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Nanostructures and Nanomaterials. Synthesis, Properties, and Applications

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Nanomaterials and Nanostructures attract tremendous attention worldwide in recent research fields, including physics, chemists, material scientists and mechanical and electrical engineers. Nanotechnology referees to the development of devices, structures, and systems whose size varies from 1 to 100 nanometers (nm).

The term *nano, originated* from the Greek with the meaning of dwarf, indicates physical dimensions that are in the range of one-billionth of a meter. Thus, one nm is approximately the length of two hydrogen atoms and 1000 nm is the mean dimension of a bacterium. Nanoscale structures permit the control of fundamental properties of materials without changing the materials chemical status, requiring knowledge drawn from a variety of scientific and engineering arenas.

This is why; designing at the nanoscale is working in a world where physics, chemistry, electrical and mechanical engineering, and even biology become unified into an integrated field. Thus, all the products are manufactured from atoms and their properties depend on how those atoms are arranged. For all these reasons, nanomaterials often have properties dramatically different from their bulk-scale counterparts.

The goal of nanotechnology is to close the size gap between the smallest fabricated structures and chemically synthesized large molecules.

The aim of this book, organized by 9 chapters and appendices, is “to summarize the fundamentals and technical approaches in synthesis, fabrication, and processing of nanostructures and nanomaterials has to provide the readers with a systematic and coherent picture of the field".

After the **Chapter 1**, introducing the attractive application of nanostructures in the practice of medicine referred to nano medicine, **Chapter 2** focuses on the *Physical Chemistry of Solid Surfaces*. Nanostructures and Nanomaterials, in fact, possess a large fraction of surface atoms per unit volume, so that the surface energy increases with the overall surface area, depending on the dimension of the material also. Due to the huge surface area, all these nanostructured materials possess a huge surface energy and, therefore, are thermodynamically unstable. Thus, the necessity to know and understanding the mechanisms governing surface energy and surface physical chemistry of solids and, of course, of all the nanomaterials, before starting their fabrication and processing.

Two are the approaches for the synthesis of nanomaterials and the fabrication of nanostructures: top-down and bottom-up, all both reported on **Chapter 3** *Zero-Dimensional Nanostructures: Nanoparticles*.

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Attrition or milling is a typical top-down method in making nanoparticles, whereas the colloidal dispersion is a good example of the bottom-up approach. The bottom-up, referring to the approach to build a material up from the bottom (atom-by-atom, molecular-by-molecular, or cluster-by-cluster), promises a better chance to obtain nanostructures with less defects, while the biggest problem with the top-down approach is the imperfection of the surface structure.

In this chapter, the attention has been focused mainly on the synthesis of nanoparticles through thermodynamically equilibrium approach, including single crystal, polycrystalline and amorphous particles with all possible morphologies, such as spheres, cubes, and platelets. However, for any practical application, the processing conditions need to be controlled in such a way that resulting nanoparticles have the following characteristics: (a) identical size and uniform distribution of all the particles; (b) identical shape and morphology; (3) identical chemical composition and crystal structure; (c) individually dispersed or mono dispersed with no agglomeration.

Spontaneous growth and template-based synthesis are considered as a bottom-up approach, whereas lithography is a top-down technique.

Spontaneous growth, process driven by the reduction of Gibbs free energy, results in the formation of single crystal nanowires or nanorods along a preferential crystal growth direction depending on the crystal structures and surface properties of the nanowire materials. In this process, for given material and growth conditions, defects and impurities on the growth surfaces can play a significant role in determining the morphology of the final products.

Template-based synthesis mostly produces polycrystalline or even amorphous materials. This the topic discussed on **Chapter 4** *One-Dimension Nanostructures: Nanowires and Nanorods*, where the fundamental and principles of the major synthesis methods to produce nanowires, nanorods, and nano tubules of various materials, including metals, semiconductors, polymers, and insulating oxides are reported.

