-based approach to nanotechnology, leveraging advances in materials metrology and synthesis which have been developed in support of microfabrication research. Materials with structure at the nanoscale often have unique optical, electronic, or mechanical properties. Nanomaterials are slowly becoming commercialized and beginning to emerge as commodities. The present review article highlighted the types of nanoparticles and their synthesis methods, characterization techniques. There are many techniques and applications are reported in the last five years but here we strictly focused on the general synthetic approaches and applications of the nanomaterials which provide a general idea to the young researchers. Additionally, this paper will discuss nanoparticles, including their types, traits, synthesis methods, application and prospects Research on nanomaterials is significant for the development and application of materials science.

INTRODUCTION

Over the last century nanotechnology branch is flourishing to a great extent. And today many types of research are directly or indirectly related to the nanotechnology. Nanotechnology can be stated as the developing, synthesizing, characterizing and application of materials and devices by modifying their size and shape in nanoscale" In each and every stream the prefix ''nano" is using as a keyword even in advertising the products also. Actually, the word ''nano" is

***Corresponding Author:** Prapti Kharat
Address: *Pravara Rural Education Society Institute of pharmacy, Loni.*
Email : kharatprapti785@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

derived from the Greek word nanos or Latin word nanus means which ‘‘dwarf’’. It is the combination of physics, chemistry, material science, solid state, and biosciences. So, profound knowledge in one field will not be sufficient, the combined knowledge of physics, chemistry, material science, solid state, and biosciences is required. The applications of Nanotechnology nanotechnology is an emerging field of research in biomedical applications. Nanoparticles are part of the technology as a molecular probe for detecting and curing diseases. The nanoparticles are very small and are 10^{-9} meters in size. It has unique physical and chemical properties when compared to bulk materials. The broad classification of nanoparticle synthesis is used of top-down and bottom-up techniques. The top-down technique involves physical participation approaches such as mechanical machining, physical vapor deposition (PVD), lithography, and pyrolysis through thermal evaporation pyrolysis. Bottom-up methods consist of chemical and biological approaches. Sol-gel, chemical vapor deposition (CVD), chemical co-precipitation, micro-emulsions, hydrothermal method, nonchemical, and microwave methods are involved in the bottom-up chemical approaches. Furthermore, other methods of synthesizing nanoparticles are through plant extracts, enzymes, agricultural waste, microorganisms, and actinomycetes.

Flow chart of synthesis method of nano material

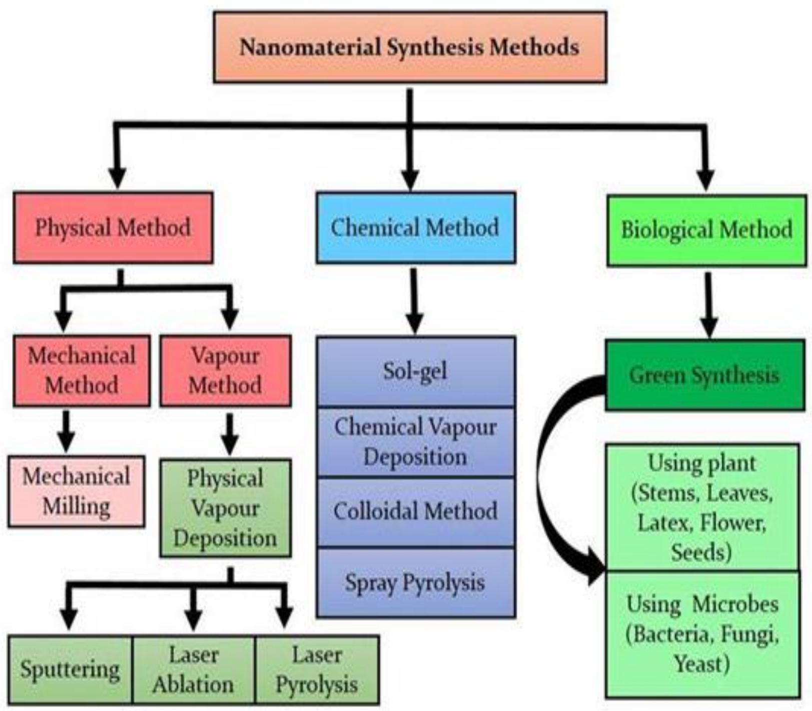
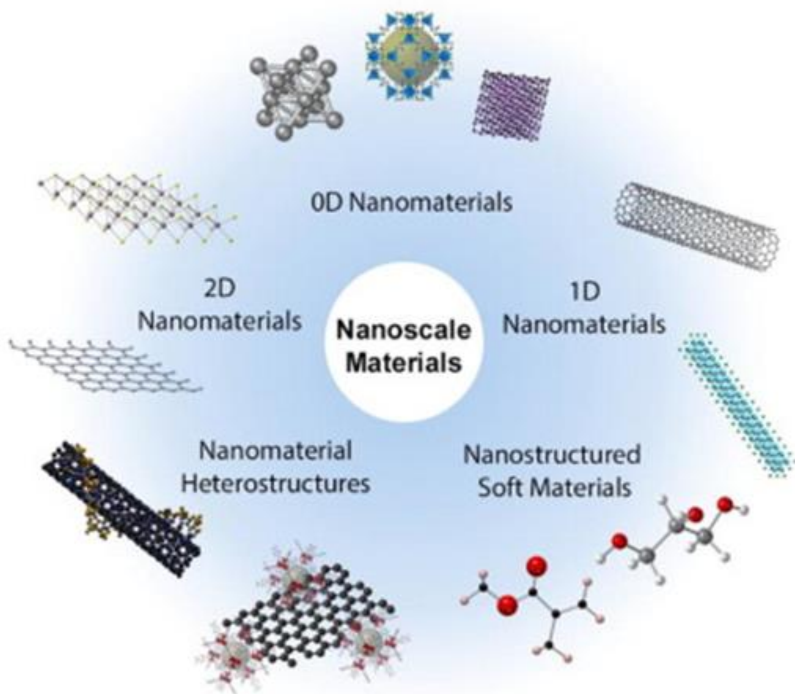


Fig.No-2 Synthesis method for nano material

The definition of nanoparticles differs depending on the materials, fields, and applications concerned. In the narrower sense, they are regarded as the particles smaller than 10e20 nm, where the physical property of solid materials themselves would drastically change. On the other hand, the particles in the three digit range of nanometer from 1 nm to 1 mm could be called as nanoparticles. In many cases, the particles from 1 to 100 nm are generally called as nanoparticles, but here they will be regarded as the particles smaller than those called conventionally "submicron particles," and concretely less than the wavelength of visible light (its lower limi is about 400 nm) as a measure, which need to be treated differently from the submicron particles. Particle size is the most important information in practical applications of powder particles. Usually, powder is constituted by particles of various sizes and, therefore, it is necessary to obtain not only the mean particle size but also the size distribution for the characterization. Recently, the methods for particle size analysis have been greatly developed. Especially, the analyzers with prominent characteristics such as rapid response, high repeatability, and covering wide range of particle size are developed as in the case of laser scattering and diffraction method.

1.1 Discovery:



The use of NPs has been traced back to the fourth century AD. In 1990, the Lycurgus cup from the British Museum collection was analyzed using transmission electron microscopy (TEM). This cup is regarded as the oldest and most popular renowned example of dichroic glass, where the display of two colors was caused by nanoparticles measuring 50–100 nm in diameter. X-Ray analysis revealed the glass was crafted using silver and gold in a 7:3 ratio, along with 10 % copper.2 The concept of nanotechnology was introduced by American physicist and Nobel Prize laureate Richard Feynman in 1959. In his lecture "There's Plenty of Room at the Bottom," presented at the annual meeting of the American Physical Society at the California Institute of Technology (Caltech), he highlighted the possibility of using machines to construct smaller machines at the molecular scale Feynman is recognized as the father of modern nanotechnology. He envisioned significant advancements in science through nanotechnology, especially in medicine and materials science. He hypothesized that tiny machines could be programmed to perform complex tasks like repairing cells. However, Feynman highlighted the potential risks of nanotechnology, particularly the challenges in controlling the nanosized machines. If NPs are not handled cautiously, they could cause potential harm to people and the environment. In 1974, Norio Taniguchi, a Japanese scientist, was the first to define the term nanotechnology, describing it as the processes of "separation, consolidation, and deformation of materials by one atom or one molecule." In 1991, Drexler also co-authored "Unbounding the Future: the Nanotechnology Revolution," introducing terms like "nanobots" and "nanomedicine" for the first time, highlighting their potential in medical applications.

