

MRS Bulletin

May 2016 Vol. 41 No. 5
www.mrs.org/bulletin

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

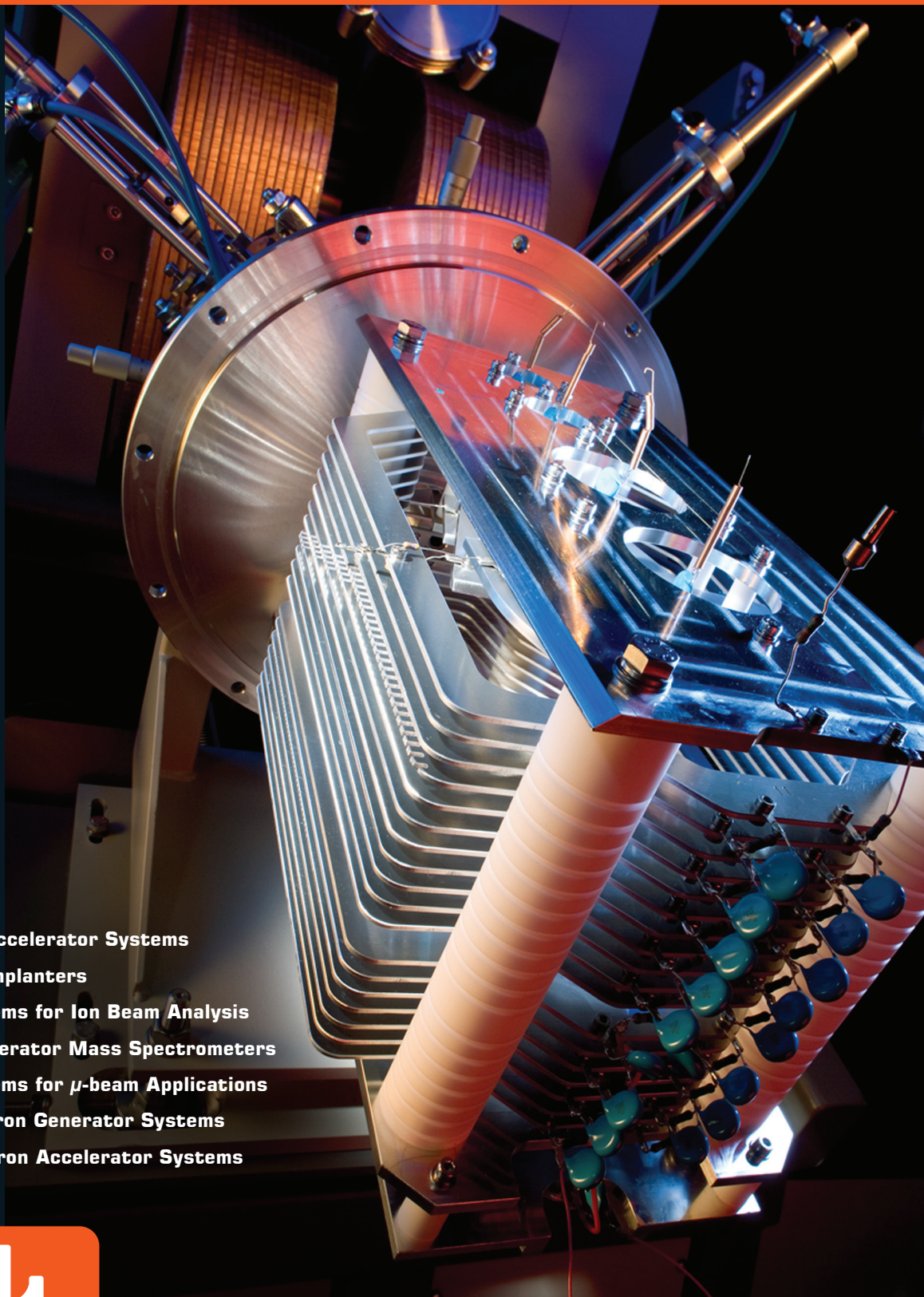
Nucleation in atomic, molecular, and colloidal systems

