AMERICAN CERAMIC SOCIETY

bulletin

emerging ceramics & glass technology

JANUARY/FEBRUARY 2019

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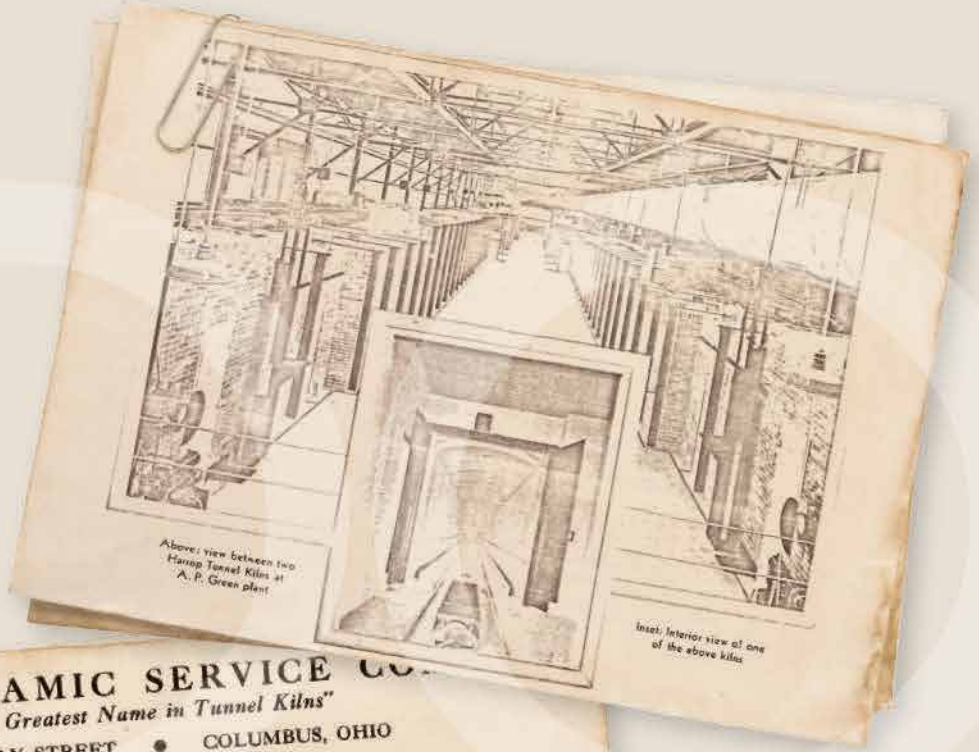

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Correction to the December/Ceramic Source 2019 *ACerS Bulletin*

An incorrect quote was included in the cover story, "Smart materials make smartphones," in the print edition of the December 2018 *ACerS Bulletin*. It appears correctly in the electronic and the downloadable PDF versions.

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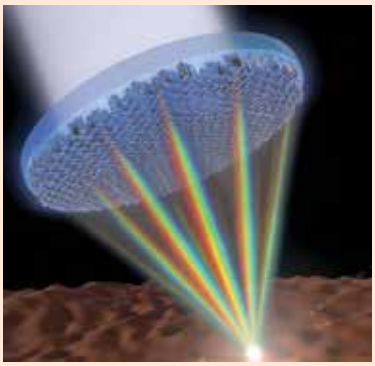
As seen on *Ceramic Tech Today*...



Credit: Jared Sisler, Harvard SEAS

Goodbye glass—optical lenses go 2D

Metalenses, a type of metasurface used for focusing light, could replace glass in cameras and imaging systems. Two recent studies advance this possibility.

Read more at www.ceramics.org/opticallenses

As seen in the December 2018 *ACerS Bulletin*...

Smart materials make smartphones

Read the *ACerS Bulletin* exclusive report on how ceramics and glass contribute to the $479B smartphone market.

Read more at www.ceramics.org/Smartphones

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. The American Ceramic Society is not responsible for the accuracy of information in the editorial, articles, and advertising sections of this publication. Readers should independently evaluate the accuracy of any statement in the editorial, articles, and advertising sections of this publication. *American Ceramic Society Bulletin* (ISSN No. 0002-7812). ©2019. 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.ceramics.org). Editorial and Subscription Offices: 550 Polaris Parkway, Suite 510, Westerville, OH 43082-7045. 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. 98, No. 1, pp 1– 48. All feature articles are covered in Current Contents.

The challenges of making foldable smartphones

Samsung, Huawei, Lenovo, Xiaomi, and LG all released plans for foldable smartphones this year, and one company, Royole Corporation, produced a working prototype that it hopes to release before the end of the year. Instead of two separate screens attached by a hinge, these phones would feature a single screen that bends for easier scrolling and viewing when the phone is opened all the way (no hinge interruption).

Despite the hype surrounding their anticipated deployment, there are several technological challenges that make it likely these first foldable phones might not perform as well as their traditional, non-bending counterparts.

Cover glass

One of the big difficulties in creating a foldable smartphone is the cover glass, the outermost layer of glass on a smartphone. Smartphone screens consist of several layers of glass and electronics embedded between the layers.

However, tough and rigid cover glasses cannot bend or fold without fractures or breakage.

Instead of glass, companies like Samsung will likely use plastic for the cover screen. Several recent reports say the company picked Japanese electronic materials firm Sumitomo Chemical as the sole supplier of polyimide (PI) films, a transparent plastic film. But there are drawbacks to using plastic instead of glass.

"It's a material reality that anything that conforms [like plastic] will be more susceptible to scratches," Mark Rolston, founder and chief creative at product design firm argodesign, says in a CNET interview. Plastic also does not keep oxygen and water out as well as glass.

Touch screen technology

Two main ways touch screens detect your finger is through capacitive or piezoelectric sensing. Both types use electrical signals to tell the screen how to react.

In both capacitive and piezoelectric screens, how hard the screen is pressed determines the strength of the electric signal. Touch sensing works best if the screen does not move from one specified shape and the only change in the screen's

mechanical stress comes from pressing on the screen. If the screen can fold, though, its mechanical stress will change during the folding, making it more difficult for the screen to accurately tell how hard you press. Therefore, bendable smartphones may feature only pre-specified bends—where the screen's mechanical stress is known for each shape.

Professor Jun-Bo Yoon and coworkers from the Korea Advanced Institute of Science and Technology are working to improve touch sensor technology. They developed a thin, flexible, and transparent hierarchical nanocomposite film that uses a soft grating and hard insulator to concentrate pressure-related stress to the gratings, thereby enhancing sensitivity.

Battery

In a foldable phone, all components—not just the glass—must bend. This can be troublesome for the phone's battery.

In an interview with CNET, Marc Juzkow, vice president of research and development for battery company Leyden Energy (Fremont, Calif.), says today's smartphones are usually powered with lithium ion batteries, whose stiffness maximizes the time a smartphone can hold a charge. While new battery technology is moving toward thin, flat cells based on solid-state electrolytes, Juzkow says their energy output cannot run a smartphone for as long as a traditional battery.

Until new battery technologies are designed, foldable smartphones must bend at fixed points, to avoid bending in areas containing the rigid battery and other inflexible parts.


Credit: Royole Corporation

Despite challenges associated with making foldable smartphones perform as well as traditional smartphones, there is no doubt that technology will improve with each new release. A bigger challenge facing smartphone companies now is marketing: why do consumers want or need a foldable smartphone? Most companies have only a few months left to answer to this question, as many foldable smartphones are expected to debut in 2019 and will be more expensive than a traditional smartphone. ■

Business news

U.S. Silica will increase prices for most of its non-contracted silica sand, cool roof granule, aplite, and specialty products (**https://ussilica.gcs-web.com**) … Rivian Automotive launched its first two products, an all-electric pickup truck and SUV (**www.products.rivian.com**) … Steklarna Hrastnik plans €45 million expansion of its production capacities (**www.glass-international.com**) … Morgan Advanced Materials opens new Carbon Science Centre of Excellence R&D facility at Penn State University (**www.morganadvancedmaterials.com**) … Tethon 3D introduces first metal/ceramic resin for upcoming Bison 1000 DLP Printer (**https://tethon3d.com**) … SCHOTT invests in AI start-up NNAISENSE (**www.us.schott.com**) … Xinglass establishes first branch office in Fairfax, Va. (**www.usglassmag.com**) … America Makes expands service offerings at satellite center (**www.americamakes.us**) … Imerys closes graphite mine in Namibia (**www.roskill.com**) … Murata to expand multilayer ceramic capacitors production (**www.murata.com**) ■

Corporate partner news

3D printed ceramic parts could support lunar colonies

Lithoz (Vienna, Austria), a company specializing in additive manufacturing of high-performance ceramics, created a collection of spare parts using a 3D printing process with simulated lunar regolith as the "ink." The company is working with the European Space Agency to create components and parts for a lunar base to allow astronauts to make replacement parts onsite.

"These parts have the finest print resolution ever achieved with objects made of regolith simulant, demonstrating a high level of print precision and widening the range of uses such items could be put to," ESA materials engineer Advenit Makaya explains in an ESA article. "If one needs to print tools or machinery parts to replace broken parts on a lunar base, precision in the dimensions and shape of the printed items will be vital."

Simulated regolith is composed of primarily silicon dioxide, but also includes other oxides such as alumina, calcia, and iron oxide, according to Makaya. The regolith is ground into small-sized particles and mixed with a binding agent, layered, and hardened by exposing to light. Sintering is the final step in the process.

"Thanks to our expertise in the additive manufacturing of ceramics, we were able to achieve these results very quickly," Lithoz CEO Johannes Homa says in the article. "We believe there's a huge potential in ceramic additive manufacturing for the Moon." ■


Credit: ESA–G. Porter, CC BY-SA 3.0 IGO

Fast-charging EV stations could be a reality in three years

A collaboration between researchers from Missouri S&T and three companies—Ameren (St. Louis, Mo.), LG Chem Michigan (Holland, Mich.), and Bitrode (St. Louis, Mo.)—could result in a charging solution that would shave as much as 20 minutes off of the charging time for electric vehicles.

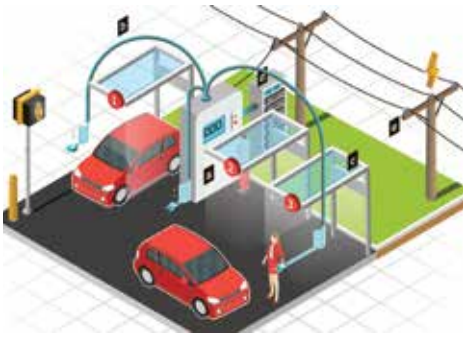
"The big problem with electric vehicles is range, and it's not so much range as range anxiety," professor of electrical and computer engineering Jonathan Kimball explains in a Missouri S&T news release. "People are nervous about not being able to get where they're going. With a conventional vehicle, you pull up, get gas, and in 10 minutes you're back on the road."

The researchers, led by Kimball, will spend the next three years developing a system that quickly charges EVs—specifically, in less than 10 minutes, the average time it takes to fill up a gas-powered car.

As exciting as this sounds for the EV industry, Kimball and his team face several challenges, according to the release. They will need to determine if lithium batteries can handle quick charges, says Kimball, and if the charging speed will damage and weaken them.

Other challenges include degradation of performance and short circuiting. "At extreme fast charging rates, lithium-ion batteries can be damaged severely due to the limited energy transfer properties of the battery materials," Missouri S&T assistant professor of mechanical engineering and team member Jonghyun Park says in the release. "This not only degrades battery performance, but also causes a short circuit that can lead to a safety issue."

The researchers will need to study the effects of using massive amounts of electricity all at once from the grid during a charging session. Because electricity will be coming from the same grid as the electricity that flows into surrounding homes, it could possibly affect the quality of the power being delivered to those homes.



Credit: Jonathan Kimball, Missouri S&T

The researchers will tap into the experience of the three industry partners to provide the expertise needed to develop a safe, fast-charging system that addresses all challenges that the researchers foresee during the project.

The collaborating team is using $2.9 million from a grant that the U.S. Department of Energy announced earlier this year for development of research projects focused on batteries and fast-charging technologies. ■

Meet ACerS president Sylvia Johnson

By Eileen De Guire

(Credit: ACerS)

ACerS president Sylvia Johnson likes to make things—an excellent mindset for an engineer. However, becoming an engineer took perseverance and a bit of serendipity.

Growing up in Sydney, Australia, she attended the Willoughby Girls High School.

In her final two years, she was the only student to register for advanced chemistry, and the class was slated for cancellation. Not willing to miss out on chemistry, she accepted the administration's challenge to find enough students to take the class. Good thing, too, because that class confirmed her ambition to pursue a career in applied chemical sciences.

When she was accepted into the Faculty of Applied Sciences at University of New South Wales, she quickly discovered ceramic engineering—in fact, only as long as it took her to read the flyer describing the fields of study available to undergraduates.

"At the very bottom, in the last inch, there was a thing called 'ceramic engineering,' ... and I thought that sounds interesting. I chose it without any real knowledge. It just struck my fancy," she recalls.

And with that stroke of the pen, Johnson became a trailblazer as the first woman to enroll in ceramic engineering full time at UNSW, where she earned a first-class honors degree, the highest distinction.

As she gained knowledge of materials science, she found it resonated with her. "It turns out there's a visual aspect and an integration [with other disciplines]. I've never been the sort of person to focus on one small thing," she says.

Graduate school beckoned, and she landed at the University of California, Berkeley (having eliminated British universities because England was too cold) working in Joseph Pask's group.

"I told my mother I was going for a master's degree for 18 months," Johnson says. "She has finally stopped asking me when I'm coming home!"

She moved to Tony Evans' group for her Ph.D., studying mechanical properties and the effects of cavitation and degradation in alumina and on creep.

Not attracted to a teaching career, Johnson took a position at SRI International in Menlo Park, Calif. Besides conducting contract research, SRI also offered business consulting to its clients, giving her the opportunity to impact companies technically and on the bottom line.

"We'd help companies with whether they should be in the business, and where the business was going to go," she says.

After 18 years at SRI she joined NASA Ames Research Center (Moffett Field, Calif.) to lead the thermal protection materials efforts, including materials for Mars expeditions, which was the topic of her Orton Award Lecture at MS&T 2015. Her work at Ames included revitalizing the ultra-high temperature ceramics program.

Johnson joined ACerS as a graduate student and found the meetings and networking events to be most valuable. "When I first started coming to the Annual Meeting, everybody was very friendly. You met all these people who were leaders in their field, and they were so friendly. Also, they remembered your name."

She helped organize the Pacific Coast Regional Meeting conferences for many years, leading those held in the Bay Area. She served on the Member Services Committee, on the Board in the 1990s and again in the 2000s, and several other society-level committees.

As president, Johnson has several goals.

"The Society is in good financial health, and we want to maintain that," she says. At the same time, Johnson says the Society needs to consider new opportunities.

"I hear very clearly the need for another meeting to fill in dips in the meetings cycles," she says. Suggestions include a Pan America meeting, and she will work with the Meetings Committee to evaluate the opportunities.

Building on the value she found in volunteering, she wants to ensure plentiful opportunities for members to have experiences as satisfying as hers have been, and also to recognize the contributions of volunteers.

Diversity and inclusion are very important to the first female ceramic engineer from UNSW. "We need to make sure we consider everybody when we're thinking about volunteer opportunities, offers of the Nominating Committee, awards, honors...whatever," she says. "I've benefited from being included, and I've understood what it's like to be excluded."

Johnson wants to hear from the members this year. To that end, she will attend Division meetings, Section meetings, and other places where ACerS members congregate in the United States and abroad.

If she visits your area, you may consider scheduling a hike into the agenda. She and her husband, Jim Evans (a metallurgist), live in the San Francisco area, are avid hikers and have hiked all over the world. They make an annual hiking excursion to Austria, and made a point of hiking all 60 of East Bay Regional Park District parks. They have two adult children, Hugh and Claire.

In her remaining spare time, Johnson likes to cook original recipes she develops for her family and friends. Ever the engineer, Johnson says, "I like to make things."

Johnson invites members to contact her at ACerSPresident@ceramics.org. ■

Highlights from ACerS 120th Annual Meeting

By Eileen De Guire

The American Ceramic Society held its 120th Annual Meeting during MS&T18 in Columbus, Ohio. For many, MS&T is primarily a technical conference, but for ACerS members it includes meetings of the Board of Directors, division executive committee and business meetings, and meetings for ACerS working committees and subcommittees. The Society's student leadership group, the President's Council of Student Advisors, also holds its annual meeting during the ACerS Annual Meeting. This year PCSA includes 46 students from 30 universities, representing eight countries.

Sylvia Johnson (right) accepts the ACerS presidency from Mike Alexander with the transfer of the ceremonial ceramic gavel.

