



Nanotechnology Applications for Improvements in Energy Efficiency and Environmental Management

M.A. Shah, M.A. Bhat, and J. Paulo Davim

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Preface

The world is a dangerous place to live; not because of the people who are evil but because of the people who don't do anything about it. - Albert Einstein

The culmination of a long line of Greek philosophers, including Democritus, Lucretius formulated the first detailed atomistic description of nature in the first century BC. This was not yet nanoscience; it was simply science. However, it was not until the beginning of the 19th century, some 20 centuries later, that the atomic theory would be scientifically established by the chemists Dalton, Lavoiser, Gay-Lussac, and others. The science of the microscopic would then work its way up through the ranks during the 19th and especially the 20th centuries.

Physics and Chemistry as we know them are largely built upon our knowledge of matter on the atomic scale. Continuing this same trend from the beginning of the 1980s, it would seem that several new chapters have been added to the history of science, associated with the prefix nano. The notions of Nanosciences and nanotechnology pop up in every sector of modern knowledge.

Young scientists today are likely to be attracted by the depth and novelty of this new technology, setting off on a voyage of discovery in an unknown world, where the ways have not yet been signposted. One of the aims of this book is precisely to provide a tool that can be used to train not only students but also teachers and research scientists. It has been written by research workers and university teachers who are experts in their own fields and fully up to date with the latest developments. It has been put together in such a way as to produce a uniform and complete entity that can be approached directly via any of the chapters.

OVERVIEW OF THE BOOK

Chapter 1: Nanomaterials, Novel Preparation Routes, and Characterizations

This chapter describes the various aspects of nanotechnology: its dimensions and manipulation of matter with primary focus on inorganic materials. Detailed accounts of various methods lying within top-down and bottom-up synthesis approaches are discussed, like Chemical Vapour Condensation (CVC), arc discharge, hydrogen plasma-metal reaction, and laser pyrolysis in the vapour phase, microemulsion, hydrothermal, sol-gel, sonochemical taking place in the liquid phase, and ball milling carried out in the solid phase. The chapter also presents a brief account of the various characterization techniques used for the identification of the nanomaterials: x-ray diffraction, UV-visible spectroscopy, and electron microscopy (e.g. Transmission Electron Microscopy [TEM], Scanning Electron Microscopy [SEM], Atomic Force Microscopy [AFM]).

Chapter 2: Nano-Mechanical Characterization of Cement-Based Materials

Nanoindentation technique is used to assess the mechanical properties of materials at nano-level. A very small tip (usually diamond) produces indents at the surface of the material to be tested. A load vs. deflection curve is generated and is used to study the elastic properties of materials. Generally, it is used for obtaining the hardness and Young's modulus of materials at nano-meter scale. Currently, the method to evaluate the mechanical properties by nanoindentation is restricted to homogeneous materials. Cement-based materials are heterogeneous in nature. Therefore, nanoindentation study of cement-based materials is critical and requires several important steps, which need to be performed accurately. This chapter provides a review of the theory of nanoindentation, instruments being used for nanoindentation, sample preparation techniques, indentation strategy, and determination of nanomechanical properties and data analysis for cement-based materials.

Chapter 3: Carbon Nanotubes: Basics, Biocompatibility, and Bio-Applications Including Their Use as a Scaffold in Cell Culture Systems

Carbon-based nanotechnology has been rapidly developing with particular interest in bio applications of Carbon Nanotubes (CNTs) as a scaffold tissue-engineering replacement in biomaterial construct or scaffold. Carbon nanotubes are essential

and compatible scaffold fabrication materials with cells as well as with surrounding tissue. In addition, synthetic polymers, which lack mechanical strength, can be functionalized easily in contrast to CNTs. In spite of many attractive features, the toxicity of CNTs is a prime concern. CNTs' toxicity in both *in vivo* and *in vitro* studies has been attributed to various factors, and there is a need of more studies on CNTs' toxicity and biocompatibility issues. The potential applications of carbon nanotubes seem countless, although few have reached a marketable status so far. This chapter aims to revisit the basics of CNTs with their bio-applications including their use as a scaffold in cell culture systems.

