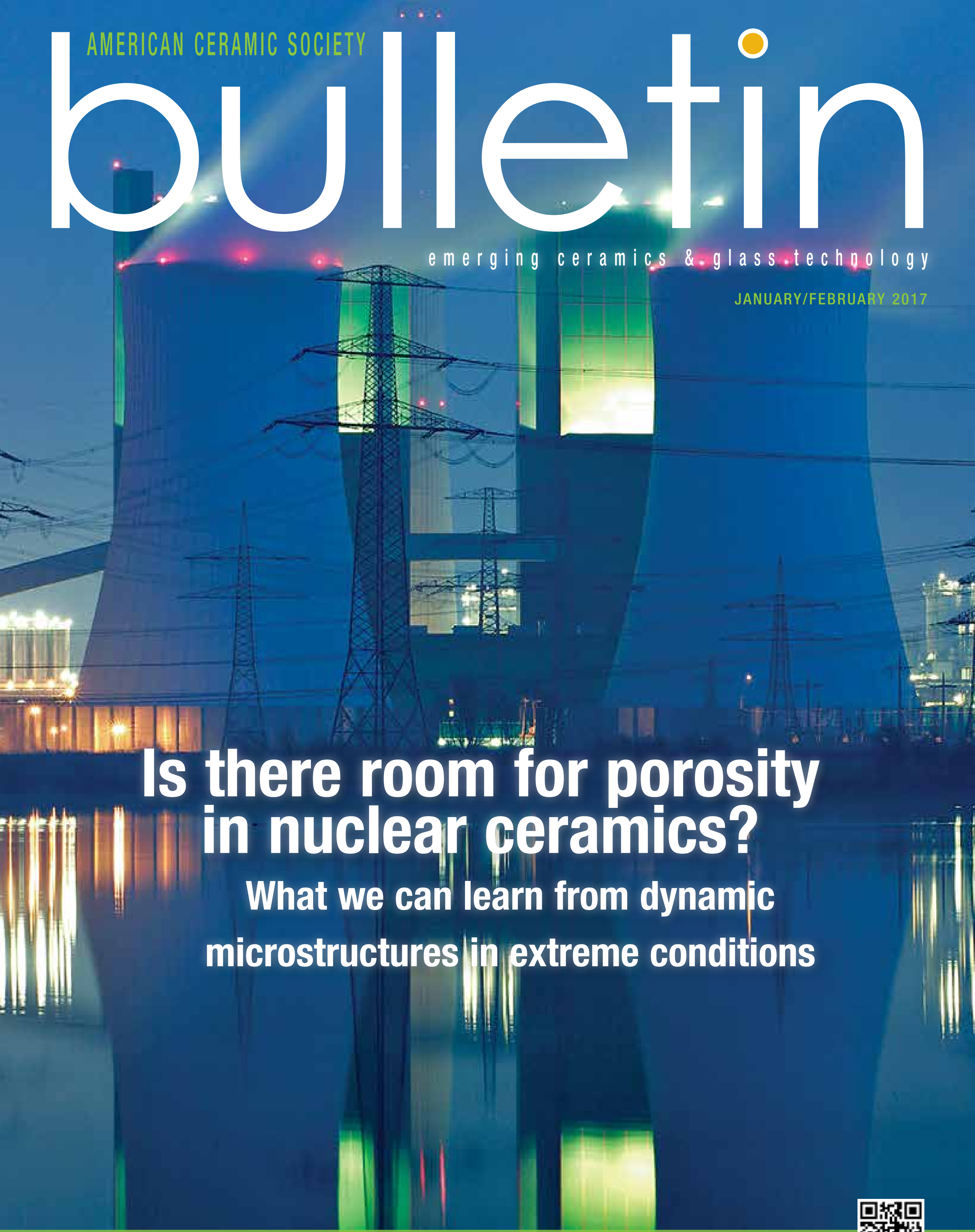
AMERICAN CERAMIC SOCIETY

bulletin

emerging ceramics & glass technology

JANUARY/FEBRUARY 2017



Is there room for porosity in nuclear ceramics?

What we can learn from dynamic microstructures in extreme conditions

Meet ACerS President | Ballistics test 3-D-printed body armor | *GlassPanacea* improves calculations

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Corrections to the December issue of the *ACerS Bulletin*

"Ceramic and glass researchers seek 'Big Ideas' at NSF-funded workshop," p. 4. The affiliation for Javier Garay was printed incorrectly as University of California, San Diego—the correct affiliation is University of California, Riverside. The affiliation for Kathy Lu was printed incorrectly as University of Virginia—the correct affiliation is Virginia Polytechnic Institute and State University.

"Ceramics and glass—Materials for diverse industries," p. 18. Table 5 incorrectly listed the revenue for HarbinsonWalker International as \$5,000M–\$10,000M. The correct revenue is \$500M–\$1,000M.

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Subscribe to our e-newsletter, Ceramic Tech Today, and recieve the latest ceramics, glass, and Society news straight to your inbox every Tuesday, Wednesday, and Friday! Sign up at http://bit.ly/acersctt.

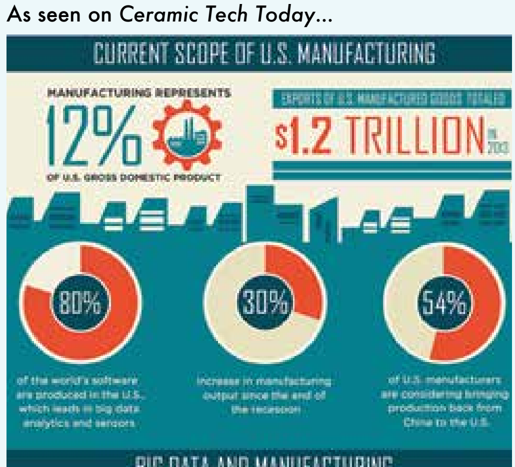
As seen in the December 2016 *ACerS Bulletin*...

What's driving growth of the ceramic and glass industry?

Ceramics and glass are materials for diverse industries—so we dug far and deep to provide you with a 2016 industry profile and manufacturing forecast. Dig in to find out what the future holds.

Read more at
ceramics.org/2016industry

As seen on *Ceramic Tech Today*...



Big data has big potential in manufacturing

How can companies boost manufacturing efficiency? While you may be more familiar with big data's role in research, that's not the only place where big data has big potential.

Read more at
ceramics.org/bigdata

American Ceramic Society Bulletin covers news and activities of the Society and its members, includes items of interest to the ceramics community, and provides the most current information concerning all aspects of ceramic technology, including R&D, manufacturing, engineering, and marketing. *American Ceramic Society Bulletin* (ISSN No. 0002-7812). ©2015. Printed in the United States of America. *ACerS Bulletin* is published monthly, except for February, July, and November, as a "dual-media" magazine in print and electronic formats (www.ceramicbulletin.org). Editorial and Subscription Offices: 600 North Cleveland Avenue, Suite 210, Westerville, OH 43082-6920. Subscription included with The American Ceramic Society membership. Nonmember print subscription rates, including online access: United States and Canada, 1 year $135; international, 1 year $150.* Rates include shipping charges. International Remail Service is standard outside of the United States and Canada. *International nonmembers also may elect to receive an electronic-only, email delivery subscription for $100. Single issues, January–October/November: member $6 per issue; nonmember $15 per issue. December issue (*ceramicSOURCE*): member $20, nonmember $40. Postage/handling for single issues: United States and Canada, $3 per item; United States and Canada Expedited (UPS 2nd day air), $8 per item; International Standard, $6 per item.

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ACSBA7, Vol. 96, No. 1, pp 1–64. All feature articles are covered in Current Contents.

news & trends

Tesla unveils solar glass roofing tiles

Although most famous for making electric cars, Tesla recently unveiled its concept for solar glass roofing tiles that will expand the company's vision for a future powered by integrated sustainable energy.

And because about 5 million new roofs are installed in the United States every year, there is a large market for sustainable energy sitting on top of each home. A small portion of that market already is taken up by solar panels, which are installed on about 1 million U.S. homes currently.

But Tesla's vision is not about adding sustainable energy—it is about completely integrating it into consumers' homes and lives. The company's three-part solution consists of energy generation, storage, and transport with its own brand of solar roofing tiles, battery packs, and electric cars, respectively.

At the recent Tesla launch event, CEO Elon Musk shared his vision for an integrated sustainable energy future and showed off an aesthetically pleasing cadre of solar cell glass roofing tiles.

According to Musk, Tesla teamed up with solar energy company SolarCity to create a solar roof that is functional as well as beautiful, affordable, and integrated. Musk says that Tesla will join forces with Panasonic to manufacture the new solar cells in a Buffalo, N.Y., facility, according to a *Business Insider* article.

Tesla has released few details about the technology behind its solar roof tiles, other than indicating that they incorporate "high-efficiency" solar cells.

According to a *TechCrunch* article, Musk says the solar cells in the roofing tiles achieve 98% of the efficiency of regular solar panels, but there is room for improvement. The article states, "He said that the company is working with 3M on coatings that could help light enter the panel and then refract within, letting it capture even more of the potential energy it carries to translate that into consumable power."

Credit: Bloomberg; YouTube

Tesla's new roofing tiles—which come in four varied styles—all hide solar cells underneath.

In true Tesla style, one of the most impressive things about the new roofing tiles is how good they look. The company is offering four styles of glass roofing tiles—textured, smooth, slate-style, and terra cotta-style—most of which almost completely mask the fact that they incorporate solar cells.

To do that, the solar cells are covered by what Tesla calls a "color louver film" that hides them from view—yet allows sunlight to pass through—and a tempered glass cover that provides the tiles with glass's durability and impact resistance.

Depending on the roofing tile style, that glass is textured, specially styled, or hydrographically printed—a process that prints a unique pattern on each tile—to hide the solar cells within and make the glass surface mimic the look of standard roofing materials.

Tesla claims that because of glass's durability, the solar roof should last two to three times longer than traditional roofs because of its toughness against even harsh elements, such as hail.

Musk says that Tesla's newly created "special glass technology group" developed the glass roof tiles and that it also will incorporate the same glass technology into the company's new Model 3 automobile, according to a *Business Insider* article.

See a preview of the new glass tiles in a short *Bloomberg* video available at youtu.be/ilTn-Wv0a_I.. ■

Glass professionals converge to tackle industry's toughest challenges

The 77th Conference on Glass Problems recently took place in Columbus, Ohio, and brought together glass manufacturers and suppliers worldwide to exchange innovations and solutions. The meeting, hosted November 7–10, 2016, and presented by the Glass Manufacturing Industry Council (GMIC) and Alfred University, is the largest glass manufacturing conference in North America.

Conferece attendance surpassed previous years—more than 500 attendees came together to share the latest research in a robust field. And the next generation of the industry made its presence known this year, too.

"We're on track to have about 100 more attendees than last year—more than 500—which is great. One of the remarkable things about it is that we've had a lot of growth with our students," says Robert Weisenburger Lipetz, executive director of the GMIC. "When we first started organizing this conference about five years ago, there were no students attending, and this year we had 43 students participate. And

Credit: ACerS

The first technical session of the 77th Conference on Glass Problems drew a packed house at the Columbus Convention Center.

that's really well received by an industry that's looking toward the next generation."

The meeting also gives industry professionals the opportunity to reconnect with old colleagues and make new connections.

"We've seen a lot of old faces, a lot of new faces. It's been a great opportunity for us to exchange ideas about our solutions to some of the challenges that continue to face our industry," adds Lipetz. "And that's really what you want out of an industry trade association meeting."

When it comes to tackling the glass industry's biggest challenges, discussions tend to turn to the usual topics, including operations, hot repairs, refractories, design of furnaces, and modeling for design of furnaces, Lipetz explained.

"Every year, the GMIC organizes a symposium that allows us to delve into some depth into topics of interest in the industry—this year we're doing it on modeling in glass manufacturing, and it looks to be a pretty popular topic for our attendees," says Lipetz.

Planning is underway for the 78th Conference on Glass Problems, including the 11th Advances in Fusion and Processing of Glass Symposium, in Columbus, Ohio, November 6–9, 2017. ■

Resources page to help keep manufacturers informed about regulations and rules

Credit: Department for Business, Innovation and Skills; Flickr CC BY-ND 2.0

It is important for manufacturers to stay updated on new regulations and rules affecting the industry—and a new resource on The American Ceramic Society's website aims to do just that.

To help manufacturers stay informed, ACerS recently added a "Resources for manufacturers" page to ceramics.org.

This information source provides resources related to regulations that impact the manufacturing community and beyond. In addition, the page hosts a handful of helpful links to outside resources, including government agencies and organizations that can offer further information and support.

Check out the new page at ceramics.org/knowledge-center/resources/resources-for-manufacturers. ■

Business news

Ceradyne wins contracts for two U.S. Army soldier protection programs (**news.3m.com**) …Şişecam becomes Europe's largest flat-glass manufacturer (**www.sisecam.com/en**)…Tesla to acquire German company to speed up electric car production (**tesla.com**)…Lucideon signs exclusive agreement with Skyepharma to develop abuse-deterrent opioid (**lucideon.com**)…Glass Solutions develops glass tube brazing furnace for Innoval Technology (**glass-solutions.com**)…SolarCity to open Pittsburgh and Buffalo facilities (**solarcity.com**)…Carlex invests €25M in Luxembourg windscreen plant (**carlex.com**)…AGC to pull out of business for glass substrates used in hard disk drives (**agc.com**)…Harper teams with Oak Ridge National Laboratory on carbon-fiber project (**harperintl.com**)…Kyocera Group consolidates optical components business (**global.kyocera.com**)…Alcoa Corp. launches an independent company for bauxite, alumina, aluminum products (**alcoa.com**)…$30M joint effort of five DOE national labs to improve solar module materials (**newscenter.lbl.gov**)…GE headquarters complex takes a big step forward (**ge.com**)…NSF awards $5.9 million to broaden participation in academic workforce (**nsf.gov**)…Ferro Corp. acquires Electro-Science Laboratories (**ferro.com**)…Energy Department launches $10M effort to develop advanced water-splitting materials (**energy.gov**)…Saint-Gobain acquires France Pare-Brise (**saint-gobain.com**)…Heraeus catalysts reduce dangerous nitrous oxide greenhouse gas emissions by 95% (**heraeus.com**)…Sika Global Automotive commissions reactor in Germany…American Concrete Institute announces publication on design of concrete wind turbine towers (**concrete.org**)…University of Buffalo awarded $2.9M to build advanced materials data research lab (**buffalo.edu**)…GE plans $1.65B acquisition of wind turbine blades manufacturer (**ge.com**)…Microban secures patents for antimicrobial technology in ceramics (**microban.com**)…AGC to set up solar control coating facility in Indonesia for architectural glass production (**agc.com**) ■

Society and Division news

Welcome to our newest Corporate Members!

ACerS recognizes organizations that have joined the Society as Corporate Members. For more information on becoming a Corporate Member, contact Kevin Thompson at kthompson@ceramics.org, or visit www.ceramics.org/corporate.

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ACerS expands Corporate Member Program to build partnerships

The American Ceramic Society is pleased to announce exciting changes to its Corporate Membership program. ACerS has offered Corporate Memberships to ceramic and glass suppliers and manufacturers for many years. "By working with Corporate Members and company executives, we created the Manufacturing Division, Corporate Achievement Awards, and Ceramics Expo, all designed to provide value to the companies who serve our industry," says Kevin Thompson, ACerS director of membership.

ACerS recognizes that forging partnerships with member companies is central to further serving suppliers and manufacturers. "Industry partnerships help member companies succeed, strengthen the Society, and ultimately benefit the technical ceramics and glass profession as a whole," says Thompson.

To achieve this goal, ACerS has recast the Corporate Membership program as a *Corporate Partnership* program. This new program is designed to give participating companies greater name recognition, branding and marketing exposure, and gain valuable employment recruiting and collaboration opportunities with universities, research institutions, and industry.

The new Corporate Partnership program is based upon a company's desired level of engagement rather than the original head count model.

"We know some corporate members use ACerS as their primary marketing

Society and Division news (continued)

arm, while others use our resources only for recruiting, for example. This 'remodeled' program allows corporate partners to customize their access to ACerS resources to meet their company's business needs," says Thompson.

Engagement opportunities include advertising, exhibiting, sponsoring and attending ACerS conferences, recruiting benefits, market report discounts, and more. This will enable ACerS to partner with companies through multiple channels, while offering company employees the many valuable benefits already available to all ACerS members.

To learn more about ACerS new Corporate Partnership program, contact Kevin Thompson, director of membership, at kthompson@ceramics.org or by phone at 614-794-5894. ■

William Fahrenholtz named editor-in chief of *Journal of the American Ceramic Society*

Fahrenholtz

Green

William G. Fahrenholtz has been appointed the new editor-in-chief of the *Journal of the American Ceramic Society (JACerS).* He succeeds retiring editor, David Green. Fahrenholtz's term will start January 1, 2017, and end December 31, 2021. As editor-in-chief, Fahrenholtz will serve as principal architect of the scientific content of *JACerS* and grow its impact worldwide.

"David has guided the editorial direction of *JACerS* since 2003 and has significantly increased the value it provides to the ceramics and glass materials community during that time period," says Mark Mecklenborg, ACerS director of publications, meetings, and membership.

Fahrenholtz is Curator's Distinguished Professor of Ceramic Engineering, director of the Materials Research Center at Missouri University of Science and Technology (Rolla, Mo.), and is a recognized expert in ultra-high-temperature ceramics and frequent participant in international technical meetings. He is a Fellow of ACerS, served on the Board of Directors 2009–2013, is former chair of ACerS Publications Committee, and has been a *JACerS* associate editor since 2009. Outside of ACerS, he has been a member of the Associate Editorial Board for *Materials Letters* since 2006. ■

ACerS announces partnership with BCC Research

The *ACerS Bulletin* will feature excerpts from market research reports written by BCC's expert analysts as a regular column starting with the January/February 2017 issue.

"We have been looking for an opportunity to bring business intelligence content to our readers. BCC is well-known for the comprehensive, reliable market research it produces, including many reports that cover ceramic and glass markets," says Eileen De Guire, *ACerS Bulletin* editor. BCC Research offers ACerS members 15% discounts on its reports as part of the partnership.

"This is our first partnership with a professional society," says John Blake, BCC Research CEO. "ACerS has a long history of engaging and serving a dynamic and diverse group of materials professionals with high-quality programming and content. We are excited to be providing market forecasts, insights, and analysis to further its member's understanding of the market." ■

Credit: S. Tanabe

Emeritus professor of Kyoto University, Naohiro Soga, past ICG President, and a Distinguished Life Member of ACerS & CerSJ, speaks at the symposium party.

Joint GOMD and CerSJ meeting a success

The Joint International Symposium on Glass Science and Technologies, which was the first ever joint meeting between the Glass Division of the Ceramic Society of Japan (CerSJ) and the Glass and Optical Materials Division of The American Ceramic Society was held November 13–15, 2016, on the main campus of Kyoto University in Japan. The symposium was colocated with the 57th Meeting on Glass and Photonic Materials and the 12th Symposium of Glass Industry Conference of Japan.

Almost 320 attendees from United States and Japanese academia and industry filled two parallel sessions. Presentations covered topics including structure analyses of glass and glass-ceramics, properties and structures of photonic materials, trends in fiber lasers and optical amplifiers, glassmelting and glass-processing technologies, technologies for glass strengthening, non-oxide and novel oxide glasses, and transparent ceramics.

Professors Setsuhisa Tanabe (Kyoto University) and John Ballato (Clemson University) organized the symposium, representing CerSJ and ACerS, respectively. ■

Saint-Gobain presents sustainability awards

Saint-Gobain recognized winners of its sustainability awards program at a companywide sustainability conference last fall. Awards and facilities recognized are

- **Waste Champion**: Saint-Gobain Crystals, Hiram/Newbury, Ohio, for development of a comprehensive program designed to reduce hazardous waste;
- **Water Champion**: Saint-Gobain Ceramic Materials, Wheatfield, N.Y., for its water reduction program;
- **Energy Champion**: SageGlass, Faribault, Minn., for its comprehensive energy reduction strategy;
- **CO_2 Champion**: CertainTeed Roofing, Oxford, N.C., for its substantial reduction in greenhouse gas emissions per unit of product made; and
- **Overall Champion**: CertainTeed Roofing, Ennis, Texas, for being a finalist in all four sustainability categories because of a broad and extensive focus on impacts inside and outside of its plant. ■

Pictured left–right, along with their championship belts: David Graham (Ennis, Texas; plant engineer), Mollie Torello (Oxford, N.C.; environmental process engineer), Don James (Hiram/Newbury, Ohio; area manager operations), Al Anderson (Faribault, Minn.; control systems engineer), Jim Richardson (Faribault, Minn.; site engineering manager), Steve Mahagnoul (Faribault, Minn., maintenance supervisor), and Ross Karipidis (Wheatfield, N.Y.; production manager).

Names in the news

Bikramjit Basu

Basu

Bikramjit Basu, member of the Engineering Ceramics Division, was awarded the Shanti Swarup Bhatnagar Prize for Science and Technology. Basu was recognized for the Engineering Science category and is the first ceramic scientist to receive the award. The award is among the highest honors for scientists in India. ■

Swetha Barkam receives UCF's highest honor

Barkam

University of Central Florida graduate student **Swetha Barkam** has been inducted into the Order of Pegasus, UCF's highest honor for students. A delegate to the President's Council of Student Advisors, she also was a Basic Science Division GEMS finalist at MS&T16 and a winner in the PCSA creativity contest, also at MS&T16. She is working on her Ph.D. under the guidance of Sudipta Seal. ■

Society and Division news (continued)

St. Louis Section/Refractory Ceramics Division 53rd Annual Symposium, March 28–30, 2017

The 2017 St. Louis Section and the Refractory Ceramics Division of The American Ceramic Society symposium theme is, "Real World Applications of Refractory Testing." The event, held at the Hilton St. Louis Airport Hotel in St. Louis, Mo., begins with a kickoff evening activity on Tuesday, March 28, and the symposium on March 29–30. Program cochairs are Ashley Hampton of Vesuvius and Brian Rayner of The Orton Ceramic Foundation.

A partial list of papers includes

- *High-definition imaging of hot refractory during operating conditions*

Bill Porter, **Saku Kaukonen**, and **Juha Roininen**; Bet-Ker America LLC & Sapotech Oy, Finland;

- *ASTM C-8 on refractories – An overview of the definitive standard tests for refractories*

Bill Headrick; MORCO;

- *Why do industrial-sized no-cement castables sometimes explode during heatup? A remedy to ensure safe and fast heatup of microsilica-gel bond castables*

Bjorn Myhre and **Hong Peng**; Elkem Silicon Materials, Norway;

- *Spinel: In-situ versus performed–Clearing the myth*

Dale Zacherl, **Marion Schnabel**, **Andreas Buhr**, **Reinhard Exenberger**, and **Christian Rampitsch**; Almatis Inc., Almatis GmbH, Germany, Voestalpine Stahl GmbH, Austria;

- *Reflections on refractory materials and their evaluation*

Victor Pandolfelli; Federal University of São Carlos, Brazil;

- *The use of heat flow analysis and infrared thermography for the identification of alternative insulation strategies*

James G. Hemrick; Reno Refractories Inc.;

- *Determining and enhancing the permeability of dense refractory castables*

Josh Pelletier, **Christoph Wöhrmeyer**, and **Carl Zetterström**; Kerneos Inc.;

- *Slag corrosion test methods*

Anna Mattione, **Ronald O'Malley**, and **Jeffery D. Smith**; Missouri University of Science & Technology;

- *The application of physical properties to refractory design and selection*

Mike Alexander; Riverside Refractories Inc.;

- *The effect of aluminosilicate calcine quality on finished monolithic refractory hot properties*

Scot Graddick, **Dave Tucker**, **Chris Beiter**, **Danilo Frulli**, and **Steffen Mohmel**; Imerys Refractory Minerals and CARRD; and

- *Turning reheat furnace into science*

Yong M. Lee and **Kurt Johnson**, ArcelorMittal Steel Global R&D.

Vendors who wish to participate in the traditional tabletop expo ($300 fee) should contact Patty Smith at 573-341-6265 or psmith@mst.edu. The expo features a two-hour appetizers and open bar "meet and greet" prior to the Wednesday evening dinner.

Find registration forms and hotel information at ceramics.org/meetings/acers-meetings and select St. Louis/RCD 53rd Annual Symposium. Hotel reservations must be made by **February 27, 2017**.

Also, the ASTM International C-8 Committee on Refractories will meet March 28 at the Hilton St. Louis Airport, St. Louis, Mo. Contact Katie Chalfin at 610-832-9717 for more information. ■

In memoriam

Richard Alliegro

Gary S. Sheffield

Francis P. Shonkwiler

Vladimir Stubican

Some detailed obituaries also can be found on the ACerS website, www.ceramics.org/in-memoriam.

Students and outreach

Refractories scholarship opportunity for students

The Refractories Institute is accepting applications for scholarships based on academic merit and demonstrated experience and interest in the field of refractories. A limited number of $5,000 scholarships will be awarded to undergraduate or advanced degree students in ceramic engineering, materials science, or a similar discipline at a North American college, university, or technical institute. For the 2017–2018 school year, the deadline for applications is **March 13, 2017**. For information, go to refractoriesinstitute.org/tri-pages/tri-scholarships.asp. ■

Grad students—Put yourself on the path to success!

Are you a current graduate student looking for opportunities to establish yourself within the ceramic and glass community? Get known and get to know others through ACerS Global Graduate Researcher Network (GGRN). ACerS GGRN is a graduate-student-level network to meet professional and career development needs of researchers whose primary interests are ceramics and glass.

GGRN aims to help graduate students

- Build a network of peers and contacts within the ceramic and glass community;
- Access professional development tools and events; and
- Engage with ACerS.

