
Physics and Technology of High-k Materials 8

Editors:**S. Kar**

Indian Institute of Technology
Kanpur, India

S. Van Elshocht

IMEC
Leuven, Belgium

D. Misra

New Jersey Institute of Technology
Newark, New Jersey, USA

M. Houssa

University of Leuven
Leuven, Belgium

D. Landheer

National Research Council of Canada
Ottawa, Ontario, Canada

K. Kita

The University of Tokyo
Tokyo, Japan

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

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. 33, No. 3**

Copyright 2010 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 978-1-56677-822-0 (Hardcover)
ISBN 978-1-60768-172-4 (PDF)

Printed in the United States of America.

Table of Contents

Preface	iii
---------	-----

Chapter 1 New and Novel Materials I

Physical and Electrical Properties of MOCVD and ALD Deposited HfZrO ₄ Gate Dielectrics for 32nm CMOS High Performance Logic SOI Technologies	3
---	---

T. Kelwing, S. Mutas, M. Trentzsch, A. Naumann, B. Trui, L. Herrmann, F. Graetsch, C. Klein, L. Wilde, S. Ohsiek, M. Weisheit, A. Peeva, I. Richter, H. Prinz, A. Wuerfel, R. Carter, R. Stephan, P. Kücher, and W. Hansch

Alternative High-k Dielectrics for Metal-Insulator-Metal Applications	15
---	----

M. Lukosius, C. Baristiran Kaynak, C. Wenger, and S. Rushworth

Crystalline Gadolinium Oxide: A Promising High-k Candidate for Future CMOS Generations	25
--	----

R. Endres, H. Gottlob, M. Schmidt, D. Schwendt, H. Osten, and U. Schwalke

(Invited) Introducing Lanthanide Aluminates as Dielectrics for Nonvolatile Memory Applications: A Material Scientist's View	31
---	----

C. Adelmann, J. Swerts, O. Richard, T. Conard, M. Popovici, V. Afanas'ev, L. Breuil, A. Cacciato, K. Opsomer, B. Brijs, H. Tielens, G. Pourtois, H. Bender, C. Detavernier, M. Jurczak, S. Van Elshocht, and J. A. Kittl

Chapter 2 Flat Band Voltage Anomaly and Control

(Invited) Issues on Interfacial Oxide Layer (IL) in EOT Scaling of High-k/Metal Gate CMOS for 22nm Technology Node and Beyond	45
---	----

C. Park and P. D. Kirsch

The V _{FB} Modulation Effect of ALD Grown Al ₂ O ₃ , SrO, La ₂ O ₃ Capping Layers with HfO ₂ Gate Dielectrics	53
---	----

S. Lee, H. Jung, H. Kim, S. Lee, Y. Choi, and C. Hwang

Role of Hetero Interface of Ionic/Covalent Oxides for Pt/High-k/SiO ₂ /Si MOS Capacitors on V _{fB} Shift	59
<i>T. Nabatame, A. Ohi, and T. Chikyow</i>	
Impact of Alkali-Earth-Elements Incorporation on V _{fB} Roll-Off Characteristics of La ₂ O ₃ Gated MOS Device	67
<i>T. Koyanagi, K. Kakushima, P. Ahmet, K. Tsutsui, A. Nishiyama, N. Sugii, K. Natori, T. Hattori, and H. Iwai</i>	
Optimizing Band-Edge High- κ /Metal Gate n-MOSFETs with ALD Lanthanum Oxide Cap Layers: Oxidant and Positioning Effects	75
<i>R. D. Clark, H. Jagannathan, S. Consiglio, P. Jamison, C. Wajda, L. Edge, V. Paruchuri, V. Narayanan, and G. Leusink</i>	
(Invited) The Role of Oxygen in the Development of Hf-Base High- κ /Metal Gate Stacks for CMOS Technologies	83
<i>E. A. Cartier</i>	

Chapter 3 High Mobility Channels I

(Invited) Tip Cleaning and Sample Design for High Resolution MOSCAP x-KPFM	97
<i>W. Melitz, J. Shen, S. Lee, J. Lee, J. Royer, S. Bentley, D. Macintyre, M. Holland, I. Thayne, and A. C. Kummel</i>	
Bonding Geometries at the In ₂ O and SiO/III-V Semiconductor Interface	105
<i>J. Shen, W. Melitz, D. L. Feldwinn, S. Lee, R. Droopad, and A. C. Kummel</i>	
Fermi-Level Unpinning of HfO ₂ /In _{0.53} Ga _{0.47} As Gate Stack Using Hydrogen Anneals	117
<i>Y. Hwang, R. Engel-Herbert, N. Rudawski, and S. Stemmer</i>	
(Invited) Electronic and Structural Properties at Ge/GeO ₂ Interfaces: A Density-Functional Investigation	123
<i>P. Broqvist, J. Binder, and A. Pasquarello</i>	

