

Transparent Conducting Oxides and Applications

**MATERIALS RESEARCH SOCIETY
SYMPOSIUM PROCEEDINGS VOLUME 1315**

Transparent Conducting Oxides and Applications

Symposium held November 29–December 3, Boston, Massachusetts, U.S.A.

EDITORS

Joseph J. Berry

National Renewable Energy Laboratory
Golden, Colorado, U.S.A.

Elvira Fortunato

Faculty of Sciences and Technology,
New University of Lisbon
Lisbon, Portugal

Julia E. Medvedeva

Missouri University of Science and Technology
Rolla, Missouri, U.S.A.

Yuzo Shigesato

Aoyama Gakuin University
Kanagawa, Japan



Materials Research Society
Warrendale, Pennsylvania



CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Tokyo, Mexico City

Cambridge University Press
32 Avenue of the Americas, New York, NY 10013-2473, USA

www.cambridge.org
Information on this title: www.cambridge.org/9781605112923

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

© Materials Research Society 2012

This publication is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without the written
permission of Cambridge University Press.

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

First published 2012

CODEN: MRSPDH

ISBN: 978-1-60511-292-3 Hardback

Cambridge University Press has no responsibility for the persistence or
accuracy of URLs for external or third-party Internet Web sites referred to
in this publication and does not guarantee that any content on such Web sites
is, or will remain, accurate or appropriate.

CONTENTS

Preface	ix
Materials Research Society Symposium Proceedings.....	xi
Thermoelectric Materials Discovery Using Combinatorial Chemistry.....	
Matin Amani, Ian Tougas, and Otto J. Gregory	1
Data Mining-aided Crystal Engineering for the Design of Transparent Conducting Oxides	
Changwon Suh, Kwiseon Kim, Joseph J. Berry, Jinsuk Lee, and Wesley B. Jones	7
Novel Fabrication Method of ZnO Films Utilizing Solid-phase Crystallized Seed Layers.....	
Naho Itagaki and Kazunari Kuwahara	15
Deposition of Zinc Oxide Thin Films Using a Surface Reaction on Platinum Nanoparticles	
Kanji Yasui, Hitoshi Miura, and Hiroshi Nishiyama	21
Visible ITO Pattern in Capacitive Touch Lens: Cause and Countermeasure	
Duk Su Kim, Gyeong-Geun Lee, Jacob Yang, and Dong Hyuk Shin	27
Growth of CuO and CuGaO ₂ Thin Films by Spin-coating Method	
Afishah Alias, Masato Sakamoto, and Katsuhiro Uesugi	35
Atomic Layer Deposition of Gallium-doped Zinc Oxide Transparent Conducting Oxide Films	
Paul R. Chalker, Paul A. Marshall, Simon Romani, Matthew J. Rosseinsky, Simon Rushworth, Paul A. Williams, John Buckett, Neil McSporran, and John Ridealgh	39

High Rate Deposition of High Quality ZnO:Al by Filtered Cathodic Arc	45
Rueben J. Mendelsberg, Sunnie H.N. Lim, Delia J. Milliron, and André Anders	
ZnBeMgO Thin Films Based UV Detectors by Spin Coating	53
Neeraj Panwar, J. Liriano, and Ram S. Katiyar	
Bandgap Engineered High Mobility Indium Oxide Thin Films for Photovoltaic Applications.	59
R.K. Gupta, K. Ghosh, and P.K. Kahol	
Optoelectronic Characterization of Morphology-controlled Zinc Oxide Nanowires	65
Shou-Yi Kuo, Fang-I Lai, Chun-Chieh Wang, and Woei-Tyng Lin	
High Mobility ZnO Thin Film Transistors Using the Novel Deposition of High-k Dielectrics.....	71
D.K. Ngawshi, R.B.M. Cross, S. Paul, Andrian P. Milanov, and Anjana Devi	
Surface Characterization of Ga-doped ZnO Layers.....	77
J.D. McNamara, J.D. Ferguson, M. Foussekis, I. Ruchala, M.A. Reschchikov, A.A. Baski, H. Liu, V. Avrutin, and H. Morkoç	
A Study of Increased Resistivity of FTO Back Contact for CZTS Based Absorber Material Grown by Electrodeposition-annealing Route	83
Prashant K. Sarswat, Michael L. Free, and Ashutosh Tiwari	
* Progress in Oxide-based Electrochromics: Towards Roll-to-roll Manufacturing.....	89
Claes G. Granqvist	
Thermochromism of VO₂ Nanoparticles: Calculated Optical Properties and Applications to Energy Efficient Windows.	101
S.-Y. Li, G.A. Niklasson, and C.G. Granqvist	