Visit www.ceramics.org/ggrn to learn what GGRN can do for you, or contact Tricia Freshour, ACerS membership engagement manager, at tfreshour@ceramics.org. ■

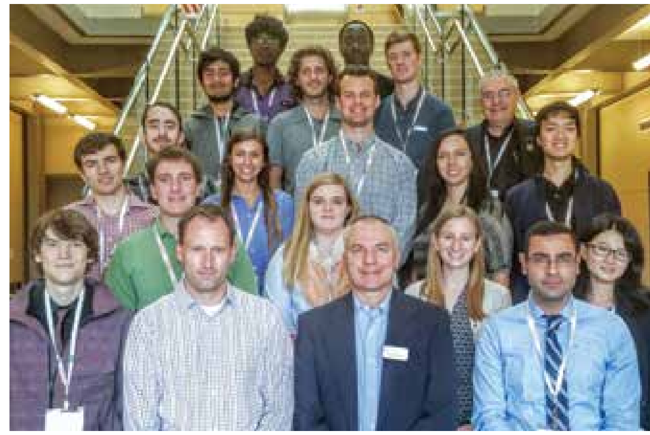
Students and outreach (continued)

Amedica's silicon nitride spinal implants highlight at ACerS student tour at MS&T

Approximately 20 students toured Amedica Corp. on Monday, October 24, during MS&T16 in Salt Lake City, Utah.

Amedica, a biomedical corporation with scientific and manufacturing expertise, produces medical-grade silicon nitride, including spinal implants made of the material. Amedica representatives explained how the spinal implants are used and how spinal fusion works. Students learned how silicon nitride compares with PEEK and titanium biomedical materials, toured the processing facilities, and learned details of how surgeons implement the devices. During the processing aspect of the tour, students saw pressing and machining of green bodies, laser etching the implants, and heat treating.

The tour concluded with refreshments with Amedica employees. The American Ceramic Society thanks Amedica Corp. for hosting this year's ACerS student tour at MS&T16! ■



Credit: Amedica

Amedica's Nate Nelson and David O'Brien (front row, second and third from left, respectively) hosted students for a tour during MS&T16 in Salt Lake City. Professor and lifelong student Delbert Day (third row, right) took the opportunity to tag along.

Register today for 2nd annual ACerS Winter Workshop

ACerS Winter Workshop, sponsored by The Ceramic and Glass Industry Foundation, will be held in conjunction with the Electronic Materials and Applications 2017 meeting, January 18 – 22, 2017, in Orlando, Fla. The Winter Workshop combines technical and professional development sessions designed specifically for students and young professionals. Find out more at ceramics.org/winter-workshop. ■

Attention students and young professionals: Going to ICACC17? Take advantage of special events

Make sure to attend the student and young professional activities at the 41st International Conference and Expo on Advanced Ceramics and Composites, January 22–27, 2017, in Daytona Beach, Fla.

- Student and Young Professional Networking Mixer, January 23, 7:30 – 9 p.m.
- SCHOTT Glass Competition (organized by ACerS PCSA), January 24, 6:45 – 8 p.m.
- Student and Young Professional Lunch and Lecture: "Practical tips for getting your research published," by Monica Ferraris, January 25, noon – 1:15 p.m.

For more information about ICACC17 and to register, visit www.ceramics.org/icacc2017. ■

Awards and deadlines

Last call for 2017 Society award nominations!

Nominations for most ACerS Society-level awards, including Distinguished Life Member, Kingery, Du-Co Ceramics, Jeppson, Coble, Corporate Achievement, Spriggs, Friedberg, Fulrath, and Purdy*, are due **January 15, 2017**.

For information, visit ceramics.org/awards or contact Erica Zimmerman at ezimmerman@ceramics.org.

**The 2017 Purdy Award is for papers published in 2015.*

ACerS corporate awards

Did you know that ACerS has four awards designed specifically for corporations? Do you know of a company that is a leader in terms of expanding industry frontiers or environmental or technical achievement? If so, consider nominating it for a 2017 corporate award to be presented at the ACerS Annual Meeting in October 2017. The nomination deadline is **January 15, 2017**. Learn more at ceramics.org/acers-blog/corpawards.

GOMD award nomination deadlines approaching fast

GOMD invites nominations for three prestigious awards, each with a **January 21, 2017**, deadline.

- **Stookey Lecture of Discovery Award:** Recognizes an individual's lifetime of innovative exploratory work or noteworthy contributions of outstanding research on new materials, phenomena, or processes involving glass that have commercial significance or the potential for commercial impact.
- **George W. Morey Award:** Recognizes new and original work in the field of glass science and technology. The criterion for winning the award is excellence in publication of work, either experimental or theoretical, done by an individual.
- **Norbert J. Kreidl Award for Young Scholars:** Recognizes research excellence in glass science and is open to all degree-seeking graduate students (M.Sc. or Ph.D.) or those who have

ACerS Science Classroom Kit outreach expands

The launch of the newly revamped Materials Science Classroom Kit continued as recent event participants were introduced to interactive lessons and demonstrations in the kit.

The Materials Science Classroom Kit was presented to materials science high school teachers from across the United States at the annual M-STEM Conference in Tulsa, Okla. The event brought together students, faculty, and businesses to strengthen understanding of Science, Technology, Engineering, and Math (STEM) principles, especially relating to materials science, and to enhance K-20 technology education integration.

Following an introduction and overview of the kit, teachers were able to experience their own hands-on, interactive learning by observing and performing three of the nine classroom demonstrations included in the kit. Activities focused specifically on labs teaching ceramic and glass science and engineering concepts.

Teachers attending the Mini-Materials Camp held during MS&T16 in Salt Lake City, Utah, in October received first-hand knowledge of several of the demonstrations included in the kit. Teachers and more than 245 students took part in the labs and experiments performed by

CERAMICANDGLASSINDUSTRY FOUNDATION

Teachers participating in lab demos at the M-STEM Conference in Tulsa.

Credit: ACerS

members of the ACerS President's Council of Student Advisors and volunteers representing the ACerS Refractory Ceramics Division.

"Thank you again for planning such an amazing opportunity. My students and I were able to learn a lot about materials science, and they were exposed to job opportunities!" stated Hannah Luna from City Academy in Salt Lake City.

The Materials Science Classroom Kit facilitates learning and inspires students to pursue materials science careers. Fun, hands-on lessons and labs introduce middle and high school students to the basic classes of materials—ceramics, composites, metals, and polymers. In addition, the popular book *The Magic of Ceramics* accompanies the kit and introduces the nontechnical reader to the many exciting applications of ceramics while teaching key scientific concepts.

To reduce costs for teachers and to promote materials science in your area, individual and corporate members are encouraged to sponsor Materials Science Classroom Kits for local schools for only $250 each. Each sponsor will be appropriately recognized so that schools receiving the kit will know of the sponsor's generosity. For more information or to conveniently purchase kits online, go to ceramics.org/donateakit.

For more information about the CGIF and Materials Science Classroom Kits, contact Marcus Fish at 614-794-5863 or mfish@ceramics.org.

graduated within a 12-month period of the GOMD meeting in Waikoloa, Hawaii, May 21–26, 2017.

Nomination details can be found at: ceramics.org/awards, or contact Erica Zimmerman at ezimmerman@ceramics.org. ■

ECD announces Best Paper, Best Poster winners from ICACC16

The Engineering Ceramics Division announced the Best Paper and Best Poster winners from the ICACC16 meeting held last January in Daytona Beach, Fla. The awards will be presented during the plenary session at ICACC17. Congratulations to the authors of these award-winning papers and posters!

Best Papers

First place

Effect of membranes in exhaust particulate filtration

Joerg Adler and **Uwe Petasch**

Second place

Fiber strength of hi-Nicalon™-S after oxidation and scale crystallization in $Si(OH)_4$ *saturated steam*

Randall Hay, **Randall Corns**, and **Bridget Larson**

Third place

Mass transfer mechanism in mullite under oxygen potential gradients at high temperatures

Satoshi Kitaoka, **Tsuneaki Matsudaira**, and **Masasuke Takata**

Best Posters

First place

Spark-plasma sintered translucent mullite ceramics with anisotropic grains

Andraz Kocjan, **Mark Cesnovar**, **Damjan Vengust**, **Ales Dakskobler**, and **Tomaz Kosmac**

Second place

Applications of Cu_2O *particles with modulated size and morphology in sensing 4-nitrophenol*

Yong-Cin Chen and **Meng-Jiy Wang**

Third place

TEM and XPS investigations of ordered MAX phases: Mo_2TiAlC_2 *and* $Mo_2Ti_2AlC_3$

Joseph Halim, **Babak Anasori**, **Martin Dahlqvist**, **Eun Moon**, **Jun Lu**, **Brian Hosler**, **El'ad Caspi**, **Steve May**, **Lars Hultman**, **Per Eklund**, **Johanna Rosen**, and **Michel Barsoum** ■

Meet ACerS president Bill Lee

By Eileen De Guire

(Credit for all photos: ACerS.)

William "Bill" Lee—professor of ceramic engineering at Imperial College in London—holds the unique distinction of being the first international president of The American Ceramic Society.

"I'm very proud of that—to be the first. It's a big deal," says Lee. "I think the timing was good for the Society to have a president from overseas. … It's important that the Society demonstrate its global credentials."

About 40% of the Society's membership live or work outside the United States. And, even more members work for multinational companies or collaborate internationally.

"I suspect now there will be a number of international presidents. I like to think so because it's an international Society—very global, very outward looking, and needs to be seen so," he says.

Lee's pathway to the ACerS' presidency started in his home country of England, where he studied physical metallurgy as an undergraduate at Aston University and then Oxford University, where he did his Ph.D. research. The young metallurgist, faced with a list of projects from which to choose, asked department head Sir Peter Hirsch for a recommendation. Hirsch guided him to study radiation damage in sapphire, and the match was made.

"Once I got into ceramics I was never going to go back. Just too many interesting and exciting things to do," Lee says.

Toward the end of his graduate work, Lee met Arthur Heuer, who was giving a talk at Leeds University. The two hit it off, and Lee found himself in the States for a two-year postdoctoral position in Heuer's group at Case Western Reserve University. Lee, who knew the Society through the *Journal of the American Ceramic Society*, became a member during his postdoc years and has maintained his membership ever since. After the postdoc, he joined the faculty at The Ohio State University and became active in ACerS Central Ohio Section, serving as secretary and treasurer.

Lee and his wife, Jacky, who also hails from England, made the decision to return home. In 1989 Lee joined the faculty at Sheffield University, where he stayed for 17 years before taking his current faculty position at Imperial College in London, where he has been for 10 years. He is taking his first sabbatical this year to focus on leading the Society.

Academia has proved to be a good match for Lee. He has supervised 60 students through to their Ph.D. A self-described "academic butterfly," whose research interests "always sort of flitted," Lee sees his breadth as an advantage. "In some ways that stands me in good stead with the Society because I've published papers in refractories, in glass technology, in whitewares, in electroceramics, in nuclear materials, and in ultra-high-temperature ceramics. There are not many areas I haven't actually done some work in or had a Ph.D. student working in," he says.

As president, Lee will focus his efforts in three areas: raising ACerS's global profile, supporting young people, and serving the needs of industry.

Lee plans to advance the international partnerships and collaborations begun by previous presidents. Goals include opening international chapters in the U.K. and elsewhere and serving the global community by "linking with communities, especially where there are clusters of students and young professionals who are eager to expand their own networks—Singapore, Malaysia, Indonesia, Vietnam, for example." As the first international president, "What I can do is raise the profile of the programs that are going forward and highlight … the international flavor of The American Ceramic Society."

Ever the professor/teacher/mentor, Lee is keen to engage young people. To that end, he intends to expand pathways for young members to participate in the Society in substantive ways through the Global Graduate Researcher Network, Young Professionals Network, and President's Council of Student Advisors. Lee would like to see young people welcomed to committees, Division meetings, and given a voice on the Board of Directors.

"I want young people to see the benefit of joining the Society, and like me, stay for the next 30, 40 years," he says.

The connection of his work to industry is never far from his mind. "I've always been very interested in working with industry. I like to think that what I did had an endpoint that was useful, either making money or for the good of society. That's what engineers do," he says.

With an eye tuned to global issues, he established an Advocacy Committee to study and make recommendations to the Board on ways to support industry regarding health, safety, and environmental legislation. Lee also will work with ACerS staff to introduce a new Corporate Partnership program and to support the new Manufacturing Division as it begins to develop programming.

Promoting the Ceramic and Glass Industry Foundation weaves together all three priorities. The role of ACerS is a crucial one, he says. "We're all materials scientists. But, if you're going to develop a product, you need a team." For example, Lee belongs to several multiuniversity consortia. "Going in as a materials person wouldn't be enough. I go in as a ceramics person, with knowledge of ceramic materials to a depth that the average materials person wouldn't have."

"Working with industry, the Foundation is a big thing, making sure we retain the ceramic skills base, making sure we match the researchers and the industry people with the jobs that are there, and that we do it in an international setting. That's important," he says.

Lee, his wife, and their daughter, Alex, make their home in Lyme Regis in the southwest coastal region of Britain. The family enjoys walking, swimming, and running and are avid gardeners. In his free moments, Lee is building a summer home, conveniently positioned at the base of their garden!

Despite the hefty agenda that comes with being ACerS president and projects at home, Lee is mulling over taking on one more discipline—campanology, the art of bell ringing. His local parish is looking for someone to ring the large outdoor bells. Perhaps this is a nod to his metallurgical roots? ■

ACerS 118th Annual Meeting

President Singh reports on a strong Society and passes the gavel to ACerS's first international president

By Eileen De Guire

President Mrityunjay Singh presided over the 118th ACerS Annual Meeting on Oct. 24, 2016, in Salt Lake City, Utah. He reported to the membership there on the state of the Society and progress on initiatives. Treasurer Dan Lease updated members on the financial health of the Society, and incoming president Bill Lee outlined his agenda for the coming year.

Singh already updated members on the status of strategic initiatives in an article published in the October/November 2016 issue of the *ACerS Bulletin*. At the Annual Meeting, he reported that the Society has grown to almost 10,400 members and has an additional 160 Corporate Members. The membership includes strong student representation, especially from the graduate student cohort of about 700 members.

ACerS president Mrityunjay Singh reports to the membership at the 118th Annual Meeting of the Society.

The Ceramic and Glass Industry Foundation expanded its programming and outreach during the past year on several fronts. The CGIF Materials Science Classroom Kit has been updated and now includes the *Magic of Ceramics* book by David Richerson. Kits—through sponsorship by companies, organizations, and individuals—are being placed into school districts, including Chicago City Schools. Also, the President's Council of Student Advisors has come under CGIF aegis as a student leadership development program.

Treasurer Daniel Lease reported that the Society continues to maintain a strong asset position and carries no debt. Reserves and the Society's asset/liability ratio are well above targets set by the Board of Directors. Lease reported that in 2015, the Society, combined with its Ceramic Publishing Company, returned budgetary surplus for the sixth consecutive year.

New leaders of the Society are sworn in at the Annual Meeting. From left: Michael Alexander (president-elect), Dana Goski (director), Lynnette Madsen (director), and Bill Lee (president).

Singh recognized past-president Kathleen Richardson for her leadership service as well as John Halloran and Edgar Lara-Curzio, who have completed their three-year terms as directors. Three new directors were inducted: Dana Goski, Lynnette Madsen, and Doreen Edwards (not present). In addition, William "Bill" Lee was sworn in as ACerS president for the 2016–2017 term—a historic moment, because Lee is the first international member to serve in that office.

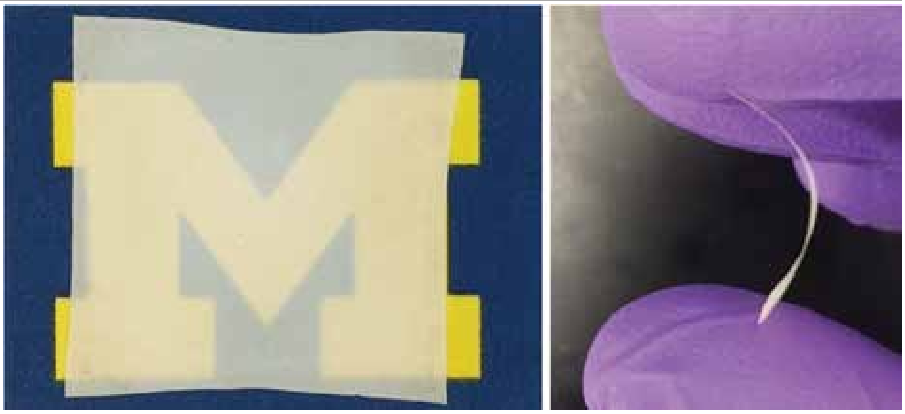
William "Bill" Lee receives the ceremonial ceramic gavel from Mrityunjay Singh.

Lee assumed the podium to outline his agenda for the coming year, which will focus on raising ACerS's international profile, supporting young members, and serving industry. See details of his plans in "Meet ACerS president Bill Lee," on opposite page.

On behalf of the entire Society, Singh recognized David Green for exemplary service as editor-in-chief of the *Journal of the American Ceramic Society*. Green retires at the end of 2016 after leading the *Journal*'s editorial function for 18 years.

The 119th Annual Meeting will be October 9, 2017, in Pittsburgh, Pa. ■

LLZO ceramic thin films offer hope for safer, thinner all-solid-state lithium-ion batteries



Credit: Laine lab; University of Michigan

A transparent and flexible thin film of LLZO (2 cm × 2 cm) produced by scientists at the University of Michigan.

Although lithium-ion batteries have come a long way, these energy powerhouses are not perfect.

Solid-state batteries—which, as the name might imply, ditch the liquid for a solid electrolyte—can help solve some of the problems that plague batteries with liquid electrolytes. For one, solid-state batteries are much safer and have the capacity to offer higher energy densities in smaller footprints.

"Collaborative research is needed to realize all-solid-state lithium batteries because of the interdisciplinary nature of the challenge this technology is faced with," says Richard Laine, professor of materials science and engineering at the University of Michigan (Ann Arbor, Mich.). Laine and his research lab staff are developing new approaches to process materials for solid-state batteries.

Laine, an ACerS member, can attest to the power of ceramic materials as a lithium-ion electrolyte option—ceramics have the potential to eliminate problems with compatible chemistries, offer a safer and more thermally stable solution, and can reduce the size of such batteries, too. In particular, one candidate ceramic is a garnet material called LLZO (c-$Li_7La_3Zr_2O_{12}$).

"For many years, LLZO has been considered the most promising solid electrolyte in the construction of all-solid-state lithium batteries using lithium-metal anodes, which potentially offer higher energy density, longer cycle life, and inherent safety. Fundamental understanding of LLZO has matured over time, whereas processing has fallen short," Eongyu Yi, a graduate student in Laine's lab, writes in an email.

An ideal ceramic electrolyte needs to have good ionic conductivity and have wide electrochemical and thermal operational windows, according to Yi. And LLZO does just that.

But an ideal ceramic electrolyte also needs to be able to be formed into thin films using low-cost, mass-producible methods, a must for commercial scale-up—and that is where LLZO falls short, because processing the material into thin films requires prolonged sintering at high temperatures (i.e., energy- and time-intensive), which volatizes lithium out of the thin film.

So Laine's research group devised a strategy to process LLZO thin films sans the prolonged sintering route. The team's work, published in *Journal of Materials Chemistry A*, describes how the scientists used flame spray pyrolysis and conventional casting–sintering—proven methods that work on a mass production scale—to fabricate thin films of LLZO.

Using liquid-feed flame spray pyrolysis (LF-FSP)—a technique the scientists previously developed to process nanoscale ceramic powders—the team first produced $Li_{6.25}Al_{0.25}La_3Zr_2O_{12}$ LLZO nanopowders containing 50-wt% excess lithium. That excess lithium helps balance loss of the element through volatization during sintering.

Then, the scientists ball-milled the nanopowders to a uniformly small size, cast them, and quickly sintered them for one hour (compared with conventional sintering times of 10–40 hours) to densify the final thin films.

The scientists' relatively simple and rapid technique produced LLZO films 20–30 μm thick—which the authors note is similar to the thickness of commercial polymer separators—that were dense despite their thinness, with fine-grained structures.

Grain structure is an important feature for a solid electrolyte, because grain boundaries impact the materials' resistance, with greater resistance inhibiting ion flow and, thus, battery performance. In addition, the team's cast-and-sintered LLZO thin films were translucent and relatively flexible, meaning that the films could help develop thin and flexible batteries.

"Our results are a step forward to the realization of all-solid-state lithium batteries. However, there are more steps to take," Yi says.

Those steps include reducing LLZO film thickness, sintering temperature, and excess lithium content. "Reduced sintering temperatures will retard Li_2O loss rates, widening the optimal processing window," Yi explains via email.

Another important challenge in developing solid-state batteries lies at the interface between the electrodes and electrolytes. Yi explains that the interphase (solid–solid interface) must be electrochemically active for solid-state batteries to perform in optimal conditions. "This is the next challenge the research community will have to solve."

The paper, published in *Journal of Materials Chemistry A*, is "Flame made nanoparticles permit processing of dense, flexible, Li^+ conducting ceramic electrolyte thin films of cubic-$Li_7La_3Zr_2O_{12}$ (c-LLZO)" (DOI: 10.1039/C6TA04492A). ■

Opening a window to better batteries: Researchers get up-close to watch lithium dendrites grow

When it comes to new strategies for energy storage, one promising option is lithium-metal batteries, which offer 10 times greater energy storage potential than today's lithium-ion batteries. But lithium-metal batteries have all-metal electrodes that are particularly prone to dendrite formation on their surface. Dendrites—tiny fingerlike structures that kill battery performance and pose safety issues—are a problem for other batteries, too, but particularly problematic for lithium-metal versions.

"As researchers try to cram more and more energy in the same amount of space, morphology problems like dendrites become major challenges. While we don't fully know why the Samsung Galaxy Note 7s exploded, dendrites make bad things like that happen," Kevin Wood, a postdoctoral researcher in mechanical engineering at the University of Michigan (Ann Arbor, Mich.), says in a UM news release. "If we want high energy density batteries in the future and don't want them to explode, we need to solve the dendrite problem."

Wood and a team of UM researchers have made important progress toward doing just that—they developed a strategy to observe dendrite formation in batteries in real time. Those observations will help scientists understand how dendrites form, a critical step toward being able to solve the dendrite problem.

The team built a battery with a visualization window—a literal window in the side of the battery that simply allows the team to watch what happens as the battery cycles.

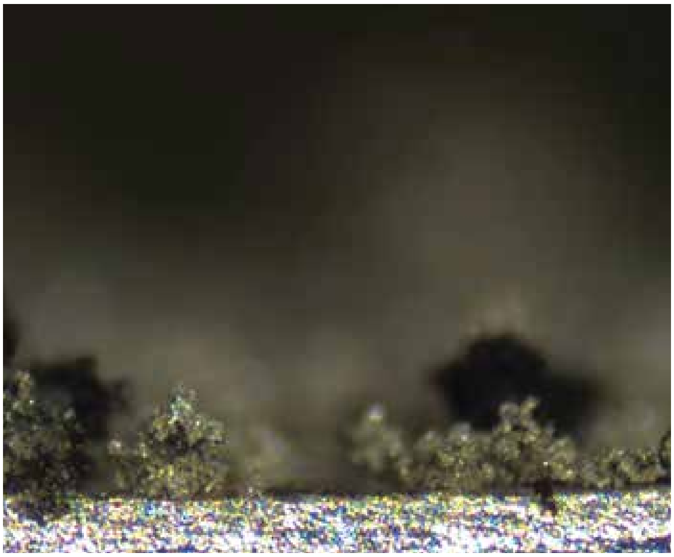
The scientists mounted the visualization-window-equipped battery onto a high-definition video microscope so they could film the dendrites as they formed. Coupling that visual data with simultaneous voltage measurements from the battery as it cycled, the scientists analyzed how the presence of dendrites correlated with battery performance.

"Our window battery is a simple platform that can be used by researchers worldwide," Neil Dasgupta, assistant professor of mechanical engineering at UM and senior author on the team's research paper, says in the new story. "It can be reproduced in any lab with an optical microscope, simple electrochemical equipment, a machine shop, and a $100 budget."

Although the scientists published some of their observations in an open-access paper published in *ACS Central Science*, they are not giving up all their secrets too easily. "Using this insight, the team discovered a way to significantly extend the lifetime of lithium electrodes, to be revealed in a future publication," according to the release.

In the meantime, watch the dendrites and hear more from the researchers themselves in a short UM video available at youtu.be/E-OvK_sgoOE.

The open-access paper, published in *ACS Central Science*, is "Dendrites and pits: Untangling the complex behavior of lithium-metal anodes through operando video microscopy" (DOI: 10.1021/acscentsci.6b00260). ■



Credit: Neil Dasgupta

Microscope image showing dendrites growing in a lithium-metal battery.

New tandem perovskite solar cell could outrank silicon's efficiency and stability

Credit: Stanford Precourt Institute for Energy; YouTube

Close-up of a new tandem perovskite solar cell developed by researchers at Stanford University and Oxford University.

Researchers from Stanford University (Stanford, Calif.) and Oxford University (Oxford, England) recently joined forces to create a new perovskite design they say "could outperform existing commercial technologies," according to a *Stanford News* article.

The team used tin and other abundant elements to create a new photovoltaic crystalline material that is thinner, more flexible, and easier to scale-up than silicon, according to the article.

"Perovskite semiconductors have shown great promise for making high-efficiency solar cells at low cost," Michael McGehee, a professor of materials science and engineering at Stanford and coauthor of the study, tells *Stanford News*. "We have designed a robust, all-perovskite device that converts sunlight to electricity with an efficiency of 20.3%, a rate comparable to silicon solar cells on the market today."

The novel design leverages two perovskite solar cells stacked on top of each other. The researchers printed the cells on a glass substrate, but the technology could easily swap glass for plastic, McGhee adds in the article.

"The all-perovskite tandem cells we have demonstrated clearly outline a roadmap for thin-film solar cells to deliver better than 30% efficiency," Henry Snaith, a professor of physics at Oxford and coauthor of the study, explains. "This is just the beginning."

Standard perovskite solar cells generate electric current by harvesting high-energy photons from the visible part of the solar spectrum that cause electrons to effectively jump across an energy gap, *Stanford News* explains.

"The cell with the larger energy gap would absorb higher-energy photons and generate an additional voltage," Giles Eperon, colead author and an Oxford postdoctoral scholar currently at the University of Washington (Seattle,Wash.), says in the article. "The cell with the smaller energy gap can harvest photons that aren't collected by the first cell and still produce a voltage."

With this concept in mind, the team used a unique combination of tin, lead, cesium, iodine, and organic materials to develop an efficient cell with a small energy gap first.

