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Review Article



Nanomaterials, Characteristics and Applications

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Abstract

This article presents a general classification of nanomaterials based on their chemistry, morphology, and dimensions. Nanomaterials can be categorized into nanoparticles, nanofilms, or nanotubes based on their dimensionality. Nanomaterials can be composed of singular elements, such as carbon or metals, or many constituents, such as composites or metal oxides. We examine the prevalent categories of nanomaterials to date, accompanied by depictions of their morphologies. A material's physicochemical characteristics in nanoform can differ significantly from those of its bulk component, depending upon the material's structure, shape, size, and functionalization.

Keywords: Nanomaterial, Types of Nanomaterials, Nanotechnology, characterization.

Introduction

Nanotechnology can refer to the design, manufacture, manipulation, and application of nanostructures, which are very small structures, or it can refer to the study of very small materials (NMs). Nanomaterials and nanostructures can have dimensions varying from sub-nanometers to several hundred nanometers (G. C. Seattle, 2003). The prefix nano originates from the Greek term "nano," signifying "very small." Due to their diminutive size, they possess substantially bigger surface areas than their bulk counterparts, enhanced reactivity, and the capacity to modulate various attributes (Salem et al., 2023).

Richard P. Feynman was the one who initially introduced the concept of nanotechnology early in 1959. Since then, many revolutionary developments in chemistry, physics, and biology developed new research fields, especially in the interfaces between the various scientific fields, resulting in interesting scientific and progress technology in multiple disciplines. These new fields of research have contributed to fascinating scientific and technological advancements. In 1974, Norio Taniguchi emerged with the term "nanotechnology" and the "top-bottom approach" was introduced. By predicting

developments and the miniaturization of integrated circuits, mechanical devices, computer memory devices, and optoelectronic devices. About ten years later, Drexler presented the "bottom-up approach," when discussing the production of larger structures from their atomic and molecular components (Ealias & Saravanakumar, 2017).

Nanomaterials are the basis of nanotechnology and are one of its most critical elements. Nanomaterials are materials with dimensions smaller than 100 nanometers in at least one of their dimensions. This shows that their size is much smaller than that of the microscale. The dimensions of nanomaterials are on the order of 10^{-9} meters, equivalent to one billionth of a meter. Due to their diminutive size and morphology, nanomaterials exhibit physicochemical properties distinct from those of bulk materials. Altering the form and size at the nanoscale generates nanomaterials that exhibit distinct characteristics and functionalities. Nanomaterials exhibit various shapes, including nanorods, nanoparticles, and nanosheets; they can be categorized according to the dimensions of their constituents (Benelmekki, 2019). Nanoparticles are the most basic category of nanomaterials, whereas nanorods and nanotubes exemplify one-dimensional

nanomaterials and two-dimensional nanomaterials often consist of layers and films of the first type. These categories are primarily utilized for single, isolated nanoparticles. They will modify their physical properties upon interaction with two or more particles. These particles composed of several elements are referred to as bulk or three-dimensional nanomaterials. They are classed according to nanoscale dimensions (<100 nm) as follows (Buzea & Pacheco, 2017).

- Zero-dimensional nanomaterials (0-D) are those in which all three dimensions are confined to the nanoscale range. This classification may include nanoparticles.
- One-dimensional nanomaterial (1-D): In this category of nanomaterial, only one dimension is within the nanoscale range, while the other two dimensions exceed the tiny range. This categorization pertains to nanorods, nanotubes, and nanowires.
- Two-dimensional nanomaterials (2-D) possess two dimensions within the nanoscale range, whereas the third dimension is outside. Nanofilms, nanolayers, and nanocoating exemplify these formations.
- Three-dimensional or bulk nanomaterials (3-D): these nanomaterials are not in the nanoscale range. In three arbitrary dimensions, they exceed 100 nm in scale. These comprise nanocomposites, core-shell structures, multilayer nanostructures, bundles of nanowires, and bundles of nanotubes.

Types of Nanomaterials

Nanomaterials can be put into many different groups based on their shape, size, properties, and the building blocks that make them up. Nanomaterials based on carbon, nanoparticles of metal, nanomaterials based on semiconductors, and nanomaterials formed on polymeric materials (Kolahalam et al., 2019).

- **Carbon-Based Nanomaterials**

Carbon constitutes the majority of the structure of this type of nanomaterial. Carbon nanotubes and fullerenes in this type are linked to this group. There are carbon nanotubes inside graphene sheets that are rolled up and then set up into a tube shape. These are a lot more expensive than steel, but they can help make buildings better. There are two types of CNTs: single-walled and multi-walled.

Fullerenes are particles with sixty or more carbon atoms that are hollow cages. As a group, these different kinds of carbon are called allotropes. It is made up of pentagonal and hexagonal carbon units that are arranged in a regular design, just like a hollow football. They are very strong and have a high electrical conductivity and electron attraction (Khan et al., 2019).

- **Inorganic-Based Nanomaterials**

These nanomaterials that metals and metal oxides are made up. Iron, gold, and copper, as well as metal oxides like TiO₂, ZnO, and MnO₂, can be used to make them. Ceramics and silicon materials can also be used to make semiconductor particles.

- **Organic-Based Nanomaterials**

The nanomaterials that are organic are made from organic materials other than carbon and inorganic materials. You can make these nanomaterials by letting them self-assemble or changing organic materials into the required shape. These materials are affected by the weak non-covalent interaction.

