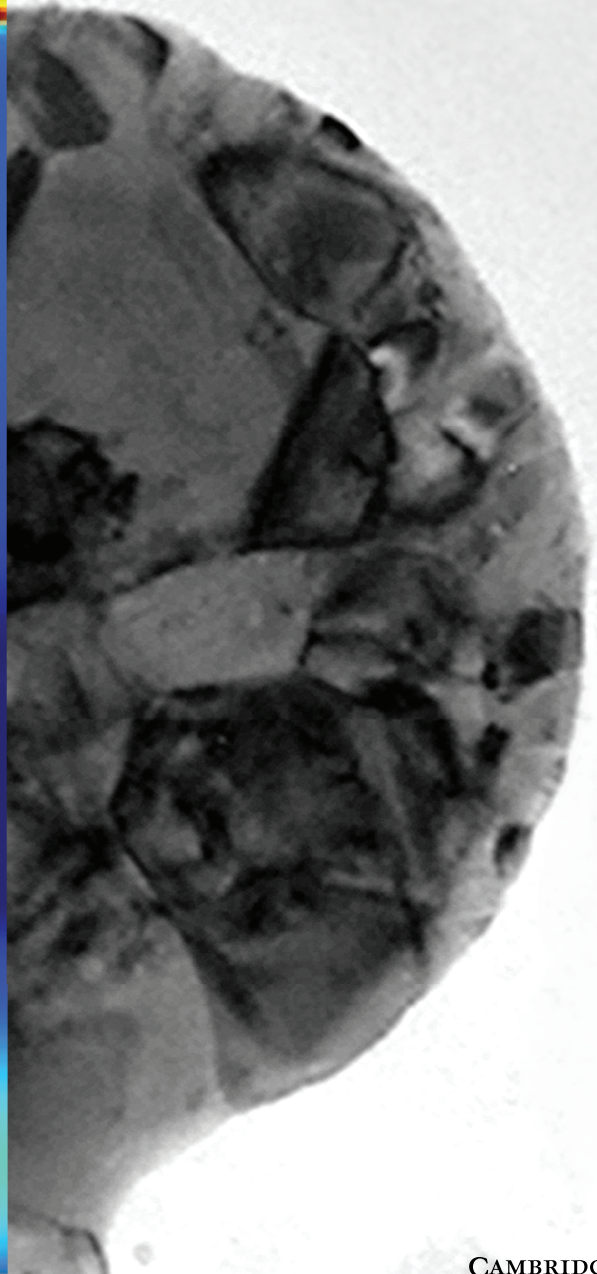
