Wide-Bandgap Semiconductors for High Power, High Frequency and High Temperature

MATERIALS RESEARCH SOCIETY
SYMPOSIUM PROCEEDINGS VOLUME 512

Wide-Bandgap Semiconductors for High Power, High Frequency and High Temperature

Symposium held April 13–15, 1998, San Francisco, California, U.S.A.

EDITORS:

Steven DenBaars
University of California
Santa Barbara, California, U.S.A.

John Palmour
Cree Research, Inc.
Durham, North Carolina, U.S.A.

Michael Shur
Rensselaer Polytechnic Institute
Troy, New York, U.S.A.

Michael Spencer
Howard University
Washington, D.C., U.S.A.

MRS
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/9781107413641

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

First published 1998
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 978-1-107-41364-1 Paperback

CONTENTS

*Invited Paper

*Invited Paper

PART V: PROCESSING CHARACTERIZATION AND PROPERTIES OF WIDE-BANDGAP MATERIALS

PREFACE

Wide-bandgap semiconductors have a long and illustrious history, starting with the first paper on SiC light-emitting diodes published by Round in 1907. However, in the last few years the number of papers on wide-bandgap semiconductors has skyrocketed. Improved material quality, important breakthroughs both in SiC and GaN technologies (most notably the development of 4H-SiC technology and SiC semi-insulating substrates), and the emergence of blue GaN-based lasers, stimulated this progress. Much credit should also go to the funding agencies, which made wide-bandgap semiconductor research a priority. Applications for this emerging technology include high-power, high-temperature, and high-frequency systems.

The symposium attracted a wide range of researchers who presented 128 papers throughout seven different sessions. Papers cover GaN-based and SiC-based devices, issues related to crystal growth, and processing and characterization of wide-bandgap materials. The invited speakers presented an excellent overview of the current state of the art and made projections for future developments. Overall, these proceedings give a fairly complete and up-to-date picture of this important field and include most of the work presented at the conference.

We would like to thank our invited speakers, Doctors Baliga, Eastman, Mishra, Khan, Slack, and Tsvetkov, and session chairs Jamie Freitas, Steve Pearton, Eric Hellman, Pirouz Pirouz, and Randy Shul. We are also grateful to our colleagues, Professor Tor Fjeldly, Dr. Stephen O'Leary, Dr. James Lu, Dr. Benjamin Iniguez, Mr. Brian Foutz, and Mr. Peter Necluidov, for their help in the preparation of this volume, as well as to the many dedicated anonymous reviewers who made this publication possible.

Generous financial support from AIXTRON, Inc., Cree Research, Inc., EMCORE Corporation, and Northrop Grumman Science and Technology Center also contributed to the success of the symposium.

