

---

# Semiconductor Process Integration 11

---

**Editors:****J. Murota****C. Claeys****H. Iwai****M. Tao****S. Deleonibus****A. Mai****K. Shiojima****Y. Cao****Sponsoring Division:****Electronics and Photonics**

Published by

**The Electrochemical Society**65 South Main Street, Building D  
Pennington, NJ 08534-2839, USA

tel 609 737 1902

fax 609 737 2743

www.electrochem.org

**ecst****transactions**<sup>TM</sup>**Vol. 92, No. 4**

---

Copyright 2019 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](mailto:ecs@electrochem.org)  
Web: [www.electrochem.org](http://www.electrochem.org)

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

ISBN 978-1-62332-582-4 (CD-ROM)  
ISBN 978-1-62332-583-1 (USB)  
ISBN 978-1-60768-878-5 (PDF)

---

Printed in the United States of America.

---

## Table of Contents

<i>Preface</i>	<i>iii</i>
<b>Chapter 1</b>	
<b>Materials and Characterizations</b>	
( <i>Keynote</i> ) Border-Trap Characterization for Ge Gate Stacks Using Deep-Level Transient Spectroscopy	3
<i>H. Nakashima, W. C. Wen, K. Yamamoto, D. Wang</i>	
( <i>Invited</i> ) Photoemission-Based Characterization of Gate Dielectrics and Stack Interfaces	11
<i>S. Miyazaki, A. Ohta</i>	
( <i>Invited</i> ) Electrical Activity of Extended Defects in III-V Semiconductors	21
<i>E. R. Simoen, P. C. Hsu, Y. Mols, B. Kunert, R. Langer, C. Merckling, A. Alian, N. Waldron, G. Eneman, N. Collaert, M. Heyns, C. Claeys</i>	
Anisotropic Biaxial Strain Evaluation in Carbon-Doped Silicon Using Water-Immersion Raman Spectroscopy	33
<i>K. Yoshioka, R. Yokogawa, N. Sawamoto, A. Ogura</i>	
( <i>Invited</i> ) Development of Germanium-Tin-Related Semiconductor Heterostructures for Energy Band Design in Electronic and Optoelectronic Applications	41
<i>O. Nakatsuka, M. Fukuda, M. Sakashita, M. Kurosawa, S. Shibayama, S. Zaima</i>	
( <i>Invited</i> ) Characteristics of Si Single-Electron Transistor under Illumination	47
<i>Y. Takahashi, M. Sinohara, M. Arita, A. Tsurumaki-Fukuchi, A. Fujiwara, Y. Ono, K. Nishiguchi, H. Inokawa</i>	

## **Chapter 2** **Advanced Post CMOS Devices and Processes**

<i>(Invited)</i> Tunneling FET Device Technology for Ultra-Low Power Integrated Circuits S. Takagi, K. Kato, D. H. Ahn, T. Gotow, R. Takaguchi, T. E. Bae, K. Toprasertpong, M. Takenaka	59
<i>(Invited)</i> Vertical Tunnel FET Technologies Using III-V/Si Heterojunction K. Tomioka, H. Gamo, J. Motohisa	71
<i>(Invited)</i> SOI Technologies for RF and Millimeter Wave Applications M. Rack, J. P. Raskin	79

## **Chapter 3** **Wide-Gap Semiconductor Devices and Processes**

<i>(Invited)</i> Epitaxial Lift-Off of GaN and Related Materials for Device Applications P. Fay, J. Wang, L. Cao, J. Xie, E. Beam, R. McCarthy, R. Reddy, C. Youtsey	97
<i>(Invited)</i> GaN-Based Multiple 2DEG Channel BRIDGE (Buried Dual Gate) HEMT Technology for High Power and Linearity K. Shinohara, C. King, E. Regan, M. P. Gomez, J. Bergman, A. Carter, A. Arias, M. Urteaga, B. Brar, R. Page, R. Chaudhuri, M. Islam, H. G. Xing, D. Jena	103
<i>(Invited)</i> Characteristics of Several High-k Gate Insulators for GaN Power Device T. Nabatame, E. Maeda, M. Inoue, M. Hirose, H. Kiyono, Y. Irokawa, K. Shiozaki, Y. Koide	109

## **Chapter 4** **Thin Film Devices and Processes**

<i>(Keynote)</i> Machine Learning and High-Speed Circuitry in Thin Film Transistors for Sensor Interfacing in Hybrid Large-Area Electronic Systems J. Sturm, Y. Mehlman, L. E. Aygun, C. Wu, Z. Zheng, P. Kumar, S. Wagner, N. Verma	121
Self-Aligned IGZO TFTs with Boron Implanted Source/Drain Regions R. R. Chowdhury, M. S. Kabir, R. G. Manley, K. D. Hirschman	135

Device Structure and Passivation Options for the Integration of Scaled IGZO TFTs <i>M. S. Kabir, R. R. Chowdhury, R. G. Manley, K. D. Hirschman</i>	143
--	-----

## **Chapter 5 Sensing Devices and Processes**

(Invited) Bacterial Identification by Using Photogate-Type Optical Sensor <i>H. Ishii, S. Tanaka, M. Ishida, K. Sawada, K. Machida, Y. Nikaido, M. Saito, S. Yoshida</i>	155
(Invited) Nanoengineered Thermoelectric Energy Devices for IoT Sensing Applications <i>T. Ono, T. H. Nguyen, K. F. Samat, J. Li, N. V. Toan</i>	163
(Invited) MEMS Accelerometer Fabricated by Gold Multi-Layer Metal Technology <i>K. Machida, D. Yamane, T. Konishi, S. I. Iida, N. Ishihara, T. F. M. Chang, M. Sone, H. Ito, K. Masu</i>	169

## **Chapter 6 Emerging Technologies & Processes**

(Keynote) Silicon-Organic Hybrid Photonics: Integration of Electro-Optical Polymers in a Photonic Integrated Circuit Technology <i>P. Steglich, C. Mai, C. Villringer, B. Dietzel, S. Schrader, A. Mai</i>	187
(Invited) Design of SiO <sub>2</sub> /4H-SiC Formation Process with H <sub>2</sub> O Annealing to Improve MOSFET Performance <i>K. Kita, H. Hirai, M. Nishida, R. Sakuta</i>	195
(Invited) Challenges of Graphene Process Integration in CMOS Technology <i>M. Lisker, M. Lukosius, R. Lukose, C. Wenger, A. Mai</i>	201
(Invited) Optimized HfO <sub>2</sub> -Based MIM Module Fabrication for Emerging Memory Applications <i>M. K. Mahadevaiah, M. Lisker, M. Fraschke, S. Marschmeyer, D. Schmidt, C. Wenger, E. Perez, A. Mai</i>	211

(Invited) Electron Emission Study of Planar-Type Electron Emission Devices Based  
on Nanocrystalline Silicon

223

*H. Shimawaki, H. Mimura, K. Murakami, M. Nagao*

Author Index

231