Advanced Structured Materials

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Advances in Nanomaterials

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Foreword

There have been remarkable new developments related to amazing properties of materials when their particle sizes reduce to nanometer scale. There are reports of applications of several of these in widely different disciplines of science ranging from physical sciences to engineering, life sciences, agriculture, textiles, cosmetics, medical and biomedical fields as well as in environmental protection. Several technological developments, particularly those related to nanoelectronics with feature sizes entering below ten nanometers have raised expectations to unprecedented levels. The potential of wide ranging applications is posing challenges in the fundamental sciences regarding clear understanding of relationship between properties and basic physical and chemical characteristics including composition, trace impurities, crystallographic structure, and defects. There are numerous reputed R&D groups in India and worldwide, which are focusing their R&D activities on different aspects of nanoscience and technology. The number of scientists engaged in this field has increased substantially and is increasing at a rapid pace. As a consequence, the scientific literature being produced is also increasing day by day.

In view of the enormous increase in activities in nanomaterials, several top international organizations have started getting involved to promote its growth. The International Standards Organization (ISO) has a standard on nanomaterials, according to which a nanomaterial is:

"Material with any external dimension in the nanoscale or having internal structure in the nanoscale. Nanoscale is, in turn, defined as: size range from approximately 1 to 100 nm." A group constituted by International Council for Science (ICSU) has been engaged in deliberations on nomenclature. There are also serious concerns about health hazards associated with production of nanomaterials and their applications. Their impact on quality of environment is also attracting attention. Nanosize particles can penetrate to any organ of human body including brain, and therefore, our natural defenses against undesirable external matter of low dimensions are ineffective.

A book covering different aspects of nanoscience and nanotechnology is very welcome, keeping in view the continuous increase in the scientific literature and

interest in this field. I congratulate Professor Mushahid Husain and Dr. Zishan Husain Khan for their initiative in bringing out this document. Besides a chapter on the fundamentals of nanomaterials, this book has covered several important topics in this field. The latest developments in carbon-based nanomaterials such as graphene, carbon nanotubes, and their applications have been included. Metal matrix nanocomposites for control of corrosion and metal oxides are important topics that have been discussed. A chapter deals with silicon nanowire arrays for solar cell applications. Grinding is a major industrial area, which has wide ranging applications from most advanced mechanical engineering to building constructions. Applications of nanodiamond grinding from industrial perspective have been included. Nanolayers of materials such as gallium nitride are widely used for fabrication of solid-state light-emitting diodes. Epitaxial growth of GaN layers is the subject of one of the chapters. Several important applications of nanomaterials in different biomedical areas have been discussed. These include application of gelatin nanoparticles and exploring graphene for drug delivery and study of antibacterial properties of nanomaterials. One of the chapters deals with optical coherence tomography as glucose sensor in blood.

In the end, I thank all the authors who have contributed articles reviewing fundamentals and applications in different aspects of nanomaterials. Several of them are well-recognized experts. I highly appreciate the efforts of editors Prof. Mushahid Husain and Dr. Zishan Husain Khan for contributing important knowledge and in bring out this book. I hope this book will be widely used as a reference by experts as well as beginners in the field.

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Preface

Evolution is an ongoing process that replaces what is existing gradually with something better. With the rapid development in the field of nanomaterials, it would not be wrong if we call this time of rapid evolution, the Nano Era. Nanomaterials are one of the most significant research areas to emerge in the past decade or so. It is an interdisciplinary field that draws on knowledge and expertise and covers a vast and diverse array of devices derived from engineering, physics, chemistry, and biology. As the research on nanomaterials matures, an increasing number of applications become commercially viable. Numerous approaches have been utilized in successfully developing different types of nanomaterials, and it is expected that with advancement of technology, new approaches may also emerge. The approaches employed thus far have generally been dictated by the technology available and the background experience of the researchers involved. It is a truly multidisciplinary field involving chemistry, physics, biology, engineering, electronics, and social sciences, which need to be integrated together in order to generate the next level of development in nanomaterials research. The "top-down" approach involves fabrication of nanomaterials via monolithic processing on the nanoscale and has been used with spectacular success in the semiconductor devices used in consumer electronics. The "bottom-up" approach involves the fabrication of nanomaterials via systematic assembly of atoms, molecules, or other basic units of matter. This is the approach nature uses to repair cells, tissues, and organ systems in living things and indeed for life processes such as protein synthesis. Tools are evolving which will give scientists more control over the synthesis and characterization of novel nanostructures yielding a range of new products in the near future. There are many applications of nanomaterials which are still in the realm of scientific fiction and will be made possible in the near future. Every day, the research on nanomaterials is enriched with new innovations/discoveries and scientists are putting serious efforts in bringing out more advancement to this research field.

