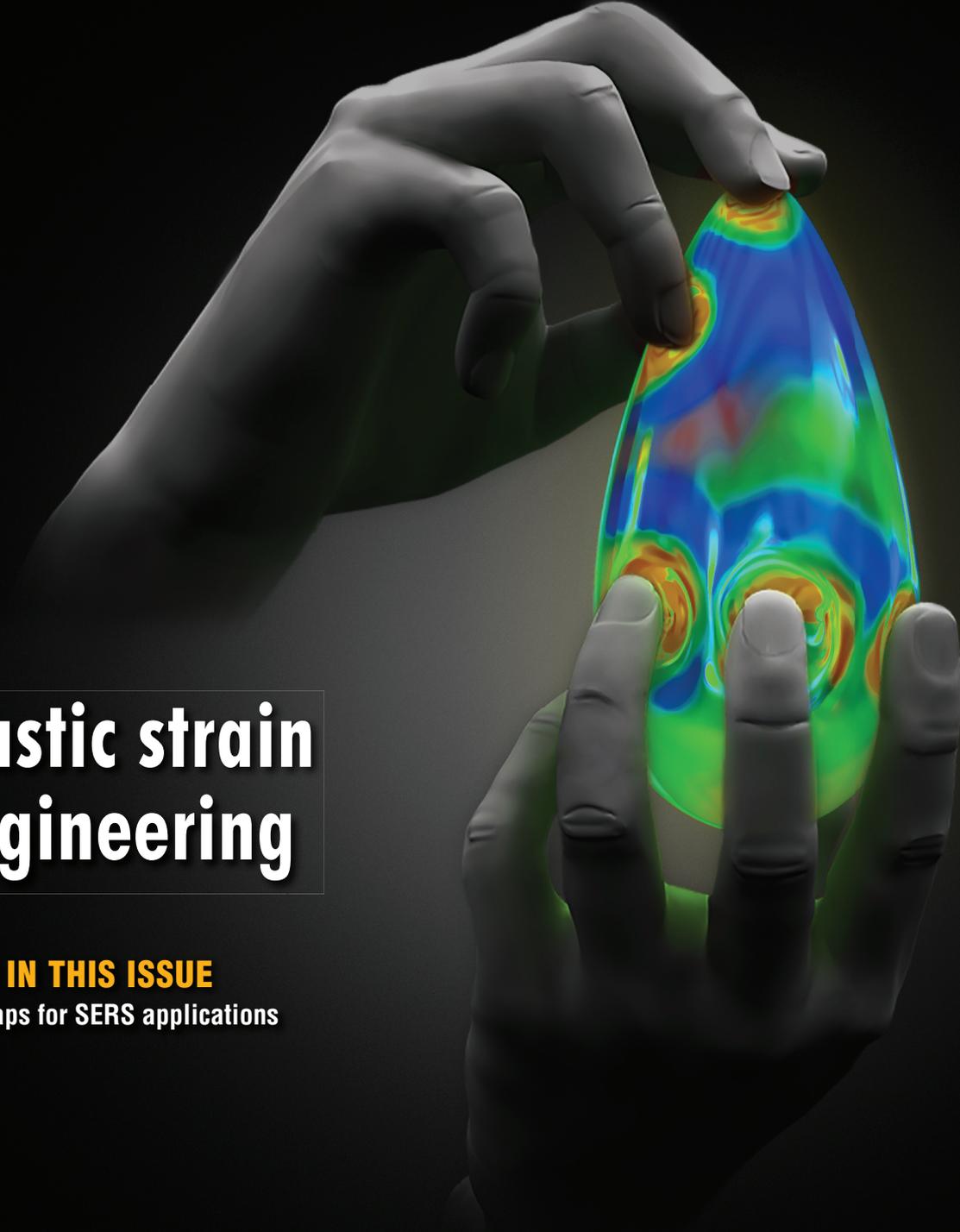


# MRS Bulletin

February 2014 Vol. 39 No. 2  
www.mrs.org/bulletin

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

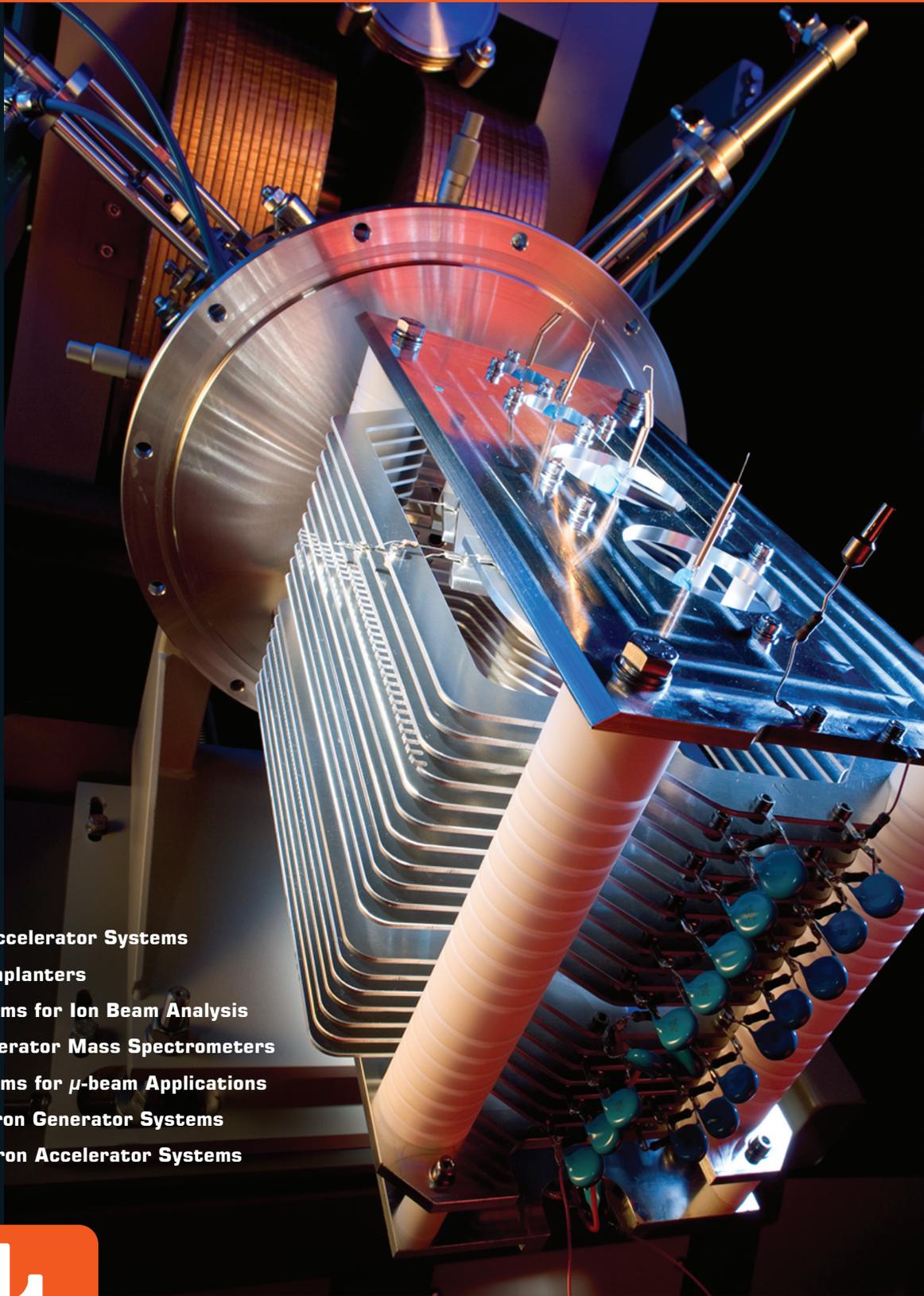


## Elastic strain engineering

**ALSO IN THIS ISSUE**  
Nanogaps for SERS applications

CAMBRIDGE  
UNIVERSITY PRESS

# PARTICLE ACCELERATOR SYSTEMS



- Ion Accelerator Systems
- Ion Implanters
- Systems for Ion Beam Analysis
- Accelerator Mass Spectrometers
- Systems for  $\mu$ -beam Applications
- Neutron Generator Systems
- Electron Accelerator Systems



## High Voltage Engineering

High Voltage Engineering Europa B.V.

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

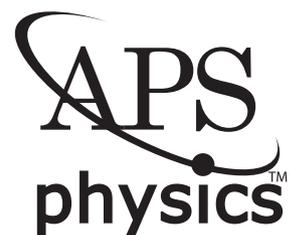
Tel: 31 33 4619741 • [info@highvolteng.com](mailto:info@highvolteng.com)

[www.highvolteng.com](http://www.highvolteng.com)

# PHYSICAL REVIEW APPLIED

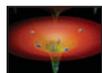
The American Physical Society (APS) is pleased to announce *Physical Review Applied*, a new journal dedicated to publishing the highest quality papers at the intersection of physics and engineering.