ALSO IN THIS ISSUE

Materials science with large-scale
data and informatics

CAMBRIDGE
UNIVERSITY PRESS

PARTICLE ACCELERATOR SYSTEMS



- Ion Accelerator Systems
- Ion Implanters
- Systems for Ion Beam Analysis
- Accelerator Mass Spectrometers
- Systems for μ -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
www.highvolteng.com

Park SmartScan™

Bringing the power and versatility of Atomic Force Microscopy to everyone

Park
SYSTEMS

www.parkAFM.com

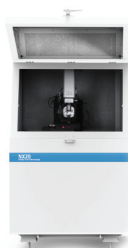
Park SmartScan™ is a revolutionary operating software for Park AFMs that lets even inexperienced, untrained users produce high quality nanoscale imaging through **three simple clicks** of a mouse in auto mode, which rivals that made by experts using conventional techniques. SmartScan manual mode also provides all of the functions and tools necessary for more seasoned users to feel at home. This combination of extreme versatility, ease-of-use, and quality makes Park atomic force microscopes the most powerful and yet the easiest to use AFMs.



Park AFM Series
Enabling Nanoscale Advances



Park NX10



Park NX20



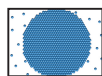
Park NX-Hivac



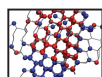
Park NX-Bio

For more information, email us at inquiry@parkafm.com or visit us at www.parkafm.com

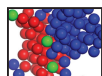
CONTENTS

NUCLEATION IN ATOMIC, MOLECULAR,
AND COLLOIDAL SYSTEMS

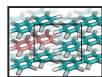
- 357 **Nucleation in atomic, molecular, and colloidal systems**
Jim De Yoreo and Stephen Whitelam, Guest Editors

361 **Meet Our Authors**

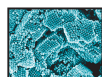
- 363 **What do crystals nucleate on? What is the microscopic mechanism? How can we model nucleation?**
Richard Sear



- 369 **Nonclassical pathways of crystallization in colloidal systems**
John Russo and Hajime Tanaka



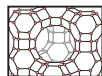
- 375 **Shape change in crystallization of biological macromolecules**
Peter G. Vekilov, Sungwook Chung, and Katy N. Olafson



- 381 **DNA-programmable particle superlattices: Assembly, phases, and dynamic control**
Oleg Gang and Alexei V. Tkachenko



- 388 **Nucleation on surfaces and in confinement**
Michael L. Whittaker, Patricia M. Dove, and Derk Joester

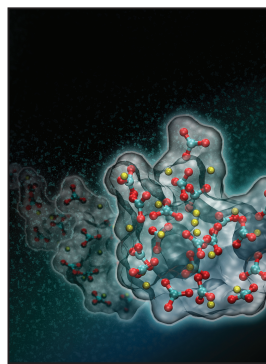


- 393 **Nucleation of open framework materials: Navigating the voids**
Jeffrey D. Rimer and Michael Tsapatsis

TECHNICAL FEATURE



- 399 **Materials science with large-scale data and informatics: Unlocking new opportunities**
Joanne Hill, Gregory Mulholland, Kristin Persson, Ram Seshadri, Chris Wolverton, and Bryce Meredig



ON THE COVER

Nucleation in atomic, molecular, and colloidal systems. Nucleation is the first step in the formation of many materials. The simple picture of nucleation, inherent in classical nucleation theory, that has prevailed for more than a century does not account for complex multistep nucleation pathways observed in recent years in experiments and simulations. This issue illustrates and describes the many complex nucleation pathways seen across a range of material systems. The cover shows an artistic rendition of nucleation from a supersaturated calcium carbonate solution. The structures of the initial clusters that form as predicted by molecular dynamics simulations are depicted in full atomistic detail in the foreground and in red in the background. The simulations further predict that the clusters are dense liquid droplets that must later dehydrate to form the solid phase. Results like these call into question the century-old view of how crystals nucleate from solution. Artwork by Adam Wallace. See the technical theme that begins on page 357.