Chapter 4 Deposition and Manufacturing

Evaluation of Narrow Gap Filling Ability in Shallow Trench Isolation by Organosiloxane Sol-Gel Precursor	135
<i>K. Watanuki, A. Inokuchi, A. Banba, N. Manabe, H. Suzuki, T. Koike, T. Adachi, T. Goto, A. Teramoto, Y. Shirai, S. Sugawa, and T. Ohmi</i>	

Development of Lanthanide Precursors as Dopants for Advanced High-k Materials <i>V. Rao, B. Besancon, V. Omarjee, and C. Dussarrat</i>	145
Methodology of ALD HfO ₂ High- κ Gate Dielectric Optimization by Cyclic Depositions and Anneals <i>H. Jagannathan, R. D. Clark, S. Consiglio, P. Jamison, B. Linder, M. Hopstaken, G. Leusink, V. Paruchuri, and V. Narayanan</i>	157
Synthesis of La _x Al _{2-x} O ₃ Films Using Ultrasonic Spray Pyrolysis Technique <i>A. N. Meza-Rocha, L. Pérez-Arrieta, E. Zaleta-Alejandro, Z. Rivera, R. Balderas-Xicohténcatl, and C. Falcony</i>	165
Comparison of HfSiO _x Thin Films Deposited by ALD with Moisture Using Different Silicon Sources <i>B. Besancon, C. Weiland, V. Omarjee, V. Rao, and C. Dussarrat</i>	171

Chapter 5 New and Novel Materials II

Electronic Properties of Silicene: Insights from First-Principles Modelling <i>M. Houssa, G. Pourtois, M. M. Heyns, V. Afanas'ev, and A. Stesmans</i>	185
Electrical Characterization of TbScO ₃ /TiN Gate Stacks of MOS Capacitors and MOSFETs on Strained and Unstrained SOI <i>E. Durğun Özben, A. Nichau, J. Lopes, S. Lenk, A. Besmehn, K. Bourdelle, Q. Zhao, J. Schubert, and S. Mantl</i>	195
(ZrO ₂) _x (La ₂ O ₃) _{1-x} Alloy as High-k Gate Dielectric for Advanced CMOS Devices <i>L. Chen, C. Hou, J. Wu, M. Wu, R. Lyu, and Y. Wu</i>	203
Liquid Injection MOCVD Grown Binary Oxides and Ternary Rare-Earth Oxide as Alternate Gate-Oxides for Logic Devices <i>R. Thomas, P. Ehrhart, R. Waser, J. Schubert, A. Devi, and R. Katiyar</i>	211
Electrical Properties of LaLuO ₃ /Si(100) Structures Prepared by Molecular Beam Deposition <i>Y. Y. Gomeniuk, Y. Gomeniuk, A. N. Nazarov, P. K. Hurley, K. Cherkaoui, S. Monaghan, H. Gottlob, M. Schmidt, J. Lopes, and O. Engström</i>	221

Chapter 6 Characterization

(Invited) Synchrotron Radiation Photoelectron Spectroscopy of Metal Gate/HfSiO(N)/SiO(N)/Si Stack Structures <i>M. Oshima, S. Toyoda, H. Kamada, T. Tanimura, Y. Nakamura, K. Horiba, and H. Kumigashira</i>	231
The Effect of Hf/(Hf+Si) Ratios in Hf _{1-x} Si _x O _y Dielectric Film on Physical and Electrical Stabilities <i>H. Kim, H. Jung, J. Jang, S. Lee, and C. Hwang</i>	241
Effect of Remote-Surface-Roughness Scattering on Electron Mobility in MOSFETs with High-k Dielectrics <i>M. Mamatrioshvili, M. Kouda, T. Kawanago, K. Kakushima, P. Ahmet, A. Aierken, K. Tsutsui, A. Nishiyama, N. Sugii, K. Natori, and H. Iwai</i>	249
(Invited) Multiparameter Admittance Spectroscopy <i>O. Engström and B. Raeissi</i>	257
(Invited) Electron Spectroscopic Measurements of Band Alignment in Metal/Oxide/Semiconductor Stacks <i>S. Rangan, E. Bersch, R. Bartynski, E. Garfunkel, and E. Vescovo</i>	267
Electrical Characterization of ALD ZnO and HfO ₂ Thin Films <i>K. Tapily, A. Raj, D. Gu, H. Baumgart, and G. Rozgonyi</i>	281

