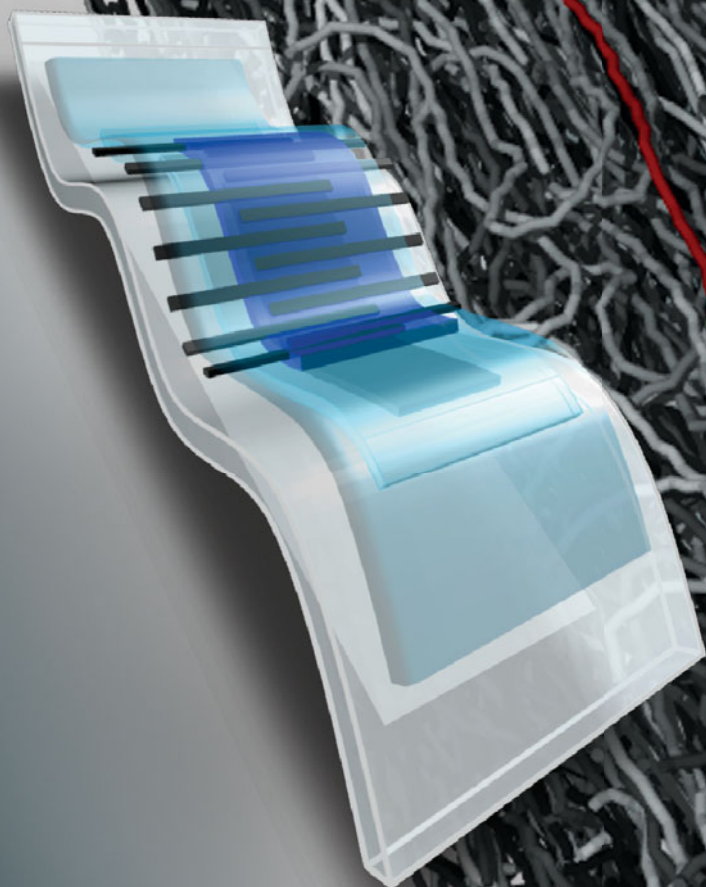


February 2017 Vol. 42 No. 2  
www.mrs.org/bulletin

# MRS Bulletin

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

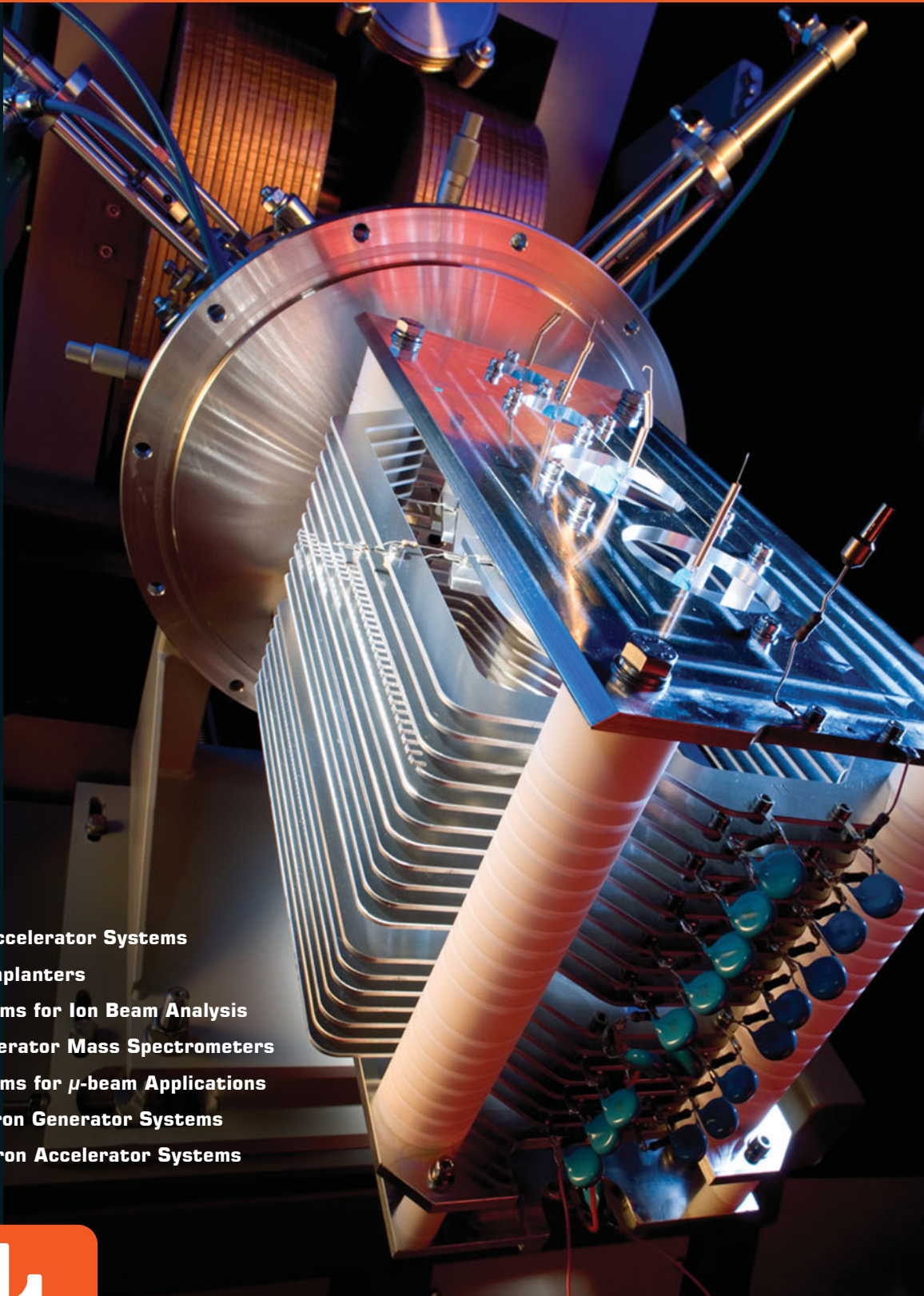
## Stretchable and ultraflexible organic electronics



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)

**Sigma-Aldrich®**

Lab Materials & Supplies

# Advanced Materials

at your fingertips



**Then. Now. Always.**

Your trusted partner in Materials Science.

[sigma-aldrich.com/matsci](http://sigma-aldrich.com/matsci)

Biomedical | Energy | Electronics

The life science business of Merck KGaA, Darmstadt, Germany operates as MilliporeSigma in the U.S. and Canada.

MilliporeSigma and the vibrant M are trademarks of Merck KGaA, Darmstadt, Germany. SIGMA-ALDRICH is a registered trademark of Sigma-Aldrich Co., LLC. Copyright © 2016 EMD Millipore Corporation. All Rights Reserved.

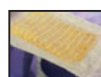
**MILLIPORE  
SIGMA**

# CONTENTS

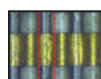
## STRETCHABLE AND ULTRAFLEXIBLE ORGANIC ELECTRONICS



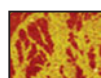
- 93 **Stretchable and ultraflexible organic electronics**  
Darren J. Lipomi and Zhenan Bao, Guest Editors



- 98 **Strategies for stretchable polymer semiconductor layers**  
Kaliannan Thiyagarajan and Unyong Jeong



- 103 **Elastic substrates for stretchable devices**  
Dianpeng Qi, Zhiyuan Liu, Wan Ru Leow, and Xiaodong Chen



- 108 **Morphological considerations of organic electronic films for flexible and stretchable devices**  
Brendan T. O'Connor, Omar M. Awartani, and Nrup Balar



- 115 **Understanding mechanical behavior and reliability of organic electronic materials**  
Jae-Han Kim, Inhwa Lee, Taek-Soo Kim, Nicholas Rolston, Brian L. Watson, and Reinhold H. Dauskardt