A highlight of the nearly week-long event is the Annual Membership Meeting, where the president reports on the state of the Society, and the new president outlines plans for the coming year. President Mike Alexander reported on the Society's growing impact through efforts that support members' activities as volunteers, advocates, and teachers. He spoke of the importance of collaboration between the "triple helix" of government, universities, and industry.

"The efforts of these groups are not complete if they don't have support of the other two groups," says Alexander.

He encouraged the membership to continue to seek opportunities to increase collaboration across all membership sectors and to be alert for ways to create more awareness of the ceramic and glass field.

Treasurer Dan Lease reported that the Society's financial position is strong, and the Society carries no debt. New officers were sworn-in, and out-going officers were recognized and thanked for their service. Incoming president Sylvia Johnson outlined her vision and goals for her year as president (see details on previous page).

The Society recognized David Johnson (right) for his many years of service to the Society as Board Parliamentarian. Charlie Spahr (left, executive director) presented Johnson with a certificate and a piece of ceramic art pottery.

Before handing the ceramic gavel to Johnson, President Alexander announced Mark Mecklenborg's appointment as ACerS new executive director, and he recognized retiring executive director Charlie Spahr for his exemplary service to the Society. That evening (Oct. 12, 2018) ACerS recognized the achievements of its members at the Annual Awards Banquet.

View images from the many activities that occurred during the Annual Meeting on ACerS Flickr website at https://www.flickr.com/photos/acersphotos/albums/72157699328585402.

Next year's Annual Membership Meeting will be Sept. 30, 2019, during MS&T19 in Portland, Ore. ■

Past president Marina Pascucci (left), president Sylvia Johnson (center), and Jingyang Wang (right, Board of Directors) select historic Drakenfeld souvenir glasses from previous Annual Meetings.

SOCIETY, DIVISION, SECTION, AND CHAPTER NEWS

Credit: Kathleen Richardson

ACerS members attend ICG 2018

Nearly 600 delegates representing 29 countries converged on Yokohama, Japan, for the International Commission on Glass' 59th Meeting on the Glass and Photonic Materials (ICG 2018) in conjunction with the 14th Symposium of the Glass Industry Conference of Japan, September 23–26. Visit http://bit.ly/ICG2018recap for the complete recap of ICG 2018. ■

We appreciate our members!

As we head into the New Year, we thank our members for being a part of ACerS. Members are the reason the Society exists. "That's the great thing about professional societies like ACerS," membership director Kevin Thompson says. "Unlike for-profit organizations, non-profits are owned and governed by the members. Income is given back to the members through benefits and services," he adds.

We continually look for ways to better serve our members, such as new journals, publications, meetings, and networking opportunities.We encourage you to take advantage of your member benefits, including:

- Access to ACerS journals: *Journal of the American Ceramic Society*, *International Journal of Applied Ceramic Technology*, *International Journal of Applied Glass Science*, and *International Journal of Ceramic Engineering & Science*
- Print and online access to *ACerS Bulletin*
- *Bulletin Archive Online*—unlimited access to 8,300 articles from all 1,100 issues of the Bulletin dating back to 1922
- *Ceramic Tech Today*—news from ceramic and glass research and industry
- Professional development at conferences, workshops, and short courses
- Networking, collaborating, and volunteering through divisions, sections, and chapters
- Opportunities to share your knowledge and present your research
- Recruitment and job-search assistance
- Professional and peer recognition from highly-regarded awards programs
- Reduced rates for meetings, technical publications, Phase Equilibria Diagrams, and ceramic materials courses
- And much more!

We look forward to serving you in 2019 and wish you all a happy and prosperous New Year! ■

Volunteer Spotlight

ACerS thanks all volunteers who donated time and resources in 2018 and seeks your continued service in 2019. A goal of the Member Services Committee is to expand ACerS volunteer programs and to recognize volunteers for their time and service. We also thank those employers who support volunteer activities of ACerS members.

We currently seek new member welcome ambassadors for EMA 2019 and ICACC19 in January. If interested in volunteering, contact Kevin Thompson, (614) 794-5894 or kthompson@ceramics.org. ■

St. Louis Section/RCD 55th Annual Symposium on Refractories set for March 26–28

The 55th Annual Symposium on Refractories takes place in St. Louis, Mo. at the Hilton St. Louis Airport Hotel on March 26–28 with the theme "Shaped Refractories." Plan to attend a kickoff event the evening of March 26. Program cochairs are Beau Billet (Edward Orton Jr. Ceramic Foundation) and Dawn Hill (Xertech Specialties/Artech).

For complete details about the event, including vendor information, registration fees, and hotel reservations, visit http://bit.ly/55thRCDSymposium. Contact Patty Smith at 573-341-6265; fax, 573-341-2071; or psmith@mst.edu with questions. ■

Names in the news

Gyekenyesi earns lifetime achievement award

Gyekenyesi

Marquis Who's Who presented ACerS Fellow John Gyekenyesi with the Albert Nelson Marquis Lifetime Achievement Award. The award recognizes individuals for noteworthy accomplishments, career successes, and prominence in a field. Gyekenyesi was a research engineer for NASA and played a major role in designing stable combustion

systems and rocket testing equipment. Gyekenyesi specialized in fatigue and fracture studies of advanced materials, and his CARES computer program for reliability analysis of ceramic components is currently used by more than 900 organizations worldwide. Gyekenyesi is a member of the Basic Science Division. ■

Saad named president and CEO of Kopp Glass

Saad

ACerS member Elie Saad became president and CEO of Kopp Glass Inc. Saad previously led corporate development at LANXESS Corporation, where he served in various roles in areas of optimizing costs and increasing profitability. Saad has a Ph.D. in materials physics and is a member of the Glass & Optical Materials Division and the Engineering Ceramics Division. ■

In memoriam

Dennis Hageman

Richard S. Floyd Jr.

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

Mazurin accepts ACerS honorary membership

Oleg Mazurin gratefully acknowledges his ACerS honorary membership.

Credit: Arun Varshneya

ACerS awarded Oleg Mazurin honorary membership in the Society for his contributions to the glass science community. In September, his colleagues greeted him with a reception where he received his award certificate. Mazurin's contributions to glass science include phase separation in glass, viscosity in the nearly solid range, viscoelastic and structural relaxation in glass transition, electrical conductivity, and glass-to-metal seals. Among his notable accomplishments was the conversion of his handbooks into the SciGlass database used by glass scientists worldwide. ■

AWARDS AND DEADLINES

Congrats to ICACC 2018 award recipients!

The Engineering Ceramics Division has announced the Best Paper and Best Poster winners from ICACC18, held last January in Daytona Beach, Fla. The awards will be presented during the plenary session at ICACC19. Congratulations to the following authors!

Best Papers

First place

Erosion behavior in a gas turbine grade oxide/oxide ceramic matrix composite, **Michael J. Presby**, **N. Kedir**, **L.J. Sanchez**, **C. Gong**, **D.C Faucett**, and **S.R. Choi**, Naval Air Systems Command; **Gregory Morscher**, The University of Akron

Second place

Phase field modelling of microstructural changes in Ni/YSZ solid oxide electrolysis cell electrodes, **Martina Trini**, **Salvatore De Angelis**, **Peter Stanley Jørgensen**, **Anne Hauch**, **Ming Chen**, and **Peter Vang Hendriksen**, Technical University of Denmark

Third place

Evaluation of power generation from biomass using solid oxide fuel cell (SOFC) and downdraft gasifiers, **Shimpei Yamaguchi**, **Kazuaki Katagiri**, **Takuya Ehiro**, **Tomoatsu Ozaki**, and **Atsushi Kakitsuji**, Osaka Research Institute of Industrial Science and Technology

Best Posters

Joint first place

Reliable measurement of fracture toughness of armour ceramics at the microstructural scale, **J. Jiang**, **S. Falco**, **N. Petrinic**, and **R. I. Todd**, University of Oxford, United Kingdom

Optimisation of SiCp/SiCf preforms prior to matrix formation using microwave enhance chemical vapour infiltration, **M. Porter**, **A. D'Angio**, and **J. Binner**, University of Birmingham, Metallurgy and Materials, United Kingdom; **M. Cinibulk**, Air Force Research Lab, United States; **B. Garcias Banos**, Universidad Politecnica de Valencia, DIMAS–ITACA Institute, Spain; **A. Aktas**, National Physical Laboratory, United Kingdom

Second place

Raman spectroscopy experiments to characterize radiation induced defects in SiC/SiC composites, **S. Agarwal**, **Y. Zhao**, and **W. J. Weber**, University of Tennessee, Material Science and Engineering; **S. J. Zinkle**, University of Tennessee, Nuclear Engineering

Third place

Crack-healing ability and strength recovery of ytterbium disilicate ceramic reinforced with silicon carbide nanofillers, **S.T. Nguyen**, **H. Iwasawa**, **H. Suematsu**, **T. Suzuki**, **K. Niihara**, and **T. Nakayama**, Nagaoka University of Technology, Japan; **L. He**, Idaho National Lab

Trustee Award

Transparent superhydro phobic coating from silica spheres, **Z. Li**, High School Attached to Harbin Normal University, China; **N. Li**, **L. Pan**, and **H. Xu**, Harbin Institute of Technology, China ■

Congratulations to Global Ambassador Award recipients

The Global Ambassador Program recognizes dedicated ACerS volunteers who demonstrate exceptional leadership and service that benefits the Society, its members, and the global ceramics and glass community.

ACerS 2017-2018 President Michael Alexander selected the following 15 volunteers for the Global Ambassador Award:

- **Nancy Bunt**, Kerneos
- **Michael Halbig**, NASA Glenn Research Center
- **William Headrick**, Missouri Refractories Co. Inc.
- **Soshu Kirihara**, Osaka University
- **Dietmar Koch**, German Aerospace Center
- **Lynnette Madsen**, National Science Foundation
- **Federico Rosei**, INRS Centre for Energy-Canada
- **Bikramit Basu**, Indian Institute of Science
- **Fred McMann**
- **John Sanders**, Clemson University
- **Shibin Jiang**, AdValue Technology LLC
- **Sanjay Mather**, University of Cologne
- **Manoj Choudhary,** International Commission on Glass
- **Greg Rohrer**, Carnegie Mellon University
- **Martin Harmer**, Lehigh University ■

Last call for 2019 award nominations!

Nominations for most ACerS Society awards, including Distinguished Life Member, Morgan Medal and Global Distinguished Doctoral Dissertation, Kingery, Du-Co Ceramics Young Professional, Jeppson, Coble, Purdy, Corporate Achievement, Spriggs, Friedberg, and Fulrath are due **January 15, 2019**. The Purdy Award will be for papers published in 2017.

We encourage nominations for deserving candidates from groups that have traditionally been underrepresented in ACerS awards relative to their participation in the Society, including women, underrepresented minorities, industry scientists and engineers, and international members.

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

Nomination deadline for GOMD awards is January 21

The Glass & Optical Materials Divisions invites nominations for three awards:

Stookey Lecture of Discovery Award
George W. Morey Award
Norbert J. Kreidl Award for Young Scholars.

Visit www.ceramics.org/awards for more details. ■

Students and young professionals: Check out these events especially for you at ICACC19!

Make sure to attend the student and young professional activities at ICACC19, January 27–Feb 1, 2019, in Daytona Beach, Fla.

- Networking mixer, January 28, 7:30–9 p.m.
- Student publication workshop, January 29, Noon–1:15 p.m.
- Shot glass competition (organized by ACerS PCSA), January 29, 6:45–8 p.m.
- Student and industry failure trials competition (organized by ACerS PCSA), January 30, 6:45–8 p.m.

Connect with other students and young professionals attending ICACC19 by visiting http://bit.ly/ICACC19students to find the Facebook event. The event discussion provides opportunities for students and young professionals to find roommates, a list of interesting technical talks happening at the conference, and social planning during the conference. For more information about ICACC19 and to register, visit www.ceramics.org/icacc2019. ■

Student volunteers needed at upcoming meetings

The Young Professionals Network steering committee is looking for volunteers for the following activities at EMA 2019 and ICACC19. You must already be attending the respective meetings. Instructions for each activity will be provided.

- One or two volunteers needed to organize and run Lunch with a Pro at EMA.
- One or two volunteers needed to organize and run Lunch with a Pro at ICACC.
- Four volunteers needed to support a publishing workshop at ICACC.

The YPN steering committee is looking for one volunteer to be available for occasional conference calls. Contact Yolanda Natividad at ynatividad@ceramics.org if you are interested in volunteering for any of the activities shown above. ■

CERAMICANDGLASSINDUSTRY FOUNDATION

CGIF welcomes new leadership

Congratulations to the new officers and members of the Board of Trustees of the Ceramic and Glass Industry Foundation.

Board of Trustees (Serving a three-year term, 2018–2021)


Brennecka

Geoff Brennecka
Professor
Colorado School of Mines
Golden, Colo.


Ebendorff-Heidepriem

Heike Ebendorff-Heidepriem
Professor
University of Adelaide
Adelaide, Australia


Fotheringham

Ulrich Georg Fotheringham
Executive scientist
SCHOTT AG
Mainz, Germany


Goto

Takashi Goto
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Tohoku University
Sendai, Japan


Ingram

Mike Ingram
CEO
McDanel Advanced Ceramic Technologies
Beaver Falls, Pa.


Snow

Bryn Snow
Manager of application technology-glass
HarbisonWalker International
Moon Township, Pa.


Tipsord

Dan Tipsord
General manager
Skyworks RF Ceramics/Trans-Tech Inc.
Middletown, Md.

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Executive director
The American Ceramic Society
Westerville, Ohio


Day

Immediate past chair:
Ted Day
Chief executive officer
Mo-Sci Corporation
Rolla, Mo.

Air Products, Owens-Illinois provide donations to CGIF and GMIC

Air Products Foundation donated $15,000 to the Ceramic and Glass Industry Foundation and the Glass Manufacturing Industry Council at the recent Glass Problems Conference. The money goes toward student travel grants to attend the GPC as well as CGIF initiatives to help attract and train ceramic and glass professionals.

Credit: ACerS

Pedro M. Riveros, Air Products director of strategy, technology, and sourcing IG Americas, presents a check to Bob Lipetz (center) of the GMIC and Marcus Fish (right) of the CGIF.

Additionally, Owens-Illinois donated $20,000 to the CGIF and the GMIC to support CGIF outreach programs and provide travel grants to college students. The CGIF will use half of the grant to bring ceramic and glass science to middle- and high-school students. The GMIC will use the other half to provide travel grants for university engineering students to attend the GPC.

For more information about the donations, visit http://bit.ly/APOIDonations. ■

Neural networks predict glass transition temperatures

Finding the glass transition temperature is an important first step in testing new glass compositions. However, finding the T_g experimentally can be expensive and time-consuming. That is why researchers at the Federal University of São Carlos created software to predict T_g using a specific form of machine learning.

Edgar Dutra Zanotto, ACerS Fellow and professor of materials science and engineering, and his coauthors Daniel R. Cassar and André C.P.L.F. de Carvalho at UFSCar used artificial neural networks (ANNs) to predict the T_g of oxide glasses containing anywhere from three to 21 elements. ANNs are a type of machine learning based on the

Credit: ClearerThinking, YouTube

Annealing requires knowledge of the glass transition temperature. Researchers at the Federal University of São Carlos created software that predicts glass transition temperatures without needing to make the glass.

Research News

Graphene on the way to superconductivity

Researchers at Helmholtz-Zentrum Berlin found evidence that double layers of graphene have a property that may let them conduct current completely without resistance. In April 2018, a group at MIT showed it is possible to generate a form of superconductivity in a system of two layers of graphene under very specific conditions, but the research at Helmholtz-Zentrum Berlin showed a much simpler way to reach flat band formation. They probed the band structure and identified a flat area next to the band gap that had previously been overlooked. This flat area is a prerequisite for superconductivity if it is situated exactly at the so-called Fermi energy. In the case of the two-layer graphene, it is possible to raise the energy level of the flat area to the Fermi energy. For more information, visit https://www.helmholtz-berlin.de/. ■

structure and functions of biological neural networks, and have been used before in materials science to predict kinetic and mechanical properties of polymers. In the realm of oxide glasses, however, Zanotto identifies only two published studies using ANNs to predict properties.

The previous oxide studies using ANNs trained their models on small data sets, using 31 and 299 examples respectively. In the current research, Zanotto and his coauthors trained their ANN model with a dataset containing 55,150 examples.

The trained ANN correctly predicted published T_g values with 95 percent accuracy, and within less than ±9 percent error; additionally, 90 percent of the data was predicted with a relative deviation less than ±6 percent. Zanotto and his coauthors also tested the ANN on approximately 5,000 compositions not included in the training dataset, with similar accuracy results.