"We developed a novel perovskite that absorbs lower-energy infrared light and delivers a 14.8% conversion efficiency," Eperon adds. "We then combined it with a perovskite cell composed of similar materials but with a larger energy gap."

When the team combined the two perovskite cells, it created a novel tandem device capable of producing a combined efficiency of 20.3%.

"Crucially, we found that our cells exhibit excellent thermal and atmospheric stability, unprecedented for tin-based perovskites," the authors explain in the article.

Optimization is on deck next for the team—it currently is working to fine-tune the tandem perovskite solar cell technology so it can absorb more light and generate an even higher current.

"The versatility of perovskites, the low cost of materials and manufacturing, now coupled with the potential to achieve very high efficiencies, will be transformative to the photovoltaic industry once manufacturability and acceptable stability also are proven," McGehee says.

A video detailing the new cells is available at youtu.be/MJqh5A3A2Cs.

The study, published in *Science*, is "Perovskite–perovskite tandem photovoltaics with optimized bandgaps" (DOI: 10.1126/science.aaf9717). ■

'DIY batteries' made from junkyard waste could be next high-performance power source

What if the answer to high-performance batteries that have a smaller environmental impact is in the junkyard?

Researchers from Vanderbilt University (Nashville, Tenn.) went back to basics and used scraps of two of the most commonly discarded materials—steel and brass—to create what they say is the world's first steel–brass battery that can store energy at levels comparable to lead–acid batteries while charging and discharging at rates comparable to ultrafast charging supercapacitors, according to a university press release.

"Imagine that the tons of metal waste discarded every year could be used to provide energy storage for the renewable energy grid of the future, instead of becoming a burden for waste processing plants and the environment," Cary Pint, assistant professor of mechanical engineering at Vanderbilt, says in the release.

The team anodized scraps of steel and brass—a process that coats the metals with a protective oxide layer—using a common household chemical and residential electrical current.

After anodization, "the metal surfaces restructured into nanometer-sized networks of metal oxide that can store and release energy when reacting with a water-based liquid electrolyte," the release explains. Those nanoscale features give the battery its ability to charge quickly and provide stability.

When put to the test through 5,000 consecutive charging cycles (or the equivalent of 13 years of daily charging and discharging), the researchers found that this fast-charging battery also is extremely stable—it retained more than 90% of its energy capacity.

And unlike the volatile lithium-ion cell phone batteries used in Samsung's Galaxy Note 7 and other similar devices, these "do-it-yourself" steel–brass batteries use nonflammable water electrolytes that contain potassium hydroxide, an inexpensive salt used in laundry detergent, the release explains.

Credit: Daniel Dubois; Vanderbilt University

Vanderbilt University researchers (left to right) Nitin Muralidharan, Andrew Westover, and Cary Pint devised a DIY process to create batteries with common household chemicals. Muralidharan is holding in his left hand the prototype junkyard battery.

"When our aim was to produce the materials used in batteries from household supplies in a manner so cheaply that large-scale manufacturing facilities don't make any sense, we had to approach this differently [from how] we normally would in the research lab," Pint adds.

The scientists say this battery could have current real-world applications—they plan to build a full-scale prototype battery capable of powering energy-efficient smart homes.

"We're seeing the start of a movement in contemporary society leading to a 'maker culture' where large-scale product development and manufacturing are being decentralized and scaled down to individuals or communities," Pint says. "So far, batteries have remained outside of this culture, but I believe we will see the day when residents will disconnect from the grid and produce their own batteries. That's the scale where battery technology began, and I think we will return there."

The study, published in *ACS Energy Letters*, "From the junkyard to the power grid: Ambient processing of scrap metals into nanostructured electrodes for ultrafast rechargeable batteries" (DOI: 10.1021/acsenergylett.6b00295). ■

Graphene coating could help mitigate glass damage

Researchers from the Center for Multidimensional Carbon Materials (CMCM) at the Institute for Basic Science (IBS) in South Korea say that graphene might help solve challenges with glass corrosion.

Anyone who works with glass has to deal with the material's problem with corrosion. Some types of glass erode over time in the presence of high humidity and pH, which cause glass to lose its transparency and strength. The corrosion of silicate glass by water, for example, is a serious issue for pharmaceutical, environmental, and optical industries, according to an IBS press release.

So researchers continue to look for solutions for how best to coat these glasses and protect them from damage. The goal is to develop a coating that is thin, transparent, and offers a solid barrier to guard against chemical infiltration.

"Graphene with its chemical inertness, thinness, and high transparency makes it very promising as a coating material," the release explains. "Moreover, owing to its excellent chemical barrier properties, it blocks helium atoms from penetrating through it. The use of graphene coating is being explored as a protective layer for other materials requiring resistance to corrosion, oxidation, friction, bacterial infection, electromagnetic radiation, etc."

To create the coating, the researchers grew graphene on copper and transferred either one- or two-atom-thick layers of graphene onto both sides of rectangular pieces of glass. Then, through water-immersion testing, the team observed the differences in corrosion between uncoated and coated pieces of glass.

The team found that "after 120 days of immersion in water at 60°C, uncoated glass samples had significantly increased in surface roughness and defects, and reduced in fracture strength," the release explains. But the single- and double-layer graphene-coated glasses "had essentially no change in fracture strength and surface roughness."

"The purpose of the study was to determine whether graphene grown by chemical vapor deposition on copper foils, a now established method, could be transferred onto glass and protect the glass from corrosion. Our study shows that even a one-atom-thick layer of graphene does the trick," Rodney Ruoff, director of the CMCM and professor at the Ulsan National Institute of Science and Technology, says in the release. "In the future, when it is possible to produce larger and yet higher-quality graphene sheets and to optimize the transfer on glass, it seems reasonably likely that graphene coating on glass will be used on an industrial scale."

The study, published in *ACS Nano*, is "Graphene coatings as barrier layers to prevent the water-induced corrosion of silicate glass" (DOI: 10.1021/acsnano.6b04363). ■

Credit: Roo Reynolds; Flickr CC BY-NC 2.0

A new graphene coating could help protect glass.

Natural defects in 2-D materials pose new challenge for next-gen flexible electronics

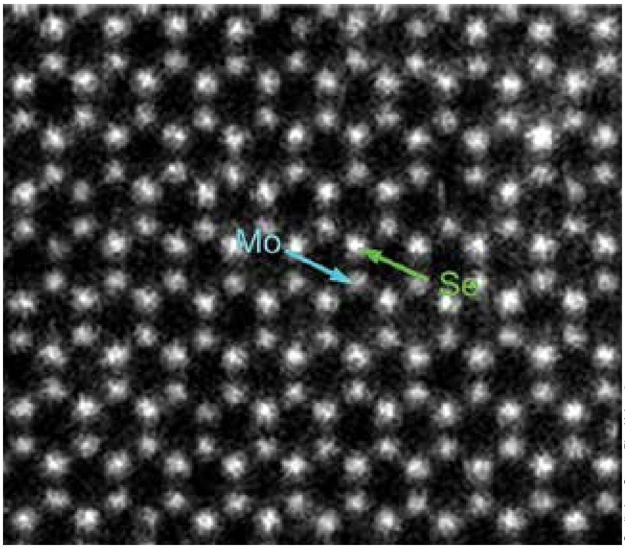
When it comes to developing next-generation flexible electronics, researchers see major potential in 2-D materials.

Molybdenum diselenide has been considered alongside graphene for use in flexible electronics and next-generation optical devices. But, can it hold up under strain?

Researchers at Rice University (Houston, Texas) recently found that 2-D semiconducting molybdenum diselenide's tensile strength is more brittle than expected because of the material's inherent flaws—as small as one missing atom can crack the material under strain, according to a university press release.

Jun Lou, materials scientist at Rice who led the study, says this finding could cause the industry to take a more scrupulous look at the properties of 2-D materials before incorporating them into new technologies.

"It turns out not all 2-D crystals are equal," Lou says in the release. "Graphene is a lot more robust compared with some of the others we're dealing with right now, like this molybdenum diselenide. We think it has something to do



Credit: Lou Group: Rice University

When seen from above, the atoms in 2-D molybdenum diselenide resemble a hexagonal grid, like graphene. But, in reality, the darker molybdenum atoms are sandwiched between top and bottom layers of selenium atoms.

with defects inherent to these materials."

And because defects can be a single atomic vacancy in the crystalline structure, "It's very hard to detect them," Lou adds. "Even if a cluster of vacancies makes a bigger hole, it's difficult to find using any technique. It might be possible to see them with a transmission electron microscope, but that would be so labor intensive that it wouldn't be useful."

Molybdenum diselenide is a semiconducting material with a hexagonal array similar to graphene, but it is actually a sandwich of metallic atoms between two layers of chalcogen atoms (selenium, in this study), the release explains. Researchers are testing the material's effectiveness in transistors and technologies, including next-generation solar cells and electronic and optical devices.

Lou and his team "measured the material's elastic modulus, the amount of stretching a material can handle and still return to its initial state, at 177.2 (±9.3) GPa," the release explains. They found that graphene is more than five times as elastic as molybdenum diselenide. Its fracture strength was measured at 4.8 (±2.9) GPa. Graphene is nearly 25 times stronger, the team says.

Watch molybdenum diselenide crack under pressure in the short video available at youtu.be/uvhyi5TwZXA .

"The important message of this work is the brittle nature of these materials," Lou says. "A lot of people are thinking about using 2-D crystals because they're inherently thin. They're thinking about flexible electronics because they are semiconductors and their theoretical elastic strength should be very high. ... But, in reality, because of the inherent defects, you rarely can achieve that much strength."

The study, published in *Advanced Materials*, is "Brittle fracture of 2-D $MoSe_2$," (DOI: 10.1002/adma.201604201). ■

3-D-printed bioceramic composite offers flexible new hope for bone replacement

Researchers at Northwestern University (Evanston, Ill.) report that they have developed a hyperelastic material that can be 3-D printed into a potential bone replacement scaffold.

The material is a 3-D printable ink that consists of hydroxyapatite and a biodegradable, biocompatible polymer binder in a solvent that evaporates during printing. The liquid ink can be rapidly 3-D printed at room temperature.

The key to the new material is its Goldilocks combination of materials to provide strength and flexibility.

Hydroxyapatite, a natural component of bone and teeth, long has been explored as a bone replacement material. But hydroxyapatite alone is hard and brittle. Mixing hydroxyapatite with polymers can help afford flexibility, but too much polymer can inhibit the bioceramic's activity.

Which is why the Northwestern scientists' ratio is just right—their unique mixture of 90% hydroxyapatite and 10% polymer is strong enough to serve as a bone replacement, but flexible enough to be easily integrated and adapted into the body.

But, in addition to adequate material properties, a bone replacement material also must have an ideal structure.

"Porosity is huge when it comes to tissue regeneration, because you want cells and blood vessels to infiltrate the scaffold," Ramille Shah, assistant professor of materials science and engineering at Northwestern and lead researcher on the new study, says in a Northwestern news story. "Our 3-D structure has different levels of porosity that are advantageous for their physical and biological properties."

As a material, the new hyperelastic bone passes all the material properties necessary to stand up with bone, too. According to the new paper's abstract, "The resulting 3-D-printed hyperelastic bone exhibited elastic mechanical properties (~32% to 67% strain to failure, ~4 to 11 MPa elastic modulus), was highly absorbent (50% material porosity), supported cell viability and proliferation, and induced osteogenic differentiation of bone-marrow-derived human mesenchymal stem cells cultured in vitro for more than four weeks with no osteo-inducing factors in the medium."

The Northwestern team tested the hyperelastic bone in mouse, rat, and primate models, which all showed promising results. In these models, the 3-D-printed hyperelastic bone material integrated well with surrounding tissues and showed excellent biocompatibility. Stem cells infiltrated the scaffolds, vascularized the area, and even laid down new bone into the scaffolds in a short time period.

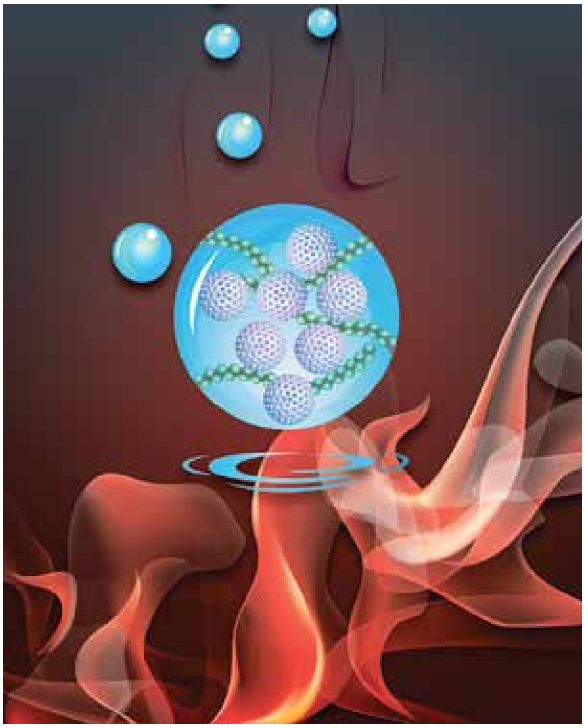
However, there is a lot more work to be done before the materials can make their way into humans. According to an article on *The Verge*, Shah says she hopes human trials can happen within five years.

A short *Science* video showing how the new porous material can bend without breaking is available at youtu.be/5-VdPeoVCAI.

Credit: Adam E. Jakus

Hyperelastic bone 3-D printed in the shape of a section of the human spine.

The open-access paper, published in *Science Translational Medicine*, is "Hyperelastic 'bone': A highly versatile, growth-factor-free, osteoregenerative, scalable, and surgically friendly biomaterial" (DOI: 10.1126/scitranslmed.aaf7704). ■



An artistic interpretation of the cold sintering of ceramic particles (white) and polymer strands (green) using low heat to evaporate added water molecules (blue).

Latest sintering technology makes ceramic-based materials faster with less heat

Pennsylvania State University (University Park, Pa.) researchers announced they have developed a new technology called cold sintering process (CSP) that has the potential to "combine incompatible materials, such as ceramics and plastics, into new, useful compound materials" that will reduce the costs associated with many types of manufacturing, according to a university press release.

Making ceramics and ceramic-based composites tends to require some serious heat—whether it is firing pottery in a kiln or sintering ceramic powders using ultra-high-temperature furnaces.

"In this day and age, when we have to be incredibly conscious of the carbon dioxide budget [and] the energy budget, rethinking many of our manufacturing processes, including ceramics, becomes absolutely vital," ACerS member Clive Randall, professor of materials science and engineering at Penn State, who developed the process with his team, says in the release. "Not only is this a low-temperature process (room temperature to 200°C), but we also are densifying some materials to [more than] 95% of their theoretical density in 15 minutes. We now can make a ceramic faster than you can bake a pizza, and at lower temperatures."

Randall and his team selected three types of polymer to complement the properties of three types of ceramics—a microwave dielectric, an electrolyte, and a semiconductor—to highlight the diversity of applicable materials. "These composite materials demonstrate new possibilities for dielectric property design and ionic and electronic electrical conductivity design, and [they] can be sintered to high density at 120°C in 15 to 60 minutes," the release explains.

The new CSP technology uses a dual process. First, the researchers wet ceramic powder with a few drops of water or acid solution. The solid surfaces of the powder particles partially dissolve in the solution, which creates a liquid phase at particle-to-particle interfaces, the release explains. When the researchers apply temperature and pressure to the liquid, the solid particles rearrange and densify.

Second, clusters of ions move away from where the particles are in contact, which aids in diffusion, minimizes surface free energy, and allows the particles to pack tightly together.

Randall notes, however, that it also is crucial to know the exact combination of moisture, pressure, heat, and time required to capture the reaction rates to ensure the material completely crystallizes and sufficiently densifies.

"I see cold sintering process as a continuum of different challenges," Randall adds. "In some systems, it's so easy you don't need pressure. In others you do. In some you need to use nanoparticles. In others, you can get away with a mixture of nanoparticles and larger particles. It really all depends on the systems and chemistries you are talking about."

The team expects their CSP technology will open up new possibilities for architectural materials, such as ceramic

Research News

Technique for creating NV-doped nanodiamonds may boost quantum computing

Researchers at North Carolina State University (Raleigh, N.C.) have developed a new technique for creating NV-doped single-crystal nanodiamonds, which could serve as components in room-temperature quantum computing technologies. NV-doped nanodiamonds contain thousands of atoms, but have only one NV center—which contains two carbon atoms, one vacancy, one carbon-13 atom, and one nitrogen atom. The researchers start with a sapphire, glass, or polymer substrate; coat it with amorphous carbon; and bombard it with nitrogen ions and carbon-13 ions while heating it with a laser pulse. Varying the substrate and duration of the laser pulse controls how quickly the carbon cools, creating nanodiamond structures. For more information, visit news.ncsu.edu.

'Conductive concrete' shields electronics from EMP attack

University of Nebraska-Lincoln engineers have developed a cost-effective concrete that shields against intense pulses of electromagnetic energy. The team replaced some standard concrete aggregates with magnetite, a mineral with magnetic properties that absorbs microwaves like a sponge. The patented recipe includes carbon and metal components for better absorption as well as reflection. This ability to absorb and reflect electromagnetic waves makes the team's concrete more effective than existing shielding technologies. In addition, it is more cost effective and flexible than current shielding methods, which use metal enclosures that require expensive metal panel or screen construction. For more information, visit news.unl.edu.

brick and thermal insulation, as well as biomedical implants and electronics.

"My hope is that a lot of the manufacturing processes that already exist will be able to use this process, and we can learn from polymer-manufacturing practices," Randall says.

The paper, published in *Advanced Functional Materials*, is "Cold sintering process of composites: Bridging the processing temperature gap of ceramic and polymer materials" (DOI: 10.1002/adfm.201602489). ■

Ripplocations help explain dislocation theory in layered materials

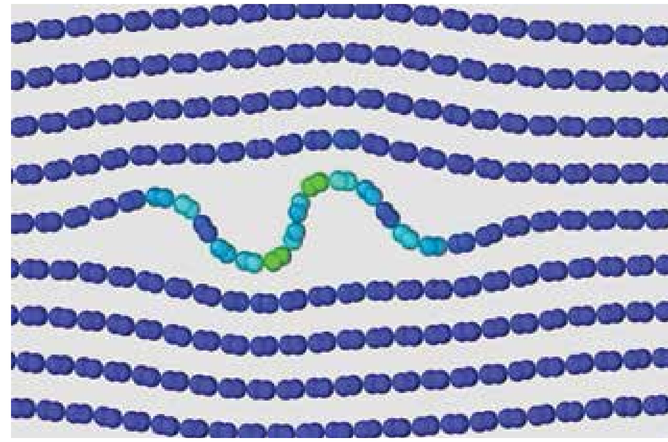
New research is maximizing on the potential of MAX phases, a group of layered ternary carbide and nitride materials with a unique combination of ceramic and metal properties.

Now researchers at Drexel University report on their studies of MAX phase ceramics that describe a completely new observation of how materials deform—a finding with broad implications for various other types of layered materials.

"Dislocation theory—in which the operative deformation micromechanism is a defect known as a dislocation—is very well established and has been spectacularly successful in our understanding the deformation of metals," Garritt Tucker, an assistant professor of materials science and engineering at Drexel University, says in a Drexel news release. "But it never really accurately accounted for the rippling and kink band formation observed in most layered solids."

Dislocation theory predicts that when deformed edge-on, the planes of a layered solid material either will become indented or, if elastic, will bounce back to the original form.

But layered materials do not quite do either—although they can bounce back, they do so while forming permanent kink bands. Michel Barsoum, Drexel distinguished professor of materials science and engineering and head of the Drexel MAX/MXene Research Group, described this effect about a decade ago, then calling it "kinking nonlinear elasticity."



Credit: Drexel University

Researchers at Drexel University have observed a new type of structural deformation mechanism in bulk materials, called ripplocation, that occurs when atomic layers inside the material ripple and buckle during compression.

Just last year, a separate MIT group published a paper describing a new phenomenon of deformation in the surface layers of 2-D materials. Dubbed "ripplocations"—a word mash-up between surface ripples and crystallographic dislocations—this option describes how deformed layered materials form internal atomic-scale ripples that dissipate energy.

"The MIT work showed that while the end result of the motion of dislocations and ripplocations is the same—one

LEDs may offer better way to clean water in remote areas

Engineers at The Ohio State University (Columbus, Ohio) are developing lightweight, flexible metal-foil-based LEDs for portable UV lights that soldiers and others can use to purify drinking water and sterilize medical equipment. In part, this new development relies on molecular beam epitaxy, in which vaporized elemental materials settle on a surface and self-organize into layers or nanostructures. The researchers grew a carpet of tightly packed aluminum gallium nitride wires on pieces of metal foil, such as titanium and tantalum. The individual wires measure about 200 nm tall and 20–50 nm in diameter. In laboratory tests, the nanowires lit up nearly as brightly as those manufactured on the more expensive and less flexible single-crystal silicon. For more information, visit osu.news.edu.

atomic layer moves relative to another—their physics were distinctly different and were thus totally and fundamentally different entities," Barsoum explains in the Drexel release.

The idea of ripplocations fits well into Barsoum's working theory of how kinking nonlinear elastic behavior works within dislocation theory. But, could the same 2-D layer phenomenon observed at MIT hold true for layers in bulk materials?

To find out, the Drexel scientists first performed simulations on the familiar layered material graphite and then extended their studies to indentation experiments with samples of MAX phase ceramic Ti_3SiC_2.

"We ran atomistic simulations on a bulk sample of graphite, because it is a layered material that has been studied quite a bit, and it is used in a number of applications where it is loaded," Jacob Gruber, first author of the new paper and Drexel doctoral candidate, says in the release. "[When we constrained] the edges of the sample while [we compressed] the material, we observed the nucleation and motion of a multitude of ripplocations that self-assemble into kink boundaries. The observation is significant, because these are the same sort of kink bands that are ubiquitous in geologic formations and layered solids that have been deformed."

After the simulations indicated how the layered materials would behave under confined compression—a response that resembled a buckling phenomenon, the authors write in the paper's abstract—the team then used a spherical indenter to see if the predictions held true in experimental samples of MAX phase ceramic Ti_3SiC_2.

"When we obtained high-resolution transmission electron microscopy images of the defects that formed as a result of the deformation, we were not only able to show that they were not dislocations, but as importantly, they were also consistent with what ripplocations would look like," Mitra Taheri, Hoeganaes associate professor of materials science and engineering at Drexel, says in the release. "We now have evidence for a new defect in solids; in other words, we have doubled the deformation micromechanisms known."

A series of YouTube videos showing the researchers' simulations of the ripplocation phenomenon is available at goo.gl/AlbPTT.

The open-access paper, published in *Scientific Reports*, is "Evidence for bulk ripplocations in layered solids" (DOI: 10.1038/srep33451). ■

Flash spark plasma sintering: Harnessing thermal runaway to densify silicon carbide in seconds

Flash spark plasma sintering has the ability to consolidate hard materials in a really short amount of time—a flash. The technique uses an electrical current to rapidly speed up the sintering process, reducing a heating process that would otherwise take hours to mere seconds. That means time savings, energy savings, and, thus, money savings when it comes to processing ceramic materials.

Researchers at San Diego State University now report that they also have developed an ultrarapid method of flash spark plasma sintering that can quickly densify even hard-to-deform materials.

"Using this process, it was possible to consolidate silicon carbide powder up to full density in few seconds," Eugene Olevsky, distinguished professor of mechanical engineering and associate dean for research and graduate studies at San Diego State University and first author of the paper describing the new work, writes in an email.

Olevsky and his colleagues explored the abilities of ultraflash spark plasma sintering to quickly densify materials by using theoretical calculations to determine what was going on behind the scenes. The calculations supported their prediction that thermal runaway could explain such rapid densification of materials under flash spark plasma sintering.

Thermal runaway is a type of uncontrolled positive feedback loop in which increasing the temperature within a material changes the reaction conditions to an extent that they cause further temperature increases. Although increased temperature are desirable, thermal runaway densifies materials nonuniformly.

So, researchers integrated pressure into

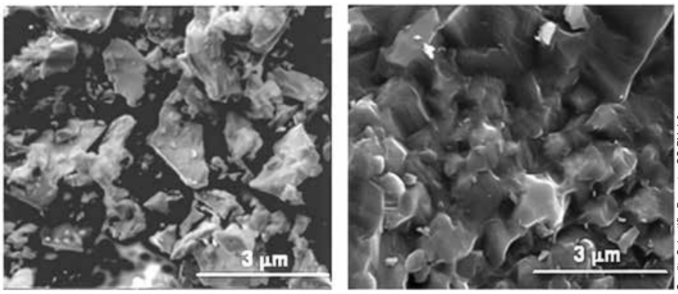
Research News

Dry adhesive holds in extreme cold, strengthens in extreme heat

Researchers from Case Western Reserve University (Cleveland, Ohio), Dayton Air Force Research Laboratory (Dayton, Ohio), and China have developed a new dry adhesive that bonds in extreme temperatures—a quality that could make the product ideal for space exploration and beyond. The gecko-inspired adhesive loses no traction in temperatures as cold as liquid nitrogen or as hot as molten silver, and actually gets stickier as heat increases, the researchers report. The adhesive contains bundled nodes of vertically aligned carbon nanotubes that penetrate surface cavities and form weblike structures, likely adding to the van der Waal's attraction. As the surface heats it becomes increasingly rough, and the bundles appear to penetrate deeper, becoming locked into place and further increasing the adhesion. For more information, visit thedaily.case.edu.

'Beautiful accident' leads to advances in high-pressure materials synthesis

Unexpected results from a neutron scattering experiment at Oak Ridge National Lab (Oak Ridge, Tenn.) could open a new pathway for the synthesis of novel materials. Researchers discovered that using high pressures—rather than high temperatures—can initiate chemical reactions. While performing a high-pressure polymerization experiment on acetonitrile, researchers detected the unexpected presence of ammonia. Collaborating with experts in advanced electron microscopy, materials science, and computing, the researchers concluded that nitrogen had left the acetonitrile sample, resulting in an enriched carbon-based material. For more information, visit ornl.gov.



SEM micrograph of SiC powder (left) and SiC specimen processed by flash hot pressing (right).

the process to keep thermal runaway in check during sintering. Therefore, the team calls their process flash hot pressing.

