FRONTIERS OF CHARACTERIZATION AND METROLOGY FOR NANOELECTRONICS: 2011

Grenoble, France 23 – 26 May 2011

EDITORS

David G. Seiler
National Institute of Standards and Technology
Gaithersburg, MD, USA

Alain C. Diebold
College of Nanoscale Science and Engineering
SUNY Albany, Albany, NY, USA

Robert McDonald
Technology Associates, Monte Sereno, CA, USA

Amal Chabli
CEA-Leti, Grenoble, France

Erik M. Secula
National Institute of Standards and Technology
Gaithersburg, MD, USA

All papers have been peer reviewed.

SPONSORING ORGANIZATIONS

Sponsors:
National Institute of Standards and Technology
College of Nanoscale Science and Engineering
CEA-LETI
MINATEC
SEMI
Semiconductor Research Corporation (SRC)
International SEMATECH Manufacturing Initiative (ISMI)
AVS
National Science Foundation (NSF)
American Physical Society (APS)
IEEE/Electron Devices Society

Gold Sponsors:
Metryx
CEA-LETI
NIST

Local Authorities:
City of Grenoble
Grenoble Suburb Community
Rhône-Alpes Region

Silver Sponsors:
Jordan Valley
Institut Nanosciences et Cryogenie

AIP
American Institute of Physics

Melville, New York, 2011
AIP | CONFERENCE PROCEEDINGS ■ 1395

Editors

David G. Seiler
National Institute of Standards and Technology
MS 8120
Gaithersburg, MD 20899-8120
USA

E-mail: david.seiler@nist.gov

Alain C. Diebold
College of Nanoscale Science and Engineering
SUNY Albany
Albany, NY 12203
USA

E-mail: ADiebold@uamail.albany.edu

Robert McDonald
Technology Associates
15270 Elm Park Ct.
Monte Sereno, CA 95030
USA

E-mail: mcdonald.r@comcast.net

Amal Chabli
CEA-Leti
MINATEC Campus
17 rue des Martyrs
38054 Grenoble Cedex 9
France

E-mail: amal.chabli@cea.fr

Erik M. Secula
National Institute of Standards and Technology
MS 8120
Gaithersburg, MD 20899-8120
USA

E-mail: erik.secula@nist.gov

Cover image provided courtesy of David Cooper, CEA-Leti. The image shows an electrical potential map of an nMOS device with a gate length of 40 nm showing the active dopants in the doped source and drain regions. The map was obtained by off-axis electron holography using a FEI Titan TEM operated at 200 kV.

Authorization to photocopy items for internal or personal use, beyond the free copying permitted under the 1978 U.S. Copyright Law (see statement below), is granted by the American Institute of Physics for users registered with the Copyright Clearance Center (CCC) Transactional Reporting Service, provided that the base fee of $30.00 per copy is paid directly to CCC, 222 Rosewood Drive, Danvers, MA 01923, USA http://www.copyright.com. For those organizations that have been granted a photocopy license by CCC, a separate system of payment has been arranged. The fee code for users of the Transactional Reporting Services is: 978-0-7354-0965-1/11/$30.00

© 2011 American Institute of Physics

No claim is made to original U.S. Government works.

Permission is granted to quote from the AIP Conference Proceedings with the customary acknowledgment of the source. Republication of an article or portions thereof (e.g., extensive excerpts, figures, tables, etc.) in original form or in translation, as well as other types of reuse (e.g., in course packs) require formal permission from AIP and may be subject to fees. As a courtesy, the author of the original proceedings article should be informed of any request for republication/reuse. Permission may be obtained online using RightsLink. Locate the article online at http://proceedings.aip.org, then simply click on the RightsLink icon/“Permissions/Reprints” link found in the article abstract. You may also address requests to: AIP Office of Rights and Permissions, Suite 1NO1, 2 Huntington Quadrangle, Melville, NY 11747-4502, USA; Fax: 516-576-2450; Tel.: 516-576-2268; E-mail: rights@aip.org.

L.C. Catalog Card No. 2011936790
ISBN 978-0-7354-0965-1"*Qtkikpcn"Rtkpv+
ISBN 978-0-7354-0973-6 (CD-ROM)
ISSN 0094-243X
Printed in the United States of America

AIP Conference Proceedings, **Volume 1395**
Frontiers of Characterization and Metrology for Nanoelectronics: 2011

Table of Contents

Preface: Frontiers of Characterization and Metrology for Nanoelectronics 2011
David G. Seiler, Alain C. Diebold, Robert McDonald, Amal Chabli, and Erik M. Secula 1

Committees 3

More than Moore or More Moore: A SWOT analysis
G. Dan Hutcheson and Herbert S. Bennett 4

KEYNOTE

Nanocharacterization challenges in a changing microelectronics landscape
Michel Brillouët 15

Nanoelectronics and More-than-Moore at IMEC
Rudi Cartuyvels, Serge Biesemans, Wilfried Vandervorst, and Jo De Boeck 24

OVERVIEWS FOR NANOELECTRONICS AND METROLOGY

Overview of optical metrology of advanced semiconductor materials
Vimal K. Kamineni and A. C. Diebold 33

