International Journal of Pharmacy and Pharmaceutical Sciences

Print ISSN: 2656-0097 | Online ISSN: 0975-1491 Vol 16, Issue 5, 2024

Review Article

A REVIEW ON TEMPLATE SYNTHESIS OF NANOPARTICLE

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Received: 15 Feb 2024, Revised and Accepted: 23 Mar 2024

ABSTRACT

In recent years, there has been a rise in interest in the development of novel drug delivery systems that utilize nanoparticles. In terms of high stability, high specificity, high drug-carrying capacity, controlled release, the ability to use different routes of administration, and the ability to deliver both hydrophilic and hydrophobic drug molecules, nanoparticles can offer significant advantages over conventional drug delivery. We try to provide a detailed overview of template techniques designed for nanomaterial production. The pores and channels in the nanoporous "template" structures are used to generate the desired nanomaterials in template synthesis. Because this process has advantages over other methods, like allowing precise control over their size, shape, and structure, it is commonly used to generate nanoparticles. The first half of the review provides information on various template preparation processes. Templates are classified as "hard" or "soft" templates. Soft templates are often fluid-like, whereas hard templates are typically solid-state materials with distinct morphology and structure. This study discusses the effect of templates on morphologies and methodology and compares hard and soft templates.

Keywords: Nanoparticles, Templates, Mesoporous, Polymer etc

DOI: https://dx.doi.org/10.22159/ijpps.2024v16i5.50661 Journal homepage: https://innovareacademics.in/journals/index.php/ijpps

INTRODUCTION

The study of matter's properties at the nanoscale is known as nanoscience, and it primarily focuses on the unique, size-dependent characteristics of solid-state materials. The famous speech by Nobel laureate Richard Feynman is usually called the birth of terms in nanoscience and nanotechnology. "There's Plenty of Room at the Bottom" was the subject of the American Physical Society meeting in 1959 [1]. The term "nanoparticle" originated from the Greek word for "dwarf" or "little." The prefix "Nano" is used to refer to small living things [2, 3]. Nanotechnology comes from the prefix nano, which denotes a billionth (1×10^{-9}). Nanotechnology is the study of different matter structures with sizes smaller than a billionth of a meter. 10^{-9} m is a nanometer. In general, nanoparticles are thought to consist of many atoms or molecules joined together with a radius of approximately 100 nm [4, 5].

Due to the unique physicochemical features of nanomaterials, research based on them is currently receiving increased attention. Among the rapidly expanding fields, the combination of nanomaterials with porous structures is the most attractive. Mesoporous (2–50 nm), macroporous (>50 nm), and microporous (<2 nm) materials are examples of porous materials with interconnected solid composite pore networks. Other than this, porous materials can include natural materials like clays, biological tissues (like bones), rocks, and synthetic materials, in addition to metal oxides, ceramics, carbonaceous materials, and membranes [6, 7].

These days, researchers have become more interested in the synthesis of nanomaterials. Metal nanoparticles can be produced through a variety of approaches. There are two known approaches to synthesis: the top-down approach and the bottom-up approach. Repeated quenching, lithography, and milling are examples of top-down methods [8]. The drawback of this method is that it does not have precise control over particle size and structure. While synthesizing nanoparticles, scientists usually use the bottom-up method, which develops material from the bottom up: molecule by molecule, atom by atom, and cluster by cluster [9]. Several factors are involved in the nucleation and subsequent formation of stabilized nanoparticles during the synthesis of nanomaterials.

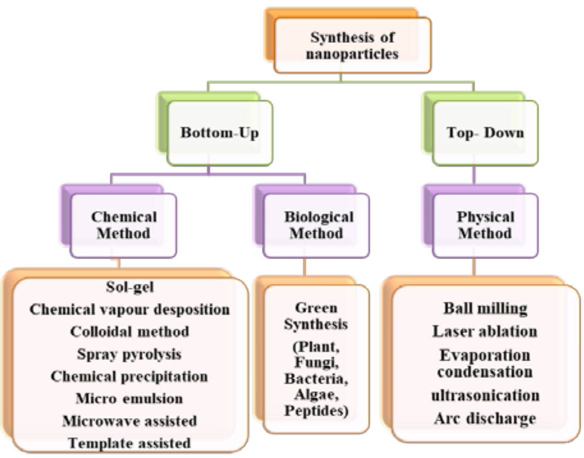

Fig. 1: Types of synthesis of nanoparticles [10]

The template-assisted method is a synthetic method that uses a scaffold or template to direct and control the development of materials with desired characteristics. The term "template" refers to any entity possessing nanostructured qualities whose dimensions, shape, and distribution of charges significantly impact the attributes directing the structure [11]. By employing a preset template as a guide throughout the synthesis process, this method is frequently used to create nanoparticles, giving exact control over their size, shape, and structure. Template-assisted methods are preferred options for many applications due to their efficiency and homogeneity. These methods provide a structured framework or template that makes process simplification easier and ensures tasks are completed consistently. Benefits from this could include reduced errors, time savings, consistency, and a simplified training process.

