
Gallium Nitride and Silicon Carbide Power Technologies 3

Editors:**K. Shenai**

Argonne National Laboratory
Argonne, Illinois, USA

M. Dudley

Stony Brook University
Stony Brook, New York, USA

M. Bakowski

Acreeo – Sweden
Kista, Sweden

N. Ohtani

Kwansei Gakuin University
Sanda, Hyogo, Japan

Sponsoring Divisions:**Electronics and Photonics****Dielectric Science & Technology**

Published by

The Electrochemical Society65 South Main Street, Building D
Pennington, NJ 08534-2839, USA

tel 609 737 1902

fax 609 737 2743

www.electrochem.org**ecs transactions**™**Vol. 58, No. 4**

Copyright 2013 by The Electrochemical Society.
All rights reserved.

This book has been registered with Copyright Clearance Center.
For further information, please contact the Copyright Clearance Center,
Salem, Massachusetts.

Published by:

The Electrochemical Society
65 South Main Street
Pennington, New Jersey 08534-2839, USA

Telephone 609.737.1902
Fax 609.737.2743
e-mail: ecs@electrochem.org
Web: www.electrochem.org

ISSN 1938-6737 (online)
ISSN 1938-5862 (print)
ISSN 2151-2051 (cd-rom)

ISBN 978-1-62332-095-9 (Hardcover)
ISBN 978-1-60768-449-7 (PDF)

Printed in the United States of America.

Table of Contents

Preface *iii*

Chapter 1 Plenary Session

A Thermodynamic Interpretation of PVT Growth of Single Crystal SiC Material and Challenges in Reducing Dislocations *3*

*T. Fujimoto, M. Katsuno, H. Tsuge, S. Sato, S. Ushio, K. Tani, H. Yashiro,
H. Hirano, T. Yano*

Unexpected Sources of Basal Plane Dislocations in 4H-SiC Epitaxy *9*

R. E. Stahlbush, N. A. Mahadik

Correlation between Defects and Electrical Characteristics/Reliability Analyzed by Integrated Evaluation Platform for SiC *17*

M. Kitabatake

Growth of High-Quality GaN Template from Nanometer-Size Lattice Channels by Hydride Vapor Phase Epitaxy *25*

*A. Usui, H. Goto, T. Matsueda, H. Sunakawa, T. Nakagawa, A. Okada, J. Mizuno,
A. A. Yamaguchi, H. Shinohara, H. Goto*

Packaging Techniques for Compact SiC Power Modules Operable in an Extended T_j Range *33*

S. Tanimoto, K. Watanabe, H. Tanisawa, K. Matsui, S. Sato

Chapter 2 SiC MOS Power Devices

Channel Transport in 4H-SiC MOSFETs: A Brief Review *51*

S. Dhar

Properties of Al-SiO ₂ -SiC(3C) Structures with Thermally Grown and PECVD Deposited SiO ₂ Layers <i>H. M. Przewlocki, T. Gutt, K. Piskorski, P. Borowicz, M. Bakowski</i>	61
Influence of Ion Implantation in SiC on the Channel Mobility in Lateral N-Channel MOSFETs <i>C. Strenger, V. Uhnevionak, A. Burenkov, A. Bauer, P. Pichler, T. Erlbacher, H. Ryssel, L. Frey</i>	71
On the Temperature Dependence of the Hall Factor in n-Channel 4H-SiC MOSFETs <i>V. Uhnevionak, A. Burenkov, C. Strenger, A. Bauer, P. Pichler</i>	81
Key Reliability Issues for SiC Power MOSFETs <i>A. Lelis, D. Habersat, R. Green, E. Mooro</i>	87

