Mechanical Behavior at Small Scales — Experiments and Modeling

MATERIALS RESEARCH SOCIETY
SYMPOSIUM PROCEEDINGS VOLUME 1224

Mechanical Behavior at Small Scales — Experiments and Modeling

Symposium held November 30 – December 3, Boston, Massachusetts, U.S.A.

EDITORS (Symposium FF):

Jun Lou
Rice University
Houston, Texas, U.S.A.

Erica Lilleodden
GKSS Forschungszentrum
Geesthacht, Germany

Brad L. Boyce
Sandia National Laboratories
Albuquerque, New Mexico, U.S.A.

Lei Lu
Chinese Academy of Sciences
Shenyang, China

EDITORS (Symposium GG):

Peter M. Derlet
Paul Scherrer Institut
Villigen, Switzerland

Daniel Weygand
Karlsruhe Institute of Technology
Karlsruhe, Germany

Ju Li
University of Pennsylvania
Philadelphia, Pennsylvania, U.S.A.

Michael Uchic
Air Force Research Laboratory
Dayton, Ohio, U.S.A.

Eric Le Bourhis
Université de Poitiers
Poitiers, France

Materials Research Society
Warrendale, Pennsylvania

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

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

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9781107408036

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

First published 2010
First paperback edition 2012

Single article reprints from this publication are available through
University Microfilms Inc., 300 North Zeeb Road, Ann Arbor, MI 48106

CODEN: MRSPDH

ISBN 978-1-107-40803-6 Paperback

CONTENTS

* Invited paper

Polymers & Composites

Simulations & Modeling

Microcompression & Nanoindentation

* Invited paper

PREFACE

Symposia FF: "Mechanical Behavior of Nanomaterials—Experiments and Modeling" and GG: "Plasticity in Confined Volumes— Modeling and Experiments," were presented Nov. 30–Dec. 4, 2009 at the 2009 MRS Fall Meeting in Boston, Massachusetts. Symposium GG began with a very attractive tutorial on experimental and simulation methods for the study of plasticity in small volumes. The strongly related themes of these two symposia motivated the publication of a single proceedings volume. These two symposia each brought experimentalists and modelers together within a single forum to exchange their ideas about the mechanical behaviour of materials where size, be it microstructural or geometric, plays an important role.

Symposium FF was focused on the understanding of the mechanical behavior of nanostructured materials, such as nanoscale thin films, nanowires, nanotubes, and nanoparticles, as well as nanoporous, nanograined and nanotwinned materials. Such materials with sub-micron length scales are important building blocks for next-generation functional devices and materials systems. In order to help them fulfill their promise, mechanics at small-length scale must be carefully investigated to understand the deformation and failure mechanisms of these material entities.

Symposium GG was focused on understanding how micron and sub-micron external and internal micro-structural length scales control the mechanical behavior, such as strength and ductility, of materials. Modern atomistic and mesoscopic simulation methods have elucidated a diverse range of atomic and meso-scale processes that can contribute to the emergent plasticity of such complex materials, ranging from dislocation dynamics in micron-sized confined volumes, and the interaction between dislocations and grain boundaries in bulk and thin-film nanocrystals, to atomic scale activity associated with grain boundary accommodation processes, as well as shear-transformation zones in metallic glasses. With the development of miniaturized mechanical testing facilities, as well as leading edge ex-situ and in-situ methods, it now becomes experimentally possible to directly probe both the spatial and temporal dynamics of such processes.

The papers herein span a representative range of topics, which have been organized in four general topic areas: nanostructured materials, polymers & composites, simulations & modelling, and microcompression & nanoindentation.

We would like to thank the authors for their contributions to this volume, as well as the presenters and session chairs for their involvement in the symposia. We greatly appreciate the excellent administrative and technical support provided by the MRS staff, which was a major contribution to the success of these symposia. We also want to extend special thanks to the Institute of Metal Research, Chinese Academy of Sciences and Nanofactory Instruments, Inc. for their financial support of symposium FF.

Jun Lou
Erica Lilleodden
Brad L. Boyce
Lei Lu
Peter M. Derlet
Daniel Weygand
Ju Li
Mike D. Uchic
Eric Le Bourhis