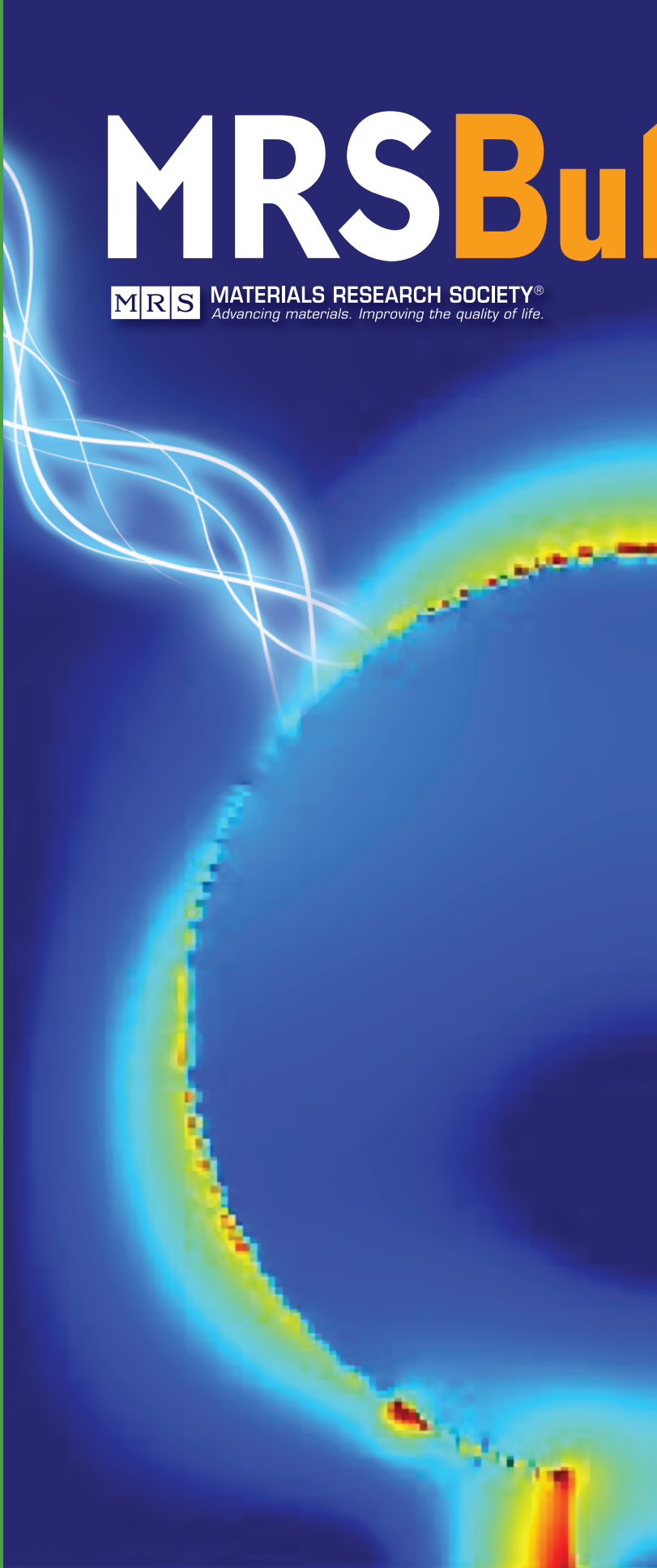


