AMERICAN CERAMIC SOCIETY
# bulletin
emerging ceramics & glass technology
MARCH 2017

## Hot matters—
## Experimental methods for high-temperature property measurement

Conductive ceramic membranes enhance water treatment | Waste-to-energy market expected to grow

# contents

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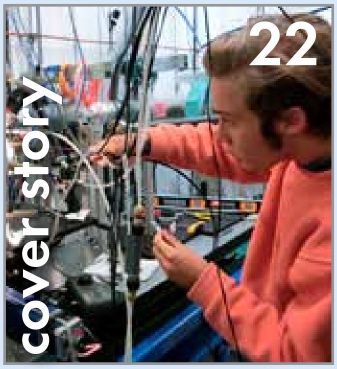
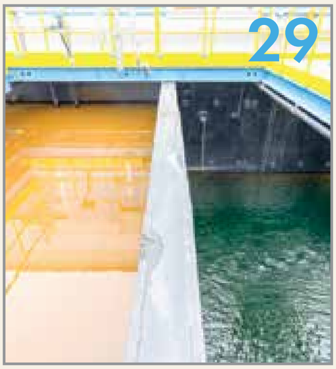
## feature articles








## departments



## columns



## meetings



## resources



**On the cover**

A molten sample of titanium-zirconium-nickel alloy floats inside an electrostatic levitator at NASA's Marshall Space Flight Center (Huntsville, Ala.). Measuring material properties during suspension prevents contamination from containers and is a technique used to make measurements of ceramic materials, too. Image credit: NASA/MSFC/Emmett Given

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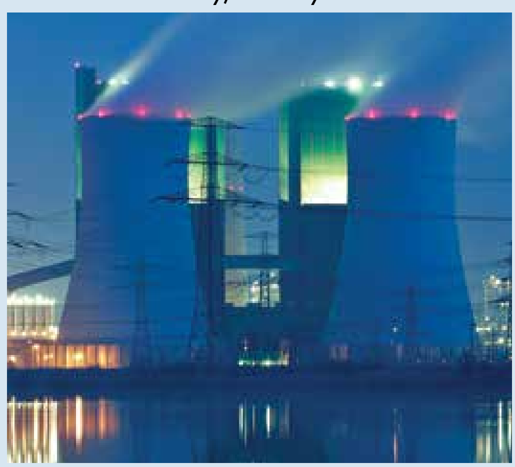
As seen in the January/February 2017 *ACerS Bulletin*...

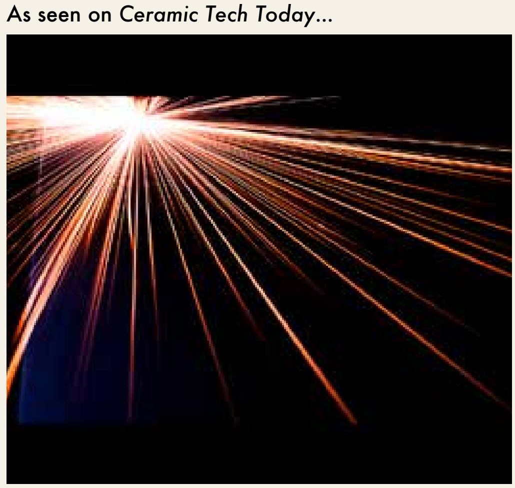


## Is there room for porosity in nuclear ceramics?

*Many applications capitalize on the stability of porous structures at elevated temperatures—can nuclear ceramics? Author Jessica Krogstad explores what we can learn from dynamic micro-structures in extreme conditions.*

**Read more at**
www.ceramics.org/nuclear-porosity

As seen on *Ceramic Tech Today*...



## Laser melting sets new record for ultra-high temperature ceramic materials

*New laser-based techniques have measured even higher melting points for hafnium carbide and tantalum carbide—making these materials promising for even more extreme applications.*

**Read more at**
www.ceramics.org/laser-melting

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

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ACSBA7, Vol. 96, No. 2, pp 1–48. All feature articles are covered in Current Contents.

# news & trends

## CES 2017 shows that the future is here, and it is built from ceramic and glass materials

The 2017 edition of the Consumer Electronics Show (CES) wrapped up its annual exhibition showcasing all the latest consumer electronics and technology in Las Vegas in early January. The show's expansive 43 football fields worth of tech displayed that the world is getting altogether smarter, brighter, more virtual, more connected, and entirely robotic.