2.Structure:

Nanoparticles (NPs) are the fundamental component of nanotechnology. Nanoparticles are the particulate matters with at carbon, metal, metal oxides or organic matter. On the basis of dimensions NPs can be classified into (Khan I., Khalid S., & Khan I., 2019; Kim K. S., Tiwari J. N. & Tiwari R. N, 2012):

1. Zero dimensional (0D) with length, breadth & height Corresponding Author fixed at a single point. Eg. Nano dots

2. One dimensional (1D) which possess only one parameter. Eg. Graphene

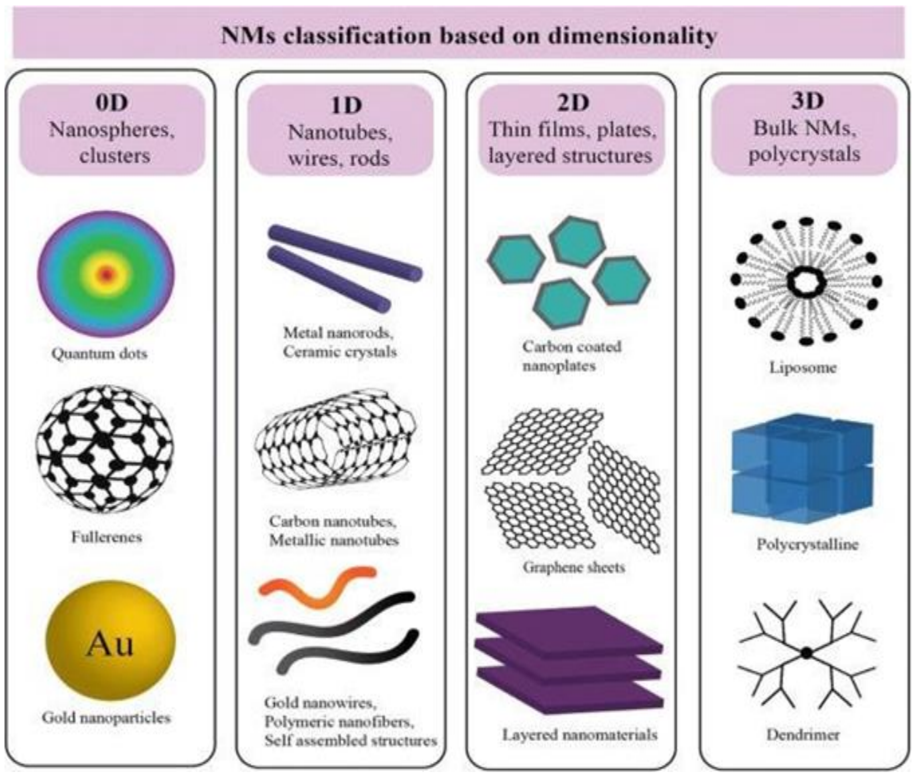
3. Two dimensional (2D) which possess only two parameters i.e., length & breadth. Eg. Carbon nanotubes

4. Three dimensional (3D) possessing all three parameters viz. length, breadth & height. Eg. Gold nanoparticles. The nanoparticles (NPs) can exist in different shape, size and structure such as spherical, cylindrical, tubular, conical, hollow core, spiral, flat, wire etc. It can be also be irregular in shape. The surface of NPs can either be uniform or irregular. They can also exist in crystalline and amorphous forms which can be either single crystal solid or multi- crystal solid. Multi- crystal solid can either be loose or agglomerated. The physio- chemical properties of these NPs are mostly influenced by their variation in size & shapes. Owing to unique physical and chemical properties, NPs has achieved great success in wide variety of applications in different fields such as medicinal, environmental, energy-based research, imaging, chemical & biological sensing, gas sensing etc. Researchers are more inclined towards nanotechnology as it is considered as one of the important factors for a clean and sustainable future. Nanoparticles (NPs) have complex structure. They are comprised of two or three layers: (i) a surface layer: functionalized by a variety of small molecules, metal ions, surfactants or polymers (ii) The shell layer: can be purposely added and is chemically different from the core, and (iii) The core material: the central portion of NPs (Shin W. K., Cho J., Kanna A. G., Lee Y. S. & Kim D. W., 2016; Ealia S. A. M. & Saravanakumar M. P, 2019). The characteristic properties of NPs are generally due to the core material. Hence, NPs are often referred to by their core material only. Based on the degree of spatial confinement, nanomaterials can be subdivided into four major types [3], i.e., (i) zero-dimensional nanomaterials (all the dimensions are in nanometer scale, e.g., nanoparticles), (ii) one-dimensional nanomaterials (any one of the three dimensions is of nanometer scale e.g., nanorods, nanowires etc.), (iii) two-dimensional nanomaterials (any two of the three dimensions are of nanometer scale e.g., nanosheets, nanoplates, and nano-coatings) and (iv) three-dimension nanomaterials (three dimensions are larger than 100 nm and electrons are not confined in any direction). Some examples include nanoflowers, nano cubes, nanocages, nanowire bundles, as well as other self-assemblies of lower-dimensional nanomaterials.

- **According to Richard W. Siegel, Nanostructured materials are classified as**:

a) Zero dimensional;
b) One dimensional;
c) Two dimensional;

Three-dimensional nano structural



a) Zero-dimensional nanomaterials:

- Materials where in all the dimension are measured within the nano scales (no dimension or 0-D, are larger than 100 nm).
- The most common representation of zero-dimensional nano materials are nano particles
- Nanoparticles can:
- Be amorphous or crystalline
- Be single crystalline or polycrystalline
- Exhibit various shape and forms
- Be metallic, ceramic or polymeric

b) One dimensional nanomaterial:

- One dimension that is outside the nanoscales
- This leads to needle like-shape nano materials
- 1-D materials include nanotubes, nanorods, and nanowires
- 1-D nanomaterial can be
- Be amorphous or crystalline
- Be single crystalline or polycrystalline
- Chemical pure and impure
- Be metallic, ceramic or polymeric

c) Two dimensional materials

- Two of the dimensions are not confined to the nano scales

- 2-D nano materials exhibit plate like shape
- Two-dimension nano materials include nanofilms, nanolayers, and nanocoating's
- 2-D nanomaterials can be:
- Amorphous or crystalline
- Made up of various chemical composition
- Deposited on a substrate
- Metallic, ceramic, or Polymeric

d) Three-dimensional nano materials

- Bulk nanomaterials are materials that are not confined to the nanoscales
- Material possess a nanocrystalline structure
- 3-D nano material can contain dispersions of nanoparticles bundles of nano wire

3. Properties and size effects of nano material:

properties of matter at the nanoscale level are substantially distinct compared to bulk counterparts. Size-dependent effects become more prominent at the nanoscale. For example, Au solution appears yellow when in the bulk and it appears purple or red at the nanoscale level. The properties of nanomaterials can be tuned *via* tuning the nanomaterial size. At the nanoscale, the electronic properties are substantially changed compared to bulk materials. For example, boron in bulk form is not considered a metal, whereas a two-dimensional network of boron (borophene) appears to be an excellent 2D metal. Compared to their bulk counterparts, the mechanical properties of nanomaterials are considerably improved due to increases in crystal perfection or reductions in crystallographic defects. The electronic properties of semiconductors in the 1–10 nm range are controlled by quantum mechanical considerations. Thus, nanospheres with diameters in the range of 1–10 nm is known as quantum dots. The optical properties of nanomaterials such as quantum dots strongly depend upon their shape and size. A photogenerated electron–hole pair has an exciton diameter on the scale of 1–10 nm. Thus, the absorption and emission of light by semiconductors could be controlled *via* tuning the nanoparticle size in this range. However, in the case of metals, the mean free path of electrons is ~10–100 nm and, due to this, electronic and optical effects are expected to be observed in the range of ~10–100 nm. The colours of aqueous solutions of metal nanoparticles can be changed *via* changing the aspect ratio. Aqueous solutions of Ag NPs show different colours at different aspect ratios. A red shift in the absorption band appears with an increase in the aspect ratio.

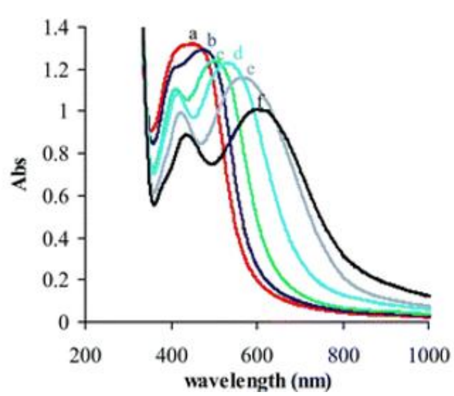


Fig. Aqueous solutions of silver nanoparticles show wide variations in visible colour depending on the aspect ratio of the suspended nanoparticles. The far left of the photograph shows silver nanospheres (4 nm in diameter) that are used as seeds for subsequent reactions, while (a–f) show silver nanorods with increasing aspect ratios from 1–10. The corresponding visit absorption spectra for (a)–(f) are also shown in the left panel. Reprinted with permission from Copyright: ©2002, WILEY-VCH Verlag GmbH, Weinheim, Fed. Rep. of Germany.

Among a range of unique properties, the following key properties can be obtained upon tuning the sizes and morphologies of nanomaterials.

- **Surface area**

The surface areas of nanomaterials are generally substantially high compared with their bulk counterparts, and this property is associated with all nanomaterials.

