IJCPS Vol. 12, No. 1, Jan-Feb 2023
www.ijcps.org
DOI Prefix:10.30731/ijcps

International Journal of Chemical and Physical Sciences
(Peer-Reviewed Journal)
ISSN:2319-6602

A Brief Review on Synthesis Procedures and Types of Nanostructures

Amritpal Singh S[1], Pushpinder G. Bhatia[1]

Department of Physics, Guru Nanak College of Arts, Science & Commerce, Mumbai, Maharashtra, India

***Corresponding Author E-Mail:** pushpindergb@gmail.com

Abstract

Nanostructures (or also known as nanomaterials) basically are the structures which have at least one dimension of the size of nanometre range (typically 1nm to 100nm). Nano-objects are frequently classified based on how many of their dimensions are on the nanoscale. Nanoscale materials frequently have distinctive optical, mechanical, thermophysical, or optical properties. This review paper briefly describes the various synthesis procedures ranging from top-down approach to bottom-up approach, adopted to synthesize nanostructures. Also, various types of nanostructures that can be formed like metal-based nanoparticle, nano porous structures, zero dimensional nanostructures, one dimensional nanostructure, two dimensional nanostructures & Bulk nanostructures are also discussed.

Keywords: *Nanostructures, nanomaterials, synthesis, nanoparticle, physical methods.*

Introduction:

Nanomaterials (NMs) are the materials covering a wide range of dimensions starting from 1nm to 100nm. [1] Types of nanomaterials include metal-based nanoparticle, nano porous structures, zero dimensional nanostructures, one dimensional nanostructures, two dimensional nanostructures & Bulk nanostructures. Nanomaterials are used in a wide range of manufacturing processes, products, and healthcare applications, including paints. [1] Various methods can alter the shape, size & properties of nanomaterials.[2] This review attempts to provide a glimpse on different types of synthesis procedures obtained for synthesizing nanomaterials. [1] It will be very difficult to give detailed information about each synthesis method, hence a brief description about each method has been reported in this paper.

Experimental:

Synthesis Procedure

The two major categories in which Nanomaterials are synthesized are Top - Down approach & Bottom - Up approach. [3] A pictorial representation of both methods is provided in Fig. (1). The top down method is breaking a bulk material into smaller fragments by applying some mechanical force, lasers etc. And they lead to the formation of nanoparticles.[4] Whereas the Bottom up approach involves atoms or molecules combining to form small clusters of nanometres size & it leads to the formation of nanoparticles.[4]

