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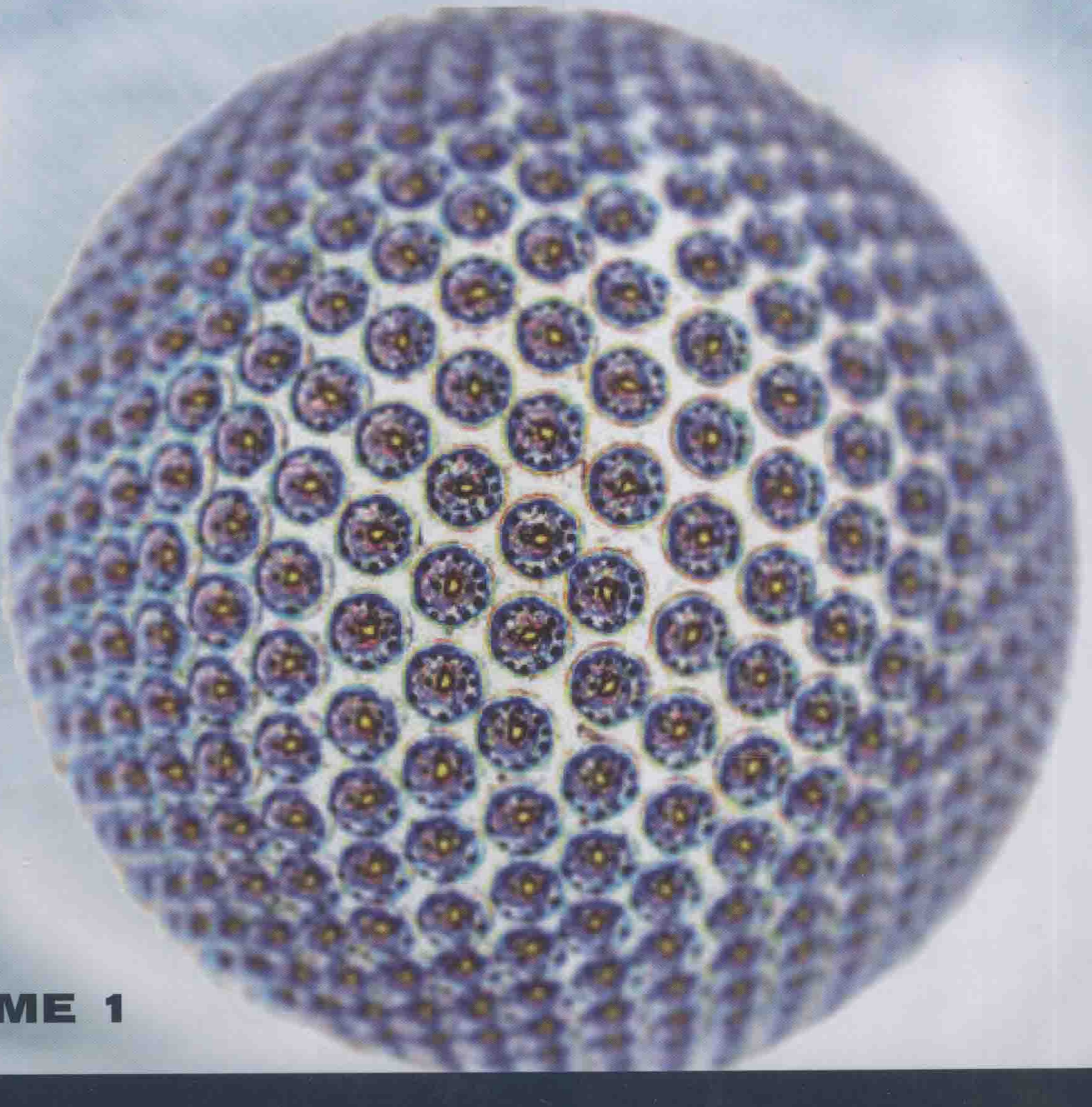