- **Composite-Based Nanomaterials**

Composite nanomaterials have one more layer of nanoparticles on top of the first. Along with these, there are also bulk materials or more complex materials like metal frameworks. Different materials can be used to make composites, including metal, ceramic, organic, inorganic, bulk polymers, and carbon-based. These materials can be in different morphologies depending on the required properties for the applications and the synthesis used (Singh et al., 2020).

Unique Nanomaterial Features

The properties of matter at the nanoscale level are very different from those at the bulk scale. The effects that depend on size stand out more when seen at the nanoscale. Because nanomaterials can be changed in size, their properties can also be changed (Čitaković, 2019):

- Area of the surface. One of the things that makes nanomaterials unique is that their surface areas are almost always much higher than those of their bulk counterparts.
- Magnetism. On the nanoscale, the magnetic properties of elements can change. An element that is non-magnetic can have magnetic properties.
- Quantum effects. It has been shown that quantum effects are prominent at the nanoscale. on the other hand, the size of these effects depends on the type of semiconductor material used.
- High electrical and thermal conductivity. At the nanoscale level, materials can have much better thermal and electrical conductivity than their bulk counterparts. This can be seen in graphene, which is made from graphite.
- Excellent mechanical properties. Nanomaterials are very strong and don't have the same mechanical properties as their macroscopic counterparts.

• Antimicrobial activity. Some nanomaterials are very good at treating germ-based diseases because they are antiviral, antibiotic, and antifungal.

In general, the presence of these properties adds value to nanoscale materials, making them usable for a wide range of applications and significantly improving the performance of numerous technologies and materials in many fields.

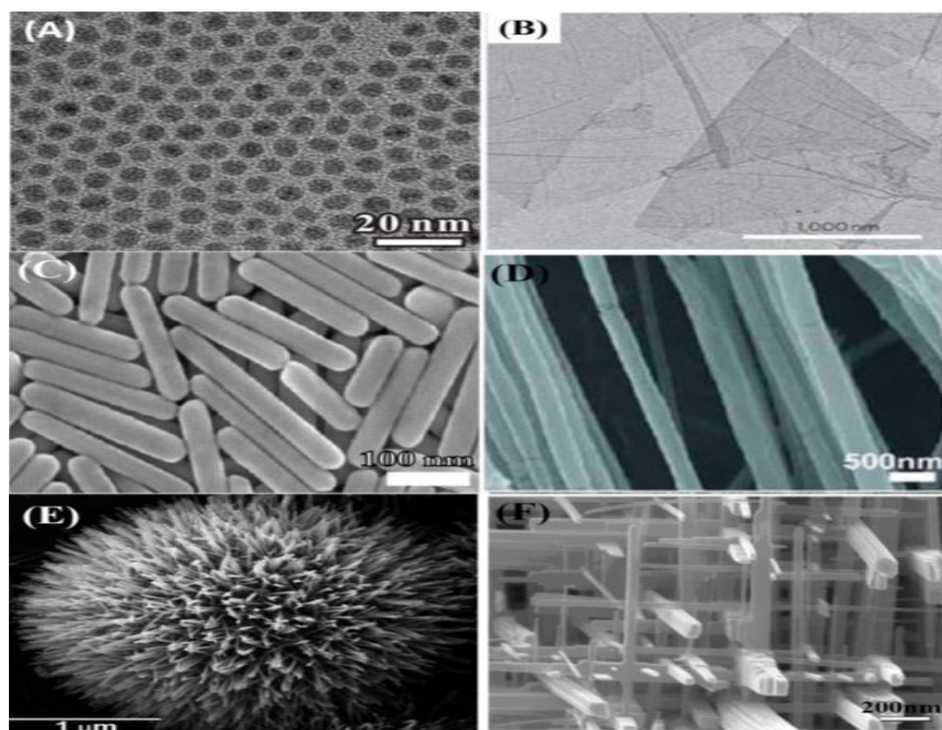


Fig. 1 Nanomaterials with different morphologies (R. A. Abd Ali et al., 2022).

Synthesis of Nanomaterials

To make metal nanoparticles, synthesis methods need to be able to separate small amounts of material. Two main ways to get things on the nanoscale scale are described below.

A. The bottom-up method, also known as the reduction method, comes from putting together the atoms that are made when ions are reduced (H. M. khudier & M. R. Al bahrani, 2019).

B. The top-down method (dispersion method) removes the material from the bulk material and leaves only the desired nanostructures. Regarding fabrication techniques, the top-down (physical approach) fabrication technique frequently calls for costly equipment and complicated processing. It also frequently faces the challenge of dealing with structural defects in the lithographically patterned one-dimensional nanostructures, such as edge roughness. The most commonly used top-down methods are milling, drilling, and grinding (Baig et al., 2021).

Conclusions

Every day, more and more new nanomaterials are being made. Nanomaterials with a mix of different components are also made to be used in various fields. The simple ways for synthesis will make nanoparticles of the shape, desired size, and properties that can handle the external conditions, but they still need to be improved. This article defined nanotechnology and described the processes for making nanomaterials from metals, metal oxides, graphene, and polymers. Therefore, the present review article will provide an opportunity to provide general information about nanomaterials.

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