

March 2017 Vol. 42 No. 3
www.mrs.org/bulletin

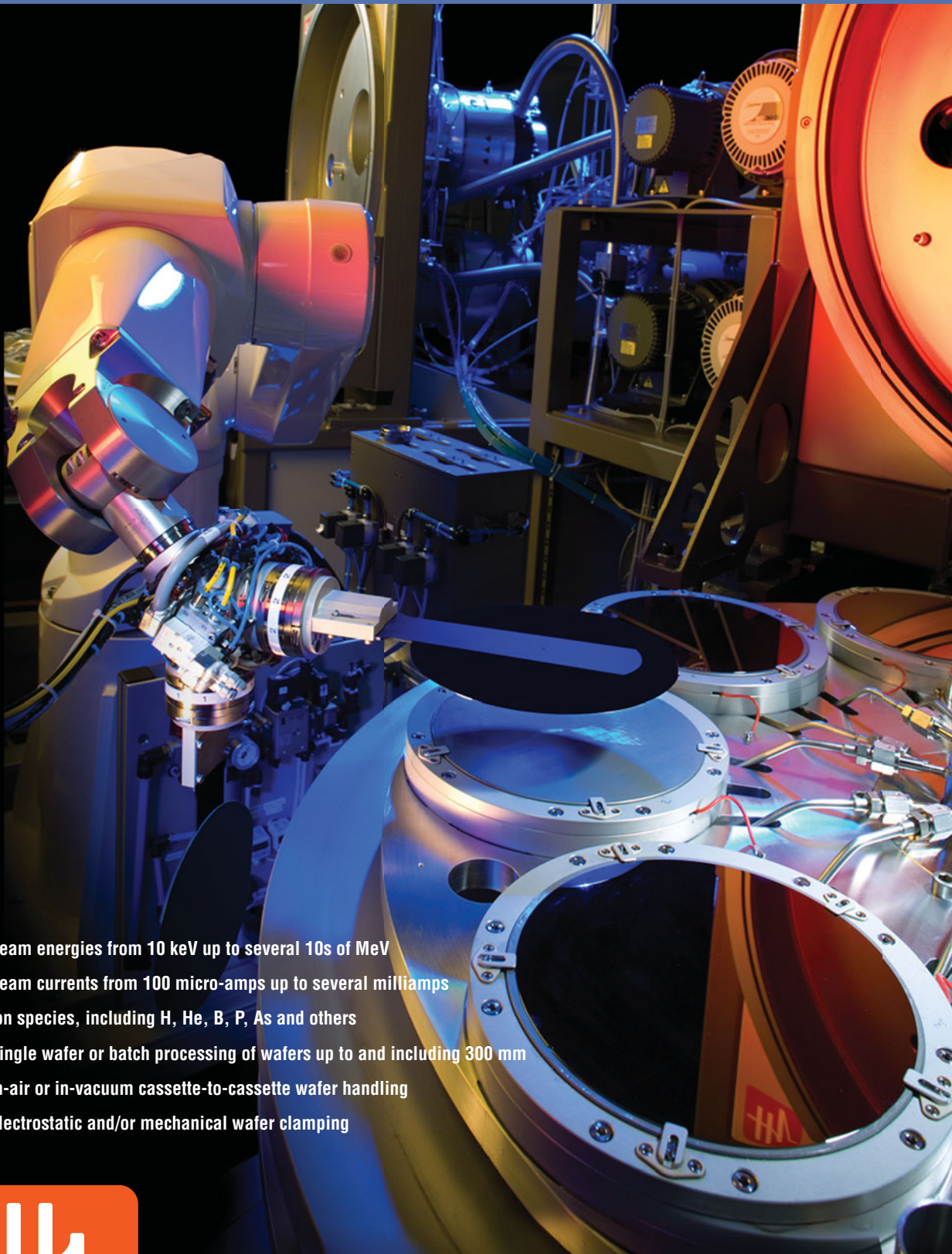
MRS Bulletin

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

Glass-ceramics

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



Visit us at
MRS
Spring Meeting
& Exhibit
Booth #306

LIKE A KID IN A CANDY STORE

That's how you'll feel at goodfellowusa.com

You'll find our shelves stocked with more than 70,000 enticing items.