VOLUME 1

COMPREHENSIVE NANOSCIENCE AND TECHNOLOGY

NANOMATERIALS

COMPREHENSIVE NANOSCIENCE AND TECHNOLOGY

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Volume 1

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COMPREHENSIVE NANOSCIENCE AND TECHNOLOGY

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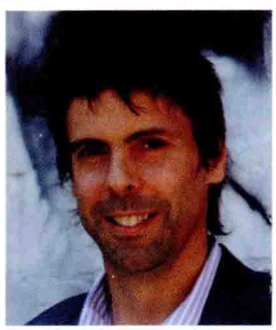

Greg Scholes is a Professor at the University of Toronto in the Department of Chemistry. His present research focuses on elucidating the principles deciding electronic structure, optical properties, and photophysics of nanoscale systems by combining synthesis, theory, and ultrafast laser spectroscopy. Recent awards honoring his research achievements include election to the Academy of Sciences, Royal Society of Canada in 2009, the 2007 Royal Society of Canada Rutherford Medal in Chemistry, a 2007 NSERC Steacie Fellowship, the 2006

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Gary Wiederrecht is the Group Leader of the Nanophotonics Group in the Center for Nanoscale Materials at Argonne National Laboratory. His research interests center on the photochemistry and photophysics of nanoparticles and periodic assemblies, hybrid nanostructures, photochemical energy conversion, and non-linear optical responses resulting from photoinduced charge separation. His experimental expertise is in the areas of ultrafast optical spectroscopy and scanning probe microscopy, including near-field scanning optical microscopy. He has received an R&D100 award, the Department of Energy Young Scientist Award, and the Presidential Early Career Award for Scientists and Engineers. He has authored or co-authored approximately 80 peer-reviewed research articles, and works collaboratively with scientists around the world. He enjoys traveling, nature, and spending time with his family.

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Preface

Volume 1: Nanomaterials

This volume considers the enormous and significant changes that have occurred in the recently emergent and now rapidly maturing fields of organic and inorganic nanomaterials. Neatly bridging the gap between nanoscience and nanotechnology, such materials now find application from functional materials in electronics, photonics and spintronics, through energy conversion and storage materials to structural materials and nanocomposites. The themes explored in this volume are dominated by the former two categories of nanomaterials and the fertile border territory between nanoscale condensed matter physics, chemical nanoscience, and nano-fabrication and nano-engineering.

The field of organic optoelectronics has progressed enormously in recent years as a result of frenetic activity in many research groups around the world. Major advances have been made both in the fields of device science and fabrication, as well as in the underlying chemistry, physics, optics, and materials science. The impact of this field continues to influence many adjacent disciplines – and especially nanomaterial technology, the focus of this volume. The first six chapters demonstrate how advances in organic optoelectronic materials have inspired a vital and growing interest in fundamental organic materials research – notably in connection with carbon nanotubes – that could potentially revolutionize a range of future applications. Examples in the area of organic nonlinear optics are discussed by Jang and Jen (Chapter 1.06). It is expected that the present worldwide funding in this field will stimulate a major research and development effort in organic materials research for lighting, photovoltaics, spintronics, and other optoelectronic applications. Organic light-emitting diodes (OLEDs), described by Shinar and Shinar (Chapter 1.04), were introduced to the scientific community about two decades ago and permeated to the market about ten years later. A bright future awaits organic white-light-emitting diodes, which are emerging as viable replacements for the classic Edison-type light bulb. It is salutary to remember that laser action in organics, a subject addressed by Polson and Vardeny (Chapter 1.03), was first revealed as recently as 1996. The initial enthusiasm paved the way for current, realistic expectations on the fabrication of current-injected organic laser action.

