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Mikel Duke, Dongyuan Zhao, Raphael Semiat

Functional Nanostructured Materials and Membranes for Water Treatment

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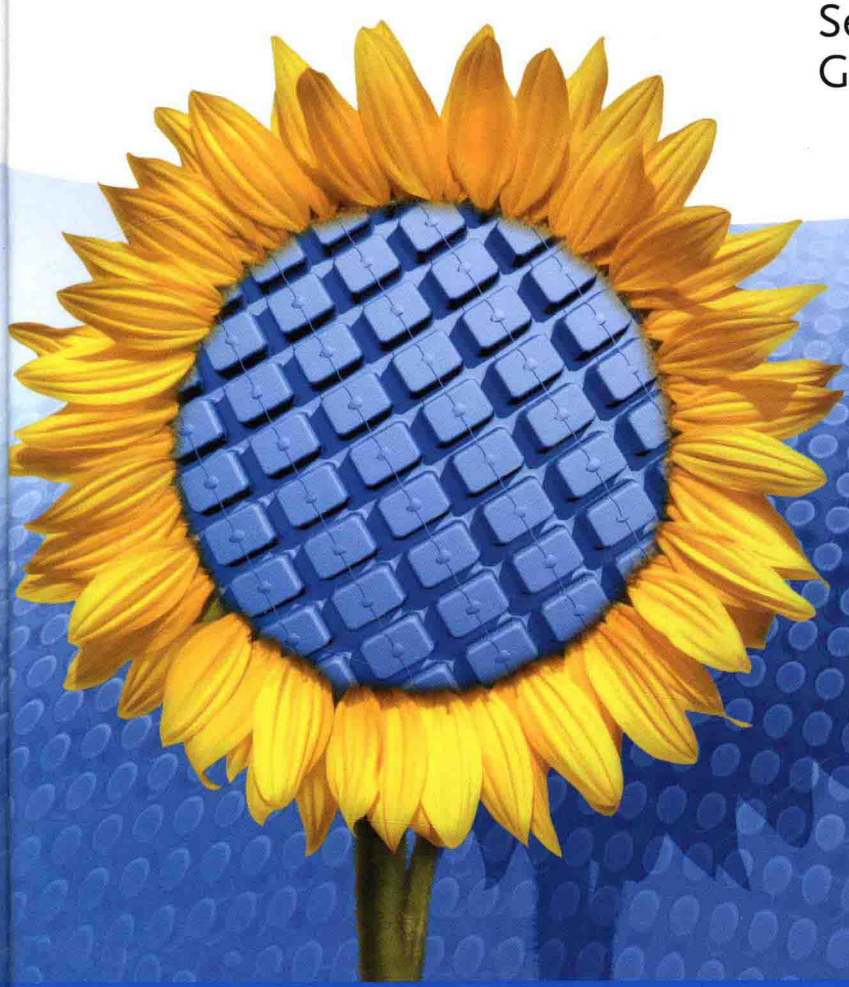

Materials for Sustainable Energy and Development

Edited by Mikel Duke, Dongyuan Zhao, and Raphael Semiat

Functional Nanostructured Materials and Membranes for Water Treatment

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Editorial Board

Foreword

It is with great pleasure to present to you this book on the "Functional Nanostructured Materials and Membranes for Water Treatment." Nanomaterials are an emerging area in science that demonstrated achievements occurring in the last two decades. We can date its beginnings from the name, 'nanotechnology', which was originally coined by Norio Taniguchi, a professor from Tokyo University of Science, in 1974. The emergence of nanotechnology research appears to have come later with the advent of the scanning tunnelling microscope in 1981 and the discovery of fullerenes in 1985. So from that time, besides the concept, we acquired the capacity to identify and characterise nanostructured materials, and this marks the start of the field of science dedicated to the nanoscale.

Nanotechnology is basically the field of science involving the manipulation of matter or theory at the atomic or molecular scale. In doing this, we have unearthed in exciting new properties that can influence the wavelength of light, increase the efficiency of catalysts, selectively diffuse small molecules, and even allow particles to penetrate living cell membranes. It is interesting to note that the natural world has been based on nanostructured materials throughout evolution, and thus, mankind has just started to recognise the need for tools to explore properties of materials in 1 to 100 nm range. It is no wonder that governments around the world have invested billions of dollars specifically in nanotechnology. While industries can harness the different benefits of such materials for energy, foods, mining and, electronics, this book focuses on the advances for water treatment.