While the prediction uncertainty did not depend on the number of elements in the glass composition, the uncertainty was larger for glasses with high T_g (above 1,250 K) because less than 0.2 percent of the dataset were these high-T_g glasses.

"At the moment, we are testing other types of predictors to check whether they can do a better job than the ANNs for these special cases of high- and low-T_g glasses," Zanotto says in an email. "In the end, an optimized algorithm should predict high-T_g glasses compositions with a closer performance."

Zanotto says they will launch a freely available beta version of the ANN with the current algorithm and dataset, but other, more powerful software is on the way. "[This software] will allow the glass community to predict the T_g of oxide glass compositions that have never been made," Zanotto says.

In the future, Zanotto says they plan to do more research using ANNs. "We are training and testing other ANNs for three other important physical properties of inorganic glass-formers: liquidus temperature, elastic modulus, and refractive index," Zanotto says.

The paper, published in *Acta Materialia*, is "Predicting glass transition temperatures using neural networks" (DOI: 10.1016/j.actamat.2018.08.022). ■

Credit: U.S. National Archives

Researchers at Arizona State University showed a way that microwave communication systems could be turned on and off electronically instead of manually, a finding that could reduce signal interference.

Switchable dielectrics could help microwave systems avoid interference

Researchers at Arizona State University showed a way that microwave communication systems could be turned on and off electronically, potentially reducing interference from dielectric materials used in microwave systems.

Nathan Newman, ACerS member and professor of solid state science, and his research group at Arizona State University have been researching the fundamental properties of dielectric materials, and their latest research builds on previous research to arrive at this possible solution to manual switching.

Back in 2012, Newman and his group published a paper showing that the loss tangent of dielectric materials is most affected by electron spin excitations, or the generation of magnetic fields by the movement of electrons. In the current

Research News

Study opens route to ultra-low-power microchips

Researchers at MIT demonstrated a "magneto-ionic" technique that controls the magnetic properties of a thin-film material by reversibly inserting and removing protons into the material structures. MIT researchers used hydrogen ions in this study instead of the oxygen ions used in previous attempts. Because the hydrogen ions are smaller than oxygen ions, they can enter and exit from the crystalline structure of the spintronic device, changing its magnetic orientation each time, without damaging the material. This technique could help prepare for a post complementary metal-oxide semiconductor world. For more information, visit http://news.mit.edu. ■

Solar cells for yeast cell biofactories

Researchers at Harvard's Wyss Institute for Biologically Inspired Engineering and the John A. Paulson School of Engineering and Applied Sciences (SEAS) created the first yeast biohybrid system using an adaptable light-harvesting semiconductor approach. They attached indium phosphide nanoparticles to the surface of yeast cells, so that the semiconductor nanoparticles could harvest electrons from light and hand them over to the yeast cells. The cells then shuttled the electrons across their cell walls into their cytoplasm, where the electrons elevated the levels of NADPH molecules and fueled shikimic acid biosynthesis. For more information, visit https://wyss.harvard.edu. ■

paper, this knowledge of the effect of spin excitations on the loss tangent value is used to create a way to electronically turn microwave systems on and off.

Usually, switching a dielectric from a low loss tangent to a high loss tangent (from an "on" state to an "off" state) requires very large and cumbersome electromagnets to generate magnetic fields of several thousand Gauss. But Newman and his group found that if the dielectric material is doped with small amounts of magnetic elements—like nickel and iron—defects are introduced into the atomic structure of the dielectric material, allowing the dielectric material to be turned "on" and "off" by applying a magnetic field of under a few hundred Gauss. The reason this technique to turn the dielectric material "on" and "off" works is because the addition of the magnetic elements changes the spin excitations in the dielectric material.

This technique will work with any dielectric material, Newman says in a phone interview. His group used the dielectric material aluminum oxide (Al_2O_3) doped with iron (Fe^{3+}) to demonstrate proof of principle.

While this research was carried out in temperatures near absolute zero, Newman and his group are working to achieve similar performance of the dielectric materials at or near room temperature. If they achieve the same effect at higher temperatures, Newman says microwave communication systems could be revolutionized in two to three years.

Newman has applied for a patent for the research.

The paper, published in *Applied Physics Letters*, is "Switching microwave dielectric resonators from a high-Q on state to an off state using low-field electron paramagnetic resonance transitions" (DOI: 10.1063/1.5042226). ■

Photonic radiation sensors survive huge doses undamaged

Researchers at the National Institute of Standards and Technology found that oxide-coated silicon photonic devices can withstand radiation exposure up to 1 million gray. One gray represents one joule of energy absorbed by one kilogram of mass, and 1 gray corresponds to 10,000 chest X-rays. To determine the effects of radiation, NIST researchers exposed two kinds of silicon photonic sensors to hours of gamma radiation from cobalt-60, a radioactive isotope. In both types of sensors, small variations in their physical properties changed the wavelength of the light that traveled through them. The NIST results suggest the sensors could be used to track levels of ionizing radiation used in food irradiation to destroy microbes and in medical device sterilization. For more information, visit https://www.nist.gov. ■

'Super turbines' and international study opportunities focus of NSF grant led by ACerS members

Gurpreet Singh (ACerS member, Kansas State University) is the principal investigator for a National Science Foundation Partnerships for International Research and Education (PIRE) study on multicomponent silicon-based polymer-derived ceramic (PDC) fibers and ceramic matrix composites (CMCs). The team, which includes co-principal investigators Alexandra Navrotsky (ACerS Fellow, University of California, Davis), Himanshu Jain (ACerS Fellow, Lehigh University), Rishi Raj (ACerS Fellow and Distinguished Life Member, University of Colorado Boulder), and Peter Kroll (ACerS member, University of Texas at Arlington), received a five-year $4.7 million grant late last year to generate new fundamental knowledge on the structure-property-processing of polymer-derived ceramics (PDCs) and ceramic matrix composites (CMCs). The ultimate goal is to reduce costs and improve performance for high-temperature applications—particularly jet aircraft turbines.

Credit: XY-AGP, Wikimedia (CC BY-SA 3.0)

A full-size mockup of CFM LEAP–X. The LEAP aircraft engine is the first widely deployed CMC-containing jet turbine.

The current PIRE study leverages support from national labs and foreign university partners to conduct PDC and CMC research. Already, in the first year, the PIRE program achieved several accomplishments, including: held the first NSF-PIRE-PDC workshop to promote face-to-face interactions among PIRE members and expand the scope of PDC fibers through research and education; organized a symposium on PDCs at the seventh International Congress on Ceramics in Brazil; and sent five undergraduate and two graduate students to PIRE partner institutions in Europe to be mentored by world renowned experts in the field of PDCs. According to the team, the global aspect of the project is key.

"Basic (and applied) research on next generation multi-component polymer-derived ceramic fibers at universities is conducted nearly entirely in Japan, Germany, France and Italy," says Singh in an email. "The PIRE team is concerned that US university research is not keeping pace with fundamental research on non-oxide ceramic fibers elsewhere in the world … Therefore, it is important to encourage and increase student opportunities for learning abroad."

During the second year of the grant, Singh says the team will continue work on molecular and rheological characterization of modified preceramic polymers and relate the rheological properties to the ability to draw fibers by hand in a lab setting.

"[The] biggest challenge would be to characterize the bulk chemical composition of the samples (especially hydrogen content) during the polymer to ceramic transformation stages," Singh says. Another challenge, Navrotsky adds, is getting well characterized samples.

Jain says they hope to build on the groundwork laid at the first NSF-PIRE-PDC workshop during the second year as well. "To realize the synergistic impact of the program, a well-coordinated effort of the various members of PIRE is needed," Jain says. "We started it at our last workshop and hope to strengthen it as we move forward."

Based on the research to date, two scientific papers were published in *Journal of Physics D: Applied Physics and Materials* and deposited in the NSF Public Access Repository while a third scientific paper—published in *Journal of the American Ceramic Society*—will be deposited in NSF–PAR. Singh was awarded a patent for his work titled "Aluminum-Modified Polysilazanes for Polymer-Derived Ceramic Nanocomposites." ■

Research News

Molecular adlayer produced by dissolving water-insoluble nanographene in water

Kumamoto University and Tokyo Institute of Technology researchers found a way to dissolve nanographene in water. Using micelle capsules—molecular containers that encapsulate water-insoluble molecules—the researchers developed a formation procedure for a nanographene adlayer by mixing the micelle capsules and nanographene together in water. The method is expected to be useful for the fabrication and analysis of next-generation functional nanomaterials. For more information, visit http://ewww.kumamoto-u.ac.jp/en/news/. ■

ceramics in the environment

Novel coating reduces corrosion and biofouling on ships

In a collaboration between Swinburne University of Technology, Defence Materials Technology Centre, MacTaggart Scott Australia, United Surface Technologies, and Defence Science and Technology, researchers may have found a way to solve the barnacle and corrosion problem on ships.

Barnacles secrete a quick-curing sort of "cement" that keeps them hanging on to boats, ships, and other seafaring vessels. For the shipping industry, barnacles can create major problems on commercial ships by increasing fuel costs as they contribute to the ship's drag.

In the recent study, the collaborative researchers developed a coating that reduced biofouling by nearly half when compared to other coatings.

"We used a supersonic combustion flame jet, i.e. a 'flame thrower,' to coat hydraulic machinery parts," senior research engineer at Swinburne and one of the lead scientists Andrew Ang says in an Australian Government Department of Defence news release.

In one of the experiments, the researchers tested three types of high velocity oxygen fuel (HVOF) coatings and compared them to an air plasma spray (APS) ceramic coating on over 100 samples of hydraulic components submerged in seawater. They found that after 20 weeks the HVOF coatings performed better than the APS coatings, as explained in the paper's abstract. In other words, HVOF coatings inhibited biofouling more effectively than APS coatings.

Although the coatings could become costly if used on the entire hulls of ships, they could at least solve biofouling and corrosion issues on the moving parts that are exposed to water.

The paper, published in *Taylor & Francis Online*, is "A comparison of the antifouling performance of air plasma spray (APS) ceramic and high velocity oxygen fuel (HVOF) coatings for use in marine hydraulic applications" (DOI: 10.1080/08927014.2018.1465052). ■

Credit: psybarartist; Flickr CC BY 2.0

A collaboration of Australian researchers developed a coating to keep barnacles from latching onto ships.

www.ceramics.org/gfmat-2-and-bio-4

ABSTRACT DEADLINE: JANUARY 14, 2019

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Organized by ACerS

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Bio-4 is organized by ACerS and its Bioceramics Division and endorsed by:

Society For Biomaterials

BMES Biomedical Engineering Society

IAOC International Academy of Ceramic Implantology

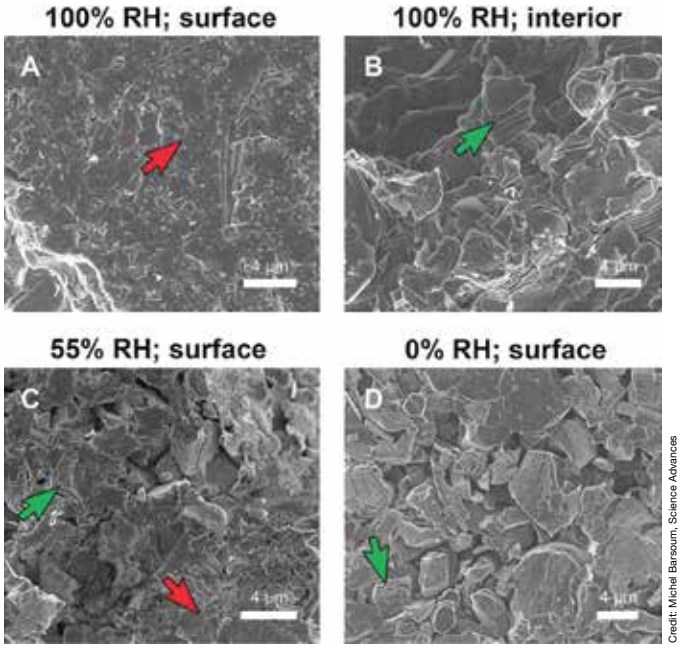
Research on MXenes expand…and so do the MXenes

In a paper by Michel Barsoum and his research group at Drexel University published in January, they found that the MXene titanium carbide exhibits pseudo-negative compressibility, a phenomenon typically limited to some clay minerals and carbon-based layered materials.

Negative compressibility is when a system increases in size isotropically as hydrostatic pressure increases, rather than decreasing in size as is typical. The reason negative compressibility occurs is because solvent molecules insert themselves between the weakly bonded layers of the compressed material, though the exact mechanisms behind the effect have not been perfectly explained to date.

In contrast to negative compressibility, pseudo-negative compressibility is where a system expands along certain directions. In the case of MXene titanium carbide, this layered material expanded along its crystallographic *c* direction by a large amount when uniaxially compressed into a disc by a steel die and to a small extent when compressed quasi-hydrostatically in a diamond anvil cell. In an email Barsoum explains the compression was quasi-hydrostatic instead of fully hydrostatic because "Water is not a fantastic transducer for perfect hydrostatic pressure in these experiments, and we had more of a slurry, so it is possible we did not have enough fluid to fully say that it was hydrostatic."

In the paper, Barsoum and his group explain the difference in expansion between the two compression methods is due to shearing. Under hydrostatic compression, pressure comes from all directions, compressing the MXene uniformly on all sides. But when the MXene is compressed uniaxially, the layers are able to slide against each other. "Imagine when you have these multilayers that there are bottlenecks around them that will not let water go in," says Barsoum in a Drexel press release. "As soon as you shear them, you break that barrier and water flows in and pushes the layers apart."



SEM images of various pressed MXene discs. Examples of multilayered particles at various states of shear are labeled with green arrows; regions of extreme shear are labeled with red arrows.

Why does it matter that MXenes exhibit pseudo-negative compressibility? One practical concern is in the area of electrical conductivity. In the paper, Barsoum and his group explain that a common way to report MXene conductivity is by first pressing the material into a disc—the compression technique shown to result in a larger expansion. Due to MXenes' hydrophilic nature (its tendency to mix with water), Barsoum and his group emphasize that humidity should be considered during disc compression, because high humidity in the compression environment could exacerbate the insertion of the water bilayer and lead to changes in the material's conductivity.

In an email Barsoum says they are not currently doing any more experiments on the expansion aspect of MXene, but there are several other aspects they are looking at. "We are more focused on what happens during etching and more importantly how MXene are [similar] or are not similar to clays," Barsoum says.

The paper, published in *Science Advances*, is "Pressure-induced shear and interlayer expansion in Ti_3C_2MXene in the presence of water" (DOI: 10.1126/sciadv.aao6850). ■

Cerium oxide's superpowers could reduce damage from radiation exposure

In new research at the University of Central Florida, scientists found that an antioxidant could substantially reduce damage to cells exposed to radiation.

Led by ACerS member Sudipta Seal, professor and chair of UCF's Department of Materials Science and Engineering, researchers discovered that treating tissues and DNA in mice with cerium oxide significantly decreased damage from radiation exposure, compared to a control group of mice that received no treatment. Their findings could be important in lowering the risks of radiation exposure astronauts face in space.

Credit: Karen Norum, UCF Office of Research

Sudipta Seal, professor and chair of the University of Central Florida's Department of Materials Science and Engineering, led research into an antioxidant that could substantially reduce damage from radiation exposure.

"The research is important in many ways besides space travel," Seal, who coauthored the study, explains in a UCF news release. "This type of material not only has a good synergistic effect to sensitize cancer cells but also to protect the good cells from radiation while you are doing therapy for treating cancer."

When the body is exposed to radiation, a chemical reaction causes molecules in the body to lose electrons, turning them into free radicals that can damage cells and especially DNA. Antioxidants are the heroes that give molecules the electron they lost in that reaction.

Cerium oxide typically is used as a powder to polish glass and other hard materials, but at the nanoscale it possesses strong antioxidant properties, according to the release.

Seal and his team tested cerium oxide nanoparticles over a one-month period on male mice that were exposed to radiation, according to the paper's abstract. Tissues examined from the mice showed a nearly 13 percent decrease in tissue damage compared to the control group that received no cerium oxide nanoparticles.

Seal has been investigating cerium oxide nanoparticles for many years, in radiation-induced cell damage and in mitigating radiation-induced lung injury. This latest research illustrates cerium oxide nanoparticles' potential for protecting DNA, which would be important not only for astronauts but for cancer patients going through radiation therapy.

The team's next step is human trials, Seal says, but they need the funding first.

The paper, published in *Nanoscale*, is "Engineered nanoceria cytoprotection in vivo: mitigation of reactive oxygen species and double-stranded DNA breakage due to radiation exposure" (DOI: 10.1039/C8NR04640A). ■

Ceramic metal composite could lower cost of electricity from solar power

The 2017 Lazard Report states that energy storage technologies have yet to be cost-competitive in most applications, and that "alternative energy systems alone will not be capable of meeting the base-load generation needs of a developed economy for the foreseeable future."