[journals.aps.org/prapplied](http://journals.aps.org/prapplied)



# CONTENTS

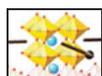
## ELASTIC STRAIN ENGINEERING



- 108 **Elastic strain engineering for unprecedented materials properties**

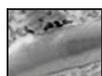
Ju Li, Zhiwei Shan, and Evan Ma, Guest Editors

- 115 **Meet Our Authors**



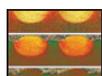
- 118 **Elastic strain engineering of ferroic oxides**

Darrell G. Schlom, Long-Qing Chen, Craig J. Fennie, Venkatraman Gopalan, David A. Muller, Xiaoqing Pan, Ramamoorthy Ramesh, and Reinhard Uecker



- 131 **Strain scaling for CMOS**

S.W. Bedell, A. Khakifirooz, and D.K. Sadana



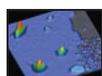
- 138 **Observing and measuring strain in nanostructures and devices with transmission electron microscopy**

Martin J. Hytch and Andrew M. Minor



- 147 **“Stretching” the energy landscape of oxides—Effects on electrocatalysis and diffusion**

Bilge Yildiz



- 157 **Elastically strained nanowires and atomic sheets**

Dapeng Yu, Ji Feng, and James Hone

## TECHNICAL FEATURE



- 163 **Nanogaps for SERS applications**

Lianming Tong, Hongxing Xu, and Mikael Käll

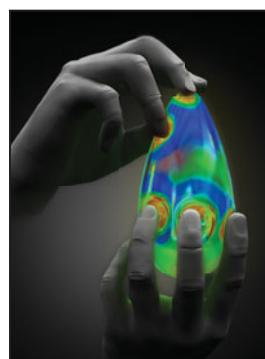
## DEPARTMENTS



## NEWS & ANALYSIS

### 101 **Materials News**

- **Molecular-sized fluorescent probes achieved with nanodiamonds**  
Jean L. Njoroge
- **Ferromagnetism revealed in suspensions of magnetic nanoplatelets in liquid crystal**  
Dirk Wouters
- **Soluble 2D supramolecular organic frameworks created**  
Lynn Yarris
- **Iron catalyst reservoir doubles CNT growth on alumina**
- **Superconductivity switched on by magnetic field**
- **Nanoparticles used to glue hydrogels**  
Jean L. Njoroge



### ON THE COVER

**Elastic strain engineering.** The articles in this issue of *MRS Bulletin* focus on the different research communities that use elastic strain to control functional properties of materials, including strained silicon technology, strain effects on chemical kinetics, strained ferroic films for tuning phase transformations, and strained atomic sheets and nanowires. The cover shows elastic deformation above 1% applied by “Feynman’s hands” at the nanoscale, which can lead to drastically different physical and chemical properties (symbolized by the colors) from the stress-free material. Image courtesy of Zhaohua Wang, Yan Liang, and Sina Moeini Ardakani (L2Molecule.com). See the technical theme that begins on page 108.

106 **Science Policy**

- **Critical minerals bill introduced in US Senate**  
Jennifer A. Nekuda Malik
- **German Research Foundation establishes new Collaborative Research Centers**



**FEATURES**

192 **Image Gallery**  
Look Again



**169 SOCIETY NEWS**

- **Preview: 2014 Materials Research Society Spring Meeting & Exhibit**
- **MRS Bulletin Volume Organizers guide technical theme topics for 2015**
- **MRS invites nominations for the Von Hippel Award, Turnbull Lectureship, MRS Medal, and Materials Theory Award**
- **2014 MRS Member Benefits and Society Activities**



**188 CAREER CENTRAL**

**ADVERTISERS IN THIS ISSUE**

Page No.

American Elements .....	Outside back cover
American Physical Society (APS) .....	97
High Voltage Engineering .....	Inside front cover
Hindawi Publishing Corporation .....	Inside back cover
National Electrostatics Corp. ....	105
Rigaku Corporation .....	130
SVC TechCon 2014 .....	156



[www.mrs.org/bulletin](http://www.mrs.org/bulletin)

MRS members—access *MRS Bulletin* online

[www.mrs.org/energy-quarterly](http://www.mrs.org/energy-quarterly)

Access Energy Quarterly online

[www.mrs.org/mymrs](http://www.mrs.org/mymrs)

MRS Publications Alert—  
receive advance Table of Contents by email

<http://journals.cambridge.org/mrsbulletin-rss>

Subscribe TODAY to the *MRS Bulletin* RSS Feed

Design images used under license from Shutterstock.com

## 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 encompassing approximately 125 topical symposia, 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.

MRS publishes *MRS Bulletin*, *MRS Communications*, the *MRS Online Proceedings Library*, *Journal of Materials Research*, *MRS Energy & Sustainability*, and books and textbooks with its publishing partner, Cambridge University Press.

