Textbook of

Nanoscience
and
Nanotechnology
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Foreword

The emergence of nanoscience and nanotechnology has opened a myriad possibilities to revolutionize a wide range of fields ranging from cosmetics to space technologies; there are also important contributions to diagnostics and therapeutic practices, especially for treating cancer. Nanoscience is also making a difference in many areas of engineering and technology, such as energy environmental pollution control, textile, automobile and electronics. Nanoscience and nanotechnology combine the essence of knowledge in many fields of science and are truly interdisciplinary. There is little doubt that the next generation of citizens will be the beneficiaries of the applications of nanoscience and nanotechnology in their daily life. It is, therefore, vital to have adequate awareness of this important field, irrespective of the specialization or profession that one may choose.

This book presents a fine insight into many aspects of nanoscience and their applications in engineering. The book has been written from the perspective of materials scientists, but the presentation is lucid and simple and easily understandable by beginners and undergraduate students. The valuable experience of the authors as teachers and scientists is borne out by the balanced perspective provided by the text. While emphasizing the applications of nanotechnology that are yet to be explored, the authors have also indicated possible issues related to environmental and ecological concerns.

I trust that students, research scholars and teachers will find this book a useful introduction to nanoscience and nanotechnology.

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Preface

The impact of anything associated with ‘nano’ can be compared to Vamana, a well-known figure in Indian Mythology; though diminutive in size, he encompassed the entire universe with one tiny step! Similarly, nanoscience’s omnipresence can be felt in almost all fields of engineering and technology. Since the Industrial Revolution, Manhattan Project (utilization of nuclear energy), deployment of Sputnik (led to space exploration) and ARPANET (resulted in information explosion), it is the only science that has brought together people of different fields, making it truly inter-disciplinary. ‘Nano’ as a term is no longer restricted to research laboratories and institutes; it is seen everywhere, in applications ranging from consumer goods such as toothpaste, wall paints, water purifiers and refrigerators to sophisticated applications such as catalysis, sensors and electronics.

Though many books on nanoscience and nanotechnology are available, very few have been written with the beginner in mind. This book attempts to bridge this gap. The presentation is kept simple so that beginners and undergraduate students will be able to understand and obtain a good overview of the subject. To kindle interest in this field in the minds of the readers, brief biographical sketches of people who contributed significantly to this field have been given. Students and research scholars in this field will find this book immensely useful. The science and technology of regulating the controlled application of this revolutionary technology for restraining the negative impacts is perhaps going to be the biggest challenge of the future.

The first chapter introduces the reader to the nano-world and brings out the exciting developments in this field. The second chapter identifies the unique properties of materials at the nanoscale. The synthesis routes, both bottom-up and top-down, have been discussed briefly in the third chapter. The applications of nanomaterials, ranging from medical to electronic, have been highlighted in the fourth chapter. The fifth chapter gives a brief description of the various tools used to characterize materials at the nanoscale. The most widely studied nanostructures such as quantum dots, carbon nanotubes, fullerenes and graphenes, nanowires, etc., are presented in the sixth chapter. The last chapter brings out the health hazards related to nanomaterials.

In this book, we have made special efforts to showcase the contributions of Indian scientists in the field of nanoscience and nanotechnology. We are grateful to Dr N Ravisankar, IISc Bangalore, Dr Bhaskar Majumdar, DMRL, Hyderabad, Prof. V Ramgopal Rao, IIT Bombay, Prof. M S Ramachandra Rao, Prof. Uday Chakkingal, Prof. T S Sampath Kumar and Dr R Sarathi, IIT Madras, who have contributed their research work to enrich this book. Prof. Murty would specially like to thank his research scholars, both past and present, Joydip, Monikanchan, Kallol, Venugopal, Parashar, Barua, Sashank, Jatin, Varalakshmi, Shanmugasundaram, Udhayabanu, Srinivasulu, Ajeet, Ramakrishna, Murugan, Praveen Kumar, Karthikeyan, Anisha, Praveen, Susila and Prakash, all of who have significantly contributed to this field and enriched his knowledge. Some parts of their work have been referred to in this book, which is gratefully acknowledged. Discussions and associations with experts in this field, such as Profs S Ranganathan, K Chattopadhyay, T Pradeep, S Ramaprabhu, S K Das, I Manna, S K Pabi and C Suryanarayana, and Drs A K Tyagi, G K Dey and B L V Prasad, are gratefully acknowledged.
The authors acknowledge the enthusiastic support and meticulous editorial coordination of Universities Press at various stages of the preparation of the book. A special word of appreciation to Ms Javanthi Singaram and Ms Madhavi Sethupathi for their untiring editorial support. We welcome suggestions from readers towards improvements that can be incorporated in future editions of this book.