- **Magnetism**

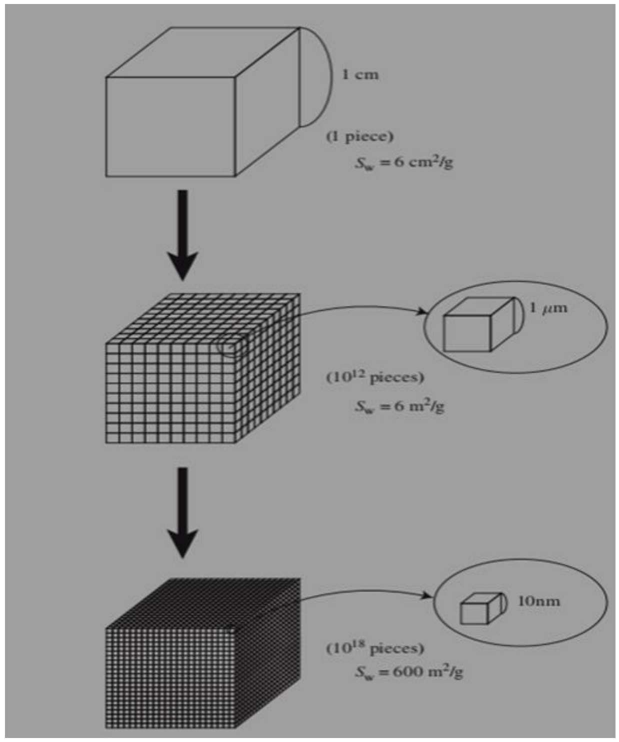
The magnetic behavior of elements can change at the nanoscale. A non-magnetic element can become magnetic at the nanoscale level.

- **Quantum effects**

Quantum effects are more pronounced at the nanoscale level. However, the size at which these effects will appear strongly depends upon the nature of the semiconductor material

- **Increase of Surface Area**

On the other hand, as the micritization of solid particles, the specific surface area increases generally in reversal proportion to the particle size. In the abovementioned case, when the particle of 1 cm is micronized to 1 mm and 10 nm, the specific surface area becomes ten thousand times and million times, respectively. As the increase in the specific surface area directly influences such properties such as the solution and reaction rate of the particles, it is one of major reasons for the unique.

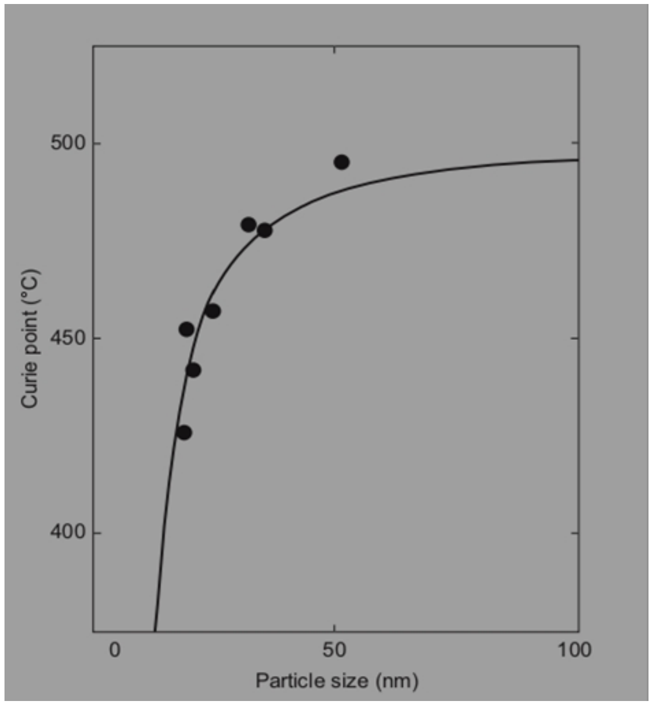


3.1 Thermal Properties

As the atoms and molecules located at the particle surface become influential in the nanometer order, the melting point of the material decreases from that of the bulk material because they tend to be able to move easier at the lower temperature. For example, the melting point of gold is 1336 K as a bulk but starts to decrease remarkably below the particle size of about 20 nm and drastically below 10 nm and then becomes more than 500 lower than that of the gold bulk around 2 nm. The reduction of the melting point of ultra- fine particles is regarded as one of the unique features of the nanoparticles related with aggregation and grain growth of the nanoparticles or improvement of sintering performance of ceramic materials.

3.2 Electromagnetic Properties

The nanoparticles are used as the raw material for a number of electronic devices. The electric properties and particle size of these nanoparticles play a great role for the improvement of the product performance as an example; there is a strong demand for the materials with a high dielectric constant to develop small and thin electronic devices. For this purpose, it has been confirmed by the XRD analysis, for instance, that the dielectric constant of $PbTiO_3$ tends to increase considerably as the particles become smaller than about 20 nm. Meanwhile, it.



3.3 Optical properties:

As the size of particles becomes in the several nanometers range, they absorb the light with a specific wavelength as the plasmon absorption caused by the plasma oscillation of the electrons and the transmitted light with different color depending on the kind of metal and particle size that is obtained.

Fig. shows the plasmon absorption of silver nanoparticles, where the spectral absorption intensity differs depending on the particle size, which is determined by the concentration of the surfactant used for their preparation. In case of gold nanoparticles, it is reported that the maximum light absorption wavelength is 525 nm for the particles of 15 nm but it is enlarged by about 50 nm for 45 nm particles. In this way, these gold and silver nanoparticles show the color phenomena with splendid tinting strength, color saturation, and transparency compared with the conventional pigments for the paint in the submicron size and the tinting strength per unit volume of silver nanoparticles becomes about 100 times higher than that of organic pigments. Furthermore, because the nanoparticles are smaller than the wavelength of visible light and the light scattering by the particles becomes negligible, higher transparency can be obtained with the nanoparticles than the conventional pigment. On the other hand, concerning the light emitting performance, the indirect transition type substances such as silicon and germanium, which do not emit the light as bulk material, give high light emitting efficiency as the direct transition type substances as a result of quantum effect, when the particle size is reduced down to several nanometers.

3.4 Mechanical Properties

It is known that the hardness of the crystalline materials generally increases with the decreasing crystalline size, and that the mechanical strength of the materials considerably increases by micronizing the structure of the metal and ceramic material or composing them in the nano range. Furthermore, with the ceramic material having crystalline size less than several hundred nanometers, the unique superplastic phenomenon is seen that it is extended several to several thousand times from the original size at the elevated temperature over 50% of the melting point, which may provide.

References

[1] M. Arakawa, J. Soc. Powder Technol. Jpn. 42 (2005) 582e585.

[2] M. Arakawa, Funsai (Micrometr.) (27) (1983) 54e64.

[3] H. Maeda, J. Control. Release 19 (1992) 315e324.

[4] K. Uchino, E. Sadanaga, T. Hirose, J. Am. Ceram. Soc. 72 (8) (1989)

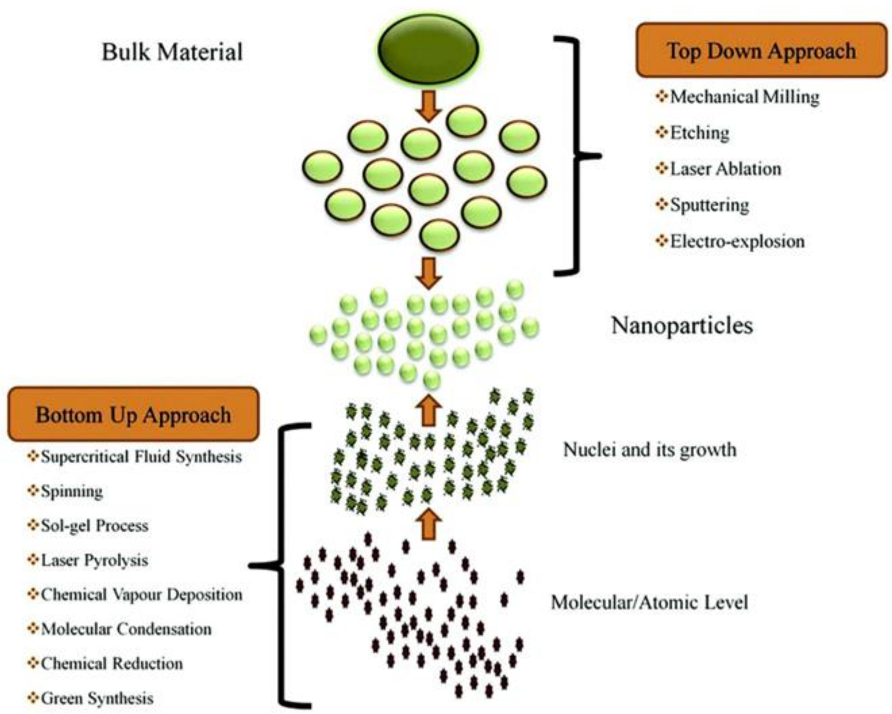
1555e1558.

