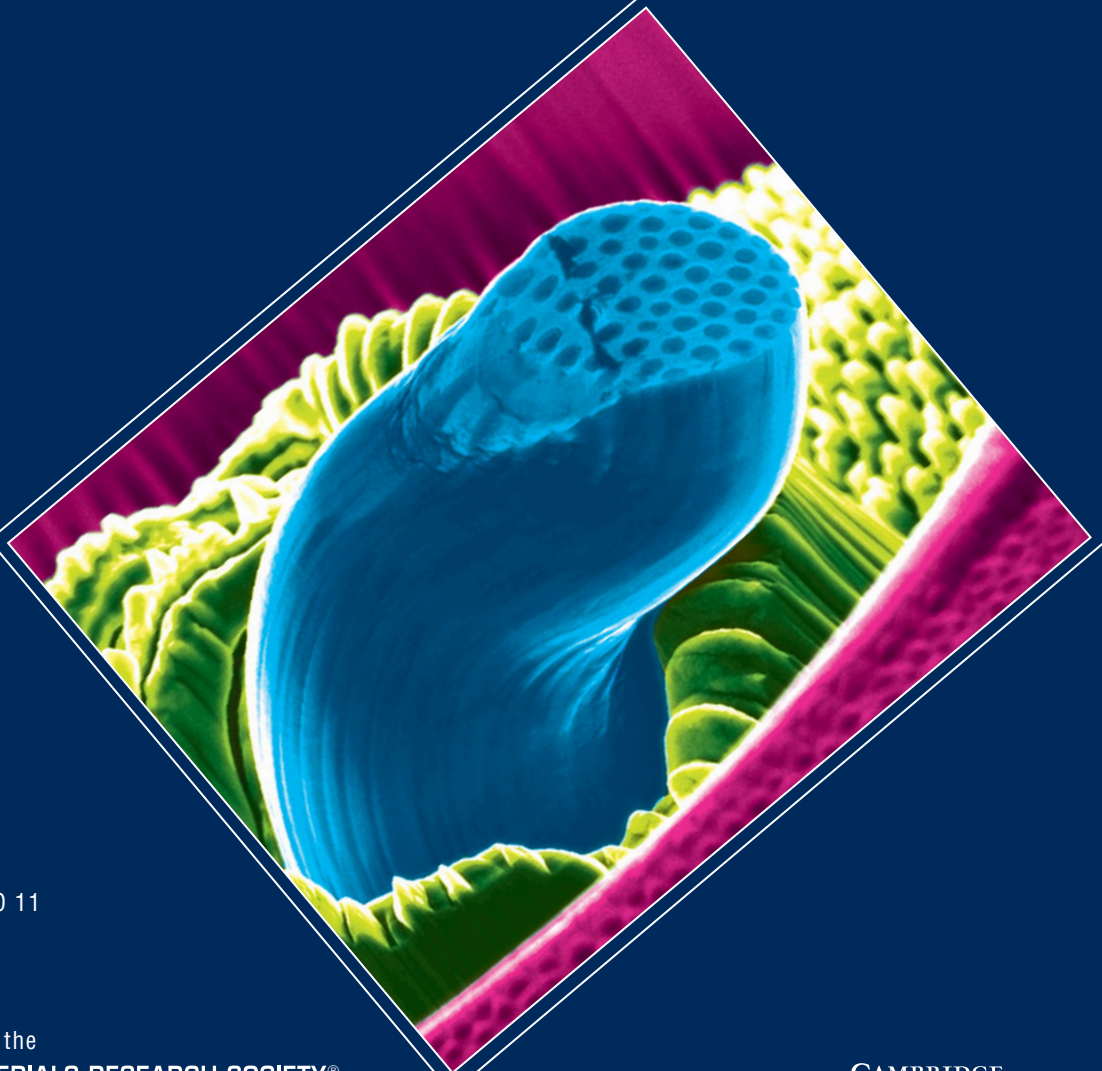




**jmr** Journal of  
MATERIALS RESEARCH



VOLUME 32 • NO 11  
JUNE 14, 2017

A publication of the

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

CAMBRIDGE  
UNIVERSITY PRESS

# Journal of MATERIALS RESEARCH

**JOURNAL OF MATERIALS RESEARCH (JMR)** is an interdisciplinary journal serving the materials research community through publication of original research articles and invited reviews encompassing the synthesis, processing, characterization, properties, and theoretical description of materials.