As expected, the show featured tons of winning tech that promises to integrate and accelerate human lives. Virtual reality and the Internet of Things—where seemingly everything will connect to an Amazon Echo—were overall prominent themes of the show.

But past the dizzying amount of new products, it is the materials that make all the tech possible. In fact, glass giant Corning was at the show debuting its concept for a glass-enabled, connected car.

Credit: Corning Incorporated; YouTube

**At January's Consumer Electronics Show 2017, glass and ceramic materials were prominent among the technologies on the show floor.**

Although Corning has already announced that Gorilla Glass is going the way of windshields, the company has much bigger ideas for how tomorrow's vehicles use glass—including integration into sunroofs, lights, connected dashboards, and windshield-embedded displays. See Corning's glass concept car at youtu.be/CFBveRoRVHY.

In addition to automobile tech, one of the big buzzes at CES 2017 was a slew of all-new impressive TVs.

LG's new incredibly thin W7 OLED TV—just 0.15-inch-thick, about the thickness of a house key—is more of a thick piece of wall art than a TV. And Sony's new not-quite-as-thin OLED TV uses its glass front to double as a built-in speaker, vibrating for audio. Today's TVs are using the latest materials to change the way we think about this familiar piece of tech.

And do not forget 3-D printing—there have been signs recently that ceramics are making strong inroads into commercial additive manufacturing, and now 3-D-printed ceramics might soon make their way out of home printers, too.

Formlabs showed off its ceramic-particle-embedded resin for conventional additive manufacturing at CES 2017, demonstrating how a standard 3-D printer can fabricate creations that, after firing, become fully ceramic. So far it is only a demo, but the company is reportedly working towards a more widespread offering later this year. ■

## Defining an epoch—Can the case be made for the Glass Age?

Corning Incorporated has boldly declared these times as the "Glass Age," claiming glass is as transformative as stone, bronze, and iron were to the eras named for them.

Thus, it seems quite appropriate that the editors of the *International Journal of Applied Glass Science* would take a scholarly approach to test the premise, which they did in an issue published recently.

Editor L. David Pye writes in his introduction to the issue, "Clearly glass has played a major role in advancing civilization and mankind throughout recorded history be it in the arts, architecture, transportation, medicine, communication, and especially important, other branches of science."

The first article, "Welcome to the Glass Age," builds on the idea. In it, Corning's chief technology officer, David Morse, and Jeffrey Evenson, chief strategy officer, recognize the past and present, but keep their focus fixed on the future. "We have an unprecedented opportunity to harness the unique capabilities of glass to solve some of our world's most urgent challenges, such as more effective healthcare, cleaner energy and water, and more efficient communication."

The other thirteen articles in the issue show the transformative history of glass and also point to advances in glass properties and processing that will enable new transforming applications. Articles cover a very interesting history of optical fiber development, bioactive glass, chemical strengthening, modeling and simulation applied to processing and properties, and advances in understanding mechanical properties.

It is one thing for glass scientists to celebrate their material and its importance—but another test of the Glass Age premise is to look for evidence beyond the glass science community.

The December issue of the *Journal of the American Ceramic Society* just happened to have two articles on glass for new, extreme applications that show that non-glass scientists are looking at glass for solutions to problems other materials cannot solve.

The first paper reports on glass dielectrics for extreme high-temperature environments and comes out of Michael Lanagan's group at Pennsylvania State University (University Park, Pa.). Engineering of wide bandgap SiC-based semiconduc-