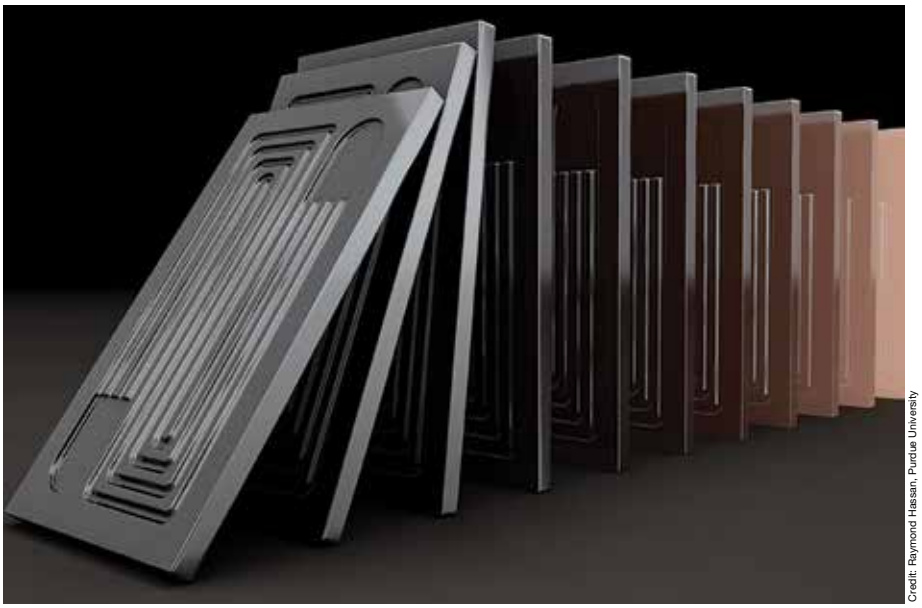
But researchers from Purdue University have already developed a way to reduce the cost and increase the efficiency of generating electricity. Led by Reilly Professor of Materials Engineering Kenneth Sandhage, in collaboration with Georgia Institute of Technology, University of Wisconsin-Madison, and Oak Ridge National Laboratory, the team created a novel ceramic-metal composite material that could replace materials typically used in heat exchangers in solar power plants.

"Storing solar energy as heat can already be cheaper than storing energy via batteries, so the next step is reducing the cost of generating electricity from the sun's heat with the added benefit of zero greenhouse gas emissions," Sandhage explains in a Purdue news release.

Solar power plants generate electricity by collecting sunlight to produce heat that goes through a system, using a turbine engine that powers an electricity-producing generator. But in order to reduce the cost of generating electricity from solar power, the engine would have to produce more electricity for a given amount of heat, according to the release.

The amount of heat produced from a heat exchanger is limited by the materials from which it is made. They are typically made of stainless steel or nickel alloys that cannot accommodate higher temperatures required to produce additional electricity at a specific heat level. But Sandhage and his team created plates out of a ceramic-metal composite of zirconium carbide and tungsten that include customized channels to facilitate improved heat exchange.

The research teams from ORNL and Wisconsin-Madison ran extensive tests for corrosion, increased temperature and pressure, and efficiency. For example, they found that the ZrC/W-based plates' thermal conductivity tested two to three times higher than iron or nickel alloys at the same temperature, according to the abstract.



Credit: Raymond Hassan, Purdue University

A team of researchers developed a ceramic-metal composite that would be cheaper to produce at scale than stainless steel or nickel alloy-based heat exchangers.

The Georgia Tech and Purdue teams conducted a cost analysis to determine that their ceramic-metal composite would cost less to produce at scale than stainless steel or nickel alloy-based heat exchangers.

The scientists have filed a patent and plan to continue their research. Their breakthrough could be a huge advancement in lowering the cost of producing energy from solar power.

"Ultimately, with continued development, this technology would allow for large-scale penetration of renewable solar energy into the electricity grid," Sandhage adds. "This would mean dramatic reductions in man-made carbon dioxide emissions from electricity production."

The paper, published in *Nature*, is "Ceramic–metal composites for heat exchangers in concentrated solar power plants" (DOI: 10.1038/s41586-018-0593-1). ■

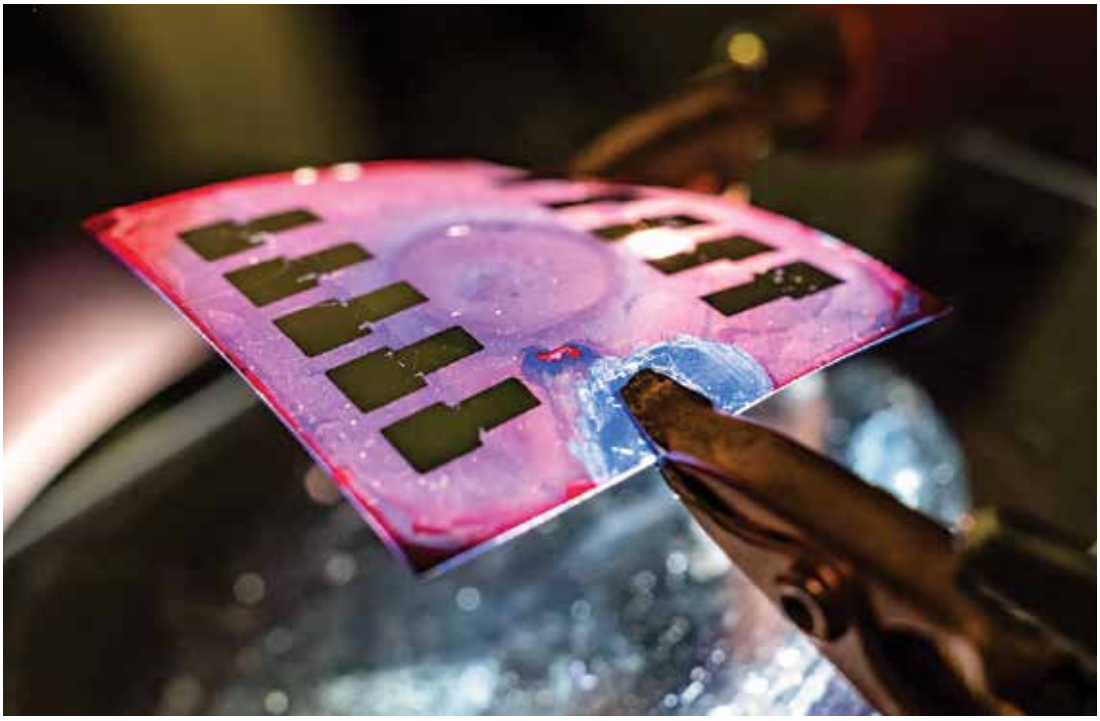
Closer to stretchy solar cells

Rafael Verduzco, chemical and biomolecular engineer, and his team at Rice University used an alternative approach to improving an organic solar cell's active layer's flexibility that did not require introducing polymeric additives. "Our idea was to stick with the materials that have been carefully developed over 20 years and that we know work, and find a way to improve their mechanical properties," Verduzco says in a Rice University news release.

Though organic solar cells are lightweight, flexible, and less expensive to fabricate than inorganic solar cells, organic cells can be brittle. There is no one component of an organic solar cell that makes it brittle—the electrodes, the substrate, and the active layer all fall victim to this issue. For organic solar cells to become less brittle, researchers must find ways to increase the flexibility of each individual part.

A number of studies have looked at improving the flexibility of the electrodes and substrate. Researchers at Gwangju Institute of Science and Technology,

Georgia Institute of Technology, and Jiangxi Science and Technology Normal University used the polymers PEDOT:PSS and polydimethylsiloxane (PDMS) and other additives to make flexible electrodes and substrates, while MIT researchers used graphene instead of the conventional material, indium tin oxide (ITO), to create flexible electrodes.



Credit: Rice University, Jeff Fitlow

Rice University researchers created flexible, organic solar cells that could be useful in situations requiring constant, low-power generation.

Creating a flexible active layer, however, has proven more of a challenge. Active layers made of an organic semiconductor blend perform multiple functions in the organic solar cell, including absorbing light and transporting both holes and electrons to the electrode. Because the active layer is a blend of materials rather than a single material, additives or compositional changes used to improve one property of the active layer—like the flexibility—could easily result in degraded performance in other areas, like the ability to absorb light.

In the article detailing their research, Verduzco and his team mixed sulfur-based thiol-ene reagents into the active layer, which was then placed on both ITO glass substrates and PDMS substrates for testing. They found there was a "Goldilocks Zone" for amount of thiol-ene: too little thiol-ene left the active layer prone to cracking under stress, while too much thiol-ene dampened the active layer's energy conversion efficiency. A thiol-ene mixture of about 20 percent balanced flexibility with efficiency.

The current research focused on P3HT:PCBM organic solar cells, so Verduzco says they expect to try different organic solar cells going forward to see if they can further optimize the thiol-ene network.

The paper, published in *Chemistry of Materials*, is "Network-Stabilized Bulk Heterojunction Organic Photovoltaics" (DOI: 10.1021/acs.chemmater.8b03791). ■

Ceramic Tech Today blog

www.ceramics.org/ceramictechtoday

Access to clean water is a daily challenge for 1.8 billion people in the developing world. The United Nations has set a goal of ensuring safe drinking water for all by 2030.

Filtering safe drinking water through granulated ceramics

Modular filters based on silver-coated ceramic granules provide sustainable, affordable access to clean water when water treatment infrastructure is lacking.

By Reid Harvey, Mike Chu, and John Hess

The world is thirsty for safe drinking water. But too many do not have access, especially in developing regions. Silver-treated ceramic granule filters offer an affordable, sustainable option for purifying water in households, and even on municipal scales.

Introduction

Worldwide, the predominant problem with drinking water is a prevalence of pathogen contamination. According to a United Nations fact sheet,[1] 80 percent of wastewater reenters the environment untreated. An estimated 1.8 billion people use water sources contaminated with pathogens from untreated urban wastewater, agricultural runoff, and other contaminated water sources, which expose them to increased risk of water-borne pathogens such as cholera, dysentery, typhoid, and polio. The problem is most pronounced in countries at the lower end of the economic spectrum that tend to lack wastewater management infrastructure such as sewer systems and water treatment plants.

Systematic challenges

Municipal water treatment involves the use of chemicals, coagulation, flocculation, and filtering through sand, along with such exotic approaches as ultraviolet and reverse osmosis. Implementing these types of water treatment systems in the developing world could work technically, but is difficult to sustain and is limited by problems with delivering water. In addition, municipal treatment can be too expensive for poor communities to implement.

On the household scale, inexpensive water treatment usually involves the use of chlorine, which requires a level of education for testing and dosing that presents a barrier to those who may never have been to school. Boiling contaminated water is an alternative. Even so, of the various household alternatives, only boiling is one purification method that has achieved scale.[2] However, those whose daily income is below poverty levels cannot afford fuel for boiling.

Other forms of acquiring clean water include solar distillation (setting a bottle of water in the sun for six hours) or rainwater catchment. However, these, too, are not sustainable nor user-friendly. Additionally, rainwater catchment depends on the bounty of the sky.

In much of the developing world, water is collected by women as part of their household duties. In their collection of water, these women may walk or stand in line for hours every day. Water collected this way is most often pathogen-contaminated, and, worldwide, well over a thousand small children die every day because of their drinking water.[3] Small children with immature immune systems get diarrhea, which leads to dysentery and death. Parents may not recognize the warning signs in time to give children life-saving oral rehydration therapy.

United Nations priority

The United Nations identified 17 Sustainable Development Goals (SDGs) comprising a roadmap "to achieve a better and more sustainable future for all" by 2030.[3] Clean Water and Sanitation—Goal 6—is both a consumer product and a human right. According to the UN, sanitation and drinking water improvements have led to "over 90% of the world's population now [having] access to improved sources of drinking water." However, the UN calls for increased investment in freshwater management and local-level sanitation systems, especially in at-risk regions of Sub-Saharan Africa, Central Asia, Southern Asia, Eastern Asia, and Southeastern Asia.

Solutions proposed for the developing world tend to focus on conventional municipal water treatment, often on a smallish scale. Unfortunately, many such development efforts have failed in the past owing to little provision by the donor for maintenance after the first couple of years.

Point-of-use water treatment

The need for point-of-use water treatment in the developing world for rural areas is obvious. However, point-of-use water treatment in urban areas, where the delivery infrastructure from municipal treatment tends to be damaged or non-existent, is also needed to avoid delivering water that gets recontaminated on its way to communities.

Modular, portable solutions that do not rely on other plant facilities and infrastructure—such as reliable electricity service—may offer an effective pathway to providing clean, safe water for millions of people. Chemical-free water purification systems also are desirable, as chemicals introduce a supply chain dependency and require physical plants or other infrastructure to implement. Low cost and ease of maintenance are urgent priorities.

Heavy metals exert a toxic effect on pathogens that generally renders them harmless. Unfortunately, consuming

United Nations Sustainable Development Goals[3]

1. No poverty
2. Zero hunger
3. Good health and well-being
4. Quality education
5. Gender equality
6. Clean water and sanitation
7. Affordable and clean energy
8. Decent work and economic growth
9. Industry, innovation, and infrastructure
10. Reduced inequalities
11. Sustainable cities and communities
12. Responsible consumption and production
13. Climate action
14. Life below water
15. Life on land
16. Peace, justice, and strong institutions
17. Partnerships for the goals

United Nations targets for achieving Goal 6: Clean water and sanitation

1. By 2030, achieve universal and equitable access to safe and affordable drinking water for all
2. By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
3. By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
4. By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
5. By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6. By 2020, protect treatment, recycling, and reuse technologies
7. Support and strengthen the participation of local communities in improving water and sanitation management

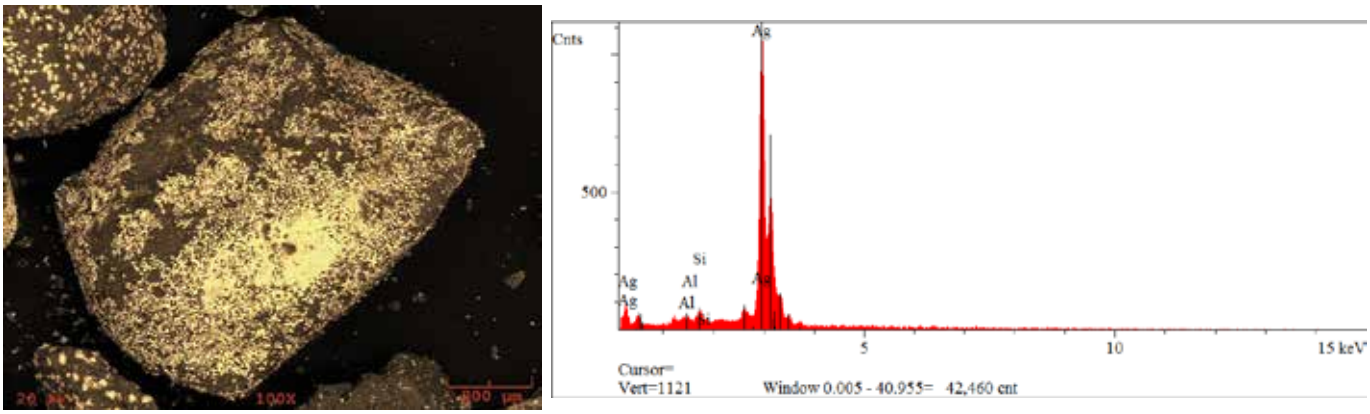


Figure 1. (a) Scanning electron micrograph showing bright regions of silver deposits on ceramic granules. (b) Energy dispersive spectroscopy X-ray spectrum confirms localized silver deposits on an aluminosilicate clay particle.

even small amounts of heavy metals can harm people. Silver, however, has no deleterious health effect for those ingesting minute amounts, and it has long been exploited for its antimicrobial properties, even in ancient times. Since the 1970s nanoscale silver has been used as the active antimicrobial ingredient in drinking water purification systems.[4] Because of the prevalence of silver-containing water purification systems, the EPA[5] set a standard for leached silver levels not to exceed 0.1 milligrams per liter (100 micrograms per liter).

For at least 10 years researchers have worked on impregnating porous clay-based ceramic filters with colloidal silver as simple water purification systems using local clay resources and not requiring infrastructure such as electricity. These silver-ceramic filters have been shown to be effective water purifiers. Oyanedel-Craver and Smith[6] made cylindrical filters from clay-rich soil, water, grog, and flour and applied silver by either dipping or painting. They measured filters exposed to water contaminated with Escherichia coli (E. coli) and found they removed 97.8 to 100 percent of the pathogen.

