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Nanotechnology Safety

Edited by

Ramazan Asmatulu

NANOTECHNOLOGY SAFETY

Edited By

RAMAZAN ASMATULU

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NANOTECHNOLOGY SAFETY

Dedications

This book is dedicated to the memory of Dr. Christopher Ibeh, who passed away in February 8, 2012. Dr. Ibeh was the original editor of the book "Nanotechnology Safety" and was also responsible for the Chapters 1, 2, 3 and 14, as well as providing advice to the authors. Dr. Ibeh was a professor in the Department of Engineering Technology of Pittsburg State University, and a colleague and friend of the many authors of this book. He will be tremendously missed since we relied on his advice and guidance during the preparation of the book chapters.

This book is also dedicated to my wife Eylem Asmatulu and my son Derin Asmatulu, without whom this book would have not been completed on time.

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Preface

The "Nanotechnology Safety" book is one of the first and most diverse books to be published in nanotechnology and nanoscience for the research, development, manufacturing, transportation, storage, handling, as well as educational and training purposes. Nanotechnology has a great potential to become the promising technology of this century because of its outstanding mechanical, electrical (conductive and semiconductive), optical, magnetic, quantum mechanics, and thermal properties of nanotechnology products. These unique properties of nanoscale materials, such as nanoparticles, nanotubes, nanowires, nanofibers, nanocomposites, nanopores, and nanofilms, allow them to be the next generation of materials/devices in many industries such as aerospace, automobile, ship, electronics, medicine, pharmacy, construction, energy, defense, food, and many others.

Nanotechnology products and devices have been growing very fast, and in the near future, more products will be available in the market for the public use. They are currently being used in sun screens, paints, toothpaste, tires, CD players, tennis rackets and balls, bicycles, as well as solar cells, fuel cells, sensors, cosmetics, drugs, and many more commercial and customers products. During the years 2006, 2009, and 2011, there were 700, 1014, and 1317 nanoproducts available in the market. They offer remarkable potentials of the applications and economic benefits worldwide. Within 10-15 years, it is expected that the industrial production of nanotechnology will be worth over $1 trillion. Numbers of technical articles and patents published in nanotechnology and nanoscience have also been continuously increasing for nearly two decades. As is stated, there is a huge demand on nanotechnology and nanoscience in many fields; thus, the editor is very pleased to see the advancement of the nanotechnology and to be engaged in the publication of this great book.

However, we regret to inform our readers of the sad news that the original editor of the "Nanotechnology Safety", Dr. Chris Ibeh, passed away on February 8, 2012, who was also responsible for Chapters 1, 2, 3, and 14 of this book. In fact, he initiated the idea of publishing the "Nanotechnology Safety" for many industrial purposes. Dr. Ibeh was a professor in the Department of Engineering Technology at Pittsburg State University and a colleague and friend of the many authors of this book. He will be enormously missed, as we relied on his advice and guidance during the preparation of the book chapters.

As nanotechnology is rapidly growing in many areas and providing huge economic, educational, and social benefits, this technology brings some environmental health and safety concerns. Some of the deadly diseases associated with nanomaterials are believed to be linked to nanotechnology, which include, but are not limited to, bronchitis, asthma, liver, lung and colon cancers, Crohn's disease, Parkinson's disease, Alzheimer's disease, and heart and kidney diseases. Because nanomaterials are all new generation of the materials produced with entirely different manufacturing techniques, there are no specific rules and regulations for many of them.

Thus, scientists, researchers, engineers, and policy makers should work collectively to create better and safer nanomaterials for the public use, and reduce or eliminate the side effects of nanotechnology and its products as much as possible for the future development in the field. Overall, the editor is very grateful to share all the new developments in the nanotechnology safety with the readers and other scientific communities.

Dr. Ramazan Asmatulu

Associate Professor, Wichita State University

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CHAPTER

1

Nanotechnology Emerging Trends, Markets, and Concerns

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1.1 INTRODUCTION

1.1.1 General Background

Nanotechnology is the creation, processing, characterization, and application of materials at nanoscale (in the range of one-billionth of a meter). It can also be related to the systems or processes that provide goods and/or services at this scale [1]. According to K. E. Drexler, "nanotechnology is the principle of manipulation of the structure of matter at the molecular level. It entails the ability to build molecular systems with atom-by-atom precision, yielding a variety of nanomachines" [1]. These materials commonly referred to as *nanomaterials* exhibit unusual and exotic properties that are not present in the traditional bulk materials of the same kinds.

