

Springer Series in Materials Science

Volume 187

Series Editors

Zhiming M. Wang, Chengdu, People's Republic of China

Chennupati Jagadish, Canberra, ACT, Australia

Robert Hull, Charlottesville, VI, USA

Richard M. Osgood, New York, NY, USA

Jürgen Parisi, Oldenburg, Germany

For further volumes:

<http://www.springer.com/series/856>

The Springer Series in Materials Science covers the complete spectrum of materials physics, including fundamental principles, physical properties, materials theory and design. Recognizing the increasing importance of materials science in future device technologies, the book titles in this series reflect the state-of-the-art in understanding and controlling the structure and properties of all important classes of materials.

Handong Li · Jiang Wu
Zhiming M. Wang
Editors

Silicon-based Nanomaterials

 Springer

Editors

Handong Li
Jiang Wu
Zhiming M. Wang
State Key Laboratory of Electronic
Thin Film and Integrated Devices
University of Electronic Science
and Technology of China
Chengdu
People's Republic of China

ISSN 0933-033X ISSN 2196-2812 (electronic)
ISBN 978-1-4614-8168-3 ISBN 978-1-4614-8169-0 (eBook)
DOI 10.1007/978-1-4614-8169-0
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2013947572

© Springer Science+Business Media New York 2013

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law. The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Silicon is one of the “oldest” electronic materials and has served the microelectronics industry for more than half a century. On the other hand, silicon is also a “young” material since both novel exciting aspects in science and new technical applications continue to be revealed. However, subject to the simple crystal and band structure, the functional extension of silicon must rely on artificial modifications to its size and electronic structure. After years of efforts to find proper ways to further expand silicon’s application areas, research interests have gradually focused on nanocrystallization, alloying, and integration with other functional materials.

Size and shape control is of central importance in developing silicon-based materials science. Nanosized silicon and porous silicon with characterized pore size dimension on the nanometer scale have been demonstrated to be irreplaceable in photovoltaics, photonics, and energy harvesting and storage. However, the full advantage of their unique properties can be exploited or utilized only if controlled preparation of these nanomaterials in terms of orientation, dimension, and size can be achieved.

One characteristic feature of silicon is its highly chemical reactivity to other elements. It can easily react with metal and carbon to form metal silicides and silicon carbide of good crystallinity. Thus a rich functional material family including metals, thermoelectric materials, direct band gap semiconductors, and wideband gap semiconductors with adjustable physical properties can be achieved by alloying methods. More excitingly, nanocrystallization further endows novel properties to these silicon contained compounds.

Besides nanocrystallization and alloying approaches, another straightforward way to expand silicon’s versatility is to integrate functional materials on available silicon chips. This can be realized by depositing heterogeneous materials such as nanosized III–V semiconductors on atomically reconstructed surfaces or patterned surfaces of silicon, i.e., a bottom-up growth process. In many cases, the performance of devices based on such heterostructures is completely determined by the epitaxial quality of heterogeneous thin films or nanostructures on silicon surface or existing circuits.

This book aims to provide a comprehensive survey of the research and development status on the above-mentioned silicon-based nanomaterials. It is organized as follows: Chaps. 1–6 are dedicated to elemental-silicon nanostructures. Chapters 1 and 2 introduce the science and applications of porous silicon nanostructures in lithium batteries. Chapter 3 describes novel optical properties of silicon nanowires whose applications in solar energy harvesting and nano-electro-mechanical systems are summarized in Chap. 4. Chapters 5 and 6 deal with the optical properties of silicon nanoparticles embedded in silica matrix and their applications for light emitting devices. Chapters 7–12 concentrate on silicon-contained compounds for nanomaterials. Chapter 7 starts with a theoretical analysis of electronic and optical properties of silicon carbide nanostructures. Chapters 8–10 discuss the fabrication and characterization of various silicon carbide nanostructures. Chapter 11 investigates the transport behaviors of silicon carbide nanostructures. Chapter 12 focuses on synthesis, properties, and applications of metal silicide nanostructures. Chapters 13–15 discuss integration of other functional nanomaterials on silicon. Chapter 13 covers the droplet epitaxy of strain-free III–V quantum dots on silicon. Chapter 14 highlights the monolithic growth of III–V quantum dots on silicon and related devices behaviors. Finally, the authors demonstrate the growth and characterization of gallium nitride quantum wells structures on patterned SiC/Si substrates in Chap. 15.

We would like to thank all of the authors who have contributed chapters to this book. It took nearly one year to put this work together, but we are confident that the effort was worthwhile and that the book will be an important reference for scientists as well as a helpful platform to explore many fundamental questions at the frontier of materials science.