Chapter 3 SiC Epitaxy

Comparison of SiC Epitaxial Growth from Dichlorosilane and Tetrafluorosilane Precursors <i>H. Song, T. Rana, M. V. S. Chandrashekhar, S. U. Omar, T. S. Sudarshan</i>	97
Reducing the Wafer Off Angle for 4H-SiC Homoepitaxy <i>K. Kojima, K. Masumoto, S. Ito, A. Nagata, H. Okumura</i>	111
3C-SiC on Si Hetero-Epitaxial Growth for Electronic and Biomedical Applications <i>M. Reyes, C. Frewin, P. J. Ward, S. E. Saddow</i>	119

Chapter 4 GaN Power Devices 1

III-Nitride Materials and Devices for Power Electronics <i>A. Dobrinsky, G. Simin, R. Gaska, M. Shur</i>	129
Normally-Off GaN Transistors for Power Switching Applications <i>O. Hilt, E. Bahat-Treidel, F. Brunner, A. Knauer, R. Zhytnytska, P. Kotara, J. Wuerfl</i>	145

High Performance Normally-off GaN MOSFETs on Si Substrates <i>H. Kambayashi, N. Ikeda, T. Nomura, H. Ueda, Y. Morozumi, K. Harada, K. Hasebe, A. Teramoto, S. Sugawa, T. Ohmi</i>	155
Characterization and Performance of D-Mode GaN HEMT Transistor Used in a Cascode Configuration <i>T. MacElwee, J. Roberts, H. Lafontaine, I. Scott, G. Klowak, L. Yushyna</i>	167
Voltage Switching Limits of Lateral GaN Power Devices <i>K. Shenai</i>	179

Chapter 5 **Power Device Reliability 1**

GaN-Based Power HEMTs: Parasitic, Reliability and High Field Issues <i>G. Meneghesso, M. Meneghini, D. Bisi, R. Silvestri, A. Zanandrea, O. Hilt, E. Bahat-Treidel, F. Brunner, A. Knauer, J. Wuerfl, E. Zanoni</i>	187
True Figure of Merit (FOM) of a Power Semiconductor Switch <i>K. Shenai</i>	199
Progress in SiC MOSFET Reliability <i>D. R. Hughart, J. D. Flicker, S. DasGupta, S. Atcitty, R. J. Kaplar, M. J. Marinella</i>	211
Reliability of GaN HEMTs: Electrical and Radiation-Induced Failure Mechanism <i>T. J. Anderson, A. D. Koehler, M. J. Tadjer, K. D. Hobart, P. Specht, M. Porter, T. R. Weatherford, B. Weaver, J. K. Hite, F. J. Kub</i>	221

Chapter 6 **Power Semiconductor Curriculum**

Systems-Driven Power Semiconductor Education <i>K. Shenai</i>	229
Power Semiconductor Device Education: Which Topics and What Depth <i>W. P. Robbins, N. Mohan</i>	237
Power Semiconductor Device, Course Contents Revisited <i>I. M. Abdel-Motaleb</i>	245

Power Electronic Module Packaging at UA <i>S. S. Ang, H. A. Mantooth, J. C. Balda</i>	253
--	-----

Chapter 7 **GaN Power Devices 2**

III-N High-Power Bipolar Transistors <i>R. D. Dupuis, J. Kim, Y. C. Lee, Z. Lochner, M. H. Ji, T. T. Kao, J. H. Ryou, T. Detchphrom, S. C. Shen</i>	261
AlGaN/GaN MIS-HEMT Gate Structure Improvement Using Al ₂ O ₃ Deposited by PEALD and BC _l ₃ Gate Recess Etching <i>R. Meunier, A. Torres, M. Charles, E. Morvan, M. Plissonnier, F. Morancho</i>	269
GaN Power Transistors with Integrated Thermal Management <i>C. R. Eddy Jr., T. J. Anderson, A. D. Koehler, N. Nepal, D. J. Meyer, M. J. Tadjer, R. Baranyai, J. W. Pomeroy, M. Kuball, T. I. Feygelson, B. B. Pate, M. A. Mastro, J. K. Hite, M. G. Ancona, F. J. Kub, K. D. Hobart</i>	279
Ammonothermal Bulk GaN Substrates for Power Electronics <i>M. P. D'Evelyn, D. Ehrentraut, W. Jiang, D. S. Kamber, B. C. Downey, R. T. Pakalapati, H. D. Yoo</i>	287
1000V Vertical JFET Using Bulk GaN <i>Q. Diduck, H. Nie, B. Alvarez, A. Edwards, D. Bour, O. Aktas, D. Disney, I. C. Kizilyalli</i>	295