Nanoscience is the study of the fundamental principles of molecules and structures with at least one dimension between 1 and 100 nm. These structures are known as *nanostructures*. Nanotechnology is the application of these nanostructures into useful nanoscale materials and devices [2]. When the materials are in the nanoscale level, they usually exhibit superior properties. For example, copper becomes transparent at the nanoscale; inert materials, such as platinum and gold, become active; and melting temperatures of the nanomaterials can be drastically reduced. Nanotechnology has the potential to change our standard of living [3–6]. Some nanomaterials applications include energy storage and production, information technology, medical technology, manufacturing, food and water purification, instrumentation, and environment. Nanotechnology-based products (currently more than 1,350 available on the market) include electronic components, nanopaints, storage devices, stain-free fabrics, cosmetics, and medical

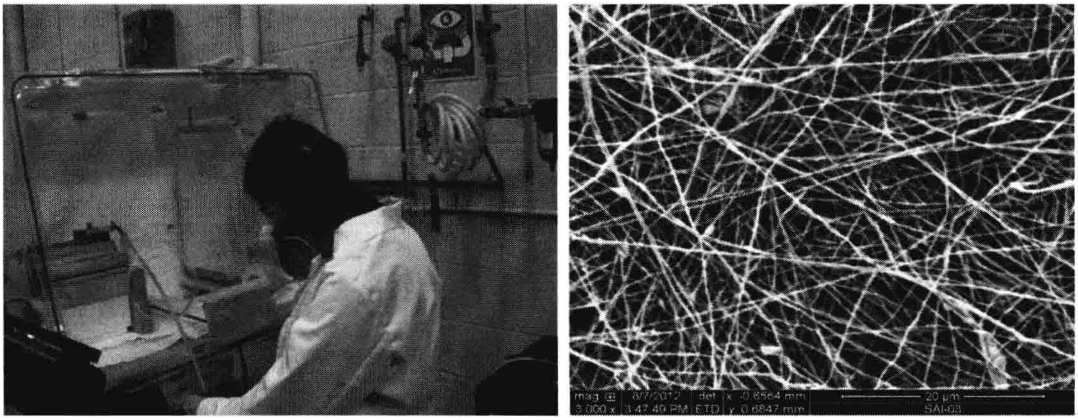

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FIGURE 1.1 (A) Electrospun nanofiber fabrication process, and (B) an SEM image of the resultant PVC nanofibers.

components [1–3]. Figure 1.1 shows the nanofiber fabrication process and a scanning electron microscopy (SME) image of the resultant nanofibers.

In 1959 renowned physicist and Nobel Laureate Richard Feynman gave a speech at the California Institute of Technology entitled "There's Plenty of Room at the Bottom," raising many questions about nanoscience and nanotechnology. Feynman highlighted the importance of controlling and manipulating matters on a small scale [3]. Although in 1974 Professor Norio Taniguchi was the first to use the term *nanotechnology*, the concept of nanotechnology is attributed to Feynman for his 1959 lecture, which was published in 1960 [15]. In the 1980s, IBM Zurich scientists invented the *scanning tunneling microscope* (STM), a landmark in nanotechnology development, which allowed scientists and researchers to analyze materials at atomic levels. The earliest commercial nanotechnology application was *atomic force microscopy* (AFM), also known as *scanning probe microscopy* (SPM). AFM uses a silicon-based needle/tip of atomic sharpness to image the topography of surfaces with atomic-scale precision. Research in nanotechnology has been increasing rapidly, and in the next few years nanotechnology is expected to have a $1 trillion impact on the global economy [12].

Nanotechnology has captured worldwide attention and excited the imagination of countless people throughout the world. Interest in nanotechnology has increased remarkably during the last few years because of potential scientific and technological applications and commercial interests [16]. The promise of nanotechnology as an economic engine that can redefine the well-being of many regions and nations is unprecedented now [16]. The National Nanotechnology Initiative (NNI) was established in 2000 to accelerate research and development. Since its establishment, the NNI has provided cooperation and collaboration to all participating federal agencies and served as the platform for priorities and strategies [4]. The objectives of NNI mainly include [4]:

- Establishing nanotechnology research and development programs
- Using nanotechnology to fabricate products for commercial and public benefit
- Training workers by developing educational programs and support infrastructure and tools for advancement in nanotechnology
- Supporting innovations in nanotechnology

The U.S. NNI has outlined four major generations of nanotechnology developments [6]: passive nanostructures, active nanostructures, nanosystems, and molecular nanosystems. The *passive nanostructures* comprise nanocoatings, dispersion, and contact nanostructures such as aerosols and colloids [6]. The *active nanostructures* include nanoelectromechanical systems, nanomachines, self-healing materials, and targeted drugs. The *nanosystems* include robotics, 3D networks, and controlled assembling. The *molecular nanosystems* consist of subatomic designed devices [6]. The advancements in nanotechnology have tremendous impacts on the environment as well as on health and safety, ethics, and legal and societal matters [4]. The NNI agencies have collaboratively developed a research strategy specifically focused on environmental health and safety aspects of nanotechnology [4].