February 2018 Vol. 43 No. 2
www.mrs.org/bulletin

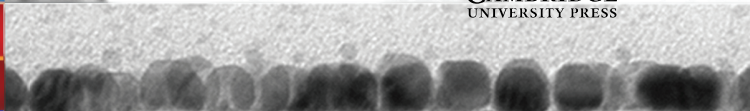
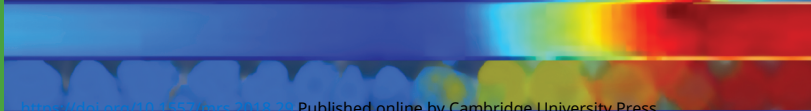
MRS Bulletin

MRS MATERIALS RESEARCH SOCIETY®
Advancing materials. Improving the quality of life.

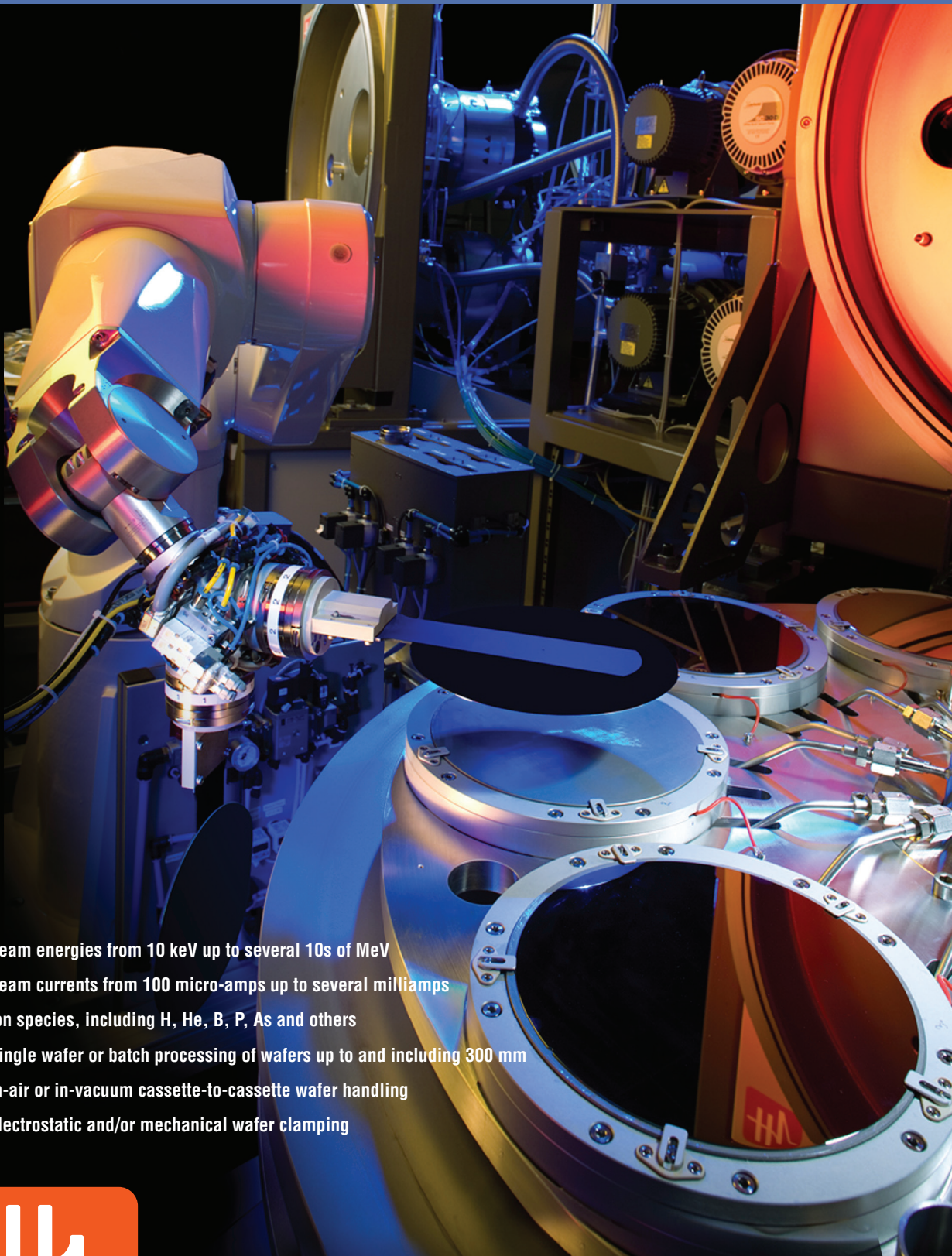
Materials for heat-assisted magnetic recording



CAMBRIDGE
UNIVERSITY PRESS



CUSTOMIZED PRODUCTION ION IMPLANTERS



- Beam energies from 10 keV up to several 10s of MeV
- Beam currents from 100 micro-amps up to several milliamps
- Ion species, including H, He, B, P, As and others
- Single wafer or batch processing of wafers up to and including 300 mm
- In-air or in-vacuum cassette-to-cassette wafer handling
- Electrostatic and/or mechanical wafer clamping



High Voltage Engineering

High Voltage Engineering Europa B.V.

P.O. Box 99, 3800 AB Amersfoort, The Netherlands

Tel: 31 33 4619741 • info@highvolteng.com

www.highvolteng.com



2018 **MRS**® SPRING MEETING & EXHIBIT
April 2–6, 2018 | Phoenix, Arizona

REGISTER BY MARCH 16 AND SAVE!