Steven DenBaars
John Palmour
Michael Shur
Michael Spencer

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

Volume 481— Phase Transformation and Systems Driven Far From Equilibrium, E. Ma, P. Bellon, M. Atzmon, R. Trivedi, 1998, ISBN: 1-55899-386-X
Volume 482— Nitride Semiconductors, F.A. Ponce, S.P. DenBaars, B.K. Meyer, S. Nakamura, S. Strite, 1998, ISBN: 1-55899-387-8
Volume 483— Power Semiconductor Materials and Devices, S.J. Pearton, R.J. Shul, E. Wolfgang, F. Ren, S. Tenconi, 1998, ISBN: 1-55899-388-6
Volume 484— Infrared Applications of Semiconductors II, S. Sivananthan, M.O. Manasreh, R.H. Miles, D.L. McDaniel, Jr., 1998, ISBN: 1-55899-389-4
Volume 485— Thin-Film Structures for Photovoltaics, E.D. Jones, R. Noufi, B.L. Sopori, J. Kalejs, 1998, ISBN: 1-55899-390-8
Volume 486— Materials and Devices for Silicon-Based Optoelectronics, J.E. Cunningham, S. Coffa, A. Polman, R. Soref, 1998, ISBN: 1-55899-391-6
Volume 487— Semiconductors for Room-Temperature Radiation Detector Applications II, R.B. James, T.E. Schlesinger, P. Siffert, M. Cuzin, M. Squillante, W. Dusi, 1998, ISBN: 1-55899-392-4
Volume 488— Electrical, Optical, and Magnetic Properties of Organic Solid-State Materials IV, J.R. Reynolds, A.K-Y. Jen, L.R. Dalton, M.F. Rubner, L.Y. Chiang, 1998, ISBN: 1-55899-393-2
Volume 489— Materials Science of the Cell, B. Mulder, V. Vogel, C. Schmidt, 1998, ISBN: 1-55899-394-0
Volume 490— Semiconductor Process and Device Performance Modeling, J.S. Nelson, C.D. Wilson, S.T. Dunham, 1998, ISBN: 1-55899-395-9
Volume 491— Tight-Binding Approach to Computational Materials Science, P.E.A. Turchi, A. Gonis, L. Colombo, 1998, ISBN: 1-55899-396-7
Volume 492— Microscopic Simulation of Interfacial Phenomena in Solids and Liquids, S.R. Phillpot, P.D. Bristowe, D.G. Stroud, J.R. Smith, 1998, ISBN: 1-55899-397-5
Volume 493— Ferroelectric Thin Films VI, R.E. Treece, R.E. Jones, S.B. Desu, C.M. Foster, I.K. Yoo, 1998, ISBN: 1-55899-398-3
Volume 494— Science and Technology of Magnetic Oxides, M. Hundley, J. Nickel, R. Ramesh, Y. Tokura, 1998, ISBN: 1-55899-399-1
Volume 495— Chemical Aspects of Electronic Ceramics Processing, P.N. Kumta, A.F. Hepp, D.B. Beach, J.J. Sullivan, B. Arkles, 1998, ISBN: 1-55899-400-9
Volume 496— Materials for Electrochemical Energy Storage and Conversion II—Batteries, Capacitors and Fuel Cells, D.S. Ginley, D.H. Doughty, T. Takamura, Z. Zhang, B. Scrosati, 1998, ISBN: 1-55899-401-7
Volume 497— Recent Advances in Catalytic Materials, N.M. Rodriguez, S.L. Soled, J. Hrbek, 1998, ISBN: 1-55899-402-5
Volume 498— Covalently Bonded Disordered Thin-Film Materials, M.P. Siegal, J.E. Jaskie, W. Milne, D. McKenzie, 1998, ISBN: 1-55899-403-3
Volume 499— High-Pressure Materials Research, R.M. Wentzocovitch, R.J. Hemley, W.J. Nellis, P.Y. Yu, 1998, ISBN: 1-55899-404-1
Volume 500— Electrically Based Microstructural Characterization II, R.A. Gerhardt, M.A. Alim, S.R. Taylor, 1998, ISBN: 1-55899-405-X
Volume 501— Surface-Controlled Nanoscale Materials for High-Added-Value Applications, K.E. Gonsalves, M-I. Baraton, J.X. Chen, J.A. Akkara, 1998, ISBN: 1-55899-406-8
Volume 502— *In Situ* Process Diagnostics and Intelligent Materials Processing, P.A. Rosenthal, W.M. Duncan, J.A. Woollam, 1998, ISBN: 1-55899-407-6
Volume 503— Nondestructive Characterization of Materials in Aging Systems, R.L. Crane, S.P. Shah, R. Gilmore, J.D. Achenbach, P.T. Khuri-Yakub, T.E. Matikas, 1998, ISBN: 1-55899-408-4
Volume 504— Atomistic Mechanisms in Beam Synthesis and Irradiation of Materials, J.C. Barbour, S. Roorda, D. Ila, 1998, ISBN: 1-55899-409-2
Volume 505— Thin-Films—Stresses and Mechanical Properties VII, R.C. Cammarata, E.P. Busso, M. Nastasi, W.C. Oliver, 1998, ISBN: 1-55899-410-6
Volume 506— Scientific Basis for Nuclear Waste Management XX, I.G. McKinley, C. McCombie, 1998, ISBN: 1-55899-411-4
Volume 507— Amorphous and Microcrystalline Silicon Technology—1998, S. Wagner, M. Hack, H.M. Branz, R. Schropp, I. Shimizu, 1998, ISBN: 1-55899-413-0