Chapter 4: Novel Synthesis of 4nm Anatase Nanoparticles at Room Temperature Obtained from TiO₂ Nanotube Structures by Anodizing Ti

The scope of the chapter is showing novel experimental findings on preparing anatase TiO₂ nanoparticles, first anodizing titanium into an organic media for obtaining TiO₂ nanotubes, and these used as a photo catalytic active electrode in treating water polluted with organic contaminants. The substrates were grit blasted in order to obtain mechanical fixation of the generated nanotubular TiO₂ structure. This was successfully achieved without diminishment of the nanotubes order and with a self-leveling of the outer surface. A new phenomenon is investigated consisting in the process of oxidation of the nanotubes in water after anodizing. Along this process, methyl orange added to the aqueous solution was discolored as part of the redox reaction involved. The final state of the modified layer was composed of conglomerates of crystalline TiO₂ nanoparticles, around 4 nm in size, consisting of anatase. This was obtained under room conditions. Moreover, another new phenomenon occurred when detached fragments from the modified layer were electrophoretically deposited. They were ordered and grow as deposits. In addition, they maintain their nanotubular shape conferring a homogeneous size in the porous structure.

Nanotechnologies as key and cross-sectional technologies exhibit the unique potential for decisive technological breakthroughs in the energy sector, thus making substantial contributions to sustainable energy supply. The range of possible nanoapplications in the energy sector comprises gradual short and medium-term improvements for a more efficient use of conventional and renewable energy sources as well as completely new long-term approaches for energy recovery and utilization.

Chapter 5: Nanotechnology, Metal Nanoparticles, and Biomedical Applications of Nanotechnology

The chapter examines the role nanotechnology and its biomedical applications. Nanotechnology has emerged as an important field of modern scientific research due to its diverse range of applications in the area of electronics, material sciences, biomedical engineering, and medicines at nano levels such as healthcare, cosmetics, food and feed, environmental health, optics, biomedical sciences, chemical industries, drug-gene delivery, energy science, optoelectronics, catalysis, reprography, single electron transistors, light emitters, nonlinear optical devices, and photoelectrochemical applications and other applications. Due to these immense applications of nanotechnology in biomedical science, it has become possible to design the pharmaceuticals in such a way that they could directly treat diseased cells like cancer and make microscopic repairs in hard-to-operate-on areas of the body. The nanomachines have been designed to clean up toxins or oil spills, recycle all garbage, eliminate landfills, etc. The chapter summarizes the present and future applications of nanotechnology for human welfare but needs further study in catalysis, optical devices, sensor technology, cancer treatment, and drug delivery systems.

Chapter 6: Nanotechnology for Environmental Control and Remediation

The chapter emphasizes nanotechnology, which is an emerging field that covers a wide range of technologies that are presently under development in nanoscale. Nanotechnology offers the potential of novel nanomaterials for treatment of surface water, ground water, and waste water contaminated by toxic metal ions, organic and inorganic solutes, and microorganisms. The advantages of the use of nanomaterials, which are related to their properties that are completely different from the bulk materials, make them extremely attractive and give them enormous potential. Among the areas that are influenced by nanotechnology, environmental remediation is highlighted in this chapter. This chapter emphasizes several nanomaterials (Zero valent iron, titanium dioxide, nanoclays, nanotubes, dendrimers, ferritin, metalloporphyrinogens, and SAAMS) and their application in water treatment, purification, and disinfection. The use of nanoparticles in environmental remediation, which inevitably leads to the release of nanoparticles into the environment and subsequent ecosystems, is also explained.

Chapter 7: Applications of Nanotechnology in Cancer

This chapter examines the importance of nanotechnology in cancer prevention, cure, and diagnosis. This chapter deals with the applications of nanomedicine in cancer and various strategies to target cancer cells by using nanotechnology such as gold nanoparticles, liposomes, nanodots, nanorods, etc. Nanotechnology is an interdisciplinary area with potential applications in fighting many diseases including cancer. Conventional drugs have poor cell specificity, solubility, and high toxicity. The continued development of cancer nanotechnology holds the promise for personalized oncology. For accurate and self-confirming cancer diagnosis, it is essential to combine dual-mode and multi-mode imaging functionalities within one nanoparticle system. Nanoparticles improve the solubility of poorly water-soluble drugs and prolong the half-life of drugs. Disadvantages of nanotechnology include the potential for mass poisoning. Understanding how nano-materials affect live cell functions, controlling such effects, and using them for disease therapeutics are now the principal aims and most challenging aspects of nanobiotechnology and nanomedicine.