- 124 **Imperceptible organic electronics**  
Takao Someya, Siegfried Bauer, and Martin Kaltenbrunner



- 131 **Intrinsically stretchable field-effect transistors**  
Jiajie Liang, Kwing Tong, Huibin Sun, and Qibing Pei



- 138 **Flexible and stretchable sensors for fluidic elastomer actuated soft robots**  
Shuo Li, Huichan Zhao, and Robert F. Shepherd

## DEPARTMENTS



### NEWS & ANALYSIS

#### 85 **Materials News**

- **Metallurgical phase transition reveals pattern in new decorative steel**  
Melissae Fellet
- **Researchers observe real-time homogeneous nucleation using cryo-TEM**  
Tim Palucka
- **New simulations suggest cost-effective materials design for H<sub>2</sub> storage**  
Rachel Berkowitz
- **Control of geometry in polymer dielectric enhances performance of organic field-effect transistors**  
Eva Karatairi
- **White Paper: Characterizing the atomic lattices of 2D crystals with AFM**  
Donna Hurley and Ben Ohler

#### 91 **Science Policy**

- **Europe's Graphene Flagship produces intended results**  
Angela Saini
- **NIST studies recommend closing tech gaps to fortify advanced manufacturing**



## 143 SOCIETY NEWS

- **2016 MRS Fall Meeting features large variety of symposia and Public Outreach offerings**
- **MRS invites nominations for the Von Hippel Award, Turnbull Lectureship, MRS Medal, Materials Theory Award, and Kavli Early Career Lectureship**
- **Preview: 2017 Materials Research Society Spring Meeting & Exhibit**

### Special Insert

- **2017 MRS Member Benefits & Society Activities**

## FEATURES

### 162 Books

- **Silver Nanoparticles: From Silver Halide Photography to Plasmonics**  
Tadaaki Tani  
Reviewed by Thomas M. Cooper
- **Computational Thermodynamics of Materials**  
Zi-Kui Liu and Yi Wang  
Reviewed by Ram Devanathan
- **X-Ray Diffraction for Materials Research: From Fundamentals to Applications**  
Myeongkyu Lee  
Reviewed by J.H. Edgar

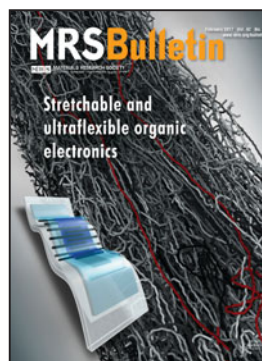
### 168 Image Gallery Look Again

## 164 CAREER CENTRAL

### ADVERTISERS IN THIS ISSUE

Page No.

American Elements .....	Outside back cover
High Voltage Engineering .....	Inside front cover
MilliporeSigma (Sigma-Aldrich Materials Science) .....	81
Rigaku Corporation .....	130



### ON THE COVER

**Stretchable and ultraflexible organic electronics.** Stretchable and ultraflexible electronic devices have a broad range of potential uses, from robust devices for energy storage and conversion to biomedical devices that make conformal interfaces with the skin and internal organs. The articles in this issue comprehensively examine highly deformable organic electronic materials and devices. The cover image depicts a large-scale coarse-grained molecular dynamics simulation of a ~80 nm thin film of highly entangled poly(3-hexylthiophene) under uniaxial tensile deformation. Two individual polymer chains are highlighted in red. Image credit: Samuel E. Root. The inset is a schematic diagram of an organic thin-film transistor in which every component is stretchable. See the technical theme that begins on page 93.



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

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

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

<http://journals.cambridge.org>

[mrsbulletin-rss](http://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

Tobias Lockwood

### Production/Design

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

### Associate Production Editor

Niki Rokicki

### Principal Development Editor

Elizabeth L. Fleischer

### Director of Communications

Eileen M. Kiley

### Guest Editors

Darren J. Lipomi and Zhenan Bao

### 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.