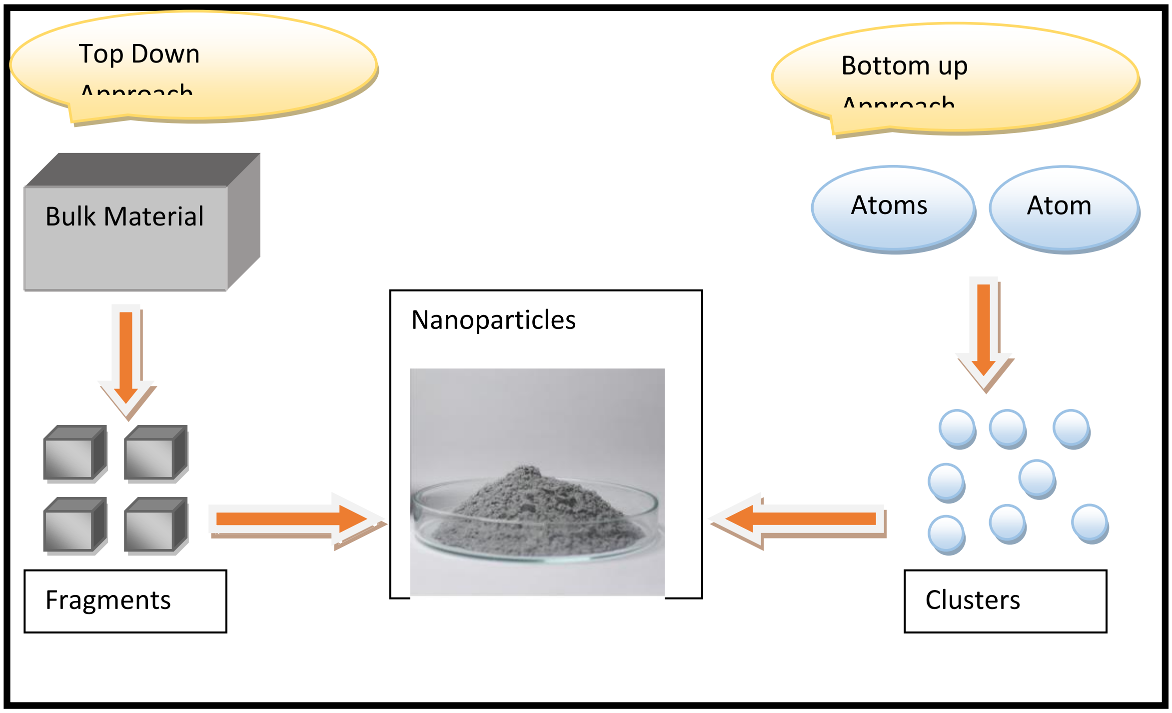

Fig. 1: *Top down & Bottom-Up approach for Synthesis of nanomaterials*

The methods of synthesizing nanomaterials in Top – down approach are explained below:

a) ***Mechanical Ball Milling*** – It is a mechanical deformation (also referred to as grinding) process that is commonly used to produce powdered nanocrystalline metals or alloys. In this method a powder mixture is subjected to high-energy collisions from the balls in a ball mill. As the name suggests, large & small balls are involved in the grinding process. Large balls are used to break down coarse materials, whereas smaller balls aid in the formation of fine product by eliminating vacuum areas between the balls. In this process the reactants are generally broken using mechanical process.[4] Mechanical milling is used to make nickel/magnesium/copper nanoalloys, wear-resistant spray coatings, and a variety of other nanocomposite materials, oxide- and carbide-strengthened aluminium alloys. [1] There are many factors on which degree of grinding depends such as rotation time, nature of the balls used, balls size and density etc. The major advantage of using this process is that one can obtain very fine powders using this process of very small size nearly in the order of few microns. There also exist disadvantage, that there can be wear & tear of the balls during the milling process, which can lead to the contamination of the material.

b) ***Sputtering*** – It involves high-energy particles, such as plasma, which are used to bombard on solid surfaces to pull the atoms one by one & deposit it on substrate.[1] Generally, the plasma is created using Argon (Ar) gas. The different types of sputtering processes involve RF radio sputtering, DC diode sputtering, Reactive sputtering & Magnetron sputtering. The sputtering process is mostly used to create thin films with thicknesses ranging from nanometre to micrometres. Thin films are widely used in a variety of industries, including microelectronics, protective coatings, and so on. [5] Since the constituents are sputtered (or sprayed) one by one, the major advantage of employing this technique is, the concentration of deposited films is comparable to that of the raw material. The disadvantage of using this method is that the equipment operation is too costly & the target area of bombardment is relatively small in size.

c) ***Arc discharge method*** – This method is useful for creating various nanostructured materials like carbon nanotube (CNT), Fullerenes etc. [2] The arc discharge process is extremely important in the production of fullerene nanomaterials. During the formation process, two graphite rods are adjusted in a chamber with a constant helium pressure. It is critical to fill the chamber with pure helium since the presence of moisture or oxygen limits fullerene production. In this method a Direct current arc voltage is applied to two graphite electrodes, inserted in He gas.[1] The major point here to note is, the different conditions in which discharge take place, alters the formation of nanomaterials. Graphene nanostructures may be effectively created using the arc discharge process. The circumstances present during graphene creation can have an impact on its characteristics.[1]

d) ***Electrospinning*** – This is a technique considered to be a viable nanofiber production technique. [6] A cutting-edge technique called electrospinning, uses electrostatic force to create nanofibers. It is suitable for fibres with a diameter of 10µm to 10nm, typically polymers. Magnetic nanoparticles, oxide nanoparticles, carbon nanoparticles, alloy/metal oxide nanoparticles can be produced using this technique. It is useful for gas sensing applications [6] Typically polymers, or wide variety of nanofibers are made from this method [1] The major advantage of using this method over others is that one can obtain control over morphology & porosity.

