Materials Issues and Modeling for Device Nanofabrication

MATERIALS RESEARCH SOCIETY
SYMPOSIUM PROCEEDINGS VOLUME 584

Materials Issues and Modeling for Device Nanofabrication

Symposia held November 29–December 2, 1999, Boston, Massachusetts, U.S.A.

EDITORS:

Lhadi Merhari
CERAMEC
Limoges, France

Luc T. Wille
Florida Atlantic University
Boca Raton, Florida, U.S.A.

Kenneth E. Gonsalves
University of Connecticut
Storrs, Connecticut, U.S.A.

Mark F. Gyure
Hughes Research Laboratories
Malibu, California, U.S.A.

Shinji Matsui
Himeji Institute of Technology
Hyogo, Japan

Lloyd J. Whitman
Naval Research Laboratory
Washington, D.C., U.S.A.

Materials Research Society
Warrendale, Pennsylvania

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Mexico City

Cambridge University Press
32 Avenue of the Americas, New York NY 10013-2473, USA

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9781107414174

Materials Research Society
506 Keystone Drive, Warrendale, PA 15086
http://www.mrs.org

First published 2000
First paperback edition 2013

Single article reprints from this publication are available through
University Microfilms Inc., 300 North Zeeb Road, Ann Arbor, MI 48106

CODEN: MRSPDH

ISBN 978-1-107-41417-4 Paperback

This work was supported in part by the Office of Naval Research under Grant Number ONR: N00014-00-1-0065. The United States Government has a royalty-free license throughout the world in all copyrightable material contained herein.

This material is based upon work supported by the National Science Foundation under Grant No. NSF: DMR-9986520. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

CONTENTS

*Invited Paper

EPITAXIAL GROWTH AND MORPHOLOGY

NOVEL CONCEPTS OF RESISTS FOR NANOLITHOGRAPHY

*Invited Paper

MODELING AND ATOMISTIC SIMULATIONS

*Invited Paper

*Invited Paper

PREFACE

The exploding market of information technology requires ultra-high-speed integrated circuits, which imposes formidable challenges in terms of nanofabrication, advanced materials, atomic scale measurements and modeling. The enormous costs of next-generation lithographic machines to mass produce integrated circuits with sub-100 nm resolution justify alternative approaches where the use of advanced materials and techniques for nanofabrication including epitaxial growth, and their powerful modeling, can lead to more cost-effective strategies.

This volume contains most of the papers that were presented during Symposium J, "Advanced Materials and Techniques for Nanolithography," and Symposium N, "Atomic Scale Measurements and Atomistic Models of Epitaxial Growth and Lithography," at the 1999 MRS Fall Meeting in Boston, Massachusetts. Because of the complementary nature of the two subject matters, particularly in their applicability to device nanofabrication, it was felt that a combined proceedings volume offered the best way to present the findings in a unified and comprehensive manner. The editors trust that the reader will find here a nice overview of the state of the art, both theoretical and experimental, as well as an indication of the future trends and remaining challenges in this technologically important field.

Symposium J focused on the materials aspect of nanolithography by highlighting the advances in resist technology, which is now increasingly recognized as a bottleneck for sub-100 nm resolution. Indeed, whatever the degree of sophistication of a lithographic machine, a non-optimum resist can completely ruin the overall lithographic process. Major papers describing new concepts of resists based on various nanocomposites and particularly on ordered polymer/inorganic structures to decrease electron proximity effects are included in this volume.

Advances in lithographic techniques such as X-ray lithography and electron beam lithography are described, while a special emphasis is put on ion projection lithography. Indeed, ion projection lithography is a very promising and versatile technique which has benefitted from more research and development efforts in Europe than in the U.S.A. Generally regarded as the next revolution in electronics, molecular electronics has been covered bearing in mind that future lithographies should aim at taking up the challenge of "molecular"-scale interconnections. For the sake of completeness, contributions exemplifying the fabrication of real nanostructures and useful nanodevices such as nanotransistors are included.