Filter effectiveness requires pathogens to encounter the silver to experience its lethal influence. Thus, a filter using silver-treated granules will expose large surface areas of silver, and the granular media introduces more pathways for contaminated water to wash past silver.

The lead author (Harvey) first developed a water filter media during a 2003 visit to Kathmandu, Nepal, in response to an urgent need for water, sanitation, and hygiene (WASH). Working with a local pottery along with a local NGO and UNICEF systems, monolithic candle filters of common earthenware red clay went into thousands of low income homes and into large-sized filter systems for 800 schools of rural districts. The use of red clay suggested the reproducibility of the model, and a subsequent such project was implemented in Kenya.

TAM Ceramics (Niagra Falls, N.Y.), long a manufacturer of high-purity ceramic granular media, has licensed the technology from the lead author (Harvey) and is optimizing a water filter media with silver-coated ceramic gran-

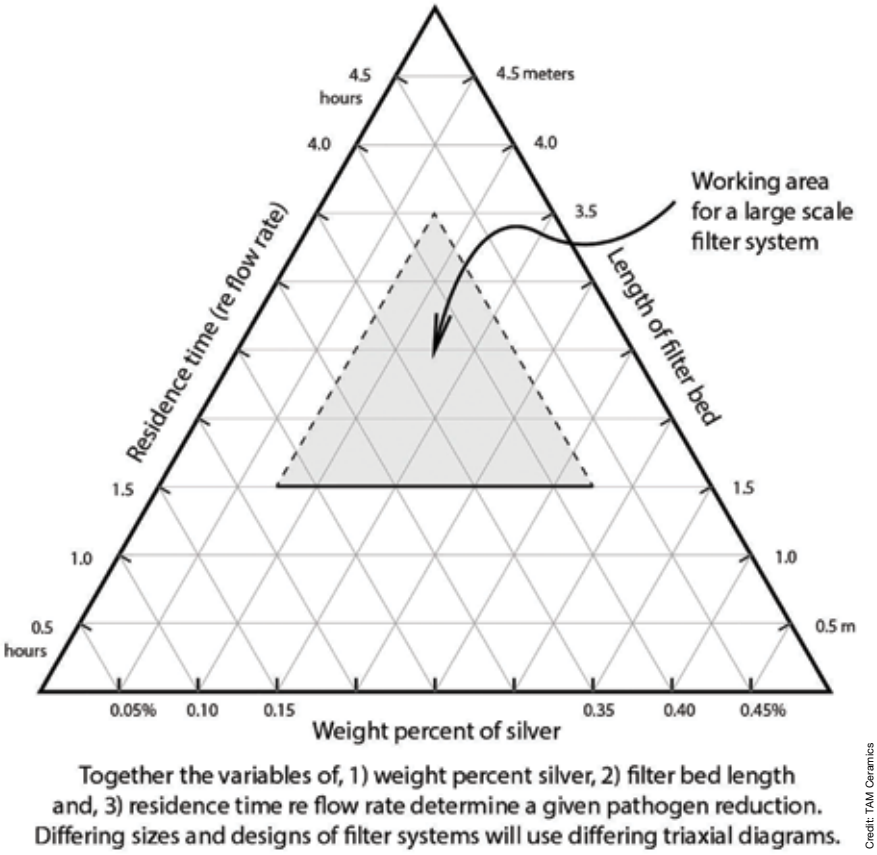


Figure 2. Triaxial diagrams aid optimization of filter system design by demonstrating relationship between amount of silver, filter bed length, and flow rate. The area shaded grey represents the region of optimal filter design. Diagrams will vary based on filter system size and design.

Credit: TAM Ceramics

Figure 3. A granulated media water filter suitable for households costs $3 to $6.

ules. As pathogens flow through the granulated filter bed they are deactivated through the oligodynamic effect from repeated contact with the silver.

For the granulated filter media, the inventive step in development was simply to crush and granulate a silver treated candle filter. This granulated media was then put into sections of thin-walled PVC pipe, ending up with a remarkably low-cost system of household water treatment. This approach is as innovative today as it was in 2003 Kathmandu, considering the dearth of sustainable technologies. Mere clay is indeed the way.

To functionalize the filter media, fired ceramic granules are treated with a silver solution followed by a second firing to bond the silver (Figure 1a). X-ray energ dispersive spectroscopy confirmed the presence of silver on the granules (Figure 1b).

We tune granule particle size distribution to the customer's filter design and application, within sensible limits. In general, coarser particles give a fast flow rate, while finer particles give a slower flow rate and longer residence time. Triaxial diagrams, such as Figure 2, help with establishing optimal conditions with respect to particular filter containment, size, and design.

The filter itself, shown in Figure 3, is not very large. A community-sized system containing four 8-inch PVC "candles" filled with silver-coated ceramic media produces up to 100 gallons of clean water per hour. A household-sized filter produces up to two liters of clean water per hour and costs $3 to $6. These systems should last about 10 years.

Testing effectiveness

The number of pathogen–silver contacts is determined by the amount of silver, the length of the granulated filter bed, and the residence time of the pathogens. Pathogen reduction varies with the amount of silver used in treatment, between 99.90 percent and 99.99999 percent (log 3 to log 7 effectiveness). While filter media providing log 3 pathogen reduction would be appropriate for such applications as hand washing, filter media yielding log 7 pathogen reduction should be acceptable in clinics or hospitals.

Water with 99.9999 percent (log 6) pathogen reduction is considered suitable for drinking. However, in worst case scenarios, a log 3 reduction or even less is arguably an acceptable, pragmatic threshold that could work for greater numbers of vulnerable populations.

TAM continuously works with certified laboratories to refine test set-up and procedures. Testing for E. coli reduction assures that the filter media does its job getting people safe drinking water. Small children are especially vulnerable to E. coli, never having had a chance to develop immunities. Filter granules have been shown to reduce E. coli between log 3 and log 7. The filter lifetime will be no less than 10 years, but can be greater if requested.

Municipal water utility treatment traps pathogens with slow sand, which allows about one percent to get through. A subsequent step with chlorine or a look-alike disinfectant destroys the one percent of pathogens that slip through slow sand filtration. In contrast, for prospective municipal-scale applications, TAM's filter media has the advantage of combining filtration and disinfection into a single step.

A scalable future

TAM's granulated ceramic filter systems are genuinely sustainable in addition to being suitable for filters of any size—a first. For the developing world, since 2003 there has been an emphasis on household water treatment, on a point-of-use basis. Now, however, large-scale filter systems offer an altogether new paradigm for delivering safe water to entire communities. Clean, safe water can be made available for everyone simply by the force of gravity. These filters offer clean water at accessible prices, too. A household-scale filter costs $3 to $6.

Is water a human right, a consumer product, or both? Despite intense debate, the question remains unresolved. However, TAM Ceramics suggests that sustainability be a qualification to help answer the question of rights versus cost.

Systems based on filter media are sustainable and low cost. The cost of the filter media will be as low as possible when granules are manufactured in close proximity to the market, a step that will happen once the market has been established. In addition, these filters are more user friendly than competing water purification systems.

Ceramists are uniquely positioned in their capacity at getting people safe drinking water and clean air around cook stoves, as well as industry from the grassroots. There is arguably no other approach to manufacturing that makes possible so much fundamental industrial development. Of the 17 Sustainable Development Goals, nearly all are addressed squarely by the capabilities of ceramists—it all starts with safe drinking water and environmental health.

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Credit: Golisano Institute for Sustainability at the Rochester Institute of Technology

Glasses, ceramics, and metals are critical to a clean energy and mobility transition

Understanding the intensity and criticality of materials used in clean energy production, low emission transportation, and lighting helps engineers design solutions for a more sustainable world.

By Alexandra Leader and Gabrielle Gaustad

The continued growth and development of our economies comes with significant attendant environmental impacts. Across the globe, raw material usage for both energy generation and manufacturing alike has increased exponentially, and the growth is likely unsustainable. Hurricanes, massive forest fires, and unprecedented flooding have become increasingly recurrent phenomena in the past few years, likely caused and/or exasperated by the impacts of climate change. Anthropogenic greenhouse gas emissions, generated by the sectors shown in Figure 1a, are proven contributors to climate change. Fortunately, the minerals, metals, glass, and ceramics industries embraced these challenges as opportunities to drive groundbreaking work in their fields. For example, they developed clean energy technologies to address electricity and heat production, building, industry, transportation, and other energy categories, tackling a total of 76 percent of the total global greenhouse gas emitting sectors.[1] These technologies, however, also require material consumption; understanding their use and supply is key to ensuring overall sustainability.

A greener, safer world

Clean energy technologies are vital for addressing climate change not only in developed countries but also in developing countries, which will continue to increase their material and energy consumptions and emissions as they reach lifestyle parity with developed nations. According to the World Resources Institute, the per capita greenhouse gas emissions for developed countries are on average approximately four times those of developing countries.[3] It is of paramount importance to provide developing countries the opportunity to progress, and clean energy technologies can help them to potentially leapfrog currently industrialized nations by avoiding having their energy infrastructure based on fossil fuels.

The United Nations Sustainable Development Goals identified 17 sustainability goals for the year 2030, a few of the most relevant here being the need for affordable and clean energy, decent work and economic growth, and reduced inequalities.[4] Many technologies were established to assist with reaching the goals while mitigating environmental damage. We will refer to these technologies as clean energy technologies, because even though they still have environmental footprints, these technologies aim to be less harmful to the environment than comparative incumbent technologies. Such advances should help create a cleaner and safer world, with less greenhouse gas emissions, pollution, and toxicity. While these technologies are imperfect, they continuously become more efficient and contain fewer hazardous and critical materials.

Life-cycle assessment (LCA) is a common tool used to determine the environmental consequences of a product or process over the entirety of its lifespan. The assessment can be used to compare different options or to find "hotspots" within a product or process that are most detrimental to the environment. For example, how do we know that the mining and production processes for critical materials and clean energy technologies do not outweigh the benefits?

The sustainability science community conducted several LCAs to answer these types of questions. For the case of lithium ion batteries, Stamp et al. used lifecycle analysis to examine whether the production process for lithium could possibly outweigh the benefits of using electric vehicles compared to internal combustion engines. They found that the environmental impacts of lithium production would only be prohibitive if seawater was used to produce lithium carbonate in the future. With the current methods of brine and ore production, the benefits of electric vehicles outweigh the negative impacts associated with lithium production.[5]

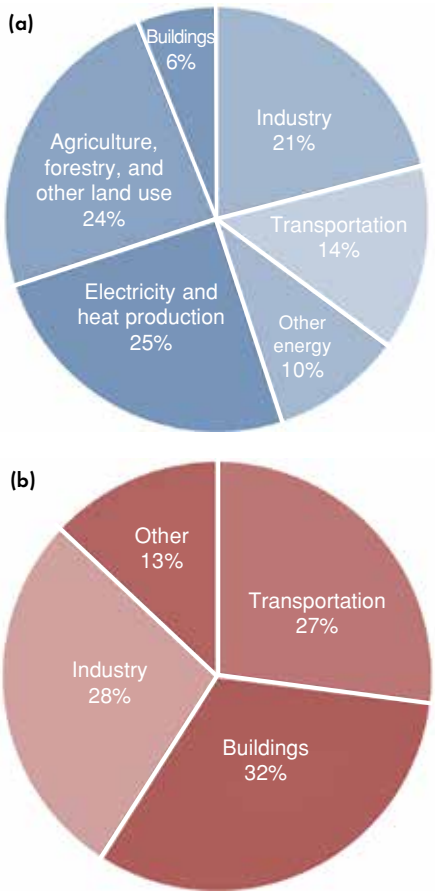

Figure 1: (a) Global greenhouse gas emissions by sector (2010), total emissions were 49 Gt CO_2eq.[2] (b) Global energy demand by end use sector (2010), total energy demand was 366 EJ.[2]

Critical materials for clean technologies

In the literature, many materials are identified as critical in seven categories of clean technologies. These categories include: the clean energy production technologies of solar panels, wind turbines, and gas turbines; the low emission mobility technologies of fuel cells, batteries, and motors; and the energy efficiency technology of efficient lighting devices. Each of these technologies relies on a set of materials, some of which are readily available, and others that are vulnerable to supply disruption, price instability, and/or high embodied energies. While different organizations define a material's "criticality" slightly differently, criticality can be described generally as the risk associated with the use of a specific material, stemming from the likelihood of a supply disruption or price spike, combined with the impact of such an event occurring.

An example of how criticality is defined is seen in how the US Department of Energy (DOE) identifies materials that are critical to clean energy technologies. The DOE uses two measures to define criticality: "supply risk" and "importance to clean energy."[6] Supply risk can come from a material having a high production concentration (geographically), high concentrations in politically unstable regions, large environmental impacts (that might be subject to environmental regulations), low recycling rates, and low substitutability. For the case of clean energy technologies, the DOE's "impact" measure of importance to clean energy technology is most relevant to this article; however, in other cases, importance to healthcare, military applications, or consumer electronics may be considered.

The DOE report titled "Critical Materials Strategy" analyzes forecast demands for 16 elements based on a range of material compositions in permanent magnets (in wind turbines and electric vehicles), batteries (in electric vehicles), semiconductors (in solar), and phosphors (in efficient lighting). To deal with the uncertainty of material intensity, level of global clean energy deployment, and market share, various scenarios are employed to capture high and low ranges in each of these uncertainty categories. The ability of supply to meet projected demand is then weighted at 40 percent for calculating the "supply risk" portion of the element's criticality, while the demand itself made up 75 percent of the

"importance to clean energy" criterion. Without getting into the details of each scenario and element, we would instead point to the chosen methodology and the results that put dysprosium, terbium, europium, neodymium, and yttrium on the list of critical elements in the short and medium term; cerium, indium, lanthanum, and tellurium as near critical in the short term; and lithium and tellurium as near critical in the medium term.[6]

Many studies used different methods for calculating metrics that measure material criticality, including an article by Graedel and Nuss that quantitatively scores the criticality of 62 elements.[7] A review article by Erdmann and Graedel is helpful in summarizing such studies.[8] Some examples of more prolific metrics include those revolving around the quantity of material resources available, the cost of the material, and market concentration (often measured by the Herfindahl-Hirschman index). For example, in a study by Olivetti et al., they analyze the criticality of lithium, cobalt, manganese, nickel, and carbon in different Li-ion battery chemistries[9] using the metrics of reserves/primary mine production, fraction of production from the top-producing country, geopolitical stability of the top producing countries, the byproduct or primary product nature of the materials, the ability of supply to meet demand projections, and the viability of recycling. Overall, the study showed that cobalt is the primary concern for Li-ion batteries in the short term, but with potential for scaling concerns for lithium as well (as Li-ion batteries are expected to experience rapid uptake in the coming years).[9]

Through literature review, we identified the critical metals, ceramics, and glasses contained in the previously described clean energy production, low emission mobility, and energy efficiency technologies shown in Table I. The three types of clean energy production technologies considered here are solar panels, wind turbines, and natural gas turbines.

Within the solar panel category, materials are listed for cadmium-tellurium (CdTe), crystalline-silicon (c-Si), and copper-indium-gallium-selenide (CIGS). In 2016, approximately 6 percent of the world's solar production was in thin-film solar, with 3.8 percent of that being CdTe and 1.6 percent being CI(G)S. The remaining 94 percent of solar production in 2016 was comprised of mono- and multi-silicon at 24.5 percent and 69.5 percent, respectively.[10] In CdTe solar cells the cadmium and tellurium make up the active (or absorber) layer in a ratio of approximately 48:52.[11] Typically, the absorber layer will have a thickness of approximately 1-3 µm,[12] yet the range found can be as large as 1-10 µm. In CIGS solar cells the indium and gallium are contained in the absorber layer, which ranges between 1-2.5 µm.[13] Recently, studies have examined replacing some of the indium content with more gallium in order to increase the bandgap, allowing for greater efficiencies.[14] In crystalline silicon solar panels, silver is used in the screen-printing pastes, especially for its low electrical resistivity.[15] Tin and indium are used in the transparent conducting oxide layers.[10]

In wind turbine technology, we specifically consider the permanent magnets used in direct-drive wind turbines. In 2015, approximately 23 percent of globally installed wind capacity relied on NdFeB permanent magnets, which can contain neodymium, dysprosium,

Table I: Metals, ceramics, and glasses in clean energy production, low emission mobility, and energy efficiency technologies. For a list of table references, check the online version of *ACerS Bulletin*.