Water will always be an essential factor to our lives, and thus, there is an ongoing cause for researchers undertaking efforts to secure sustainable water sources and reduce water pollution. Water treatment is an area where I have spent much of my career, principally in the field of membrane science. During my work I have explored membrane transport properties and fouling mechanisms, which has contributed towards the underpinning science of the widespread membrane technology in the water industry. This is quite remarkable for a technology that was little heard of nearly half a century ago, and is recently one of the most widely adopted water treatment technologies. Over the years, membrane technology has involved working with nanostructured materials, although until now it has not been considered as a branch of nanotechnology. Now researchers are turning to

nanotechnology to address the challenges to a sustainable water future, and in many cases this involves the marriage between nanotechnology and membrane technology. Many of the contributors to this book are membrane scientists and engineers who have the vision that membranes are an invaluable technology in water treatment and it can be enhanced by nanotechnology. Conventional membrane technology already includes a process of separating nano-dimensional molecules known as Nanofiltration. This technique is commercially applied, for example, to remove organic materials (e.g. natural organic matter or sugars) from salts. However, a recently successful development that deliberately combines membrane technology and nanotechnology is the inclusion of nanoparticles in desalination membranes. This work, coming out of the birthplace of reverse osmosis membranes, the University of California at Los Angeles in the USA, has now entered the market as a commercial desalination membrane. The inclusion of nanoparticles within the polymer structure of membranes has performance and practical benefits, that has also been explored in other forms of membranes, including ultra and microfiltration. While we see this activity rising rapidly into commercialisation, this book also presents work in catalysis, sensing, adsorption, membrane modification, ion exchange, inorganic membranes, and nanoscale modelling of membrane diffusion and interactions. Therefore, this book presents a comprehensive overview of the progress in nanotechnology to enhance membranes and other processes in water treatment. Whether you are an academic or working in industry, scientist or engineer, student or professional, this book will have relevance in your practice.

Professor Tony Fane
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Series Editor Preface

The Wiley Series on New Materials for Sustainable Energy and Development

Sustainable energy and development is attracting increasing attention from the scientific research communities and industries alike, with an international race to develop technologies for clean fossil energy, hydrogen and renewable energy as well as water reuse and recycling. According to the REN21 (Renewables Global Status Report 2012 p. 17) total investment in renewable energy reached $257 billion in 2011, up from $211 billion in 2010. The top countries for investment in 2011 were China, Germany, the United States, Italy, and Brazil. In addressing the challenging issues of energy security, oil price rise, and climate change, innovative materials are essential enablers.

In this context, there is a need for an authoritative source of information, presented in a systematic manner, on the latest scientific breakthroughs and knowledge advancement in materials science and engineering as they pertain to energy and the environment. The aim of the *Wiley Series on New Materials for Sustainable Energy and Development* is to serve the community in this respect. This has been an ambitious publication project on materials science for energy applications. Each volume of the series will include high-quality contributions from top international researchers, and is expected to become the standard reference for many years to come.

This book series covers advances in materials science and innovation for renewable energy, clean use of fossil energy, and greenhouse gas mitigation and associated environmental technologies. Current volumes in the series are:

Supercapacitors. Materials, Systems, and Applications
Functional Nanostructured Materials and Membranes for Water Treatment
Materials for High-Temperature Fuel Cells
Materials for Low-Temperature Fuel Cells
Advanced Thermoelectric Materials. Fundamentals and Applications
Advanced Lithium-Ion Batteries. Recent Trends and Perspectives
Photocatalysis and Water Purification. From Fundamentals to Recent Applications

In presenting this volume on Functional Nanostructured Materials and Membranes for Water Treatment, I would like to thank the authors and editors of this important book, for their tremendous effort and hard work in completing the manuscript in a timely manner. The quality of the chapters reflects well the caliber of the contributing authors to this book, and will no doubt be recognized and valued by readers.

Finally, I would like to thank the editorial board members. I am grateful to their excellent advice and help in terms of examining coverage of topics and suggesting authors, and evaluating book proposals.

I would also like to thank the editors from the publisher Wiley-VCH with whom I have worked since 2008, Dr Esther Levy, Dr Gudrun Walter, and Dr Bente Flier for their professional assistance and strong support during this project.

I hope you will find this book interesting, informative and valuable as a reference in your work. We will endeavour to bring to you further volumes in this series or update you on the future book plans in this growing field.

Brisbane, Australia
31 July 2012

Gao Qing Max Lu

Acknowledgments

Mikel Duke, Dongyuan Zhao and Raphael Semiat would like to thank all the authors for their hard work and commitment in producing their original contributions for this book. Also, we appreciate their responsiveness to our requirements in their ongoing comments and revision requests during the production phase of the chapters.

All contributions were peer reviewed, so we also extend a warm thanks to the reviewers for their time and effort in providing detailed and quality comments to the authors.

We would finally like to thank Esther Levy, Martin Graf and Claudia Nussbeck at the Wiley Editorial Office for their assistance, rapid response to questions, and enduring patience that enabled this book to be completed.

