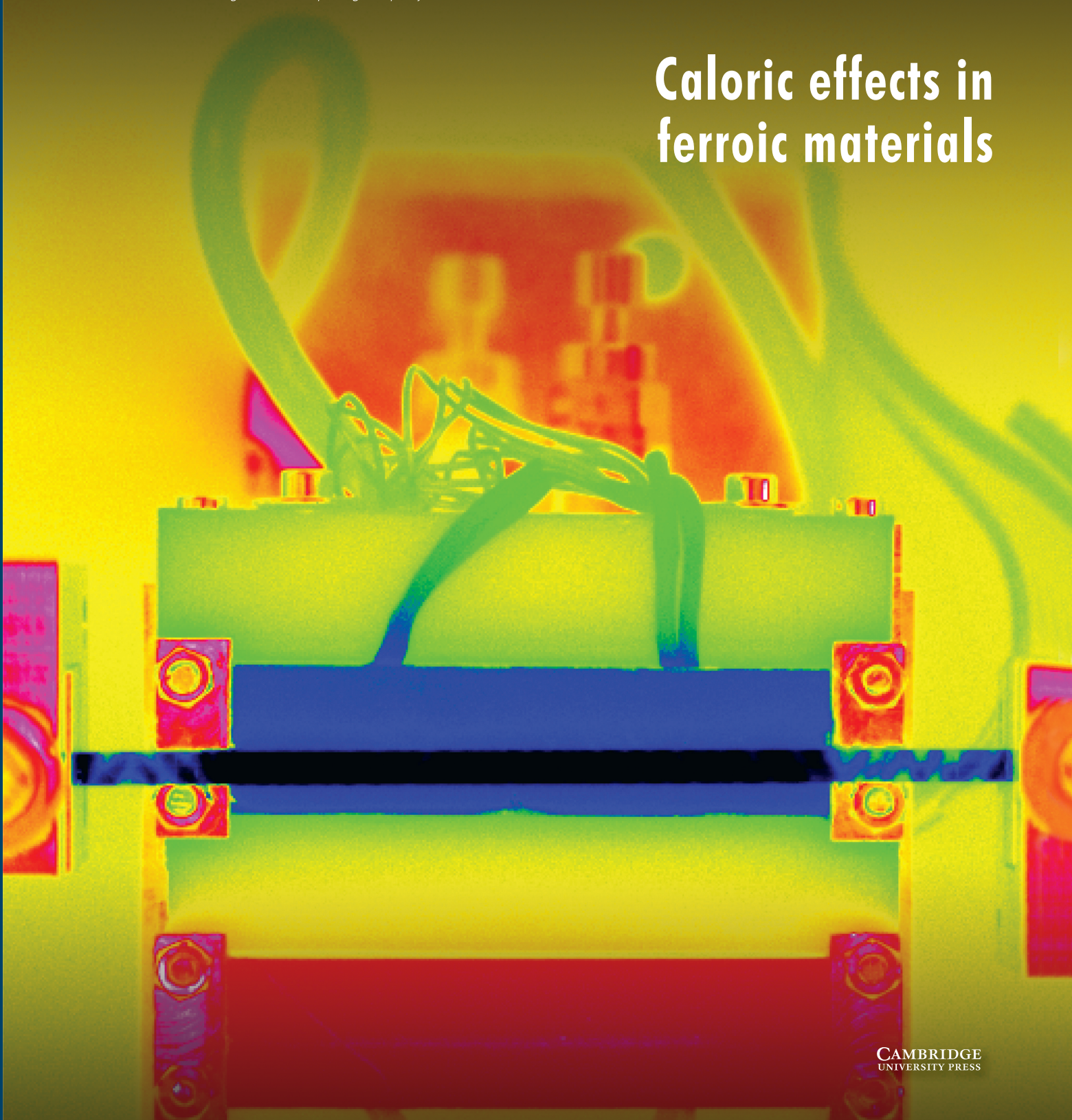


April 2018 Vol. 43 No. 4
www.mrs.org/bulletin

MRS Bulletin

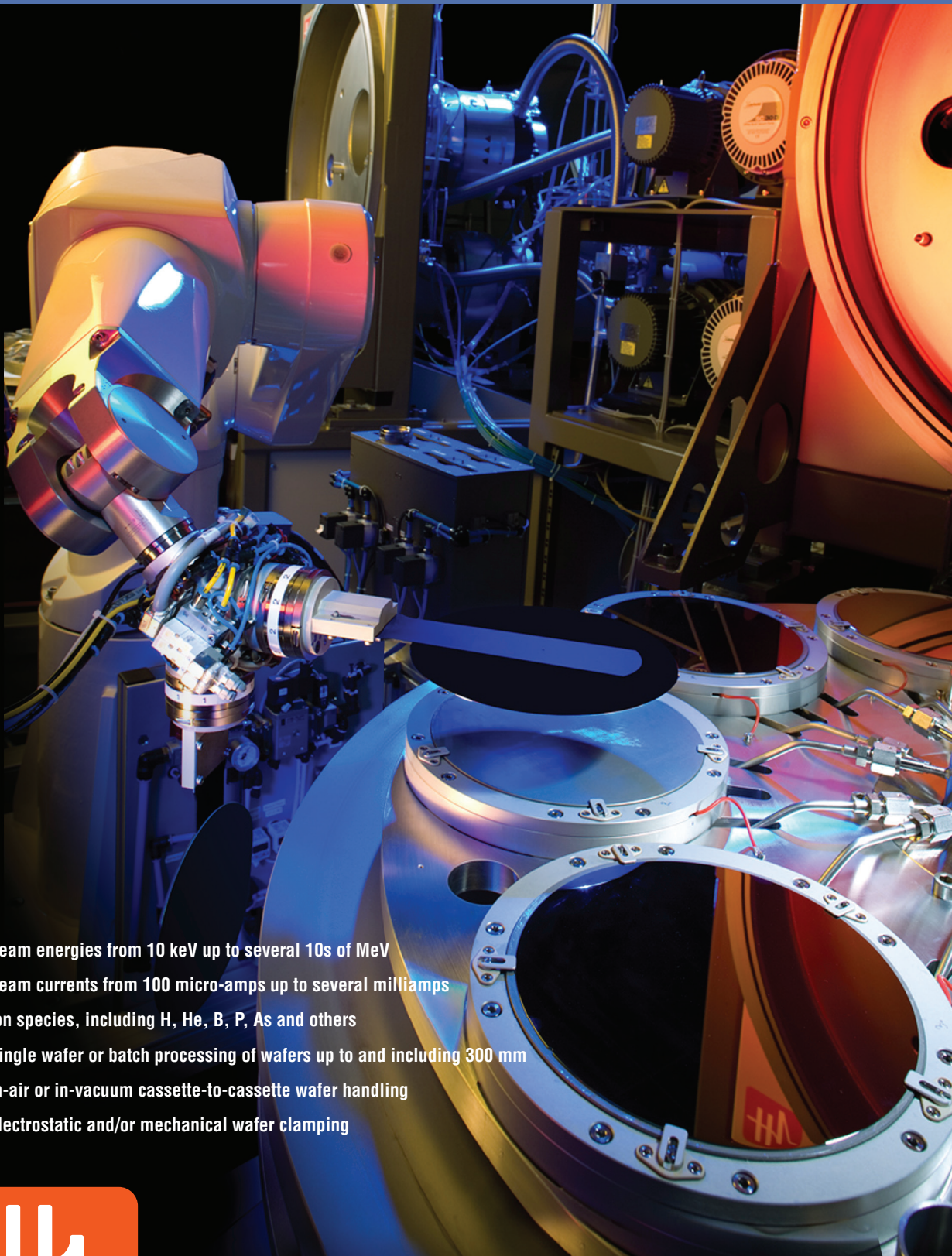
MRS MATERIALS RESEARCH SOCIETY®
Advancing materials. Improving the quality of life.

Caloric effects in ferroic materials



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® FALL MEETING & EXHIBIT

November 25–30, 2018 | Boston, Massachusetts

CALL FOR PAPERS

Abstract Submission Opens
May 14, 2018

Abstract Submission Deadline
June 14, 2018

Fall Meeting registrations include MRS Membership January – December 2019

BROADER IMPACT

- BI01 Sustainable Development in Materials Science and Related Societal Aspects
- BI02 The Future of Materials Science Academia—Preparing for a Career in Higher Education

BIOMATERIALS AND SOFT MATERIALS

- BM01 3D Printing of Passive and Active Medical Devices
- BM02 Electronic and Coupled Transport in Biology
- BM03 Multiscale Modeling of Soft Materials and Interfaces
- BM04 Biomaterials for Regenerative Engineering
- BM05 Advanced Manufacturing Technologies for Emulating Biological Tissues
- BM06 Plasma Processing and Monitoring for Bioengineering and Biomedical Engineering
- BM07 Bioelectronics—Fundamentals, Materials and Devices
- BM08 Materials-to-Devices for Integrated Wearable Systems—Energy Harvesting and Storage, Sensors/Actuators and Integration
- BM09 Bioinspired Macromolecular Assembly and Inorganic Crystallization—From Tissue Scaffolds to Nanostructured Materials