*Invited Paper

Effect of Growth Conditions on Electronic and Structural Properties of GZO Films Grown by Plasma-enhanced Molecular Beam Epitaxy on p-GaN(0001)/Sapphire Templates107
H.Y. Liu, V. Avrutin, N. Izyumskaya, M.A. Reschikov, S. Wolgast, C. Kurdak, A.B. Yankovich, A. Kvit, P. Voyles, Ü. Özgür, and H. Morkoç	
ZnO Thin Films of High Crystalline Quality Deposited on Sapphire and GaN Substrates by High Temperature Sputtering.....	.113
Michał A. Borysiewicz, Iwona Pasternak, Elżbieta Dynowska, Rafał Jakieła, Marek Wzorek, Valery Kolkovski, Anna Dużyńska, Eliana Kamińska, and Anna Piotrowska	
Optimal Design of a CIGS Module Grid119
Yiyang Li, Shihang Yang, Xieqiu Zhang, and Xudong Xiao	
Thermal Conductivity of Amorphous Indium Zinc Oxide Thin Films125
Ryo Endoh, Takayuki Hirano, Masaaki Takeda, Manabu Oishi, Nobuto Oka, and Yuzo Shigesato	
Author Index131
Subject Index133

PREFACE

Low cost, high performance transparent conducting oxides are of great interest for reduced-cost optoelectronics while amorphous oxides of ranging conductivity have attracted attention for interface modification, transistor, and other technological applications. The basic material and physical properties of these systems is still being illuminated in these oxide systems, even as they become integral in a number of optoelectronic devices. Symposium MM, "Transparent Conducting Oxides and Applications," held during the November 29–December 3, 2010 MRS Fall Meeting in Boston, Massachusetts, discussed the basic materials issues in transparent oxide systems such as structure, doping, carrier transport, and optical properties. These topics along with the development of solution and other novel deposition techniques for development of these materials and process related properties were covered in this symposium. This proceeding includes a cross-section of the research on basic materials properties and technological application of these materials covered during the symposium.