Chengdu, People's Republic of China

Handong Li
Jiang Wu
Zhiming M. Wang

Contents

1	Porous Silicon as Anode Material for Lithium-Ion Batteries	1
	Madhuri Thakur, Roderick Pernites, Steve L. Sinsabaugh, Michael S. Wong and Sibani L. Biswal	
2	The Development of Si and Ge-Based Nanomaterials for High Performance Lithium Ion Battery Anodes	25
	Xiao-Liang Wang and Wei-Qiang Han	
3	Light Trapping in Coaxial Nanowires of c-Si Cores and a-Si Shells	45
	Jeong Il Oh, Wenfu Liu, Weiqiang Xie and Wenzhong Shen	
4	Applications of Ordered Si Nanowire Array to Solar Energy Harvesting and NEMS	67
	Yuerui Lu and Amit Lal	
5	Synchrotron-Excited Photoluminescence Spectroscopy of Silicon- and Carbon-Containing Quantum Dots in Low Dimensional SiO₂ Matrices	89
	Anatoly F. Zatsepin and Evgeny A. Buntov	
6	Silicon Nanoparticles-Based Light Emitting Capacitors	119
	A. Morales Sánchez, J. Barreto, C. Domínguez Horna, M. Aceves Mijares, J. A. Luna López and L. Licea Jiménez	
7	Electronic and Optical Properties of Silicon Carbide Nanostructures	139
	Hung-Chung Hsueh, Guang-Yu Guo and Steven G. Louie	
8	Plasma Enabled Fabrication of Silicon Carbide Nanostructures	161
	Jinghua Fang, Igor Levchenko, Morteza Aramesh, Amanda E. Rider, Steven Praver and Kostya (Ken) Ostrikov	

9	Catalyst-Free Chemical Vapor Deposition for Synthesis of SiC Nanowires with Controlled Morphology	179
	Jyoti Prakash, Sunil Kumar Ghosh and Dakshinamoorthy Sathiyamoorthy	
10	Adhesion and Indentation Fracture Behavior of Silicon Carbonitride Nanocomposite Coatings Deposited by Magnetron Sputtering	215
	S. K. Mishra and A. S. Bhattacharyya	
11	Impact of Defects and Doping on Electron Transport in SiCNTs	243
	Sudhanshu Choudhary and S. Qureshi	
12	Synthesis, Properties, and Applications of One-Dimensional Transition Metal Silicide Nanostructures	265
	Guangwei She, Hailong Liu, Lixuan Mu and Wensheng Shi	
13	Integration of Strain Free III–V Quantum Dots on Silicon	327
	Stefano Sanguinetti, Sergio Bietti and Giovanni Isella	
14	III–V Quantum-Dot Materials and Devices Monolithically Grown on Si Substrates	357
	Huiyun Liu	
15	Cubic GaN on Nanopatterned 3C-SiC/Si (001) Substrates	381
	Ricarda Maria Kemper, Donat Josef As and Jörg K. N. Lindner	
	Index	407

Contributors

Donat Josef As Department of Physics, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

Morteza Aramesh University of Melbourne, Melbourne VIC 3010, Australia

A. S. Bhattacharyya Central University of Jharkhand, Ranchi 835205, India

Evgeny A. Buntov Institute of Physics and Technology, Ural Federal University, Mira street 19, Ekaterinburg, Russia 620002

J Barreto Centro de Investigación en Materiales Avanzados, Parque de Investigación e Innovación Tecnológica, Alianza Norte 202, 66600 Apodaca, Nuevo León C.P., México

S. Bietti Polo di Como, Politecnico di Milano, Via Anzani 42, 22100 Como, Italy

S. L. Biswal Department of Chemical and Biomolecular Engineering, Rice University, Houston, TX 77005, USA

Sudhanshu Choudhary Department of Electrical Engineering, I. I. T. Kanpur, Kanpur, Kanpur 208016, India

Jinghua Fang CSIRO Materials Science and Engineering—Lindfield, Bradfield Road, West Lindfield NSW 2070, Australia

Guang-Yu Guo Department of Physics, National Taiwan University, Taipei 10617, Taiwan

Sunil Kumar Ghosh Bio Organic Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

C. Domínguez Horna Centro de Investigación en Materiales Avanzados, Parque de Investigación e Innovación Tecnológica, Alianza Norte 202, 66600 Apodaca, Nuevo León C.P., México

Hung-Chung Hsueh Department of Physics, Tamkang University, New Taipei City, Tamsui 25137, Taiwan

Wei-Qiang Han Ningbo Institute of Material Technology and Engineering, Chinese Academy of Sciences, 315202 Ningbo, People's Republic of China

G. Isella Politecnico di Milano, Polo di Como, Via Anzani 42, 22100 Como, Italy

L. Licea Jiménez Centro de Investigación en Materiales Avanzados, Parque de Investigación e Innovación Tecnológica, Alianza Norte 202, 66600 Apodaca, Nuevo León C.P., México

R. M. Kemper Department of Physics, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

Amit Lal SonicMEMS Laboratory, School of Electrical and Computer Engineering, Cornell University, Ithaca, NY 08541, USA

Handong Li State Key Laboratory of Electronic Thin Film and Integrated Devices, University of Electronic Science and Technology of China, 610054 Chengdu, People's Republic of China