Chapter 7 Memory I

(Invited) Identity of the Conducting Nanofilaments in TiO ₂ and the Resistance Switching Mechanism of TiO ₂ /NiO Stacked Layers <i>K. Kim, D. Kwon, J. Jang, M. Lee, S. Song, G. Kim, J. Seok, B. Lee, S. Han, M. Kim, and C. Hwang</i>	291
Interface Analysis of MIM Capacitor Using ZrN Electrodes and ALD-ZrO ₂ Dielectrics <i>J. Choi, Y. Kim, J. Lim, M. Park, S. Chung, S. Kang, K. Cho, C. Yoo, J. Moon, H. Lee, K. Kim, H. Choi, and J. Chung</i>	299
Stress-Induced Deterioration of Nanocrystalline ITO Embedded ZrHfO High-k Nonvolatile Memories <i>C. Yang, Y. Kuo, C. Lin, and W. Kuo</i>	307

Metal-Organic Chemical Vapor Deposition of Ti-Doped NiO Layers for Application in Resistive Switching Memories <i>J. Meerschaut, M. Toeller, M. Schaekers, X. Wang, B. Brijs, D. Wouters, M. Jurczak, L. Altamime, S. Van Elshocht, and E. Vancoille</i>	313
(Invited) Size-Dependent Switching and Reliability of NiO RRAMs <i>D. Ielmini</i>	323
Density and Grain Size of the IrO _x Metal Nanocrystals in n-Si/SiO ₂ /Al ₂ O ₃ /IrO _x /Al ₂ O ₃ Memory Capacitors <i>W. Li, W. Banerjee, S. Maikap, and J. Yang</i>	333
Combinatorial Investigation of ZrO ₂ -Based Dielectric Materials for DRAM Capacitors <i>Y. Kiyota, Y. Iwashita, K. Itaka, T. Adachi, T. Chikyow, and A. Ogura</i>	339
Characteristics of ALD High-k HfAlO _x Nanocrystals in Memory Capacitors Annealed at High Temperatures <i>W. Li, W. Banerjee, S. Maikap, and J. Yang</i>	347

Chapter 8 **High Mobility Channels II**

(Invited) Non-Planar Transistors with High-Mobility SiGe/Ge Channels for CMOS Applications <i>T. Tezuka, Y. Kamata, K. Ikeda, Y. Kamimuta, Y. Moriyama, M. Koike, M. Oda, and T. Irisawa</i>	357
Maxwell-Wagner Instabilities and Defects Generation during CVS in REO-HfO ₂ Gate Stacks Grown on Germanium Based MOS Devices <i>M. Rahman, E. Evangelou, and A. Dimoulas</i>	367
Direct LaLuO ₃ /Ge Gate Stack Formation by Interface Layer Scavenging and Subsequent Low Temperature O ₂ Annealing <i>T. Tabata, C. Lee, K. Kita, and A. Toriumi</i>	375
(Invited) Buried-Channel In _{0.7} Ga _{0.3} As MOSFETs and Vertical In _{0.7} Ga _{0.3} As Tunneling FETs for beyond CMOS Applications <i>J. Lee, H. Zhao, Y. Chen, Y. Wang, F. Xue, and F. Zhou</i>	383

Chapter 9 Memory II

(Invited) First-Principles Investigation of High-k Dielectrics for Nonvolatile Memories <i>G. Pourtois, K. Sankaran, I. Radu, R. Degraeve, M. B. Zahid, S. Van Elshocht, C. Adelmann, S. De Gendt, M. M. Heyns, D. Wouters, J. A. Kittl, M. Jurczak, G. Rignanese, and J. Van Houdt</i>	393
Leakage Current Improvement of Doped and Bilayer High-k for MIM Capacitor <i>H. Lim, K. Cho, C. Yoo, and S. Nam</i>	409
Evaluation of HfLaO _x as Blocking Layer for Innovative Nonvolatile Memory Applications <i>A. Del Vitto, R. Piagge, E. Ravizza, S. Spadoni, A. Sebastiani, C. Scozzari, C. Wiemer, G. Ghidini, M. Alessandri, M. Fanciulli, J. Maes, and M. Verghese</i>	417
(Invited) Performance and Reliability of Nanocrystals Embedded High-k Nonvolatile Memories <i>Y. Kuo</i>	425