July 2010

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

Volume 1194E —High-k Dielectrics on Semiconductors with High Carrier Mobility, M. Hong, W. Tsai, A. Dimoulas, P.D. Ye, 2010, ISBN 978-1-60511-167-4
Volume 1195 — Reliability and Materials Issues of Semiconductor Optical and Electrical Devices and Materials, O. Ueda, M. Fukuda, S. Pearton, E. Piner, P. Montanegro, 2010, ISBN 978-1-60511-168-1
Volume 1196E —Large-Area Processing and Patterning for Optical, Photovoltaic and Electronic Devices—2009, I. Kymissis, M. Shtein, A.C. Arias, T. Sekitani, 2010, ISBN 978-1-60511-169-8
Volume 1197E —Organic Materials for Printable Thin-Film Electronic Devices, M.L. Chabinyc, D. Gundlach, J. Nelson, T. Someya, 2010, ISBN 978-1-60511-170-4
Volume 1198E —Advanced Materials for Half-Metallic and Organic Spintronics, M.-T. Lin, C. Felser, J. Shen, A. Gupta, 2010, ISBN 978-1-60511-171-1
Volume 1199E —Multiferroic and Ferroelectric Materials, A. Gruverman, C.J. Fennie, I. Kunishima, B. Noheda, T.W. Noh, 2010, ISBN 978-1-60511-172-8
Volume 1200E —Magnetic Shape Memory Alloys, E. Quandt, M. Wuttig, T. Kakeshita, S. Fähler, 2010, ISBN 978-1-60511-173-5
Volume 1201 — Zinc Oxide and Related Materials—2009, S.M. Durbin, H. von Wenckstern, M. Allen, 2010, ISBN 978-1-60511-174-2
Volume 1202 — III-Nitride Materials for Sensing, Energy Conversion and Controlled Light-Matter Interactions, S. Gwo, J.W. Ager, F. Ren, O. Ambacher, L. Schowalter, 2010, ISBN 978-1-60511-175-9
Volume 1203 — Diamond Electronics and Bioelectronics—Fundamentals to Applications III, P. Bergonzo, J.E. Butler, R.B. Jackman, K.P. Loh, M. Nesladek, 2010, ISBN 978-1-60511-176-6
Volume 1204 — Nanotubes and Related Nanostructures—2009, Y.K. Yap, K. Hata, A. Loiseau, M. Zheng, 2010, ISBN 978-1-60511-177-3
Volume 1205E —Large-Area Electronics from Carbon Nanotubes, Graphene, and Related Noncarbon Nanostructures, M. Chhowalla, J.A. Rogers, C.M. Tanner, P. Papakonstantinou, A.C. Ferrari, 2010, ISBN 978-1-60511-178-0
Volume 1206E —Multifunction at the Nanoscale through Nanowires, K. Nielsch, A. Fontcuberta i Morral, J.K. Holt, C.V. Thompson, 2010, ISBN 978-1-60511-179-7
Volume 1207E —Colloidal Nanoparticles for Electronic Applications—Light Emission, Detection, Photovoltaics and Transport, J. Steckel, N. Kotov, D. Norris, M. Bawendi, M.K. Kuno, 2010, ISBN 978-1-60511-180-3
Volume 1208E —Excitons and Plasmon Resonances in Nanostructures II, A.O. Govorov, A.L. Rogach, Z.M. Wang, J.-K. Wang, V.M. Shalaev, 2010, ISBN 978-1-60511-181-0
Volume 1209 — Business and Safety Issues in the Commercialization of Nanotechnology, L. Tsakalakos, L. Merhari, S.S. Mao, J. van Schijndel, T. Webster, H. Liu, R. Hurt, 2010, ISBN 978-1-60511-182-7
Volume 1210 — Photovoltaic Materials and Manufacturing Issues II, B. Sopori, J. Yang, T. Surek, B. Dimmler, 2010, ISBN 978-1-60511-183-4
Volume 1211E —Advanced Nanostructured Solar Cells, A.J. Frank, N.-G. Park, T. Miyasaka, L. Peter, S. Dai, 2010, ISBN 978-1-60511-184-1
Volume 1212 — Organic Materials and Devices for Sustainable Energy Systems, J. Xue, C. Adachi, R.J. Holmes, B.P. Rand, 2010, ISBN 978-1-60511-185-8
Volume 1213E —Nanomaterials for Polymer Electrolyte Membrane Fuel Cells, K. Swider-Lyons, B. Park, T. He, 2010, ISBN 978-1-60511-186-5
Volume 1214E —Materials Challenges Facing Electrical Energy Storage, Y. Gogotsi, J.R. Miller, K. Naoi, Y. Shao-Horn, B. Scrosati, 2010, ISBN 978-1-60511-187-2
Volume 1215 — Materials Research Needs to Advance Nuclear Energy, G. Baldinozzi, K.L. Smith, K. Yasuda, Y. Zhang, 2010, ISBN 978-1-60511-188-9
Volume 1216E —Hydrogen Storage Materials, E. Akiba, W. Tumas, P. Chen, M. Fichtner, S. Zhang, 2010, ISBN 978-1-60511-189-6
Volume 1217 — Catalytic Materials for Energy, Green Processes and Nanotechnology, C.-Y. Mou, J. Liu, H.H. Kung, S. Dai, 2010, ISBN 978-1-60511-190-2

