

MRS Bulletin

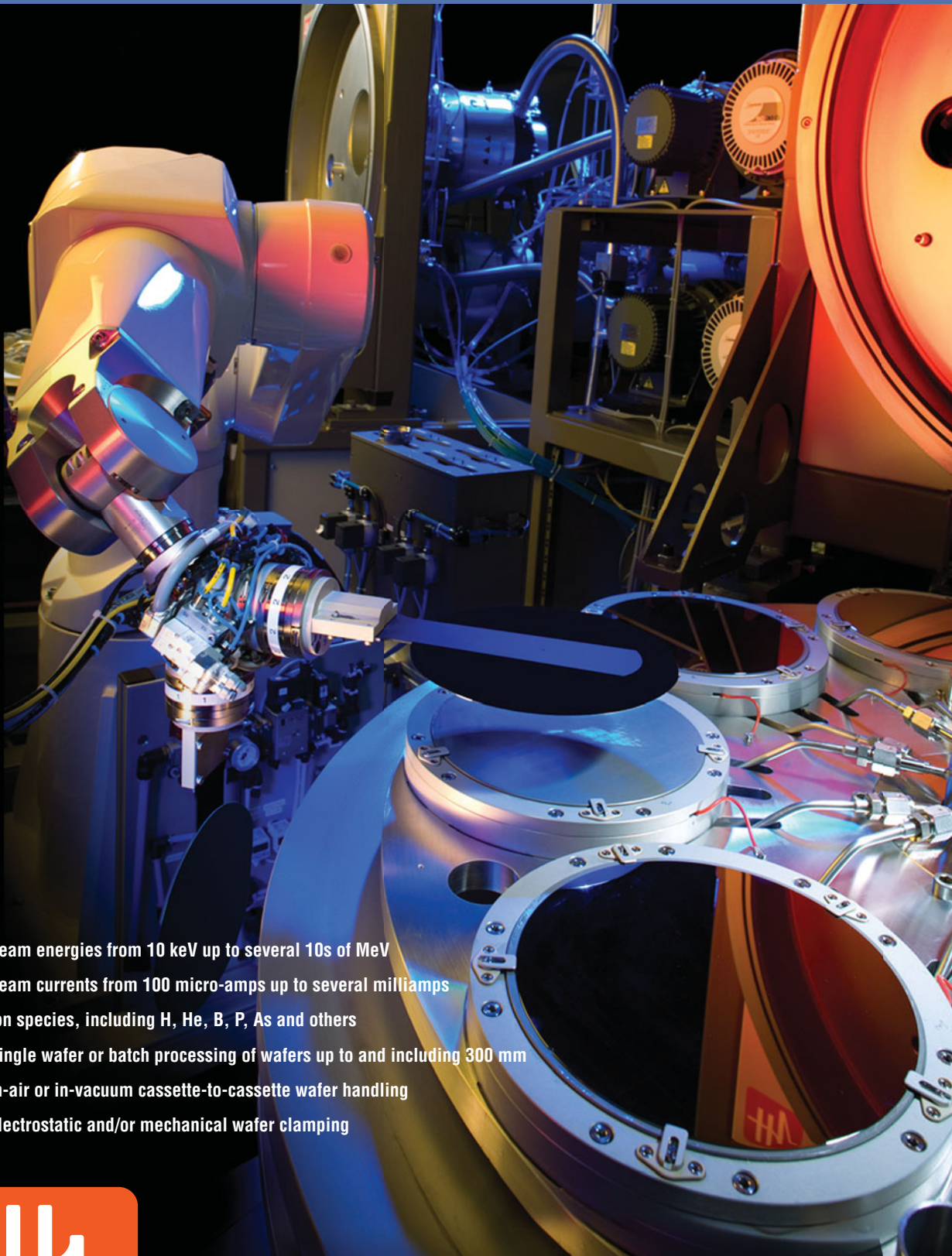
MRS MATERIALS RESEARCH SOCIETY®
Advancing materials. Improving the quality of life.

CVD diamond— Research, applications, and challenges

ALSO IN THIS ISSUE
Materials for flexible
semiconductor devices

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

HORIBA

Scientific



nanos are now the Heavyweights in labs

As nano research drives bigger discoveries, a big thing like learning to use a new instrument shouldn't get in the way.

HORIBA Scientific's LabRAM HR Evolution Raman Microscope and UVISEL 2 Spectroscopic Ellipsometer are powerful, yet easy to use, and fully automated with the highest performance and specifications available. Our AFM-Raman systems offer the most comprehensive and flexible solutions for chemical specificity at nanoscale.

When you need accuracy, flexibility, power and ease for your lab, think heavy hitters... think HORIBA Scientific, the leader in high performance spectroscopic instrumentation. Backed by a global team of world renowned applications scientists, dedicated to providing unsurpassed training and support.