CHARACTERIZATION, MECHANICAL PROPERTIES AND STRUCTURE–PROPERTY RELATIONSHIPS

- CM01 Solid-State Chemistry of Inorganic Materials
- CM02 Structure–Property Relations in Non-Crystalline Materials
- CM03 *In Situ/Operando* Analysis of Electrochemical Materials and Interfaces
- CM04 Ultrafast Optical Probes for Advanced Materials Characterization and Development
- CM05 Fundamentals of Materials Property Changes Under Irradiation

ELECTRONIC, PHOTONIC AND MAGNETIC MATERIALS

- EP01 New Materials and Applications of Piezoelectric, Pyroelectric and Ferroelectric Materials
- EP02 Materials for Manipulating and Controlling Magnetic Skyrmions
- EP03 Beyond-Graphene 2D Materials—Synthesis, Properties and Device Applications
- EP04 Novel Photonic and Plasmonic Materials Enabling New Functionalities
- EP05 Excitons, Electrons and Ions in Organic Materials
- EP06 Coherent Electronic Spin Dynamics in Materials and Devices

- EP07 Tailored Disorder—Novel Materials for Advanced Optics and Photonics
- EP08 Ultra-Wide-Bandgap Materials and Devices
- EP09 Diamond Electronics, Sensors and Biotechnology—Fundamentals to Applications

ENERGY—TRANSFER, STORAGE AND CONVERSION

- ET01 Solid-State Batteries—Materials, Interfaces and Performance
- ET02 Silicon for Photovoltaics
- ET03 Application of Nanoscale Phenomena and Materials to Practical Electrochemical Energy Storage and Conversion
- ET04 Perovskite Solar Cells—Challenges and Opportunities
- ET05 Fundamental Aspects of Halide Perovskite (Opto)electronics and Beyond
- ET06 Advanced Materials and Chemistries for High-Energy and Safe Rechargeable Batteries
- ET07 Advanced Processing and Manufacturing for Energy Conversion, Storage and Harvesting Devices
- ET08 Emerging Materials and Characterization for Selective Catalysis
- ET09 Materials for Chalcogen Electrochemistry in Energy Conversion and Storage
- ET10 Redox Active Materials and Flow Cells for Energy Applications
- ET11 Emerging Materials and Device Concepts for Flexible, Low-Cost Photovoltaic Technologies
- ET12 Harvesting Functional Defects in Energy Materials
- ET13 Materials for Multifunctional Windows
- ET14 Materials Science Facing Global Warming—Practical Solutions for Our Future
- ET15 Scientific Basis for Nuclear Waste Management

GENERAL INTEREST

- GI01 Machine Learning and Data-Driven Materials Development and Design
- GI02 Materials for Next-Generation Robotics

NANOMATERIALS

- NM01 Carbon Nanotubes, Graphenes and Related Nanostructures
- NM02 Nanometal—Synthesis, Properties and Applications
- NM03 Nanowires and Related 1D Nanostructures—New Opportunities and Grand Challenges
- NM04 Nanomaterials and Nanomanufacturing for Sustainability

PROCESSING AND MANUFACTURING

- PM01 Architected Materials—Synthesis, Characterization, Modeling and Optimal Design
- PM02 Conductive Materials Reliability in Flexible Electronics
- PM03 Hierarchical, Hybrid and Roll-to-Roll Manufacturing for Device Applications
- PM04 High-Entropy Alloys
- PM05 Electromagnetic Fields in Materials Synthesis—Far from Equilibrium Effects
- PM06 Advances in Intermetallic-Based Alloys for Structural and Functional Applications
- PM07 Plasma-Based Synthesis, Processing and Characterization of Novel Materials for Advanced Applications

THERMAL PROPERTIES AND THERMOELECTRIC MATERIALS

- TP01 Caloric Materials for Highly Efficient Cooling Applications
- TP02 Thermal Analysis—Materials, Measurements and Devices
- TP03 Emerging Low-Temperature Thermal Energy Conversion Technologies

MEETING CHAIRS

- Kristen H. Brosnan** GE Global Research
- David LaVan** National Institute of Standards and Technology
- Patrycja Paruch** University of Geneva
- Joan M. Redwing** The Pennsylvania State University
- Takao Someya** The University of Tokyo

www.mrs.org/fall2018

2018 iMatSci Innovator Showcase

CALL FOR EARLY-STAGE STARTUPS

Submission Site Opens: June 1, 2018

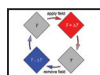
www.mrs.org/imatsci

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

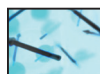
506 Keystone Drive • Warrendale, PA 15086-7573
Tel 724.779.3003 • Fax 724.779.8313
info@mrs.org • www.mrs.org

CONTENTS

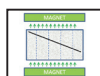
CALORIC EFFECTS IN FERROIC MATERIALS



- 264 **Caloric effects in ferroic materials**
Sebastian Fähler and Vitalij K. Pecharsky, Guest Editors