DEPARTMENTS



NEWS & ANALYSIS

351 **Materials News**

- **Elastic carbon films for micro-supercapacitors fabricated by wafer-scale process**
YuHao Liu
- **Lithium-ion intercalation visualized *in situ* with new atomic-scale imaging technique**
Antonio Cruz
- **Glassy poly(lactide) toughened with diblock copolymer micelles**
Rachana Acharya
- **Carbon nanotubes improve radiation resistance of aluminum**
YuHao Liu

355 **Science Policy**

- **US administration makes efforts to increase inclusiveness in STEM industries**
Jennifer A. Nekuda Malik



SOCIETY NEWS

- 410 ■ **Robert Cammarata of Johns Hopkins University remembered**
Howard Katz
- **ABET proposes accreditation criteria revisions**



FEATURES

412 **Books**

- **Solar Energy: An Introduction**
Michael E. Mackay
Reviewed by Rosaria A. Puglisi
- **Moore's Law: The Life of Gordon Moore, Silicon Valley's Quiet Revolutionary**
Arnold Thackray, David C. Brock, and Rachel Jones
Reviewed by Ram Devanathan
- **Nanoparticles**
Raz Jelinek
Reviewed by K. Kamala Bharathi

415 **Postterminaries**

- **The large problem of water shortages**
Steve Moss

ADVERTISERS IN THIS ISSUE

Page No.

American Elements	Outside back cover
High Voltage Engineering.....	Inside front cover
JEOL USA, Inc.	350
Lake Shore Cryotronics, Inc.	Inside back cover
Park Systems Inc.	345
Rigaku Corporation.....	374



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.

2016 MRS BOARD OF DIRECTORS

President Kristi S. Anseth, University of Colorado Boulder, USA
Immediate Past President Oliver Kraft, Karlsruhe Institute of Technology, Germany
Vice President and President-Elect Susan Trolier-McKinstry, The Pennsylvania State University, USA
Secretary Sean J. Hearne, Sandia National Laboratories, 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
Alexandra Boltasseva, Purdue University, USA
C. Jeffrey Brinker, Sandia National Laboratories and The University of New Mexico, USA
Matthew Copel, IBM TJ Watson Research Center, USA
Paul S. Drzaic, Apple, Inc., USA
Yury Gogotsi, Drexel University, USA
Hideo Hosono, Tokyo Institute of Technology, Japan
Young-Chang Joo, Seoul National University, South Korea
Karen L. Kavanagh, Simon Fraser University, Canada
Kornelius Nielsch, Leibniz Institute for Solid State and Materials Research, Germany
Christine Ortiz, Massachusetts Institute of Technology, USA
Sabrina Sartori, University of Oslo, Norway
Magaly Spector, The University of Texas at Dallas, USA
Loucas Tsakalacos, GE Global Research, USA
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 Whittlesey, CA Institute for Regenerative Medicine, USA
Meetings David S. Ginley, National Renewable Energy Laboratory, USA
Member Engagement Yves J. Chabal, The University of Texas at Dallas, USA
Public Outreach Elizabeth Kupp, The Pennsylvania State University, USA
Publications Richard A. Vaia, US Air Force Research Laboratory

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, Felicia Turano, Rebecca Yokum, and TNQ

Associate Production Editor
Lauren Marra

Principal Development Editor
Elizabeth L. Fleischer

Director of Communications
Eileen M. Kiley

Guest Editors

Jim De Yoreo and Stephen Whitelam

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 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, 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

2016 Ilke Arslan, Pacific Northwest National Laboratory, USA
Rick Barto, Lockheed Martin Advanced Technology Laboratories, USA
Boaz Pokroy, Technion-Israel Institute of Technology, Israel
Zhiwei Shan, Xi'an Jiaotong University, China

2015 Ying-Hao (Eddie) Chu, National Chiao Tung University, Taiwan
Kaipana S. Katti, North Dakota State University, USA
Tommie W. Kelley, 3M, USA
W. Jud Ready, Georgia Institute of Technology, 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 © 2016 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 \$125 annually for regular members, \$30 for students. Dues include an allocation of \$29 for a subscription to *MRS Bulletin*. Individual member subscriptions are for personal use only. Non-member subscription rates are \$483 for one calendar year (12 issues) within North America and \$580 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.