Nanotechnology can be seen everywhere in our daily lives now. It is in toothpaste, car tires, CD players, tennis rackets and tennis balls as well as solar cells, fuel cells, toilets and washbasins, and many more commercial and consumer items [5]. Nanotechnology is the frontier between scientific reality and ambition, between accomplishments and expectations. Nanotechnology has the potential to become the promising technological advancement of this century. It offers a remarkable potential in terms of applications and economic benefits. Nanotechnology is a collection of different technologies and approaches in which the physical properties of dimension are the factors that influence all the material properties. To have a comprehensive picture of nanotechnology, it is necessary to look at the subareas of nanotechnology, such as nanoelectronics, nanobiotechnology, nanotools, nanomedicines, nanomaterials, nanoinstruments, and nanodevices [5].

Nanomaterials have major impact on all the fields of science and technology in which these materials are used for numerous purposes. Nanoelectronics enable future generations of electronics based on new devices and circuit architectures [5]. Nanobiotechnology involves designing nanotools to remedy medical problems, help modern medicine progress for the further treatment of symptoms, and generate biological tissues for lost functions of various body parts. Nanotools also have major applications in manufacturing, electronics, and chemical industries and are used in electron microscopes and ultraprecision machines [5].

1.1.2 Classification of Nanomaterials

Nanomaterials are mostly classified based on five factors: nanoparticle geometry, morphology, composition, uniformity, and agglomeration [3,10,22]. Based on nanoparticle geometry, nanomaterials are classified as 1D, 2D, or 3D [10].

- *1D nanomaterials* have one dimension of particulate in the nanometer scale and are generally referred to as *nanolayers, nanoclays, nanosheets, nanoflakes*, or *nanoplatelets*. Graphite, clay, and silicate nanoplatelets are examples of 1D nanomaterials. Figure 1.2 shows some of the different kinds of nanomaterials and platelets [6].
- *2D nanomaterials* have two dimensions of particulate in the nanometer scale and a third dimension could be in micro- or macroscale. These materials form an elongated structure and are generally referred to as *nanotubes, nanofibers, nanorods*, or *whiskers*. CNTs and carbon nanofibers (CNFs) are good examples of 2D nanomaterials. Figure 1.3 shows various types of nanotubes [6].

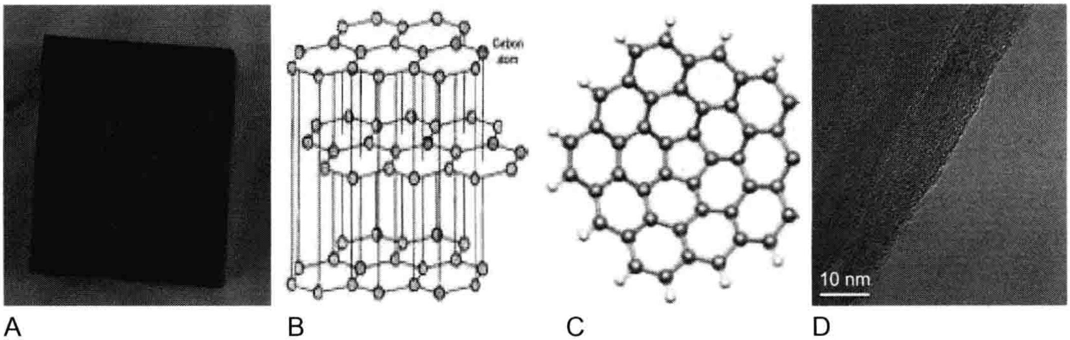
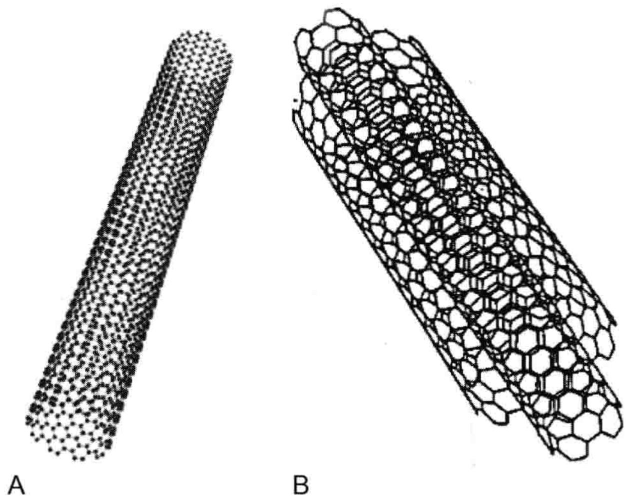


FIGURE 1.2 (A) Bulk graphite, (B) graphene flakes, (C) a nanographene sheet, and (D) a TEM image of graphene layers.