			Glasses and ceramics	Glasses and Ceramics Sources	Metals	Metals Sources
Clean energy production	Solar panels	CdTe	SnO_2, Zn_2SnO_4, ZnO, SnO_2, Cd_2SnO_4	[1, 2]	Cd, Te, Ni, Cr, Mo	[3-9]
		Crystalline silicon	c-Si	[10]	Ag, Sn, Ni	[6]
		CIGS	ZnO, NaO, CaO, SiO_2	[11, 12]	In, Ga, Se, Sn, Ni, Cr, Mo	[3-6]
	Wind turbines	Permanent magnet	$Sr_6Fe_2O_3$, $Ba_6Fe_2O_3$, Si_3N_4	[13, 14]	Dy, Nd, Mo, Tb, Pr	[6, 15-21]
	Gas turbines	Superalloy coating	Y_2O_3-ZrO_2, CMC, Si_3N_4, 1-xBaO·xSrO·Al_2O_3·2SiO_2, $0 \leq x \leq 1$, Al_2O_3, Si_3N_4, SiC	[14, 22]	Co, Ni, Re, Hf, Mo, Y	[23, 24]
Low emission mobility	Fuel cells	SOFC	Ni/YSZ, $LaMnO_3$, LSCF, ScSZ, LSGM, YSZ, LSM, LSC, $LaMnSrO_3$, La(Sr, Mn, Ca)CrO_3	[14, 25-27]	Y, La, Ce, Co, Sm, Gd, Sr, Ni	[26, 28]
		PEM			Pt	[5, 19, 29, 30]
	Batteries	Li-ion	$LiCoO_2$, $LiMn_2O_4$, $LiFePO_4$, $LiMn_{1.5}Ni_{0.5}O_4$, $LiNiMnCoO_2$, $LiNiCoAlO_2$, $Li_4Ti_5O1_2$	[31, 32]	Li, Co, Ni, Mn, Dy, Pr, Nd, V, Tb	[5, 19, 33-35]
		NiMH			Pr, Nd, La, Co, Mn, Ni, Ce, V, Tb, Dy	[5, 15, 18, 33, 36, 37]
	Motors	Permanent magnet	$Sr_6Fe_2O_3$, $Ba_6Fe_2O_3$, Si_3N_4	[13, 14]	Dy, Pr, Nd, Co, Tb	[5, 15, 16, 18, 21, 36, 38]
Energy efficiency	Lighting devices	CFL	BAM, CAT, LAP, YAG, GaAs, GaN, InGaN	[39]	Ga, La, Ce, Tb, Eu, Y, Gd, Mn, Ge, In	[5, 39, 40]
		LFL	BAM, CAT, LAP, YAG, GaAs, GaN, InGaN	[39]	La, Ce, Tb, Eu, Y, Mn, Ga, Ge, In	[5, 39, 40]
		LED	$Y_3Al_5O_{12}$:Ce^{3+}, YAG, LuAG, GAL, $LaPO_4$:Ce, Tb, $BaMgAl_{10}O_{17}$:Eu & (Sr, Ca, Ba)$_5$(PO_4)3Cl:Eu, Y_2O_3:Eu, (Y,Eu)$_2O_3$, InGaN	[39, 41-43]	In, Ga, Ce, Eu, Y, Gd, La, Ni, Tb, Ge, Ag, Sn	[40]

praseodymium, and terbium. The other 77 percent used electromagnetic generators containing steel and copper for their functionality, neither of which are considered critical materials.[16] Wind turbines can be classified into two major categories: geared and gearless (direct-drive). Gearless, direct-drive turbines operate best at low speeds and have the advantages of better overall efficiency, lower weight, and fewer maintenance requirements.[16] Geared turbines, on the other hand, will operate at higher speeds on smaller turbines (< 5MW) and contain few or no rare earth elements.[16] Pavel et al. estimate that permanent magnets could be dematerialized from currently containing 29-32 percent Nd/Pr and 3-6 percent Dy to 25 percent Nd/Pr and <1 percent Dy by 2020.[16] Direct substitution for rare earth elements will be challenging, but efforts are being focused on finding new magnet compositions and/or using different components that don't rely on rare-earth-containing permanent magnets at all.[16]

Natural gas turbines may not typically be considered a clean energy technology. However, it is widely agreed that natural gas, while still an imperfect finite resource, is a cleaner alternative than coal. Gas turbine blades have to withstand high centrifugal stresses and are exposed to extreme temperatures,[17] so the superalloy coating on the blades contains critical materials to address these challenges. Currently, nickel-based superalloys contain rhenium and hafnium (for their high temperature properties) to achieve sufficient refractoriness.[17,18] Rhenium is often the focus of dematerialization efforts because it is used in much greater quantities in the superalloys than hafnium. In addition, rhenium has a history of price volatility, and after the large price spike in 2007, companies that use rhenium, such as General Electric, began to apply methods such as dematerialization and in-house recycling to reduce their risk.[19] Alloys have been designed containing half as much, or no, rhenium, but at this point none can match the high temperature creep resistance of the superalloys currently used.[20] About 80 percent of rhenium production is a byproduct of copper mining, adding to its criticality.[20]

For clean mobility we focus on electric vehicle components, including the energy sources of fuel cells and batteries as well as the permanent magnets in the motors. We considered permeable exchange membrane (PEM) and solid oxide fuel cells (SOFCs), and lithium-ion (Li-ion) batteries and nickel metal-hydride (NiMH) batteries. Currently PEM fuel cells dominate the fuel cell electric vehicle marketplace, with little or no SOFCs present. While NiMH batteries are currently the dominant battery choice for hybrid electric vehicles, some expect numbers as high as 70 percent of hybrid electric and 100 percent of plug-in and full electric vehicles to use lithium ion batteries by 2025.[21] Of primary concern are the rare earth elements in the permanent magnets and NiMH batteries, lithium and cobalt in the Li-ion batteries, and platinum in the fuel cells.[22]

Finally, in representation of energy efficiency technologies we choose three types of light bulbs: compact fluorescent lightbulbs (CFLs), linear fluorescent lightbulbs (LFLs), and light-emitting diodes (LEDs), all of which are more energy efficient than traditional incandescent bulbs. In lighting, most of the critical materials (especially rare earth elements) are found in the lamp phosphors.[23] The phosphor is coated on the inside of the bulb and therefore the quantity of rare earths used often varies directly with the size of the bulb (especially for linear fluorescents).[6] Europium and yttrium create red, terbium produces green, and europium gives blue phosphors.[24] LEDs use fewer rare earths than fluorescent bulbs; however, they also contain gallium and indium in their semiconductor diodes.[23]

The materials used in the technologies listed in Table I are required in certain quantities per effective unit of output. This so called "material intensity" is important, especially as a metric of comparison between two or more materials within a technology or between two or more comparable technologies. For example, when discussing the quantity of tellurium per CdTe solar panel, depending on the application, it would be less useful to speak in terms of tellurium per panel but rather to discuss the intensity of tellurium in mass per kW of solar capacity. Identifying material intensities of important materials for clean energy technologies is the first step to selecting technologies that not only have the desired properties and costs as has been done historically, but that also have lower social, environmental, and economic impacts. While material intensity is an important indicator in terms of quantity of material that is being used per functional output of the technology, it is also important to consider the more qualitative aspects of the materials these technologies contain, such as their degree of criticality, as previously discussed.

Engineering a better world

By better understanding the materials used in clean technologies and their implications in terms of environmental impact, social impact, and potential for supply disruption, we can engineer solutions for a better, more sustainable world. This trend of considering broader implications when selecting materials is becoming more common. When designing products, many firms have started thinking more comprehensively about material qualities beyond the traditional material properties and price, considering recyclability, carbon and water footprints, overall lifecycle impacts, supply risk, and social implications. Material selection software continues to integrate sustainability impacts to aid engineers and scientists in making properly robust but environmentally aware material decisions. Computational material discovery efforts also aid in producing low impact materials by design. A variety of this work uses machine learning to look at common recipes that result in the combination of desired properties, an efficient production or scale-up technique, and an understanding of the likely environmental impacts.

Many studies consider material requirements on the basis of meeting various climate change mitigation targets. These studies are important to consider as they reflect on the larger picture of whether we have the quantity of materials necessary to produce these clean energy technologies to the extent needed to mitigate climate change to various levels, as described in the individual

studies. For example, Alonso et al. considered only rare earth elements in wind turbines and electric vehicles and found that if atmospheric CO_2 is to be kept at 450 ppm, neodymium and dysprosium may experience an increase in demand of more than 700 percent and 2600 percent, respectively (from 2010 numbers), by 2035.[25] Another analysis by Grandell et al. identifies potential "bottlenecks" for critical metal supply through 2050. They consider solar, wind turbines, fuel cells, batteries, electrolysis, hydrogen storage, electric vehicles, and efficient lighting as clean energy technologies. Silver is identified as the most likely issue, alongside other potential bottlenecks for tellurium, indium, dysprosium, lanthanum, cobalt, platinum, and ruthenium. Their stance is that these bottlenecks could prove enough to render the IPCC renewable energy scenarios "partly unrealistic from the perspective of critical metals."[26] A paper by Jacobson and Delucchi theorizes the impact of providing "all global energy with wind, water, and solar power." In terms of material limitations, they conclude that such a system would likely not be inhibited by the availability of bulk materials but other materials, such as neodymium, platinum, and lithium, would need to be recycled, substituted out, or found in new deposits.[22] Finally, a study by Bustamante and Gaustad considers a very specific case study of tellurium in CdTe solar cells. They find that tellurium availability is likely to dampen CdTe adoption; however, they go on to explain that this is more likely to occur due to the byproduct nature of tellurium rather than its overall resource quantity. Based on the current supply infrastructure for tellurium—in which it is a byproduct mineral—they predict that tellurium availability is insufficient to meet even conservative demand estimates.[27]

Material criticality is dynamic, and as clean energy technologies evolve, so are the material compositions and forecasted adoption rates. We must be proactive in designing clean energy technologies in terms of our material choices so as to use those materials that are not only cost effective and functional but also sustainable. It is also important that we continue predicting and monitoring the material requirements for clean energy technology demand so as not to impede the implementation of the technologies that will play a critical role in providing a cleaner, safer, and more sustainable world.

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National Science Foundation awards in the Ceramics Program starting in 2018

By Lynnette D. Madsen

As an independent federal agency of the United States government, the National Science Foundation (NSF) funds basic research conducted at America's colleges and universities. NSF's Ceramics Program in the Division of Materials Research resides within the Mathematical and Physical Sciences Directorate. There are six other science and engineering research and education directorates at NSF, including Engineering.

The mission of the Ceramics Program is to support fundamental scientific research in ceramics (e.g., oxides, carbides, nitrides, and borides), glass-ceramics, inorganic nonmetallic glasses, ceramic-based composites, and inorganic carbon-based materials. The program aims 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. Proposals relating to discovery or creation of new ceramic materials are welcome, as are the development of new experimental techniques or novel approaches. The Ceramics Program supports research at universities and colleges of all sizes, from research universities to colleges that serve undergraduates. The principal investigators (PIs) of these projects include faculty at all levels from assistant to full professors.

This article marks the fourth annual summary of NSF Ceramics Program awards to appear in *ACerS Bulletin* [1, 2, 3] and the second year that the Ceramics Program has been piloting no-deadlines for submissions (NSF 16-597). This approach has been used in the Geosciences and Engineering Directorates at NSF and by foreign agencies. In June 2018, the Engineering Directorate announced removal of deadlines for many of its core programs (NSF 18-082).[4]

Eliminating deadlines better accommodates the schedules of PIs and encourages submission of emerging ideas. In addition, it opens the door to better proposal quality and spreads the workload for reviewers and NSF program directors more evenly throughout the year, resulting in quicker review and award cycles. Under this pilot, PIs submitting to the Ceramics Program are requested to suggest reviewers, and annual budget requests are typically $110,000 to $160,000 per year for each project, subject to the availability of funds; smaller budgets are permissible. Budgets in excess of $160,000 per year may be returned without review.

The number of full proposals received by the Ceramics Program continues to be fewer than years with a deadline. However, the number of submissions increased significantly between 2017 and 2018. There are about 130-150 active awards in the Ceramics Program at any given point in time.

Table 1 provides a key to types of grants awarded in FY 2018 by the NSF Ceramics Program, and Table 2 lists FY 2018 awards. Detailed 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, instrumentation awards, and other programs focused on one or two investigators (e.g., in the Engineering Directorate).

FY 2019 began Oct. 1, 2018, and the first awards have appeared. NSF recommends submitting full proposals 9–12 months before the funds are needed to allow six months for review and time to process awards. Supplemental proposals are best submitted in February. In particular, NSF encourages supplemental requests for the addition of veteran and underrepresented minority graduate students to projects (through MPS-GRSV: NSF 15-024 and AGEP-GRS: NSF 16-125), Career–Life Balance supplements (for leaves of absence for dependent care responsibilities), collaborations with NIST (NSF-NIST 11-066), and interactions with industry (through GOALI or INTERN NSF 17-091). PIs must acknowledge NSF support in any publications or presentations. An example of appropriate wording is: "This material is based upon work supported by the National Science Foundation under Grant No. (NSF grant number)." Annual reports are due in the spring (regardless of anniversary date). All products listed in the reports should acknowledge NSF support. See www.nsf.gov/funding for full information about proposal submission and award requirements.

About the author

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

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Table 1. Types of NSF awards made in FY 2018. Colors key to awards listed in Table 2.

Conferences

Special Guidelines are found in the Proposal & Award Policies & Procedures Guide for conference and workshop proposals.

Faculty Early Career Development Program (CAREER)

The CAREER program (NSF 17-537) is restricted to single investigators who are assistant professors.

Grant Opportunities for Academic Liaison with Industry (GOALI)

GOALI (described in the Proposal & Award Policies & Procedures Guide) 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.

RUI

Facilitating Research at Primarily Undergraduate Institutions (14-579).

Collaborative Research

A collaborative effort on a unified research project through the simultaneous submission of proposals from different organizations, with each organization requesting a separate award.

Table 2. NSF Ceramics Program awards made during FY 2018

Title (award no.)	Principal investigator (PI), organization; co-PIs
2018 Professional Development Workshop in Ceramics, Columbus, Ohio (1833207)	Candace Chan, Arizona State University
CAREER: Probing Oxygen-Mediated Electrochemical Processes of Oxides at High Spatial and Temporal Resolution (1753383)	Min Hwan Lee, University of California - Merced
CAREER: Confining Magnetism to Two-Dimensions in Transition Metal Oxide Atomic Layers (1751455)	Divine Kumah, North Carolina State University
CAREER: Controlling Two-Dimensional Heterointerface in Layered Oxides for Electrodes with Advanced Electrochemical Properties (1752623)	Ekaterina Pomerantseva, Drexel University
CAREER: Probing Crystallization of Atomic Layers Using In Situ Electron Diffraction (1752956)	Nicholas Strandwitz, Lehigh University
GOALI: Mechanisms of Lithiation and Delithiation Reactions in Layered Materials Combining Transmission Electron Microscopy and Atomic Scale Modeling (1835848)	C. Carter, University of Connecticut; Avinash Dongare, Arthur Dobley (Industrial partnership with EaglePicher Technologies' Yardney Division)
GOALI: Synergistic Computational, Experimental, and Thermo-electric Device-related Research for Multinary Chalcogenides with Earth-Abundant Constituents (1748188)	Lilia Woods, University of South Florida; George Nolas, Jeff Sharp (Industrial partnership with Marlow Industries, Inc.)
GOALI - Collaborative Research: Chemically Induced Stresses and Degradation Mechanisms in Ceramic Materials for Li ion Batteries (1832808)	Yue Qi, Michigan State University (Industrial partnership with General Motors)
GOALI - Collaborative Research: Chemically Induced Stresses and Degradation Mechanisms in Ceramic Materials for Li ion Batteries (1832829)	Brian Sheldon, Brown University; Yan Wu (Industrial partnership with General Motors)
RUI: Structure and Properties of New, Practical Glasses (1746230) (Ceramics lead; Condensed Matter Physics secondary)	Steven Feller, Coe College; Ugur Akgun, Mario Affatigato
Collaborative Research: Experimental and Computational Study of Structure and Thermodynamics of Rare Earth Oxides-above 2000 C (1835848)	Alexandra Navrotsky, University of California-Davis; Sergey Ushakov
Collaborative Research: Experimental and Computational Study of Structure and Thermodynamics of Rare Earth Oxides Above 2000 C (1835939)	Axel van de Walle, Brown University
Collaborative Research: Chemomechanical Degradation of Oxide Cathodes in Li-ion Batteries: Synchrotron Analysis, Environmental Measurements, and Data Mining (1832707)	Kejie Zhao, Purdue University
Collaborative Research: Chemomechanical Degradation of Oxide Cathodes in Li-ion Batteries: Synchrotron Analysis, Environmental Measurements, and Data Mining (1832613)	Feng Lin, Virginia Polytechnic Institute and State University,
Fragile-to-Strong Transitions in Phase-Change Materials for Next-Generation Memory Devices (1832817)	Pierre Lucas, University of Arizona
Spin Functionality in Perovskite Stannates Through Complex Oxide Heteroepitaxy (1762971)	Yuri Suzuki, Stanford University
Tailoring Exchange Interactions in Complex Oxide Heterostructures (1745450)	Yayoi Takamura, University of California-Davis
The Emergence of Ferroic Phenomena and Size- Effects in Fluorite-Based Nanoparticles (1832733)	Jennifer Andrew, University of Florida; Carlos Rinaldi
A Combined Theory-Experiment Study of Electronic, Magnetic and Thermal Properties of Complex Oxide Nanostructures (1831406)	Robert Klie, University of Illinois at Chicago; Serdar Ogut
Chiral Ceramic Nanoparticles of Tungsten Oxides (1748529)	Nicholas Kotov, University of Michigan Ann Arbor
Rational Design of High-performance Semiconductors based on Inorganic Perovskites Containing Bismuth (1806147)	Rohan Mishra, Washington University; Pratim Biswas
Ammonothermal Cubic Boron Nitride Single Crystal Growth Near Ambient Pressure and Temperature (1832824)	Siddha Pimputkar, Lehigh University; Kai Landskron
Oxide Ion Conduction Mechanisms in Bismuth Perovskites (1832803)	David Cann, Oregon State University; Michelle Dolgos
Understanding and Designing Novel Anode Materials for Solid Oxide Fuel Cells (1832809)	Fanglin (Frank) Chen, University of South Carolina at Columbia; Salai Ammal, Andreas Heyden
NMR Methodologies for Measuring Correlated Structural Distributions in Oxide Glasses (1807922) (Chemical Measurement& Imaging lead; Ceramics secondary)	Philip Grandinetti, Ohio State University