The synthesis methods reported is limited to the more common fundamentals and concepts techniques used. Among them the electrospinning technique is reported and discussed. This technique uses electrical forces to produce polymer fibers with nanometer-scale diameters. Polymer nanofibers obtained via electrospinning have found wide applications in optics, microelectronics, protective clothing, drug and cosmetic release, and advanced medications. Electrospinning occurs when the electrical forces, at the surface of a polymer solution or melt, overcome the surface tension and cause an electrically charged jet to be ejected. When the jet dries or solidifies, an electrically charged fiber remains. This charged fiber can be directed or accelerated by electrical forces and then collected in sheets or other geometrical forms. The morphology of the obtained fibers depends on the process parameters, including solution concentration, applied electrical field strength, and the feeding rate of the precursor solution.

These nanofibers have some unique properties: they are highly porous, i.e., they have a large interconnected void volume in the range of 50% or even greater than 90% and possess a very high surface-to-volume ratio, making them fibrous scaffolds useful for many biomedical and industrial applications.

In any way electrospinning is not only an effective method to prepare nanofibers, but it is also a convenient technique to incorporate other nanomaterials such as nanoparticles into nanofibers. Moreover, this innovative technique can also be utilized to synthesize core-shell nanostructures that

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have potential applications in biomedical areas such as protective labeled biomedical ingredients and delivering the drug in a sustained way.

Two-Dimensional Nanostructures: Thin Films is the subject focused on **Chapter 5** where the fundamentals and the typical experimental techniques used for film deposition are reported.

Film growth can be divided into two groups: vapor phase deposition and liquid-based growth. The former includes for example, evaporation, chemical vapor deposition (CVD), molecular beam epitaxy (MBE), and atomic layer deposition (ALD), while examples of latter are electrochemical deposition, chemical solution deposition (CSD), and Langmuir-Blodgett films and self-assembled mono layers (SAMs). However, film deposition involves heterogeneous processes, such as evaporation, adsorption and desorption on growth surfaces, and heterogeneous nucleation and surface growth, on the substrate also, generally carried out in a vacuum.

In practice, the integration between film and substrate plays a very important role in determining the initial nucleation and the film growth, as well as the deep knowledge of the vacuum science, amply discussed into the book.

In biomedicine the self-assembly method is considered of great importance for the synthesis of thin films to be used, for example, as advanced medications. By this method, nanostructured materials can be assembled (organic or inorganic-organic) into ordered macro scale structures, such as thin films.

Self-assembly is a generic term used to describe a process that induces the arrangement of molecules and small components under the influence of chemical reactions, electrostatic attraction, and capillary forces. At this purpose, it is to remember how the concept of self-assembly derives from observing that, in natural biological processes, molecules self-assemble to create complex structures with nanoscale precision. Examples are the formation of the DNA double helix or the formation of the membrane cell from phospholipids.

These processes, which self-assemble and organize sub-units into well defined structures, are guided by information coded into the same sub-units capable to form the final structure with the lowest free energy. External factor, such as change in temperature, or change in pH, can disrupt this natural organization, as well as the self-assembling nanostructures created by the nano-technological approach to make new materials. However, the self-assembly technology is limited to the fabrication of organic or inorganic hybrid thin films, while both MBE and ALD offer the most precise control of deposition at the single atomic level with the best quality.

Special Nanomaterials is the topic discussed on **Chapter 6**. Carbon is a unique material that can be a good metallic conductor in the form of graphite, a wide band gap semiconductor in the form of diamond, or a polymer when reacted with hydrogen.

The different property of graphite and diamond are a consequence of the different way the carbon atoms in the materials are bonded. Thus, graphite is soft, light, flexible, and conduct electricity, while diamond is extremely strong, hard and does not conduct electricity. Both materials are made of atoms of carbon linked through strong binding, but in graphite each carbon atom uses three out of its four electrons to form single bonds with its neighbors, forming a linear sheet, whereas in diamonds each carbon atom uses all its electrons to form four single bonds, resulting in a 3-D structure.