Mikel Duke wishes to thank the team at his group, the Institute for Sustainability and Innovation, Victoria University, for their patience and support in developing this book. He also acknowledges the funding agencies that provided research support related to the theme of this book including the Australian Research Council Linkage and Discovery Project schemes, the Victorian Smart Water Fund, the Australian Endeavour Awards, The Ian Potter Foundation, the National Centre of Excellence in Desalination Australia, the Australian Water Recycling Centre of Excellence, and the numerous industry and government partners. Max Lu's invitation to develop this book is greatly appreciated as well as the partnership of Dongyuan Zhao and Raphael Semiat in co-editing this book. Finally, Mikel wishes to thank Alicia and daughters, Eva and Lila, for their personal support.

Dongyuan Zhao would like to thank the NSF of China, the Fudan University, the China Ministry of Education, and the China Ministry of Science and Technology, who provided their support for research during the writing of the book.

Raphael Semiat would like to thank the team of the Rabin Desalination Laboratory at the Technion IIT for their help during this work.

About the Series Editor

Professor Max Lu
Editor, New Materials for Sustainable Energy and Development Series

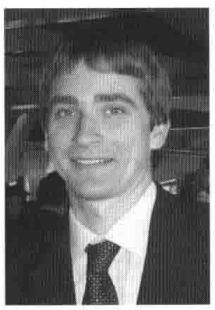
Professor Lu's research expertise is in the areas of materials chemistry and nanotechnology. He is known for his work on nanoparticles and nanoporous materials for clean energy and environmental technologies. With over 500 journal publications in high-impact journals, including Nature, *Journal of the American Chemical Society, Angewandte Chemie, and Advanced Materials*, he is also coinventor of 20 international patents. Professor Lu is an Institute for Scientific Information (ISI) Highly Cited Author in Materials Science with over 17 500 citations (h-index of 63). He has received numerous prestigious awards nationally and internationally, including the Chinese Academy of Sciences International Cooperation Award (2011), the Orica Award, the RK Murphy Medal, the Le Fevre Prize, the ExxonMobil Award, the Chemeca Medal, the Top 100 Most Influential Engineers in Australia (2004, 2010, and 2012), and the Top 50 Most Influential Chinese in the World (2006). He won the Australian Research Council Federation Fellowship twice (2003 and 2008). He is an elected Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE) and Fellow of Institution of Chemical Engineers (IChemE). He is editor and editorial board member of 12 major international journals including *Journal of Colloid and Interface Science and Carbon*.

Max Lu has been Deputy Vice-Chancellor and Vice-President (Research) since 2009. He previously held positions of acting Senior Deputy Vice-Chancellor (2012),

acting Deputy Vice-Chancellor (Research), and Pro-Vice-Chancellor (Research Linkages) from October 2008 to June 2009. He was also the Foundation Director of the ARC Centre of Excellence for Functional Nanomaterials from 2003 to 2009.

Professor Lu had formerly served on many government committees and advisory groups including the Prime Minister's Science, Engineering and Innovation Council (2004, 2005, and 2009) and the ARC College of Experts (2002–2004). He is the past Chairman of the IChemE Australia Board and former Director of the Board of ATSE. His other previous board memberships include Uniseed Pty Ltd., ARC Nanotechnology Network, and Queensland China Council. He is currently Board member of the Australian Synchrotron, National eResearch Collaboration Tools and Resources, and Research Data Storage Infrastructure. He also holds a ministerial appointment as member of the National Emerging Technologies Forum.

About the Volume Editors



Professor **Mikel Duke** is the Principal Research Fellow of Membrane Science and Deputy Director of the Institute for Sustainability and Innovation at Victoria University, Australia. He has worked in membrane research for over 12 years and has 92 peer-reviewed publications in this field. His focus is on development of ceramic and polymeric membranes and their processes, specializing in molecular scale diffusion and optimizing functional material parameters. He is the recipient of an Australian Research Council Linkage International Fellowship and an Endeavour Executive Award and the founding chair of the Membrane Society of Australasia.

Professor **Dongyuan Zhao** is Cheung Kong Professor of the China Education Ministry, Vice Director of the Advanced Materials Laboratory at Fudan University and Visiting Professor at Monash University (Australia). He is an academician of the Chinese Academy of Sciences. With over 350 peer-reviewed papers earning >20 000 citations, he is the 65th Most-Cited Scientist in Chemistry (according to ISI). His research interests are in the synthesis of porous materials and their application in catalysis, separation, photonics, sorption, environmental decontamination, sensors, and so on.

Professor **Raphael Semiat** is the Yitzhak Rabin Memorial Chair in Science, Engineering and Management of Water Resources at Technion, Israel Institute of Technology. He has wide industrial experience in the research and development of chemical processes. His current interests and activities are centered on water technologies, including desalination, and chemical-environmental processes and use of nano particles for removal of organic matter and heavy metals from water. He has published more than 140 papers in scientific journals.

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