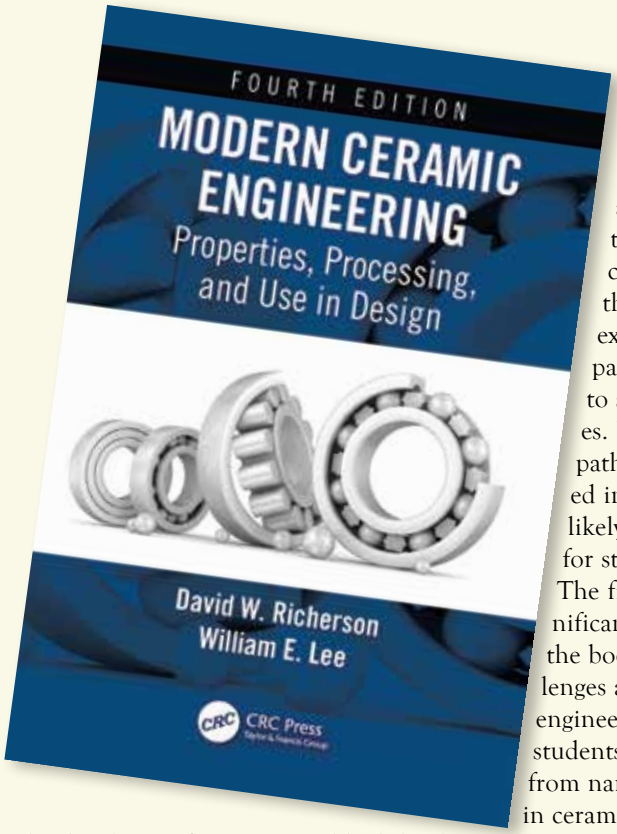
Aldo R. Boccaccini
Guest columnist

Review of *"Modern Ceramic Engineering, 4th Edition"*

This 4th edition of "Modern Ceramic Engineering"—Properties, Processing and Use in Design—written by David W. Richardson and William E. Lee, has evolved notably from the previous editions published in 1982, 1992, and 2006. Almost all of the chapters (organized in four parts: i) Ceramics as Engineering Materials, ii) Structure and Properties, iii) Processing of Ceramics and iv) Design with Ceramics) have been updated, and two new chapters dealing with case histories and future challenges and trends in the field, respectively, have been incorporated in this last edition as Part v (Applying Ceramics to Real-world Challenges).

In my opinion, readers will find that the book fills a gap in the market for a standalone, complete course in ceramic engineering for undergraduate students covering processing, properties, and structures of all types of ceramic materials. The book is superbly presented, with clear and relevant illustrations and diagrams, and it is easy to read and includes example problems throughout. The book also includes further reading suggestions, as well as problems sections at the end of each chapter. In comparison to the previous edition, the book has more than 30 new figures.

The "classical" Parts (i-iv) in the book encompass all relevant aspects of ceramics that should be included in any ceramic engineering undergraduate course, from definitions and history of ceramics and glasses to processing, properties, and applications, thus becoming a valuable source of information for the ceramic engineering lecturer. Indeed, the extensive professional experience of the authors has led to a book characterized by the clarity of concepts and high level of detail of the subjects handled. A notable change in this 4th edition is the new emphasis given throughout the book to the use of modelling and simulation at all scales, given their importance to the understanding of ceramic materials behavior in all engineering applications.



I am of the opinion that the book became even more interesting and indeed unique in its class with the addition of the last two chapters, in which the authors expand on applications of ceramics to real-world challenges. The new Chapter 21 includes a series of case studies involving engineering ceramics that have made a high impact in our society, nicely covering the path to success, showing how scientists and engineers have tackled and solved the challenges, and how the materials and technologies have evolved to a series of current ceramic technology successes. This chapter also illustrates for the reader, based on excellent examples, how different career paths are possible in the quest to solve technological challenges. Indeed, reading the career paths of the two authors included in this chapter will quite likely be a source of inspiration for students and young scientists. The final chapter is another significant addition to this edition of the book. It discusses future challenges and trends in the ceramics engineering field that might guide students to launching their careers, from nanotechnology and advances in ceramic processing to environmental cleanup, raw materials, and extreme environment challenges.

I applaud the authors for this excellent book, an invaluable addition to modern ceramic engineering literature.

Aldo R. Boccaccini is professor and chair of the Department of Materials Science and Engineering at the University of Erlangen-Nuremberg, Germany.

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New book series features nanotechnology innovation and applications

The book series Nanotechnology Innovation & Applications features nine nanoscience-related topics: Nanoscience and Nanotechnology for Human Health, Pharmaceutical Nanotechnology, Micro- and Nanophotonic Technologies, Nanomagneticism, Metrology and Standardization for Nanotechnology, Nanotechnology in Agriculture and Food Science, Nanotechnology for Energy Sustainability, Nanoelectronics, and Nanotechnology in Catalysis. The series was edited by ACerS Fellow Marcel Van de Voorde.

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Materials scientists gather in Columbus, Ohio, to reconnect, learn, compete, honor peers

(Credit all images: ACerS)

MS&T18

MS&T offered many opportunities for attendees to make new connections through networking.

More than 3,200 attendees from five organizing societies, 92 vendors, and thousands of presentations all helped make MS&T18 a success. This year, Columbus, Ohio, hosted the annual materials science conference that included dozens of lectures, networking receptions, student activities, exhibitor demonstrations, ACerS Annual Meeting, awards banquet, and short courses.

It was a busy week!

The Orton Lecture award recipient, Cato T. Laurencin, M.D, Ph.D., served as conference plenary session speaker. He spoke on "Regenerative Engineering: Materials in Convergence." He defined convergence as the "coming together of insights and applications from originally distinct areas to create new science," which could impact healing and quality of life for millions of people.

Other ACerS-related award lectures at MS&T included the Friedberg Lecture by Jennifer Lewis, Rustum Roy Lecture by David Morse, Basic Science Division Sosman Lecture by Jürgen Rodel, the Fulrath Award Symposium, and the GOMD Cooper Symposium.

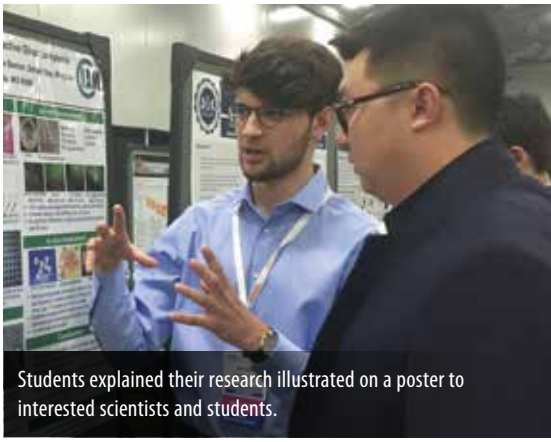
The exhibit floor was bustling with company reps demonstrating their products to prospective buyers.

Student activities, a big part of MS&T, offered students opportunities to participate in several competitions, including the ceramographic exhibit competition, student poster session, and the ever-popular mug drop and disc golf competitions. Students from local high schools also had a chance to watch scientific demonstrations at the Materials Camp.

Exhibitors talked to prospective buyers about their products and services.

The student mug drop competition is always a favorite competition at MS&T.

Cato T. Laurencin's talk on "Regenerative Engineering: Materials in Convergence" generated a lot of interest at the conference plenary session.



Students explained their research illustrated on a poster to interested scientists and students.

Interspersed between lectures and contests were opportunities to reconnect with colleagues at the networking receptions. Members stopped by the ACerS booth to catch up with old friends and meet new ones.

The ACerS awards banquet gave members, colleagues, family, and friends the opportunity to recognize members who have made significant contributions to the discipline and to the Society.

Plans are well underway for next year's Annual Meeting and MS&T19, and we hope you will join us **September 29–October 3 in Portland, Ore.!**

CALL FOR PAPERS ABSTRACTS DUE JANUARY 15, 2019

25TH International Congress on Glass (ICG2019)

Hosted by ACerS Glass & Optical Materials Division

100 years

June 9–14, 2019 | Boston Park Plaza Hotel and Towers | Boston, Massachusetts | USA

Make your plans now to attend the International Congress on Glass (ICG) 2019 in Boston, Mass., June 9 – 14, 2019 and join the expected 1,000 attendees and more than 900 papers and posters representing the best and brightest glass science and technology minds in the world.

Held every three years, the International Congress on Glass provided valuable networking and collaborative efforts since the late 1980s. ICG 2019 will include:

- Special recognition of the 100th anniversary of GOMD
- Technical, cultural, and historical excursions in and around the Boston area
- Student career roundtables
- Student poster contest

Save the date for this important glass science and technology meeting. ACerS Glass & Optical Materials Division is the ICG 2019 host.

Organization Chairs:

ICG 2019 Congress president

Brow

Richard K. Brow
Missouri University of Science & Technology
brow@mst.edu

ICG 2019 program chair

Mauro

John C. Mauro
Pennsylvania State University
jcm426@psu.edu

Symposia and Sessions

Symposium I: **Glass Structure and Chemistry**

Symposium II: **Glass Physics**

Symposium III: **Glass Technology and Manufacturing**

Symposium IV: **Emerging Applications of Glass**

Symposium V: **Glass Education (TC23)**

Symposium VI: **Archaeometry (TC17)**

Symposium VII: **Arun K. Varshneya Festschrift**

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January 23 – 25, 2019 | DoubleTree by Hilton Orlando at Sea World Conference Hotel | Orlando, FL, USA

Electronic Materials and Applications (EMA 2019)

Organized by the ACerS Electronics and Basic Science Divisions

The 2019 Conference on Electronic Materials and Applications is an international conference focused on fundamental properties and processing of ceramic and electroceramic materials and their applications in electronic, electro/mechanical, magnetic, dielectric, and optical components, devices, and systems. Jointly programmed by the Electronics Division and Basic Science Division of The American Ceramic Society, EMA 2019 will take place at the DoubleTree by Hilton Orlando at Sea World January 23 – 25, 2019.

EMA 2019 includes several networking opportunities to facilitate collaborations for scientific and technical advances related to materials, components, devices, and systems. Special lunchtime sessions will be geared toward students and young professionals. The grand finale of the meeting will again be the popular "Failure: The Greatest Teacher," where established researchers discuss the great ideas that they have had that did not work out for one reason or another.

PLEASE JOIN US IN ORLANDO, FLORIDA TO PARTICIPATE IN THIS UNIQUE EXPERIENCE!

PLENARY SPEAKERS

WEDNESDAY, JANUARY 23

Maria

Jon-Paul Maria

Professor, Materials Science and Engineering Department, The Pennsylvania State University, USA

Title: *Electroceramic thin films for IR plasmonic applications*

Abstract: Transparent conductive oxides (TCOs) are an attractive materials platform for plasmonics and metamaterials in the near- and mid-infrared (MIR). This presentation will briefly review plasmonic oscillation modes, some interesting applications for plasmon polaritons, and the conductors and devices that have been recently explored. Among TCOs, the doped electroceramic cadmium oxide (CdO) exhibits exceptional electronic and plasmonic characteristics with tunable carrier concentration and high electron mobility, which enables low-loss plasmonic resonances. We have shown that through careful control of thin film growth and defect chemistry, doped CdO supports high quality plasmonic resonances across the entire MIR with tunable carrier concentrations spanning nearly two orders of magnitude, accompanied by maximum carrier mobilities over 500 cm^2/V·s.

We will show that by controlling electron concentration, mobility, thickness, and film-substrate geometry, we can grow doped CdO films to target multiple plasmonic modes, including surface plasmon polaritons (SPP), epsilon-near-zero (ENZ) modes, and Brewster/Berreman modes. Additionally, by growing stacked doped/intrinsic/doped CdO layers, we are able to access additional SPP dispersion branches below the lightline resulting from coupling between the doped layers. Such control further allows us to grow multilayer CdO films with arbitrary layer thickness and doping: in a single stack, we achieve multiple (3+) absorption peaks associated with the ENZ modes of each individual layer. We will also show that these stacks display multiple thermal emission peaks, also associated with the ENZ mode frequency of individual layers. As they require no lithography and contain no physical interfaces, these devices are, in effect, "bulk metamaterials." This discovery enables a scalable method to engineer the optical properties of monolithic MIR metamaterials for MIR absorption and emission by design.

THURSDAY, JANUARY 24

Chiang

Yet-Ming Chiang

Kyocera Professor, Materials Science and Engineering Department, Massachusetts Institute of Technology, USA

Title: *Ceramics are enabling the next generation of energy storage technologies*

Abstract: The advent of near-zero cost renewable electricity coupled with other societal trends is driving the development of new energy storage technologies for transportation and electric power. Even before the inception of the lithium-ion battery three decades ago, ceramic materials played a central role in battery technologies as either ion storage host or electrolyte. This remains true across multiple current trends in electrochemical storage, which can be broadly distinguished by a focus on very high energy density storage for portable devices and/or transportation (including air vehicles), or very low cost storage to enable reliable, dispatchable power from intermittent renewable electricity generation. The performance and techno-economic drivers for energy storage in these sectors will be discussed. Several examples will be given that highlight the important role that compositional design, physical properties, and processing of ceramic components continue to play in enabling new battery technologies.

www.ceramics.org/ema2019

TENTATIVE SCHEDULE

Wednesday, January 23, 2019

Conference registration	7:30 a.m. – 6 p.m.
Plenary session I	8:30 – 9:30 a.m.
Coffee break	9:30 – 10 a.m.
Concurrent technical sessions	10 a.m. – 12:30 p.m.
Poster session set up	12:30 p.m. – 5 p.m.
Lunch on own	12:30 – 2 p.m.
Overview of topics at EMA: A student guide to the meeting	12:30 – 2 p.m.
Concurrent technical sessions	2 – 5:30 p.m.
Coffee break	3:30 – 4 p.m.
Poster session and reception	5:30 – 7:30 p.m.
Basic Science Division tutorial	7:40 – 8:45 p.m.

Thursday, January 24, 2019

Conference registration	7:30 a.m. – 6 p.m.
Plenary session II	8:30 – 9:30 a.m.
Coffee break	9:30 – 10 a.m.
Concurrent technical sessions	10 a.m. – 12:30 p.m.
Lunch on own	12:30 – 2 p.m.
What's next: What to expect in different career paths	12:30 – 2 p.m.
Concurrent technical sessions	2 – 5:30 p.m.
Coffee break	3:30 – 4 p.m.
Young Professionals reception	5:30 – 6:30 p.m.
Conference dinner	7 – 9 p.m.

Friday, January 25, 2019

Conference registration	7:30 a.m. – 4 p.m.
Concurrent technical sessions	8:30 a.m. – 12:30 p.m.
Coffee break	9:30 – 10 a.m.
Lunch on own	12:30 – 2 p.m.
Concurrent technical sessions	2 – 5 p.m.
Coffee break	3:30 – 4 p.m.
Failure: The Greatest Teacher	3:30 – 5 p.m.