4. Synthesis Of Nano Materials

Two main approaches are used for the synthesis of nanomaterials: top-down approaches and bottom-up approaches

4.1 Top-down approaches

In top-down approaches, bulk materials are divided to produce nanostructured materials. Top-down methods include mechanical milling, laser ablation, etching, sputtering, and electro-explosion.



Methods:

4.1.1 Mechanical method / Ball milling:

- The ingredients are ground in a closed container during this procedure. Shear force is created during grinding by small glass, ceramic, and stainless-steel pebbles. Bulk materials are loaded into a closed container. The grinding process converts bulk materials to fine- tuned nanoparticles.
- We can make metallic hydrides and nitrides using this procedure. Their hardness and

stability are employed in microelectronic applications to cut tools and coat tooling (e.g., titanium nitride (Tin) alloy).

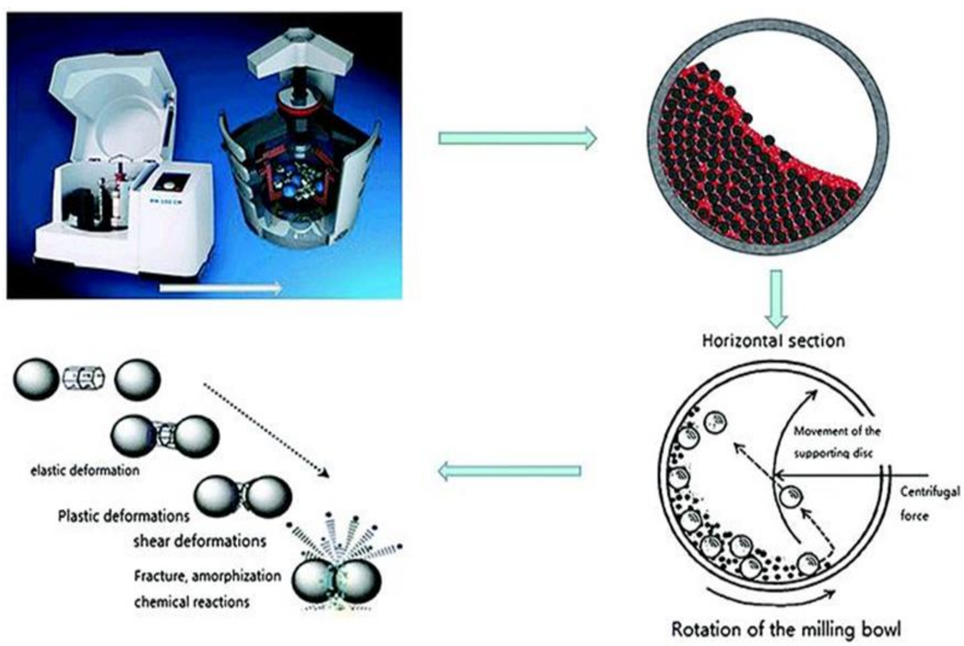
- It is created through the reactive ball milling method. In this method, the bulk metallic powder is deposited in a closed container with a nitrogen gas atmosphere that is then exposed to high-energy ball milling.
- Metallic powders are degraded to generate tiny particles, and oxygen-free active surfaces on nanomaterials are formed.
- By including a functional moiety on the surface of the nanotube in the container, the quality of the nanotubes is improved.
- The size of the pebbles, rotational speed, milling time, and amount of nanotube injected are all parameters that influence nanotube dispersion.
- The advantages of the ball-milling method include:

a) producing fine powder

b) being suitable for milling hazardous materials; and milling abrasive materials.

- The disadvantages of the ball-milling approach include:

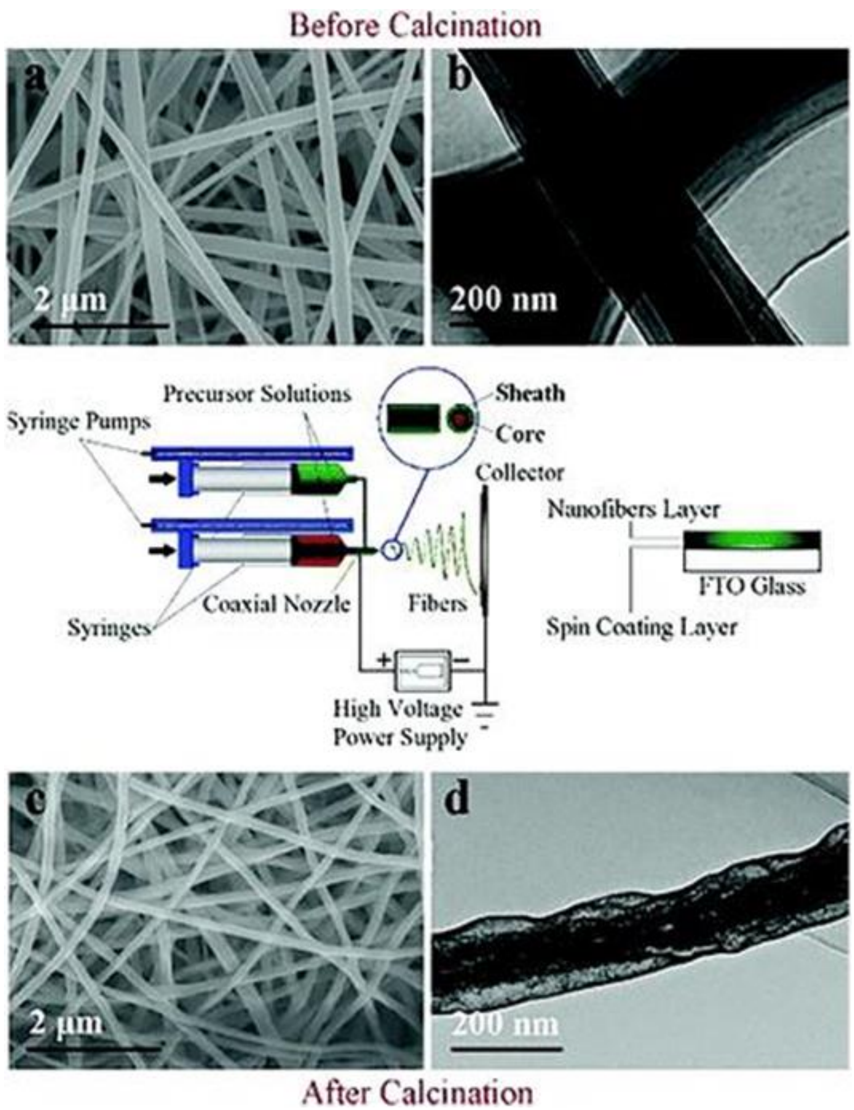
a) an increase in contamination caused by wear and tear in ball collisions; an increase in machine noise when the concealed cylinder is made of metal; a time-consuming operation



The principle of the ball milling method. Reprinted with permission from. Copyright: ©2016, John Wiley & Sons, Ltd.

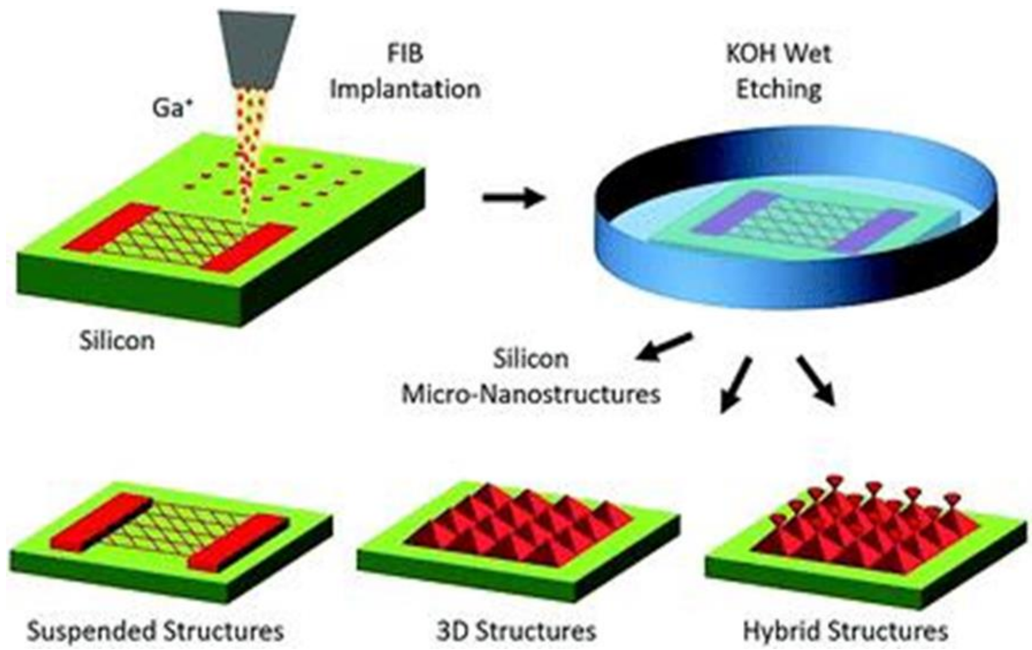
4.1.2 Electrospinning

Electrospinning is one of the simplest top-down methods for the development of nanostructured materials. It is generally used to produce nanofibers from a wide variety of materials, typically polymers.28 One of the important breakthroughs in electrospinning was coaxial electrospinning. In coaxial electrospinning, the spinneret comprises two coaxial capillaries. In these capillaries, two viscous liquids, or a viscous liquid as the shell and a non-viscous liquid as the core, can be used to form core–shell nanoarchitectures in an electric field. Coaxial electrospinning is an effective and simple top-down approach for achieving core–shell ultrathin fibres on a large scale. The lengths of these ultrathin nanomaterials can be extended to several centimetres. This method has been used for the development of core–shell and hollow polymer, inorganic, organic, and hybrid materials.29 A schematic diagram of the coaxial electrospinning approach can be seen in Schematic diagram of the coaxial electrospinning technique (center), and FESEM (a and c) and TEM (b and d) images of fibres before and after calcination. Reprinted with permission from ref. 30. Copyright: ©2012, Elsevier Ltd. All rights reserved.