FIGURE 1.3 Various types of (A) single-wall carbon nanotubes (SWCNTs) and (B) multiwall carbon nanotubes (MWCNTs).



- *3D nanomaterials* have all three dimensions of particulate in nanometer scale and are generally referred to as *equiaxed nanoparticles, nanogranules*, or *nanocrystals*. Fullerenes, dendrimers, and quantum dots are examples of 3D nanomaterials. Figure 1.4 shows images of ferrite nanoparticles.

Nanoparticles possess a variety of morphologies, such as spherical, flat, needle, or random orientations. Based on their morphologies, nanomaterials are generally classified as materials with either high- or low-aspect-ratio nanoparticles. Nanotubes and nanowires with various shapes, such as helices, zigzags, and belts, are examples of high-aspect-ratio nanoparticles [6]. The low-aspect-ratio nanomaterials include nanoparticles with different shapes (e.g., helical, spherical, cubic, pillar, and oval). Most of these nanoparticles occur in the form of powder, suspensions, or colloids [3].

Nanomaterials can be composed of either a single constituent material or a composite of several materials such as metals, alloys, polymers, or ceramics. Nanoparticles produced by natural processes are often agglomerations of various compositions, so pure

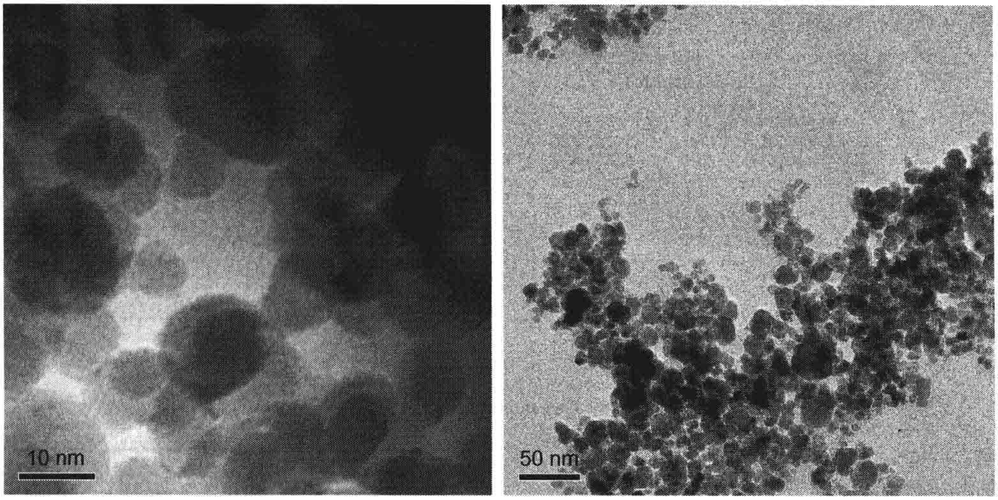


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FIGURE 1.4 TEM images showing (A) zinc oxide nanoparticles and (B) magnetite nanoparticles.

single-composition nanoparticles (engineered nanomaterials) can be synthesized by various processes, such as mechanical processes, gas-phase processes, vapor deposition synthesis, coprecipitation, and so on [6–10]. Nanoparticles can exist in an agglomerate state or can be dispersed uniformly in a matrix, depending on their chemistry and electrostatic properties. Due to their surface energy, nanoparticles come together and tend to form clusters or agglomerates, which can be avoided with the proper chemical treatment that changes the surface energy and distributes them uniformly. Figure 1.5 shows the classification of nanomaterials based on these characteristics [10,11].

1.2 THE CURRENT STATE OF NANOTECHNOLOGY

Commercialization of nanotechnology is still in its infancy stage. Nanotechnology is also receiving tremendous attention from the academic world, where new programs and centers are being established to accelerate the knowledge of nanotechnology through conferences, seminars, and presentations. In 2007 there were around 370 nanotech companies worldwide. Of these, 78 companies were producing nanoparticles, 50 were fabricating equipments, 49 were involved in analysis and characterization, 46 were engaged in the synthesis of carbon nanotubes, 21 were involved in semiconductors, 21 were working on sensors, 17 were working on coatings, 12 were producing batteries, and another 12 companies were working on solar cells [6–12]. Figure 1.6 shows the market share of nanotechnology in various industries.

Carbon Nanotechnologies (Houston, Texas) and Sumitomo (Tokyo, Japan) are two companies that are currently producing carbon fullerenes and CNTs on a mass scale [7]. Quantum Dot Corp. (Hayward, CA) and Evident Technologies (New York, NY) are both manufacturing quantum dots with various conjugates and colors. Nanosphere (Chicago, IL) and Genicon