**JMR** publishes new research that demonstrates a significant impact or advance of scientific understanding of interest to the materials research community. Engineering studies and applications to commercial products are beyond the scope of *JMR* and should be submitted elsewhere. Manuscripts that report data without giving an analysis, interpretation, or discussion are only acceptable if the data are sufficiently important that publication is expected to lead to significant new studies or advancements in science or technology.

**Manuscripts** must be submitted to the *Journal of Materials Research* electronically via ScholarOne manuscripts, at the following website address: <http://mc.manuscriptcentral.com/jmr>. Electronic submission expedites the review process and also allows authors to track the status of their manuscripts at any time. Complete instructions are available on the ScholarOne site and authors will be prompted to provide all necessary information.

Manuscripts must be prepared in English, using a word processing program, formatted to fit 8½ x 11 in. paper, and saved as .doc, .pdf, .rtf, or .ps files. Separate graphics files (.eps and .tif) must be uploaded for each figure. Authors may also upload .xls or .ppt supplemental files as part of the manuscript submission process. All of these files will be converted to .pdf format. Detailed instructions are available on the submission web site. During submission, authors must enter all coauthor names and e-mail addresses. Manuscripts will not be considered for peer review until this information is provided. Authors must also enter manuscript keywords using the *JMR* keyword list (located on the submission web site). Authors who are not fluent in English must have their manuscript edited for correct English grammar and sentence structure before submission.

Authors are expected to follow the conventional writing, notation, and illustration style prescribed in *Scientific Style and Format: the CSE Manual for Authors, Editors and Publishers, 7th edition, 2006*. Authors should also study the form and style of printed material in this journal. SI units should be used. Authors should use an identical format for their names in all publications to facilitate use of citations and author indexes.

Manuscripts are accepted with the understanding that they represent original research, except for review articles, and that they have not been copyrighted, published, or submitted for publication elsewhere. Authors submitting manuscripts to *JMR* who have related material under consideration or in press elsewhere should send a copy of the related material to *JMR* at the time of submission. While their manuscripts are under consideration at *JMR*, authors must disclose any such related material. To expedite the review process, authors may provide names and contact information for up to four possible reviewers.

**Articles** are original research reports that include complete, detailed, self-contained descriptions of research efforts. All articles must contain an abstract and section headings.

**Commentaries and Reviews:** *Journal of Materials Research* occasionally publishes commentaries on topics of current interest or reviews of the literature in a given area. If an author proposes a review, the title, abstract, and a brief outline should be submitted to the Editorial Office via e-mail for prior consultation on the appropriateness of the topic.

**Color policy:** It is not necessary for authors to indicate that a figure should be displayed in color online. *JMR* will assume that any author who submits figures in color wants and agrees to their being produced in color online. Figures may be printed in color at the author's request for an additional charge. Color figures must be submitted before the paper is accepted for publication, and cannot be received later in the process. Authors cannot submit two versions of the same figure, one for color and one for black and white; only one version can be submitted. Authors need to carefully consider the following when submitting figures in color that will

be published in color online only: 1) The colors chosen must reproduce effectively and the colors should be distinguishable when printed in black and white; 2) The descriptions of figures in text and captions must be sufficiently clear for both online and print copy. When submitting figures to be in color online only, authors should include the phrase <<color online>> in the figure captions. This is the author's responsibility. Authors will see these color figures when viewing their author page proofs on screen. Authors should always print their page proofs in black and white to see how they will appear in print. Authors will NOT be allowed to submit color figures to replace black and white figures in the page proof stage. To maximize the probability that figures will be published in color online and also print as good quality black and white or grayscale graphics, authors are encouraged to follow these figure submission guidelines: 1) Submit a color graphic in Tagged Image File Format (.tif); 2) Submit color graphics with a resolution of at least 300 dpi (600 dpi if there is text or line art in the figure); 3) Submit color graphics in CMYK format; 4) Submit figures sized to fit the actual column or page width of the journal so that reduction or enlargement is not necessary; 5) Submit multipart figures in one single electronic file.