4.1.3 Lithography

Lithography is a useful tool for developing nanoarchitectures using a focused beam of light or electrons. Lithography can be divided into two main types: masked lithography and maskless lithography. In masked nanolithography, nanopatterns are transferred over a large surface area using a specific mask or template. Masked lithography includes photolithography, nanoimprint lithography, and soft lithography. Maskless lithography includes scanning probe lithography, focused ion beam lithography, and electron beam lithography. In maskless lithography, arbitrary nanopattern writing is carried out without the involvement of a mask. 3D freeform micro-nano-fabrication can be achieved via ion implantation with a focused ion beam in combination with wet chemical etching, as shown in figure.



Schematic diagram of the fabrication of 3D micro-nanostructures with an ion beam through bulk Si structuring. This involves implantation in Si through Ga FIB lithography and mask-writing at nanometer resolution, subsequent anisotropic wet etching in KOH solution, and the fabrication of Si micro-nanostructures via the selective removal of the unplanted region. Reprinted with permission from ref. 37. Copyright: ©2020, Elsevier B.V. All rights reserved

4.1.4 Laser ablation method

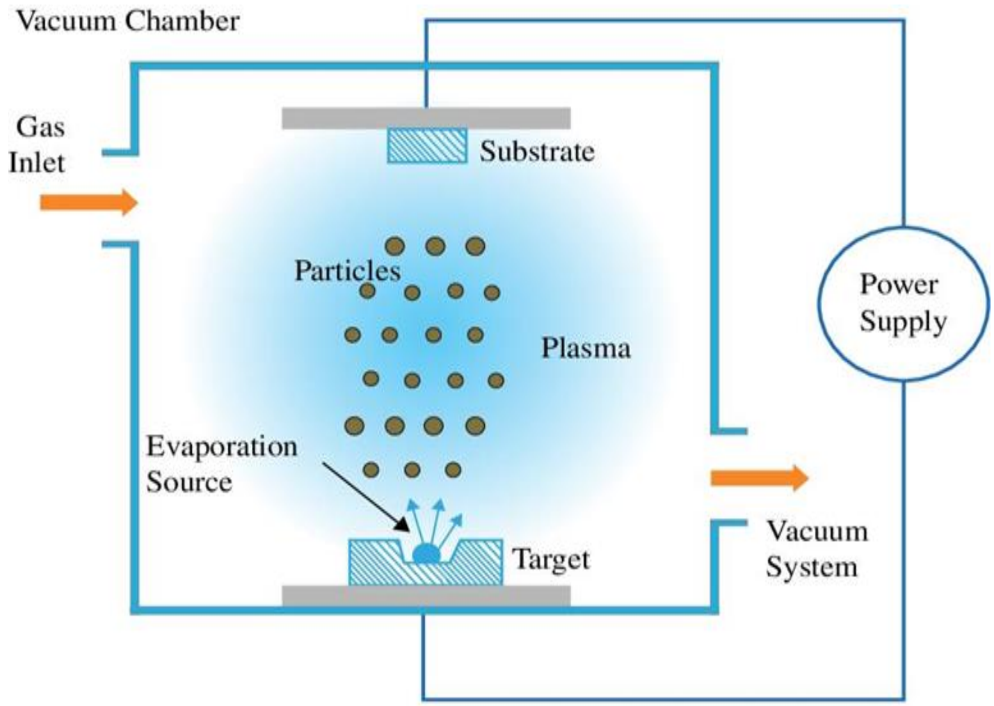
Laser ablation synthesis generates nanoparticles by striking the target material with a powerful laser beam. Metal atoms vaporize in a laser ablation experiment and are immediately solvated by surfactant molecules to form nanoparticles in the solution.

4.1.5Sputtering method

Sputtering is the phenomenon of nanoparticle deposition using ejected particles colliding with ions. Sputtering is typically defined as the deposition of a thin layer of nanoparticles followed by annealing.

4.1.6 Physical Vapor Deposition (PVD) Method

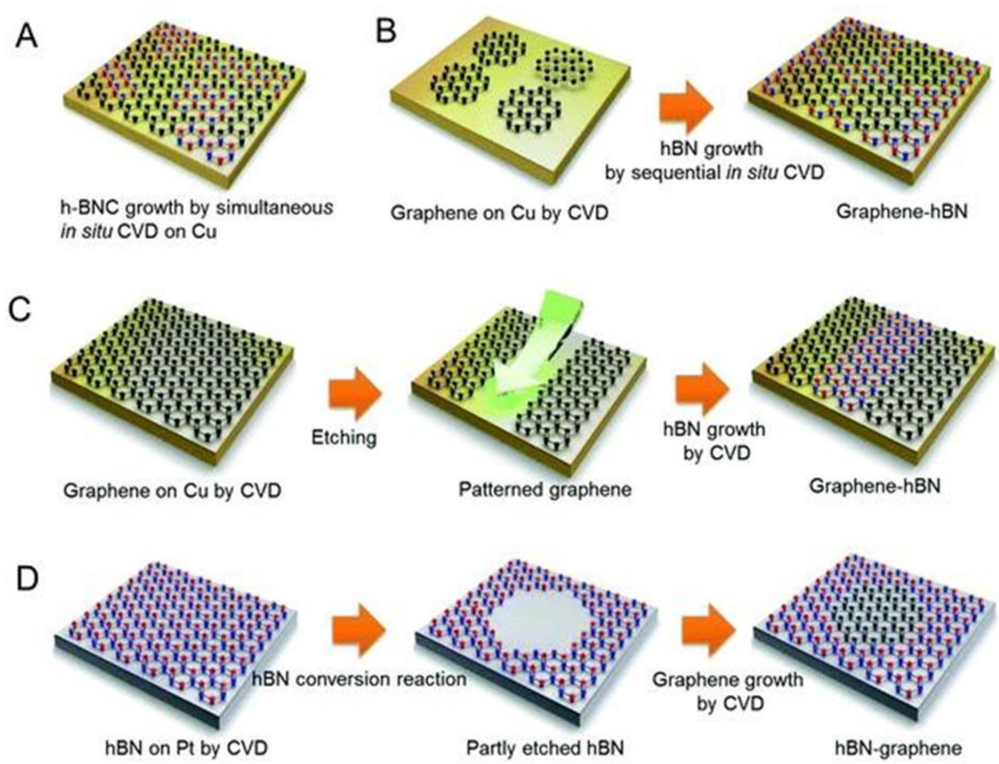
Physical vapor deposition (PVD) is a process applied to the synthesis of ultra-thin films and surface coatings. It is used to produce metal vapor that can be deposited on the conductive layer as ultra-thin films and alloy coatings. The whole process is carried in a vacuum held in a vacuum chamber about 10−6 torr from a cathodic-arc source. In a clean atmosphere, vacuum deposition is held in the chamber and the metals are deposited as wider or sputtered in the localized area. Reactive PVD is designed in a method to deposit metal on the surface and reactive gas such as oxygen, nitrogen, or methane passed in the vacuum chamber. Plasma, the high energetic beam bombards the metal surfaces ensuring hard and dense coating. Using this method, we can synthesis nano-particles and allow to fabricate nanocomposites. Thin film formation is characterized by the metal ions in the vapor phase obtained from condense phase and return back to condense phase of thin films [30]. The PVD includes evaporation and a sputtering process to fabricate thin films. The procedure for PVD includes sputtering process that is carryover in the vapor phase under supersaturation. In an inert atmosphere the metal vapors are promoted to condense phase, and it is subjected to thermal treatment to get nanocomposites. The advantage of the PVD techniques include (i) having improved properties as compared with the substrate material; (ii) inorganic and few organic materials are used, and it is an ecofriendly approach as compared to electroplating technique. This technique also faces few difficulties such as (i) coating with complex structures; (ii) it is not cost-effective and produces a low output; and (iii) it is a complex process.