Spring Meeting registrations include MRS Membership July 1, 2018 – June 30, 2019

LATE NEWS—HOT TOPICS

- LN01 Materials Science to Empower Quantum Information Technologies
- LN02 Artificial Intelligence for Materials Development Forum

CHARACTERIZATION, MODELING AND THEORY

- CM01 Exploring Nanoscale Physical Properties of Materials via Local Probes
- CM02 *In Situ* TEM Characterization of Dynamic Processes During Materials Synthesis and Processing
- CM03 Investigating Nanostructures with X-Rays—Fundamentals and Applications
- CM04 *In Situ* and *Operando* Characterization of Materials and Devices by X-Ray and Neutron
- CM05 Strain Localization, Avalanches and Intermittent Deformation Mechanisms
- CM06 Frontiers in Functional Imaging in Aberration-Corrected Electron Microscopy

ELECTRONIC AND PHOTONIC MATERIALS

- EP01 Materials for Beyond the Roadmap Devices in Logic, Memory and Power
- EP02 Excitonic Materials—Physics, Characterization and Devices
- EP03 Materials and Processes for Nonlinear Optics and Nonlinear Photonics
- EP04 Reliability and Materials Issues of Semiconductor Optical and Electron Devices and Materials
- EP05 Emerging Light-Emitting Materials and Devices—Halide Perovskite and Low-Dimensional Nanoscale Emitters
- EP06 Materials, Devices and Systems for Machine Learning and Neuromorphic Computing
- EP07 Phase-Change Materials and Their Applications—Memories, Photonics, Displays and Non-von Neumann Computing
- EP08 Advanced Polymer Semiconductors—Key Properties and High-Performance Electronics

ENERGY MATERIALS AND TECHNOLOGIES

- EN01 Solid-Solid Interfaces in Batteries, Energy Storage and Conversion—Diagnostic and Modeling
- EN02 Advances in Perovskite Solar Cell Devices and Applications
- EN03 Superconducting Materials—From Basic Science to Applications
- EN04 Advanced Materials for Carbon Capture and Other Important Gas Separations
- EN05 Field-Responsive Composites for Sustainable Energy
- EN06 Safer and More Energy-Dense Rechargeable Batteries
- EN07 Issues, Challenges and Opportunities in Actinide Materials
- EN08 Low-Cost Tandem Photovoltaic Cells
- EN09 Materials and Systems for Grid Energy Storage—Redox Flow Batteries
- EN10 Thermoelectric Materials, Devices and Applications
- EN11 Nanomaterials for the Water and Energy Nexus
- EN12 Hierarchical Materials for Nuclear Waste Management
- EN13 Capacitive Energy Storage—Fundamentals, Materials and Devices
- EN14 Materials Science and Device Engineering for Safe and Long-Life Electrochemical Energy Storage
- EN15 Novel Materials Physics of Perovskite Semiconductors
- EN16 Combining Materials, Technologies and Societal Awareness to Harvest Natural and Human-Made Energy Sources
- EN17 Fundamental Materials Science to Enable the Performance and Safety of Nuclear Technologies
- EN18 Multiscale Designing and Constructing Photocatalytic Materials for Solar Fuels
- EN19 Novel Inorganic Semiconductors for Optoelectronics and Solar Energy
- EN20 Deposition, Transformation and Reaction at Functional Interfaces for Electrochemical Energy Systems
- EN21 Next-Generation Solid-State Super Ion Conductors

MANUFACTURING

- MA01 Advanced Materials for Analog and Digital Functional Printing
- MA02 Organic Electronics—Processing, Microstructure and Multifunctioning
- MA03 Directed Matter—Atom-by-Atom Assembly with Electron Beams and Scanning Probes
- MA04 Advances in Additive Manufacturing—Materials, Processes and Devices
- MA05 Dynamic Materials and Textiles for Next-Generation Clothing