**Copyright © 2017**, Materials Research Society. All rights reserved. No part of this publication may be reproduced, in any form or by any means, electronic, photocopying, or otherwise, without permission in writing from Cambridge University Press. Policies, request forms and contacts are available at: <http://www.cambridge.org/rights/permissions/permission.htm>. Permission to copy (for users in the USA) is available from Copyright Clearance Center at: <http://www.copyright.com>, email: [info@copyright.com](mailto:info@copyright.com).

---

## **Journal of Materials Research Subscription Prices (2017)**

[includes on-line web access]

	USA and Poss.	Non-US	Online Only
MRS Regular and Student Members	\$273.00	\$334.00	\$105.00
Institutions	\$2053.00	\$2053.00	\$1852.00

---

*Journal of Materials Research* (ISSN: 0884-2914) is published twenty-four times a year by Cambridge University Press, One Liberty Plaza, 20th Floor, New York, NY 10006 for the Materials Research Society. Periodical Postage Paid in New York, NY and additional mailing offices. **POSTMASTER:** Send address changes to *Journal of Materials Research*, c/o Journals Dept., Cambridge University Press, One Liberty Plaza, 20th Floor, New York, NY 10006, USA.

**Subscriptions, renewals, address changes, and single-copy orders** should be addressed to Subscription Fulfillment, *Journal of Materials Research*, Cambridge University Press, One Liberty Plaza, 20th Floor, New York, NY 10006, USA (for USA, Canada, and Mexico); or Cambridge University Press, University Printing House, Shaftesbury Road, Cambridge, CB2 8BS, England (for UK and elsewhere). Allow at least six weeks advance notice. For address changes, please send both old and new addresses and, if possible, include a mailing label from a recent issue. 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; otherwise, the issue may be purchased at the single-copy price.

**Reprints** of individual articles in *Journal of Materials Research* may be ordered. For information on reprints, please contact Cambridge University Press. Reprints of complete back issues older than the prior volume year may be ordered on an individual basis via the Cambridge Journals Online website. To determine availability, visit the appropriate page for the *JMR* back issue desired ([cambridge.org/journal-of-materials-research](http://cambridge.org/journal-of-materials-research)).

**Individual member subscriptions are for personal use only.**

# Journal of MATERIALS RESEARCH

**Editor-in-Chief:** Gary L. Messing, *Ceramic materials, The Pennsylvania State University, USA*

**Associate Editor,** Susmita Bose, *Biomaterials, Washington State University, USA*

**Associate Editor,** Jürgen Eckert, *Metallic materials, Montanuniversität Leoben, Austria*

**Associate Editor,** Linda S. Schadler, *Polymeric materials, Rensselaer Polytechnic Institute, USA*

## 2017 Principal Editors:

Amit Bandyopadhyay, *Hard biomaterials, Additive manufacturing, Washington State University, USA*

Jinju Chen, *Soft materials/thin films, Nanoindentation, Newcastle University, United Kingdom*

Xiaobo Chen, *Photocatalysis and batteries, University of Missouri-Kansas City, USA*

Yang-T. Cheng, *Mechanical behavior, Electrochemical energy storage, University of Kentucky, USA*

Sung-Yoon Chung, *Energy, Electron microscopy, Interface science, KAIST, Korea*

Paolo Colombo, *Pre-ceramic polymers, Porous ceramics, University of Padova, Italy; The Pennsylvania State University, USA*

Franz Faupel, *Functional nanomaterials, VPD, Metallic glasses, University of Kiel, Germany*

Mathias Göken, *Superalloys, Nanomaterials, Nanomechanics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany*

Amit Goyal, *Superconductors, Photovoltaics, 2D materials, Self-assembly, State University of New York at Buffalo, USA*

Erik G. Herbert, *Nanoindentation, Small-scale mechanical behavior, Michigan Technological University, USA*

Himanshu Jain, *Inorganic glass, Optical, Electrical properties, Lehigh University, USA*

C. Robert Kao, *Metallic materials, Diffusion and joining, National Taiwan University, Taiwan*

Edson Roberto Leite, *Materials chemistry, Nanocrystals, Synthesis, Universidade Federal de São Carlos, Brazil*

Jörg Löffler, *Metallic materials/synthesis and properties, ETH Zurich, Switzerland*

Michele Manuel, *Phase transformations, Materials design, University of Florida, USA*

Michael E. McHenry, *Magnetic materials, Carnegie Mellon University, USA*

Scott T. Miture, *In-situ diffraction, Electrochemically active ceramics, Alfred University, USA*