"Conducting flash sintering in a device designed for spark plasma sintering requires extra thought in die design," the authors write in the open-access *Scientific Reports* paper describing their work. "The goal is to pass current through the die alone, heating the specimen by radiation heating, then switching so that electrical current can only flow through the specimen."

The team specifically designed sacrificial dies that restrict current to the die itself, allowing indirect heating of the sample to a critical temperature before application of voltage through the sample itself—that way, the sample will receive electric current only under elevated temperature.

The team's specially designed die consists of a sacrificial conducting collar made of copper, which buffers the sample from the electric current until the die reaches copper's melting point. At that temperature, the collar deforms, allowing the sample to make contact with the electrical field.

The design worked—the authors report that these preliminary studies with silicon carbide show a "high degree of almost instantaneous densification with limited grain growth."

And because the authors used an industrial spark plasma sintering device, the technique could have widespread applicability to densify hard materials in seconds, saving precious processing time and significant amounts of energy for a variety of materials.

The paper, published in *Scientific Reports*, is "Flash (ultra-rapid) spark-plasma sintering of silicon carbide" (DOI: 10.1038/srep33408). ■

Improved microscale energy storage units for wearable and miniaturized electronic devices

A research team from King Abdullah University of Science and Technology (Thuwal, Saudi Arabia) has developed a microsupercapacitor with improved energy storage. The integrated microsupercapacitors have vertically scaled 3-D porous current collectors made of nickel foams, which offer increased surface area. The microsupercapacitors also are asymmetric, using two dissimilar electrode materials for the cathode (nickel cobalt sulfide) and anode (carbon nanofiber), which nearly doubles the operating voltage. As a result, the microsupercapacitors deliver high power and energy densities. These micropower units are expected to enable a new generation of "smart" products. For more information, visit kaust.edu.sa. ■

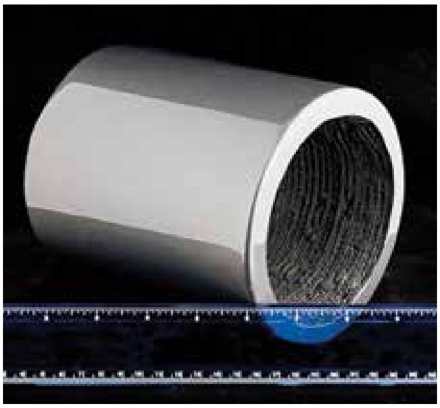
3-D printing key to conserving rare-earth materials for high-power-magnet production

A team of researchers at the Department of Energy's Oak Ridge National Laboratory (Oak Ridge, Tenn.) is focused on using 3-D printing to create permanent magnets that outperform conventional versions—a process the researchers say can help preserve the rare-earth materials used to create magnets.

The team used the Big Area Additive Manufacturing (BAAM) machine to 3-D print permanent magnets that can "outperform bonded magnets made using traditional techniques while conserving critical materials," according to an ORNL press release.

"While conventional sintered magnet manufacturing may result in material waste of as much as 30%–50%, additive manufacturing will simply capture and reuse those materials with nearly zero waste," ACerS member Parans Paranthaman, principal investigator and a group leader in ORNL's Chemical Sciences Division, says in the release.

ORNL's 3-D printing process is designed to conserve neodymium and dysprosium—rare-earth elements that are mined and separated outside the United States, the release explains. Neodymium magnets are the most powerful on earth and used in computer hard drives, headphones, and clean-energy tech-



Credit: ORNL

This isotropic, neodymium–iron–boron-bonded permanent magnet was 3-D printed at DOE's Manufacturing Demonstration Facility at Oak Ridge National Laboratory.

Credit: Christa Neu; Lehigh University

Ph.D. candidate Guosong Zeng is part of a Lehigh research group that was the first to explore wear resistance of gallium nitride.

nologies, such as electric vehicles and wind turbines.

"The 3-D printing process not only conserves materials but also produces complex shapes, requires no tooling, and is faster than traditional injection methods, potentially resulting in a much more economic manufacturing process," Paranthaman adds.

An ORNL video detailing the research and printing process is available at youtu.be/-GJ2R9V93Eo.

The study, published in *Scientific Reports*, is "Big area additive manufacturing of high-performance bonded NdFeB magnets" (DOI: 10.1038/srep36212). ■

Gallium nitride has wear resistance approaching that of diamond

Gallium nitride has electronic and optoelectronic properties that make it a contending semiconductor for many electronic applications—but how well does gallium nitride stand up to wear?

Researchers at Lehigh University now report that, in addition to gallium nitride's checklist of other useful attributes, the material's tribological behavior approaches that of diamond—which could open the material's foray into even more diverse applications.

"Our group is the first to investigate the wear performance of GaN," Guosong Zeng, a Ph.D. candidate in mechanical engineering at Lehigh and first author of the new paper describing the work, says in a Lehigh news release. "We have found that its wear rate approaches that of diamond, the hardest material known."

Using a custom microtribometer, the scientists performed dry sliding wear experiments on gallium nitride and measured a wear rate of 10^{-7}–10^{-9} $mm^3/(N \bullet m)$. Diamond has a wear rate of 10^{-9}–10^{-10} $mm^3/(N \bullet m)$. According to the scientists, although similar wear experiments usually measure results after ~1,000 sliding cycles, they had to increase testing to 30,000 cycles to generate measureable wear on gallium nitride.

But such wear rates were not uniform, the authors report—gallium nitride has a wear rate that ranges depending on several variables, including environmental conditions (especially humidity) and crystallographic properties.

"The first time we observed the ultralow wear rate of GaN was in winter," Zeng says in the release. "These results could not be replicated in summer, when the material's wear rate increased by two orders of magnitude."

In a controlled environment in the laboratory, the team measured similar fluctuations in wear rate depending on humidity—increasing humidity during testing also increased the material's wear rate.

Despite the variation, however, the surprisingly high wear rate of this already useful material opens up even further avenues of applications for gallium nitride.

"The wear resistance of GaN gives us the opportunity to replace the multiple layers in a typical semiconductor device with one layer made of a material that has excellent optical and electrical properties and is wear resistant as well," Nelson Tansu, one of the paper's authors and the Daniel E. and Patricia M. Smith Endowed Chair Professor in the Electrical and Computer Engineering Department and director of the Center for Photonics and Nanoelectronics at Lehigh, says in the release.

"Using GaN, you can build an entire device in one platform without multiple layers of technologies," Tansu continues. "You can integrate electronics, light sensors, and light emitters and still have a mechanically robust device. This will open up a new paradigm for designing devices. And because GaN can be made very thin and still strong, it will accelerate the move to flexible electronics."

The paper, published in *Applied Physics Letters*, is "Ultralow wear of gallium nitride" (DOI: 10.1063/1.4960375). ■

Sol–gel products, applications, and markets

by Andrew McWilliams

The sol–gel technique enables processing of glasses and ceramics at low temperature in various desirable shapes, such as monoliths, films, fibers, or nanometer-sized powders. More importantly, the sol–gel technique makes it possible to combine and distribute organic molecules within inorganic oxide networks to form organic/inorganic hybrids. Such combinations form the basis for countless novel materials.

Besides abrasives, fibers, and antireflective coatings, other applications have reached the market, including catalysts, chromatography materials, aerogels, and several optical- and medical-related coatings and components. In the next five years other applications will be entering the marketplace.

The United States market for sol–gel products in 2013 was almost $600 million. This included prototype and production quantities as well as sales from companies providing contract research. The U.S. market was dominated by structural applications, which include abrasives, high-temperature-related applications, and coatings.

Table 1 shows BCC Research's estimate of the U.S. and global markets for sol-gel-derived products in 2013 through 2019.

Electronic and biomedical applications are the fastest growing segments of the U.S. market, with 2014–2019 CAGRs of 14.9% and 11.3%, respectively. The U.S. market for optical applications also is expected to grow rapidly, at a CAGR of 10.2% through 2019.

In terms of market share, the U.S. had about a 37% share of the world market in 2013 and is expected to increase this market share to almost 42% by 2019.

The U.S. has become a leader in sol–gel research and development, although historically Japan has been able to commercialize sol–gel technology and market products faster. Competition in Europe is mainly from Germany.

U.S. companies involved in sol–gel R&D range in size from small start-up companies to large Fortune 500 corporations. At least 50 U.S. companies are actively pursuing R&D, testing, and commercialization of sol-gel-derived products, either for internal use and/or for external markets. There also are many universities working in this area, funded by the National Science Foundation, companies, or government agencies, while others are looking for companies to license their technology.

U.S. market

BCC Research has followed the sol–gel products market for more than 15 years. BCC Research's 2002 report on the sol-gel industry estimated the 2001 market for sol-gel products at $232 million, which grew to an estimated $598.7 million by 2013 and is expected to reach approximately $1,052.1 million in 2019.

The markets for various sol–gel applications are shown in Table 2. BCC expects the fastest growth to be in electronic applications, followed by biomedical and optical applications.

Table 1. U.S. and world markets for sol–gel products, through 2019

	Market ($ millions)			CAGR 2014-2019 %
Market	2013	2014	2019	
U.S.	598.7	656.6	1,052.1	9.9
Total world market	1,618.7	1,741.6	2,532.1	7.8

Table 2. Forecast for U.S. sol–gel market by application, through 2019

	Market ($ millions)			CAGR 2014-2019 %
Application	2013	2014	2019	
Optical	155.0	170.0	276.0	10.2
Electronic	150.0	172.0	345.0	14.9
Structural	230.0	244.0	325.0	5.9
Chemical	48.0	53.0	76.0	7.5
Biomedical	15.7	17.6	30.1	11.3
Total	598.7	656.6	1,052.1	9.9

Table 3. Global forecast for the sol–gel products market by region, through 2019

	Market ($ millions)			CAGR 2014-2019 %
Region	2013	2014	2019	
U. S.	598.7	656.6	1,052.1	9.9
Japan	575.0	610.0	825.0	6.2
Europe	295.0	315.0	435.0	6.7
Rest of the world	150.0	160.0	220.0	6.6
Total	1,618.7	1,741.6	2,532.1	7.8

The largest share of the sol–gel market in 2013 was for structural applications, such abrasives, which had a 38.4% share of the total market in 2013. The share is projected to drop to 30.9% in 2019. Electronic applications will have a 32.8% share in 2019, growing from 25.1% in 2013.

World market

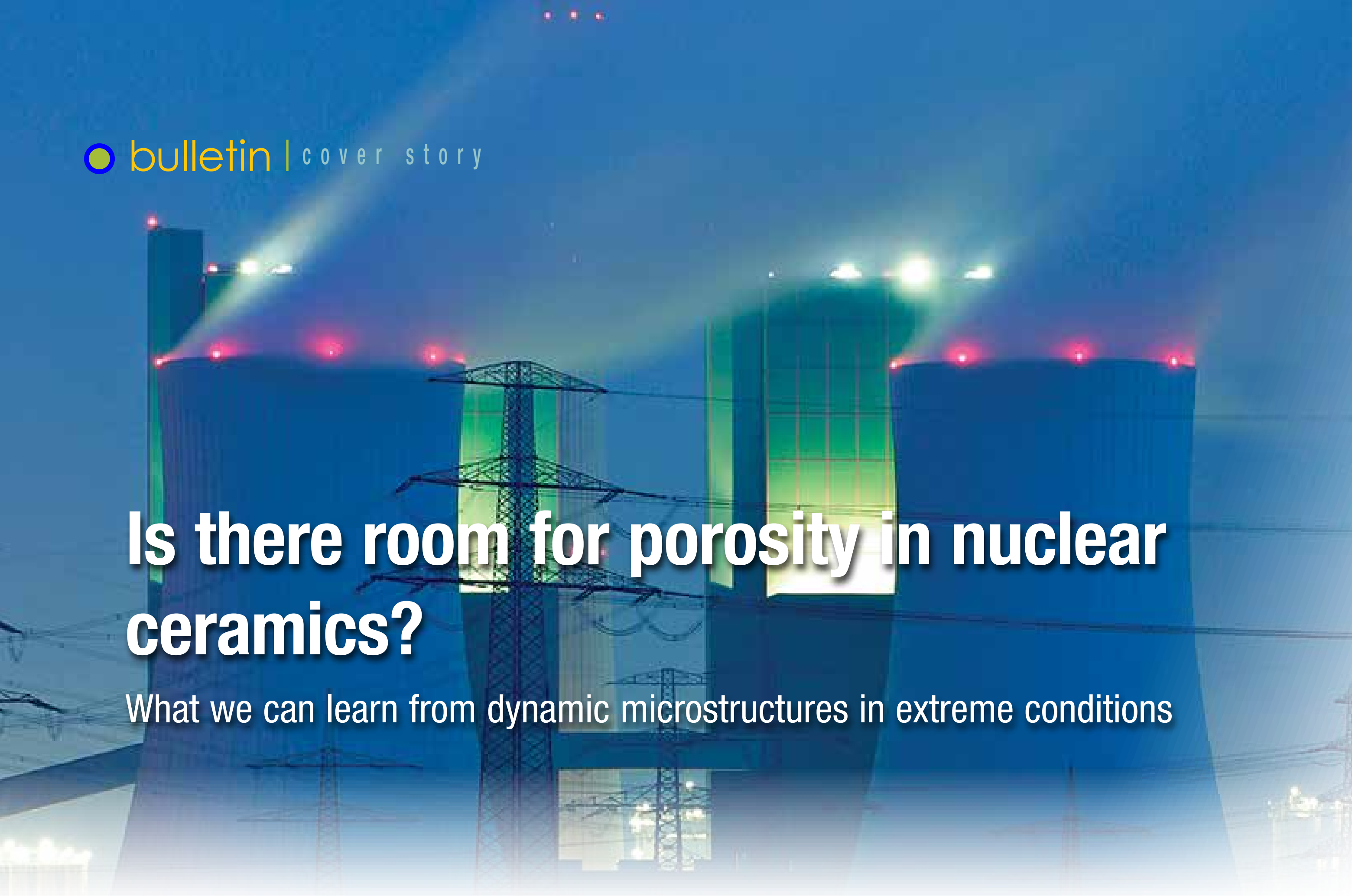
BCC Research's estimates of the world sol–gel market for 2013–2019 by region are shown in Table 3.

About the author

Andrew McWilliams is project analyst for BCC Research. Contact McWilliams at analysts@bccresearch.com.

Resource

A. McWilliams, "Sol–gel processing of ceramics and glass," BCC Research Report AVM016G, June 2014. www.bccresearch.com. ■



Is there room for porosity in nuclear ceramics?

What we can learn from dynamic microstructures in extreme conditions

Experimental approaches are needed to significantly explore the synergistic effects of radiation-enhanced diffusion and thermal gradients to enable the use of ceramics within a wide range of nuclear applications.

By Jessica A. Krogstad

Porosity is an inherent feature of ceramic materials that can be difficult to eliminate completely. However, there are many applications that capitalize on the relative stability of porous structures at elevated temperatures, ranging from catalysis to filtration to bone scaffolding to thermal barrier coatings.[1] Can nuclear ceramics become another example?

To date, porosity and void evolution within nuclear ceramics—fuels, cladding, or waste containment schemes—have been difficult to characterize and control, making it one of many consequences of extreme thermal, mechanical, and irradiative conditions. However, as mechanisms for radiation damage and recovery within ceramics continue to be clarified,[2] engineered porosity may allow for additional radiation tolerance.

Numerous strategies aimed at reducing radiation damage involve the incorporation of a high density of defect sinks, typically grain boundaries within single-phase or multiphase systems.[3] A pore surface is an infinite defect sink, provided that the defects have sufficient mobility to reach the pore and that the pore itself does not migrate, shrink, coarsen, or otherwise drastically change its morphology.

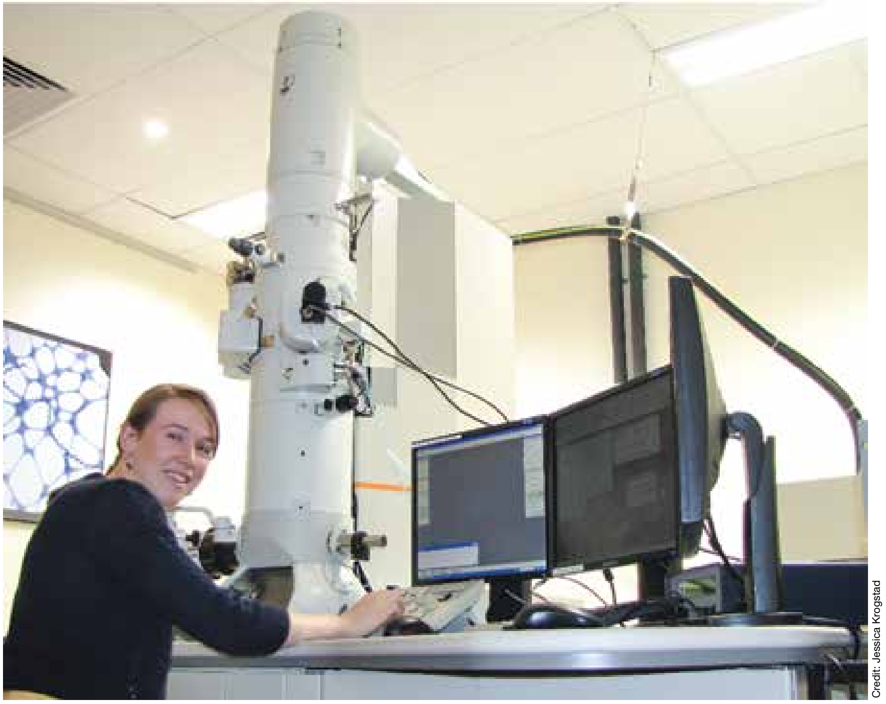
The rate of pore evolution in conventional ceramics is a strong function of surface energy and local diffusion phenomena. Yet, in an irradiative environment, diffusion behavior is significantly altered by heterogeneous radiation-induced defects and strong thermal gradients. Our ability to capitalize upon radiation tolerance provided by engineered microstructures, therefore, first requires a greater appreciation of these synergistic relationships.

Ceramics in the nuclear industry

Materials research for nuclear power generation has overwhelmingly focused on the behavior of metals and metallic alloys under irradiation. Continued emphasis on metallic systems is necessary for needed improvements and advancements in safety and efficiency. However, there are many areas wherein an improved understanding of irradiation damage in ceramic materials could lead to further developments. For example, silicon (or other metal) carbides have been proposed as cladding material for accident-tolerant concepts, oxide fuels (e.g., UO_2) are promising for high burn-up applications, numerous waste storage concepts rely upon inert ceramic matrices (e.g., pyrochlores, spinels, ZrO_2, or MgO), and ceramics have been proposed for use as first-wall materials in fusion reactors.[4]

In many of these applications, thermal and environmental stability relative to metallic counterparts make ceramics attractive options. However, they continue to be plagued by complications from low mechanical toughness and, in many cases, low (or otherwise incompatible) thermal conductivity. Both of these shortcomings can be at least partially attributed to porosity within the ceramic body.

Given that some porosity is unavoidable, improving the understanding of microstructural evolution assisted by radiation-enhanced diffusion and thermal or mechanical gradients may allow a paradigm shift away from tolerating porosity toward exploiting it—expanding the suitability and applications for ceramics within the nuclear industry and other radiation-sensitive fields.



Jessica Krogstad operates an electron microscope in the laboratory.

Irradiation damage within ceramics

The key microstructural features incorporated into metallic systems to mitigate radiation damage are susceptible to destabilization. Ceramics offer a promising, thermally stable alternative. However, differences in defect generation, mobility, and ultimate recovery within ceramic systems must first be appreciated before this enhanced thermal stability can be fully utilized.

Radiation damage in ceramics has been studied intensely in the interest of understanding UO_2 fuel lifecycles and opportunities for geological waste containment. Based on increased complexity of composition, structure, and bonding, ceramics exhibit more varied damage responses. Because of the directionality of bonding and Coulombic interactions, probability of displacement is different for each atom.

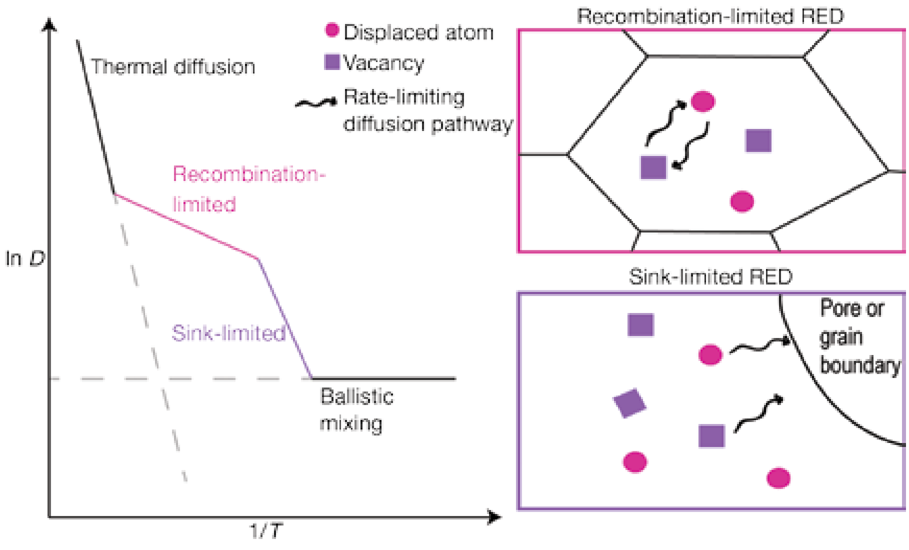


Figure 1. Schematic illustration of radiation-enhanced diffusion in ceramics, highlighting the intermediate temperature regime.

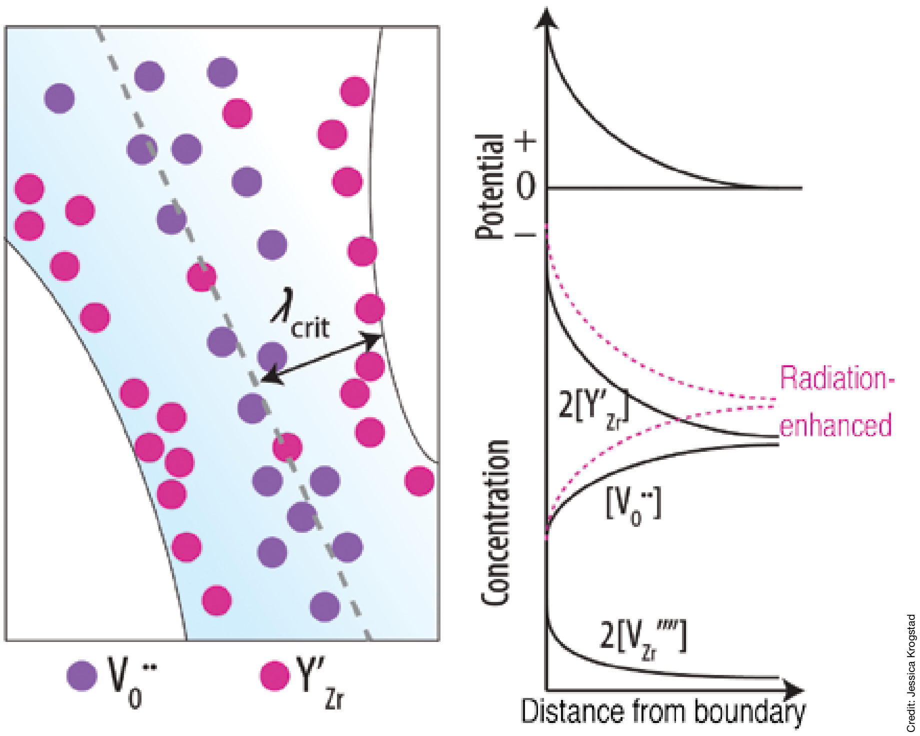


Figure 2. Schematic illustration of dopant segregation toward pore surfaces in response to the naturally depleted vacancy concentrations of these surfaces. Point defects are described using Kröger-Vink notation: $V_O^{\bullet\bullet}$, oxygen vacancy with a 2^+ charge; Y'_{Zr}, yttrium cation on a zirconium cation site with a 1^+ charge; V_{Zr}'''', zirconium cation vacancy with a 4^- charge. Critical diffusion distance (half the width of the strut) is labeled as λ_{crit}. A potential gradient is established because vacancy population in the grain interior differs from the surface, thus driving aliovalent dopants to segregate and satisfy a local space charge imbalance. Dopant segregation may reduce boundary mobility via a solute drag mechanism, thus stabilizing the microstructure.

The consequent aversion to antisite defects also means that the probability of Frenkel defect recombination is higher—affecting primary defect formation and secondary defect mobility.

Defect motion is possible at very low homologous temperatures, because Coulomb and strain potentials are primary driving forces for diffusion at these temperatures.[5] Given this added complexity, ionizing radiation may result in significant or very little damage accumulation depending on the specific material, type of radiation and energy, and temperature.[6] For example, Sickafus et al.[2] and later Debelle et al.[7] showed that damage accumulation in fluorite-structured yttria-stabilized zirconia (YSZ or FSZ) progressed in three stages: formation of isolated defects; rapid damage accumulation as the defects link or coalesce; and a final saturation stage where defects may even begin to disappear.

Saturation recovery behavior observed in YSZ (as well as other ceramics systems[6]) is largely attributed to radiation-enhanced diffusion (RED), a phenomenon that has received considerable attention within metals[8] and ceramics.[9,10] Figure 1 schematically depicts the conventional understanding of RED.

The intermediate temperature regime—below thermally activated diffusion but above pure ballistic mixing—includes sink- and recombination-limited kinetic regimes. In ceramics, the progression from sink- to recombination-limited behavior is opposite of that observed in metallic systems, with sink-limited kinetics observed at lower temperatures and recombination-limited kinetics dominating at higher temperatures.[4]

Van Sambeek et al.[9] argued that reordering of kinetic regimes is the result of inhomogeneous defect production or distribution and disparate defect mobilities in the vicinity of collision cascades—interstitials are excluded to the periphery, while vacancies form a loose cluster in the cascade center. This understanding makes it likely that the radiation tolerance for specific temperature ranges could be improved by chemistry or microstructural changes aimed at further suppressing the mobility of one defect type relative to the other.