Template synthesis of nanomaterials has become known as an advanced method since the 1990s. Early in 1992 C. T. Kresge *et al.* researched ordered Mesoporous molecular sieves synthesized by a liquid crystal Template mechanism [12]. In 1995 Dmitri Routkevitch *et al.* did research on a technique which is described for fabricating arrays of uniform CdS nanowires with lengths up to 1 µm and diameters as small as 9 nm by electrochemically depositing the semiconductor directly into the pores of anodic aluminum Oxide films from an electrolyte containing Cd2+and S in dimethyl sulfoxide [13]. Isamu Moriguchi *et al.* in 1999 studied phenol-formaldehyde polymer and surfactant assembly was structuralized into lamella and disordered mesophases depending on surfactant/phenol molar ratio at the synthesis [14]. Tae-Wan Kim *et al.* studied the Assembly of mesostructured silica using Pluronic P123 triblock copolymer (EO20-PO70-EO20) And the n-butanol mixture is a facile synthesis route to the MCM-48-like ordered large mesoporous silica with the cubic Ia3hd mesostructured [15].

Particularly in the case of mesoporous materials, morphology is the most important aspect for characterizing the properties of the material. Particle size, surface area, pore structure, and morphology all contribute together to define the morphology of mesoporous materials, which in turn helps determine their specific uses [16-18]. The most common method by which the template approach affects product morphology is by controlling crystal nucleation and growth during the nanomaterial preparation process [19, 20]. The following three steps are usually involved in the template syntheses of nanostructured materials: template preparation, target material synthesis (using sol-gel, precipitation, hydrothermal synthesis, and other methods) based on the template, and lastly template removal [21, 22]. The proper removal technique must be selected to ensure that the product's chemical and physical qualities are unaffected. Physical and chemical techniques including dissolution, sintering, and etching are examples of common removal techniques [23].

The ease and speed with which template synthesis, electrodeposition, and Chemical Vapor Deposition (CVD) can be modified and applied to new study areas is a huge benefit. Thus, there are still many opportunities to investigate alternative approaches to nanoscience and nanoscale manufacturing [24, 25]. One of the main challenges with these techniques is that it takes a lot of work to remove the template completely, which gradually reduces the purity of the nanoparticles. These methods have gained a lot of interest recently due to their simple and fast preparation process, which produces a crystalline powder that is fine, homogenous, and free of agglomerations [26].

Types of template method

Mesoporous materials are being manufactured using a wide range of synthetic techniques. The two most popular approaches are "hard" (also known as "nanocasting") and "soft" (also known as "soft") [29].

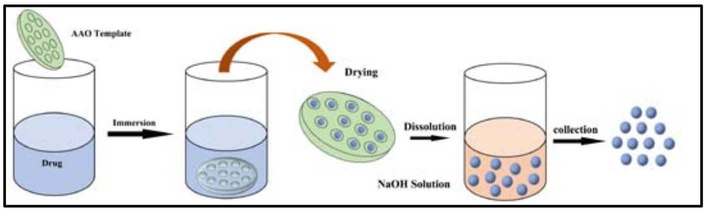

Fig. 2: Schematic presentation of nanoparticles using template synthesis [27, 28]

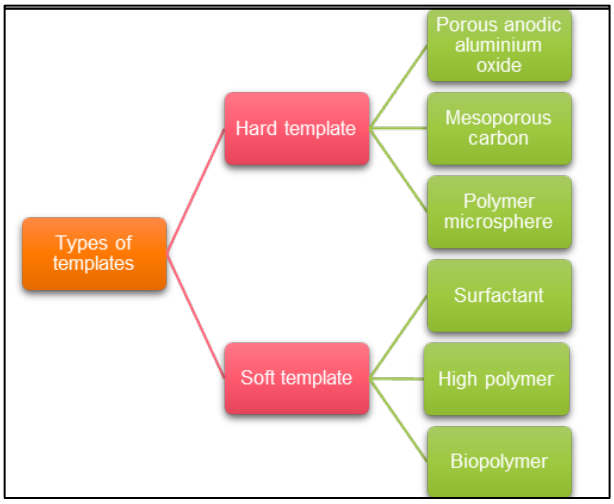

Fig. 3: Types of templates [30-32]

