Advances in GaN, GaAs, SiC and Related Alloys on Silicon Substrates

MATERIALS RESEARCH SOCIETY
SYMPOSIUM PROCEEDINGS VOLUME 1068

Advances in GaN, GaAs, SiC and Related Alloys on Silicon Substrates

Symposium held March 24–28, 2008, San Francisco, California, U.S.A.

EDITORS:

Tingkai Li
Sharp Laboratories of America, Inc.
Camas, Washington, U.S.A.

Joan M. Redwing
The Pennsylvania State University
University Park, Pennsylvania, U.S.A.

Michael Mastro
U.S. Naval Research Laboratory
Washington, D.C., U.S.A.

Edwin L. Piner
Nitronex Corporation
Durham, North Carolina, U.S.A.

Armin Dadgar
Otto-von-Guericke-Universitaet Magdeburg
Magdeburg, Germany

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/9781107408562

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

First published 2008
First paperback edition 2012

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

CODEN: MRSPDH

ISBN 978-1-107-40856-2 Paperback

CONTENTS

*Invited Paper

*Invited Paper

CONVENTIONAL III-V MATERIALS AND DEVICES ON SILICON

*Invited Paper

*Invited Paper

PREFACE

Symposium C, "Advances in GaN, GaAs, SiC and Related Alloys on Silicon Substrates," was held March 24–28 at the 2008 MRS Spring Meeting in San Francisco, California. To meet increasingly challenging and complex system requirements as well as staying cost effective, it is not enough to use one single semiconductor materials system. Therefore, major efforts have been expended in recent years to combine the low cost and well established Si-based CMOS processing attributes with the superior performance attributes of Compound Semiconductors (CS). Such a combination—marrying the best of both worlds—will enable performance superior to that achievable with CS and CMOS alone with CMOS affordability. With an approach that directly integrates the CS into the CMOS wafer, only one wafer is processed to achieve a finished chip. Therefore, great efforts have been made to achieve direct integration of III-V materials systems such as GaN, GaAs, SiC and related alloys with Si. Many different approaches have been developed to overcome major lattice and thermal expansion mismatches between these systems with great success as illustrated by the multitude of excellent work presented, and the fact that excellent device performance has been achieved and are starting to become commercially available.

The *GaN Based Electronic Device and Sensors on Silicon* chapter gives an overview of the exciting new high power GaN-on-Si high electron mobility transistor (HEMT) devices, field effect transistor (FET) devices and sensors, and also reported on the new results on crack-free AlGaN/GaN HEMT devices grown on 6" Si substrates with low sheet resistance. The high efficiency GaN base light emission diode (LED), rare earth co-doping LEDs, and other optical devices on silicon are discussed in the *GaN Based Optical Devices on Silicon* chapter. The *GaN and Related Alloys on Silicon Growth and Integration Techniques* chapter focuses on materials challenges one faces when trying to grow GaN and Related Alloys respectively onto Si substrates due to lattice mismatch and the relative large thermal expansion mismatches. Discussed are various approaches taken to overcome those challenges and how they affect electrical and optical properties, followed by device performance. The chapter also presents very promising results on H-MOVPE growth of thick crack-free GaN on nanopatterned Si substrates, and InGaN thin film growth on Si(111) by the newly developed ENABLE technique (Energetic Neutral Atomic-Beam Lithography and Epitaxy) for electronic and optoelectronic devices, including solar cells. The *Conventional III-V Materials and Devices on Silicon* chapter describes a wide variety of III-V materials integrated on silicon, as well as high speed III-V devices introducing HEMTs, modulation doping and quantum well structures. The devices evolved from GaAs-based to InP-based HEMTs and HBTs, leading to next generation Sb based devices. In turn, various concepts were introduced, and examples were discussed, including fabrication processes and the challenges of producing good ohmic contacts due to the doping limitations in GaAs. The chapter also presents the growth of semiconductor nanowires as a route to combining heavily mismatched materials with focus on the growth of III-V nanowires on group IV substrates. The *Silicon and Other Materials on Silicon* chapter includes the current states of SiC and other materials integrated on silicon for electronics and optical devices applications.

The strong and increasing interest in GaN, GaAs, SiC and related alloys on silicon substrates indicates the worldwide importance of these materials and devices. This symposium proceedings represents the latest technical advancements and information on III-V materials and devices on silicon substrates from universities, national laboratories and industries. It also provides insight into emerging trends in these exciting technologies.