The papers from Symposium N contained in this volume focus on recent advances made in both atomic scale measurements and models of epitaxial growth as well as lithography. They strike a nearly equal balance between theoretical and experimental approaches. Scanning probe microscopy is the dominant experimental theme, although other techniques are also represented. As described here, advances in plan view and cross

sectional techniques make it clear that characterization of device materials has now reached the point where feedback from such measurements can be used to improve device growth. The theory papers are divided primarily between kinetic Monte Carlo (KMC) simulations of growth and ab initio calculations of basic surface properties. A few papers discuss how to combine ab initio data for transition energies with KMC simulations, and this appears to be a promising approach for the development of robust models for growth. Validation of such models by scanning probe microscopy is now at hand and promises to be an exciting area for the future, offering rich collaboration between theorists and experimentalists, ultimately leading to a faster design cycle, reduced costs, and more efficient devices.

Lhadi Merhari
Luc T. Wille
Kenneth E. Gonsalves
Mark F. Gyure
Shinji Matsui
Lloyd J. Whitman

January 2000

ACKNOWLEDGMENTS

The editors wish to thank contributors to this volume from both Symposium J, "Advanced Materials and Techniques for Nanolithography," and Symposium N, "Atomic Scale Measurements and Atomistic Models of Epitaxial Growth and Lithography." Special thanks are due to HerSong Chen (SEH America, Inc.) and Paul Nealey (University of Wisconsin-Madison) for co-organizing Symposium J, and to all the symposium chairs who directed and guided the discussions. Timely and conscientious efforts of the manuscript reviewers are greatly appreciated.

The organizers of the two symposia are grateful for the generous support provided by the following organizations:

Symposium J

CERAMEC France
City Technology Ltd.
ComSys GmbH
Conexant Systems, Inc.
National Science Foundation
Office of Naval Research
SEH America, Inc
STMicroelectronics

Symposium N

Bede Scientific
Center for Theoretical and Computational Materials Science, NIST (National Institute for Standards and Technology)
JEOL USA
Nippon Telegraph and Telephone (NTT)
Omicron Associates
RHK Technology