Compatible routes for microstructural stabilization

Despite that the temperature regimes for sink- and recombination-limited kinetics in ceramics are opposite of those observed in metallic systems, similar radiation damage mitigation strategies, such as nanocrystallinity (increasing the density of grain-boundary sinks), have been used for ceramics. For example, Dey et al.[11] recently demonstrated that coarse-grain, fully-stabilized zirconia (specifically yttria-stablized) has a higher concentration of defect clusters when compared with nanograin specimens subject to the same level of irradiation. However, abnormal grain growth also is observed in nanograin specimens, suggesting that the stability of such a microstructure is insufficient to preserve radiation tolerance over extended periods.

Further, the interface between irradiated and unirradiated grains cannot accommodate local residual stresses from accelerated grain growth, resulting in intergranular fracture at the interface. Clearly, application of the conventional interfacial sink strategy commonly used in metallic systems must be modified to accommodate the unique characteristics of ceramic systems, specifically reduced toughness, and the role of charge balance in RED. The fundamental mechanism behind the microstructural destabilization is not immediately clear.

We hypothesize that increased boundary mobility results from radiation-induced disruption of localized space charge potentials. An example of this local desegregation is provided in Figure 2. Solute segregation to grain boundaries is commonly observed in ionic ceramics and has been attributed to reduced boundary mobility via a solute drag mechanism. However, under irradiation in specific temperature regimes, concentration of point defects is not homogeneous in the bulk and is a strong function of recombination rates.

If the kinetics are sink limited, recombination rates are high, and an oxygen vacancy gradient cannot be stabilized to enhance diffusion of boundary pinning solutes, resulting in rapid grain growth under irradiation. Following this logic and the currently accepted description of RED within ceramics, there should be an intermediate temperature range in which abnormal grain growth is limited.

Solute segregation and resulting microstructural changes are not temperature independent. Yet, even in the absence of an external gradient, low thermal conductivity of most insulating ceramics could easily result in an internal thermal gradient, as is commonly observed for UO_2 fuel pellets. The extent and scale over which a thermal gradient is experienced (hundreds of micrometers to millimeters) can be orders of magnitude greater than the scale of defect damage accumulation and recovery previously described.

This has two consequences: the defect type and potential recovery mechanisms may vary significantly across a specimen based on different kinetic regimes accessible for a given temperature; and the thermal gradient also contributes to a gradient in chemical potential, thereby driving mass transport across large distances—an effect known as thermally induced mass transport (TIMT, but also referred to as the Soret effect or thermophoresis).

In the case of the former, presence of the thermal gradient is not anticipated to influence defect formation and migration around a singular cascade event, because local temperature over the scale of defect mobility will be effectively homogeneous. However, in the latter case, mobility of voids and pores toward the hot side has potential to expand the recombination-limited kinetic regime by increasing density and strength of local defect sinks over time, thereby stabilizing and improving radiation tolerance of the material with increasing exposure (Figure 3).

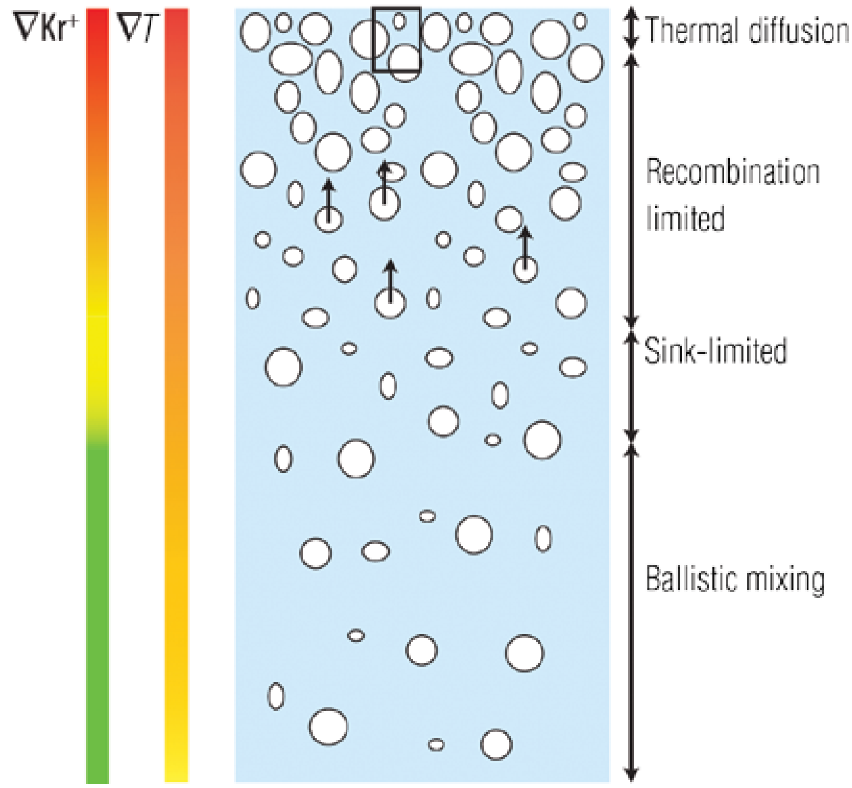


Figure 3. Both thermal and radiation gradient from a representative Kr^+ ion are superimposed on a schematic porous microstructure. Such a strong thermal gradient across an irradiated ceramic body will have two consequences: different RED mechanisms will be active in different parts of the component, which may alter microstructural evolution; and the thermal gradient (∇T) may result in a chemical potential gradient driving mass transport over relatively large distances. Thermally induced mass transport typically forces porosity toward the hotter side of the gradient and will contribute to microstructural dynamics.

Looking forward

The thermal and structural stability of ceramics are ideal for extreme conditions associated with nuclear power generation, waste handling, or even deep space thermal protection schemes. Radiation tolerance within ceramics often rely on similar mechanistic approaches applied to metallic systems. However, the complexity of diffusion mechanisms caused by the covalent–ionic nature of bonding as well as other physical properties, including thermal conductivity, may significantly alter routes by which radiation tolerance of ceramics can be enhanced or tailored for specific applications.

This is an extremely challenging problem that the community has conventionally approached by isolating specific aspects of the extreme environment, such as studying the impact of thermal gradients in isolation from radiation damage. This approach has established a wide body of literature characterizing the ceramic-specific nature of radiation damage and radiation-enhanced diffusion, but these individual components may overlook important synergistic contributions to microstructural evolution in irradiative environments.

The modeling community has begun to tackle integration of these contributions, but it has been limited by the paucity of scale/temperature/dosage-appropriate experimental data necessary to establish physics-based models that are properly benchmarked. Experimental approaches that are thoughtfully designed for eventual integration with state-of-the-art modeling efforts are necessary to answer outstanding fundamental questions.

Given the complexity of these experiments, our forward-looking approach hinges upon several strategic collaborations. Specifically, our efforts to carefully tailor the microstructure of fully-stabilized zirconia (grain size, pore size, and distribution) will enable in situ observation of damage creation and recovery as a function of temperature and critical microstructural dimensions (e.g., diffusion distances to free surfaces or grain boundaries) through collaborations with the Center for Integrated Nanotechnologies and the Ion Radiation Laboratory at Sandia National Laboratory (Albuquerque, N.M.).

Contributions to microstructural evolution from thermal gradients can be evaluated by unique, in-house diffusion couple experiments within laser-established thermal gradients and in situ synchrotron X-ray tomography (at the Advanced Photon Source at Argonne National Laboratories (Lemont, Ill.)) with postmortem spatially resolved chemical analysis. With the support of a DOE Early Career Award (Office of Science, Basic Energy Science Award No. DE-SC0015894), we will integrate these experimental approaches over the next five years to truly explore the synergistic effects of radiation-enhanced diffusion and thermal gradients—hopefully enabling the introduction or expansion of ceramics within a wide range of nuclear applications.

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References

[1]P. Colombo, "Engineering porosity in polymer-derived ceramics," *J. Eur. Ceram. Soc.*, **28** [7] 1389–95 (2008).

[2]K.E. Sickafus, H. Matzke, T. Hartmann, K. Yasuda, J. A. Valdez, P. Chodak III, M. Nastasi, and R.A. Verrall, "Radiation damage effects in zirconia," *J. Nucl. Mater.*, **274** [1] 66–77 (1999).

[3]W. Han, M.J. Demkowicz, N.A. Mara, E. Fu, S. Sinha, A.D. Rollett, Y. Wang, J.S. Carpenter, I.J. Beyerlein, and A. Misra, "Design of radiation tolerant materials via interface engineering," *Adv. Mater.*, **25** [48] 6975–79 (2013).

[4]D. Simeone, J.M. Costantini, L. Luneville, L. Desgranges, P. Trocellier, and P. Garcia, "Characterization of radiation damage in ceramics: Old challenge new issues?" *J. Mater. Res.*, **30** [9] 1495–515 (2015).

[5]F. Clinard and L.W. Hobbs, "Radiation effects in non-metals"; pp. 387–472 in *Physics of Radiation Effects in Crystals, Part II*. Elsevier-North Holland, Amsterdam, Netherlands, 1986.

[6]S. Zinkle, V. Skuratov, and D. Hoelzer, "On the conflicting roles of ionizing radiation in ceramics," *Nucl. Instr. Meth. Phys. Res. B (Beam Interactions with Materials and Atoms)*, **191** [1] 758–66 (2002).

[7]A. Debelle, S. Moll, B. D´ecamps, A. Decl´emy, L. Thom´e, G. Sattonnay, F. Garrido, I. Jozwik, and J. Jagielski, "Ability of cubic zirconia to accommodate radiation damage," *Scr. Mater.*, **63** [6] 665–68 (2010).

[8]G.J. Dienes and A. Damask, "Radiation-enhanced diffusion in solids," *J. Appl. Phys.*, **29** [12] 1713–21 (1958).

[9]A.I. Van Sambeek, R. Averback, C. Flynn, and M. Yang, "Radiation-enhanced diffusion in MgO"; p. 293 in *MRS Proceedings*, Vol. 373. Cambridge University Press, Cambridge, U.K., 1994.

[10]H.K. Pappas, B.J. Heuser, and M.M. Strehle, "Measurement of radiation-enhanced diffusion of La in single-crystal thin-film CeO_2," *J. Nucl. Mater.*, **405** [2] 118–25 (2010).

[11]S. Dey, J.W. Drazin, Y. Wang, J.A. Valdez, T.G. Holesinger, B.P. Uberuaga, and R.H. Castro, "Radiation tolerance of nanocrystalline ceramics: Insights from yttria-stabilized zirconia," *Sci. Rep.*, **5** [Article No. 7746] (2015).

First static and dynamic analysis of 3-D-printed sintered ceramics for body armor applications

by Tyrone L. Jones, Christopher S. Meredith, and Benjamin Becker

Initial ballistic tests show that additive manufacturing is a feasible solution to improve agility, responsiveness, and customization of ceramic armor.

Traditional manufacturing of ceramics used for ballistic impact protection is limited by long lead times, inability to fabricate complex geometries, and expensive components. Ceramic 3-D printing offers engineering-grade components in approximately 90% less time than traditional ceramics manufacturing. Typical turnaround can be days, instead of weeks, depending on the part's complexity. This enables faster time to market and allows for more iterations during the design process, resulting in a better end-product. Additionally, 3-D-printed parts can have a higher degree of complexity for weight reduction while saving on the cost of the part, because less material is required.

The U.S. Army Research Laboratory (Adelphia, Md.) collaborated with HotEnd Works LLC (Oberlin, Ohio) to evaluate the feasibility of producing ceramic armor by 3-D printing. This report examines static and quasi-static parameters (including density, hardness, and fracture strength), semi-infinite penetration performance, and postimpact fracture profiles of 3-D-printed sintered alumina as compared with baseline performance of traditionally sintered alumina.

Although typical U.S. body armor tends to use higher-performance ceramics (such as boron carbide), this program examined 8-mm-thick alumina tiles as the initial, cost-effective material for evaluation of depth of penetration (DOP). Additionally, we used 6-mm- and 8-mm-thick alumina to develop a deeper understanding of the stages of ceramic failure caused by a small steel rod at low-speed impact. We obtained rod-shaped specimens of alumina, nominally 3 mm in diameter and 50 mm in length, to quantify static and quasi-static material properties. The experiments evaluated the following ceramics:

- Traditionally manufactured, sintered alumina AD-995 (also called CAP3) from CoorsTek (Golden, Colo.); and
- 3-D-printed sintered alumina from HotEnd Works (HEW).

Processing 3-D-printed ceramic armor

Manufacturing advanced ceramics typically involves methods such as die pressing or isopressing of ceramic powder that has been combined with binders and plasticizers.[1] To form powder to the desired shape, manufacturers must create tooling that replicates component geometry. If the geometry of a component is beyond a basic shape—such as a rectangle, square, or cylinder—secondary green machining using a computer numerical control mill or lathe is required.

Additive manufacturing of advanced ceramics differs from traditional manufacturing processes mostly in terms of formation of the initial green part. HotEnd Works uses pressurized spray deposition (PSD), which mixes a proprietary blend of advanced ceramic raw material (ceramic powder) with a unique polymeric binder (support material). The polymeric support material serves as a temporary support structure during part formation to accommodate overhangs and other intricate features.[2]

A typical PSD setup deposits materials through high-preci-

Capsule summary

LIMITATIONS

Traditional manufacturing of ceramic armor is limited in time, design, and cost. Additive manufacturing can offer solutions to all of these limitations—but is it feasible?

TAKING A SHOT

A collaboration evaluated the ability to produce 3-D-printed ceramic armor and tested how well these additively manufactured materials held up in ballistic tests.

THE TAKEAWAY

Additive approaches to manufacturing ceramic armor are feasible and offer benefits of customization, improved theater agility, and rapid responsiveness. However, further work is needed to adequately qualify and improve 3-D-printed ceramic armor.

sion deposition nozzles that use mechanical shaping methods to allow patterns of 0.127–3.810 mm in diameter. After the first layer is complete, the process initiates formation of the next layer. Tooling fabrication as well as green machining can be omitted because of the geometric complexity that is possible with PSD.

After forming, the component is thermally debinded followed by densification in a traditional electric or gas furnace. Because shrinkage occurs with additive processing, postprocessing, such as diamond grinding, may be required for components with tight tolerance requirements in terms of flatness or other parameters.

We designed DOP or residual penetration experiments to determine the relative ballistic performance of ceramic materials.[3] DOP testing fires a projectile into a ceramic tile attached to a semi-infinite-thick metal plate, such that the projectile penetrates through the ceramic tile and into the metal plate without deforming the back surface. These experiments avoid the fundamental problem of V_{50} (the velocity at which 50% of a type of projectile is expected to perforate a target) ballistic dependence on armor design (e.g., front-to-back plate ratio and material), require fewer shots than V_{50} tests, and have a sensitivity equivalent to that of other ballistic test methods.[4]

Change in penetration into the metal plates provides a comparison by which to rank performance of ceramic materials. Figure 1 illustrates the target configuration used for these experiments. The target consisted of a 90-mm × 90-mm ceramic tile at a nominal thickness of 8 mm, backed by two aluminum alloy 6061 plates (AA6061, MIL-DTL-32262) with a thickness of 50.8 mm each.[5] We used an epoxy resin (optical aliphatic polyether polyurethane, Dureflex® Grade A4700, Bayer, South Deerfield, Mass.) to attach each tile to the front surface of the first 50.8-mm plate.

We used AA6061 because it is a well-characterized and readily available residual penetration material, and we expected that aluminum plates would provide better resolution than steel backer plates. We used no cover plates.

We conducted three ballistic impact experiments for each alumina manufacturing process at the U.S. Army Research Laboratory. Tests used projectiles of copper-jacketed 12.7 mm APM2, which includes a hardened steel core penetrator with a length of 47.6 mm, a diameter of 10.87 mm, and an aspect ratio of 4. Projectiles had a nominal weight of 46 g and core density of 7.85 g/cm^3.

Ballistic tests used a nominal impact velocity of 848 m/s, although some shots varied from 824 to 872 m/s. This variability could result from interior barrel conditions, variations in APM2 material properties, or gun operator influence, such as projectile powder measurements. We intentionally chose this impact velocity to produce a range of measureable residual penetrations while being consistent with real-world ballistic impact conditions. The schematic in Figure 2 shows how residual penetration was measured.[3]

We performed additional experiments with a high-speed camera to qualitatively assess fracture propagation of the alumina caused by low-speed impact by a small rod-shaped projectile. These

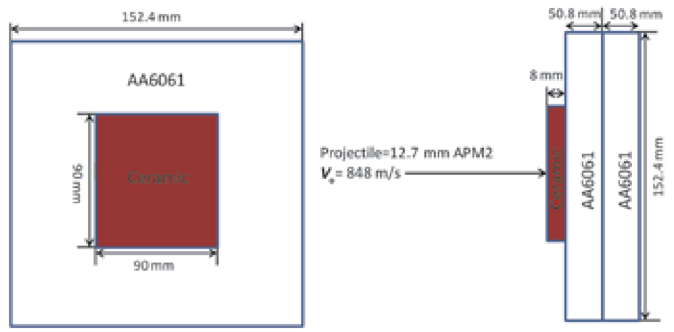


Figure 1. Sketch and dimensions of ceramic laminate.

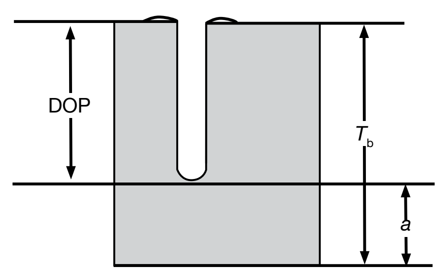


Figure 2. Strategy for measurement of residual penetration in ballistic tests. Measurement of *a* avoided errors that could be caused by deformation of the aluminum block around the cavity entrance.[6]

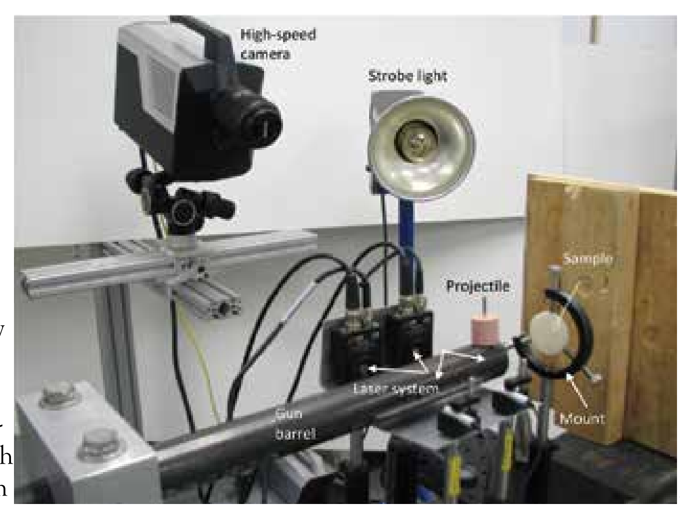
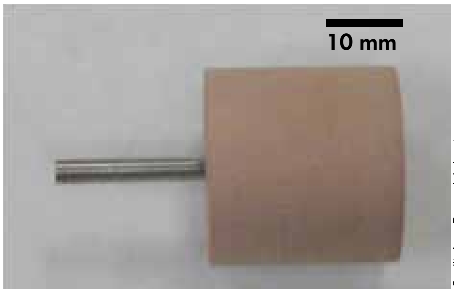
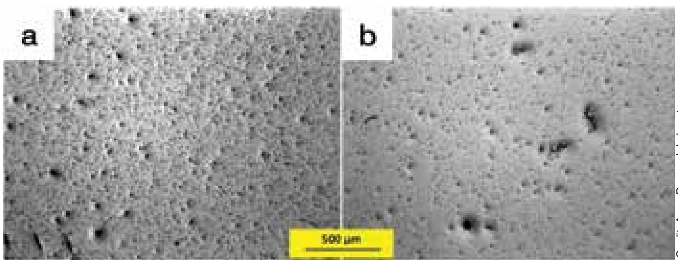


Figure 3. Experimental setup for recording fracture of samples during ballistic tests.



Credit: Army Research Laboratory

Figure 4. A rod projectile attached to a sabot, which properly positioned the rod within the gun barrel.



Credit: Army Research Laboratory

Figure 5. Representative microstructure of (a) CoorsTek AD-995 manufactured by isopressing and sintering and (b) HotEnd Works alumina manufactured by pressurized spray deposition and sintering.

Credit: Army Research Laboratory

Figure 6. Residual penetrator after impact of shot No. 13159 against CoorsTek alumina AD-995.

Credit: Army Research Laboratory

Figure 7. Residual penetrator after impact of shot No. 13161 against HotEnd Works alumina.

experiments impacted 6- and 8-mm-thick tiles at approximately 210 m/s because of limitations of the gas gun. Thus, direct comparisons with ballistic tests may be dubious.

Figure 3 shows the experimental setup. The gun fired a right-circular-cylinder steel-rod projectile with a diameter of 3.18 mm and a length of 35 mm, which was connected to a machinable foam sabot that held the rod as it accelerated down the larger-diameter gun barrel (Figure 4). The projectile, made of hardened M2 steel with a Rockwell C (R_C) hardness of 62, weighed 7.5 g, including the weight of the sabot. The projectile hardness was similar to that of an APM2 projectile.

Table 1. Properties of CoorsTek and HotEnd Works alumina samples

Material	Density (g/cm^3)	Flexure strength (MPa)	Knoop hardness (GPa)
CoorsTek AD-995	3.92 ± 0.00	162 ± 54	13.2 ± 1.3
HotEnd Works	3.89 ± 0.08	130 ± 38	14.7 ± 1.0

Comparison of performance of HotEnd Works 3-D-printed alumina with CoorsTek AD-995

Prior to examining ballistic behavior, we determined density, hardness, quasi-static flexural strength, and microstructure of each rod-shaped alumina specimen, nominally 3 mm in diameter and 50 mm in length. The Archimedes method provided density determinations, ASTM C1684 guidelines determined flexure strength,[7] and ASTM C1326 guidelines determined Knoop Hardness at 2,000 g.[8] Table 1 summarizes these data. Figure 5 shows microstructure of each alumina sample.

Alumina materials appeared similar based on these properties. The CoorsTek sample had seemingly higher pore density, but the HotEnd Works sample had larger maximum pore size, with some cracks connecting neighboring pores. The HotEnd Works alumina was 0.03 ± 0.08 g/cm^3 less dense than the CoorsTek alumina.

We fired a few shots into monolithic AA6061 plates at velocities of 824–872 m/s to quantify DOP without the ceramic.[9] Deceleration was the primary penetrator defeat mechanism of AA6061 over the velocity regime. We then measured residual penetration values and plotted them as a function of striking velocity to produce a baseline curve. Linear regression of the reference data yielded the following equation:

$$\mathrm{DOP} = 0.1959V_{\text{X-ray}} - 84.406 \qquad (1)$$

where $V_{\text{X-ray}}$ is striking velocity quantified using X-ray measurements. A square of the correlation coefficient (R^2) of 0.946 indicates that this curve is a reasonable approximation. For example, an experimental impact velocity of 848 m/s would be expected to result in a DOP of 81.73 mm. For these experiments, this is the DOP baseline for AA6061.

As previously described, we fabricated ceramic target assemblies for all materials. In general, we evaluated three tiles of equal thickness (or areal density) for each material. To adjust for variations in the actual strike velocity, we normalized all residual penetration values to a striking velocity of 848 m/s based on the empirical fit shown in Eq. (1). The correction was made as follows:

$$\text{Corrected DOP} = \text{Measured DOP} + [0.1959(848 - V_{\text{X-ray}})] \qquad (2)$$

This technique is valid provided that a significant amount of the penetrator reaches the backup plate, the correction is relatively small, and the penetrator defeat mechanism has not significantly changed with velocity.[9] In support of this assumption, observations of the size and shape of impact showed no significant differences in penetrator cavity for impact velocity variations.

We obtained data for alumina tiles at a nominal thickness of 8 mm. Table 2 lists ballistic impact measurements. We measured an average DOP with correction of 14.43 mm with a standard deviation of 3.01 mm for CoorsTek AD-995. We measured an average DOP with correction of 24.01 mm with a standard deviation of 2.06 mm for HotEnd Works alumina. The difference between HotEnd Works and CoorsTek aluminas, 9.58 mm, is equivalent to about three-quarters of the projectile diameter or one-sixth of the projectile length.

In these limited experiments, CoorsTek AD-995 tiles caused

Table 2. Ballistic impact measurements for alumina tiles

Shot No.	Alumina type	Striking velocity (m/s)	Pitch (deg)	Yaw (deg)	Total yaw (deg)	DOP (mm)	DOP_{corr} (mm)
13157	CoorsTek	840	0.47	–0.62	0.78	16.00	17.56
13158	CoorsTek	843	0.61	–0.39	0.72	13.21	14.18
13159	CoorsTek	846	0.26	–0.48	0.54	11.18	11.56
13160	HotEnd Works	860	0.51	–0.50	0.72	28.70	26.34
13161	HotEnd Works	850	0.31	–0.58	0.65	23.62	23.22
13162	HotEnd Works	850	0.32	–0.46	0.56	22.86	22.46

more damage to the penetrator than HotEnd Works alumina tiles. Interestingly, the DOP for each ceramic laminate increased as yaw increased. More experiments are needed to determine if this response is a coincidence or a phenomena.

The penetrator underwent two failure mechanisms, fragmentation and erosion, when it impacted Coorkstek AD-995 tiles (Figure 6). However, the penetrator underwent only erosion when it impacted HotEnd Works alumina tiles (Figure 7).

We measured recovered residual projectile cores and calculated curve fits for these data (Figures 8 and 9), although it is unlikely that all debris was recovered because projectiles shattered and eroded on impact. Nonetheless, we measured length of the largest piece as the residual penetrator length. We did not measure length of shot No. 13159 because only small fragments of the projectile were recovered. However, we did measure mass of these recovered core fragments. The unaltered core was added to the figure as a point of reference at the striking velocity of 825 m/s.

We optically examined postexperimental targets for ceramic failure analysis. CoorsTek and HotEnd Works alumina began failing with tensile fracture, then continued into comminution to dissipate energy of the penetrator. Both types of alumina exhibited similar extents of ceramic damage. Typical ceramic failures are shown in Figures 10 and 11. However, the DOP cavity profile into AA6061 plates distinctly differed.