## Business news

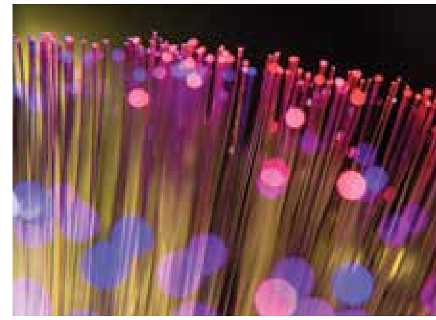
Corning makes equity investment in Menlo Micro (**www.corning.com**)…Imerys contemplates acquisition of Kerneos (**www.imerys.com**)…Ceramco achieves ISO9001:2015 certification (**www.ceramcoceramics.com**)…Vesuvius acquires Brazilian mold flux business for £9.2M (**www.vesuvius.com**)…DOE announces funding to support breakthrough technologies for advanced manufacturing (**www.energy.gov**)…Tesla starts battery cell production at gigafactory (**www.reuters.com**)…Amedica announces positive scientific data and re-files FDA submission (**www.amedica.com**)…Vitro to purchase Pittsburgh Glass Works OEM auto glass business (**www.vitro.com**)…Industrial gas giants Linde and Praxair plan to merge (**www.the-linde-group.com**)…Kyocera receives FDA clearance for Bioceram Azul ceramic hip replacement (**www.kyocera.com**)…Panasonic develops first IPS liquid crystal panel with contrast ratio of over 1,000,000:1 (**www.panasonic.com**…Study shows Innovnano's 4YSZ produces low thermal conductivity TBCs (**www.innovnano-materials.com**)…Glass manufacturers forecast steady growth for industry in 2017 (**www.glass-magazine.com**)…SolarWindow to expand products with paper-thin flexible glass that generates electricity (**www.solarwindow.com**)…Asahi Glass to set up TFT-LCD glass substrate facility in China (**www.asahi-glass.com**)…Koch Industries acquires full ownership of Guardian (**www.guardian.com**)…DOE awards $1M to develop composites for solid lithium conductors (**www.news.psu.edu**)…Harper designs advanced thermal system to process battery materials for Prayon (**www.harperintl.com**)…Guardian Glass to add jumbo glass coater in North America (**www.guardian.com**)…Netzsch intensifies activities in minerals sector with acquisition of Ecutec (**www.netzsch-grinding.com**)…Saint-Gobain buys Pietta Glass plant in Romania (**www.saint-gobain.com**)…Tesla officially acquires SolarCity (**www.tesla.com**) ■

tor devices is nearing its promise of delivering high-temperature electronics that can be used in the realm of 200°C–400°C. The group looked at commercially available, rare-earth modified alumino-borosilicate glass and studied "high-field electrical properties at temperatures above 200°C where ion transport becomes significant." Besides offering superior dielectric properties at elevated temperature, glasses have the advantage of competing with polymer films in terms of thinness and bendability for roll-to-roll processing.

The second *JACerS* paper reported on superior ablation properties of glass coatings containing graphene nanoplatelets for thermal protection systems. Pilar Miranzo's group at the Institute of Ceramics and Glass (Madrid, Spain) is hunting for a coating to protect critical regions of suborbital reentry vehicles from temperatures up to 1,350°C and ablation from debris. Yttria-aluminosilicate glasses containing aligned graphene nanoplatelets were thermal sprayed onto SiC substrates and subject to thermal cycling and ablation tests. The glass composition was chosen because of its high melting temperature as well as its crystallization properties. The ability of the glass to crystallize into a glass-ceramic gives the coating a degree of self-healing.

In their *IJAGS* article, Morse and Evenson must have had examples such as these in mind when they wrote, "The true excitement of the Glass Age derives from combining the rich palette of the Periodic Table with modern analytic and control technologies to unleash new capabilities for a broad range of industries."

It would seem, then, that ample evidence backs Pye's statement in the opening of his *IJAGS* editorial, "…we are at a special moment in time where the arrival of the Glass Age can be declared with



Credit: Groman123; Flickr CC BY-SA 2.0

**Glass technologies have wide-ranging impacts on day-to-day life, including optical fiber networks that make the internet and digital communications possible.**

certainty and pride by glass scientists, engineers, educators, artists, and glass manufacturers across the globe."

Corning Incorporated provided financial sponsorship of the issue, in addition to supporting a large number of the authors who contributed articles.

One additional note—two articles in the issue are open access: "Welcome to the Glass Age" and "Glass: The Carrier of Light – A Brief History of Optical Fiber." ■

# news & trends

Credit: Under Armour; YouTube

**An illustration of the bioceramic printed pattern on the inside of Under Armour's new athletic recovery sleepwear, which is designed to radiate far infrared energy to help heal the body during sleep.**

## Under Armour's bioceramic pajamas heal Tom Brady's body while he sleeps

Athletic apparel maker Under Armour unveiled a bioceramic-laden line of sleepwear at the Consumer Electronics Show 2017, touting the line's endorsement by famed United States football player Tom Brady.

Under Armour's athletic recovery sleepwear is made from a fabric printed with ceramic particles that absorb the body's heat and radiate it back as far infrared energy—which claims a variety of health benefits.

According to Under Armour's website, "The soft bioceramic print on the inside of the garment absorbs the body's natural heat and reflects far infrared back to the skin. This helps your body recover faster, promotes better sleep, reduces inflammation, and regulates cell metabolism."

The apparel is now available for sale on Under Armour's website—individual items (tops and bottoms sold separately) cost \$80–\$100. But can a bioceramic print restore your body while you sleep?

