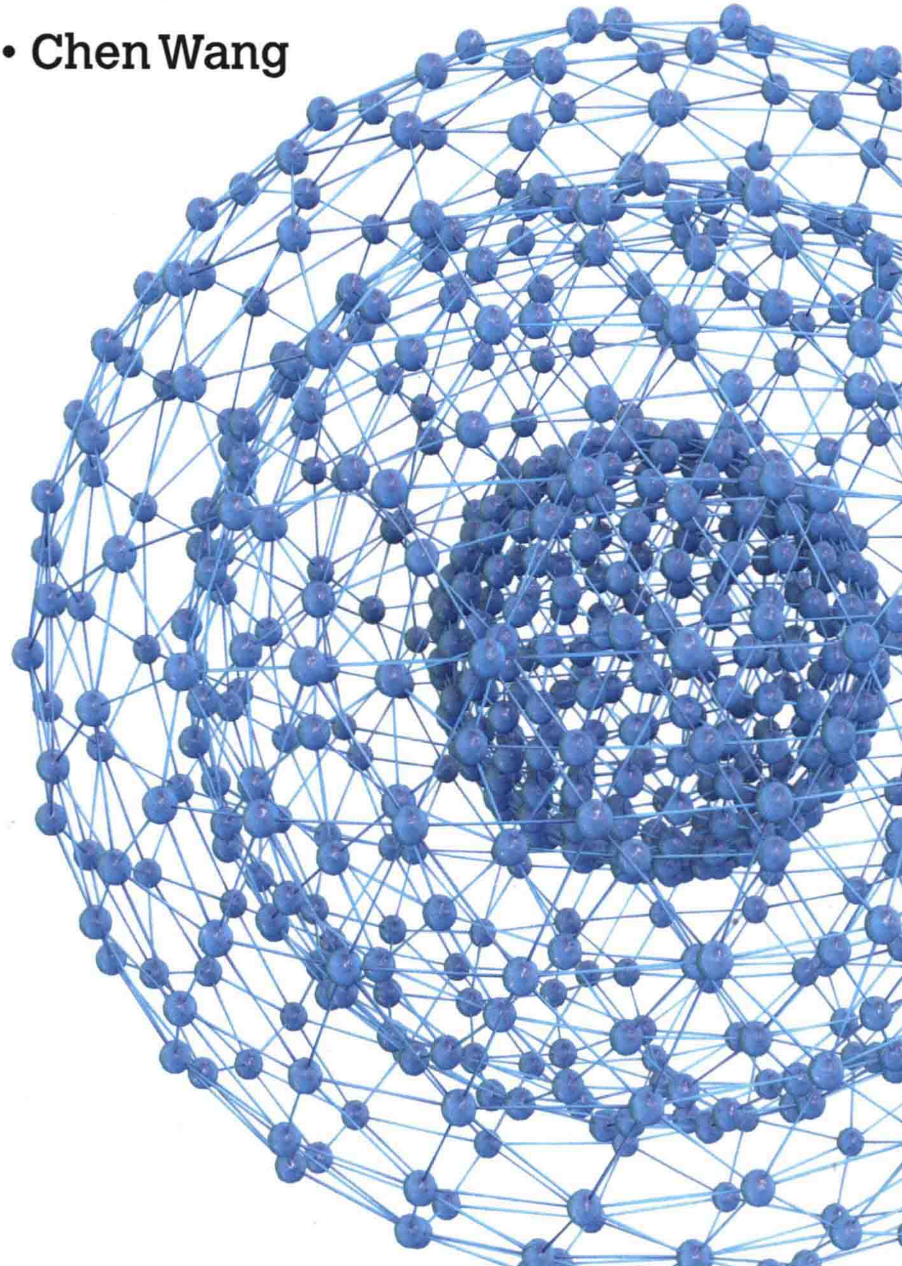
Molecular Nanostructure and Nanotechnology