During ballistic impact, CoorsTek AD-995 alumina typically fractured the penetrator into two large pieces and some small chips before starting the erosion process. As a result, the AA6061 plate contained two projectile canals. The HotEnd Works alumina did not fracture but eroded only the penetrator. As a result, the HotEnd Works plate contained one residual penetrator canal.

Because this study used AA6061 as the reference material, Eq. (3) provided a coefficient of performance (C_p) of the ceramics compared with the reference material:

$$C_p = (\ _{AA6061})\frac{DOP_{Base\_AA6061}\quad DOP_{Corr\_AA6061}}{AD_{Ceramic}} \tag{3}$$

where DOP_{Base_AA6061} is the average expected residual depth of penetration into bare aluminum at 848 m/s; DOP_{Corr_AA6061} is the residual DOP into AA6061 after perforating the ceramic tile, corrected for variations in striking velocity; and $AD_{ceramic}$ is the areal density of the ceramic. In these tests, DOP_{Base_AA6061} was 81.73 mm, $AD_{AD\text{-}995}$ was 31.36 kg/m^2, $AD_{HEW\_Alumina}$ was 31.12 kg/m^2, and ρ_{AA6061} was 2.70 g/cm^3.

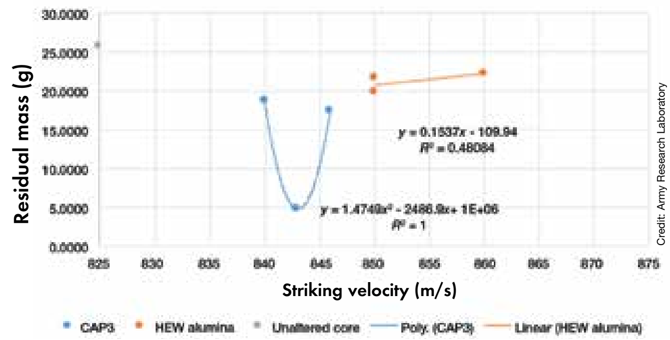


Figure 8. Analysis of residual penetrator with residual penetrator mass of 12.7-mm APM2 into AA6061 as a function of striking velocity.

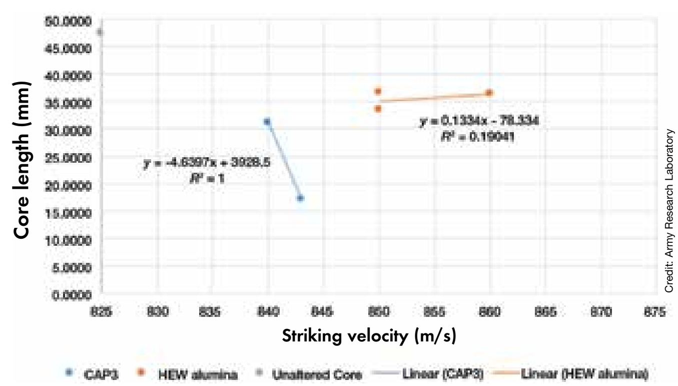


Figure 9. Analysis of residual penetrator with residual penetrator length of 12.7-mm APM2 into AA6061 as a function of striking velocity.

Figure 10. CoorsTek AD-995 alumina tile after impact. The left image shows the complete sample, whereas the right displays a cross section of the same sample.

Figure 11. HotEnd Works alumina tile after impact. The left image shows the complete sample, whereas the right displays a cross section of the same sample.

For each alumina sample, we calculated a C_p value, which provides a relative comparison of the ceramic with AA6061 (i.e., a C_p of 5 means the ceramic is 5 times more weight-effective than AA6061) (Table 3). Figure 12 illustrates a ceramic performance map, which clearly shows that CoorsTek alumina has superior performance than HotEnd Works alumina.

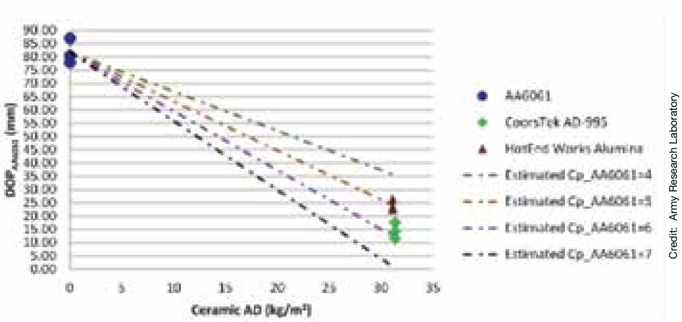


Figure 12. Ceramic performance map comparing AA6061, CoorsTek AD-995, and HotEnd Works alumina samples.

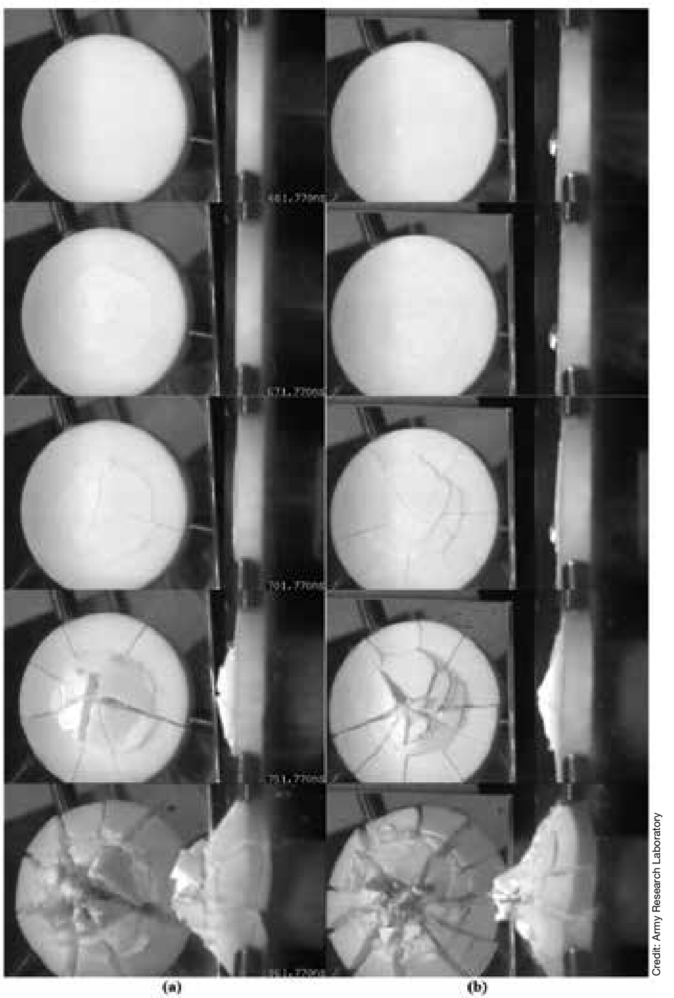


Figure 13. Progressive fracture of 6-mm alumina samples from (a) CoorsTek and (b) HotEnd Works.

Table 3. Comparative performance of ceramics

Experiment	Coefficient of performance (C_p) CoorsTek AD-995	HotEnd Works alumina
1	5.52	4.81
2	5.82	5.08
3	6.04	5.14

Figure 13 shows progressive failure through brittle fracture of the 6-mm-thick ceramic samples with no backing plate. CoorsTek and HotEnd Works alumina samples

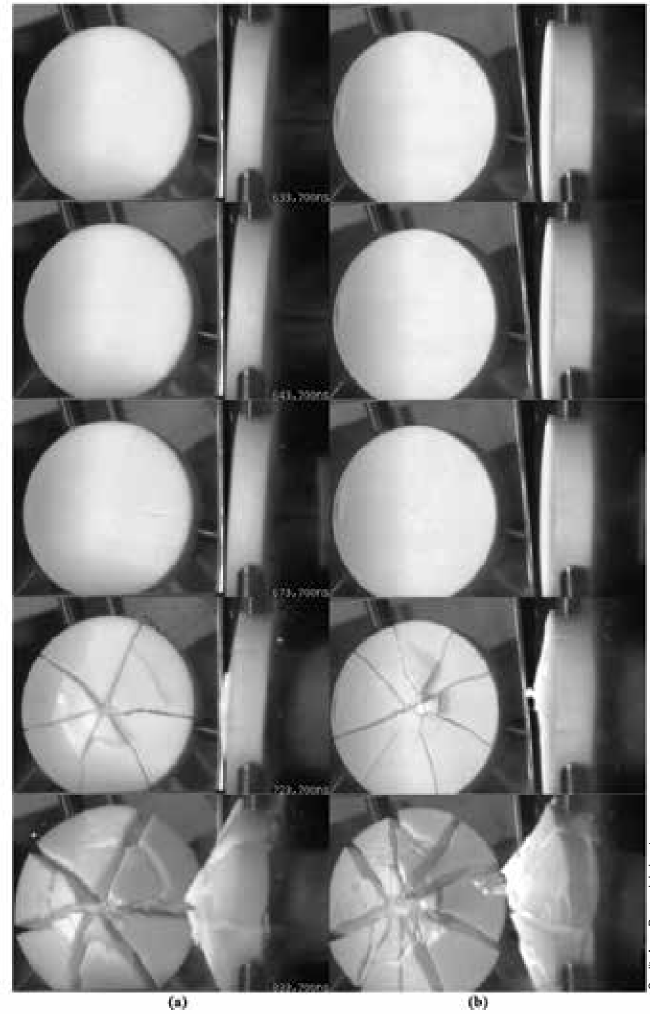


Figure 14. Progressive fracture of 8-mm alumina samples from (a) CoorsTek and (b) HotEnd Works.

underwent projectile velocities of 206 and 214 m/s, respectively. The series of images shows the samples immediately before impact and 10, 40, 90, and 200 µs after impact. The samples showed similar overall features—concentric cracks first appear several microseconds after impact, and then radial cracks appear.

Concentric cracks at the back face probably form a cone crack through the thickness of the sample, but it cannot be seen because the alumina is opaque. After 90 µs, concentric cracks have clearly coalesced, because the rod has pushed out inner material to a greater extent than material near the outer edge. At 200 µs, the samples appear similar, although the HotEnd Works alumina is slightly more fragmented.

The biggest difference between the two materials is that the CoorsTek sample has less radial cracks than the HotEnd Works 3-D printed sample. Additionally, the area within concentric cracks of the HotEnd Works alumina has further cracked and started to break up after 90 µs, whereas the same region of the CoorsTek alumina shows no further cracks. Table 4 shows a summary of the dynamic failure modes.

Figures 13 and 14 show failure progression of 6- and 8-mm-thick samples, respectively, with projectile velocities of 216 and

224 m/s immediately before impact and 10, 40, 90, and 200 µs after impact. As before, the two alumina samples display overall similar features. The 8-mm-thick samples show very few concentric cracks following impact, and radial cracks are the first damage to appear.

As expected, it takes longer for cracks to emerge on the backside of samples, and thicker samples have less damage at the same time after impact. In addition, the CoorsTek alumina has fewer radial cracks than the HotEnd Works alumina sample. At a couple hundred microseconds after impact, the HotEnd Works alumina shows greater fragmentation. Table 5 shows a summary of the dynamic failure modes.

Future armor

This program was a preliminary investigation into the viability of using a 3-D-printed alumina ceramic for body armor applications. Initial results show the feasibility of additive approaches to manufacturing ceramic armor, which could lead to customized armor for soldiers, vehicles, and equipment. In addition, additive manufacturing of armor in the field could improve theater agility and responsiveness.

However, although the results show feasibility, they also point to further work that needs to be done. Specifically, the coefficient of performance showed that CoorsTek alumina AD-995 was 13% more efficient against ballistic penetration than HotEnd Works 3-D-printed alumina tiles. The low-velocity, rod-impact experiments into unbacked ceramic disks provide initial clues as to why.

These exploratory experiments show there is a critical thickness limit at a given velocity that is needed to simulate the realistic failure modes of the alumina ceramic under ballistic impact. In 6-mm-thick ceramic tiles, the rod impact exhibited more plugging mode failure, which is not desirable in conventional armor. In 8-mm-thick ceramic tiles, the HotEnd Works alumina had a greater number of radial cracks and fragmented to a greater extent than the CoorsTek alumina. Further, the disk diameters were adequate for low-velocity rod impact.

Next, the 3-D deposition process needs to be improved to reduce pore size and increase flexural strength of the 3-D-printed ceramic material. Improvements to the sintering method will be the critical correlation to improve ceramic failure mechanisms and penetrator failure mechanisms during low-velocity rod impacts and ballistic penetrator impacts.

Further, Hugoniot shock pressure limit experiments are imperative. At pressures just above the elastic limit—called the Hugoniot elastic limit (HEL)—a shock wave is split into a two-wave structure by the HEL, which is determined by strength.[10] Up to the HEL, a single, elastic, supersonic shock wave propagates. At higher pressures, shock compression causes plastic deformation as well.

A solid just above its HEL is softer (i.e., more compressible) than it is below its HEL. By measuring time-resolved shockwave profiles, we can derive HELs, mechanical constitutive properties, and equations of state,[10] which then allow us to analytically predict quantification of the fracture behavior between ceramics manufactured by various methods. Successful implementation of these steps, including initial correlation between these dynamic variables and manufacturing process variables, are expected to elevate the 3-D-printed ceramic static, quasi-static, and dynamic properties to match, or exceed, those of conventionally sintered alumina. ■

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The authors acknowledge assistance from Jeffrey Swab in characterization of the initial material properties.

About the authors

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References

[1]A. King, *Ceramic technology and processing*, 1st ed. William Andrew Publishing, Norwich, N.Y., 2002.

[2]B. Becker, "Additive changes to advanced ceramics," *Ceram. Ind.*, Apr. 10, 2014 (accessed May 10, 2016) http://www.ceramicindustry.com/articles /93848-additive-changes-to-advanced-ceramics.

[3]P. Woolsey, D. Kokidko, and S. Mariano, "Alternative test methodology for ballistic performance ranking of armor ceramics," Report No. MTL-TR 89-43, Army Materials Technology Laboratory, Watertown, Mass., 1989.

[4]"V50 ballistic test for armor," Report No. MIL-STD-662F, Army Research Laboratory, Aberdeen Proving Ground, Md., Dec. 18, 1997.

[5]"Armor plate, aluminum alloy, unweldable applique 6061," Report No. MIL-DTL-32262, Army Research Laboratory, Aberdeen Proving Ground, Md., July 2007.

[6]T. Jones, "Investigation of the kinetic energy characterization of advanced ceramics," Report No. ARL-TR-7263, Army Research Laboratory, Aberdeen Proving Ground, Md., April 2015.

[7]ASTM C1684, "Standard test method for flexural strength of advanced ceramics at ambient temperature-cylindrical rod strength," ASTM International, West Conshohocken, Pa., 2008.

[8]ASTM C1326, "Standard test method for Knoop indentation hardness of advanced ceramics," ASTM International, West Conshohocken, Pa., 2013.

[9]T. Jones, "Investigation of the kinetic energy characterization of advanced ceramics," Report No. ARL-TR-7263, Army Research Laboratory, Aberdeen Proving Ground, Md., April 2015.

[10]W.J. Nellis, "Dynamic compression of materials: Metallization of fluid hydrogen at high pressures," *Rep. Prog. Phys.*, **69** [5] 1479 (2006). ■

Table 4. Dynamic failure modes of 6-mm-thick alumina disks

Time interval (µs)	CoorsTek AD-995	HotEnd Works 3-D printed alumina
Preimpact, 0	Disk intact	Disk intact
Postimpact, 10	Radial-forming cracks	Radial-forming cracks
Postimpact, 40	Longitudinal cracks forming	Longitudinal cracks forming
Postimpact, 90	Seven longitudinal cracks that run from center to edge of disk; plugging with discrete fragments forming	Nine longitudinal cracks that run from center to edge of disk; plugging with comminution process beginning
Postimpact, 200	Fragmentation process is converting to comminution process	Comminution process is occurring

Table 5. Dynamic failure modes of 8-mm-thick alumina disks

Time interval (µs)	CoorsTek AD-995	HotEnd Works 3-D printed alumina
Preimpact, 0	Disk intact	Disk intact
Postimpact, 10	Disk intact	Disk intact
Postimpact, 40	Longitudinal cracks forming	Longitudinal cracks forming
Postimpact, 90	Six longitudinal cracks that run from center to edge of disk; plugging mode beginning; discrete fragments forming	Eight longitudinal cracks that run from center to edge of disk; no plugging mode; comminution process is beginning
Postimpact, 200	Fragmentation process is transforming into comminution process	Comminution process is occurring

5 new National Science Foundation CAREER Ceramic awardees: Class of 2016

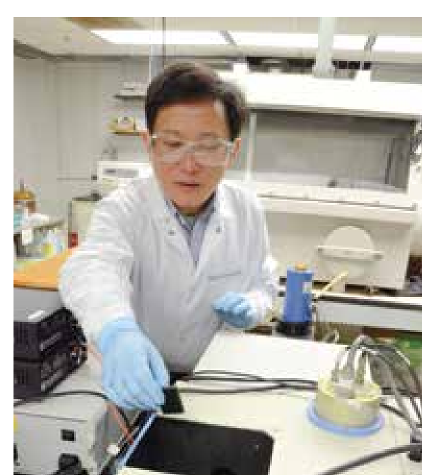
Five junior faculty showcase the research and engagement activities that make them exemplary teachers–scholars.

By Lynnette D. Madsen

The National Science Foundation's Faculty Early Career Development (CAREER) program supports junior faculty who exemplify the role of teachers–scholars by performing and integrating excellent research and education. I started writing this series of articles about the NSF CAREER awardees in 2009.[1–7] Why? To give these young professors and their work greater visibility in the broad ceramics and glass community and to encourage academic careers of ceramic researchers and educators. We need to advance fundamental research in ceramics and glass while educating the next generation. Therefore, I am honored to introduce you to the five 2016 CAREER awardees from the Ceramics Program of the Division of Materials Research at NSF.

Award 155409—Mechanism for controlling ionic valences in transition-metal-doped laser materials

SCIENCE: Yiquan Wu at Alfred University (Alfred, N.Y.) is working to understand formation, stability, and manipulation of defects in optoelectronic materials. His research may open new avenues for utilizing dopants to design and synthesize optical and photonic materials with new functionalities. Wu will address the fundamental materials science questions associated with using off-valence ion substitution to control the valency of dopant ions in laser and optoelectronic materials by developing a



Credit: Alfred University

Yiquan Wu in his laboratory at Alfred University.

thorough understanding of the formation, stability, and manipulation of cation defects and ionic valencies in select materials. His research will examine mechanisms for tuning valencies of dopant ions by controlling local oxidizing or reducing environments, which can generate various electronic and coordination structures and control behavior of optically active ion centers in materials. Wu will apply simulation methods to model dopants and dopant combinations to predict possible spectroscopic properties.

TECHNOLOGY: The research has potential impacts on a wide range of important applications, including laser machining and manufacturing, laser-sparked fusion energy, laser communications, high-energy particle and radiation detection, and medical imaging. This line of research is extremely important to effectively synthesize high-quality laser materials with tailored properties. The work brings about unique opportunities to design new optical materials for applications in next-generation devices, such as ceramic lasers and scintillation detectors.

ENGAGEMENT: Wu's group has developed an educational exchange program called "Collaborative Exchange Research and Materials in Ceramic Sciences" (CERAMICS) to help students gain research experience abroad, primarily in Asian countries. This experience provides a more global view of research approaches and activities and is jointly funded by NSF's Office of International Science and Engineering.

Award 1553607—Controlling carbonation degradation in sustainable cements by stabilizing amorphous calcium carbonate

SCIENCE: Claire White at Princeton University (Princeton, N.J.) is investigating chemical reactions occurring during degradation of alkali-activated materials (AAMs) under exposure to atmospheric carbon dioxide, which plagues Portland cement and new cementitious materials. White is exploring the ability to arrest degradation reactions by exploiting the stabilizing effect of magnesium on carbonate-based reaction products (amorphous calcium carbonate). This project will provide a deep understanding of complex phase formation processes that occur during carbonation-induced degradation of slag-based AAM pastes. Key objectives include obtaining a fundamental understanding of the role of magnesium in stabilizing precipitated amorphous carbonate and determining the short- and long-term stability of disordered phases, including calcium (sodium) aluminosilicate hydrate gel and amorphous carbonates. White's studies will use a suite of state-of-the-art experimental techniques, including micrometer-resolved atomic structural information obtained using X-ray pair distribution function analysis combined with microtomography, nanoscale elemental mapping using nanofluorescence, X-ray diffractometry, infrared spectroscopy, thermal analysis, and synchrotron X-ray absorption fine structure.

Credit: David Kelly Crow; Office of Engineering Communications, Princeton University

Claire White presents her research on low-CO_2 cements at the Andlinger Center for Energy and the Environment Building Opening Celebration and Symposium, Princeton University in May 2016.

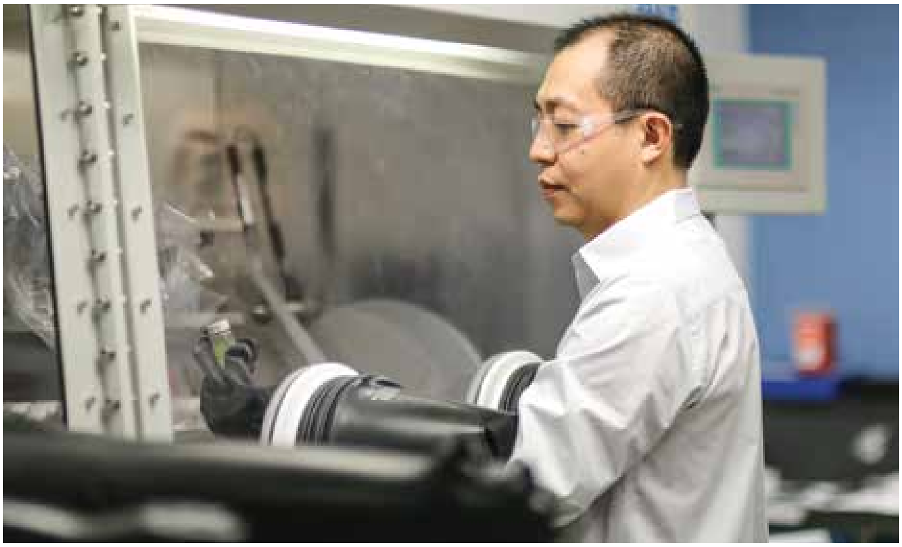
SUSTAINABILITY: Portland cement manufacturing accounts for 5%–8% of global anthropogenic carbon dioxide emissions. With concrete use set to double during the next few decades, there is a pressing need for sustainable concrete alternatives. AAMs, a class of cement whose manufacture emits less carbon dioxide than Portland cement, comprise one such alternative. However, long-term durability of AAMs must be understood and optimized prior to their use in the construction industry. This research will develop highly carbonation-resistant slag-based AAMs with potential to supplant existing cement technologies. These materials can lead to new sustainable products for the construction industry with significantly reduced associated carbon dioxide emissions.

EDUCATION: This project will help train the next generation of scientists in cutting-edge research. Also, White will promote and encourage underrepresented minorities and women in science, technology, engineering, and mathematics (STEM) through outreach components centered on the new applied science and engineering curriculum that is being instituted in high schools in New Jersey.

Award 1554315—Structure–property relationships in bifunctional battery materials

SCIENCE: Wei Lai at Michigan State University (Lansing, Mich.) studies structure–property relationships of a unique family of bifunctional sodium electrode materials to shed light on fundamental mechanisms that could enhance materials performance and inspire rational design and discovery of new materials. Sodium nickel titanates are a unique family of materials that can function either as anode or cathode because of coexistence of high- and low-redox-potential transition metals. However, the structure–property relationship of these materials remains elusive. Lai's research seeks to understand atomic and electronic structures and their effects on ionic and electronic conductivity of model materials in the sodium nickel titanate family. Through an integrated experimental and

Five new National Science Foundation CAREER Ceramic awardees: Class of 2016



Wei Lai handles bi-functional sodium electrode materials in a glovebox at his laboratory at Michigan State University.

computational approach—combining neutron/X-ray scattering probes, atomistic simulation, and electrical property measurement—Lai's studies will examine local distribution, migration pathways, and ionic conductivity of sodium atoms as well as local electron distribution and its effect on electronic conductivity. This work has an immediate impact on this family of technologically important and scientifically intriguing materials and contributes to understanding structure–property relationships in general mixed ionic-electronic conductors, thus leading to rational design and discovery of new materials with superior performance.

SUSTAINABILITY: Although lithium-ion batteries are predominant power sources for portable electronics, their large-scale applications in the transportation and stationary markets may be hindered by lithium availability. Sodium is 1,000 times more abundant than lithium and is available domestically and internationally. Therefore, development of sodium-based battery chemistry may be essential to ensure a sustainable energy future.

ENGAGEMENT: Part of this grant supports a museum exhibition—"Batteries: Powering the past, present, and future"—to raise awareness and inspire public interest in the science and engineering principles of battery devices used today.

Award 1553519—Engineering structure and ionic conductivity in $Li_7La_3Zr_2O_{12}$ nanowire-based solid electrolytes

SCIENCE: Candace Chan at Arizona State University (Tempe, Ariz.) explores a promising safe electrolyte candidate, lithium lanthanum zirconate (LLZO). This material has good thermal and chemical stability and ionic transport properties. Therefore, novel LLZO nanowire structures and composites with unique nanoscale properties have potential to improve conductivity of lithium ions and integrate them into safer, all-solid-state batteries. Chan uses nanowires to understand LLZO phase stability, crystallization, and sintering processes, using core–shell nanowire structures to investigate interfacial properties and transport in composites and understand how to maximize highly conducting pathways for lithium ions and uniformly modify grain boundaries. Chan is using in situ and aberration-corrected transmission electron microscopy characterization to correlate ionic conductivity and electrochemical cycling tests on nanowire solid electrolyte materials and compare them with bulk materials. Insights gained from this work will enable better control of composition, stabilization of metastable phases, sintering processes, and lithium-ion transport, which can ultimately lead to ceramic electrolytes with higher ionic conductivity.