4.2 Bottom-up approaches

4.2.1Chemical vapor deposition (CVD)

Chemical vapor deposition methods have great significance in the generation of carbon-based nanomaterials. In CVD, a thin film is formed on the substrate surface *via* the chemical reaction of vapor-phase precursors. A precursor is considered suitable for CVD if it has adequate volatility, high chemical purity, good stability during evaporation, low cost, a non-hazardous nature, and a long shelf-life. Moreover, its decomposition should not result in residual impurities. For instance, in the generation of carbon nanotubes *via* CVD, a substrate is placed in an oven and heated to high temperatures. Subsequently, a carbon-containing (such as hydrocarbons) gas is slowly introduced to the system as a precursor. At high temperatures, the decomposition of the gas releases carbon atoms, which recombine to form carbon nanotubes on the substrate. However, the choice of catalyst plays a significant role in the morphology and type of nanomaterial obtained. In the CVD-based preparation of graphene, Ni and Co catalysts provide multilayer graphene, whereas a Cu catalyst provides monolayer graphene. Overall, CVD is an excellent method for producing high-quality nanomaterials and it is well-known for the production of two-dimensional nanomaterials.



4.2.2 Sol-gel process

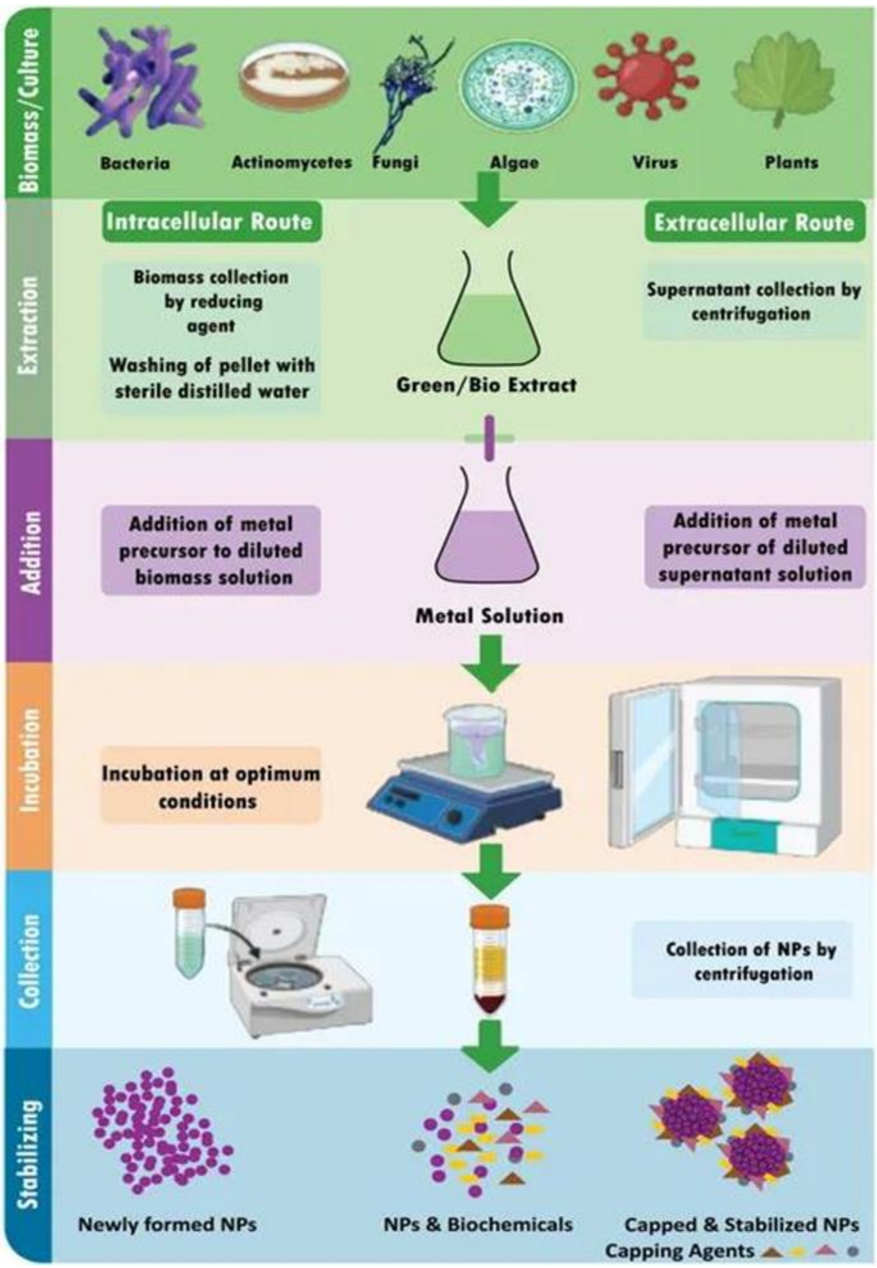
A wet-chemical approach, called the sol-gel method, is widely utilized to create nanomaterials (Das and Srivastava, 2016; Baig et al., 2021). Metal alkoxides or metal precursors in solution are condensed, hydrolyzed, and thermally decomposed. The result is a stable solution or sol. The gel gains greater viscosity as a result of hydrolysis or condensation. The particle size may be seen by adjusting the precursor concentration, temperature, and pH levels. It may take a few days for the solvent to be removed, for Ostwald ripening to occur, and for the phase to change during the mature stage, which is necessary to enable the growth of solid mass. To create nanoparticles, the unstable chemical ingredients are separated. The generated material is environmentally friendly and has many additional benefits thanks to the sol-gel technique (Patil et al., 2021). The uniform quality of the material generated, the low processing temperature, and the method's ease in producing composites and complicated nanostructures are just a few of the sol-gel technique's many advantages (Parashar et al., 2020).

4.2.3 Co-precipitation

It is a solvent displacement technique and is a wet chemical procedure. Ethanol, acetone, hexane, and non-solvent polymers are examples of solvents. Polymer phases can be either synthetic or natural. By mixing the polymer solution, fast diffusion of the polymer-solvent into the non-solvent phase of the polymer results. Interfacial stress at two phases results in the formation of nanoparticles (Das and Srivasatava, 2016). This method's natural ability to produce high quantities of water-soluble nanoparticles through a straightforward process is one of its key benefits. This process is used to create many commercial iron oxide NP-based MRI contrast agents, including Feridex, Reservist, and Combidex (Baig et al., 2021; Patil et al., 2021).

4.3 Green/biological synthesis

The synthesis of diverse metal nanoparticles utilizing bioactive agents, including plant materials, microbes, and various biowastes like vegetable waste, fruit peel waste, eggshell, agricultural waste, algae, and so on, is known as "green" or "biological" nanoparticle synthesis (Kumari et al., 2021). Developing dependable, sustainable green synthesis technologies is necessary to prevent the formation of undesirable or dangerous by products. The green synthesis of nanoparticles also has several advantages, including being straightforward, affordable, producing NPs with high stability, requiring little time, producing non-toxic by products, and being readily scaled up for large-scale synthesis (Malhotra and Alghuthaymi, 2022).



4.3.1 Biological synthesis using microorganisms

Microbes use metal capture, enzymatic reduction, and capping to create nanoparticles. Before being converted to nanoparticles by enzymes, metal ions are initially trapped on the surface or interior of microbial cells (Ghosh et al., 2021). Use of microorganisms (especially marine microbes) for synthesis of metallic NPs is environmental friendly, fast and economical (Patil and Kim, 2018). Several microorganisms are used in the synthesis of metal NPs, including:

4.3.2 Biosynthesis of NPs by bacteria: A possible bio factory for producing gold, silver, and cadmium sulphide nanoparticles is thought to be bacterial cells. It is known that bacteria may produce inorganic compounds either inside or outside of their cells (Hulkoti and Taranath, 2014). *Desulforibrio cladogenesis* (Qi et al., 2013), *Enterococcu*s sp. (Rajeshkumar et al., 2014), *Escherichia coli* VM1 (Maharani et al., 2016), and *Urobacterium anthropic* (Thomas et al., 2014) based metal NPs are reported previously for their potential photocatalytic properties (Qi et al., 2013), antimicrobial activity (Rajeshkumar et al., 2014), and anticancer activity (Maharani et al., 2016).

4.3.3 Extracellular synthesis of NPs by bacteria: The microorganisms' extracellular reductase enzymes shrink the silver ions to the nanoscale range. According to protein analysis of microorganisms, the NADH-dependent reductase enzyme carries out the bio-reduction of silver ions to AgNPs. The electrons for the reductase enzyme come from NADH, which is subsequently converted to NAD+. The enzyme is also oxidized simultaneously when silver ions are reduced to nano silver. It has been noted that bio-reduction can occasionally be caused by nitrate-dependent reductase. The decline occurs within a few minutes in the quick extracellular creation of nanoparticles (Mathew et al., 2010). At pH 7, the bacterium *R. capsulate* produced gold nanoparticles with sizes ranging from 10–20 nm. Numerous nanoplates and spherical gold nanoparticles were produced when the pH was changed to four (Sriram et al., 2012). By adjusting the pH, the gold nanoparticles' form may be changed. Gold nanoparticle shape was controlled by regulating the proton content at various pH levels. The bacteria *R. capsulate*s release cofactor NADH and NADH-dependent enzymes may cause the bio reduction of Au (3+) to Au (0) and the generation of gold nanoparticles. By using NADH-dependent reductase as an electron carrier, it is possible to start the reduction of gold ions (Sriram et al., 2012).