Joseph J. Berry
Elvira Fortunato
Julia E. Medvedeva
Yuzo Shigesato

September 2011

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

- Volume 1275— Structural and Chemical Characterization of Metals, Alloys and Compounds, R. Pérez Campos, A. Contreras Cuevas, R.A. Esparza Muñoz, 2011, ISBN 978-1-60511-252-7
- Volume 1276— Advanced Structural Materials—2010, H.A. Calderon, A. Salinas Rodriguez, H. Balmori-Ramirez, 2010, ISBN 978-1-60511-253-4
- Volume 1277E— Biomaterials—2010, S.E. Rodil, A. Almaguer-Flores, K. Anselme, 2010, ISBN 978-1-60511-254-1
- Volume 1278E— Composite, Hybrid Materials and Ecomaterials, R. Bernal, C. Cruz Vazquez, L.E. Rendon Diaz Miron, V.M. Castaño, 2010, ISBN 978-1-60511-255-8
- Volume 1279— New Catalytic Materials, J.A. Wang, J. Manuel Domínguez, 2010, ISBN 978-1-60511-256-5
- Volume 1280E— Nanomaterials for Biomedical Applications, L. Zhang, T.J. Webster, A. Salinas Rodriguez, 2010, ISBN 978-1-60511-257-2
- Volume 1282— Diamond Electronics and Bioelectronics—Fundamentals to Applications IV, P. Bergonzo, J.E. Butler, C.E. Nebel, M. Nesladek, A.T.S. Wee, 2011, ISBN 978-1-60511-259-6
- Volume 1283E— Carbon-Based Electronic Devices—Processing, Performance and Reliability, M. Chhowalla, R.R. Keller , M. Meyyappan, W.J. Ready, 2011, ISBN 978-1-60511-260-2
- Volume 1284— Fundamentals of Low-Dimensional Carbon Nanomaterials, J.J. Boeckl, L. Dai, W. Lu, M.H. Rummeli, J. Warner, 2011, ISBN 978-1-60511-261-9
- Volume 1285E— Challenges in Roll-to-Roll (R2R) Fabrication for Electronics and Other Functionalities, T. Blauddeck, G. Cho, J.H. Daniel, M.R. Dokmeci, 2011, ISBN 978-1-60511-262-6
- Volume 1286E— Molecular and Hybrid Materials for Electronics and Photonics, J. Liu, 2011, ISBN 978-1-60511-263-3
- Volume 1287E— Low-Temperature-Processed Thin-Film Transistors, E. Fortunato, 2011, ISBN 978-1-60511-264-0
- Volume 1288E— Novel Fabrication Methods for Electronic Devices, P. Andrew, 2011, ISBN 978-1-60511-265-7
- Volume 1289E— Controlling Material Properties and Charge-Carrier Interactions with Quantum-Dot Coupling, 2011, ISBN 978-1-60511-266-4
- Volume 1290E— Magnetism and Correlated Electronic Structure of Nitrides—Rare-Earth and Transition Metals as Constituents and Dopants, W.R.L. Lambrecht, A. Ney, K. Smith, H.J. Trodahl, 2011, ISBN 978-1-60511-267-1
- Volume 1291E— Integrated Nonreciprocal Photonics—Materials, Phenomena and Devices, V. Fratello, M. Levy, B. Stadler, M. Vanwolleghem, 2011, ISBN 978-1-60511-268-8
- Volume 1292— Oxide Nanoelectronics, H. Hwang, J. Levy, P. Makysymovych, G. Medeiros-Ribeiro, R. Waser, 2011, ISBN 978-1-60511-269-5
- Volume 1293E— Liquid-Crystal Materials—Beyond Displays, N.L. Abbott, D.J. Broer, T. Kato, T.J. White, 2011, ISBN 978-1-60511-270-1
- Volume 1294E— Resonant Optical Antennas—Sensing and Shaping Materials, K.B. Crozier, N. Engheta, G. Ju, R. Quidant, R. Zia, 2011, ISBN 978-1-60511-271-8
- Volume 1295— Intermetallic-Based Alloys for Structural and Functional Applications, M. Palm, B. Bewlay, S. Kumar, K. Yoshimi, 2011, ISBN 978-1-60511-272-5
- Volume 1296E— New Methods in Steel Design—Steel Ab Initio, Y. Adachi, R. Dronskowski, D. Raabe, P.E.A. Turchi, 2011, ISBN 978-1-60511-273-2
- Volume 1297— Deformation Mechanisms, Microstructure Evolution and Mechanical Properties of Nanoscale Materials, J.R. Greer, D.S. Gianola, B.G. Clark, T. Zhu, A.H.W. Ngan, 2011, ISBN 978-1-60511-274-9
- Volume 1298— Advanced Materials for Applications in Extreme Environments, T.S. Byun, R. Smith, M. Li, 2011, ISBN 978-1-60511-275-6
- Volume 1299— Microelectromechanical Systems—Materials and Devices IV, M.P. de Boer, F.W. DelRio, C. Eberl, E.P. Gusev, 2011, ISBN 978-1-60511-276-3
- Volume 1300E— Bulk Metallic Glasses and their Applications, K.F. Yao, 2011, ISBN 978-1-60511-277-0