Until a few years ago, electron spin was ignored in organic electronics. However, in 2002, with the achievement of substantive magnetoresistance in a two-terminal organic device at room temperature, a new field was born, namely organic spintronics (Chapter 1.05). The associated technology of spin-based electronics, where carrier spin is used as information carrier in addition to charge, offers opportunities for a new generation of electronic devices that combine standard microelectronics with spin-dependent effects arising from interactions between the carrier spin and externally applied magnetic fields. Adding the spin degree of freedom to more conventional charge-based electronics should substantially increase the functionality and performance of electronic devices.

Semiconductor nanocrystals (or quantum dots) play a dominant role in the field of inorganic nanomaterials. Their size-dependent optical properties and the wide variety of available materials and synthesis methods make them ideal candidates for the study of mesoscopic phenomena. Moreover, they have a broad range of applications in fields as diverse as bioimaging or lasing. Four chapters of this volume are dedicated to semiconductor nanocrystals and their properties: Vukmirović and Wang (Chapter 1.07) introduce the theory. The following chapter (Chapter 1.08) on wet-chemical synthesis and characterization has a strong emphasis on the frequently used II_B/VI semiconductors. Manna *et al.* cover all of the relevant synthesis methods, including timely approaches such as continuous flow synthesis or thermospray methods. This chapter is concluded with a comprehensive discussion on the most important characterisation methods. The epitaxial growth of additional shells onto quantum dots (and other nanoparticles) is an important field in its own right.

Building on the fundamentals introduced in the previous contribution, Parak *et al.* (Chapter 1.09) describe methods for the growth of inorganic shells onto (primarily semiconductor) nanocrystals. They particularly focus on the physical properties of different types of semiconductor core/shell structures, which differ significantly from core-only nanocrystals. Finally, the important issue of shape control is discussed. Next, Kambhampati *et al.* (Chapter 1.15) discuss semiconductor nanocrystals. Their chapter is primarily dedicated to the optical and physical properties of quantum dots, and also takes into account assemblies of these nanoparticles. The chapter concludes by introducing devices to use/characterize quantum dot-based structures. Silicon nanostructures differ slightly from typical quantum dots, since their optical properties are not dominated by band-gap luminescence, but by defect photoluminescence. Chao (Chapter 1.16) discusses the fabrication and properties of both, porous silicon and silicon nanoparticles. As with II_B/VI quantum dots, optical properties dominate the physics of these particles.

The role of anisotropy in inorganic nanomaterials is never more profoundly exhibited than in the existence of nanowires and nanotubes. Rao *et al.* (Chapter 1.10) discuss the multitude of inorganic compounds that can now be synthesized as solid (filled) one-dimensional structures on the nanoscale. Examples are drawn from elemental and alloyed metals through oxides to nitrides, chalcogenides, and beyond. The importance of the evolving approaches of the synthetic chemist in this ongoing discovery process are highlighted as are the many characterization techniques and tools now available that have made this discovery possible. Finally, the myriad of useful, and at times unexpected, properties from such structures are discussed in depth. These range, for example, from high tensile strength fibers, through conducting wires, nanoscaled arrays of photovoltaics and electrode materials, to light-emitting diodes and nanocomposites. The special case of inorganic nanotubes is considered in the chapter by Remskar (Chapter 1.11). The author draws initial parallels with the carbon nanotubes which preceded documented inorganic examples only by a year or so. The chapter highlights that, despite ostensible similarities, the growth mechanisms of inorganic nanotubes are profoundly different from their carbon brethren. Further, the compositional range afforded by combining many different elements across the periodic table in nanotubular forms, gives rise to a wide range of contrasting properties that might find potential application as lubricants, inert reaction vessels, or drug delivery systems.