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

Volume 508— Flat-Panel Display Materials—1998, G. Parsons, T.S. Fahlen, S. Morozumi, C. Seager, C-C. Tsai, 1998, ISBN: 1-55899-414-9
Volume 509— Materials Issues in Vacuum Microelectronics, W. Zhu, L.S. Pan, T.E. Felter, C. Holland, 1998, ISBN: 1-55899-415-7
Volume 510— Defect and Impurity Engineered Semiconductors and Devices II, S. Ashok, J. Chevallier, K. Sumino, B.L. Sopori, W. Goetz, 1998, ISBN: 1-55899-416-5
Volume 511— Low-Dielectric Constant Materials IV, C. Chiang, J.T. Wetzel, T-M. Lu, P.S. Ho, 1998, ISBN: 1-55899-417-3
Volume 512— Wide-Bandgap Semiconductors for High Power, High Frequency and High Temperature, S. DenBaars, M.S. Shur, J. Palmour, M. Spencer, 1998, ISBN: 1-55899-418-1
Volume 513— Hydrogen in Semiconductors and Metals, N.H. Nickel, W.B. Jackson, R.C. Bowman, 1998, ISBN: 1-55899-419-X
Volume 514— Advanced Interconnects and Contact Materials and Processes for Future Integrated Circuits, S.P. Murarka, D.B. Fraser, M. Eizenberg, R. Tung, R. Madar, 1998, ISBN: 1-55899-420-3
Volume 515— Electronic Packaging Materials Science X, D.J. Belton, R. Pearson, M. Gaynes, E.G. Jacobs, 1998, ISBN: 1-55899-421-1
Volume 516— Materials Reliability in Microelectronics VIII, T. Marieb, J. Bravman, M.A. Korhonen, J.R. Lloyd, 1998, ISBN: 1-55899-422-X
Volume 517— High-Density Magnetic Recording and Integrated Magneto-Optics: Materials and Devices, K. Rubin, J.A. Bain, T. Nolan, D. Bogy, B.J.H. Stadler, M. Levy, J.P. Lorenzo, M. Mansuripur, Y. Okamura, R. Wolfe, 1998, ISBN: 1-55899-423-8
Volume 518— Microelectromechanical Structures for Materials Research, S.B. Brown, C. Muhlstein, P. Krulevitch, G.C. Johnston, R.T. Howe, J.R. Gilbert, 1998, ISBN: 1-55899-424-6
Volume 519— Organic/Inorganic Hybrid Materials, R.M. Laine, C. Sanchez, E. Giannelis, C.J. Brinker, 1998, ISBN: 1-55899-425-4
Volume 520— Nanostructured Powders and Their Industrial Application, G. Beaucage, J.E. Mark, G. Burns, H. Duen-Wu, 1998, ISBN: 1-55899-426-2
Volume 521— Porous and Cellular Materials for Structural Applications, D.S. Schwartz, D.S. Shih, H.N.G. Wadley, A.G. Evans, 1998, ISBN: 1-55899-427-0
Volume 522— Fundamentals of Nanoindentation and Nanotribology, N.R. Moody, W.W. Gerberich, S.P. Baker, N. Burnham, 1998, ISBN: 1-55899-428-9
Volume 523— Electron Microscopy of Semiconducting Materials and ULSI Devices, C. Hayzelden, F.M. Ross, C.J.D. Hetherington, 1998, ISBN: 1-55899-429-7
Volume 524— Application of Synchrotron Radiation Techniques to Materials Science IV, S.M. Mini, D.L. Perry, S.R. Stock, L.J. Terminello, ISBN: 1-55899-430-0
Volume 525— Rapid Thermal and Integrated Processing VII, M.C. Öztürk, F. Roozeboom, P.J. Timans, S.H. Pas, 1998, ISBN: 1-55899-431-9
Volume 526— Advances in Laser Ablation of Materials, R.K. Singh, D.H. Lowndes, D.B. Chrisey, J. Narayan, T. Kawai, E. Fogarassy, 1998, ISBN: 1-55899-432-7
Volume 527— Diffusion Mechanisms in Crystalline Materials, Y. Mishin, N.E.B. Cowern, C.R.A. Catlow, D. Farkas, G. Vogl, 1998, ISBN: 1-55899-433-5
Volume 528— Mechanisms and Principles of Epitaxial Growth in Metallic Systems, L.T. Wille, C.P. Burmester, K. Terakura, G. Comsa, E.D. Williams, 1998, ISBN: 1-55899-434-3
Volume 529— Computational and Mathematical Models of Microstructural Evolution, J.W. Bullard, R. Kalia, M. Stoneham, L-Q. Chen, 1998, ISBN: 1-55899-435-1
Volume 530— Biomaterials Regulating Cell Function and Tissue Development, D. Mooney, A.G. Mikos, K.E. Healy, Y. Ikada, R.C. Thomson, 1998, ISBN: 1-55899-436-X
Volume 531— Reliability of Photonics Materials and Structures, E. Suhir, M. Fukuda, C.R. Kurkjian 1998, ISBN: 1-55899-437-8
Volume 532— Silicon Front-End Technology—Materials Processing and Modelling, N.E.B. Cowern, D. Jacobson, P. Griffin, P. Packan, R. Webb, 1998, ISBN: 1-55899-438-6
Volume 533— Epitaxy and Applications of Si-Based Heterostructures, E.A. Fitzgerald, P.M. Mooney, D.C. Houghton, 1998, ISBN: 1-55899-439-4

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