According to an article in *Time*, "Under Armour is certain the product works. 'We've tested it,' says Kevin Haley, UA's president of innovation. 'We've had actual third party testing. And it's clear. Believe me, we have some of the biggest skeptics in the world running around here. This isn't some outlandish thought, this is something people have been working on for a long, long time. We've had our best Ph.D. scientists here breaking down all the science. It definitely works. When you say 'how confident are we?' I'm confident saying we're very confident.'"

And, surprisingly, he may be right.

First of all, ceramics do emit infrared radiation. Actually, most all objects emit infrared energy—ceramics are just really good at it.

But does infrared radiation affect living cells?

Yes—far infrared energy is absorbed by water molecules within cells and tissues, causing local temperature changes that alter the membrane potential of cell membranes. And because the membranes govern a vast majority of cellular functions, changing the membrane potential provides the ability to influence many cellular processes.

But does infrared radiation have positive health benefits?

Well, maybe. There actually is a decent amount of preliminary medical research on the health benefits of far infrared radiation. Studies have indicated that far infrared radiation can increase microcirculation and reduce inflammation to promote healing, cell proliferation, and cell viability.

But the results from these studies are still somewhat preliminary, because many of them have been done on cultured human cells in the lab or in animal models—which, while they are valuable indicators, only provide conjecture on whether the same might hold true in living, breathing humans.

And while there has been a fair number of clinical trials on the effects of far infrared radiation in living, breathing humans, the nature of medical research is that the results of these studies provide no certain answers.

Take for example, a previous study that also examined the effect of pajamas with small embedded ceramic disks. Individuals in the study reported "improvement of their health" after using the disks—but what specific conclusions can be made from such a subjective report?

A more recent review article seems to echo the overall sentiment—while there is evidence to indicate there are benefits to far infrared radiation, more research is needed to really prove the effects and the ways in which infrared radiation specifically affects the body.

However, some studies do suggest there are specific metabolic benefits for athletes who wear bioceramic clothing. One study reports that far infrared-emitting ceramic clothing reduced the amount of oxygen cyclists consumed during physical exertion, although the statistically significant difference was small—just ~1%.

So it is plausible that bioceramics that emit far infrared energy could help restore your body as your sleep. It is not going to heal a broken bone or repair a torn ligament, but infrared radiation could feasibly lend the body a helping hand in the ongoing repair and upkeep processes that happen during sleep.

Whether these fancy pajamas actually emit enough infrared radiation to make a difference remains a question, however. ■

## Ceramic materials gain momentum at international additive manufacturing exhibition

Additive manufacturing is breaking boundaries in manufacturing—changing the way manufacturers think about processes, components, and materials themselves.

And while additive manufacturing may be dominated by polymers, that does not mean that ceramics and glass are exempt from the reaches of this revolutionary manufacturing technique. In fact, additive manufacturing of ceramics is making incredible strides this year.

So it is perhaps no surprise that at Formnext, a recent international exhibition about additive manufacturing, ceramic materials had a strong presence on the show floor. Formnext 2016 hosted over 300 exhibitors and 13,000 visitors in Frankfurt, Germany, Nov. 15–18.

*TCT Magazine*, which helps host Formnext, talked to some of the companies advancing additive manufacturing of ceramics at this year's exhibition.

TCT talked with Lithoz cofounder and CEO Johannes Homa, who says that "Ceramics are used where other materials fail—they have superior materials properties to metals and polymers."

Lithoz (Vienna, Austria) designs and builds additive manufacturing systems to fabricate high-performance ceramic parts using stereolithography, employing mixtures of ceramic particles in photopolymer resins to achieve its quality ceramics.

But it is not just a niche opportunity that Lithoz is interested in. The company has one emphasis when it comes to additive manufacturing of ceramics. As Homa puts it, "There are three important things in ceramics. It's first quality; second quality; and the third point is quality."

In addition to Lithoz, Admatec and 3DCeram each debuted its own commercial ceramic-specific 3-D printer at Formnext. And other companies flexed their ceramic printing muscles, too, with Xjet and Roland DG displaying the promising 3-D printing technologies each company is working to develop.

See more from the Formnext show floor with a series of videos available at bit.ly/2jH64iD. ■

Credit: Lithoz

**Additively manufactured ceramic components, like these ones manufactured by Lithoz, were prominent at a recent international additive manufacturing exhibition.**

# Thermal and biological waste-to-energy markets

by Maya Agnani

Waste-to-energy is a form of energy recovery that refers to any waste treatment that generates energy in the form of electricity or heat from a waste source. The rising focus on these technologies is due to their potential to reduce or eliminate waste that otherwise would contribute to greenhouse gas emissions from landfills. Several waste-to-energy technologies have already been commercialized and successful in generating interest and investment in these projects.