Chapter 8 **Manufacturing Challenges**

Manufacturing Challenges in Wide Band Gap (WBG) Power Electronics <i>K. Shenai</i>	301
Production Readiness of AlGaN/GaN HEMT on 6"/8" Si <i>D. S. Lee, J. Su, B. Krishnan, G. D. Papasouliotis, A. Paranjpe</i>	311

Synchrotron X-ray Topography Studies of the Evolution of the Defect Microstructure in Physical Vapor Transport Grown 4H-SiC Single Crystals <i>M. Dudley, B. Raghothamachar, H. Wang, F. Wu, S. Byrappa, G. Chung, E. K. Sanchez, S. Mueller, D. Hansen, M. Loboda</i>	315
--	-----

Basal Plane Dislocation Mitigation Using High Temperature Annealing in 4H-SiC Epitaxy <i>N. A. Mahadik, A. Nath, E. A. Imhoff, R. E. Stahlbush, R. Nipoti</i>	325
---	-----

3D TCAD Simulations for More Efficient SiC Power Devices Design <i>L. V. Phung, D. Planson, P. Brosselard, D. Tournier, C. Brylinski</i>	331
---	-----

Chapter 9 Power Device Reliability 2

Heat Dissipation in GaN Based Power Electronics <i>Z. Su, J. A. Malen</i>	343
--	-----

High Voltage InAlN/GaN HFETs Achieved by Schottky-Contact Technology for Power Applications <i>Q. Zhou, W. Chen, S. Liu, B. Zhang, Z. Feng, S. Cai, K. J. Chen</i>	351
--	-----

Interaction of Defects with Quantum Well States: Electrostatic-Dependant Response Time for Traps in AlGaN/GaN HEMTs <i>M. J. Marinella, S. DasGupta, R. J. Kaplar, M. Sun, S. Atcitty, T. Palacios</i>	365
--	-----

Monolithic Integration of High Temperature Silicon Carbide Integrated Circuits <i>M. Alexandru, V. Banu, J. Montserrat, P. Godignon, J. Millán</i>	375
---	-----

Chapter 10 Power Electronics Curriculum

Power Semiconductor Device Modeling and Simulation <i>H. A. Mantooth, S. Ahmed, S. S. Ang</i>	391
--	-----

Application Engineering of Wide Bandgap Semiconductors <i>B. Sarlioglu, D. Han, J. Noppakunkajorn, A. Ogale</i>	399
--	-----

Studying the Performance of Series-Connected GaN FETs in Higher Voltage Switching Applications <i>A. Hasanzadeh, A. Khaligh</i>	413
Chapter 11	
Material Synthesis and Processing	
Materials Issues for Vertical Gallium Nitride Power Devices <i>A. D. Williams, T. D. Moustakas</i>	427
Electrochemical Hydrogenation of Dimensional Carbon <i>K. M. Daniels, S. Shetu, J. Staser, J. W. Weidner, C. Williams, T. Sudarshan, M. V. S. Chandrashekhar</i>	439
Abrasive-Free Polishing of SiC Wafer Utilizing Catalyst Surface Reaction <i>Y. Sano, K. Arima, K. Yamauchi</i>	447
Growth of GaN by MOCVD on Rare Earth Oxide on Si(111) <i>F. E. Arkun, R. Dargis, A. Clark, R. S. Smith, M. Lebby, J. M. Leathersich, F. Shahedipour-Sandvik</i>	455
Author Index	463