Chapter 8: Nanotechnology in Food Industry

This chapter addresses the potential application of nanotechnology in various areas of the food industry. Nanotechnology is having an impact on several aspects of the food industry, from product development to packaging processes. Nanotechnology is capable of solving the very complex set of engineering and scientific challenges in the food processing industries. This chapter focuses on exploring the role of nanotechnology in enhancing food stability at the various stages of processing. Research has highlighted the prospective role of nanotechnology use in the food sector, including nanoencapsulation, nanopackaging, nanoemulsions, nanonutraceuticals, and nanoadditives. Industries are developing nanomaterials that will make a difference not only in the taste of food but also in food safety and the health benefits that food delivers. While proposed applications of nanotechnologies are wide and varied, developments are met with some caution as progress may be stifled by lack of governance and potential risks.

Chapter 9: Nanosuspensions in Nanobiomedicine

The concept of nanobiomedicine is one of the most important and exciting ideas ever generated by the applications of nanoscience. Although there have been extensive interdisciplinary activities, major collaborative efforts are needed to jointly address some of the most challenging issues in life and medical sciences. One of the most challenging tasks for formulators in the pharmaceutical industry is the formulation

of poorly soluble drugs. Conventional techniques employed for improving solubility of these drugs have gained limited success. This holds true more often when dealing with drugs having poor aqueous as well as organic solubility. Nanoparticles facilitate formulation of hydrophobic drugs to improve solubility and efficacy mainly through nanosuspension approach. Nanosuspensions are submicron colloidal dispersions of pure drug particles, stabilized by surfactants. This nanobiomedicine delivery system is simple and advantageous compared to other strategies. Techniques such as media milling, high-pressure homogenization, and use of microemulsion as a template have been used for production of nanosuspensions. This green nanobiomedicine can be delivered by various routes, such as oral, parenteral, pulmonary, and ocular systems. It is also possible to convert nanosuspensions to patient-acceptable dosage forms like tablets, capsules, and lyophilized powder products. Nanosuspension technology has also been studied for active and passive targeted drug delivery systems. This chapter focuses on various manufacturing and formulation perspectives and applications of nano-suspensions as a drug delivery system.

Chapter 10: A Review of Various Nanostructures to Enhance the Efficiency of Solar-Photon-Conversions

The problem of dwindling energy can be attributed to the rapidly increasing worldwide energy demand compared with the supply and excessive greenhouse gas emissions resulting from ever-growing fuel consumption. It has led to an urgent need for alternative energy-harvesting technologies to sustain the economic growth by maintaining our appetite for energy through cost-effective and cost-efficient economies. Among them, solar-energy-harvesting is the most promising as solar energy is the most abundant, renewable, clean, and free source of energy available. Thus, the huge demand for clean, cost-effective, and cost-efficient energy can be met by solar-energy conversions. The large-scale solar energy utilization has not become fully possible because of the high cost and inadequate efficiencies of the current solar-energy-conversions.

Nanotechnology offers tools to develop cost-effective and cost-efficient based technologies for solar-energy conversions. It has the potential to increase the efficiency of current solar-energy-harvesting devices and also in the energy storage and use. Nanostructures such as nanowires, nanopillars, nanocones, nanodomes, nanotubes, nanorods, quantumdots, nanoparticles, etc. facilitate photon absorption, electron transport, and electron collection properties of the solar-energy-conversion devices and also lead to new generation devices for more efficient, cost-effective, and reliable solar energy conversion. This review specifically summarizes the contribution of the nanotechnology to photovoltaics, dye-sensitive solar cells, quantum-dot-sensitized solar cells, and solar hydrogen production devices.