TECHNOLOGY: Lithium-ion batteries are ubiquitous in laptops and cell phones and may gain more use in transportation applications. However, these batteries suffer from safety issues originating from flammable liquid electrolytes that transport lithium ions within the batteries. Nanowire solid electrolytes may offer advantages over bulk materials—namely milder calcination conditions for crystallization, stabilization of metastable phases, and unique structures, such as core–shell composites. These characteristics can lead to improved ionic conductivity, sintering ability, and integration into all-solid-state batteries.

EDUCATION: This grant supports activities to improve the pipeline and retention of female students in science and engineering through hands-on experiences. Chan exchanges teaching methodologies with faculty in South Korea to understand strategies promoting female student achievement and how to best engage students from diverse backgrounds in student-centered learning environments.

Candace Chan holds lithium-ion battery pouch cells containing advanced nanostructured materials developed in her research group at Arizona State University.

ENGAGEMENT: Chan's project also includes a battery-related challenge that engages local middle school girls and provides context on issues related to electric cars and research opportunities.

Award 1555015—Dynamic defect interactions in ferroelectrics

SCIENCE: Geoff Brennecka at the Colorado School of Mines (Golden, Colo.) remarks that all ceramics contain defects, impurities, and interfaces—it is simply unavoidable. Significant research has attempted to understand the effects of defects on properties, with the vast majority of work focused on static or steady-state conditions. However, ferroelectrics and piezoelectrics—which are important for applications ranging from memory devices and capacitors to actuators—commonly are used under dynamic conditions in which moving domain walls dominate property responses. Brennecka brings new experimental techniques and unique sample sets to improve quantitative descriptions of interactions of moving domain walls with ubiquitous point defects and interfaces, such as vacancies and grain boundaries. His work links the abstract energy barriers used to describe domain nucleation and pinning processes to actual chemical and structural features to identify and generalize conditions under which various features serve as nucleation and pinning sites. Through sample sets and experiments, Brennecka will endeavor to isolate variables (e.g., separate domain wall interactions with cation vacancies and with grain boundaries) and apply new tools (e.g., atom probe and X-ray tomographies, time domain thermal reflectance, and custom low-impedance drive circuitry) to develop fundamental mechanistic descriptions of domain nucleation and pinning that can be applied broadly across many materials families.

SUSTAINABILITY: Brennecka expects that better understanding of domain wall interactions with defects and interfaces will result in improved performance from lead-free piezoelectrics and active control of high-value catalysts that are free of toxic or precious metals. In turn, his discoveries will enable use of more sustainable materials to produce devices that contribute to increased energy efficiency and manufacturing sustainability across a variety of industries.

Geoff Brennecka in the furnace lab of the Colorado Center for Advanced Ceramics at the Colorado School of Mines.

ENGAGEMENT: Brennecka is expanding student engagement through an annual "Discover STEM!" camp, curriculum development, and introduction of a campus hot glass shop. In addition, a student swap agreement allows graduate students to work with collaborators in Virginia and Australia, taking advantage of the tools and expertise available in those groups and benefitting from the experience of working in a different environment.

Closing remarks

The CAREER award is a defining step for these principal investigators. The single-investigator award identifies them as emerging world leaders in their respective fields. The junior faculty supported through these NSF awards hope to

- Attain transformative research results;
- Serve as mentors to undergraduate and graduate students and postdoctoral associates;
- Integrate new research results into teaching curriculums;
- Establish research reputations through presentations and publications;
- Grow a network through professional society connections and collaborations with industry, government laboratories, international researchers, and other U.S.-based academics;
- Build a more impactful, and often larger, research group;
- Leverage their CAREER awards to expand funding sources and extend their reach;
- Provide broad education to the general public and attract students to science and engineering fields;
- Address ceramic and glass grand challenges; and
- Contribute to sustainable technologies.

Ceramic and glass research is in an exciting era. To realize the full potential of these unique materials, we celebrate rising professors undertaking fundamental research and educating the next generation.

About the author

Lynnette D. Madsen has been the program director, Ceramics Program, at NSF since 2000. Contact her at lmadsen@nsf.gov.

References

[1]L.D. Madsen, "NSF recognizes three assistant professors with 2009 CAREER Awards in Ceramics," *Am. Ceram. Soc. Bull.*, **88** [3] 30–33 (2009).

[2]L.D. Madsen, "An update on the National Science Foundation Ceramic CAREER Awards: Class of 2010," *Am. Ceram. Soc. Bull.*, **91** [6] 22–23 (2012).

[3]L.D. Madsen, "Class of 2011 National Science Foundation CAREER Awards in Ceramics," *Am. Ceram. Soc. Bull.*, **91** [8] 27–29 (2012).

[4]L.D. Madsen, "Where are the Ceramic CAREER Awards: Class of 2012?" *Am. Ceram. Soc. Bull.*, **92** [1] 30–31 (2013).

[5]L.D. Madsen, "NSF's CAREER Program: New opportunities and the Ceramics Class of 2013," *Am. Ceram. Soc. Bull.*, **92** [8] 34–37 (2013).

[6]L.D. Madsen, "NSF's CAREER competition and the Class of 2014," *Am. Ceram. Soc. Bull.*, **93** [8] 34–37 (2014).

[7]L.D. Madsen, "NSF's CAREER Class of 2015 in ceramics and cross-cutting programs," *Am. Ceram. Soc. Bull.*, **94** [8] 36–39 (2015). ■

National Science Foundation awards in the Ceramics Program starting in 2016

By Lynnette D. Madsen

The National Science Foundation is an independent federal agency that serves as a funding source for basic research conducted at America's colleges and universities. NSF is divided into seven science and engineering research and education directorates. The Mathematical and Physical Sciences Directorate is home to the Division of Materials Research, which includes the Ceramics Program.

The Ceramics Program supports fundamental scientific research in ceramics (e.g., oxides, carbides, nitrides, and borides), glass-ceramics, inorganic glasses, ceramic-based composites, and inorganic carbon-based materials. The objective of the program is to increase fundamental understanding and to develop predictive capabilities for relating synthesis, processing, and microstructure of these materials to their properties and ultimate performance in various environments and applications. Research to enhance or enable the discovery or creation of new ceramic materials is welcome. Development of new experimental techniques or novel approaches to conduct projects is encouraged.

During fiscal year (FY) 2016, the Ceramics Program provided support for 30 awards, 12 supplemental awards, and cofunding of an Optics and Photonics grant managed in the Chemistry Division. The 30 awards are listed in Table 1, but more information on any NSF award is available by adding the 7-digit award number to the end of www.nsf.gov/awardsearch/showAward?AWD_ID= or by searching the NSF awards database.

Additional ceramics research is supported through centers; group grants, such as Designing Materials to Revolutionize and Engineer our Future (DMREF); instrumentation awards (procurement and development); and other programs focused on individual investigators (e.g., in the Chemistry Division, Office of International Science and Engineering, and Engineering Directorate).

NSF also provided supplemental funding to support new international collaborations; small instrumentation repairs, upgrades, and purchases; and the addition of veteran and underrepresented minority graduate students to projects (through MPS-GRSV: NSF 15-024 and AGEP-GRS: NSF 16-125). Although the Ceramics Program also has funded Career–Life Balance supplements (for leaves of absence for dependent care responsibilities) in the past, no requests were received during FY 2016.

The Ceramics Program announced at the end of August 2016 that it was undertaking a pilot alongside the Condensed Matter and Materials Theory Program to remove the proposal submission window, deadline, or target date—proposals are now accepted anytime, with a few restrictions (NSF 16-597). This approach is not unique—it is used in the Geosciences Directorate at NSF and also is used by other agencies in Germany and the United Kingdom. NSF anticipates this change will better accommodate the schedules of principal investigators and encourage submission of emerging ideas. In addition, NSF hopes the change will increase proposal quality and spread workflow (for reviewers and NSF program directors) more evenly throughout the year.

Although FY 2017 began on October 1, 2016, often the first awards appear in late winter or early spring. At any given time, one can generate a map or list of active awards near the bottom of the Ceramics Program homepage at www.nsf.gov/funding/pgm_summ.jsp?pims_id=5352.

About the author

Lynnette D. Madsen has been the program director, Ceramics Program, at NSF since 2000. Contact her at lmadsen@nsf.gov. ■

Collaborative Research

When there is more than one investigator at the same institution, one researcher is designated as PI and others are co-PIs. If more than one institution is involved, there can be one proposal with a subaward to the other institution(s), or multiple coordinated proposals can be submitted as a joint project. The latter is labeled as "Collaborative Research" in the title, and each institution has an award number and budget. See NSF's Proposal & Award Policies & Procedures Guide (PAPPG) for further details, including responsibilities.

Israel Binational Science Foundation (BSF)

A Dear Colleague Letter (DCL) (NSF 15-097) provides guidance for submitting collaborative materials research proposals to foster cooperation between U.S. academics and their Israeli counterparts.

Faculty Early Career Development Program (CAREER)

The CAREER solicitation (NSF 15-555) is restricted to single investigators who are assistant professors. The five awards made in FY 2016 are described on page 42.

Sustainable Chemistry, Engineering, and Materials (SusChEM)

The SusChEM initiative addresses interrelated challenges of sustainable supply, engineering, production, and use of chemicals and materials. The latest DCL, NSF 16-093, provides additional details and there is a description in the budget request to Congress.

EArly-concept Grants for Exploratory Research (EAGER)

"The EAGER funding mechanism may be used to support exploratory work in its early stages on untested, but potentially transformative, research ideas or approaches. This work may be considered especially 'high risk–high payoff' in the sense that it, for example, involves radically different approaches, applies new expertise, or engages novel disciplinary or interdisciplinary perspectives." Full details are provided in the PAPPG.

Grant Opportunities for Academic Liaison with Industry (GOALI)

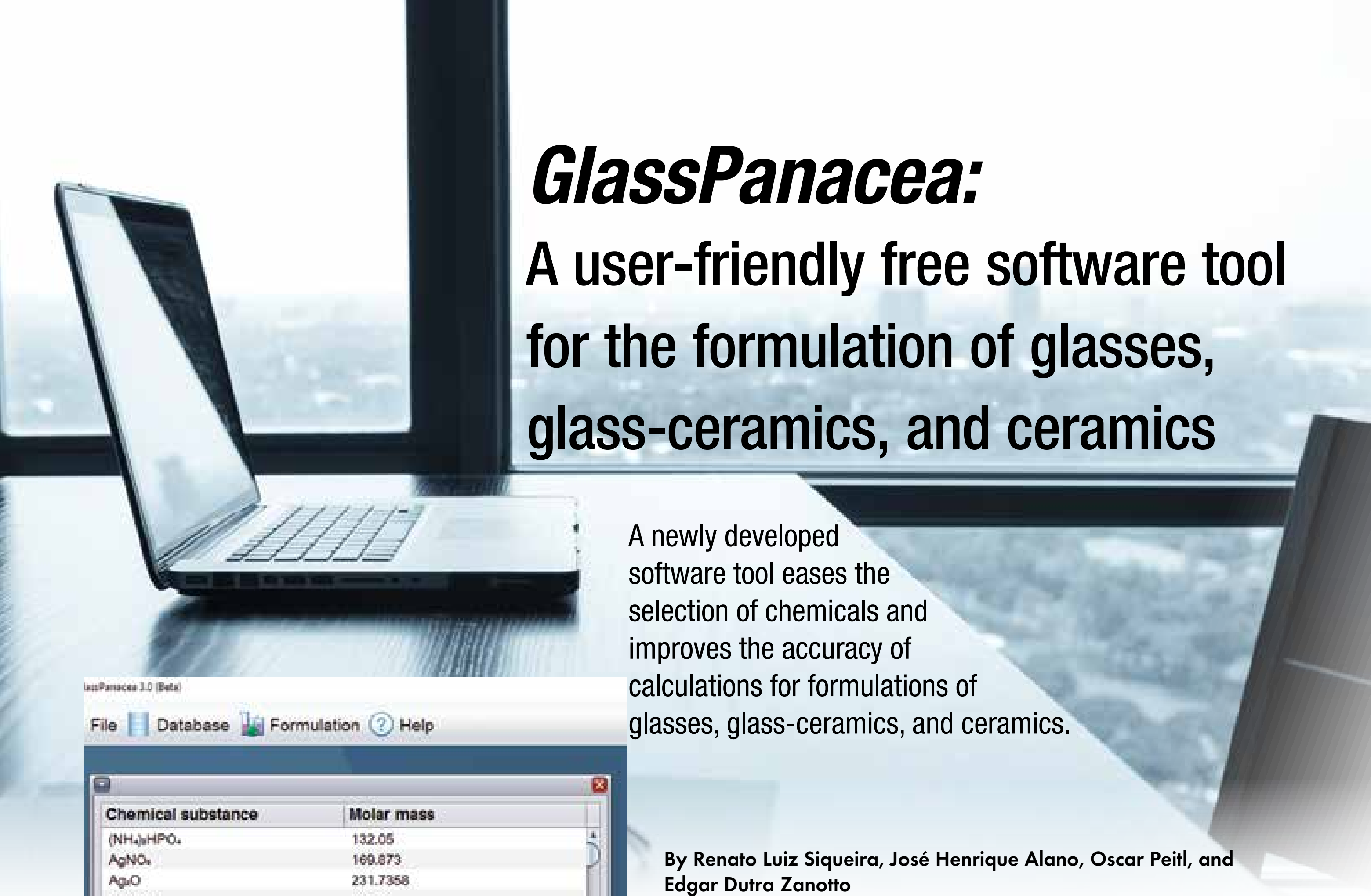
GOALI (DCL NSF 16-099) promotes university–industry partnerships by making project funds or fellowships and traineeships available to support universities working with industry. Projects must meet certain conditions, including having at least one co-PI from industry. For the 2016 award, the GOALI industry partner is Quantum Design.

Conferences

Submissions should follow ***Special Guidelines*** found in the PAPPG for ***Conference Proposals***.

Table 1. NSF Ceramics Program awards made during FY 2016

Title (award no.)	Principal investigator (PI), organization; co-PIs
Advancing understanding of semiconducting oxide nano-heterostructure gas sensors (1609142)	Sheikh Akbar, Ohio State University; co-PI: Patricia Morris
Atomic-level structural characterization of metal/gamma-alumina interfaces combining theory and experiments (1610507)	Melissa Santala, Oregon State University; co-PI: Liney Arnadottir
Comparative evaluation of ionic transport mechanisms in solid-state electrolytes (1610742)	John Kieffer, University of Michigan Ann Arbor
Controlling and understanding thermal energy exchange at single domains of functional materials (1608899)	Junqiao Wu, University of California, Berkeley
Controlling charges on oxide surfaces for enhanced photochemical reactivity (1609369)	Gregory Rohrer, Carnegie Mellon University; co-PI: Paul Salvador
Direct conversion of carbon into diamond and useful micro and nanostructures (1560838)	Jagdish Narayan, North Carolina State University
Entropy stabilized complex oxides (1610844)	Jon-Paul Maria, North Carolina State University
From atomic scale strain probing to smart 3-D interface design (1565822)	Haiyan Wang, Purdue University
Fundamental mechanisms for mechanochemical behaviors of glass surfaces—An integrated experimental and computational approach (1609107)	Seong Kim, Pennsylvania State University; co-PIs: Carlo Pantano, Susan Sinnott, and Adri van Duin
Interface structure and dynamics in multiferroic phase transformations (1609545)	Paul Evans, University of Wisconsin-Madison
Interfacial science and defect engineering of functional oxides for Na-ion storage and transport (1608968)	Ying Meng, University of California, San Diego
Metal diborides: Investigating the structure, processing, and properties of a new class of two-dimensional materials (1610153)	Alexander Green, Arizona State University; co-PI: Qing Hua Wang
Proximate two-dimensional electron and hole gases in ambipolar cuprates (1610781)	Darrell Schlom, Cornell University
Residual stress in nitride thin films: Integrated experiments and development of a predictive model (1602491)	Eric Chason, Brown University
Structure, composition, and ionic conduction in amorphous lithium solid electrolyte (1608398)	Yan Wang, Worcester Polytechnic Institute
Thermal conductivity and grain boundary energy of interfaces in multiphase ceramics (1611457)	Martha Mecartney, University of California, Irvine
Thermochemistry of nanoceramics: Understanding and controlling densification and grain growth (1609781)	Ricardo Castro, University of California, Davis
Collaborative proposal: Designer glass-ceramics (1600783, 1600837)	Jacqueline Johnson, University of Tennessee Space Institute
	Amanda Petford-Long, Northwestern University
NSF/DMR-BSF: Origin of large electromechanical response in non-classical electrostrictors (1606840/1701747)	Anatoly Frenkel, Yeshiva University and transferred to Stony Brook University
CAREER: Engineering structure and ionic conductivity in $Li_7La_3Zr_2O_{12}$ nanowire-based solid electrolytes (1553519)	Candace Chan, Arizona State University
CAREER: Mechanism for controlling ionic valences in transition metal-doped laser materials (1554094)	Yiquan Wu, Alfred University
CAREER: SusChEM: Controlling carbonation degradation in sustainable cements by stabilizing amorphous calcium carbonate (1553607)	Claire White, Princeton University
CAREER: SusChEM: Dynamic defect interactions in ferroelectrics (1555015)	Geoff Brennecka, Colorado School of Mines
CAREER: SusChEM: Structure–property relationships in bifunctional battery materials (1554315)	Wei Lai, Michigan State University
SusChEM: Elucidating structure–property relationships in lead-free piezoelectrics (1606909)	Michelle Dolgos, Oregon State University
EAGER: Mechanical behavior of metal/ceramic nanolaminate composites: Experiments and simulation (1647568)	Nikhilesh Chawla, Arizona State University
GOALI: Magnetic measurements to characterize chemistry and structure in nanoscale-doped oxides (1563754)	Ivar Reimanis, Colorado School of Mines; co-PIs: Stefano Spagna and Jianhua Tong
Conference: Solid state studies in ceramics Gordon Research Conference, Holyoke College, Mass., July 31–August 5, 2016 (1639791)	Michael Hoffmann, Gordon Research Conferences
Conference: Emerging opportunities in ceramic and glass science—A workshop (1619666)	Katherine Faber, California Institute of Technology



GlassPanacea:

A user-friendly free software tool for the formulation of glasses, glass-ceramics, and ceramics

A newly developed software tool eases the selection of chemicals and improves the accuracy of calculations for formulations of glasses, glass-ceramics, and ceramics.

By Renato Luiz Siqueira, José Henrique Alano, Oscar Peitl, and Edgar Dutra Zanotto

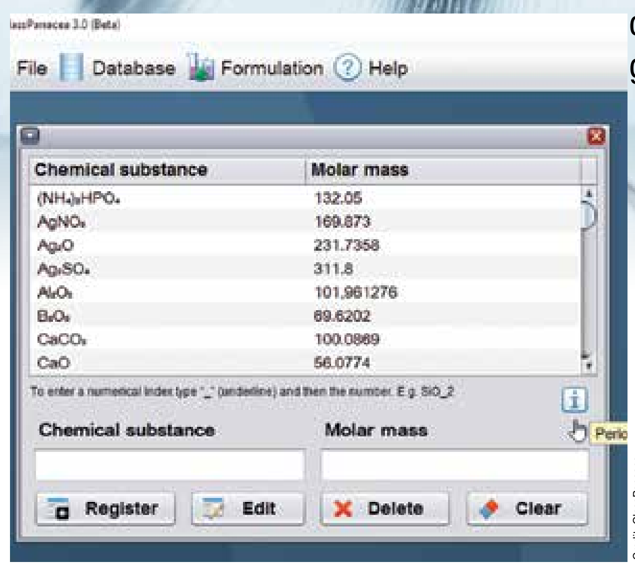


Figure 1. Database for query and registration of chemical substances

Glasses, glass-ceramics, and ceramics are extremely versatile materials with a wide range of applications in numerous segments of modern society. To synthesize existing and new materials of this class, immense chemical combinations are possible from all the 80 useful elements of the periodic table.[1] However, one must determine which chemicals and how much of each to use to prepare any formulation and batch.

Although this is a routine task, it can be time consuming to search for the molar mass of all necessary elements. In addition, the process easily is subject to errors when transforming units of the material composition, such as from moles to weight percent. During 40 years of teaching and research and 20 years as a journal editor, Edgar D. Zanotto has seen many students and researchers err in such calculations—unfortunately, these errors sometimes are never detected or are found only in later stages of research, when authors discover that some property of the material (e.g., density, viscosity, coefficient of thermal expansion, or glass transition temperature) falls far short of the expected value.

Therefore, to provide flexibility in the selection of suitable chemical formulations and to improve speed and accuracy of calculations of relative proportions of each chemical in a batch, we introduce a novel software tool called GlassPanacea. The software uses Java programming language and runs directly from an executable file with multiplatform support. Therefore, GlassPanacea can be used on various operating systems without installation. Its user-friendly and intuitive interface enables immediate application, even for users with little computer experience. This makes GlassPanacea a valuable tool for students, researchers, and engineers who develop ceramic materials using various synthesis techniques, including melting, solid-state reactions, sintering, and sol–gel processing.

Basic software options and additional features

GlassPanacea's workspace is simple and intuitive yet offers robust features. For instance, a "database" button in the menu command allows query and registration of new chemical substances for the purpose of a batch calculation (Figure 1). This is an open database that allows users to extend the default database or build their own. To assist this task, a periodic table is available through the "information" icon at the bottom right of the section. In addition, a "formulation" button opens a window for material batch calculations (Figure 2). This user-friendly section is divided into simple steps:

- ***Step 1—Determination of amount of product.*** We developed the program to simulate preparation of quantities ranging from a few grams to several tons of material. Therefore, the program can meet the requirements of laboratories, research centers, and the industrial sector.
- ***Step 2—Indication of number of components per system (up to 10).*** When a system composed of oxides, such as Li_2O–ZrO_2–SiO_2 (LZS) is considered, each individual oxide constitutes one component of the system. In this case, there are three components—Li_2O, ZrO_2, and SiO_2. Choosing the number of components enables only a corresponding number of data entry fields in additional steps.
- ***Step 3—Selection of components to compose the intended system.*** A selection filter is provided to facilitate this step. Therefore, it is possible to search for components of interest in the complete list of substances registered in the database or by grouping them into oxides, for example.
- ***Step 4—Selection of composition based on mol%, wt%, or molar fraction.*** To assist in filling out these fields, a percentage counter is displayed in yellow to show progress as the fields are filled. A value of 100% indicates that all fields are empty, and percentage decreases progressively as data are entered.
- ***Step 5—Selection of chemicals that will provide components of the system.*** Accessing the "select" tab for each component provides a list of preregistered chemical substances in the database. This provides flexibility in choices and enables simulation of various chemical combinations that may be more appropriate for experimental purposes.
- ***Step 6—Setting parameters.*** To meet the needs of many users, the software offers additional features available through "purity degree," "extra chemical," and "double chemical" tabs. Additional information about each feature can be accessed through the "information" icon at the top of the section.
- ***Step 7—Formulation report.*** After completing previous steps and pressing a "calculate" button, the software generates a report listing steps adopted by the user as well as the mass of all chemicals that should be weighed to obtain the desired amount of product. The software also provides optional buttons to reset calculations or save results. Partial reports are generated in this section to warn the user of possible errors that may have occurred in the preceding steps.

The "help" button in the standard menu command provides access to a user guide containing general information and step-by-step instructions for software features. Another available option is the "about" dialog box, which provides information about the software release, updates, and developer contacts. Because GlassPanacea is a beta version, the software may have some bugs and instability issues. Therefore, criticisms and suggestions are welcome and are valuable to enable improvement of the software and expansion of its functionalities.

GlassPanacea 3.0 (beta) is freely available in three languages—Portuguese, Spanish, and English. An archive containing the software, initial information for use, and logo (~6 MB) can be downloaded for free at certev.ufscar.br.

Acknowledgments

We are grateful to the Brazilian research funding agencies São Paulo Research Foundation FAPESP (Project No. 2013/07793-6 (CEPID)), CNPq (Project No. 140516/2013-1), and CAPES (Project No. 182441/2013-71) for funding of scholarships granted to R.L. Siqueira and J.H. Alano. We also thank A.M.N. Muñoz and J.F.O. Mosquera from LaMaV/UFSCar for helping with the Spanish version and to T.S. Pinto from LIPEMVALE/UFVJM for valuable input.

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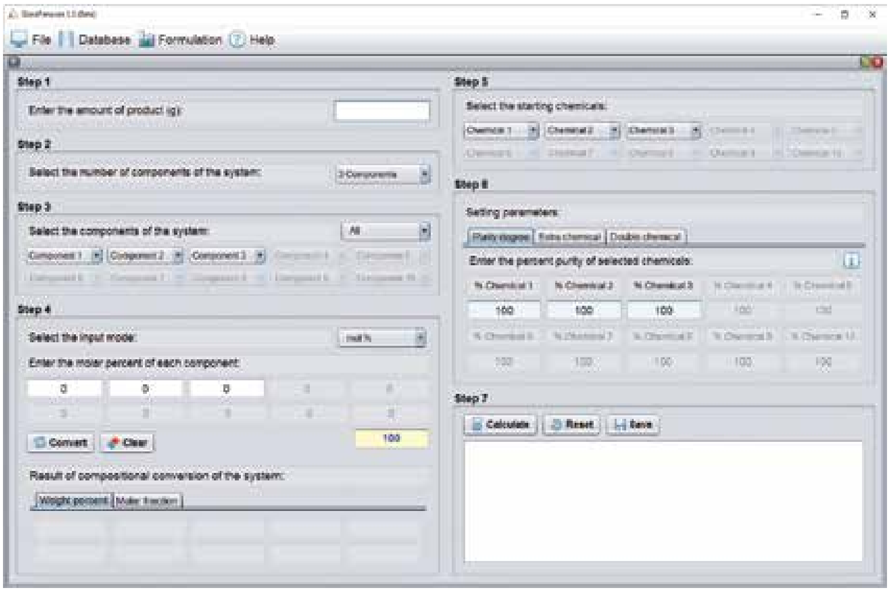
References

[1]E.D. Zanotto and F.A.B. Coutinho, "How many noncrystalline solids can be made from all the elements of the periodic table?" *J. Non-Cryst. Solids*, **347**, 285–88 (2004).



Credit: GlassPanacea

Figure 2. Overview of the formulation section.