Sarah E. Morgan, *Polymer surfaces and interfaces, The University of Southern Mississippi, USA*

Paul Muralt, *Thin films, Piezoelectric and ferroelectric materials, Ecole Polytechnique Federale de Lausanne, Switzerland*

Lakshmi S. Nair, *Biomaterials, Tissue regeneration, Drug delivery, University of Connecticut, USA*

Akira Nakajima, *Photocatalysis, Surface wettability, Ceramic processing, Tokyo Institute of Technology, Japan*

Cewen Nan, *Ferroelectric, Multiferroic materials, Tsinghua University, China*

George M. Pharr, *Mechanical behavior, Nanoindentation, Texas A&M University, USA*

Ian M. Reaney, *Electroceraamics, TEM, Thin films, The University of Sheffield, United Kingdom*

Edward M. Sabolsky, *Electroceraamics, Electrochemistry, Processing, West Virginia University, USA*

Winston Schoenfeld, *Optical materials, University of Central Florida, USA*

Don W. Shaw, *Epitaxy, Vapor deposition, Semiconductors, The University of Texas at Dallas, USA*

Susan B. Sinnott, *Computational materials science, The Pennsylvania State University, USA*

Terry M. Tritt, *Thermoelectrics, Clemson University, USA*

Chongmin Wang, *Energy storage, Microscopy, In-situ/operando technique, Pacific Northwest National Laboratory, USA*

William J. Weber, *Radiation effects, Nuclear ceramics, University of Tennessee; Oak Ridge National Laboratory, USA*

Sam Zhang, *Thin films/coatings, Nanyang Technological University, Singapore*

Yanchun Zhou, *Structural ceramics, Electronic structure, Aerospace Research Institute of Materials and Processing Technology, China*

**Editorial Office:** Ellen W. Kracht, *Publications Manager, Materials Research Society, Warrendale, PA*  
Linda A. Baker, *JMR Editorial Assistant, Materials Research Society, Warrendale, PA*  
Kirby L. Morris, *JMR Production Assistant, Materials Research Society, Warrendale, PA*  
Eileen M. Kiley, *Director of Communications, Materials Research Society, Warrendale, PA*

Cover: SEM micrograph of directionally-solidified NiAl-Cr microcompression pillar prepared by FIB milling. Buckling in the multi-fiber pillar possibly occurred due to misalignment. [A. Kumar, C. Ensslen, A. Krüger, M. Klimenkov, O. Kraft, R. Schwaiger: Micromechanical study on the deformation behavior of directionally solidified NiAl-Cr eutectic composites. p. 2127].

# Journal of MATERIALS RESEARCH

Volume 32, Number 11, June 14, 2017

## INVITED FEATURE PAPERS

- 1993–2002 **Phase transitions in stable nanocrystalline alloys** Arvind R. Kalidindi, Christopher A. Schuh
- 2003–2013 **The weakest size of precipitated alloys in the micro-regime: The case of duralumin** Kefu Gan, Rui Gu, Alfonso H.W. Ngan

## INVITED PAPERS

- 2014–2021 **Comparing the atomic and macroscopic aging dynamics in an amorphous and partially crystalline  $Zr_{44}Ti_{11}Ni_{10}Cu_{10}Be_{25}$  bulk metallic glass** Zach Evenson, Alba Payes-Playa, Yuriy Chushkin, Marco di Michiel, Eloi Pineda, Beatrice Ruta
- 2022–2034 **Film thickness dependent microstructural changes of thick copper metallizations upon thermal fatigue** Stephan Bigl, Claus O.W. Trost, Stefan Wurster, Megan J. Cordill, Daniel Kiener