NANOMATERIALS

- NM01 Nanomaterials and Devices by Cluster Beam Deposition
- NM02 Active Colloids with Order
- NM03 Rational Designed Hierarchical Nanostructures for Photocatalytic Systems
- NM04 Porous Materials and Nanocomposites for Catalysis
- NM05 Colloidal Nanoparticles—From Synthesis to Applications
- NM06 Nanodiamonds—Synthesis, Characterization, Surface Chemistry and Applications
- NM07 Nanoscale Magnetic Structures and Materials
- NM08 Graphene Oxide Liquid Crystals and 2D Soft Material Systems
- NM09 Novel Approaches and Material Platforms for Plasmonics and Metamaterials
- NM10 Nanometallic Materials by Design
- NM11 Deformable Atomically Thin Materials—Mechanics, Materials and Devices
- NM12 Transitioning Quantum Dots from Benchtop to Industry
- NM13 Functionalization of Topological Materials

SOFT MATERIALS AND BIOMATERIALS

- SM01 Soft Materials, Sensors, Electronics, Displays and Actuators—Functional Components for Soft Machines and Robots
- SM02 Immune Modulatory Materials—From Design to Translational Applications
- SM03 Engineered Functional Biointerfaces—From Electronics and Nanomaterials to Biocircuits and Bionanomaterials
- SM04 Understanding and Controlling the Structure and Function of Biomolecules at Material Interfaces
- SM05 Biomaterials for Tissue Interface Regeneration
- SM06 The Future of Neuroengineering—Relevant *In Vivo* Technology
- SM07 Functional (Bio)polymers in Energy and Environment Applications
- SM08 Smart Hydrogels and Living Materials

Meeting Chairs

Edward Botchwey Georgia Institute of Technology/Emory University
Catherine Dubourdieu Helmholtz-Zentrum Berlin
Quanxi Jia University at Buffalo, The State University of New York
Shane Kennett Exponent Failure Analysis Associates
Cheolmin Park Yonsei University

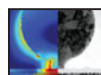
www.mrs.org/spring2018

MRS MATERIALS RESEARCH SOCIETY®
Advancing materials. Improving the quality of life.

506 Keystone Drive • Warrendale, PA 15086-7573
Tel 724.779.3003 • Fax 724.779.8313
info@mrs.org • www.mrs.org

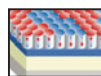
CONTENTS

MATERIALS FOR HEAT-ASSISTED MAGNETIC RECORDING



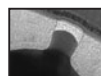
- 87 **Materials for heat-assisted magnetic recording**

M.T. Kief and R.H. Victora, Guest Editors



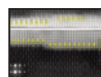
- 93 **Heat-assisted magnetic recording media materials**

K. Hono, Y.K. Takahashi, Ganping Ju, Jan-Ulrich Thiele, Antony Ajan, XiaoMin Yang, Ricardo Ruiz, and Lei Wan



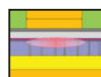
- 100 **Materials for heat-assisted magnetic recording heads**

Michael C. Kautzky and Martin G. Blaber



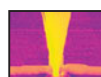
- 106 **Read sensor technology for ultrahigh density magnetic recording**

Tomoya Nakatani, Zheng Gao, and Kazuhiro Hono



- 112 **Nanoscale thermal transport aspects of heat-assisted magnetic recording devices and materials**

James A. Bain, Jonathan A. Malen, Minyoung Jeong, and Turga Ganapathy



- 119 **Materials challenges for the heat-assisted magnetic recording head-disk interface**

James D. Kiely, Paul M. Jones, and Joel Hoehn

DEPARTMENTS



OPINION

- 77 **Material Matters**

Climate change and materials virology

Ahmad R. Kirmani



NEWS & ANALYSIS

- 78 **Materials News**

■ **Neural network identifies lattice defects in electron microscope images of 2D materials**

Lauren Borja

■ **Kirigami art and geometric manipulation transform rigid solids to flexible auxetic materials**