Tingkai Li
Joan M. Redwing
Michael Mastro
Edwin L. Piner
Armin Dadgar

July 2008

ACKNOWLEDGMENTS

The symposium chairs are pleased to acknowledge the following contributed and invited authors for the outstanding quality of their presentations and proceedings manuscripts, including:

Erik Bakkers	Edward Y. Chang
Ken Elliott	Augusto Gutierrez
Ulrich Heinle	Wayne Johnson
Fabrice Letertre	Armand Rosenberg

Authors who gave invited presentations included:

Takashi Egawa	Katherine Herrick
Olga Kryliouk	Fabian Schulze

The tutorial instructors are: Hongxing Jiang and Edward Y. Chang

The symposium chairs are also deeply indebted to the session chairs for their efforts in overseeing the sessions, guiding subsequent discussions, and reviewing the proceedings manuscripts:

Katherine Herrick	Augusto Gutierrez
Ken Elliott	Fabian Schulze
John Roberts	Fatemeh Shahedipour-Sandvik
Ulrich Heinle	Takashi Egawa
Edward Y. Chang	Mark Fanton
Olga Kryliouk	

The symposium chairs also wish to express their gratitude to Aixtron AG who provided financial support, enabling us to present the "Advances in GaN, GaAs, SiC and Related Alloys on Silicon Substrates" symposium.

A special thanks is extended to the Materials Research Society staff, as well as the 2008 MRS Spring Meeting Chairs, for the development of the outstanding conference.

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

Volume 1066 — Amorphous and Polycrystalline Thin-Film Silicon Science and Technology—2008, A. Nathan, J. Yang, S. Miyazaki, H. Hou, A. Flewitt, 2008, ISBN 978-1-60511-036-3
Volume 1067E —Materials and Devices for "Beyond CMOS" Scaling, S. Ramanathan, 2008, ISBN 978-1-60511-037-0
Volume 1068 — Advances in GaN, GaAs, SiC and Related Alloys on Silicon Substrates, T. Li, J. Redwing, M. Mastro, E.L. Piner, A. Dadgar, 2008, ISBN 978-1-60511-038-7
Volume 1069 — Silicon Carbide 2008—Materials, Processing and Devices, A. Powell, M. Dudley, C.M. Johnson, S-H. Ryu, 2008, ISBN 978-1-60511-039-4
Volume 1070 — Doping Engineering for Front-End Processing, B.J. Pawlak, M. Law, K. Suguro, M.L. Pelaz, 2008, ISBN 978-1-60511-040-0
Volume 1071 — Materials Science and Technology for Nonvolatile Memories, O. Auciello, D. Wouters, S. Soss, S. Hong, 2008, ISBN 978-1-60511-041-7
Volume 1072E —Phase-Change Materials for Reconfigurable Electronics and Memory Applications, S. Raoux, A.H. Edwards, M. Wuttig, P.J. Fons, P.C. Taylor, 2008, ISBN 978-1-60511-042-4
Volume 1073E —Materials Science of High-k Dielectric Stacks—From Fundamentals to Technology, L. Pantisano, E. Gusev, M. Green, M. Niwa, 2008, ISBN 978-1-60511-043-1
Volume 1074E —Synthesis and Metrology of Nanoscale Oxides and Thin Films, V. Craciun, D. Kumar, S.J. Pennycook, K.K. Singh, 2008, ISBN 978-1-60511-044-8
Volume 1075E —Passive and Electromechanical Materials and Integration, Y.S. Cho, H.A.C. Tilmans, T. Tsurumi, G.K. Fedder, 2008, ISBN 978-1-60511-045-5
Volume 1076 — Materials and Devices for Laser Remote Sensing and Optical Communication, A. Aksnes, F. Amzajerdian, N. Peyghambarian, 2008, ISBN 978-1-60511-046-2
Volume 1077E —Functional Plasmonics and Nanophotonics, S. Maier, 2008, ISBN 978-1-60511-047-9
Volume 1078E —Materials and Technology for Flexible, Conformable and Stretchable Sensors and Transistors, 2008, ISBN 978-1-60511-048-6
Volume 1079E —Materials and Processes for Advanced Interconnects for Microelectronics, J. Gambino, S. Ogawa, C.L. Gan, Z. Tokei, 2008, ISBN 978-1-60511-049-3
Volume 1080E —Semiconductor Nanowires—Growth, Physics, Devices and Applications, H. Riel, T. Kamins, H. Fan, S. Fischer, C. Thelander, 2008, ISBN 978-1-60511-050-9
Volume 1081E —Carbon Nanotubes and Related Low-Dimensional Materials, L-C. Chen, J. Robertson, Z.L. Wang, D.B. Geohegan, 2008, ISBN 978-1-60511-051-6
Volume 1082E —Ionic Liquids in Materials Synthesis and Application, H. Yang, G.A. Baker, J.S Wilkes, 2008, ISBN 978-1-60511-052-3
Volume 1083E —Coupled Mechanical, Electrical and Thermal Behaviors of Nanomaterials, L. Shi, M. Zhou, M-F. Yu, V. Tomar, 2008, ISBN 978-1-60511-053-0
Volume 1084E —Weak Interaction Phenomena—Modeling and Simulation from First Principles, E. Schwegler, 2008, ISBN 978-1-60511-054-7
Volume 1085E —Nanoscale Tribology—Impact for Materials and Devices, Y. Ando, R.W. Carpick, R. Bennewitz, W.G. Sawyer, 2008, ISBN 978-1-60511-055-4
Volume 1086E —Mechanics of Nanoscale Materials, C. Friesen, R.C. Cammarata, A. Hodge, O.L. Warren, 2008, ISBN 978-1-60511-056-1