Chapter 10 High Mobility Channels III

(Invited) Equivalent Oxide Thickness Correction in the High-k/In _{0.53} Ga _{0.47} As/InP System <i>P. K. Hurley, R. Long, T. O'Regan, E. O'Connor, S. Monaghan, V. Djara, M. Negara, A. O'Mahony, I. Povey, A. Blake, R. Nagle, D. O'Connell, M. Pemble, and K. Cherkaoui</i>	433
(Invited) Identification of Intrinsic Point Defects at Ge _x Si _{1-x} /Oxide Interfaces by ESR Probing <i>A. Stesmans, A. Nguyen, V. Afanas'ev, R. Lieten, and G. Borghs</i>	445
(Invited) Atomic-Layer-Deposited High-k Dielectric Integration on Epitaxial Graphene <i>P. Ye, A. T. Neal, T. Shen, J. J. Gu, M. L. Bolen, and M. A. Capano</i>	459
Study of HfO ₂ /Si/Strained-Ge/SiGe Using Angle Resolved X-ray Photoelectron Spectroscopy <i>A. Komatsu, K. Nasu, Y. Hoshi, T. Kurebayashi, K. Sawano, M. Myronov, H. Nohira, and Y. Shiraki</i>	467

Effect of Thermal Treatments on HfO ₂ /In _{0.7} Ga _{0.3} As Metal-Oxide-Semiconductor Capacitor Characteristics	473
<i>C. Chang, T. Shie, Y. Lin, K. Kakushima, H. Iwai, P. Lu, T. Lin, G. Huang, and E. Chang</i>	
Investigation of Surface Channel InGaAs MOSFETs with Al ₂ O ₃ and ZrO ₂ ALD Gate Dielectric	479
<i>F. Xue, H. Zhao, Y. Chen, Y. Wang, F. Zhou, and J. Lee</i>	
Atomic-Layer-Deposition HfO ₂ -Based InP n-Channel Metal-Oxide-Semiconductor Field Effect Transistor Using Different Thicknesses of Al ₂ O ₃ as Interfacial Passivation Layer	487
<i>Y. Wang, H. Zhao, Y. Chen, F. Xue, F. Zhou, and J. Lee</i>	

Chapter 11 Defects, Traps, and Reliability I

Oxygen Diffusion Barrier Applied To High-k Thin Films Deposition	497
<i>E. Rauwel, P. Rauwel, F. Ducroquet, I. Matko, and A. Lourenço</i>	
(Invited) A Study of Dielectric Breakdown Mechanisms in MG/HK MISFETs: From the Viewpoint of TDDB Statistics	507
<i>I. Hirano, K. Kato, Y. Nakasaki, S. Fukatsu, M. Sato, S. Inumiya, M. Goto, K. Sekine, and Y. Mitani</i>	
The Effect of Nitrogen in HfO _x N _y and ZrO _x N _y on Dielectric Properties and BTI Characteristics	521
<i>H. Jung, H. Kim, J. Kim, S. Lee, J. Park, W. Kim, M. Song, N. Lee, and C. Hwang</i>	
TiN Capping Effect on High Temperature Annealed RE-Oxide MOS Capacitors for Scaled EOT	527
<i>D. Kitayama, T. Koyanagi, K. Kakushima, P. Ahmet, K. Tsutsui, A. Nishiyama, N. Sugii, K. Natori, T. Hattori, and H. Iwai</i>	
Leakage Current in TiN/HfO ₂ /TiN MIM Capacitors and Degradation Due to Electrical Stress	537
<i>S. Cimino, A. Padovani, L. Larcher, V. Afanas'ev, H. Hwang, Y. Lee, M. Jurczak, D. Wouters, B. Lee, H. Hwang, and L. Pantisano</i>	
Competing Charge Relaxation Mechanisms in HfSiON Insulator Field Effect Transistors	545
<i>J. K. Mee, R. Devine, and L. Trombetta</i>	
Stress-Induced Leakage Current and Charge Trapping in Cerium Dioxide Thin Film	551
<i>F. Chiu and S. Chang</i>	

Simulation of the Breakdown Spots Spatial Distribution in High-K Dielectrics and Model Validation Using the Spatstat Package for R Language <i>E. Miranda, E. O'Connor, and P. K. Hurley</i>	557
---	-----

Chapter 12 **Defects, Traps, and Reliability II**

(Invited) Charge Trapping and the Negative Bias Temperature Instability <i>W. Goes, F. Schanovsky, P. Hehenberger, P. Wagner, and T. Grasser</i>	565
Field Dependent Electrical Conduction in TiN/HfO ₂ /SiO ₂ /P-Si (nMOS) Capacitor for Before and After Stressing <i>S. K. Sahoo and D. Misra</i>	591
Author Index	601