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

- Volume 1301— Soft Matter, Biological Materials and Biomedical Materials—Synthesis, Characterization and Applications, A.J. Nolte, K. Shiba, R. Narayan, D. Nolte, 2011, ISBN 978-1-60511-278-7
- Volume 1302E—Nanowires—Growth and Device Assembly for Novel Applications, 2011, ISBN 978-1-60511-279-4
- Volume 1303— Nanomaterials Integration for Electronics, Energy and Sensing, D. E. Perea, Y. Jung, J. B. Hannon, M. A. Reed, S. T. Picraux, 2011, ISBN 978-1-60511-280-0
- Volume 1304E—Hierarchical Materials and Composites—Combining Length Scales from Nano to Macro, J.H. Moon, G.M. Odegard, M.S.P. Shaffer, B.L. Wardle, 2011, ISBN 978-1-60511-281-7
- Volume 1305E—Group IV Semiconductor Nanostructures and Applications, L. Dal Negro, 2011, ISBN 978-1-60511-282-4
- Volume 1306E—Aerogels and Aerogel-Inspired Materials, S. Brock, G. Gould, A. Roig, D. Rolison, 2011, ISBN 978-1-60511-283-1
- Volume 1307E—Boron and Boron Compounds—From Fundamentals to Applications, M. Dudley, J.H. Edgar, M. Kuball, 2011, ISBN 978-1-60511-284-8
- Volume 1308E—Artificially Induced Crystalline Alignment in Thin Films and Nanostructures, A.T. Findikoglu, R. Huehne, T. Shimada, J.Z. Wu, 2011, ISBN 978-1-60511-285-5
- Volume 1309— Solid-State Chemistry of Inorganic Materials VIII, K-S. Choi, S.J. Clarke, P.S. Halasyamani, D.G. Mandrus, 2011, ISBN 978-1-60511-286-2
- Volume 1310E—Magneto Calorics and Magnetic Cooling, A. Fujita, K. Gschneidner Jr., O. Gutfleisch, K.G. Sandeman, A. Yan, 2011, ISBN 978-1-60511-287-9
- Volume 1311— Next-Generation Fuel Cells—New Materials and Concepts, T. He, K. Swider-Lyons, B. Park, P.A. Kohl, 2011, ISBN 978-1-60511-288-6
- Volume 1312— Polymer-Based Materials and Composites—Synthesis, Assembly, Properties and Applications, V. Bharti, M. Chipara, D. Venkataraman, 2011, ISBN 978-1-60511-289-3
- Volume 1313— Materials for Advanced Lithium Batteries, G.-A. Nazri, J-M Tarascon, D. Guyomard, A. Yamada, 2011, ISBN 978-1-60511-290-9
- Volume 1314E—Thermoelectric Materials for Solid-State Power Generation and Refrigeration, Y. Grin, G.S. Nolas, J. Sharp, T.M. Tritt, 2011, ISBN 978-1-60511-291-6
- Volume 1315— Transparent Conducting Oxides and Applications, J.J. Berry, E. Fortunato, J. Medvedeva, Y. Shigesato, 2011, ISBN 978-1-60511-292-3
- Volume 1316E—Nanofunctional Materials, Nanostructures and Nanodevices for Biomedical Applications II, R. Rao, 2011, ISBN 978-1-60511-293-0
- Volume 1317E—Interdisciplinary Approaches to Safe Nanotechnologies, C. Chaneac, S. Harper, G.V. Lowry, R.I. MacCuspie, 2011, ISBN 978-1-60511-294-7
- Volume 1318— Advances in Spectroscopy and Imaging of Surfaces and Nanostructures, J. Cumings, J. Guo, F.M. Granozio, O.V. Kolosov, 2011, ISBN 978-1-60511-295-4
- Volume 1319— Materials Issues in Art and Archaeology IX, P.B. Vandiver, C.L. Reedy, J.L. Ruvalcaba Sil, W. Li, 2011, ISBN 978-1-60511-296-1
- Volume 1320— Materials Education Development and Outreach—From K-Grad, D. Bahr, K. Jones, M. Glass, E. Allen, 2011, ISBN 978-1-60511-297-8

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