This book includes some of the latest advancements and applications in the field of nanomaterials. It provides an overview of the present status of this rapidly developing field. The book includes twelve chapters authored by the experts in the

field of nanomaterials and applications. Chapter 1 is an introductory chapter and presents an introduction of nanomaterials. It presents an overview of nanomaterials, their classification, different methods of synthesis of nanomaterials, and potential applications. Chapter 2 shows the significant progress made in the field of carbon nanomaterials specifically carbon nanotubes (CNTs). This chapter summarizes various fabrication techniques, characterization, and potential applications of carbon nanomaterials. It includes various methods to fabricate CNT fibers or yarns via spinning from CNT solutions, spinning from vertically aligned CNT arrays on substrates, direct spinning from CNT aerogels synthesized in chemical vapor deposition (CVD) chambers, spinning from cotton-like precursors, spinning with dielectrophoresis and rolling from CNT films/sheets. The chapter also provides the difference among thin films composed of free standing CNTs of different thicknesses known as membranes, sheets, buckypapers or papers. It also presents a brief discussion about 3D nanomaterials based on CNTs that include bulks, foams, and gels.

Chapter 3 summarizes the significant development in theoretical and experimental study of doped graphenes. The chapter discusses various doping methods, doping levels, heteroatom sources, chemical bond structures between heteroatom and graphene, their synthesis by several techniques such as thermal CVD, arc discharge approach, graphite oxide post-treatment, and plasma treatment synthesis. It also includes important properties such as electrical stability, quality of doped material, and technological applications.

Chapter 4 discusses the effect of varying size from chalcogenides to nanoscale chalcogenides, i.e., nanochalcogenides on physical properties of chalcogenides. It presents a brief discussion of methods for preparation of chalcogenide thin films via physical vapor condensation, sputtering, pulsed laser deposition, and chemical vapor deposition. Various models such as CFO model and Davis–Mott model for describing the electrical properties of nanochalcogenides have been discussed briefly in this chapter. It also includes the optical and thermal properties of nanochalcogenides. The applications of chalcogenides in memories based on phase change and electrical switching has also been discussed in detail in this chapter.

Chapter 5 presents a review on metal oxide nanostructures, their growth, and applications. The chapter includes the introduction of metal oxide nanostructures with chemical growth process CVD technique. The growth of indium oxide nanostructures with effect of ambient conditions such as tunable growth of nanowires, nanotubes, and octahedrons, effect of time, pressure, gas flow dynamics has been discussed in this chapter. This chapter also includes the growth of 3-D indium zinc oxide and gallium oxide nanostructures. Finally, the applications of metal oxide nanostructures such as environmental sensors and photodetector have been discussed in detail at the end of this chapter.

Chapter 6 gives an overview on metal matrix nanocomposites and their applications in corrosion control. The chapter includes the introduction of nanocomposites, its various types such as CMNCs, MMNCs, and PMNSCs. Solid- and liquid-state methods for synthesizing routes for fabrication of nanocomposites have been described in this chapter. This chapter also discusses major application of

nanocomposites mainly corrosion and its various forms, mechanism, calculation, and control of corrosion.

Chapter 7 describes the process of diamond nanogrinding. The chapter includes the principle of the process of nanogrinding using coated piezoelectric materials. The chapter also discusses about the bonds in porous tools engineered to minimize abrasive grain loss and the ways to process the vitrified bonding bridges using a laser to form extremely sharp nanoscale cutting wedges.

Chapter 8 presents the epitaxial growth of GaN layer by using laser molecular beam epitaxy technique. It includes the structural and optical properties of the epitaxial GaN layers by using HRXRD, AFM, FTRAMAN, SIMS, and Pl spectroscopy techniques.

Chapter 9 presents a review on aperiodic SiNWs array fabrication by silver-assisted wet chemical etching method. The chapter includes the light trapping properties of aperiodic SiNWs array and PV applications with emphasis on SiNWs array-based solar cells. This chapter also discusses the challenges in use of SiNWs arrays in PV devices and its future perspective.

Chapter 10 presents the recent trends in gelatin nanoparticles (GNPs) and its biomedical applications. It includes chemical structure, methods used to synthesize GNPs and the characterization of these GNPs by SEM, AFM, and HRTEM. The use of GNPs for target delivery of drug and gene for a range of diseases such as cancer, malaria, and infectious diseases has also been included in this chapter. It also discusses ocular, pulmonary drugs delivery as well as nutraceutical, proteins, peptides delivery and their application in tissue engineering.