Hard template

The size and shape of the sample particle are directly determined by the hard template, which is a rigid material with a fixed structure. By using a cooperative assembly between the surfactant and inorganic species, the hard-template approach is an effective way to create Mesoporous materials that are challenging to synthesize by conventional methods [33]. The idea is extremely straightforward and was first put forward by Ryoo *et al.* and Hyeon and coworkers. There are three primary steps in the synthetic pathway: selecting and creating the original template (ideally, mesoporous carbon or silica is used as the original template→Introducing the target precursors to the mesoporous and turning them into an inorganic solid (creating a composite that includes the original template and the target inorganic solid); and→Removing the original template [34-36].

Porous Anodic Aluminum Oxide (AAO)

It is a self-organized material with a honeycomb-like structure formed by a high-density array of uniform and parallel nanopores. Anodization, or the electrochemical oxidation of a metal, is a straightforward and inexpensive electrochemical technique that covers a sizable portion of the target metallic surface with an oxide layer [37-40]. Via anodization of aluminum metal in an acidic solution, porous alumina membranes are produced. Aluminum metal is anodically oxidized in solutions of sulfuric, oxalic, or phosphoric acid to produce alumina membranes with a homogeneous and parallel porous structure [41-44]. The Steps involved in the formation of the AAO template are as follows.

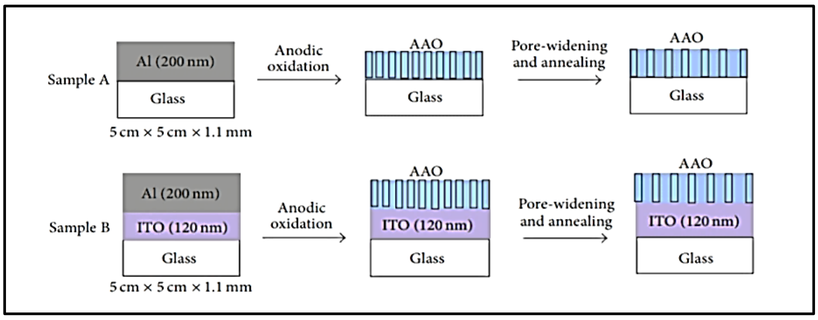

Fig. 4: The steps involved in the formation of the AAO template [41]

Mesoporous carbon

One significant component of mesoporous materials is mesoporous carbon. Its pore diameter typically ranges from 2 to 50 nm, and its pore dispersion is uniform. Its specific Surface area is high and its pore structure is regular. In addition, it has chemical and thermal stability [45-46]. The most common approach for synthesizing mesoporous carbon is template-assisted synthesis [47]. The following is the standard template synthetic process for porous carbons:

Additional procedures like chemical vapor deposition or soft-templating techniques may also be employed, depending on the necessities [48-51].

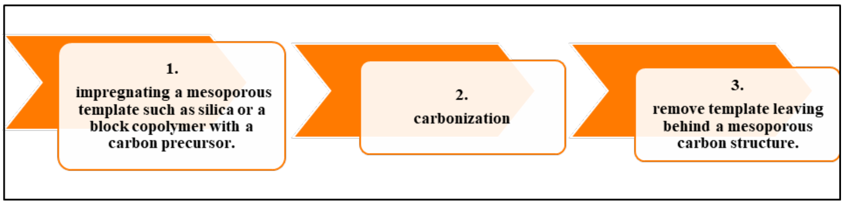

Fig. 5: Preparation of mesoporous carbon template

Polymer microspheres

The polymer microsphere exhibits strong dispersity and is readily adjustable in terms of particle size. It is usually used to produce spherical particles with a hollow structure or nearly spherical core-shell particles following surface modification [52]. Several methods are employed to produce polymer microspheres, including emulsion polymerization, microemulsion polymerization, soap-free emulsion polymerization, suspension polymerization, and dispersion polymerization [53-56]. Solvent evaporation is used to produce microsphere templates [57, 58].