Edited by
Chunli Bai • Chen Wang



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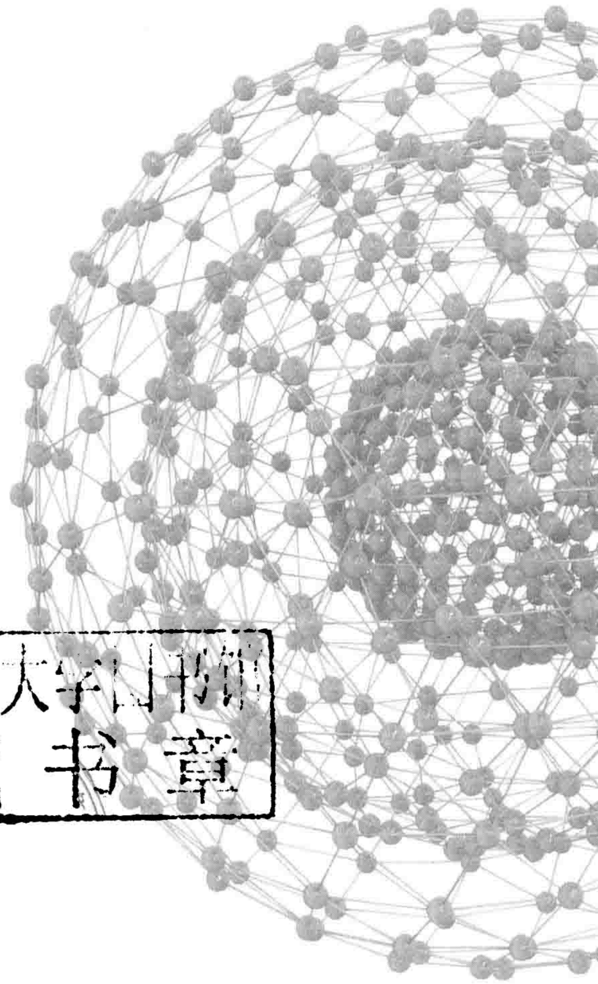

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Preface

This book was originally published as an issue of the *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* (371, 2000) but has been materially changed and updated.

Acknowledgments

After the appearance of the theme issue in 2013, we were encouraged to consider a book version of the updated collection of contributions. We are grateful for the communications with Professor Dave Garner of *Philosophical Transactions of the Royal Society A* and Dr. Merlin Fox of Imperial College Press that led to this book project. Also, we sincerely thank Professors Steven De Feyter and Thomas Russell and all of our Chinese colleagues for valuable contributions to, and creative scientific perspectives of, molecular nanostructures and nanotechnology presented in their works.

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About the Editors

Chunli Bai, Lead Editor, is Professor of Chemistry and President of the Chinese Academy of Sciences (CAS). He graduated from Department of Chemistry, Peking University in 1978, received his M.S. and Ph.D. degrees from CAS Institute of Chemistry in 1981 and 1985, respectively. During 1985-1987, he was at Caltech as a research associate. From 1991–1992, he was a visiting professor at Tohoku University in Japan. His research area involves the structure and property of catalysts, X-ray crystallography of organic compounds, molecular process and EXAFS research on electro-conducting polymers. Since the mid-1980s, he has shifted his research interests to the fields of scanning probe microscopy (SPM), single molecule, molecular nanostructure and self-assembly, molecular nanodevice, and novel nanomaterials. His scientific achievements include developing new technique and methodology, and their applications in molecular sciences. He is one of the pioneers in the field of scanning probe microscopy, nanoscience and nanotechnology in China. He has more than 350 scientific publications in refereed journals and authored 12 monographs and several book chapters in the field. He was elected a member of CAS and a fellow of the Academy of Sciences for the Developing World (TWAS) in 1997. He is also a foreign associate of the US National Academy of Sciences, foreign member of Russian Academy of Sciences, Foreign Fellow of the Royal Society, UK and honorary doctor or named fellowship in several universities of the USA, UK, Sweden, Denmark, Russia, Australia etc. He is a recipient of the UNESCO first medal "for contributions to the development of nanoscience and nanotechnology" (shared with Nobel Laureate Zhores Ivanovich Alferov), International Medal awarded by the Society of Chemical Industry (London-based) and the TWAS 2002 Medal Lecture in Chemical Sciences.

Chen Wang, Editor, is a professor in National Center for Nanoscience and Technology, China. He received his B.S. degree from University of Science and Technology of China in 1986, and obtained his Ph.D. from University of Virginia in 1992. His research focuses on surface physical chemistry and nano-bio interface, including the principle of scanning tunneling microscopy and its applications, molecular self-assembly, etc. In recent years, he has been engaged in the molecular mechanisms of peptide assembly and its modulation, and disease diagnosis and treatment based on peptide nanostructures. He has received several awards including National Outstanding Young Scientists Award of the NSFC. He has published more than 200 papers in international peer-reviewed journals, and four books which include Chinese and English versions.