METROLOGY FOR BEYOND CMOS

Metrology and characterization challenges for emerging research materials and devices
C. Michael Garner, Dan Herr, and Yaw Obeng 43

THEORY, MODELING, AND SIMULATION

Effects of roughness on scatterometry signatures
M. Foldyna, T. A. Germer, and B. C. Bergner 49

MICROSCOPY FOR NANOELECTRONICS

TSOM method for nanoelectronics dimensional metrology
Ravikiran Attota 57

Field mapping of semiconductors in a state-of-the-art electron microscope
David Cooper, Armand Béché, Jean-Luc Rouvière, Germain Servanton, Roland Pantel, Pierre Morin, and Amal Chabli 64

Investigation of boron redistribution during silicidation in $TiSi_2$ using Atom Probe Tomography
K. Wedderhoff, M. Ogiewa, A. Shariq, and S. Teichert 74

Scanning He+ ion beam microscopy and metrology
David C. Joy 80

MOTIS: A focused ion beam source based on laser-cooled atoms
B. Knuffman, A. V. Steele, J. Orloff, M. Maazouz, and J. J. McClelland 85

Characterization of strain induced by PECVD silicon nitride films in transistor channels
R. Thomas, D. Benoit, L. Clément, P. Morin, D. Cooper, and F. Bertin 90

Recent advances in 2D-band structure imaging by *k*-PEEM and prospects for technological materials
C. Mathieu, O. Renault, H. Rotella, N. Barrett, and A. Chabli 95

Characterization of nanodevices by STEM tomography
O. Richard, A. Vandooren, G. S. Kar, P. Van Marcke, and H. Bender 100

Annealed Si/SiGeC superlattices studied by dark-field electron holography, ToF-SIMS and infrared spectroscopy
T. Denneulin, J. L. Rouvière, A. Béché, M. Py, J. P. Barnes, N. Rochat, J. M. Hartmann, and D. Cooper 105

NOVEL CHARACTERIZATION METHODS

Analytical study of BAM (Al/GaAs) and photovoltaic samples using state-of-the-art Auger nanoprobes
P. Yadav, M. Bouttemy, E. Martinez, J. Vigneron, O. Renault, P. Mur, D. Munoz, A. Etcheberry, and A. Chabli 113

The protocol of KFM characterization on cross-section of CdS/CdTe thin film solar cell
L. You, N. Chevalier, S. Bernardi, E. Martinez, D. Mariolle, G. Feuillet, M. Kogelschatz, G. Bremond, A. Chabli, and F. Bertin 118

Enhanced spatial resolution electrical scanning probe microscopy by using carbon nanotube terminated tips
Joseph J. Kopanski, Ilona Sitnitsky, Victor Vartanian, Paul McClure, and Vladimir Mancevski 123

High resolution multiwavelength μ-Raman spectroscopy for nanoelectronic material characterization applications
Victor Vartanian, Takeshi Ueda, Toshikazu Ishigaki, Kitaek Kang, and Woo Sik Yoo 128

Current voltage characteristics through grains and grain boundaries of high-k dielectric thin films measured by tunneling atomic force microscopy
Katsuhisa Murakami, Mathias Rommel, Vasil Yanev, Anton J. Bauer, and Lothar Frey 134

Electrical characterization of resistive switching memories
An Chen and Ming-Ren Lin 139

Observation of work functions, metallicity, band bending, interfacial dipoles by EUPS for characterizing high-k/metal interfaces
Toshihisa Tomie, Tomoaki Ishitsuka, Teruhisa Ootsuka, and Hiroyuki Ota 148

Multi-technique approach for the evaluation of the crystalline phase of ultrathin high-*k* gate oxide films
E. Bersch, J. D. LaRose, I. Wells, S. Consiglio, R. D. Clark, G. J. Leusink, R. J. Matyi, and A. C. Diebold 154

SiC epitaxial layer resistivity monitoring; a look at existing and novel electrical methods
Robert J. Hillard and Edward Tsidilkovski 161

UV-photoreflectance and Raman characterization of strain relaxation in Si on silicon-germanium films
Michael Current, Will Chism, Woo Sik Yoo, and Victor Vartanian 165

Ultimate backside sample preparation for ultra thin high-k/metal gate stack characterization
M. Py, M. Veillerot, E. Martinez, J. M. Fabbri, R. Boujamaa, J. P. Barnes, and F. Bertin 171

Thin films mechanical characterization using Colored Picosecond Acoustics
Patrick Emery 176

CMOS METROLOGY

Metrology challenges for the ultra-thin SOI
Oleg Kononchuk, Gregory Riou, Roland Brun, and Cecile Moulin 183

Thickness variation of HfO_2 films under post-deposition annealing investigated by X-ray reflectivity and X-ray photoelectron spectroscopy
Yong-Qing Chang and Wei-En Fu 188

Atomic layer deposited Al_2O_3 as characterized reference samples for nanolayer metrology
A. Nutsch, M. Lemberger, and P. Petrik 193