- ✓ Metals
- ✓ Alloys
- ✓ Ceramics
- ✓ Polymers
- ✓ Compounds
- ✓ Composites
- ✓ Intermetallics
- ✓ Glasses

And if you don't see what you want, just ask! Chances are we can supply whatever you need to your precise specifications.

So don't hold back. Let Goodfellow help you recapture that youthful feeling of excitement!

Goodfellow

Metals & Materials

Sweet

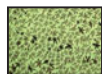
goodfellowusa.com

info@goodfellowusa.com

1-800-821-2870 (real live person)

CONTENTS

GLASS-CERAMICS



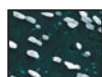
- 195 **Glass-ceramics and realization of the unobtainable: Property combinations that push the envelope**
Mark J. Davis and Edgar D. Zanotto, Guest Editors



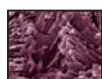
- 200 **Transparent glass-ceramics for optical applications**
O. Dymshits, M. Shepilov, and A. Zhilin



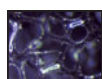
- 206 **Ion-conducting glass-ceramics for energy-storage applications**
Hellmut Eckert and Ana Candida Martins Rodrigues



- 213 **Ferroelectric glass-ceramics**
Manuel Pedro Fernandes Graça and Manuel Almeida Valente



- 220 **Nature-inspired design of strong, tough glass-ceramics**
Qiang Fu, George H. Beall, and Charlene M. Smith



- 226 **Bioactive glass-ceramic scaffolds: Processing and properties**
Elena Boccardi, Francesca E. Ciraldo, and Aldo R. Boccaccini



- 233 **Glass-ceramics for nuclear-waste immobilization**
John S. McCloy and Ashutosh Goel

Energy Quarterly



- 185 **Editorial**
Water in the desert
Thomas A. Davis
- 188 **Energy Sector Analysis**
Can carbon capture and storage deliver on its promise?
Prachi Patel
FEATURE EDITOR: Partow Pakdel Henriksen
- 190 **Energy Sector Analysis**
Search for water-splitting catalysts for global usage
Melissae Fellet
FEATURE EDITOR: David M. Tiede

DEPARTMENTS



173 OPINION

- Editorial**
Change is inevitable; change is constant
Gopal R. Rao



ON THE COVER

Glass-ceramics contain one or more crystalline phases dispersed in a residual glass phase. The articles in this issue of *MRS Bulletin* highlight property combinations in glass-ceramics relevant to distinct applications. There are several overarching themes in common, including the proper selection of bulk composition to allow for crystallization of desired phases. Innovative applications of glass-ceramics owe their importance and continuing

interest to hard-to-combine properties. The micrograph on the cover shows the result of devitrification of a supercooled CaO-MgO-SiO₂ liquid during cooling. The pyramid-shaped crystals are ~1.5 mm in size and are embedded in residual glass. The micrograph was taken at the Vitreous Materials Laboratory of the Federal University of São Carlos, Brazil, by Eduardo B. Ferreira and Raphael M.C.V. Reis. See the technical theme that appears on page 195.



NEWS & ANALYSIS

175 Materials News

- **Research highlights: Perovskites**
Prachi Patel
FEATURE EDITOR: Pabitra K. Nayak
- **High pressure and small spaces create order from disorder**
Tim Palucka
- **Finite-difference methods used to model photonic wave localization in 3D quasicrystals**
Aditi Risbud
- **3D self-assembly of microgel dispersion coordinated by an electric field**
Antonio Cruz
- **Soft graphene–polymer composite makes an extremely sensitive sensor**
Tim Palucka
- **White Paper: Nanoscale impedance and permittivity properties at microwave frequencies using SMM**
Ferry Kienberger and Georg Gramse

183 Science Policy

- **American Innovation and Competitiveness Act becomes law**
Jennifer A. Nekuda Malik
- **EU companies' R&D Investment grows faster than global and US trends**



SOCIETY NEWS

241 L. Eric Cross of Pennsylvania State University remembered

- Clive A. Randall and Susan Trolrier-McKinstry
- **DeSimone to present Kavli lecture during 2017 MRS Spring Meeting plenary session**
- **2017 MRS Spring Meeting Exhibitors**