2016 **MRS**[®] FALL MEETING & EXHIBIT
November 27 – December 2, 2016 | Boston, Massachusetts

CALL FOR PAPERS

Abstract Submission Opens
May 16, 2016

Abstract Submission Deadline
June 16, 2016

BROADER IMPACT

- BI1 Today's Teaching and Learning in Materials Science—Challenges and Advances
- BI2 The Business of Materials Technology

BIOMATERIALS AND SOFT MATERIALS

- BM1 Spatiotemporally and Morphologically-Controlled Biomaterials for Medical Applications
- BM2 Stimuli Responsive Organic and Inorganic Nanomaterials for Biomedical Applications and Biosafety
- BM3 Biomaterials for Regenerative Medicine
- BM4 Materials and Manufacturing of Biointerfaces Devices and Stretchable Electronics
- BM5 Materials for Biointegrated Photonic Systems
- BM6 Fabrication, Characterization and Applications of Bioinspired Nanostructured Materials
- BM7 Functional Nanostructured Polymers for Emerging Energy Technologies

ELECTROCHEMISTRY

- EC1 Redox Activity on the Molecular Level—Fundamental Studies and Applications
- EC2 Facilitating Charge Transport in Electrochemical Energy Storage Materials
- EC3 Catalytic Materials for Energy and Sustainability
- EC4 Material, Devices and Systems for Sustainable Conversion of Solar Energy to Fuels
- EC5 Proton Transfer and Transport—From Biological Systems to Energy Applications

ELECTRONICS, MAGNETICS AND PHOTONICS

- EM1 Materials Issues for Quantum Computing
- EM2 Rare-Earths in Advanced Photonics and Spintronics
- EM3 Electronic and Ionic Dynamics at Solid-Liquid Interfaces
- EM4 Structure-Property Relationships of Organic Semiconductors
- EM5 Materials and Mechanisms of Correlated Electronic Phenomena in Oxide Heterostructures
- EM6 Thin-Film Transistors—New Materials and Device Concepts
- EM7 Functional Plasmonics
- EM8 Spin Dynamics in Nonmagnetic Materials and Devices
- EM9 Materials and Nanostructures for Magnetic Skyrmions
- EM10 Emerging Materials and Technologies for Nonvolatile Memories
- EM11 Wide-Bandgap Materials for Energy Efficiency—Power Electronics and Solid-State Lighting
- EM12 Diamond Electronics, Sensors and Biotechnology—Fundamentals to Applications

ENERGY AND SUSTAINABILITY

- ES1 Materials Science and Chemistry for Grid-Scale Energy Storage
- ES2 Materials Challenges for Flow-Based Energy Conversion and Storage
- ES3 Perovskite Solar Cell Research from Material Properties to Photovoltaic Function
- ES4 Thermoelectric Polymers and Composites—Nontraditional Routes to High Efficiency
- ES5 Materials Research and Design for A Nuclear Renaissance
- ES6 Scientific Basis for Nuclear Waste Management

MECHANICAL BEHAVIOR AND FAILURE MECHANISMS OF MATERIALS

- MB1 Intermetallic-Based Alloys—From Fundamentals to Applications
- MB2 Materials under Mechanical Extremes
- MB3 High-Entropy Alloys
- MB4 Glassy, Nanocrystalline and Other Complex Alloy Systems and Their Applications
- MB5 Size Effects and Small-Scale Mechanical Behavior of Materials
- MB6 Cyclic Deformation and Fracture at the Nanoscale
- MB7 Shear Transformation Mechanisms and Their Effect on Mechanical Behavior of Crystalline Materials

NANOMATERIALS

- NM1 Semiconducting Nanowires, Nanoribbons and Heterostructures—Synthesis, Characterizations and Functional Devices
- NM2 2D Layers and Heterostructures beyond Graphene—Theory, Preparation, Properties and Devices
- NM3 Nanotubes and Related Nanostructures
- NM4 Nanomaterials-Based Solar Energy Conversion
- NM5 Nanomembrane Materials—From Fabrication to Application
- NM6 Nanoscale Materials and Devices by High-Temperature Gas-Phase Processes

PROCESSING AND MANUFACTURING

- PM1 Ion Beam-Enabled Nanoscale Fabrication, Modification and Synthesis
- PM2 Plasma Processing via Liquid for Life Sciences and Environmental Applications
- PM3 Science-Enabled Advances in Materials- and Manufacturing-Technologies
- PM4 Novel Materials, Fabrication Routes and Devices for Environmental Monitoring
- PM5 Hierarchical, Hybrid and Roll-to-Roll Manufacturing for Device Applications