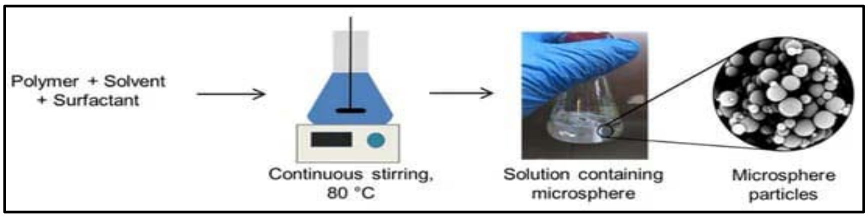

Fig. 6: Synthesis of microsphere template via solvent evaporation method [58, 59]

Emulsion polymerization

An emulsion including a monomer, water, and surfactant is usually the first step in this type of radical polymerization process. Emulsion polymerization mostly uses oil in water. Emulsion, in which the monomer droplets are emulsified in the oil in a constant water phase (with surfactants). Water: soluble polymers, such as hydroxyethyl or polyvinyl alcohol in some cases Furthermore, celluloses can be used as emulsifiers and stabilizers [60].

Microemulsion polymerization

Microemulsion in which monomers can be added to the system's water or oil phases to aid in the polymerization of the monomers. There are three methods for polymerizing microemulsions: chemical, photochemical, and high-energy radiation. Numerous morphologies of droplet-containing microemulsions have been used to study polymerization reactions. Some of the studies that were conducted in this category are as follows: The processes of polymerization in water-in-oil and oil-in-water microemulsions [61].

Soap-free emulsion polymerization

Also known as surfactant-free heterogeneous polymerization using water as a solvent, soap-free emulsion polymerization is a suggested environmentally acceptable method for producing monodisperse particles of polymers at low impurity levels. During water polymerization, the contacts amongst the polymer particles were stabilized by electrostatic forces. The main use of conventional soap-free emulsion polymerization has been the creation of submicron-sized polymer particles [62].

Suspension polymerization

In a typical suspension polymerization system, one or more water-insoluble monomers are distributed with an oil-soluble initiator in the continuous aqueous phase by using small amounts of suspending agents (stabilizers) with rapid stirring [63].

Dispersion polymerization

When a monomer is polymerized with a suitable polymeric stabilizer that is soluble in the reaction solution, a type of precipitation polymerization is known as dispersion polymerization. [64]. This process includes dissolving a monomer in a solvent or solvent mixture and polymerizing it with the help of a steric stabilizer. At first, the molecules of the stabilizer and monomer dissolve in a single phase. The process of homogenous nucleation of particles from the medium is similar to that of particle production in emulsion polymerization. As a result, the growing particles separate from the medium as the polymerization process occurs. A two-phase system is created at the end of the polymerization process [65].

Soft template

Flexible nanostructures composed of intermolecular interactions are frequently used as soft templates in the soft-template technique. Block copolymers, flexible organic molecules, and surfactants are examples of soft matter that compose the soft templates. Weak non-covalent bonds, such as hydrogen bonding, electrostatic, or van der Waals interactions, are often how these templates interact with the precursors [66]. Nowadays, the soft template technique has been employed to create polymer nanoparticles with a range of morphologies. Many soft templates include functionalized polymer, cyclodextrin, liquid crystalline polymer, and surfactant. Surfactants, which include cationic, anionic, and non-ionic amphiphiles, are the most commonly utilized in micelle creation as a nanoreactor [67,68]. The soft template has a wide range of potential applications in the synthesis of nanomaterials Because of its benefits, such as strong reproducibility, simplicity of the process, and the absence of the need for silicon removal [69, 70].

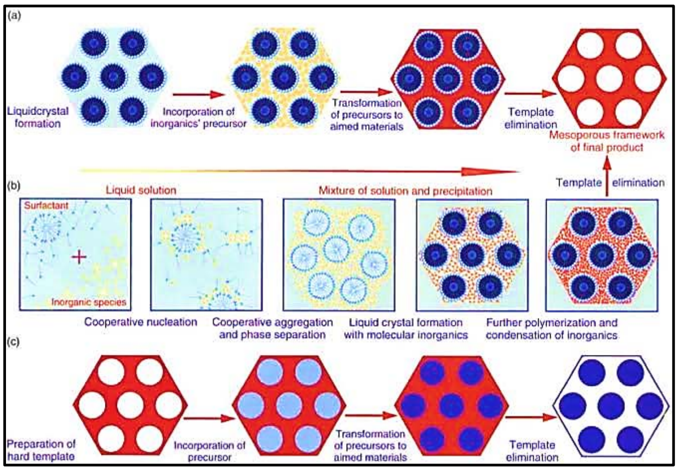

Fig. 7: Soft template [68, 69]

Surfactant

Surfactant is a helpful chemical that may direct structure [71]. The surfactant employed has a large influence on particle sizes ranging from 1 to 50 nm. Surfactant-assisted nanoparticle production produces particles with a large surface area. A surfactant can also be used to prevent nanoparticle agglomeration in the solution [72, 73]. Surfactant Surfactant-assisted precipitation has recently gained attention in synthesis due to its ease of use, low cost, and capacity to develop different features [74]. Because polymer–surfactant complexes have an effective structure completely distinct from that of pure surfactant systems or pure water-soluble polymers, they are promising candidates for the production of diverse nanostructures [75, 76].