This chapter describes two new forms of carbon that do not exist in nature: fullerene and nanotube. The former is an allotrope of carbon formed of 60 atoms of carbons linked together through single

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covalent bonds arranged in a highly symmetrical closed shell that resembles a football. The latter appears as a rolled-up tubular shell of graphene sheet, which is made of benzene-type hexagonal rings of carbon atoms. Thus, the body of the tubular shell is mainly made of hexagonal rings of carbon atoms whereas the ends are capped by half-dome shaped half-fullerene molecules. All both these structure, bringing unique physical properties have great potential in numerous promising fields, such as *materials and manufacturing* (replacing heavy metals, produce innovative polymers and sensors,etc); *environment and energy* (solar converters, groundwater treatment, membranes for cleaning gases,etc); *electronics and computers* (transistors, fibers and displays,nano fabrication of chip,etc); *space, aircraft and transportation* (replacing metallic components, micro fuel cell technology, filtering gases,etc).

Nanostructures Fabricated by Physical Techniques is the topic reported on **Chapter 7**, focused mainly on the top-down fabrication of nanoscale structures with different processing techniques, derived from the industrial experience of the microstructures. Various techniques are discussed such as lithography and nanolithography. Also if these technologies have the capability of a mass production, until now they results in surfaces damages that impact the performance of the resultant nanostructures and nano devices.

One of the critical challenges faced by the researches in the nanotechnology and nanoscience fields remains the lack of instruments to observe, measure, and manipulate the materials at the nanometer level. Characterization and manipulation of individual nanostructures requires not only the extreme sensitivity and accuracy, but also the atomic level resolution.

For this reason, the development of novel tools and instruments is one of the greatest challenges in the nanotechnology. This is the topic reported on **Chapter 8** *Characterization and Properties of Nanomaterials, where* the fundamentals and basic principles of the characterization methods for controlling the usual chemicals are used for nanomaterials also. Among them X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission microscopy (TEM), and scanning probe microscopy (SPM), are focused and discussed. However new methods have to be recovered in the next future because the size effects on mechanical properties of bulk nanostructured materials is far more complicated, since there are other mechanisms involved, such as grain boundary phase and stresses.

In conclusion, nanotechnology offers a broad range of potential applications from electronics, optical communications, and biological systems to new materials, opening new exiting challenges. Thus, in nanomedicine the major challenge is *miniaturization*, such as the fabrication of new instruments capable to analyze the human tissues at molecular level, or the production of *sensors* smaller than a cell, or the possibility to make nano devices so small to have the capacity to enter into the blood stream for controlling tissues and organs or neutralizing chemical toxins.

These so called nanobots have the potential to serve as vehicle for delivering therapeutic agents, detecting early diseases, or repairing metabolic or genetic defects. The goal of these innovative machines could be that of releasing a drug in a designed area, minimizing its potential side effects, or binding a particular active ingredient to an assigned target for preventing a virus to infect a cell. These and others the possibilities that innovative materials and devices may have in the next future. This the final fascinating topic developed by the final **Chapter 9** *Applications of Nanomaterials*.

The authors ends the book affirming that "nanotechnology, penetrating into every aspects of our life, will make the world different from what know now", especially when it is possible to demonstrate its value over the existing legacy systems.

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So the main issues of adoption, for example, of new technologies in the medical field must tap into the value stream to be candidates for adoption. Thus, the benefits of time and cost reduction, together with the improved capability to determine what these values are and how we can demonstrate them, must be analyzed in advance.

This interesting book, useful as general introduction to people just entering the field of nanomaterials and nanotechnologies, may be of interest of the experts seeking for information in other subfields, such as material and biomedical engineers, clinical medical doctors, molecular cell biologists, hystologists, as well as experts of bioethics, regulatory affairs, business administration and commercialization, but also students of the chemical and medical communities having an interest on nanoscience.

P.Morganti
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