Chapter 11 presents the studies on graphene and its application in drug delivery. The chapter gives a brief introduction of method of synthesis and functionalization of graphene and deals with the applications of graphene in medicine and biomedical.

Chapter 12 describes the optical coherence tomography (OCT) as glucose sensor in blood. The chapter includes basic principle of OCTs and application of OCT for glucose monitoring. This chapter describes the use of OCT technique for measuring glucose in liquid phantoms, whole blood (in vitro *and* in vivo) based on temporal dynamics of light scattering.

Mushahid Husain
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We sincerely offer our gratitude to the authors, who have contributed to this book for their comprehensive coverage of current research in the exciting area of nanotechnology that fulfill a wide variety of application in nanomedicine, nanoelectronics, and renewable energy.

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We take this opportunity to express our deep sense of gratitude to Prof. Vikram Kumar, Former Director, National Physical Laboratory, New Delhi (India), for his constant support and encouragement for establishing nanotechnology research in Jamia Millia Islamia.

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support of University Grants Commission, Government of India, is a landmark and inspired us to excel the higher impacted research in nanotechnology. The world-class facilities established in this center with the untiring efforts of one of the editors, Prof. Mushahid Husain, are praiseworthy and provided a huge platform for nanotechnology researchers at the university to utilize them for benefit of the institution as well as society.

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Editors and Contributors

About the Editors

Prof. Mushahid Husain is the vice-chancellor of M.J.P. Rohilkhand University, Bareilly. Formerly, he was a senior professor and director in "Centre for Nanoscience and Nanotechnology" at Jamia Millia Islamia (Central University), New Delhi. He has been instrumental in starting M.Tech. Nanotechnology course in 2007 in Jamia Millia Islamia. Professor Husain has completed several major research projects on amorphous semiconductors funded by various government agencies such as DST and DRDO. He has been a vice chairman of Semiconductor Society of India for two consecutive terms (1999–2003). He is also holding various positions in different academic societies. In addition, he also held the office of the vice president of Indian Physical Society during the session 1990–1992. At present, he is the president of Society for NanoScience and Technology and secretary of one of the prestigious "Society for Semiconductor Devices." He has made about 27 foreign visits including University of Cambridge—UK; University of Southampton—UK; University of Princeton, New Jersey; and ICTP, Italy; UNAM, Mexico; SIRIM, Malaysia; National University, Singapore; National Tsing Hua University, Hsinchu, Taiwan; US Naval Research Laboratory, Washington, DC, and University of Arkansas, Fayetteville, where he had delivered lectures. He has delivered 111 invited talks at national and international forums. A number of popular talks on All India Radio and the National TV Channel (Doordarshan) have also been presented by him. Professor Husain has about 182 research papers in reputed international journals to his credit. He has produced 36 Ph.Ds. He has also edited one book on "Advances in Physics of Materials."

Zishan Husain Khan is working as an associate professor (applied physics) in the Department of Applied Sciences & Humanities, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi-110025 (India). He specializes in nanotechnology with special emphasis of carbon nanotubes, semiconducting nanostructures, and nanochalcogenides. His work on the fabrication of a FET based on an individual carbon nanotube using e-beam lithography and its I–V

characteristics was significant. He also studied the electrical transport properties and field emission properties of bulk carbon nanotubes. Dr. Khan has also contributed significantly in the field of oxide semiconductors and synthesized ZnO nanostructures for various applications. His contribution in the field of carbon nanotubes-based sensors is notable. His recent work on OLEDs based on the organic semiconductors and nanomemory devices based on the nanochalcogenides is expected to have significant impact on emerging field of nanotechnology. Dr. Khan has earned his Ph.D. on amorphous semiconductors from Jamia Millia Islmia, New Delhi-110025 (India) in 1996. He joined as a postdoctoral researcher at the Center of Nanoscience and Nanotechnology, National Tsing Hua University (NTHU), Hsinchu, Taiwan in December 2001 and continued there up to February 2005. While pursuing his postdoc, Dr. Khan worked extensively on different types of nanostructures with special focus of carbon nanotubes. He has published around 84 research papers in outstanding and high impact factor journals and made over 40 presentations in conferences and symposia, which includes invited talks in the conferences. Dr. Khan has been one of founder members of Center of Nanotechnology, King Abdulaziz University, Jeddah, Saudi Arabia). He has been the guest editor of International Journal of Nanoparticles (UK), International Journal of Nano-Biomaterials (UK), International Journal of Nanomanufacturing (UK), Journal of Nanomaterials (USA), and Advanced Science Letters (USA). He is also a regular reviewer of many reputed international journals.

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