e) ***Laser Ablation*** – A very high energy beam is focussed at a single place on a solid target during the laser ablation process in order to remove the material off the surface. [1] Electromagnetic radiation is absorbed by the target electrons when a laser pulse irradiates a bulk material's surface, and energy is transferred to the material's vibrating lattice. As a result, material in the form of a plasma plume is ejected from the surface. Laser characteristics including wavelength, pulse duration and repetition rate, light absorption efficiency of the target material, and liquid's chemical composition often affect the ablation rate. By using Nucleation method, one can obtain nanoparticles using this method. Not only nanoparticles but also Quantum dots, Carbon nanotubes can be produced using this technique. [7] High production rates, superb particle size control, and good monodispersity are all benefits of laser ablation. Through the use of process variables like multi-target precursors and laser tuning, this method enables control over material characteristics. [1]

f) ***Lithography*** – This method uses a focused beam of light or electrons [1] It can be done in two ways viz. using a masked lithograph or by using non masked lithograph, followed by wet etching. [1]

The methods of synthesizing nanomaterials in Bottom – Up approach are explained below:

a) ***Chemical Vapor Deposition (CVD)*** – This technique is mainly used for Carbon based nanomaterials. [1] It is an example of solid – vapor reaction, because in this method, using some chemical reaction, a solid material is deposited from a vapour, in the vicinity of heated substrate. [8] The volatile precursors are introduced in the chamber in gaseous form and allowed to react at room temperature in CVD. The substrate's surface is coated with thin films of the desired product, and the process does not include any chemical reactions. It is widely used technique to make 2D nanomaterials & thin films on solid substrate. [8] CVD has several benefits, including the ability to produce homogenous films with, high purity, minimal porosity, and stability. However, it has several drawbacks, such as the need for expensive instrumentation and the release of harmful gaseous by products during the reaction.

b) ***Reverse Micelle Method*** – Reverse Micelles are formed in presence of a surface active reagent in which aqueous & organic phases are mixed. [9][1] It is a technique used to make nanomaterials of desired shape & size. Changes in the chemical structure of the surfactant, as well as changes in solution parameters such as temperature and electrolyte addition, can be used to regulate the form and size of the micelles. An oil-in-water emulsion produces normal micelles with hydrophobic tails aimed at a core that contains trapped oil droplets.[1]

c) ***Solvothermal & Hydrothermal methods*** – These methods are generally carried out in closed system. [1] The solvothermal approach may be used with both aqueous and nonaqueous liquids. When water is employed as the solvent, the word "solvothermal" changes to "hydrothermal." The procedure begins with the precursors being mixed in the solvent and then sealed in an autoclave. In hydrothermal method, nanomaterials can be formed over a wide temperature range i.e. ranging from very high temperatures to room temperatures. [10] An aqueous medium is used in hydrothermal method whereas in solvothermal method a non-aqueous medium is adopted. [5] The key advantage of this technique is that it allows for high vapour pressures and little nanomaterial loss via liquid-phase or multiphase chemical processes. Its drawbacks include the utilisation of costly equipment and extreme temperatures.[10]

d) ***Sol – Gel method*** – This technique is also known as wet chemical process.[11] It is majorly used for synthesizing high quality metal oxide (Si, Ti etc.) based nanomaterials. [1] It is also used to make ceramic nanoparticles. In this method, a colloidal solution known as “sol” is formed & that sol is converted to a network diphasic structure called as “gel” [1] Sol-gel synthesis provides several advantages for manufacturing high quality materials with uniformity and purity at lower temperatures than traditional processes, but it has a long processing time as a downside.

e) ***Soft – Hard template approach*** – A hard template is a hard substance with a stable structure controls the size and shape of the sample particle. Polymer microspheres, porous membranes, and other hard templates are available. The soft template lacks a definite hard structure. The intermolecular or intramolecular contact force is used to produce an aggregate with certain structural properties in the manufacture of nanoparticles. Surfactant, polymer, and biopolymer are examples of common soft This method is majorly used for making nano porous materials. [1] Soft templates are generally in fluid like state whereas hard templates are solid state materials with particular structure & morphology.