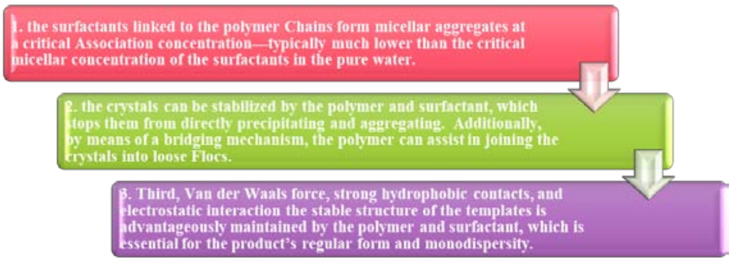

Fig. 8: Steps of the general role of surfactant in template synthesis [75]

High polymer

High surface area nanonetworks are being created by working with soft templates based on polymers. The resulting network can have a high surface area, big pore volume, and porous dispersion due to the polymer soft-template approach [77]. Mesoporous materials provide extremely large surface areas, finely regulated pore diameters, and clearly defined pore structures. Numerous mesoporous silica materials have found broad use as host materials for catalysts, polymers, metals, semiconductor nanoparticles, and carbon because of these advantageous features [78, 79]. This approach depends on the self-assembly of polymerizing organics (used as carbon precursors and templates, respectively) and triblock copolymers to generate organic–organic nanocomposites [80]. High polymers, known as block copolymers are made up of two or more chemically distinct polymer chains joined together at their ends. It can self-assemble into a large range of ordered forms via covalent bonding. Because block copolymers include multiple blocks with varying properties, it is easy to mold them into various morphologies, such as thin films or three-dimensional templates. The block copolymer's overall synthesis approach. The three steps of assisted synthesis are (1) copolymer micelle generation; (2) precursor addition; and (3) self-assembly to a specific shape. Thus, the final product with the Intended morphology is formed upon the removal of the template [81].

Preparation of tri-block polymer

Poly (styrene-block-acrylic acid-block-ethylene glycol) block polymer CTA: cellulose trans acetate, AIBN: Azobisisobutyronitrile.

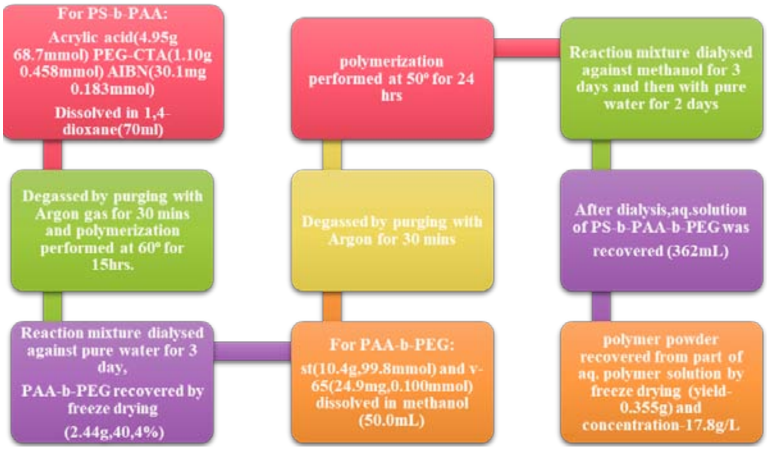

Fig. 9: Preparation of triblock polymer [81, 82]

Biopolymer

Especially in many synthetic processes and in several natural processes, biopolymers as well as their colloids can serve as templates and regulating agents [83]. The idea of employing biological substances as soft templates is quite intriguing, and a great deal of work has been done to use biological materials with regulated properties that are easily obtainable and economically priced. Biomolecules, unicellular creatures, and complex tissues are just a few examples of biological materials that can be used to create soft templates. The naturally occurring, distinctive structure of this biological template is superior to that of artificially made templates and permits extraordinary chemistry to occur on the template, promoting the production of regulated morphology, composition, and crystal structure [84, 85].