BASIC SCIENCE DIVISION TUTORIAL

WED, JAN. 23 | 7:40 – 8:45 P.M. | CITRUS A

Impedance spectroscopy: Opportunities and its application in materials

7:40 p.m. Introduction

7:45 p.m. **Rosario Gerhardt**, Georgia Tech
Impedance spectroscopy: Basics, challenges and opportunities

8:15 p.m. **Daniel Lewis**, Rensselaer Polytechnic Institute
Progress on understanding the relationship between impedance measurements and microstructure

FAILURE – THE GREATEST TEACHER

FRI, JAN. 25 | 3:30 P.M. – 5 P.M. | ORANGE B

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.

3:30 p.m. **Dragan Danjanovic**, École Polytechnique Fédérale de Lausanne
Failure of communication: Example of lead-free piezoelectrics

4:00 p.m. **Andrew Bell**, Institute for Materials Research, University of Leeds
Failures: The stepping stones to success

4:30 p.m. **Susan Trolier-McKinstry**, The Pennsylvania State University
Memory failure

TECHNICAL PROGRAM

S1 Characterization of Structure–Property Relationships in Functional Ceramics

S2 Advanced Electronic Materials: Processing Structures, Properties, and Applications

S3 Frontiers in Ferroic Oxides: Synthesis, Structure, Properties, and Applications

S4 Complex Oxide Thin Film Materials Discovery: From Synthesis to Strain/Interface Engineered Emergent Properties

S5 Mesoscale Phenomena in Ferroic Nanostructures: Beyond the Thin-Film Paradigm

S6 Complex Oxide and Chalcogenide Semiconductors: Research and Applications

S7 Superconducting and Magnetic Materials: From Basic Science to Applications

S8 Structure-property Relationships in Relaxor Ceramics

S9 Ion Conducting Ceramics

S10 Current Challenges in Microstructural Evolution: From Basic Science to Electronic Applications

S11 Electronic Materials Applications in 5G Telecommunications

S12 Thermal Transport in Functional Materials and Devices

S13 From Basic Science to Agile Design of Functional Materials: Aligned Computational and Experimental Approaches and Materials Informatics

43RD INTERNATIONAL CONFERENCE AND EXPOSITION ON ADVANCED CERAMICS AND COMPOSITES

Organized by the Engineering Ceramics Division of The American Ceramic Society

JANUARY 27 – FEBRUARY 1, 2019 | Hilton Daytona Beach Resort and Ocean Center | Daytona Beach, Florida, USA

The 43rd International Conference and Exposition on Advanced Ceramics and Composites (ICACC) continues a strong tradition as the leading international meeting on advanced structural and functional ceramics, composites, and other emerging ceramic materials and technologies.

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JAMES I. MUELLER AWARD

Singh

Dileep Singh, Senior materials scientist, Argonne National Laboratory, USA

Title: *Renewable energy: Role of ceramics and composites*

BRIDGE BUILDING AWARD

Lis

Jerzy Lis, Vice rector of cooperation and president of the board of INNO AGH, AGH University of Science and Technology, Poland

Title: *Processing of complex ceramic materials by rapid high-energy techniques*

PLENARY SPEAKER

Yamazaki

Shunpei Yamazaki, President, Semiconductor Energy Laboratory Co., Ltd., Japan.

Title: *Crystalline oxide semiconductor (IGZO ceramics)- based devices for artificial intelligence (AI) and Internet of Things (IoTs)*

PLENARY SPEAKER

Cima

Michael J. Cima, David H. Koch professor of engineering, faculty director of the Lemelson-MIT Program, Associate dean for innovation, Massachusetts Institute of Technology, USA

Title: *Drug, device, or diagnostic? Engineering in a new world of medicine*

GLOBAL YOUNG INVESTIGATOR AWARD

Ji

Wei Ji, Assistant professor, Wuhan University of Technology, China

Title: *Sintering of advanced ceramics by plastic deformation as dominant mechanism*

ENGINEERING CERAMICS DIVISION JUBILEE GLOBAL DIVERSITY AWARD

Balázsi

Katalin Balázsi, Hungarian Academy of Sciences, Hungary

Title: *Effect of deposition parameters on cubic TiC and hexagonal Ti phase formation of thin films deposited by magnetron sputtering*

Rueschhoff

Lisa M. Rueschhoff, Air Force Research Lab, USA

Title: *Nano to bulk scale ceramic processing and structure control for enhanced properties*

Zhang

Jie Zhang, Institute of Metal Research, China

Title: *Integrated design of ceramic coatings for accident-tolerant fuel cladding in LWRs*

Exhibition Information

Reserve your booth today for the premier international advanced ceramics and composites expo. Connect with decision makers and influencers in government labs, industry, and research and development fields. ICACC19 is your destination to collaborate with business partners, cultivate prospects, and explore new business opportunities.

Exhibit hours

Tues., January 29, 2019, 5 – 8 p.m.

Wed., January 30, 2019, 5 – 7:30 p.m.

Exposition location

Ocean Center Arena, 101 North Atlantic Avenue, Daytona Beach, FL

Exhibit space is filling up fast. To reserve your booth, visit www.ceramics.org/event-subpage/icacc-exhibitor-information or contact **Mona Thiel** at mthiel@ceramics.org or 614-794-5834.

Exhibitor	Booth
3DCeram Sinto Inc.	318
AdValue Technology LLC	317
Alfred University	315
AVS	307
American Ceramic Society	101
Centorr Vacuum Industries	200
Ceramics Expo	311
CM Furnaces	210
Fritsch Milling & Sizing Inc.	217
Gasbarre	203
Haiku Tech	215
Harper International	309
H.C. Starck Surface Technology and Ceramic Powders GmbH/Höganäs AB	305
Keyence Corporation of America	301
Lithoz America LLC	103
Microtrac	314
Netzsch Instruments	300
Nordson Sonoscan	302
Oxy-Gon Industries Inc.	214
Praxair Surface Technologies	219
Reserved	208
SPEX SamplePrep	316
Springer Nature	107
TAV Vacuum Furnaces Spa.	313
Tev Tech	206
Tethon 3D	218
Thermal Technology LLC	319
Thermcraft, Inc.	303
Wiley	216
Zeiss Microscopy	201
Zircar Ceramics	202

STOP BY any vendor booth in our ICACC 2019 Expo and receive a raffle ticket for a drawing to win the following exciting prizes:

First prize

Phase Equilibria Diagrams PC Database, Version 4.3 USB single license ($1,095 value)

Second prize

ICACC 2020 free registration ($730 value)

Third prize

"Engineered Ceramics: Current Status and Future Products" technical book ($175 value)

Turn your raffle tickets in during exhibit hours at the ACerS booth in the Exhibit Hall. You may turn in as many tickets as you gather from exhibitors, so the more you visit with our vendors, the better your odds to win! The prizes will be drawn at 6:30 p.m., Wednesday, January 30, at the ACerS booth. You need not be present to win. This is a great opportunity to collaborate with potential business partners, and walk away with something useful for your business or career. It can be a win-win, literally.

Mechanical Properties of Ceramics and Glass Short Course*

JANUARY 28, 2019 | 8:30 a.m. – 4:30 p.m.

FEBRUARY 1, 2019 | 8:30 a.m. – 4 p.m.

LOCATION: HILTON – FLAGLER A

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.

* Additional fee required. To sign up, please visit www.ceramics.org/courses or the registration booth at ICACC.

resources

Calendar of events

January 2019

9–10 82nd Annual Session of the Indian Ceramic Society in conjunction with the 70th Annual Session of All India Pottery Manufacturers' Association and 44th Annual Session of Indian Institute of Ceramics – The Wave International, Jamshedpur, India; www.bit.ly/Incers82nd

23–25 EMA2019: 2019 Conference on Electronic Materials and Applications – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla.; www.ceramics.org/ema2019

25–29 ACerS Winter Workshop in conjunction with ICACC19 – Hilton Daytona Beach Resort and Ocean Center, Daytona Beach, Fla.; www.ceramics.org/winter-workshop-2019

27–Feb. 1 ICACC19: 43rd Int'l Conference and Expo on Advanced Ceramics and Composites – Daytona Beach, Fla.; www.ceramics.org/icacc2019

February 2019

14–16 ➨ 8th IAOCI World Congress, Int'l Academy of Ceramic Implantology – Grand Hyatt, Tampa, Fla.; www.iaoci.com

March 2019

10–15 ➨ Electric Field Enhanced Processing of Advanced Materials II: Complexities and Opportunities – Hotel Dos Templarios, Tomar, Portugal; www.bit.ly/ElecFieldProc

26–28 55th Annual St. Louis Section/Refractory Ceramics Division Symposium on Refractories – Hilton St. Louis Airport Hotel, St. Louis, Mo.; www.bit.ly/StLouis2019

April 2019

22–26 2019 MRS Spring Meeting & Exhibit – Phoenix, Ariz.; www.mrs.org/spring2019

30–May 1 5th Ceramics Expo – I-X Center, Cleveland, Ohio; www.ceramicsexpousa.com

June 2019

9–14 25th Int'l Congress on Glass – Boston Park Plaza Hotel and Towers, Boston, Mass.; www.ceramics.org/icg2019

July 2019

10–11 ➨ Ceramics UK colocated with The Advanced Materials Show – The International Centre, Telford, UK; www.ceramics-uk.com

21–26 4th Int'l Conference on Innovations in Biomaterials, Biomanufacturing, and Biotechnologies (Bio-4), combined with the 2nd Global Forum on Advanced Materials and Technologies for Sustainable Development (GFMAT-2) – Toronto Marriott Downtown Eaton Centre Hotel, Toronto, Canada; www.ceramics.org/gfmat-2-and-bio-4

September 2019

22–27 HTCMC10: 10th Int'l Conference on High-Temperature Ceramic-Matrix Composites – Palais des Congrès, Bordeaux, France; www.ht-cmc10.org

29–Oct. 3 MS&T19 combined with the ACerS 121st Annual Meeting – Portland, Ore.; www.matscitech.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.

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Career Opportunities

THREE POSTDOCTORAL POSITIONS AVAILABLE

Applications for postdoctoral fellowships are invited for conducting fundamental research at the Center for Research, Technology and Education in Vitreous Materials (CeRTEV) in São Carlos, Brazil; http://www.certev.ufscar.br. The period of the fellowship is two years, starting in April-June 2019, renewable for two additional years upon mutual consent.

The postdoctoral research will be focused on fundamental investigations by Molecular Dynamics (MD) Simulations, NMR and in-situ, high-temperature Raman Spectroscopy of structural links to kinetic processes (diffusion, viscous flow, relaxation, phase separation, crystallization) in supercooled liquids of interest to glass and glass-ceramic science. The researcher is expected to conduct the post-doc activities in one of the joint CeRTEV laboratories and supervised by one of our Principal Investigators in close collaboration with the other CeRTEV researchers and students.

Applicants should have a Ph.D. degree in Physics, Chemistry, Materials Science or Engineering, previous experience with computer simulations, or Raman spectroscopy or NMR, and have a genuine interest in conducting interdisciplinary research in an international environment. Previous experience in glass science, solid state physics or chemistry is advantageous. The language requirements are English, Spanish or Portuguese. The monthly fellowships (non-taxable) include ca. R$ 7.300,-plus 15% professional expenses (e.g., for travel). Our post-docs from Canada, Russia, Iran, India, Colombia, Pakistan and Brazil typically spend from R$2000 to R$2500/month for comfortable living style. Travel expenses from and to their home countries will also be covered.

Please send your application including CV, list of publications, a 2-page research proposal, and the names and email addresses of two senior references by March 20, 2019 to the following persons: MD simulations: Profs. José Pedro Rino (djpr@ufscar.br) and Edgar D. Zanotto (dedz@ufscar.br) – Raman Spectroscopy, Prof. Paulo Sergio Pizani (pizani@ufscar.br), NMR – Prof. Hellmut Eckert (eckert@ifsc.usp.br).

CeRTEV
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Please always copy Laurie Leal: certevlamav@gmail.com

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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.

Jeff Braun
Guest columnist

Thermal circuit elements to enable active control of heat

The estimated United States energy usage report conducted annually by Lawrence Livermore National Lab indicated that in 2017, nearly 67 percent of energy was wasted, primarily in the form of heat.[1] Regulating and recycling this excess heat would enable breakthroughs in energy conversion systems, heating and refrigeration, manufacturing and materials processing, data storage, and electronics thermal management. The current toolbox used by engineers to manage heat flow, however, is highly limited.

Temperature difference (ΔT) and heat flux (Q) are analogous to electrical voltage and current, respectively. Unlike their electrical counterparts, analogous thermal circuit elements are underdeveloped or nonexistent, being largely limited to resistors and capacitors based on materials that have static thermal properties.[2]

What if the thermal toolbox could be expanded to include other circuit elements? Three examples of thermal circuit elements under investigation include diodes, switches, and regulators (Figure 1).

A thermal diode is a device which allows heat to flow preferentially in one direction, meaning the heat flux under a positive ΔT will be different from that of a negative ΔT. Although fluid-based thermal diodes such as heat pipes are well established, development in the solid-state is more challenging. One way to achieve this is to exploit the temperature dependence of thermal conductivity. For example, if a glass and a crystalline ceramic are placed in series to make the diode, the glass will have a relatively low thermal conductivity that increases with temperature, while the crystal will have a relatively high thermal conductivity that decreases with temperature. The opposite trends of these thermal conductivities with temperature allow the heat flux to differ across the diode when the temperature difference is reversed.

A thermal switch is a device that can maintain an "on" state in which heat flows freely and an "off" state in which little to no heat flow is allowed. This state change is associated with a change in a material's thermal conductivity under an applied stimulus. For example, ferroelectric oxides have been shown to change thermal conductivity under an applied electric field.[3] The ability to actively tune thermal conductivity allows for direct manipulation of heat flow through a material.

Lastly, a thermal regulator is a device that allows high heat fluxes under large temperature differences but maintains lower heat fluxes under smaller differences. Commonly proposed thermal regulator materials include phase change materials that undergo a discrete change in thermal conductivity at some critical temperature. For example, VO_2 undergoes a metal-insulator transition at the transition temperature, consequently obtaining a higher thermal conductivity to enable higher heat flow.[4] Similarly, some magnetic materials undergo a martensitic phase transition at a critical temperature to obtain high thermal conductivities above that temperature.[5] Thermal regulators are highly appealing for applications requiring operation within a narrow temperature range.

A major challenge in determining the efficiency of these devices is accurate measurement of thermal conductivity. Traditional techniques used for bulk materials involve long measurement times that cannot capture the ultrafast response of a thermal switch, nor measure the nanometer length scales associated with thin film thermal diodes. My research focuses on laser pump-probe techniques to characterize such thermal properties of materials. The primary technique I use—time-domain thermoreflectance—is capable of high-throughput thermal conductivity measurements with length scales downwards of 10s of nanometers, making it ideal for the study of thermal circuit elements.

While ongoing research points to promising prospects for these devices, the development of thermal circuit devices is still in its infancy. For example, solid-state thermal switch ratios of heat flux in the "on" state to "off" state typically do not exceed 2:1, which is far below the order of magnitude ratio needed for a disruptive technological impact. Therefore, there is a need for discovery of materials with unique and tunable thermal properties that will enable solid-state thermal diodes, switches, and regulators to become an everyday part of an engineer's toolbox. Doing so will promote better heat control technologies to support a more energy-efficient world.

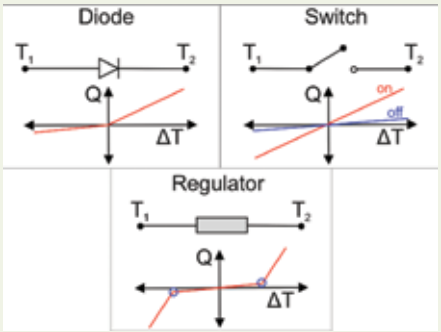

Figure 1. Examples of thermal circuit elements.

References

[1]Lawrence Livermore National Laboratory. Estimated U.S. Energy consumption in 2017: 97.7 Quads. Retrieved from https://flowcharts.llnl.gov/commodities/energy

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[5]Zheng, Q. et al. Thermal transport through the magnetic martensitic transition in Mn_xMGe (M = Co,Ni). *Phys. Rev. Mater.* **2**, 075401 (2018).

Jeff Braun is a Ph.D. candidate working with Patrick Hopkins at the University of Virginia. In his free time, Jeff enjoys hiking and being outdoors.

Technical Meeting and Exhibition

MS&T19

MATERIALS SCIENCE & TECHNOLOGY

SAVE THE DATE

SEPTEMBER 29 – OCTOBER 3, 2019

PORTLAND OREGON

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