Introduction

This book is based on the theme issue of ***Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*** that appeared in October 2013. The collection of chapters exemplifies the significant progress that has been made in our understanding of the formation and nature of molecular assemblies and the consequent construction of functional nanostructures. The diversity of nanostructures derived from molecular assemblies is a manifestation of a convergence of research interests in the physical, chemical, material and biological sciences. The discussions of the characteristics of the various molecular assemblies presented in this book reflect the diverse nature of the interactions between the various building blocks; this versatility leads to a wide variety of molecular nanomaterials which have a broad range of technological applications.

Molecular assembly is generally considered to be an ideal strategy when seeking to construct a functional nanostructure *via* a 'bottom-up' approach since this allows the incorporation of a rich variety of designed building blocks. The outcome of the molecular self-assembly process depends upon a variety of factors, including: the nature of the functional groups present on the assembling molecules; the temperature at which the molecules assemble; the environment in which the process occurs (*e.g.* ultra-high vacuum or solution) and the concentration of the building blocks (Mali *et al.*, Yan *et al.*). Therefore, each of these parameters can have a significant influence on the nature of the nanomaterial produced and be critical for the extent of its practical utility due to, for example, its magnetic (Wang *et al.*) or optical (Liu *et al.*) properties.

The intrinsic diversity in the chemical functionality of building blocks requires an understanding of the principles of assembly at all levels, *i.e.* from the molecules to the nanoparticles and beyond. Complementary interactions between building blocks are the major factor in determining the stability of a molecular assembly and are the key to understanding the nature of a phase-separated molecular assembly, the heterogeneity of structures in a multi-component assembly and the influence of the environment on the kinetics of product formation. A variety of intermolecular interactions, *e.g.* hydrogen bond, van der Waals force, covalent and coordinate bonds, have been employed successfully in the designed assembly of polymeric architectures. Hydrogen bonding has the advantages of selectivity and directionality and is an important interaction in many systems, *e.g.* those containing carboxylate groups, whilst van der Waals forces are the dominant interaction in the molecular interactions of molecules that involve a long linear alkane chain (Yan *et al.*). These interactions are faithfully reflected in the structural analysis of peptide assemblies relating to various degenerative diseases (Yang *et al.*).

The potential applications of molecular nanostructures are manifold and, as illustrated in this book, increasing rapidly. Block copolymers are showing considerable promise in photolithographic approaches to the generation of semiconductor devices that may lead to advances in computing power beyond those predicted by Moore's law (Gu *et al.*). Another promising application can be observed in the development of high efficacy drug delivery systems derived from controlled-release drugs encapsulated in polymeric micelles (Wang *et al.*). Also, RNA nanotechnology has emerged as a new field with the production of nanoparticles which show considerable promise in molecular-scale computing (Lee *et al.*). Microporous organic frameworks can possess a large internal surface area yet exhibit a high stability; some of these materials bind greenhouse gases from dry air (Pei *et al.*) and others have been used as the host of a dye in the photoanode of a solar cell (Liu *et al.*). With an amazingly rich variety of molecularly decorated nano/micro structures, the exploratory efforts in various environmental and chemical processes can be very rewarding (Zhao *et al.*). Further examples of the potential applications of molecular self-assembly in nanotechnology have arisen in the field of plastic electronics, including the construction of nanowires, field-effect transistors, photodetectors and optical waveguides (Xie *et al.*). The incorporation with novel nanostructures, such as conducting graphene for carbon electronic (Zhu *et al.*) and silicon nanowire-based sensory structures (Wang *et al.*), is key for developing novel devices based on molecular nanotechnology.

Thus, this dynamic field of interdisciplinary science is experiencing major developments and generating an exciting range of novel materials, many of which have exciting possible application implications. The dedicated efforts reflected in these contributions also indicated a number of genuine challenges towards tangible technological impacts. The fundamental insights of molecular nanotechnology for overcoming the limiting factors, such as control of assembly kinetics, stability of assembly architectures, availability of materials suitable for assembly processes, etc., will be key for shaping up the future trends in this field. We are confident that, for the foreseeable future, the advances achieved in the control of molecular assembly will continue, thereby generating new and strategically important applications of the resultant nanotechnology.

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