4.3.4 Intracellular synthesis of NPs by bacteria: Three processes are involved in the intracellular creation of NPs: trapping, bio reduction, and capping. The cell walls of microorganisms and ions charge contribute significantly to creating NPs in the intracellular route. This entails specific ion transit in the presence of enzymes, coenzymes, and other molecules in the microbial cell. Microbes have a range of polysaccharides and proteins in their cell walls, which function as active sites for the binding of metal ions (Slavin et al., 2017). Not all bacteria can produce metal and metal oxide nanoparticles. The only ions that pose a significant hazard to microorganisms are heavy metal ions, which, in response to a threat, cause the germs to react by grabbing or trapping the ions on the cell wall *via* electrostatic interactions. This occurs because a metal ion is drawn to the cell wall's carboxylate groups, including cysteine and polypeptides, and certain enzymes with a negative charge (Zhang et al., 2011). Additionally, the electron transfers from NADH *via* NADH-dependent educates, which serves as an electron carrier and is located inside the plasma membrane, causing the trapped ions to be reduced into the elemental atom. The nuclei eventually develop into NPs and build up in the cytoplasm or the pre-plasmic space. On the other hand, the stability of NPs is provided by proteins, peptides, and amino acids found inside cells, including cysteine, tyrosine, and tryptophan (Mohd Yusof et al., 2019).

4.3.5 Biosynthesis of NPs by fungi: Because monodisperse nanoparticles with distinct dimensions, various chemical compositions, and sizes may be produced, the biosynthesis of nanoparticles utilizing fungus is frequently employed. Due to the existence of several enzymes in their cells and the ease of handling, fungi are thought to be great candidates for producing metal and metal sulphide nanoparticles (Mohanpuria et al., 2008). The nanoparticles were created on the surface of the mycelia. After analysing the results and noting the solution, it was determined that the Ag + ions are initially trapped on the surface of the fungal cells by an electrostatic interaction between gold ions and negatively charged carboxylate groups, which is facilitated by enzymes that are present in the mycelia's cell wall. Later, the enzymes in the cell wall reduce the silver ions, causing the development of silver nuclei. These nuclei then increase as more Ag ions are reduced and accumulate on them. The TEM data demonstrate the presence of some silver nanoparticles both on and inside the cytoplasmic membrane. The findings concluded that the Ag ions that permeate through the cell wall were decreased by enzymes found inside the cytoplasm and on the cytoplasmic membrane. Also possible is the diffusion of some silver nanoparticles over the cell wall and eventual cytoplasmic entrapment (Mukherjee et al., 2001; Hulkoti and Taranath, 2014). It was observed that the culture's age does not affect the shape of the synthesized gold nanoparticles. However, the number of particles decreased when older cells were used. The different pH levels produce a variety of shapes of gold nanoparticles, indicating that pH plays a vital role in determining the shape. The incubation temperature also played an essential role in the accumulation of the gold nanoparticles. It was observed that the particle growth rate was faster at increased temperature levels (Mukherjee et al., 2001; Ahmad et al., 2003). The form of the produced gold nanoparticles was shown to be unaffected by the age of the culture. However, when older cells were utilized, the particle count fell. The fact that gold nanoparticles take on various forms at different pH levels suggests that the pH is crucial in determining the shape. The incubation temperature significantly influenced the accumulation of the gold nanoparticles. It was found that higher temperatures caused the particle development rate to accelerate (Mukherjee et al., 2001; Ahmad et al., 2003). *Verticillium lute album* is reported to synthesize gold nanoparticles of 20–40 nm in size (Erasmus et al., 2014). *Aspergillus terreus* and *Penicillium brevicompactum* KCCM 60390 based metal NPs are reported for their antimicrobial (Li G. et al., 2011) and cytotoxic activities (Mishra et al., 2011), respectively.

4.3.6 Biosynthesis of NPs using actinomycetes: Actinomycetes have been categorized as prokaryotes since they share significant traits with fungi. They are sometimes referred to as ray fungi (Mathew et al., 2010). Making NPs from actinomycetes is the same as that of fungi (Sowani et al., 2016). *Thermomonospora* sp., a new species of extremophilic actinomycete, was discovered to produce extracellular, monodispersed, spherical gold nanoparticles with an average size of 8 nm (Narayanan and Sakthivel, 2010). Metal NPs synthesized by *Rhodococcus* sp. (Ahmad et al., 2003) and *Streptomyces* sp. Al-Dhabi-87 (Al-Dhabi et al., 2018) are reported for their antimicrobial activities.

5. Application

Nanomaterials are used in many fields of application, as shown in Table, which are nanomedicine fields such as nano drugs, medical devices, tissue engineering, and chemical and cosmetic fields such as nanoscale chemicals and compounds, paints, and coatings, in materials science. Nanoparticles field, carbon nanotubes, biopolymers, paints, and coatings, in the Food Sciences field such as processing, nutraceutical food, nano capsules, in Environment and Energy field such as water and air purification filters, fuel cells, photovoltaic, Military and Energy field such as biosensors, weapons, sensory enhancement, in Electronics Semiconductors field chips, memory storage, photonic, optoelectronics, and in Scientific tools fields, atomic force fields such as a microscopic and scanning tunneling microscope, and agriculture field atomic force, microscopic and scanning tunneling microscope and air purification filters, fuel cells, photovoltaic, Military and Energy field such as biosensors, weapons, sensory enhancement, in Electronics Semiconductors field chips, memory storage, photonic, optoelectronics, and in Scientific tools fields, atomic force fields such as a microscopic and scanning tunnelling microscope, and agriculture field atomic force, microscopic and scanning tunnelling microscope.

Table. Summary of some applications of nano- materials.

Field of application	Principles of application	Nanomaterials
Solar cell	Convert photon energy in to electricity	Ag NW, Cu NW
OLED	To emit light	ITO electrodes
Super capacitor	Very fast charger or discharger, high power storage	Lithium, sodium, potassium
Transistor	For amplifying or switching electrical power	Si & Ge
Lithium-ion batteries	Produce rechargeable batteries	Carbon nanotubes, nanosized transition metal oxide, nano-sized composite material
Imaging	Ability to penetrate cells, good analytical signals	Ag and Cu bimetallic nanoparticles
Cancer diagnosis	Biomedical Imaging Used for Cancer and tumor detection	Gold and iron-based nanoparticles
Drug delivery and cancer therapy	The aim of drug delivery includes precise targeting and therapeutic efficacy	Au nanoparticle, silicon nanoparticle, carbon nanotube, nano graphene
Biomedicine	Gene delivery	CNTs
COVID-19 diagnosis and Prevention	rSARS-CoV-2 tagging and development of COVID-19 mRNA vaccines	Lipid nanoparticles Au nanoparticle
Against monkey pox	Chelating the vires circulating in the blood stream. Block vires host cell binding and penetration	Iron oxide nanoparticle Ag nano particle
Medical	Selective reactivity with certain biomolecules and antiviral activity	Fullerenes

Food industry	Despite toxicological concerns, detect volatile organic compounds	TiO_2 and Ag
Agricultural	Fertilizer developer	SiO_2, ZnO, CuO, Fe, and Mg
Potential vaccine adjuvant	Used for the development of robust immune response.	Aluminum hydro-oxide, gold nanoparticle
Anti -bacterial activity	Used in treatment of disease caused by bacteria.	Gold, silver, copper, titanium, iron nanoparticle
High sensitivity sensor	For detecting varies parameters like electrical resistivity, magnetic permeability, thermal conductivity and capacitance	ZnSe, CdS, ZnS, CdTe
Data storage	The aim of this is to store a large amount of information	Spintronics & nanowires
Aero industry	To protect air craft from lighting strike	Cu Mesh
Electromagnetic interference shielding	Blocking EM radiation	Al, Cu, steel
Display	Resolution of the image on the monitor by reducing pixel size	CNTs
Micro-electronics	To produce faster logic gates	Carbon nanotube, lead telluride, cadmium sulphide
Construction	Increase the strength of material	SiO_2, Fe_2O_3
Cutting tools	For hard material	Tungsten carbide
Environmental	Increase growing rate of plants	CNTs
Elimination of pollutants	Used as catalysts to react with toxic gases	Titanium oxide, calcium carbonate mixed silicon-based polymer
Energy	Alternating energy storage media	CNTs
Textile	Coating textiles such as nylon, to provide antimicrobial characteristics	Ultra-hydrophobic water-resistant and strain resistance fabrics
Cosmetics	Used in sunscreen and in the cosmetic industry	Titanium oxide, zinc oxide
Car tires	Mechanical reinforcement	Carbon block
Car bumpers	To make car exterior lighter	Nanosized clay

Nanoparticles exhibit unique physical and chemical properties such as: electronic & optical properties, mechanical properties, magnetic properties & thermal properties. This uniqueness has led to its application in different areas. Some of the significant applications of NPs are discussed below:

A. Medicine

Nanoparticles have made major contributions to clinical medicine in the areas of medical imaging and drug/gene delivery. Iron oxide particles such as magnetite (Fe3O4) or its oxidized form hametite (Fe2O3) are most commonly employed for biomedical applications. Ag NPs are being used increasingly in wound dressings, catheters and various households' products due to their antimicrobial activity. Gold nanoparticles are emerging as promising agents for cancer therapy, as drug carriers, photothermal agents, contrast agents and radiosensitizers (Cai, W., Gao, T., Hong, H., & Sun, J., 2008; Jain, S., Hirst, D. G., & O'Sullivan, J., 2012; Sztandera, K., Gorzkiewicz, M., & Klajnert-Maculewicz, B., 2018). Over past few decades there has been considerable interest in developing biodegradable NPs as effective drug delivery devices. Various polymers have been used in drug delivery research as they can effectively deliver the drugs to the target site thus increases the therapeutic benefit, while minimizing side effects.