LabRAM HR Evolution



AFM Raman



UVISEL 2

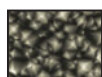
www.horiba.com/scientific
email: adsci-mrs@horiba.com

Solutions for:
Elemental Analysis
Fluorescence
Ellipsometry
Raman
Optical Components
Forensics
Particle Characterization



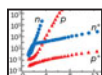
CONTENTS

CVD DIAMOND—RESEARCH, APPLICATIONS, AND CHALLENGES

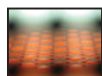


- 490 **CVD diamond—Research, applications, and challenges**
Robert J. Nemanich, John A. Carlisle, Atsushi Hirata, and Ken Haenen, Guest Editors

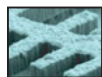
495 **Meet Our Authors**



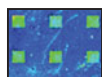
- 499 **Doping and interface of homoepitaxial diamond for electronic applications**
Satoshi Yamasaki, Etienne Gheeraert, and Yasuo Koide



- 504 **Large-area high-quality single crystal diamond**
Matthias Schreck, Jes Asmussen, Shinichi Shikata, Jean-Charles Arnault, and Naoji Fujimori



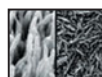
- 511 **MEMS/NEMS based on mono-, nano-, and ultrananocrystalline diamond films**
Anirudha V. Sumant, Orlando Auciello, Meiyong Liao, and Oliver A. Williams



- 517 **Surface functionalization and biological applications of CVD diamond**
Sabine Szunerits, Christoph E. Nebel, and Robert J. Hamers



- 525 **Diamond electrodes: Diversity and maturity**
Yasuaki Einaga, John S. Foord, and Greg M. Swain

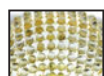


- 533 **Diamond electron emission**
I-Nan Lin, Satoshi Koizumi, Joan Yater, and Franz Koeck



- 542 **Diamond surface conductivity: Properties, devices, and sensors**
Christopher I. Pakes, Jose A. Garrido, and Hiroshi Kawarada

TECHNICAL FEATURE



- 549 **Materials for semiconductor devices that can bend, fold, twist, and stretch**
2013 MRS Mid-Career Researcher Award
John A. Rogers

Energy Quarterly



- 483 **Editorial**
Future loves history
Hideo Hosono
- 484 **Energy Sector Analysis**
Science of hydraulic fracturing contains materials questions
Melissae Fellet
FEATURE EDITORS: Michael Marder and Tad Patzek
- 486 **Interview**
Manufacturing energy: Jay Whitacre zeroes in on what technologies address the market
Interviewed by Steve Yalisove and Judy Meiksin
- 488 **Regional Initiative**
India's thorium-based nuclear vision
Prachi Patel
FEATURE EDITOR: L.V. Krishnan

www.mrs.org/energy-quarterly

ADVERTISERS IN THIS ISSUE

Page No.

Agilent Technologies	482
American Elements	Outside back cover
CRAIC Technologies, Inc.	498
Furuya Metal Americas, Inc.	494
High Voltage Engineering	Inside front cover
Hindawi Publishing Corporation	Inside back cover
Horiba	473
iplas Innovative Plasma Systems GmbH	524
Janis Research Company, Inc.	494
Microwave Enterprises, Ltd.	541
National Electrostatics Corp.	503
Rigaku Corporation	556

DEPARTMENTS



NEWS & ANALYSIS

477 **Materials News**

- **Healthcare-on-a-patch: Responsive wearable materials**
Lukmaan A. Bawazer
- **Copolymerization of nanorods generates one-dimensional plasmonic heterostructures**
Soma Chattopadhyay
- **Polymer series enables all-polymer solar cells**
Colin McCormick
- **Grain size determines nanoscale grain rotation**
Anthony S. Stender

480 **Science Policy**

- **Advanced materials manufacturing gets a government-backed boost**
Jennifer A. Nekuda Malik
- **South Africa may be ending its downward trend in R&D investment**

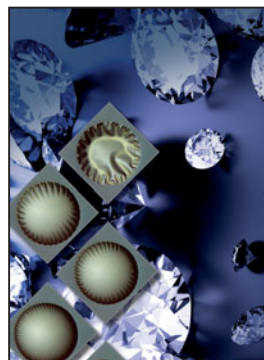


FEATURES

560 **Image Gallery** Look Again



557 CAREER CENTRAL



ON THE COVER

CVD diamond—Research, applications, and challenges. This issue of *MRS Bulletin* introduces the latest research, recent applications, and the challenges ahead for chemical vapor deposited (CVD) diamond films. The advent of thin nanocrystalline CVD diamond (NCD) films has unlocked a whole new research field. Based on the unique properties of diamond, a versatile range of new applications is currently being studied. The cover image shows

a series of ultrathin NCD membranes, 150 nm thick and 550 μm wide, fabricated in the middle of a Hall bar structure and supported by a glass substrate, under differential pressures. The top 50 nm of these structures are heavily boron-doped, making them conducting and suitable as pressure sensors for harsh environments based on the piezoresistive effect, leading to resistance changes as a function of the pressure applied to the membrane. The differential pressures under the membrane vary from 0 bar in the top image to 0.55 bar in the bottom image. See the technical theme that begins on page 490.



www.mrs.org/bulletin

MRS members—access *MRS Bulletin* online

www.mrs.org/energy-quarterly

Access Energy Quarterly online

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, 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

Graeme Lister

Michelle S. Raley, raley@mrs.org

Mary Wilmoth

Associate Technical Editor

Birgit Schwenzer

Production/Design

Andrea Pekelnicky, Felicia Turano,

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

Robert J. Nemanich, John A. Carlisle,
Atsushi Hirata, and Ken Haenen

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

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, 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

Kalpana 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 Schwenzer, 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.