Eva Karatairi

■ **Catalyst technique “upgrades” methane into methanol, acetic acid**

Doug Main

■ **Fluorescent nanodiamonds detect H₂O₂**

Eva Karatairi

- 84 **Science Policy**

■ **Materials research to benefit from UK’s industrial strategy**

Michael Kenward

■ **Chanette Armstrong appointed DOE Director of the Office of Technology Transitions**



SOCIETY NEWS

- 125 ■ **2017 MRS Fall Meeting honors Dresselhaus, presents inaugural awards**

■ **Science in Video Awards**

■ **Bao, Dunn, Mhaisalkar, Schwaiger, and Shinde to chair 2019 MRS Spring Meeting**

■ **MRS invites nominations for awards program**

■ **NICE 2018: 4th International Conference on Bioinspired and Biobased Chemistry & Materials to be held October 14–17**

- 135 **Special Insert**

■ **2018 MRS Member Benefits & Society Activities**



DIVERSITY IN MS&E

- 131 ■ **Latino engineering faculty in the United States**
Gerardo N. Arellano, Oscar Jaime-Acuña,
and Olivia A. Graeve
Feature Editor: Lynnette D. Madsen



FEATURES

- 148 **Book Reviews**
- **Piezoelectric Materials: Applications in SHM, Energy Harvesting & Biomechanics**
Suresh Bhalla, Sumedha Moharana,
Visalakshi Talakokula, and Naveet Kaur
Reviewed by Mariana Amorim Fraga
 - **An Introduction to Graphene and Carbon Nanotubes**
John Edward Proctor, Daniel Alfonso Melendrez Armada,
and Aravind Vijayaraghavan
Reviewed by Ram Devanathan
 - **Magnetic Resonance of Semiconductors and Their Nanostructures: Basic and Advanced Applications**
Pavel G. Baranov, Hans Jürgen von Bardeleben,
Fedor Jelezko, and Jörg Wrachtrup
Reviewed by Gen Long

- 152 **Image Gallery**
Look Again

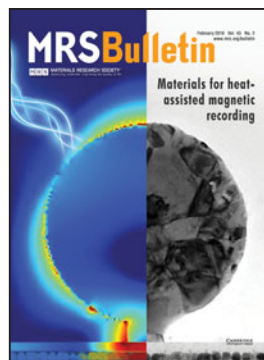


CAREER CENTRAL

ADVERTISERS IN THIS ISSUE

Page No.

American Elements	Outside back cover
High Voltage Engineering	Inside front cover
Rigaku Corporation	105



ON THE COVER

Materials for heat-assisted magnetic recording. Increasing the density of data storage in hard-disk drives is crucial to the future of inexpensive digital technology. Heat-assisted magnetic recording achieves this using heat from a laser beam confined well below the diffraction limit to write to media with high magnetic anisotropy that would normally be unwritable under magnetic fields. On the cover, the right section shows an electron micrograph of a "lollipop" near-

field transducer (NFT) and granular media separated by typical head-media spacing. The left section shows the computed electric field in the transducer and interface with the resulting temperature increase in the media. Laser illumination of the NFT is shown schematically by wave oscillations in the upper left. The top right NFT is from Seagate Technology, and the bottom right section of media is from K. Hono, National Institute for Materials Science. The left section is courtesy of Ali Ghoreyshi, University of Minnesota. See the technical theme that begins on page 87.



www.mrs.org/bulletin

www.mrs.org/energy-quarterly

www.mrs.org/mymrs

<http://journals.cambridge.org>

[mrsbulletin-rss](https://twitter.com/mrsbulletin)

[@mrsbulletin](https://twitter.com/mrsbulletin)

About the Materials Research Society

The Materials Research Society (MRS), a not-for-profit scientific association founded in 1973 and headquartered in Warrendale, Pennsylvania, USA, promotes interdisciplinary materials research. Today, MRS is a growing, vibrant, member-driven organization of over 16,000 materials researchers spanning over 80 countries, from academia, industry, and government, and a recognized leader in the advancement of interdisciplinary materials research.