The most widely used type of biodegradable nanoparticles are called Biopolymeric Nanoparticles (BPNs), which are made of natural polymers found in biological species like proteins (like collagen, gelatin, β-casein, zein, and albumin), protein-mimicking polypeptides (like cationic polypeptides like polylysine and polyornithine), and polysaccharides (like hyaluronic acid, chitosan, alginate, starch, and heparin). These nanoparticles made of different biopolymers are presently being developed to deal with toxicity, biocompatibility, and biodegradability issues. Both metallic and biopolymeric nanoparticles (BPNs) are used in many different industries, while the latter are safer and eco-friendly. BPNs are currently being actively used in the food business, biomedical applications, diagnostic tool development, and household chemical sector [86]. Biomacromolecules (such as polysaccharides, proteins, and nucleic acids) can serve two primary purposes: (i) regulating the nucleation and development of the inorganic material and (ii) providing structural support by enclosing areas or serving as scaffolds or supports for the growth. The interplay between organic and inorganic matter allows nature to produce hybrid materials whose remarkable shapes and characteristics never cease to astound humans [87].

Table 1: Difference between soft template and hard template

S. No.	Hard template	Soft template	Reference
1	The size and shape of the sample particle are directly determined by the hard template, which is a rigid material with a fixed structure	The soft template lacks a definitive rigid structure.	
2	Hard templates are prepared before the reaction.	Soft templates are generated during the reaction.	[88]
3	They are very reproducible and stable.	They are not stable	[89]
4	Hard templates are hard to remove.	Soft templates are easier to make and remove than hard templates.	
5	Hard templates are those created by the in situ physical or chemical conversion of a substance into its precursors.	The soft-template method frequently employs flexible nanostructures as soft-templates, which are composed of intermolecular interactions.	[90]
6	The hard template method consumes more time.	The soft template method consumes less time than the hard template method.	
7	Hard templating is a tedious strategy.	Soft-templating synthesis of mesoporous carbons, this simple and cost-effective strategy	
8	Hard template, the templating approach is more challenging and complicated.	The soft templating approach is the simplicity of the one-step synthetic procedure for generating mesostructured materials.	[90]
9	It applies to the physical or chemical growth or deposition of nanomaterials into the template's nanopores, and the template is eventually removed; this allows for exact control over the target production's dimensions and requirements.	The aggregation by weak intermolecular or intramolecular interaction develops a specific structure of space. These aggregates feature a prominent structural interface that offers a special interface to produce a certain propensity. The dispersion of inorganic spices ultimately results in the production of nanomaterials with certain structures.	[91]
10	The majority of the time, hard templates are made from previously prepared materials such as polymer microspheres, mesoporous carbon, and AAO templates [88-92]	The soft template depends mostly on the micelle's action to produce the organic-inorganic phase between target production, high polymer, biopolymer, and surfactant.	[92]

CONCLUSION

Because nanoscience and nanotechnology are by definition, multidisciplinary fields, biologists need to understand not only the basic principles of nanoscience but also the tools and techniques commonly used to manipulate nanomaterials. Since the hard template approach offers the potential to use multiple configurations for the tagging of mesoporous silica nanoparticles, it is a highly effective technology for making a variety of metal oxide and carbon-based mesoporous materials. In summary, construction frameworks and pore diameters can be used to differentiate between porous materials. The mesoporous microstructure of mesoporous silica is found in pores with diameters ranging from 2 to 50 nm. The mesoporous silica synthesis using template intervention approaches was reorganized into two groups: the endotemplate strategy (also known as the soft template) and the hard template (also known as the exotemplate method). Three separate steps that typically comprise a template-assisted approach are the formation of mesoporous substances using the template (e. g., sol-gel, precipitation, hydrothermal process, etc.) and template expulsion. While soft templates are found in fluid-like, non-rigid substances, such as surfactants, hard templates are typically solid-state materials with certain morphological properties and frameworks.

ABBREVIATIONS

Anodic Aluminum Oxide-(AAO)

FUNDING

Nil

AUTHORS CONTRIBUTIONS

Sakshi and Aishwarya collected the data and drafted the manuscript. Swapnil Guide to all authors the way of research study. Vishal serially analyzed, arranged, and evaluated the manuscript. Aditi, Darshana, and Deepti are translators. All the authors have contributed equally.

CONFLICTS OF INTERESTS

The authors declare no conflicts of interest.

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