

# Preface

Let's imagine we have a block of gold and a pair of metal-cutting scissors, and we start cutting the gold into small pieces. The original block of gold is typically of millimeter dimension, i.e., macro or bulk material. If we keep on cutting the gold to smaller and smaller sizes, such that the smallest piece is 1 millionth in size of the original block, that dimension is a nanometer, and now that "nano" piece of gold is a nanomaterial. The properties of a nanomaterial are significantly different from its bulk counterpart. For example, bulk gold melts at above 1000 °C while a gold nanoparticle melts at around room temperature. Also, gold as we know it is yellowish in color, but a nano-piece of gold is typically ruby red in color due to different light absorption properties. The fundamental discovery that material properties are different, and in many cases, better when nanostructured rather than as macroscopic particles has paved the way for a widespread interest in nanoscience.

Just to give a perspective, the thickness of an average human hair is about 100,000 nm while the diameter of an atom is about 0.4 nm. Thus, nanotechnology, in essence, is really looking at the physical and chemical mechanisms of atoms and molecules, and more importantly, as presented in this book, strategies to control and engineer these properties to create new and advanced materials that can improve our lives. The 2010 Nobel Prize in Physics for the 2004 discovery of a two-dimensional nanomaterial of carbon called graphene with remarkable electrical, thermal, and mechanical properties catapulted the interest and scientific funding in nanomaterials, not only in the developed countries, but across the globe. Interestingly, several layers of graphene when put together make graphite, which is what pencils, that we so regularly use to write, contain.

The history of nanoscience dates back to 1959, when Richard Feynman gave his extensively referred talk on molecular machines with atomic precision. It was two decades later when Eric Drexler presented molecular nanotechnology concepts at MIT. Since then, research in nanomaterials has consistently found academic interest with the discovery of buckyball in 1985 by Smalley and his colleagues and the 1991 discovery of carbon nanotubes by Iijima in Japan. Research in nanotechnology has grown exponentially over the last two decades, especially with significant commercial interest in products containing nanoparticles. For example, several of our

everyday products contain nanomaterials—many sunscreens contain zinc oxide and titanium oxide nanoparticles, nano-silver contained in bandages and dressings used to treat wounds and burns, nanoparticle suspensions in fluids used as coolants for cars—as well as for certain ambitious applications such as lightweight carbon nanotube containing composite materials for aerospace components, and atomically engineered metallic alloys for radiation-tolerant nuclear energy systems. Hybrid nanomaterials have had the major (almost 35%) share of the nanotechnology industry focus, again certifying the importance of this technological field.

The progresses in nanomaterials are due to the cross-disciplinary efforts from scientists and engineers with a wide range of expertise in Physics, Chemistry, Biology, Mathematics, as well as Mechanical, Chemical, Materials, and Computer Engineering. The chapters in this book offer a strong flavor of the interdisciplinary nature of the research in nanomaterials. The six chapters of this book give detailed description of advanced nanomaterials including their synthesis, testing, and properties that are strongly associated with fundamental novelties in molecular mechanisms. The authors, who are nationally and internationally renowned experts in nanomaterials, and their corresponding chapters provide an overview to the uninitiated while a deeper understanding and knowledge to readers with specialized interests. The chapters are organized accordingly to the dimensionality of the principal nanomaterial discussed by the authors. In other words, Chaps. 1 and 2 discuss one-dimensional nanomaterial (carbon nanotube), Chaps. 3 and 4 discuss two-dimensional nanomaterial (graphene and its analogs), Chap. 5 presents advances in nanostructured three-dimensional oxide interfaces, and Chap. 6 relates to progress in nanofluidic materials.

In Chap. 1, M. Tehrani and P. Khanbolouki discuss the different aspects associated with the synthesis, processing, characterization, and properties of carbon nanotubes. As mentioned earlier, these materials have captured the interest of scientists over two decades and their commercial relevance has triggered their use in combination with other materials for designer structures. The authors begin from the very fundamentals of carbon chemistry and sequentially explain the engineering processes associated with developing these advanced materials. Their approach provides an easy read for the newcomers in this field, but also a comprehensive description of state-of-the-art technological aspects that would interest a specialist.

In Chap. 2, R. P. Sahu, I. K. Puri, and coauthors describe how carbon nanotubes in combination with magnetic nanoparticles have found significant interest and application in sensing opening new avenues for these nanomaterials. They meticulously discuss the synthesis procedures that include different methods of functionalization, and printable sensors that are magnetically and electrically responsive. The future of such advanced nanomaterials is extremely bright, to say the least, with unbound opportunities in supercapacitors, Lithium ion batteries as well as soft composite materials with significantly improved and controllable material properties.

In Chap. 3, S. Hu, S. Das, and H. Monshat present the progresses in the use of two-dimensional materials in electrochemical energy storage devices. The motivation for the research is rooted in the superior performance of these nanomaterials relative to the traditional materials employed in such applications. The discussion

on supercapacitors builds organically from the previous chapter as the authors present the fundamental contributions of defects and functional groups to the material properties. An important aspect underlined in the outlook includes further research, regulation, and awareness on the effect of nanomaterials on environment and health.

In Chap. 4, O. Sanchez and coauthors summarize the knowledge on new elemental two-dimensional materials analogous to graphene. The elements in group four of the periodic table have found a niche interest in nanomaterials, the idea being mimicking the nanostructural aspects of carbon in silicon, germanium, and tin. Although the research is still in its infancy, the authors review the achievements in synthesis of silicene, germanene, and stanene, and their corresponding structural, electronic, and thermal properties.

In Chap. 5, TeYu Chien takes us to a different yet related territory of nanomaterial interfaces. The author discusses the novel phenomena that arise at the contact zones of dissimilar bulk complex oxide materials. Although the materials are of larger dimensions, the electronic properties are governed by the nanoscale features at the interfaces of these advanced materials. While advanced synthesis techniques can create these materials, the recent progress in cross-sectional scanning probe microscopy has facilitated the characterization of the typically challenging interfacial regions. The author provides a comprehensive background of the fundamentals of oxide materials, the properties at the interfaces that are investigated through state-of-the-art characterization, and next-generation applications that would benefit from these complex materials.

In Chap. 6, B. Ma and D. Banerjee show how dispersion of nanoparticles in fluids can enable improved properties for nanofluidic materials. The focus of the chapter is on synthesis procedures associated with “nanofluids.” The considerable interest in these materials, albeit the controversies in the repeatability of their properties, requires a diligent synthesis protocol to facilitate desired functionality and material properties in such advanced fluids. The emphasis on the effect of synthesis conditions on the thermo-physical properties of nanofluids is particularly important for scalable manufacturing of these materials. In addition to providing fundamentals of nanofluids and their properties, the authors show how these futuristic liquids can be used for solar energy storage and power generation.

I sincerely express my appreciation to all the authors for sharing their knowledge and expertise through their respective chapters, and their impetus and interest towards the book. I thank Brian Halm, Michael Luby, and Nicole Lowary for extending this opportunity to me, and most importantly for their faith and patience through this process. I would also like to express my love and gratitude to my wife, Tanumita, for her love and support, and understanding my irregular work schedules, especially during the time that I was engaged with this book.

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