ELECTRONIC MATERIALS AND APPLICATIONS 2017

ceramics.org/ema2017

JANUARY 18 – 20, 2017

DOUBLETREE BY HILTON, ORLANDO, FLA. USA

Electronic Materials and Applications 2017 addresses emerging needs, opportunities, and key challenges in the field of electronic materials and applications. Technical presentations highlight advancements in materials and devices for electronics, sensors, energy generation and storage, photovoltaics, and LEDs.

EMA is organized by the Basic Science Divsion and Electronics Division of The American Ceramic Society

PLENARY SPEAKERS

Sossina Haile, Walter P. Murphy professor of materials science and engineering, Northwestern University

Thermochemistry of redox active oxides and its relevance to solar fuel generation

Abstract: Laboratories around the world are pursuing a variety of promising strategies for converting solar energy into a reliable energy source for on-demand utilization. We describe a thermochemical approach for achieving this goal using solar heat as the energy source and redox active nonstoichiometric oxides as the reaction medium. Specifically, upon exposure to high temperatures and/or inert gas, the oxide undergoes reduction (without change in crystalline phase) to release oxygen. Upon exposure to H_2O (or CO_2), the oxide is reoxidized, releasing H_2 (or CO). We compare the thermochemical fuel production behavior of a variety of oxides, including those of the fluorite structure type (ceria and its derivatives) and those of the perovskite structure type ($La_{1-x}Sr_xMnO_3$). A shared characteristic of the most promising materials is that bulk oxygen diffusion (chemical diffusion) is fast, such that fuel production rates are limited either by surface reaction kinetics or, at high temperatures, by gas-phase mass transfer rates. We develop an analytical model to treat the behavior under gas-phase limited behavior and explore the implications on fuel production rates.

Neil Alford, professor of physical electronics and thin-film materials, vice-dean (research) Faculty of Engineering, Imperial College London, U. K.

From ultra-high-Q dielectrics to the room-temperature maser

Abstract: In this talk, we will look at the problem of dielectric loss (the tan δ) in oxides and, specifically, methods to beat the dielectric limit. We do this using a Bragg reflector in which the Bragg layers, which are made of sapphire, are of equal thickness. In this case the Q factor (or the inverse of the tan δ) saturates to a plateau after approximately three layers. Surprisingly, we find that if the layers are aperiodic in thickness, there is no saturation, and the *Q* factor rises quadratically to reach remarkably high values of $Q = 0.6 \times 10^6$ at 30 GHz. This result suggests that it might be possible to reach the threshold for masing. We recently demonstrated that in P-terphenyl that is doped with pentacene, when located inside a very-high-*Q* sapphire resonator, maser action can be observed. This is the first time a solid-state maser has been demonstrated at room temperature and in the earth's magnetic field. Recent work has shown that miniaturization is feasible, and considerable reduction in pumping power is possible by using a strontium titanate resonator, which, by virtue of a higher relative permittivity, leads to a factor of >5 in size reduction. Purcell factor, which is the ratio of the *Q* factor to the mode volume, remains high. This is a key factor in the ability to exceed the threshold for masing.

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Group Name: American Ceramic Society – 2017 Electronic Materials and Application Conference
Group Code: ACE

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Group Name: American Ceramic Society – 2017 GOVERNMENT ROOM BLOCK

Group Code: ACG

Group rates available until December 20 or sold out.
Make your reservations early!

FAILURE: THE GREATEST TEACHER

The vast majority of scientific literature and conference talks report positive results, but there is a lot to be learned from negative results and missteps as well. After the "successful" part of the meeting closes, come hear recognized leaders in the field discuss failure—and perhaps recount some of their most spectacular learning experiences—during a frank and friendly discussion in a relaxed atmosphere. Speakers and audience alike are encouraged to check their egos at the door for this event that has turned into an EMA highlight. In addition to highlighted failures, this year we also will be including contributed vignettes on failure and lessons from experience. If you would like to speak at this symposium, please contact Geoff Brennecka (geoff.brennecka@mines.edu).

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SCHEDULE

Current as of December 1, 2016

Tuesday, January 17, 2017

Conference registration	5 – 6:30 p.m. Oceans Ballroom Foyer

Wednesday, January 18, 2017

Conference registration	7:30 a.m. – 6 p.m. Oceans Ballroom Foyer
Plenary session I – Sossina Haile, Northwestern University	8:30 – 9:30 a.m. | Indian
Coffee break	9:30 – 10 a.m. | Atlantic
Concurrent technical sessions	10 a.m. – 12:30 p.m. Indian, Pacific, Coral A & B, Mediterranean A, B, C
Poster session set up	Noon – 5 p.m. Arctic/Atlantic
Lunch on own	12:30 – 2 p.m.
Student award finalist presentations	12:45 – 1:50 p.m. | Coral A
Concurrent technical sessions	2– 5:30 p.m. Indian, Pacific, Coral A & B, Mediterranean A, B, C
Coffee break	3:30 – 4:p.m. | Atlantic
Poster session & reception	5:30 – 7:30 p.m. Arctic/Atlantic
Basic Science Division tutorial	7:45 – 9:45 p.m. | Coral A

Thursday, January 19, 2017

Conference registration	7:30 a.m. – 6 p.m. Oceans Ballroom Foyer
Plenary session II – Neil Alford, Imperial College London	8:30 – 9:30 a.m. | Indian
Coffee break	9:30 – 10 a.m. | Atlantic
Concurrent technical sessions	10 a.m. – 12:30 p.m. Indian, Pacific, Coral A & B, Mediterranean A, B, C
Lunch on own	12:30 – 2 p.m.
Student award finalist presentations	12:45 – 1:45 p.m. | Coral A
Concurrent technical sessions	2 – 5:30 p.m. Indian, Pacific, Coral A & B, Mediterranean A, B, C
Coffee break	3:30 – 4 p.m. | Atlantic
Young Professionals reception	5:30 – 6:30 p.m. Barefoot Bar
Conference dinner	7 – 9 p.m. Arctic/Atlantic

Friday, January 20, 2017

Conference registration	7:30 a.m. – 5:30 p.m. Oceans Ballroom Foyer
Concurrent technical sessions	8:30 a.m. – 12:30 p.m. Indian, Pacific, Coral A & B, Mediterranean A, B, C
Coffee break	9:30 – 10 a.m. | Atlantic
Lunch on own	12:30 – 2 p.m.
Concurrent technical sessions	2 – 5:30 p.m. Indian, Pacific, Coral A & B, Mediterranean A, B, C
Coffee break	3:30 – 4 p.m. | Atlantic
Failure – The greatest teacher	5:45 – 6:45 p.m. Mediterranean B/C

January 22 – 27, 2017 | Hilton Daytona Beach Resort and Ocean Center Daytona Beach, Fla., USA

41ST INTERNATIONAL CONFERENCE AND EXPOSITION ON ADVANCED CERAMICS AND COMPOSITES

ceramics.org/icacc2017

ICACC17 showcases cutting-edge research and product developments in advanced ceramics, armor ceramics, solid oxide fuel cells, ceramic coatings, bioceramics, and more. The technical program and Industry Expo provide an open forum for scientists, researchers, engineers, and industry leaders from around the world to present and exchange findings on recent advances in ceramic science and technology.

AWARD AND PLENARY SPEAKERS

JAMES I. MUELLER AWARD

Waltraud Kriven, professor, University of Illinois at Urbana-Champaign

Geopolymers: Structural inorganic polymers

BRIDGE BUILDING AWARD

Pavol Sajgalik, president, Slovak Academy of Sciences, and department head, Ceramic Department, Institute of Inorganic Chemistry, Slovak Academy of Sciences, Bratislava, Slovakia

Additive-free, hot-pressed silicon carbide ceramics—A material with exceptional properties

PLENARY SPEAKER

Thomas J. Webster, chair and professor of chemical engineering, Northeastern University

Fifteen years of commercializing ceramic medical devices using nanotechnology

PLENARY SPEAKER

Hiroshi Kishi, operating officer, research and development laboratory manager, Taiyo Yuden Co. Ltd., Japan

MLCC/inductor trends and technological evolution

ECD GLOBAL YOUNG INVESTIGATOR AWARD

Gang Liu, Shenyang National Laboratory for Materials Science, China

Multiscale designing of solar-driven photocatalysts

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The American Ceramic Society www.ceramics.org

Engineering Ceramics Division

MECHANICAL PROPERTIES OF CERAMICS AND GLASS SHORT COURSE

JANUARY 26, 2017 | 8:30 a.m. – 4:30 p.m.
JANUARY 27, 2017 | 8:30 a.m. – 4 p.m.
LOCATION: HILTON DAYTONA BEACH RESORT AND OCEAN CENTER
INSTRUCTORS: George D. Quinn, NIST, and Richard C. Bradt, University of Alabama

This two-day course addresses mechanical properties of ceramics and glasses for elastic properties, strength measurements, fracture parameters, and indentation hardness. For each of these topical areas, fundamentals of properties are discussed, explained, and related to structure and crystal chemistry of the materials and their microstructure. Standard test methods are covered. Learn from industry experts with more than 80 years of combined experience.

OFFICIAL NEWS SOURCES

bulletin — CeramicTechToday

MEDIA SPONSOR

International Journal of Applied Ceramic Technology

EXHIBITION INFORMATION

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Exhibit hours: Tuesday, January 24, 5 – 8 p.m.
Wednesday, January 25, 5 – 7:30 p.m.

Exhibit location: Ocean Center Arena, 101 North Atlantic Avenue, Daytona Beach, FL 32118

Exhibit space is filling up fast. To reserve your booth, visit ceramics.org/icacc2017 or contact Mona Thiel at 614-794-5834 or mthiel@ceramics.org.

Exhibitor	Booth
AdValue Technology	205
Alfred University	315
AVS	307
BCC Research	301
Centorr	200
CM Furnaces	311
C-Therm	220
Gasbarre (PTX)	207
H.C. Stark	305
Haiku Tech	214
Harper International Corp.	317
J. Rettenmaier USA	201
Lithoz GmbH	107
MEL Chemicals	313
Microtrac	306
Nanoscience Instruments	202
Netzsch Instruments	300
NGS Advanced Fibers	204
Noritake	302
Oxy-Gon Industries Inc.	320
Quantachrome Instruments	TBD
Reserved	216
Sonoscan	221
Superior Graphite	203
TA Instruments	210
Tev Tech	212
Thermal Wave	321
Thermcraft Inc.	303
Verder Scientific (Carbolite)	206
Zircar Ceramics	304

Marketing for Manufacturers Forum at

THE AMERICAN CERAMIC SOCIETY'S

6TH CERAMIC BUSINESS AND LEADERSHIP SUMMIT

APRIL 24, 2017 | ceramics.org/CBLS2017

CLEVELAND, OHIO

Gain insight into marketing technical products to technical customers
Develop successful marketing strategies | Understand business intelligence
Expand your network

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- Marketing trends, analysis, and techniques for engineering, scientific, technical companies.
- Comprehensive, ceramic industry business intelligence from industry analyst.
- Case studies showcasing top companies' technical marketing strategies.

CBLS solves your unique challenges. Join industry leaders, ACerS Corporate Members, scientific start-ups, and others engaged in the ceramic and glass industry at this focused forum. Register today to gain valuable insight from industry experts!

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HOTEL INFORMATION

Cleveland Airport Marriott
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216-252-5333

Room Rate: $134 plus tax

Make reservations online at ceramics.org/cbls2017.

Program at a glance

Monday, April 24

9 – 10:15 a.m. ***Business intelligence – How to dissect a market opportunity***

Gordon Nameni, senior editor, BCC Research LLC

10:30 – 11:45 a.m. ***Growth in the Glass Age—Managing product introductions***

Kevin T. Gahagan, senior manager, technology strategy, Corning Incorporated

Céline Guermeur, director, exploratory markets and technologies, Corning Incorporated

The glass and ceramics industry is uniquely positioned to solve some of the difficult challenges currently faced in information technology, architecture, transportation, and other industries. Opportunities are driven by new capabilities, new problems, new applications, or a combination of these. Achieving those opportunities requires a rapid assessment and deeper understanding of the portfolio. Tools to guide innovation and real world case studies from recent product introductions will be discussed.

11:45 a.m. – 1 p.m. Lunch

1– 2:30 p.m. ***Smart marketing for engineers***

Rebecca Geier, CEO and co-founder, TREW Marketing

Ceramic company business leaders across disciplines often question what the best marketing investment is for their company. Redesign the website? Attend the same trade shows, or try new ones? Start an AdWords or LinkedIn ad campaign? When you add in new marketing terms—from content marketing to inbound marketing—it is even more difficult to understand the language. Finally, while there are many viable marketing investment options, all have different measures of ROI and varying degrees of effectiveness for skeptical, technical audiences. Attendees will hear answers to these and other common marketing challenges, while learning about new data and best marketing practices for marketing to highly technical audiences.

2:30 – 3:30 p.m. ***Case study: Marketing new technology—Additive manufacturing for ceramic materials***

Johannes Homa, CEO and co-founder, Lithoz

With their ability to produce functional parts directly from CAD data, additive manufacturing (AM) technologies offer enormous potential for industry. The ultimate advantage of AM over traditional manufacturing methods is the freedom of design; it is possible to introduce new features in the design of parts without limitations of conventional forming techniques. While these kinds of technologies have already been established in plastics processing and metalworking over the last decade, their use for fabricating ceramic materials is still in its infancy.

Attendees will gain insight into how a new technology can be brought to market. This session will focus on opportunities, difficulties, and hurdles when marketing an upcoming technology. The pros and cons of conducting business in a hyped-up industry and how to take advantage of this will be explored, along with the question of which marketing instruments are the most effective for pioneering technologies.

3 – 3:30 p.m. ***Case study***

Speaker TBD

4 – 5 p.m. ***Develop your marketing action plan***

Rebecca Geier, CEO and co-founder, TREW Marketing

This interactive break-out session enables attendees to get a jump start on creating a marketing action plan for their company and products. Rebecca Geier guides participants through the process of using TREW Marketing's "Customized Marketing Action Plan Worksheet" and how to start putting the concepts, principles, and techniques discussed during the Ceramic Business and Leadership Summit into action.

7 – 9 p.m. ***CBLS dinner and speaker***

Speaker TBD


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International Exhibition for Advanced Ceramics and Powder Metallurgy Technology, Equipment & Products
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Calendar of events

January 2017

18–20 EMA 2017: ACerS Electronic Materials and Applications – DoubleTree by Hilton Orlando Sea World, Orlando, Fla.; www.ceramics.org/ema2017

18–22 ACerS Winter Workshop 2017 – DoubleTree by Hilton Orlando Sea World, Orlando, Fla.; www.ceramics.org/winter-workshop

22–27 ICACC'17: 41st Int'l Conference and Expo on Advanced Ceramics and Composites – Hilton Daytona Beach Resort/Ocean Walk Village, Daytona Beach, Fla.; www.ceramics.org/icacc2017

February 2017

20–24 MCARE 2017: Materials Challenges in Alternative and Renewable Energy – Jeju, Korea; www.ceramics.org/mcare2017

March 2017

29–30 53rd Annual St. Louis Section/RCD Meeting – Hilton St. Louis Airport, St. Louis, Mo.; www.ceramics.org/sections/st-louis-section

April 2017

24 6th Ceramic Business and Leadership Summit – I-X Center, Cleveland, Ohio; www.ceramics.org/cbls2017

25–27 Ceramics Expo 2017 – I-X Center, Cleveland, Ohio; www.ceramicsexpousa.com

May 2017

9–11 ACerS Structural Clay Products Division and Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Fort Worth, Texas; www.ceramics.org/scpd2017

21–26 12th Pacific Rim Conference on Ceramic and Glass Technology, including Glass & Optical Materials Division Meeting – Hilton Waikoloa Village, Waikoloa, Hawaii; www.ceramics.org/pacrim12

June 2017

26–28 Cements 2017: 8th Advances in Cements-Based Materials – Georgia Tech, Atlanta, Ga.; www.ceramics.org

July 2017

4–7 6th European PEFC & H_2 Forum: 21st Conference in Series with Tutorial, Exhibition, and Application Market – Lucerne, Switzerland; www.EFCF.com

9–13 15th Conference & Exhibition of the European Ceramic Society – Budapest, Hungary; www.ecers2017.eu

24–28 9th Int'l Conference on Borate Glasses, Crystals, and Melts; Int'l Conference on Phosphate Glasses – Oxford, U.K.; www.sgt.org

September 2017

17–20 ➨ Ultra-High Temperature Ceramics: Materials for Extreme Applications IV – Cumberland Lodge, Windsor, U.K.; www.engconf.org

27–29 ➨ UNITECR 2017 – CentroParque Convention and Conference Center, Santiago, Chile; www.unitecr2017.org

October 2017

1–6 EPD 2017: 6th International Conference on Electrophoretic Deposition: Fundamentals and Applications – Gyeongju, South Korea; www.engconf.org/conferences/materials-science-including-nanotechnology/electrophoretic-deposition-vi-fundamentals-and-applications

8–12 MS&T17 combined with ACerS 119th Annual Meeting – Pittsburgh, Pa.; www.matscitech.org

22–25 ➨ 2017 ICG Annual Meeting and 32nd Sisecam Glass Symposium – Sisecam and Technology Center, Istanbul, Turkey; www.icginstanbul2017.com

November 2017

6–9 ➨ 78th Conference on Glass Problems – Greater Columbus Convention Center, Columbus, Ohio; www.glassproblemsconference.org

12–16 Int'l Conference on Sintering 2017 – Hyatt Regency Mission Bay Spa and Marina, San Diego, Calif.; www.ceramics.org/sintering2017

January 2018

17–19 EMA 2018: ACerS Electronic Materials and Applications – DoubleTree by Hilton Orlando Sea World, Orlando, Fla.; www.ceramics.org

21–26 ICACC'18: 42nd Int'l Conference and Expo on Advanced Ceramics and Composites – Hilton Daytona Beach Resort/Ocean Walk Village, Daytona Beach, Fla.; www.ceramics.org

May 2018

20–24 GOMD 2018: Glass and Optical Materials Division Meeting – Hilton Palacio de Rio, San Antonio, Texas; www.ceramics.org

August 2018

20–23 MCARE 2018: Materials Challenges in Alternative & Renewable Energy – Vancouver, BC Canada; www.ceramics.org

Dates in RED denote new entry in this issue.

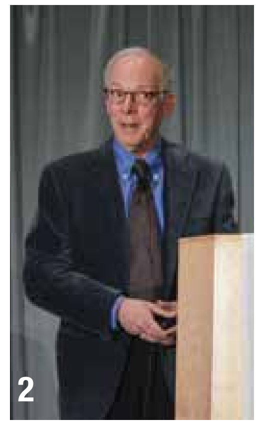
Entries in BLUE denote ACerS events.

➨ denotes meetings that ACerS cosponsors, endorses, or otherwise cooperates in organizing.

Celebrating ACerS 118th Annual Meeting at MS&T16

MATERIALS SCIENCE & TECHNOLOGY

(Credit for all photos: ACerS.)



Materials Science and Technology 2016 brought 3,000 scientists, researchers, engineers, exhibitors, business people, and many more to the Salt Palace Convention Center in Salt Lake City, Utah, October 23–27, 2016, to discuss the latest in all aspects of materials science and engineering. Bringing together so many engaged attendees with common interests led to pop-up meetings to discuss science, share results, begin collaborations, and do business.

With stunning mountainous views in the background, conference attendees roamed the convention center's expansive halls, choosing from more than 2,000 presentations and an expanse of special events hosted by the conference's five sponsoring organizations—ACerS, AIST, ASM International, TMS, and NACE International.

The technical program is the centerpiece of MS&T, but it also hosts the annual membership meetings of The American Ceramic Society and ASM International. All four partner societies also hold myriad award lectures, committee meetings, business meetings, protocol events, and student activities.

It's not too soon to start planning for MS&T17 in Pittsburgh, Pa., Oct 8–12, 2017.

1 Conference attendees stopped by the ACerS booth to say hello, spin the prize wheel, and pick up valuable information.

2 Bruce Dunn, professor of materials science and engineering at the University of California, Los Angeles, delivered ACerS' Orton Memorial Award lecture at MS&T's plenary session. He showed the audience the roles ceramic materials will play in the next generation of energy storage devices.

3 Attendees gathered to celebrate the achievements of women at the Women in Materials Science reception.

4 Entries into the annual Mug Drop contest came in many shapes, sizes, and forms—some pretty, and some pretty creative.

5 The well-attended poster session stimulated discussion among conference attendees.

6 Students at ASM Materials Camp learn about the heat-resistant properties of refractories.

new products

Mass spectrometer

Shimadzu Scientific Instruments' new GCMS-TQ8050 triple quadrupole gas chromatograph mass spectrometer enables new possibilities in sensitivity, durability, performance, stability, and reliability. The instrument's newly designed detector offers an instrument detection limit approximately 10 times more sensitive than the current system, enabling reliable detection of femtogram-level concentrations of trace components. The system also features a new turbomolecular pump and high-efficiency collision cell to further enable various high-sensitivity analyses.

Shimadzu Scientific Instruments (Columbia, Md.)
ssi.shimadzu.com
800-477-1227

Mixing system

Ross' new portable high-shear-mixing system is designed for powder dispersion into liquid, emulsification, and homogenization in a closed, temperature-controlled vessel. The top cover includes ports with dip tubes extending into the vessel for suctioning and transferring finished product as well as for incorporating liquid ingredients. The mixer's four-blade rotor runs up to 3,600 rpm within a close-tolerance slotted stator, delivering intense mechanical and hydraulic shear. The mixer is driven by a 5-hp stainless-steel wash-down duty explosion-proof motor.

Charles Ross & Son Co. (Hauppauge, N.Y.)
mixers.com
800-243-ROSS

Viscometer

The new Visco portable viscometer has a fully digital display that allows quick and easy reading of viscosity results for a range of substances. The compact viscometer runs on either AC power or battery power, allowing portability even in places lacking a power source. Measurement can be done with a small amount of sample, resulting in less waste and significant cost reduction—Visco is capable of taking measurements with 15 mL of sample, a fraction of the standard sample amount.

Paul N. Gardner Co. Inc. (Pompano Beach, Fla.)
gardco.com
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Atmospheric plasma torch

The Cirrus atmospheric plasma torch is used to enhance adhesion characteristics of a variety of materials. The torch allows in-line plasma activation of hybrid materials, glass, ceramics, metal, and polymers. The compact, standalone device has the potential to deliver a consistent plume (8–10-mm wide) of active plasma gas and can be easily incorporated with production lines with or without robot handling. The atmospheric plasma functions with compressed air and does not need special gases or other services.

Henniker Plasma (Warrington, U.K)
plasmatreatment.co.uk
+44-0-1925-830-771

Potting cement

Aremco's Ceramacast 586 is a zirconium silicate-based, phosphate-bonded, chemically setting ceramic compound ideal for bonding and potting high-temperature electrical components, including power resistors, infrared heaters, cartridge heaters, gas igniters, halogen lamps, and temperature sensors. The compound exhibits exceptional electrical and mechanical properties and is suitable for applications to 2,800°F (1,535°C). Ceramacast 586 is supplied as a powder and is mixed with water to a pastelike consistency that is dispensed easily through pneumatic dispensing equipment. Cured product exhibits a porosity of less than 2% and zero shrinkage.

Aremco Products Inc. (Valley Cottage, N.Y.)
aremco.com
845-268-0039

Graphene films

Goodfellow's new Easy Transfer is a transferable graphene monolayer on a polymer film that makes it easy to transfer the graphene file onto virtually any substrate at a user's facility. Easy Transfer provides high-quality graphene that is ready to deposit onto a substrate of choice. Users can experiment with any novel substrate, keeping the project in-house and speeding up R&D. Because the bottom layer already has been removed, users can avoid metal or hazardous-chemical etching.

Goodfellow Corp. (Coraopolis, Pa.)
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deciphering the discipline

A regular column offering the student perspective of the next generation of ceramic and glass scientists, organized by the ACerS Presidents Council of Student Advisors.

Rachel Sherbondy
Guest columnist

Balancing industry and academia in a collaborative project

In fall semester of 2016, during my senior year of undergraduate study at Pennsylvania State University, I worked on a joint ceramic project between the university and GE Oil and Gas. This invaluable research opportunity allowed me to study flexible lead zirconate titanate ultrasonic transducers for permanently installed sensors that monitor corrosion in petroleum pipelines. I worked full time as a co-op at the GE Oil and Gas plant in Lewistown, Pa.—located close to Penn State's campus in University Park, Pa.—which allowed me to experience the best of industry and academia.

Under the guidance of Matthew Krohn of GE and Susan Trolier-McKinstry of Penn State, I achieved a proper formulation and processing parameters for the ceramic sensors during my co-op. Not only did I learn much about materials science during the process, but I also discovered many differences between academic research and industry research, which made the experience critical as a scientist and young professional planning my career.

From the industry prospective, the project was all about timing. The pace of industry research is fast—it is measured in the amount of work that needs to be completed by a certain time, and in the number of iterations that must be produced in rapid succession. For every round of testing, industry expects that testing will result in a new batch that solves at least one experimental question. So, because I had to deliver measurable outcomes, I evolved batch changes in parallel to research. Although this high-pressure environment was stressful, the challenge helped me develop focus and planning.

Credit: Rachel Sherbondy

Rachel Sherbondy at the GE Oil and Gas plant in Lewistown, Pa.

In contrast, academia places a stronger focus on fully understanding the phenomena underlying the results. Rather than simple pass–fail manufacturing tests, I often performed repeated, wide-range tests on samples to determine small-scale effects of various processing parameters. This work sought to build an understanding and create a database of information on new products, so that future troubleshooting could be completed if necessary.

This research collaboration's unique combination of industry and academia provided me with a clear delineation between the two worlds, because it allowed me to view the same project through very different lenses. Although I could have benefitted separately from either the results-oriented industry perspective or the understanding-oriented academia perspective, the two in concert provided a comprehension that was greater than their sum.

From this experience, I have gained insight into what it takes to succeed in both worlds. I encourage other students to engage in similar opportunities that allow them to experience industry and academia—the experience can provide an understanding of the strengths and foci of each, which can be very informative for shaping students' future goals.

Rachel Sherbondy is an undergraduate student in her senior year of study at Pennsylvania State University. Sherbondy is president of the Penn State chapter of Material Advantage and is planning to pursue a doctorate degree after graduation. When not in the lab, she enjoys running and reading.


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