MATERIALS RESEARCH SOCIETY SYMPOSIUM PROCEEDINGS

Volume 1218E —Energy Harvesting—From Fundamentals to Devices, H. Radousky, J.D. Holbery, L.H. Lewis, F. Schmidt, 2010, ISBN 978-1-60511-191-9
Volume 1219E —Renewable Biomaterials and Bioenergy—Current Developments and Challenges, S. Erhan, S. Isobe, M. Misra, L. Liu, 2010, ISBN 978-1-60511-192-6
Volume 1220E —Green Chemistry in Research and Development of Advanced Materials, W.W. Yu, H. VanBenschoten, Y.A. Wang, 2010, ISBN 978-1-60511-193-3
Volume 1221E —Phonon Engineering for Enhanced Materials Solutions—Theory and Applications, 2010, ISBN 978-1-60511-194-0
Volume 1222 — Microelectromechanical Systems—Materials and Devices III, J. Bagdahn, N. Sheppard, K. Turner, S. Vengallatore, 2010, ISBN 978-1-60511-195-7
Volume 1223E —Metamaterials—From Modeling and Fabrication to Application, N. Engheta, J. L.-W. Li, R. Pachter, M. Tanielian, 2010, ISBN 978-1-60511-196-4
Volume 1224 — Mechanical Behavior at Small Scales—Experiments and Modeling, J. Lou, E. Lilleodden, B. Boyce, L. Lu, P.M. Derlet, D. Weygand, J. Li, M.D. Uchic, E. Le Bourhis, 2010, ISBN 978-1-60511-197-1
Volume 1225E —Multiscale Polycrystal Mechanics of Complex Microstructures, D. Raabe, R. Radovitzky, S.R. Kalidindi, M. Geers, 2010, ISBN 978-1-60511-198-8
Volume 1226E —Mechanochemistry in Materials Science, M. Scherge, S.L. Craig, N. Sottos, 2010, ISBN 978-1-60511-199-5
Volume 1227E —Multiscale Dynamics in Confining Systems, P. Levitz, R. Metzler, D. Reichman, 2010, ISBN 978-1-60511-200-8
Volume 1228E —Nanoscale Pattern Formation, E. Chason, R. Cuerno, J. Gray, K.-H. Heinig, 2010, ISBN 978-1-60511-201-5
Volume 1229E —Multiphysics Modeling in Materials Design, M. Asta, A. Umantsev, J. Neugebauer, 2010, ISBN 978-1-60511-202-2
Volume 1230E —Ultrafast Processes in Materials Science, A.M. Lindenberg, D. Reis, P. Fuoss, T. Tschentscher, B. Siwick, 2010, ISBN 978-1-60511-203-9
Volume 1231E —Advanced Microscopy and Spectroscopy Techniques for Imaging Materials with High Spatial Resolution, M. Rühle, L. Allard, J. Etheridge, D. Seidman, 2010, ISBN 978-1-60511-204-6
Volume 1232E —Dynamic Scanning Probes—Imaging, Characterization and Manipulation, R. Pérez, S. Jarvis, S. Morita, U.D. Schwarz, 2010, ISBN 978-1-60511-205-3
Volume 1233 — Materials Education, M.M. Patterson, E.D. Marshall, C.G. Wade, J.A. Nucci, D.J. Dunham, 2010, ISBN 978-1-60511-206-0
Volume 1234E —Responsive Gels and Biopolymer Assemblies, F. Horkay, N. Langrana, W. Richtering, 2010, ISBN 978-1-60511-207-7
Volume 1235E —Engineering Biomaterials for Regenerative Medicine, S. Bhatia, S. Bryant, J.A. Burdick, J.M. Karp, K. Walline, 2010, ISBN 978-1-60511-208-4
Volume 1236E —Biosurfaces and Biointerfaces, J.A. Garrido, E. Johnston, C. Werner, T. Boland, 2010, ISBN 978-1-60511-209-1
Volume 1237E —Nanobiotechnology and Nanobiophotonics—Opportunities and Challenges, 2010, ISBN 978-1-60511-210-7
Volume 1238E —Molecular Biomimetics and Materials Design, J. Harding, J. Evans, J. Elliott, R. Latour, 2010, ISBN 978-1-60511-211-4
Volume 1239 — Micro- and Nanoscale Processing of Biomaterials, R. Narayan, S. Jayasinghe, S. Jin, W. Mullins, D. Shi, 2010, ISBN 978-1-60511-212-1
Volume 1240E —Polymer Nanofibers—Fundamental Studies and Emerging Applications, 2010, ISBN 978-1-60511-213-8
Volume 1241E —Biological Imaging and Sensing using Nanoparticle Assemblies, A. Alexandrou, J. Cheon, H. Mattoussi, V. Rotello, 2010, ISBN 978-1-60511-214-5
Volume 1242 — Materials Characterization, R. Pérez Campos, A. Contreras Cuevas, R.A. Esparza Muñoz, 2010, ISBN 978-1-60511-219-0
Volume 1243 — Advanced Structural Materials, H.A. Calderon, A. Salinas-Rodríguez, H. Balmori-Ramirez, J.G. Cabañas-Moreno, K. Ishizaki, 2010, ISBN 978-1-60511-220-6

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