Commercial waste-to-energy technologies can be broadly segmented as:

- Thermal technologies
  - Incineration
  - Pyrolysis and gasification
  - Thermal depolymerization
  - Plasma arc gasification
- Biological technologies
  - Anaerobic digestion
  - Mechanical biological treatment.

**Table 1. Global waste-to-energy market by technology, through 2019 ($ millions)**

| Technology | 2013 | 2014 | 2019 | CAGR (%) 2014–2019 |
|---|---|---|---|---|
| Thermal | 22,316.1 | 23,434.0 | 30,244.1 | 5.2 |
| Biological | 2,105.9 | 2,346.1 | 3,930.9 | 10.9 |
| Physical | 898.0 | 957.8 | 1,337.1 | 6.9 |
| Total | 25,320.0 | 26,737.9 | 35,512.1 | 5.8 |

Waste-to-energy is gaining status as an important component of integrated waste management strategies in which it plays the role of an alternative strategy to relieve pressure on landfills. The added benefit of waste-to-energy over other waste management strategies is the potential for the extraction of energy. A major portion of this energy is used by the plant itself for its internal energy requirements; the remainder is supplied to the community. For example, through its Renaissance Center, General Motors recycles, reuses, and converts about 5 million metric tons of waste to generate energy by effectively diverting it from landfills.

BCC Research expects that in the next four years, the waste-to-energy market will undergo significant growth, as the participation of developing countries will increase due to their consciousness of environment pollution and the need to find alternate sources of energy.

The global waste-to-energy market was valued at $25.3 billion in 2013, and is expected to reach $35.5 billion by 2019—growing at a compound annual growth rate (CAGR) of 5.8% from 2014 to 2019 (Table 1). Thermal technologies have emerged as the leading technology used for generating energy from waste, while biological treatment is expected to be the fastest growing technology from 2014 to 2019.

The global market for waste-to-energy is highly fragmented, with four companies accounting for just over 30% of the total market in 2013. Japan-based Hitachi Zosen led the global market for waste-to-energy technologies in 2013 (Table 2).

Key drivers of the growth of the global waste-to-energy market over the forecast period are trends toward energy security and decreasing landfill space.

**Table 2. Global waste-to-energy company market share in 2013**

| Company | Market share (%) |
|---|---|
| Hitachi Zosen | 12.0 |
| Babcock & Wilcox | 8.0 |
| Foster Wheeler | 7.2 |
| Veolia | 5.0 |
| Suez Environment SA | 4.5 |
| Waste Management Inc | 4.0 |
| Others | 59.3 |
| Total | 100.0 |

Other key market trends include:

- Extensive presence of government initiatives aimed at promoting waste-to-energy as an alternative form of energy;
- Presence of large untapped opportunities in the emerging markets of Asia Pacific and Latin America; and
- Declining availability of landfill space promoting waste-to-energy market growth.

However, other established renewable energy sources, including solar, wind, and hydro, are expected to present a competitive challenge for waste-to-energy in terms of technology and economics, and may act to restrain waste-to-energy from penetrating the renewable energy market. High upfront costs associated with establishment of waste-to-energy plants are also expected to remain a hurdle for market participants over the next five years.

## About the author

Maya Agnani is project analyst for BCC Research. Contact Agnani at analysts@bccresearch.com.

## About BCC Research

BCC Research (Wellesley, Mass.) has 45 years experience publishing market research reports that cover major industrial and technology sectors, including emerging markets. View the full catalog of reports at www.bccresearch.com.

## Resource

M. Agnani, "Thermal and biological waste-to-energy markets," BCC Research Report EGY063B, January 2016. www.bccresearch.com.

# acers spotlight

## Society and Division news

### L. Eric Cross pioneered piezoelectric transducers for modern medical ultrasound

**By Clive Randall and Susan Trolier-McKinstry**

Cross

ACerS Fellow and Distinguished Life Member Leslie Eric Cross (1923–2016) passed away peacefully on December 29, 2016. He was an Evan Pugh Professor Emeritus of Electrical Engineering, Pennsylvania State University, a member of the U.S. National Academy of Engineering, and a founding member of the Penn State Materials Research Laboratory.