Four more chapters of this volume are dedicated to specific inorganic nanoparticles. Yi *et al.* (Chapter 1.12) focuses on the extraordinary opportunities afforded by zinc oxide nanorods for electrical and optical nanodevice applications – significant examples including field-effect transistors and logic gates. Chapter 1.13 then deals with noble metal nanoparticles, Chapter 1.14 with magnetic nanocrystals, and Chapter 1.18 with rare-earth doped particles. Hubenthal starts Chapter 1.13 with a comprehensive introduction to the optical properties specific for metal nanoparticles. The synthetic methods for these particles include both top-down and bottom-up approaches, the latter further subdivided into gas-phase and wet-chemical methods. A variety of applications is envisaged. Magnetic nanoparticles also have a high potential for commercial applications – they are already used in many fields, such as contrast agents for magnetic resonance imaging. Mørup *et al.* (Chapter 1.14) introduce and discuss the properties of these materials , including important issues such as superparamagnetism, magnetic fluctuations, and anisotropy. This chapter concludes with a discussion of several applications of magnetic nanocrystals and their occurrence in nature.

With much of the synthetic effort in nanoscience relating directly or indirectly to solar energy, it is not surprising to find solar cell and photocatalytic objectives driving much of the current effort in both bottom-up and top-down nanostructure fabrication. Nosaka (Chapter 1.17) surveys a field in which numerous nanotechnological motifs are already deployed, including dye and plasmon sensitization, and the incorporation of quantum-well and quantum-dot components. Up-converting nanoparticles have a huge potential for applications in bioimaging, cancer therapy and electro-optics, although the preparation of highly luminescent up-converting nanoparticles is still challenging. Wang and Liu (Chapter 1.18) give a comprehensive overview of synthesis methods and applications of this class of nanomaterials. The chapter especially highlights current challenges such as colour tuning and surface modification.

The range of topics in this volume attests to the grand breadth and scale of research and development activity in the field of nanomaterials. We gladly record our indebtedness to the numerous experts who have shared their vision of this rapidly growing area of nanoscience and technology.

Duncan H. Gregory, Thomas Nann, Zeev Valentine Vardeny and David L. Andrews

Foreword

Nanotechnology and its underpinning sciences are progressing with unprecedented rapidity. With technical advances in a variety of nanoscale fabrication and manipulation technologies, the whole topical area is maturing into a vibrant field that is generating new scientific research and a burgeoning range of commercial applications, with an annual market already at the trillion dollar threshold. The means of fabricating and controlling matter on the nanoscale afford striking and unprecedented opportunities to exploit a variety of exotic phenomena such as quantum, nanophotonic, and nanoelectromechanical effects. Moreover, researchers are elucidating new perspectives on the electronic and optical properties of matter because of the way that nanoscale materials bridge the disparate theories describing molecules and bulk matter. Surface phenomena also gain a greatly increased significance; even the well-known link between chemical reactivity and surface-to-volume ratio becomes a major determinant of physical properties, when it operates over nanoscale dimensions.

Against this background, this comprehensive work is designed to address the need for a dynamic, authoritative, and readily accessible source of information, capturing the full breadth of the subject. Its five volumes, covering a broad spectrum of disciplines including material sciences, chemistry, physics, and life sciences, have been written and edited by an outstanding team of international experts. Addressing an extensive, cross-disciplinary audience, each chapter aims to cover key developments in a scholarly, readable, and critical style, providing an indispensible first point of entry to the literature for scientists and technologists from interdisciplinary fields. The work focuses on the major classes of nanomaterials in terms of their synthesis, structure, and applications, reviewing nanomaterials and their respective technologies in well-structured and comprehensive articles with extensive cross-references.

It has been a constant surprise and delight to have found, among the rapidly escalating number who work in nanoscience and technology, so many highly esteemed authors willing to contribute. Sharing our anticipation of a major addition to the literature, they have also captured the excitement of the field itself in each carefully crafted chapter. Along with our painstaking and meticulous volume editors, full credit for the success of this enterprise must go to these individuals, together with our thanks for (largely) adhering to the given deadlines. Lastly, we record our sincere thanks and appreciation for the skills and professionalism of the numerous Elsevier staff who have been involved in this project, notably Fiona Geraghty, Megan Palmer, Laura Jackson, and Greg Harris, and especially Donna De Weerd-Wilson who has steered it through from its inception. We have greatly enjoyed working with them all, as we have with each other.

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