NanoScience and Technology

The series NanoScience and Technology is focused on the fascinating nano-world, mesoscopic physics, analysis with atomic resolution, nano and quantum-effect devices, nanomechanics and atomic-scale processes. All the basic aspects and technology-oriented developments in this emerging discipline are covered by comprehensive and timely books. The series constitutes a survey of the relevant special topics, which are presented by leading experts in the field. These books will appeal to researchers, engineers, and advanced students.

More information about this series at http://www.springer.com/series/3705

Quan Li
Editor

Anisotropic Nanomaterials

Preparation, Properties, and Applications

Springer

Editor
Quan Li
Liquid Crystal Institute
Kent State University
Kent, OH
USA

ISSN 1434-4904 ISSN 2197-7127 (electronic)
NanoScience and Technology
ISBN 978-3-319-18292-6 ISBN 978-3-319-18293-3 (eBook)
DOI 10.1007/978-3-319-18293-3

Library of Congress Control Number: 2015939641

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

Preface

Human civilization, from its beginning to date, has been fondly using wood for building home and furniture, and as a superior construction material. One of the hallmarks of wood's success is its "anisotropy" of strength and hardness in different directions/orientations. Hence wood represents an intrinsically anisotropic material in our natural environment, which candidly manifests the beneficial consequences of anisotropy in its properties. This anisotropy, i.e., the direction-dependency of physical properties, of such natural materials has inspired materials scientists and sparked the quest for anisotropic materials with useful properties. With such an inspiration, the scientists have ventured into the realm of nanometer length-scale and have been curiously exploring the anisotropic nanoscale building blocks such as metallic and nonmetallic particles as well as organic molecular aggregates. It turns out that anisotropic nanoscale building blocks, in addition to direction-dependent properties, exhibit the dimension and morphology dependence of physical properties. Anisotropic nanoparticles in particular display several spectacular unique and unusual properties owing to spatial confinement of electrons, photons, and electric fields around the particles as well as due to their large surface to volume ratio. These promising properties have qualified them as enabling building blocks of twenty-first century materials science, nanoscience, and nanotechnology. There has been tremendous development involving isotropic nanoparticles; however, anisotropic nanoparticles made of metals and metal oxides, etc., are emerging as a burgeoning endeavor because of their superior mechanical, electrical, magnetic, optical and chemical properties. Their applications have been demonstrated in electronics, photonics, biological and chemical sensing, imaging and drug delivery, etc. Owing to their preferred orientation and ordering, anisotropic nanoparticles can be organized into a multitude of well-defined higher-order assembled structures. Moreover, ordered arrays of anisotropic nanoparticles' assemblies furnish novel properties which are often distinctly different from the properties of individual building blocks. Thus unprecedented and synergetic properties are observed in numerous occasions resulting from the mutual cooperative interaction of individual components. On the other hand, anisotropic supramolecular nanostructures of organic molecular and macromolecular components are known to assemble into functional soft and dynamic architectures with applicable properties. These are easily processable and display greater response to smaller external stimuli thereby expanding their functionalities and controllability toward practical applications.

This book is not an attempt to exhaustively cover all the relevant topics on anisotropic nanomaterials as it is extremely difficult to do so within a single book. Instead, the book focuses on the recent developments of the most fascinating themes on anisotropic nanomaterials: preparation, properties, and applications. The various chapters cover the following contemporary topics: silicon nanowires: fabrication, devices and application (Chap. 1), methods and structures for self-assembly of anisotropic 1D nanocrystals (Chap. 2), anisotropic gold nanoparticles: preparation, properties, and applications (Chap. 3), synthesis and applications of solution-based II–VI and IV–VI semiconducting nanowires (Chap. 4), rare earth-based anisotropic nanomaterials: synthesis, assembly, and applications (Chap. 5), liquid crystalline anisotropic nanoparticles: from metallic and semiconducting nanoparticles to carbon nanomaterials (Chap. 6), self-assembled 1D semiconductors: liquid crystalline columnar phase (Chap. 7), self-organization of metal nanoparticles in two and three dimensions (Chap. 8), self-organized 3D photonic superstructure: liquid crystal blue phase (Chap. 9), interfacial interactions in 1D and 2D nanostructure-based material systems (Chap. 10), mesoporous carbons for energy (Chap. 11), hyperbolic metamaterials: design, fabrication, and applications of ultra-anisotropic nanomaterials (Chap. 12), and printed anisotropic molecular alignments (Chap. 13). In each chapter, the state of the art, along with future potentials in the respective fields, is discussed and highlighted by leading experts.