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

Volume 557— Amorphous and Heterogeneous Silicon Thin Films: Fundamentals to Devices—1999, H.M. Branz, R.W. Collins, H. Okamoto, S. Guha, R. Schropp, 1999, ISBN: 1-55899-464-5
Volume 558— Flat-Panel Displays and Sensors—Principles, Materials and Processes, F.R. Libsch, B. Chalamala, R. Friend, T. Jackson, H. Ohshima, 2000, ISBN: 1-55899-465-3
Volume 559— Liquid Crystal Materials and Devices, T.J. Bunning, S.H. Chen, L.C. Chien, T. Kajiyama, N. Koide, S-C.A. Lien, 1999, ISBN: 1-55899-466-1
Volume 560— Luminescent Materials, J. McKittrick, B. DiBartolo, K. Mishra, 1999, ISBN: 1-55899-467-X
Volume 561— Organic Nonlinear Optical Materials and Devices, B. Kippelen, H.S. Lackritz, R.O. Claus, 1999, ISBN: 1-55899-468-8
Volume 562— Polycrystalline Metal and Magnetic Thin Films, D.E. Laughlin, K.P. Rodbell, O. Thomas, B. Zhang, 1999, ISBN: 1-55899-469-6
Volume 563— Materials Reliability in Microelectronics IX, C.A. Volkert, A.H. Verbruggen, D.D. Brown, 1999, ISBN: 1-55899-470-X
Volume 564— Advanced Interconnects and Contacts, D.C. Edelstein, T. Kikkawa, M.C. Öztürk, K-N. Tu, E.J. Weitzman, 1999, ISBN: 1-55899-471-8
Volume 565— Low-Dielectric Constant Materials V, J. Hummel, K. Endo, W.W. Lee, M. Mills, S-Q. Wang, 1999, ISBN: 1-55899-472-6
Volume 566— Chemical-Mechanical Polishing—Fundamentals and Challenges, S.V. Babu, S. Danyluk, M. Krishnan, M. Tsujimura, 2000, ISBN: 1-55899-473-4
Volume 567— Ultrathin SiO_2 and High-K Materials for ULSI Gate Dielectrics, H.R. Huff, C.A. Richter, M.L. Green, G. Lucovsky, T. Hattori, 1999, ISBN: 1-55899-474-2
Volume 568— Si Front-End Processing—Physics and Technology of Dopant-Defect Interactions, H-J.L. Gossmann, T.E. Haynes, M.E. Law, A.N. Larsen, S. Odanaka, 1999, ISBN: 1-55899-475-0
Volume 569— *In Situ* Process Diagnostics and Modelling, O. Auciello, A.R. Krauss, E.A. Irene, J.A. Schultz, 1999, ISBN: 1-55899-476-9
Volume 570— Epitaxial Growth, A-L. Barabási, M. Krishnamurthy, F. Liu, T.P. Pearsall, 1999, ISBN: 1-55899-477-7
Volume 571— Semiconductor Quantum Dots, S.C. Moss, D. Ila, H.W.H. Lee, D.J. Norris, 2000, ISBN: 1-55899-478-5
Volume 572— Wide-Bandgap Semiconductors for High-Power, High-Frequency and High-Temperature Applications—1999, S.C. Binari, A.A. Burk, M.R. Melloch, C. Nguyen, 1999, ISBN: 1-55899-479-3
Volume 573— Compound Semiconductor Surface Passivation and Novel Device Processing, H. Hasegawa, M. Hong, Z.H. Lu, S.J. Pearton, 1999, ISBN: 1-55899-480-7
Volume 574— Multicomponent Oxide Films for Electronics, M.E. Hawley, D.H.A. Blank, C-B. Eom, D.G. Schlom, S.K. Streiffer, 1999, ISBN: 1-55899-481-5
Volume 575— New Materials for Batteries and Fuel Cells, D.H. Doughty, L.F. Nazar, M. Arakawa, H-P. Brack, K. Naoi, 2000, ISBN: 1-55899-482-3
Volume 576— Organic/Inorganic Hybrid Materials II, L.C. Klein, L.F. Francis, M.R. DeGuire, J.E. Mark, 1999, ISBN: 1-55899-483-1
Volume 577— Advanced Hard and Soft Magnetic Materials, M. Coey, L.H. Lewis, B-M. Ma, T. Schrefl, L. Schultz, J. Fidler, V.G. Harris, R. Hasegawa, A. Inoue, M.E. McHenry, 1999, ISBN: 1-55899-485-8
Volume 578— Multiscale Phenomena in Materials—Experiments and Modeling, D.H. Lassila, I.M. Robertson, R. Phillips, B. Devincre, 2000, ISBN: 1-55899-486-6
Volume 579— The Optical Properties of Materials, J.R. Chelikowsky, S.G. Louie, G. Martinez, E.L. Shirley, 2000, ISBN: 1-55899-487-4
Volume 580— Nucleation and Growth Processes in Materials, A. Gonis, P.E.A. Turchi, A.J. Ardell, 2000, ISBN: 1-55899-488-2
Volume 581— Nanophase and Nanocomposite Materials III, S. Komarneni, J.C. Parker, H. Hahn, 2000, ISBN: 1-55899-489-0
Volume 582— Molecular Electronics, S.T. Pantelides, M.A. Reed, J. Murday, A. Aviram, 2000, ISBN: 1-55899-490-4