## ARTICLES

- 2035–2044 **Influence of a high magnetic field on the solidification structures of ternary Al–Fe–Zr alloy** Lei Li, Chunyan Ban, Xuchen Shi, Haitao Zhang, Yubo Zuo, Qingfeng Zhu, Xiangjie Wang, Jianzhong Cui, Hiromi Nagaumi
- 2045–2054 **Effect of a traveling magnetic field on freckle formation of directionally solidified Pb–Sn alloys** Ling Qin, Jun Shen, Qiudong Li, Zhao Shang
- 2055–2066 **Microstructural evolution, mechanical profile, and fracture morphology of aluminum matrix composites containing graphene nanoplatelets** Mahmood Khan, Maham Amjad, Ansa Khan, Rafi Ud-Din, Iftikhar Ahmad, Tayyab Subhani
- 2067–2078 **Effect of Fe on microstructures and mechanical properties of an Al–Mg–Si–Cu–Cr–Zr alloy prepared by low frequency electromagnetic casting** Yi Meng, Jian-zhong Cui, Zhi-hao Zhao
- 2079–2091 **The microstructure and mechanical properties of Al<sub>2024</sub>-SiC<sub>p</sub> composite fabricated by powder thixoforming** Pubo Li, Tijun Chen, He Qin
- 2092–2099 **Study of orientation relationship between Al matrix and several typical inclusions in Al alloy by edge-to-edge matching model** Yu Liu, Yuanchun Huang, Zhengbing Xiao
- 2100–2108 **Phase stability, elastic, and thermodynamic properties of the L<sub>12</sub> (Co,Ni)<sub>3</sub>(Al,Mo,Nb) phase from first-principles calculations** Qiang Yao, Shun-Li Shang, Kang Wang, Feng Liu, Yi Wang, Qiong Wang, Tong Lu, Zi-Kui Liu
- 2109–2116 **Microstructure of Al<sub>1.3</sub>CrFeNi eutectic high entropy alloy and oxidation behavior at 1000 °C** Xiao Chen, Yanwei Sui, Jiqiu Qi, Yezeng He, Fuxiang Wei, Qingkun Meng, Zhi Sun
- 2117–2126 **Effect of rare earth element on the oxidation behavior of novel  $\gamma/\gamma'$ -strengthened Co–9Al–10W alloys** Qiong Wang, Qiang Yao, Jin-Zhu Song, Yan Wang, Yu-Hong Zhu, Tong Lu, Bao-Jun Han
- 2127–2134 **Micromechanical study on the deformation behavior of directionally solidified NiAl–Cr eutectic composites** Amrithesh Kumar, Charlotte Ensslen, Antje Krüger, Michael Klimenkov, Oliver Kraft, Ruth Schwaiger

(Continued)

- 2135–2142 **Prediction of the contact time through modeling of heat transfer and fluid flow in compound casting process of Al/Mg light metals** Morteza Morakabian Esfahani, Esmaeil Hajjari, Ali Farzadi, Seyed Reza Alavi Zaree
- 2143–2152 **Ratcheting behavior of ZEK100 magnesium alloy with various loading conditions and different immersing time** Hong Gao, Wenbo Ye, Zhe Zhang, Lilan Gao
- 2153–2160 **Tribological and corrosion properties of AM70 magnesium alloy processed by equal channel angular pressing** Karekere Rangaraju Gopi, Hanumanthappa Shivananda Nayaka
- 2161–2168 **Effects of heat treatment on the wear behavior of surfacing AZ91 magnesium alloy** Qingqiang Chen, Kaiyue Li, Yuyang Liu, Zhihao Zhao, Kai Tao, Qingfeng Zhu
- 2169–2178 **Enhancing the tensile and ignition response of monolithic magnesium by reinforcing with silica nanoparticulates** Gururaj Parande, Vyasraj Manakari, Ganesh Kumar Meenashisundaram, Manoj Gupta
- 2179–2187 **Influence of heat treatment on cyclic deformation and low-cycle fatigue behavior of sand-cast Mg–10Gd–3Y–0.5Zr magnesium alloy** Quan Wang, Wencai Liu, Guohua Wu, Xiangjun Chen, Haohao Zhang
- 2188–2201 **High-throughput measurements of interdiffusivity matrices in face centered cubic Ni–Al–Mo alloys at 1273–1473 K** Shiyi Wen, Ying Tang, Jing Zhong, Lijun Zhang, Yong Du, Feng Zheng
- 2202–2209 **Thermal, structural, and microstructural characterization of eutectoid steel at different heat treatments** A. Lara-Guevara, I. Rojas-Rodríguez, César J. Ortiz-Echeverri, M. Robles-Agudo, M.E. Rodríguez-García
- 2210–2217 **Effect of Si content on the microstructure and properties of Al–Si alloys fabricated using hot extrusion** Pan Ma, Yandong Jia, Konda Gokuidoss Prashanth, Zhishui Yu, Chonggui Li, Jian Zhao, Shanglei Yang, Lixin Huang