This book offers up-to-date and accessible coverage of diverse anisotropic materials with emphasis on their preparation, properties, and applications to undergraduate and graduate students, as well as researchers both in academia and industries working in inorganic chemistry, organic chemistry, polymer chemistry, physics, biology, materials science, and engineering, electrical engineering, chemical engineering, photonics, biomedical science, optic-electronics, nanoscience, nanotechnology, and energy. It is hoped that readers will find the book useful and this book may serve as a melting pot of truly multidisciplinary knowledge in the field of anisotropic nanomaterials to stimulate future developments of advanced materials and devices while strengthening our fundamental understanding of these intriguing materials.

Finally, I would like to express my gratitude to Claus Ascheron at Springer for inviting us to bring this fascinating and rapidly emerging field to a wider audience, and to all our distinguished contributors for their dedicated efforts. Also, I am indebted to my wife Changshu, my sons Daniel and Songqiao for their great support and affectionate encouragement.

Kent, USA Quan Li

Contents

Contributors

Ammathnadu S. Achalkumar Department of Chemistry, Indian Institute of Technology, Guwahati, India

Hari Krishna Bisoyi Liquid Crystal Institute and Chemical Physics Interdisciplinary Program, Kent State University, Kent, OH, USA

Chun-Wei Chen Department of Photonics, National Sun Yat-sen University, Kaohsiung, Taiwan

Xiaoming Chen Department of Mechanical Engineering, State University of New York at Binghamton, Binghamton, NY, USA

Sheng Dai Chemical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA; Department of Chemistry, University of Tennessee, Knoxville, TN, USA

Antonio De Luca Department of Physics and CNR-NANOTEC UOS di Cosenza, University of Calabria, Rende, Italy

Hao Dong Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

S. Holger Eichhorn Department of Chemistry and Biochemistry, University of Windsor, Windsor, ON, Canada

Ming-Yong Han Institute of Materials Research and Engineering, Agency for Science, Engineering and Research, Singapore, Singapore

Chun-Jiang Jia School of Chemistry and Chemical Engineering, Shandong University, Jinan, China

Changhong Ke Department of Mechanical Engineering, State University of New York at Binghamton, Binghamton, NY, USA

Munehiro Kimura Department of Electric Engineering, Nagaoka University of Technology, Nagaoka, Japan

Masaru Kuno Department of Chemistry and Biochemistry, University of Notre Dame, Notre Dame, IN, USA

Lin-Dong Li Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Quan Li Liquid Crystal Institute and Chemical Physics Interdisciplinary Program, Kent State University, Kent, OH, USA

Tsung-Hsien Lin Department of Photonics, National Sun Yat-sen University, Kaohsiung, Taiwan

Guang-Ming Lyu Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Manoj Mathews Post Graduate & Research Department of Chemistry, St. Joseph's College, Devagiri, Calicut, India

Thomas Mikolajick NaMLab GmbH, Dresden, Germany; Institute of Semiconductor and Microsystems, TU Dresden, Dresden, Germany; Center for Advancing Electronics Dresden (CfAED), TU Dresden, Dresden, Germany

Kwok Wei Shah Institute of Materials Research and Engineering, Agency for Science, Engineering and Research, Singapore, Singapore

Shuo Shi Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Kandammathe Valiyaveedu Sreekanth Department of Physics, Case Western Reserve University, Cleveland, OH, USA

Giuseppe Strangi Department of Physics, Case Western Reserve University, Cleveland, OH, USA; Department of Physics and CNR-NANOTEC UOS di Cosenza, University of Calabria, Rende, Italy

Ling-Dong Sun Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Pornthip Tongying Department of Chemistry and Biochemistry, University of Notre Dame, Notre Dame, IN, USA

Yan-Jie Wang Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Walter M. Weber NaMLab GmbH, Dresden, Germany; Center for Advancing Electronics Dresden (CfAED), TU Dresden, Dresden, Germany

Chenming Xue Liquid Crystal Institute and Chemical Physics Interdisciplinary Program, Kent State University, Kent, OH, USA

Chun-Hua Yan Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Jonathan K. Yu Department of Chemistry and Biochemistry, University of Windsor, Windsor, ON, Canada

Chao Zhang Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Pei-Zhi Zhang Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Pengfei Zhang Chemical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN, USA

Shuang-Yuan Zhang Institute of Materials Research and Engineering, Agency for Science, Engineering and Research, Singapore, Singapore

Xiao-Yu Zheng Beijing National Laboratory for Molecular Sciences, State Key Laboratory of Rare Earth Materials Chemistry and Applications, PKU-HKU Joint Laboratory in Rare Earth Materials and Bioinorganic Chemistry, College of Chemistry of Molecular Engineering, Peking University, Beijing, China

Maksym Zhukovskyi Department of Chemistry and Biochemistry, University of Notre Dame, Notre Dame, IN, USA