Special Insert

- **Materials Research Society 2016 year-end review**



FEATURES

251 Books

- **Materials Science and Engineering: Problems with Solutions**
M.N. Shetty
Reviewed by Joana Vaz Pinto
- **Thermophysical Properties of Multicomponent Liquid Alloys**
Jürgen Brillo
Reviewed by Roberto Ribeiro de Avillez
- **Metamaterials: Beyond Crystals, Noncrystals, and Quasicrystals**
Tie Jun Cui, Wen Xuan Tang, Xin Mi Yang, Zhong Lei Mei, and Wei Xiang Jiang
Reviewed by Dieter Vollath

255 Posterminaries

- **The new (old?) materials zoo**
Steve Moss



253 CAREER CENTRAL

ADVERTISERS IN THIS ISSUE

Page No.

American Elements	Outside back cover
* CRAIC Technologies, Inc.	182
* Goodfellow Corporation	169
High Voltage Engineering	Inside front cover
* International Centre for Diffraction Data (ICDD)	219
* Janis Research Company, LLC	199
* Kurt J. Lesker Company	212
* Lake Shore Cryotronics, Inc.	194
* MilliporeSigma (Sigma-Aldrich Materials Science)	174
* National Electrostatics Corp.	205
* Rigaku Corporation	193
Thermo-Calc Software Inc.	Inside back cover

**Please visit us at the exhibit, April 18–19, during the 2017 Materials Research Society Spring Meeting in Phoenix, Ariz.*



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.

2017 MRS BOARD OF DIRECTORS

President Susan Trolier-McKinstry, The Pennsylvania State University, USA
Immediate Past President Kristi S. Anseth, University of Colorado Boulder, USA
Vice President and President-Elect Sean J. Hearne, Sandia National Laboratories, USA
Secretary Eric A. Stach, Brookhaven National Laboratory, USA
Treasurer David J. Parrillo, The Dow Chemical Company, USA
Executive Director Todd M. Osman, Materials Research Society, USA

Charles T. Black, Brookhaven National Laboratory, USA
Li-Chyong Chen, National Taiwan University, Taiwan
Matt Copel, IBM Research Division, 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
Karen L. Kavanagh, Simon Fraser University, Canada
Lincoln J. Lauhon, Northwestern University, USA
Christine Ortiz, Massachusetts Institute of Technology, USA
Sabrina Sartori, University of Oslo, Norway
Magaly Spector, The University of Texas at Dallas, USA
Molly M. Stevens, Imperial College London, UK
Anke Weidenkaff, University of Stuttgart, 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

Carol Tseng

Production/Design

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

Associate Production Editor

Brian Mazeski

Principal Development Editor

Elizabeth L. Fleischer

Director of Communications

Eileen M. Kiley

Guest Editors

Mark J. Davis and Edgar D. Zanotto

Special Consultant

Angelika Veziridis

Energy Quarterly

George Crabtree (Co-Chair), Elizabeth A. Kócs (Co-Chair), Andrea Ambrosini, Monika Backhaus, David Cahen, Russell R. Chianelli, 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
V.S. Arunachalam, Center for Study of Science, Technology & Policy, India
Christopher J. Bettinger, Carnegie Mellon University, USA
Paul S. Drzaic, Apple, Inc., USA
Igor Lubomirsky, Weizmann Institute, Israel
Amit Misra, University of Michigan, USA
Steven C. Moss, The Aerospace Corporation, USA
Julie A. Nucci, Cornell University, USA
Linda J. Olafsen, Baylor University, USA
James W. Stasiak, HP Inc., USA
Carol Trager-Cowan, University of Strathclyde, UK
Anke Weidenkaff, University of Stuttgart, Germany
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

2017 Ken Haenen, Hasselt University & IMEC vzw, Belgium
John C. Mauro, Corning Incorporated, USA
Michael S. Strano, Massachusetts Institute of Technology, USA
Joyce Y. Wong, Boston University, USA

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

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. © 2017 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 \$533 (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.