B S Murty, P Shankar, Baldev Raj, B B Rath and James Murday
About the Series

The study of metallurgy and materials science is vital for developing advanced materials for diverse applications. In the last decade, the progress in this field has been rapid and extensive, giving us a new array of materials, with a wide range of applications, and a variety of possibilities for processing and characterizing the materials. In order to make this growing volume of knowledge available, an initiative to publish a series of books in Metallurgy and Materials Science was taken during the Diamond Jubilee year of the Indian Institute of Metals (IIM) in the year 2006. As part of the series we have already brought out five books, and all of them have been copublished by CRC Press, USA, for distribution overseas. This is the sixth book in the series and the second textbook to be published.

The IIM is a premier professional body representing an eminent and dynamic group of metallurgists and materials scientists from R&D institutions, academia and industry in India. It is a registered professional institute with the primary objective of promoting and advancing the study and practice of the science and technology of metals, alloys and novel materials. The institute is actively engaged in promoting academia–research and institute–industry interactions.

Universities Press, an associate of Orient Blackswan, with its long tradition of publication of quality books in engineering and sciences, has come forward to undertake the publication of this series, thus synergising the professional expertise of IIM with the publishing experience of Universities Press towards effective knowledge dissemination. This book series shall include different categories of publications: textbooks to satisfy the requirements of undergraduates and beginners in the field, monographs on select topics by experts in the field, and proceedings of select international conferences organized by IIM after mandatory peer review. To increase the readership and to ensure wide dissemination, some of the books in the series will be copublished with international publishers.

The international character of the authors and editors has helped the books command a global readership. An eminent panel of international and national experts acts as the advisory body in overseeing the selection of topics, important areas to be covered, and the selection of contributing authors. These publications are expected to serve as a source of knowledge to a wide spectrum of students, engineers, researchers and industrialists in the field of metallurgy and materials science. I look forward to receiving your valuable response to the present book as well as the other books in the series.

Baldev Raj
Editor-in-Chief
About the Authors

B S Murty, Professor, Department of Metallurgical and Materials Engineering, IIT Madras, Chennai, India, has pioneered the synthesis of nanomaterials by high-energy ball milling/mechanical alloying route and has also made significant contributions to the field of bulk metallic glasses and their nanocrystallization. His other fields of interest are in-situ composites and metal foams.

P Shankar, Principal, Saveetha Engineering College, Chennai, India, is a prolific researcher and teacher with National and International credentials. As senior research scientist at the Department of Atomic Energy, he made several pioneering contributions in the field of characterization of advanced nuclear materials and in the development of novel surface engineering processes that are being used in our nuclear reactors.

Baldev Raj, President–Research, PSG Institutions, Coimbatore, India, has made pioneering contributions in the area of non-destructive characterization, evaluation of defects, microstructures and stresses in structural and strategic materials. His contributions also encompass the design and development of nuclear materials such as austentic steels, low-activation martensitic/ferritic steels and nuclear fuels, which have a wide range of applications in fission and fusion reactors, advanced clean energy systems and aerospace structures. He is a leading authority in materials, welding, corrosion and structure–property correlation studies. His work in nanoscience and technology relates to nanofluids, nanosensors and coatings.

Bhakta B Rath, Associate Director, Materials Science and Component Technology Directorate, Naval Research Laboratory, Washington DC, USA, is an educator, researcher and administrator. His research interests are in the fields of solid state transformations and structure–property relationships. He serves on the planning and advisory boards of a number of US Government agencies, academies and universities.