THEORY, CHARACTERIZATION AND MODELING

- TC1 *In Silico* Materials Chemistry
- TC2 Design, Discovery and Understanding of Materials Guided by Theory, Computation and Data Mining
- TC3 Materials Issues in Art and Archaeology
- TC4 Advances in Spatial, Energy and Time Resolution in Electron Microscopy

www.mrs.org/fall2016

Meeting Chairs

Bernard Bewlay, GE Global Research
Silvija Gradečak, Massachusetts Institute of Technology
Sarah Heilshorn, Stanford University
Ralph Spolenak, ETH Zürich
T. Venky Venkatesan, National University of Singapore

Don't Miss These Future MRS Meetings!

2017 MRS Spring Meeting & Exhibit
April 17 – 21, 2017
Phoenix, Arizona

2017 MRS Fall Meeting & Exhibit
November 26 – December 1, 2017
Boston, Massachusetts

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

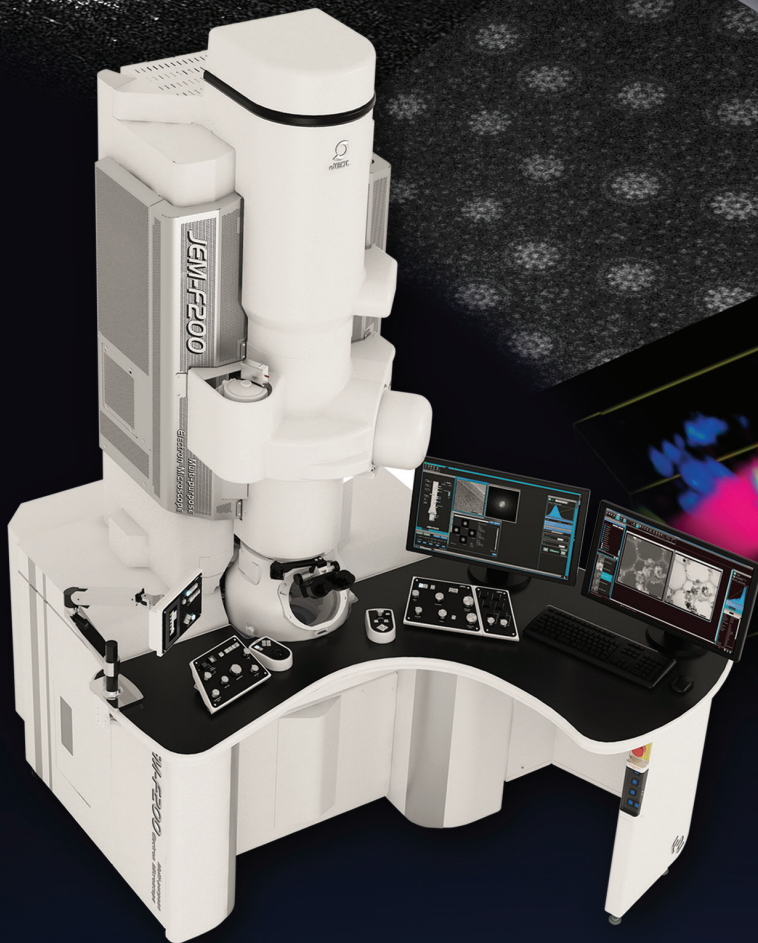
NO COMPROMISE

ATOMIC RESOLUTION + FAST ANALYSIS

The New "Go-To" TEM from JEOL

F2

- Cold FEG boosts probe current
- Fast 3D EDS with dual SDD
- Wide-field STEM-EELS spectrum imaging
- Push-button beam conditions
- Ultra-stable, ultra-fast



10 nm⁻¹

2 nm

JEOL

Solutions for Innovation



www.jeolusa.com
salesinfo@jeol.com • 978-535-5900

Learn more at www.jeolusa.com/F2

*STEM-HAADF image of Quasicrystal • Courtesy of Professor Emeritus K. Hiraga - Tohoku University