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

Volume 583— Self-Organized Processes in Semiconductor Alloys, A. Mascarenhas, B. Joyce, T. Suzuki, D. Follstaedt, 2000, ISBN: 1-55899-491-2
Volume 584— Materials Issues and Modeling for Device Nanofabrication, L. Merhari, L.T. Wille, K. Gonsalves, M.F. Gyure, S. Matsui, L.J. Whitman, 2000, ISBN: 1-55899-492-0
Volume 585— Fundamental Mechanisms of Low-Energy-Beam-Modified Surface Growth and Processing, S. Moss, E.H. Chason, B.H. Cooper, T. Diaz de la Rubia, J.M.E. Harper, R. Murti, 2000, ISBN: 1-55899-493-9
Volume 586— Interfacial Engineering for Optimized Properties II, C.B. Carter, E.L. Hall, C.L. Briant, S. Nutt, 2000, ISBN: 1-55899-494-7
Volume 587— Substrate Engineering—Paving the Way to Epitaxy, D.P. Norton, D.G. Schlom, N. Newman, D.H. Matthiesen, 2000, ISBN: 1-55899-495-5
Volume 588— Optical Microstructural Characterization of Semiconductors, J. Piqueras, T. Sekiguchi, M.S. Unlu, N.M. Kalkhoran, 2000, ISBN: 1-55899-496-3
Volume 589— Advances in Materials Problem Solving with the Electron Microscope, J. Bentley, U. Dahmen, C. Allen, I. Petrov, 2000, ISBN: 1-55899-497-1
Volume 590— Applications of Synchrotron Radiation Techniques to Materials Science V, S.R. Stock, D.L. Perry, S.M. Mini, 2000, ISBN: 1-55899-498-X
Volume 591— Nondestructive Methods for Materials Characterization, T. Matikas, N. Meyendorf, G. Baaklini, R. Gilmore, 2000, ISBN: 1-55899-499-8
Volume 592— Structure and Electronic Properties of Ultrathin Dielectric Films on Silicon and Related Structures, H.J. von Bardeleben, D.A. Buchanan, A.H. Edwards, T. Hattori, 2000, ISBN: 1-55899-500-5
Volume 593— Amorphous and Nanostructured Carbon, J. Robertson, J.P. Sullivan, O. Zhou, T.B. Allen, B.F. Coll, 2000, ISBN: 1-55899-501-3
Volume 594— Thin Films—Stresses and Mechanical Properties VIII, R. Vinci, O. Kraft, N. Moody, P. Besser, E. Shaffer II, 2000, ISBN: 1-55899-502-1
Volume 595— GaN and Related Alloys—1999, R. Feenstra, T. Myers, M.S. Shur, H. Amano, 2000, ISBN: 1-55899-503-X
Volume 596— Ferroelectric Thin Films VIII, R.W. Schwartz, S.R. Summerfelt, P.C. McIntyre, Y. Miyasaka, D. Wouters, 2000, ISBN: 1-55899-504-8
Volume 597— Thin Films for Optical Waveguide Devices and Materials for Optical Limiting, K. Nashimoto, B.W. Wessels, J. Shmulovich, A.K-Y. Jen, K. Lewis, R. Pachter, R. Sutherland, J. Perry, 2000, ISBN: 1-55899-505-6
Volume 598— Electrical, Optical, and Magnetic Properties of Organic Solid-State Materials V, S.P. Ermer, J.R. Reynolds, J.W. Perry, A.K-Y. Jen, Z. Bao, 2000, ISBN: 1-55899-506-4
Volume 599— Mineralization in Natural and Synthetic Biomaterials, P. Li, P. Calvert, R.J. Levy, T. Kokubo, C.R. Scheid, 2000, ISBN: 1-55899-507-2
Volume 600— Electroactive Polymers, Q.M. Zhang, T. Furukawa, Y. Bar-Cohen, J. Scheinbeim, 2000, ISBN: 1-55899-508-0
Volume 601— Superplasticity—Current Status and Future Potential, P.B. Berbon, M.Z. Berbon, T. Sakuma, T.G. Langdon, 2000, ISBN: 1-55899-509-9
Volume 602— Magnetoresistive Oxides and Related Materials, M. Rzchowski, M. Kawasaki, A.J. Millis, M. Rajeswari, S. von Molnár, 2000, ISBN: 1-55899-510-2
Volume 603— Materials Issues for Tunable RF and Microwave Devices, Q. Jia, F.A. Miranda, D.E. Oates, X. Xi, 2000, ISBN: 1-55899-511-0
Volume 604— Materials for Smart Systems III, M. Wun-Fogle, K. Uchino, Y. Ito, R. Gotthardt, 2000, ISBN: 1-55899-512-9
Volume 605— Materials Science of Microelectromechanical Systems (MEMS) Devices II, M.P. deBoer, A.H. Heuer, S.J. Jacobs, E. Peeters, 2000, ISBN: 1-55899-513-7
Volume 606— Chemical Processing of Dielectrics, Insulators and Electronic Ceramics, A.C. Jones, J. Veteran, S. Kaushal, D. Mullin, R. Cooper, 2000, ISBN: 1-55899-514-5
Volume 607— Infrared Applications of Semiconductors III, B.J.H. Stadler, M.O. Manasreh, I. Ferguson, Y-H. Zhang, 2000, ISBN: 1-55899-515-3
Volume 608— Scientific Basis for Nuclear Waste Management XXIII, R.W. Smith, D.W. Shoesmith, 2000, ISBN: 1-55899-516-1

Prior Materials Research Society Symposium Proceedings available by contacting Materials Research Society