Chapter 11: Convergence of Nanotechnology and Microbiology

The convergence of nanotechnology with microbiology is a nifty interdisciplinary research area that could amplify the limits of technology, enhance global health through formation of different drugs that can be effective against different infectious diseases, and for treatment of drinking water to kill the pathogens and make it safe for public use. Bacteria, fungi, and actinomycetes have been successfully used for the formation of nanoparticles of silver, gold, zinc, etc. The nature of cilia and flagella, which are molecular machines, nanotechnology can be extremely helpful in studying these structures in details. The formation of aerial hyphae by bacteria and fungi is directed by the order and controlled assembly of building blocks, and the formation of capsid in a virus is a process of molecular recognition and self assembly at the nano-scale. The size of nanoparticles is similar to that of most biological molecules and structures; therefore, nanoparticles can be useful for both in vivo and in vitro biomedical research and applications. As the microorganisms, especially bacteria, are becoming resistant to the commonly used antibiotics, an alternative antimicrobial agent that can be effective against the antibiotic resistant bacteria is needed. Much research is going on in the formation of nanoparticles from natural sources like plants to find effective and safe antimicrobial agents. Noble metal nanoparticles, particularly Silver Nanoparticles (SNPs), have shown a good antimicrobial activity against antibiotic-resistant bacteria. In the present chapter, we have highlighted the relationship between these two mighty disciplines. The chapter deals with many aspects like antimicrobial activity of nanoparticles, formation of nanoparticles using microorganisms, etc. The green synthesis of nanoparticles is an emerging new field of science; hence, it has been discussed in detail. As the use of nanoparticles is expected to increase in the coming years, there are concerns about the safety and effect of these NPs on human health and on environment. Hence, it is necessary to be aware of the precautionary measures while dealing with the nanoparticles.

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The important aspect of nanotechnology is the remarkable size dependant physico-chemical properties of nanomaterials that have led to the development of synthesis protocols for synthesizing nanomaterials over a range of sizes, shapes, and chemical compositions. This book chapter describes the various aspects of nanotechnology: its dimensions and manipulation of matter with primary focus on inorganic materials. Detailed account of various methods lying within top down and bottom up synthesis approaches has been discussed like Chemical Vapour Condensation (CVC), Arc discharge, Hydrogen plasma-metal reaction, and Laser pyrolysis in the vapour phase, Microemulsion, Hydrothermal, Sol-gel, Sonochemical taking place in the liquid phase and ball milling carried out in the solid phase. The book chapter also presents a brief account of the various characterization techniques used for the identification of the nanomaterials: X-ray diffraction, UV-Visible Spectroscopy and Electron microscopy viz Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM).

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Nanoindentation technique is used to assess the mechanical properties of materials at nano- level. A very small tip (usually diamond) produces indents at the surface of the material to be tested. A load versus deflection curve is generated and is used to study the elastic properties of materials. Generally, it is used for obtaining the hardness and Young's modulus of materials at nano-meter scale. Currently, the method to evaluate the mechanical properties by nanoindentation is restricted to homogeneous materials. Cement-based materials are heterogeneous in nature. Therefore, nanoindentation

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Chapter 3

Carbon Nanotubes: Basics, Biocompatibility, and Bio-Applications Including Their Use as a Scaffold in Cell Culture Systems56

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India*

Carbon-based nanotechnology has been rapidly developing, with a particular interest in the bio-application of carbon nanotubes (CNTs) as a scaffold in tissue engineering. It is essential that the materials used in scaffold fabrication are compatible with cells, as well as with the biological milieu. Many synthetic polymers have been used for tissue engineering so far; however, many lack the necessary mechanical strength and may not be easily functionalized, in contrast to CNTs, which have shown very attractive features as a scaffold for cell culture system. In spite of many attractive features, the toxicity of CNTs is a prime concern. The potential applications of CNTs seem countless, although few have reached a marketable status so far and there is need of more studies on CNTs biocompatibility issues. This chapter aims to revisit the basics of CNTs with their bio-applications including their use as a scaffold in cell culture systems.

Chapter 4

Novel Synthesis of 4nm Anatase Nanoparticles at Room Temperature Obtained from TiO₂ Nanotube Structures by Anodizing Ti87

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