The Society's interdisciplinary approach differs from that of single-discipline professional societies because it promotes information exchange across many scientific and technical fields touching materials development. MRS conducts three major international annual meetings and also sponsors numerous single-topic scientific meetings. The Society recognizes professional and technical excellence and fosters technical interaction through University Chapters. In the international arena, MRS implements bilateral projects with partner organizations to benefit the worldwide materials community. The Materials Research Society Foundation helps the Society advance its mission by supporting various projects and initiatives.

2018 MRS BOARD OF DIRECTORS

President Sean J. Hearne, Sandia National Laboratories, USA

Immediate Past President Susan Trolier-McKinstry,

The Pennsylvania State University, USA

Vice President and President-Elect Michael Fitzsimmons,

Oak Ridge National Laboratory and The University of Tennessee, USA

Secretary Eric A. Stach, University of Pennsylvania, USA

Treasurer David J. Parrillo, The Dow Chemical Company, USA

Executive Director Todd M. Osman, Materials Research Society, USA

Griselda Bonilla, IBM T.J. Watson Research Center, USA

Li-Chyong Chen, National Taiwan University, Taiwan

Matt Copel, IBM T.J. Watson Research Center, USA

Paul S. Drzaic, Apple, Inc., USA

Dawnielle Farrar-Gaines, Johns Hopkins University, USA

Yury Gogotsi, Drexel University, USA

Claudia E. Gutiérrez-Wing, Instituto Nacional de Investigaciones Nucleares, Mexico

Young-Chang Joo, Seoul National University, South Korea

Lincoln J. Lauhon, Northwestern University, USA

Paul C. McIntyre, Stanford University, USA

Christopher A. Schuh, Massachusetts Institute of Technology, USA

Rachel A. Segalman, University of California, Santa Barbara, USA

Magaly Spector, The University of Texas at Dallas, USA

Molly M. Stevens, Imperial College London, UK

Ehrenfried Zschech, Fraunhofer Institute for Ceramic Technologies and Systems, Germany

MRS OPERATING COMMITTEE CHAIRS

Academic Affairs Bruce M. Clemens, Stanford University, USA

Awards Albert Polman, FOM Institute AMOLF, The Netherlands

Government Affairs Kevin J. Whittlesey, 4D Molecular Therapeutics, USA

Meetings Terry Aselage, Sandia National Laboratories, USA

Member Engagement Sossina M. Haile, Northwestern University, USA

Public Outreach Elizabeth Kupp, The Pennsylvania State University, USA

Publications Shefford Baker, Cornell University, USA

MRS HEADQUARTERS

Todd M. Osman, Executive Director

J. Ardie Dillen, Director of Finance and Administration

Damon Dozier, Director of Government Affairs

Patricia Hastings, Director of Meetings Activities

Eileen M. Kiley, Director of Communications

Editor

Gopal R. Rao, rao@mrs.org

Managing Editor

Lori A. Wilson, lwilson@mrs.org

News Editor

Judy Meiksin, meiksin@mrs.org

Technical Editor

Lisa C. Oldham, oldham@mrs.org

Editorial Assistants

Michelle S. Raley, raley@mrs.org

Mary Wilmoth

Associate Technical Editor

Tim Palucka

Production/Design

Andrea Pekelnicky-Frye, Rebecca Tokarczyk, Felicia Turano, and TNQ

Associate Production Editor

Katie Wurtzel

Principal Development Editor

Elizabeth L. Fleischer

Director of Communications

Eileen M. Kiley

Guest Editors

M.T. Kief and R.H. Victora

Special Consultant

Angelika Veziridis

Energy Quarterly

Andrea Ambrosini (Chair), Monika Backhaus, Kristen Brown, David Cahen, Russell R. Chianelli, George Crabtree, Elizabeth A. Köcs, Shirley Meng, Sabrina Sartori, Anke Weidenkaff, M. Stanley Whittingham, and Steve M. Yalisove