A novel X-ray diffraction and reflectivity tool for front-end of line metrology
M. Wormington, B. Yokhin, D. Berman, A. Krokhmal, I. Mazor, P. Ryan, J. Wall, and R. Bytheway 198

A method for USJ process control
Edward Tsidilkovski 204

Advanced use of Therma-Probe for ultra-shallow junction monitoring
Janusz Bogdanowicz, Trudo Clarysse, Gerrit Smets, Erik Rosseel, and Wilfried Vandervorst 208

Advanced metrologies for topography and thickness measurements
G. Riou, P. Acosta, M. Darwin, and B. Kamenev 212

The impact of organic contamination on the oxide-silicon interface
D. Codegoni, M. L. Polignano, L. Castellano, G. Borionetti, F. Bonoli, A. Nutsch, A. Leibold, and M. Otto 217

Analysis of the noble metals on silicon wafers by chemical collection and ICPMS
H. Fontaine, D. Hureau, M. Groz, D. Despois, and C. Louis 222

Advanced monitoring of trace metals applied to contamination reduction of silicon device processing
P. Maillot, C. Martin, and A. Planchais 227

INTERCONNECT METROLOGY

Metrology and failure analysis for 3D IC integration
Ehrenfried Zschech and Alain Diebold 233

Nanomechanical characterization and metrology for low-k and ULK materials
Ude D. Hangen, Kong-Boon Yeap, David Vodnick, Ehrenfried Zschech, Han Li, and Joost Vlassak 240

Stress-induced effects caused by 3D IC TSV packaging in advanced semiconductor device performance
V. Sukharev, A. Kteyan, J.-H. Choy, H. Hovsepyan, A. Markosian, E. Zschech, and R. Huebner 249

Reliability testing of advanced interconnect materials
R. R. Keller, M. C. Strus, A. N. Chiaramonti, Y. L. Kim, Y. J. Jung, and D. T. Read 259

Measurement of nanograin orientations: Application to Cu interconnects
G. Brunetti, R. Galand, J. L. Rouvière, L. Clément, C. Cayron, E. F. Rauch, D. Robert, J. F. Martin, F. Bertin, and A. Chabli 264

Characterization and failure analysis of 3D integrated systems using a novel plasma-FIB system
Laurens Kwakman, German Franz, Maaike Margrete Visser Taklo, Armin Klumpp, and Peter Ramm 269

FIB/SEM structural analysis of through-silicon-vias
H. Bender, C. Drijbooms, and A. Radisic 274

METROLOGY FOR PATTERNING

Overview of mask metrology
Bryan J. Rice, Vibhu Jindal, C. C. Lin, Jenah Harris-Jones, Hyuk Joo Kwon, Hsing-Chien Ma, Michael Goldstein, Yau-Wai Chan, and Frank Goodwin 281

Hybrid metrology & 3D-AFM enhancement for CD metrology dedicated to 28 nm node and below requirements
J. Foucher, P. Faurie, L. Dourthe, B. Irmer, and C. Penzkofer 290

Advances in CD-metrology (CD-SAXS, Mueller Matrix based scatterometry, and SEM)
Bradley L. Thiel, Aron J. Cepler, Alain C. Diebold, and Richard J. Matyi 298

Line edge roughness of directed self-assembly PS-PMMA block copolymers—A candidate for future lithography
Chengqing Wang, Gila E. Stein, August W. Bosse, and Wen-li Wu 305

A traceable scatterometry measurement of a silicon line grating
Thomas A. Germer, Heather J. Patrick, and Ronald G. Dixson 309

Micro roughness determination of periodic microelectronics structures using optical far field measurements
Alexandre Vauselle, Philippe Maillot, Gaëlle Georges, and Carole Deumié 314

Joint research on scatterometry and AFM wafer metrology
Bernd Bodermann, Egbert Buhr, Hans-Ulrich Danzebrink, Markus Bär, Frank Scholze, Michael Krumrey, Matthias Wurm, Petr Klapetek, Poul-Erik Hansen, Virpi Korpelainen, Marijn van Veghel, Andrew Yacoot, Samuli Siitonen, Omar El Gawhary, Sven Burger, and Toni Saastamoinen 319

Fourier scatterometry for characterization of sub-wavelength periodic two photon polymerization structures
K. Frenner, V. Ferreras Paz, S. Peterhänsel, W. Osten, A. Ovsianikov, K. Obata, and B. Chichkov 324

NEXT-GENERATION DEFECT INSPECTION

Fundamental limits of optical patterned defect metrology
Richard M. Silver, Bryan M. Barnes, Yeung-Joon Sohn, Hui Zhou, and Jing Qin 333

CHARACTERIZATION NEEDS AND METHODS FOR "MORE THAN MOORE"

Positioning More than Moore characterization needs and methods within the 2011 ITRS
Mart Graef 345

Standards for nano-enabled applications of electronics: Perspectives from IEC
Norbert Fabricius 351

Frontiers of more than Moore in bioelectronics and the required metrology needs
Anthony Guiseppi-Elie, Christian Kotanen, and A. Nolan Wilson 360

Author Index 371

Key Words Index 375