B. Environmental Remediation

Nanoparticles are commonly used for environmental remediation, since they are highly flexible towards both in situ and ex situ applications in aqueous systems. Silver nanoparticles (AgNPs) due to their antibacterial, antifungal, and antiviral activity have been extensively used as water disinfectants (Zhang, C., Hu, Z., Li, P., & Gajaraj, S., 2016). TiO2 NPs have been increasingly studied for waste treatment, air purification (Haider, A., Al-Anbari, R., Kadhim, G., & Jameel, Z., 2018), self-cleaning of surfaces (Veziroglu, S., Hwang, J., Drewes, J., Barg, I., Shondo, J., Strunskus, T., & Aktas, O. C., 2020), and as a photocatalyst in water treatment (Peng, Y., Yu, Z., Pan, Y., & Zeng, G., 2018) application due to their characterized low-cost, non-toxicity, semiconducting, photocatalytic, electronic, gas sensing, and energy converting properties.

C. Mechanical Industries

Owing to excellent young modulus, stress and strain properties, NPs finds applications in mechanical industries especially in coating, lubricants (Ghaednia, H., Hossain, M. S., & Jackson, R. L., 2016), adhesives (Cao, Z., & Dobrynin, A. V., 2016) and manufacturing of mechanically stronger nanodevices. Pal et al. (2021) reported two-step dip-coating method using silver nanoparticles (AgNPs) and fluorine-free silane monomer, 3-(Trimethoxy silyl) propyl methacrylate (TMSPM) for the fabrication of hydrophobic coating on cotton fabric.

D. Food

Nanoparticles have been increasingly incorporated into food packaging to control the ambient atmosphere around food, keeping it fresh and safe from microbial contamination (Bhardwaj M. & Saxena D.C., 2017). Now-a-days, inorganic & metal NPs are extensively used as alternatives to petroleum plastics in the food packaging industry as they can directly introduce the anti-microbial substances on the coated film surface (Hosein Nejad, M., Jafari, S. M., & Katouzian, I., 2018).

E. Electronics

Unique structural, optical and electrical properties of one-dimensional semiconductor and metals make them the key structural block for a new generation of electronic, sensors and photonic materials.

F. Energy Harvesting

Due to scarcity of fossil fuels scientist have been shifting their research interests in the development of different strategies which can help in generating renewable energies from easily available resources at cheap cost. NPs are the suitable candidate for this purpose due to their large surface area, optical behavior and catalytic nature. NPs are widely used to generate energy from photoelectrochemical (PEC) and electrochemical water splitting (Avasare et al., 2015). Other advanced options such as electrochemical CO2 reduction to fuels precursors, solar cells and piezoelectric generators also utilized to generate energy. Ibrahim et al. (2019) reported use of graphene as a source of energy as well as next generation smart energy storage devices.

6. CONCLUSION

This paper introduced nanomaterials and reviewed their type of classification based on different characteristics, varying synthesis methods in relation to their applications and properties, and the application of nanotechnology in different fields by manufacturing nanomaterials. In general, the physical, chemical, electrical, optical, magnetic, and mechanical properties of bulk materials are independent of their size, but the physical, chemical, electrical, optical, magnetic, and mechanical properties of nanomaterials are dependent on their size. Day to day the synthesis of novel nanomaterials is increasing. The nanomaterials with mixed compositions are also synthesizing to apply in different fields We have critically studied different synthesis methods for nanomaterials. Nanomaterials are synthesized using bottom-up and top-down methods. Lithography, mechanical milling or ball milling, laser ablation, sputtering, electron explosion arc discharge, and thermal decomposition are examples of the top-down method or physical method. But bottom-up methods are classified as chemical: CVD, sol-gel, spinning, pyrolysis, and biological methods; in biological synthesis, microorganisms (bacteria, algae, and fungi), biological templates, and various plant parts are used. The properties of nanometer-scale materials differ significantly from those of atoms and bulk materials because of the surface charge/interaction, crystallography, composition, surface area, and nanoscale size effects that can be seen in the magnetic, optical, electrical, mechanical, chemical, and physical properties of nanomaterials. Nanomaterials have a big role for societies due to their fantastic and power-full applications in many fields like agriculture, electrical engineering, medicine, etc. We have critically studied different synthesis methods for nanomaterials. Nanomaterials are synthesized using bottom-up and top-down methods. Lithography, mechanical milling or ball milling, laser ablation, sputtering, electron explosion arc discharge, and thermal decomposition are examples of the top-down method or physical method. But bottom-up methods are classified as chemical: CVD, sol-gel, spinning, pyrolysis, and biological methods; in biological synthesis, microorganisms (bacteria, algae, and fungi), biological templates, and various plant parts are used. The properties of nanometer-scale materials differ significantly from those of atoms and bulk materials because of the surface charge/interaction, crystallography, composition, surface area, and nanoscale size effects that can be seen in the magnetic, optical, electrical, mechanical, chemical, and physical properties of nanomaterials. Nanomaterials have a big role for societies due to their fantastic and power-full applications in many fields like agriculture, electrical engineering, medicine, etc.

REFERENCES

1. F. J. Heiligtag and M. Niederberger, Mater. Today, 2013, 16, 262–271 CrossRef CAS.
2. P. Walter, E. Welcomme, P. Hallégot, N. J. Zaluzec, C. Deeb, J. Castaing, P. Veyssière, R. Bréniaux, J.-L. Lévêque and G. Tsoucaris, Nano Lett., 2006, 6, 2215–2219 CrossRef CAS PubMed.
3. J. Jeevanandam, A. Barhoum, Y. S. Chan, A. Dufresne and M. K. Danquah, Beilstein J. Nanotechnol., 2018, 9, 1050–1074 CrossRef CAS PubMed.
4. Freestone, N. Meeks, M. Sax and C. Higgitt, Gold Bull., 2007, 40, 270–277 CrossRef CAS.
5. Santamaria, Nanotoxicity, Humana Press, Totowa, NJ, 2012, pp. 1–12 Search PubMed.

6. R. P. Feynman, Eng. Sci., 1960, 23, 22–36 Search PubMed.
7. S. Bayda, M. Adeel, T. Tuccinardi, M. Cordani and F. Rizzolio, Molecules, 2019, 25, 112 CrossRef PubMed.
8. S. L. Pal, U. Jana, P. K. Manna, G. P. Mohanta, R. Manavalan, JAPS 2011, 228, 234
9. C. Buzea, I. I. Pacheco, K. Robbie, Biointerphases2 2007, MR17. https://doi.org/10.1116/1.2815690
10. Iavicoli, V. Leso, W. Ricciardi, L.L. Hodson, M.D. Hoover, Environ Health 13, 78 (2014)
11. 3F. Findik, Period. Eng. Nat. Sci. 2021, 62, 75. https://doi.org/10.21533/pen.v9i3.1837
12. 9D. Mrinmoy, P. S. Ghosh, V. M. Rotello. Adv. Mater. 2008, 20, 4225. https://doi.org/10.1002/adma.200703183
13. Introduction to Nanotechnology Book – Risal Singh, Shipra Mital Gupta. • D. Vollath, Nanomaterials: An Introduction to Synthesis, Properties and Applications, 2nd ed. 2019.
14. M. Prathap Kumar et al., J. Environ. Chem. Eng. 6 (4) (2018) 3907–3917
15. B. Raval, I. Banerjee, Functionalized graphene nanocomposites and their derivatives, (2019) 295–322. [17] N. Sharma, V. Sharma, S. Sharma, K. Sachdev, Mater. Lett. 236 (2019) 444– 447. Websites WWW.nano.gov/nanotech
16. WWW.nanotechgroup.org.

HOW TO CITE: Prapti Kharat*, Ishwari Kachare, Ankita Joshi, Nikita Jori, Madhavi Joshi, Nano Material: Synthesis and Application, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 8, 730-752. https://doi.org/10.5281/zenodo.16759604