### 2014 MRS BOARD OF DIRECTORS

**President** Tia Benson Tolle, The Boeing Company, USA

**Immediate Past President** Orlando Auciello, University of Texas at Dallas, USA

**Vice President and President-Elect** Oliver Kraft, Karlsruhe Institute of Technology, Germany

**Secretary** Sean J. Hearne, Sandia National Laboratories, USA

**Treasurer** Michael R. Fitzsimmons, Los Alamos National Laboratory, USA

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

Shenda M. Baker, Synedgen, Inc./Harvey Mudd College, USA

Alexandra Boltasseva, Purdue University, USA

C. Jeffrey Brinker, Sandia National Laboratories and University of New Mexico, USA

David Cahen, Weizmann Institute of Science, Israel

Steve Eglash, Stanford University, USA

Chang-Beom Eom, University of Wisconsin-Madison, USA

Susan Ermer, Lockheed Martin Advanced Technology Center, USA

Eric Garfunkel, Rutgers University, USA

Sossina M. Haile, California Institute of Technology, USA

Andrea M. Hodge, University of Southern California, USA

Hideo Hosono, Tokyo Institute of Technology, Japan

Fiona C. Meldrum, University of Leeds, UK

Kornelius Nielsch, University of Hamburg, Germany

Eric A. Stach, Brookhaven National Laboratory, USA

Stephen Streiffer, Argonne National Laboratory, USA

Lucas Tsakalakos, General Electric-Global Research Center, USA

### MRS OPERATING COMMITTEE CHAIRS

**Academic Affairs** Bruce Clemens, Stanford University, USA

**Awards** C. Barry Carter, University of Connecticut, USA

**Government Affairs** Nabil Bassim, US Naval Research Laboratory, USA

**Meetings Committee** David S. Ginley, National Renewable Energy Laboratory, USA

**Member Engagement** Yves Chabal, The University of Texas at Dallas, USA

**Public Outreach** Aditi Risbud, University of Utah in Salt Lake City, USA

**Publications** Susan Trolier-McKinstry (Acting Chair), The Pennsylvania State University, USA

### MRS OFFICE OF PUBLIC AFFAIRS

Ron Kelley 499 South Capitol St. SW, Suite 600, Washington, DC 20003

#### Editor

Gopal R. Rao, rao@mrs.org

#### Managing Editor

Judy Meiksin, meiksin@mrs.org

#### Technical Editor

Lori A. Wilson, lwilson@mrs.org

#### Editorial Assistants

Ben Moriarty, moriarty@mrs.org

Mary Wilmoth

#### Associate Technical Editor

Tobias Lockwood

#### Production/Design

Andrea Pekelnicky, Rebecca Yokum, and TNQ

#### Production Editor

Catherine Paduani

#### Science News Editor

Tim Palucka

#### Principal Development Editor

Elizabeth L. Fleischer

#### Director of Communications

Eileen Kiley Novak

#### Guest Editors

Ju Li, Zhiwei Shan, and Evan Ma

#### Special Contributors

Gilbert Nessim

#### Energy Quarterly

Anke Weidenkaff (Chair), Anshu Bharadwaj, David Cahen, Russell R. Chianelli, George Crabtree, Sabrina Sartori, 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

Paul S. Drzaic (Chair), Apple, Inc., USA

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

Marie-Isabelle Baraton, University of Limoges, France

Hanns-Ulrich Habermeier, Max Planck Institute for Solid State Research, Germany

Igor Lubomirsky, Weizmann Institute, Israel

Fiona C. Meldrum, University of Leeds, UK

Amit Misra, Los Alamos National Laboratory, USA

Steven C. Moss, Aerospace Corporation, USA

Julie A. Nucci, Cornell University, USA

Linda J. Olafsen, Baylor University, USA

James W. Stasiak, Hewlett-Packard Co., USA

Carol Trager-Cowan, University of Strathclyde, UK

Anke Weidenkaff, Empa, Swiss Federal Laboratories for Materials Science, Switzerland and University of Stuttgart, Germany

Eric Werwa, Washington, DC, USA

Steve M. Yalisove, University of Michigan, USA

### VOLUME ORGANIZERS

2015 Ying-Hao (Eddie) Chu, National Chiao Tung University, Taiwan

Kalpna S. Katti, North Dakota State University, USA

Tommie W. Kelley, 3M, USA

Jud Ready, Georgia Institute of Technology, USA

2014 Deborah E. Leckband, University of Illinois at Urbana-Champaign, USA

Yuri Suzuki, Stanford University, USA

Enrico Traversa, King Abdullah University of Science and Technology, Saudi Arabia

Yonhua Tzeng, National Cheng Kung University, Taiwan

2013 Mark T. Lusk, Colorado School of Mines, USA

Eva Olsson, Chalmers University of Technology, Sweden

Birgit Schwenzler, Pacific Northwest National Laboratory, USA

James W. Stasiak, Hewlett-Packard Co., 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. Copyright © 2014 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 \$115 annually for regular members, \$30 for students. Dues include an allocation of \$29 (\$17 for students) to a subscription to *MRS Bulletin*. Individual member subscriptions are for personal use only. Non-member subscription rates are \$439 for one calendar year (12 issues) within North America and \$527 elsewhere. 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.

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