Hailong Liu Key Laboratory of Photochemical Conversion and Optoelectronic Materials, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, 100190 Beijing, People's Republic of China

Huiyun Liu Department of Electronic and Electrical Engineering, University College London, Torrington Place, London WC1E 7JE, UK

Igor Levchenko CSIRO Materials Science and Engineering—Lindfield, Bradfield Road, West Lindfield NSW 2070, Australia

J A Luna López Centro de Investigación en Materiales Avanzados, Parque de Investigación e Innovación Tecnológica, Alianza Norte 202, 66600 Apodaca, Nuevo León C.P., México

Jörg K. N. Lindner Department of Physics, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

Siyuan Luo State Key Laboratory of Electronic Thin Film and Integrated Devices, University of Electronic Science and Technology of China, 610054 Chengdu, People's Republic of China

Steven G. Louie Department of Physics, University of California at Berkeley, Berkeley, California 94720, USA; Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Wenfu Liu Laboratory of Condensed Matter Spectroscopy and Opto-Electronic Physics, Key Laboratory of Artificial Structures and Quantum Control (Ministry of Education), Department of Physics, Institute of Solar Energy, Shanghai Jiao Tong University, 800 Dong Chuan Road, 200240 Shanghai, China

Yuerui Lu SonicMEMS Laboratory, School of Electrical and Computer Engineering, Cornell University, Ithaca, NY 08540, USA

Lixuan Mu Key Laboratory of Photochemical Conversion and Optoelectronic Materials, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, People's Republic of China

M Aceves Mijares Centro de Investigación en Materiales Avanzados, Parque de Investigación e Innovación Tecnológica, Alianza Norte 202, 66600 Apodaca, Nuevo León C.P., México

S. K. Mishra CSIR-National Metallurgical Laboratory, Jamshedpur, Jharkhand 831007, India

Jeong Il Oh Laboratory of Condensed Matter Spectroscopy and Opto-Electronic Physics, Key Laboratory of Artificial Structures and Quantum Control (Ministry of Education), Department of Physics, Institute of Solar Energy, Shanghai Jiao Tong University, 800 Dong Chuan Road, 200240 Shanghai, China

Kostya (Ken) Ostrikov CSIRO Materials Science and Engineering—Lindfield, Bradfield Road, West Lindfield NSW 2070, Australia

Jyoti Prakash Powder Metallurgy Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

R. Pernites Department of Chemical and Biomolecular Engineering, Rice University, Houston, TX 77005, USA

Steven Prawer University of Melbourne, Melbourne, VIC 3010, Australia

S. Qureshi Department of Electrical Engineering, I. I. T. Kanpur, Kanpur 208016, India

Amanda E. Rider CSIRO Materials Science and Engineering—Lindfield, Bradfield Road, West Lindfield NSW 2070, Australia

A Morales Sánchez Centro de Investigación en Materiales Avanzados, Parque de Investigación e Innovación Tecnológica, Alianza Norte 202, 66600 Apodaca, Nuevo León C.P., México

Dakshinamoorthy Sathiyamoorthy Powder Metallurgy Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

Guangwei She Key Laboratory of Photochemical Conversion and Optoelectronic Materials, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, People's Republic of China

S. Sanguinetti Dipartimento di Scienza dei Materiali, Università degli Studi di Milano-Bicocca, via R. Cozzi 53, 20125 Milan, Italy

S. L. Sinsabaugh Lockheed Martin MS2, Akron, OH, USA

Wensheng Shi Key Laboratory of Photochemical Conversion and Optoelectronic Materials, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, 100190 Beijing, People's Republic of China

Wenzhong Shen Laboratory of Condensed Matter Spectroscopy and Opto-Electronic Physics, Key Laboratory of Artificial Structures and Quantum Control (Ministry of Education), Department of Physics, Institute of Solar Energy, Shanghai Jiao Tong University, 800 Dong Chuan Road, 200240 Shanghai, China

M. Thakur Department of Chemical and Biomolecular Engineering, Rice University, Houston, TX 77005, USA

M. S. Wong Department of Chemical and Biomolecular Engineering, Rice University, Houston, TX 77005, USA

Zhiming M. Wang State Key Laboratory of Electronic Thin Film and Integrated Devices, University of Electronic Science and Technology of China, 610054 Chengdu, People's Republic of China

Weiqiang Xie Laboratory of Condensed Matter Spectroscopy and Opto-Electronic Physics, Key Laboratory of Artificial Structures and Quantum Control (Ministry of Education), Department of Physics, Institute of Solar Energy, Shanghai Jiao Tong University, 800 Dong Chuan Road, 200240 Shanghai, China

Xiao-Liang Wang Ningbo Institute of Material Technology and Engineering, Chinese Academy of Sciences, 315202 Ningbo, People's Republic of China

Anatoly F. Zatsepin Institute of Physics and Technology, Ural Federal University, Mira street 19, Ekaterinburg, Russia 620002