Advertising/Sponsorship

Mary E. Kaufold, kaufold@mrs.org

Donna L. Watterson, watterson@mrs.org

Member Subscriptions

Michelle Judt, judt@mrs.org

Non-Member Subscriptions

subscriptions_newyork@cambridge.org

EDITORIAL BOARD

Fiona C. Meldrum (Chair), University of Leeds, UK

Ilke Arslan, Pacific Northwest National Laboratory, USA

V.S. Arunachalam, Center for Study of Science, Technology & Policy, India

N. (Balu) Balasubramaniam, Bangalore, India (retired)

Christopher J. Bettinger, Carnegie Mellon University, USA

Tommie Kelley, 3M, USA

Igor Lubomirsky, Weizmann Institute, Israel

Amit Misra, University of Michigan, USA

Steven C. Moss, The Aerospace Corporation, USA (retired)

Julie A. Nucci, Cornell University, USA

Linda J. Olafsen, Baylor University, USA

Boaz Pokroy, Technion-Israel Institute of Technology, Israel

Zhiwei Shan, Xi'an Jiaotong University and Hysitron, China

James W. Stasiak, HP Inc., USA

Carol Trager-Cowan, University of Strathclyde, UK

Eric Werwa, Washington, DC, USA

M. Stanley Whittingham, Binghamton University, The State University of New York, USA

Steve M. Yalisove, University of Michigan, USA

VOLUME ORGANIZERS

2018 **Karsten Albe**, Technische Universität Darmstadt, Germany

Hiroshi Funakubo, Tokyo Institute of Technology, Japan

Michael Hickner, The Pennsylvania State University, USA

Bethanie Stadler, University of Minnesota, USA

2019 **Craig B. Arnold**, Princeton University, USA

Claus Daniel, Oak Ridge National Laboratory and The University of Tennessee,

Knoxville, USA

Seung Min Han, Korea Advanced Institute of Science and Technology, South Korea

Gabriel Montaño, Los Alamos National Laboratory/Northern Arizona University, USA

MRS Bulletin (ISSN: 0883-7694, print; ISSN 1938-1425, online) is published monthly by the Materials Research Society, 506 Keystone Drive, Warrendale, PA 15086-7573. © 2018 Materials Research Society. Permission required to reproduce content. Periodical postage paid at New York, NY, and at additional mailing offices. POSTMASTER: Send address changes to *MRS Bulletin* in care of the Journals Department, Cambridge University Press, 100 Brook Hill Drive, West Nyack, NY 10994-2113, USA. Printed in the U.S.A.

Membership in MRS is \$130 annually for regular members, \$32 for students, and includes an electronic subscription to *MRS Bulletin*. Print subscriptions are available to MRS members for an additional \$25. Individual member subscriptions are for personal use only. Non-member subscription rates are \$560 (USD) for one calendar year (12 issues). Requests from subscribers for missing journal issues will be honored without charge only if received within six months of the issue's actual date of publication.

MRS Bulletin is included in Current Contents®/Engineering, Computing, and Technology; Current Contents®/Physical, Chemical, and Earth Sciences, the SciSearch® online database, Research Alert®, Science Citation Index®, and the Materials Science Citation Index™. Back volumes of *MRS Bulletin* are available on microfiche through University Microfilms Inc., 300 North Zeeb Road, Ann Arbor, MI 48106, USA.

Authors of each technical article appearing in *MRS Bulletin* are solely responsible for all content in their article(s), including accuracy of the facts, statements, and citing resources. Facts and opinions are solely the personal statements of the respective authors and do not necessarily represent the views of the editors, the Materials Research Society, or Cambridge University Press.

Send Letters to the Editor to **Bulletin@mrs.org**. Include your name, affiliation, and full contact information.