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

Volume 1087E —Crystal-Shape Control and Shape-Dependent Properties—Methods, Mechanism, Theory and Simulation, K-S. Choi, A.S. Barnard, D.J. Srolovitz, H. Xu, 2008, ISBN 978-1-60511-057-8
Volume 1088E —Advances and Applications of Surface Electron Microscopy, D.L. Adler, E. Bauer, G.L. Kellogg, A. Scholl, 2008, ISBN 978-1-60511-058-5
Volume 1089E —Focused Ion Beams for Materials Characterization and Micromachining, L. Holzer, M.D. Uchic, C. Volkert, A. Minor, 2008, ISBN 978-1-60511-059-2
Volume 1090E —Materials Structures—The Nabarro Legacy, P. Müllner, S. Sant, 2008, ISBN 978-1-60511-060-8
Volume 1091E —Conjugated Organic Materials—Synthesis, Structure, Device and Applications, Z. Bao, J. Locklin, W. You, J. Li, 2008, ISBN 978-1-60511-061-5
Volume 1092E —Signal Transduction Across the Biology-Technology Interface, K. Plaxco, T. Tarasow, M. Berggren, A. Dodabalapur, 2008, ISBN 978-1-60511-062-2
Volume 1093E —Designer Biointerfaces, E. Chaikof, A. Chilkoti, J. Elisseeff, J. Lahann, 2008, ISBN 978-1-60511-063-9
Volume 1094E —From Biological Materials to Biomimetic Material Synthesis, N. Kröger, R. Qiu, R. Naik, D. Kaplan, 2008, ISBN 978-1-60511-064-6
Volume 1095E —Responsive Biomaterials for Biomedical Applications, J. Cheng, A. Khademhosseini, H-Q. Mao, M. Stevens, C. Wang, 2008, ISBN 978-1-60511-065-3
Volume 1096E —Molecular Motors, Nanomachines and Active Nanostructures, H. Hess, A. Flood, H. Linke, A.J. Turberfield, 2008, ISBN 978-1-60511-066-0
Volume 1097E —Mechanical Behavior of Biological Materials and Biomaterials, J. Zhou, A.G. Checa, O.O. Popoola, E.D. Rekow, 2008, ISBN 978-1-60511-067-7
Volume 1098E —The Hydrogen Economy, A. Dillon, C. Moen, B. Choudhury, J. Keller, 2008, ISBN 978-1-60511-068-4
Volume 1099E —Heterostructures, Functionalization and Nanoscale Optimization in Superconductivity, T. Aytug, V. Maroni, B. Holzapfel, T. Kiss, X. Li, 2008, ISBN 978-1-60511-069-1
Volume 1100E —Materials Research for Electrical Energy Storage, J.B. Goodenough, H.D. Abruña, M.V. Buchanan, 2008, ISBN 978-1-60511-070-7
Volume 1101E —Light Management in Photovoltaic Devices—Theory and Practice, C. Ballif, R. Ellingson, M. Topic, M. Zeman, 2008, ISBN 978-1-60511-071-4
Volume 1102E —Energy Harvesting—From Fundamentals to Devices, H. Radousky, J. Holbery, B. O'Handley, N. Kioussis, 2008, ISBN 978-1-60511-072-1
Volume 1103E —Health and Environmental Impacts of Nanoscale Materials—Safety by Design, S. Tinkle, 2008, ISBN 978-1-60511-073-8
Volume 1104 — Actinides 2008—Basic Science, Applications and Technology, B. Chung, J. Thompson, D. Shuh, T. Albrecht-Schmitt, T. Gouder, 2008, ISBN 978-1-60511-074-5
Volume 1105E —The Role of Lifelong Education in Nanoscience and Engineering, D. Palma, L. Bell, R. Chang, R. Tomellini, 2008, ISBN 978-1-60511-075-2
Volume 1106E —The Business of Nanotechnology, L. Merhari, A. Gandhi, S. Giordani, L. Tsakalakos, C. Tsamis, 2008, ISBN 978-1-60511-076-9
Volume 1107 — Scientific Basis for Nuclear Waste Management XXXI, W.E. Lee, J.W. Roberts, N.C. Hyatt, R.W. Grimes, 2008, ISBN 978-1-60511-079-0

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