Conclusion:

In this paper, various methods are listed which can be used for synthesis of nanomaterials depending upon the starting materials & type of end product we want to achieve. The various factors affecting synthesis procedures are Temperature, time, pressure, particle size & shape, pore size, environment, pH value, etc. Broadly, the synthesis methods are categorized into two viz. Top - Down approach & Bottom - Up approach. The major disadvantage of Top - Down approach is that they require huge installation & capital for building their set up. The growth process is also slow; hence these processes cannot be adopted for large scale production. Also, imperfection of surface structure. These imperfections can have a huge impact on physical & chemical properties of nanomaterials. For instance, Nanowires made from lithography technique may not be smooth enough and may contain lot of impurities. Apart from the methods listed in this paper, there are also many other methods for synthesizing nanomaterials such Physical Vapor Deposition (PVD), Pyrolysis, Green synthesis, Freeze Drying, Polymerization, Chemical Precipitation, Sonochemical process & some biological methods etc. To conclude, different synthesis procedures can form different types of nanostructures like carbon nanorods, carbon nanotubes, nano porous materials, nanofibers etc.

Acknowledgements:

Authors would like to thank UGC-DAE Consortium for Scientific Research, Mumbai Centre (BARC Campus, Mumbai) for funding the project work.

Conflict of Interest:

The authors declared that they have no conflict of interest.

References:

[1] N. Baig, I. Kammakakam, W. Falath, and I. Kammakakam, "Nanomaterials: A review of synthesis methods, properties, recent progress, and challenges," *Mater. Adv.*, vol. 2, no. 6, pp. 1821–1871, 2021, doi: 10.1039/d0ma00807a.

[2] V. Harish *et al.*, "Nanoparticle and Nanostructure Synthesis and Controlled Growth Methods," *Nanomaterials*, vol. 12, no. 18, pp. 1–30, 2022, doi: 10.3390/nano12183226.

[3] B. Prof, B. P. Singh, and K. E. Drexler, "Top-down and Bottom-up approaches for synthesis of nanomaterials," *J. Alloys Compd.*, vol. 81, pp. 663–697, 1986.

[4] S. Wang and L. Gao, *Laser-driven nanomaterials and laser-enabled nanofabrication for industrial applications*. Elsevier Inc., 2019. doi: 10.1016/B978-0-12-815749-7.00007-4.

[5] A. V. Rane, K. Kanny, V. K. Abitha, S. Thomas, and S. Thomas, *Methods for Synthesis of Nanoparticles and Fabrication of Nanocomposites*. Elsevier Ltd., 2018. doi: 10.1016/B978-0-08-101975-7.00005-1.

[6] S. Zhang, Z. Jia, T. Liu, and G. Wei, "Electrospinning Nanoparticles-Based Materials," 2019.

[7] M. Kim, S. Osone, T. Kim, H. Higashi, and T. Seto, "Synthesis of nanoparticles by laser ablation: A review," *KONA Powder Part. J.*, vol. 2017, no. 34, pp. 80–90, 2017, doi: 10.14356/kona.2017009.

[8] A. Behera, P. Mallick, and S. S. Mohapatra, "Nanocoatings for anticorrosion," *Corros. Prot. Nanoscale*, pp. 227–243, 2020, doi: 10.1016/b978-0-12-819359-4.00013-1.

[9] R. S. Chaurasiya and H. U. Hebbar, *Reverse Micelles for Nanoparticle Synthesis and Biomolecule Separation*. 2017. doi: 10.1007/978-3-319-53112-0_5.

[10] Y. X. Gan, A. H. Jayatissa, Z. Yu, X. Chen, and M. Li, "Hydrothermal Synthesis of Nanomaterials," *J. Nanomater.*, vol. 2020, 2020, doi: 10.1155/2020/8917013.

[11] S. R. Gawali, "Synthesis and characterization of samarium doped nio nanoparticles," *Int. J. Sci. Technol. Res.*, vol. 9, no. 4, pp. 2960–2964, 2020.