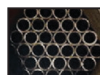
- 269 **Magnetocaloric materials for refrigeration near room temperature**
Anja Waske, Markus E. Gruner, Tino Gottschall, and Oliver Gutfleisch



- 274 **The evolution of magnetocaloric heat-pump devices**
Carl Zimm, Andre Boeder, Bryant Mueller, Kyle Rule, and Steven L. Russek



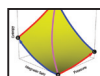
- 280 **High-performance elastocaloric materials for the engineering of bulk- and micro-cooling devices**
Jan Frenzel, Gunther Eggeler, Eckhard Quandt, Stefan Seelecke, and Manfred Kohl



- 285 **Overcoming fatigue through compression for advanced elastocaloric cooling**
Huilong Hou, Jun Cui, Suxin Qian, David Catalini, Yunho Hwang, Reinhard Radermacher, and Ichiro Takeuchi



- 291 **Electrocaloric effects in multilayer capacitors for cooling applications**
Xavier Moya, Emmanuel Defay, Neil D. Mathur, and Sakyo Hirose



- 295 **Multicaloric materials and effects**
Enric Stern-Taulats, Teresa Castán, Lluís Mañosa, Antoni Planes, Neil D. Mathur, and Xavier Moya

DEPARTMENTS



NEWS & ANALYSIS

253 **Materials News**

- **Optical blasting of polycrystals manipulates grain boundaries**
Ahmad R. Kirmani
- **Probing the buried interface between graphite layers**
YuHao Liu
- **Flexoelectricity found in bone**
Vineet Venugopal
- **Influence of grain boundaries on Li-ion conductivity characterized at atomic scale**
Tianyu Liu
- **Health monitoring reaches new heights with human trials of ingestible sensor**
Rahim Munir

257 **Materials Education**

- **The materials science and engineering undergraduate enrollment floodgates are open**
R. Allen Kimel and Susan B. Sinnott

262 **Science Policy**

- **US National Academies report on integrity in science**
Jennifer A. Nekuda Malik
- **EU aviation and shipping face big challenges in reducing environmental impact**



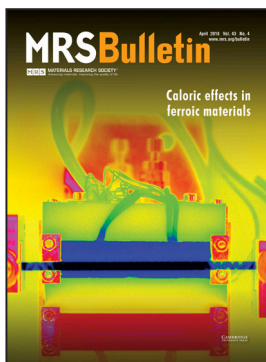
SOCIETY NEWS

- 300 ■ **MRS Communications Abstracts**
- 308 ■ **Profiles**
Sophie Robinson, Environmentalist and Film Producer
Humaira Taz



DIVERSITY IN MS&E

- 303 ■ **Queer identities in materials science and engineering**
Keith J. Bowman
Feature Editor: Lynnette D. Madsen



ON THE COVER

Caloric effects in ferroic materials. The worldwide energy usage for cooling by refrigerators and air conditioners is substantial. This issue of *MRS Bulletin* introduces ongoing developments in ferroic-caloric materials and their applications to cooling devices, including those beyond refrigeration such as magnetocaloric materials being explored for hyperthermia therapy. The cover shows a color-coded infrared thermograph obtained during elastocaloric cooling. The image documents temperature changes in the elastocaloric NiTi ribbon subjected to mechanical cycling between two Cu blocks. A significant temperature difference between the two blocks is established after a few elastocaloric cycles. Image courtesy of Marvin Schmidt. See the technical theme that begins on p. 264.



FEATURES

- 309 **Book Reviews**
- **The Development of Catalysis: A History of Key Processes and Personas in Catalytic Science and Technology**
Adriano Zecchina and Salvatore Califano
Reviewed by Karen Swider Lyons
 - **Materials for a Healthy, Ecological and Sustainable Built Environment: Principles for Evaluation**
Emina Kristina Petrović, Brenda Vale, and Maibritt Pedersen Zari
Reviewed by Miriam Sánchez Pozos
 - **Advanced Transmission Electron Microscopy: Imaging and Diffraction in Nanoscience**
Jian Min Zuo and John C.H. Spence
Reviewed by Wanfeng Li
- 312 **Image Gallery**
Look Again



CAREER CENTRAL

ADVERTISERS IN THIS ISSUE

Page No.

American Elements	Outside back cover
High Voltage Engineering	Inside front cover
National Electrostatics Corp.	268
Rigaku Corporation	290



www.mrs.org/bulletin

www.mrs.org/energy-quarterly

www.mrs.org/mymrs

<http://journals.cambridge.org>

mrsbulletin-rss

[@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 R. 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 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 David P. Norton, University of Florida, 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 P. 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

Michael P. Moran, 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

Sebastian Fähler and Vitalij K. Pecharsky

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.