James S Murday, Director of Physical Sciences, University of Southern California’s Research Advancement Office in Washington DC, USA, led the Naval Research Laboratory’s Chemistry Division for twenty years. He served as Director of the US National Nanotechnology Coordination Office in 2001–2002 and as Executive Secretary to the US National Science and Technology Council’s Subcommittee on Nanometer Science Engineering and Technology (NSET) in 2001–2006.
List of Colour Plates

Plate 1  
Fig. 1.3 : Colours of stained glass panels  
Fig. 1.4 : Supported lipid bilayer formation

Plate 2  
Fig. 1.5 : Nanoshells designed to absorb various wavelengths of light  
Fig. 1.6 : Famous 4th century Roman cup

Plate 3  
Fig. 1.17 : Schematic illustration of nanotubes  
Fig. 1.21 : Nanotechnology in nature

Plate 4  
Fig. 2.6 : Grain growth restriction in Cu–W nanocomposites  
Fig. 2.19 : Image of Don Quixote

Plate 5  
Fig. 5.4 : Ray diagrams for SEM and TEM  
Fig. 5.10 : AFM image of a Cu–Ta nanocomposite

Plate 6  
Fig. 5.12 : The principle of FIM  
Fig. 6.2 : CdSe NCQDs that fluoresce into different colours

Plate 7  
Fig. 6.7 : Ball–stick model of a nanotube

Plate 8  
Image of Barak Obama produced using nanoparticles
## Contents

**Foreword**  
**Preface**  
**About the Series**  
**List of Editors**  
**About the Authors**  
**List of Colour Plates**

### 1. The Big World of Nanomaterials

1.1 History and Scope  3  
1.2 Can Small Things Make a Big Difference?  8  
1.3 Classification of Nanostructured Materials  10  
1.4 Fascinating Nanostructures  13  
1.5 Applications of Nanomaterials  17  
1.6 Nature: The Best Nanotechnologist  22  
1.7 Challenges and Future Prospects  25

### 2. Unique Properties of Nanomaterials

2.1 Microstructure and Defects in Nanocrystalline Materials  29  
2.2 Effect of Nano-dimensions on Materials Behaviour  36

### 3. Synthesis Routes

3.1 Bottom-Up Approaches  67  
3.2 Top-Down Approaches  85  
3.3 Consolidation of Nanopowders  100

### 4. Applications of Nanomaterials

4.1 Nano-electronics  108  
4.2 Micro- and Nano-electromechanical systems (MEMS/NEMS)  118  
4.3 Nanosensors  119  
4.4 Nanocatalysts  131
Contents

4.5 Food and Agriculture Industry 134
4.6 Cosmetics and Consumer Goods 135
4.7 Structure and Engineering 136
4.8 Automotive Industry 137
4.9 Water Treatment and the Environment 138
4.10 Nano-medical Applications 139
4.11 Textiles 140
4.12 Paints 141
4.13 Energy 142
4.14 Defence and Space Applications 143
4.15 Structural Applications 146

5. Tools to Characterize Nanomaterials 149
5.1 X-ray Diffraction (XRD) 150
5.2 Small Angle X-ray Scattering (SAXS) 151
5.3 Scanning Electron Microscopy (SEM) 152
5.4 Transmission Electron Microscopy (TEM) 155
5.5 Atomic Force Microscopy (AFM) 159
5.6 Scanning Tunnelling Microscope (STM) 165
5.7 Field Ion Microscope (FIM) 169
5.8 Three-dimensional Atom Probe (3DAP) 170
5.9 Nanoindentation 172

6.1 Quantum Dots 176
6.2 Carbon Nanotubes 182
6.3 GaN Nanowires 196
6.4 Nanocrystalline ZnO 198
6.5 Nanocrystalline Titanium Oxide 207
6.6 Multilayered Films 210

7. Concerns and Challenges of Nanotechnology 214

Glossary 225
Index 231
Chapter 1

The Big World of Nanomaterials

Learning objectives

- Introduction to nanocrystalline materials
- Brief history of research in nanomaterials
- Exciting developments in the science and technology of nanomaterials
- Classification of nanomaterials

Materials have been of great interest to human beings since time immemorial. A few million years ago, it was found that rocks could be used to break things that were impossible to break with bare hands. Stones were the first tools and even today they are still in use in kitchens and laboratories to pound and grind, or as mortars and pestles. Around 5000–6000 years ago, it was accidentally discovered that when a rock containing copper was placed on a fire, molten copper could be collected. This discovery led to the reduction of metal ores to produce metals for the fabrication of items from ploughshares to swords. New materials with greater hardness and longer use than stone became available for making tools. Our growth and progress have paralleled the development of metals and metallurgy.

Traditionally, civilizations were named after the metals or materials used. Thus, we have the Stone Age, Bronze Age and Iron Age (Fig. 1.1). The current age is driven by the applications

Fig. 1.1  Materials evolution—from the Stone Age (a) to the Space Age (b)

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