Cross was a world leader in the field of ferroelectrics from a fundamental perspective, as an inventor of new characterization techniques, and in materials applications. He was beloved for his intelligence, vision, wit and humanity, as well as the charm with which he shared his fascination with ferroelectrics and his newest ideas. He was also an excellent mentor and many of his students and postdoctoral researchers went on to scientific leadership positions themselves.

During his career, Cross was honored by many professional organizations. He was a Fellow of The American Ceramic Society, Materials Research Society, American Physical Society, Optical Society of America, and IEEE. In 1983, he was elected to the National Academy of Engineering for his contributions to the development of electroceramic, dielectric, and piezoelectric materials. ACerS honored him in 2001 with its highest honor, Distinguished Life Member. He also received the Von Hippel award of the Materials Research Society in 2010, its highest honor.

Cross joined Penn State as a senior research associate in 1961, rose through the ranks, and, in 1985, was named Evan Pugh Professor of Electrical Engineering—the highest distinction the university can bestow on a faculty member. He was the author or coauthor of more than 850 refereed papers, held 20 patents, and published a comprehensive textbook, *Domains in Ferroic Crystals and Thin Films*.

At Penn State, he mentored more than 50 graduate students from across the world, including Professor Yao Xi, the first Chinese Ph.D. (1982) educated in the U.S. following the Cultural Revolution. ■

**In memoriam**

*R. Bruce*
*L. Eric Cross*
*John Megles*
*Hayne Palmour*
*William Prindle*

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

### Welcome to our newest Corporate Members!

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

Monofrax

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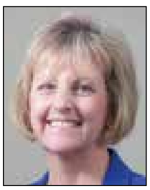
**Falconer, N.Y. 14733**
**www.monofrax.com**

## Society and Division news (continued)

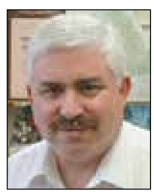
## Names in the news

### Richardson to deliver Rutgers' McLaren Lecture


Richardson

Kathleen Richardson, professor at the University of Central Florida, will deliver the Malcom G. McLaren Distinguished Lecture on March 31 at the eponymous symposium in memory of the late Professor McLaren. Her talk, "Chalcogenide glasses—a versatile platform for innovations in the infrared," highlights the symposium theme of "Photonics, Optical Physics and Beyond." There is no cost to attend the March 31 technical symposium, which will be held at Rutgers University – Busch Campus. A ticketed reception and banquet will follow. Contact Nahed Assal at nahedassal@rutgers.edu for event details or online at mse.rutgers.edu/news. ■

### Feller awarded first Centenary Fellow of the Society of Glass Technology


Feller

Steve Feller, Coe College B.D. Silliman Professor of Physics, was named Centenary Fellow of the Society of Glass Technology at its gala anniversary celebration in September 2016. Feller is the first recipient of the award, which was created to celebrate the 100th anniversary of the founding of SGT. ■

### Singh recognized at events abroad


Singh

Mrityunjay Singh of the Ohio Aerospace Institute received an honorary doctorate from the Slovak Academy of Sciences in Bratislava, Slovakia. Also, the Japan Fine Ceramics Association presented him with the JFCA 30th Anniversary Special Award for Distinguished Contributions at its anniversary celebration. ■

## Mo-Sci and Saint-Gobain are first Diamond-level Corporate Partners

ACerS is pleased to announce Mo-Sci Corp. (Rolla, Mo.) and Saint-Gobain (Northboro, Ma.) as the first companies to join as Diamond Corporate Partners in ACerS new Corporate Partnership program. The new program, launched in early 2017 and announced in the January/February issue of the *Bulletin*, will replace the existing Corporate Membership program by the end of 2017.

The program creates more value for member companies, provides increased visibility for those companies, and forges stronger relationships with the Society, its members, and other partner companies.

"I would highly recommend the Diamond Corporate Partnership level to all companies that are, or plan to become, active in ACerS," says Ted Day, CEO of Mo-Sci. "Based upon the value of the benefits only, it's the best plan for corporate membership."

According to Kevin Thompson, ACerS director of membership, the new program is geared toward engagement with the Society. "We want to have a partnership with member companies, not only by providing resources, but to have ongoing dialogue with our industry partners. We are here to serve all members. If we can help member companies succeed, it helps ACerS achieve its goals of serving a vibrant industry."

Three levels of Corporate Partnership (Corporate, Sapphire, and Diamond) offer specific benefits in three key areas: marketing/business development; professional development; and technical resources.


Credit: ACerS

**Kevin Thompson (right) describes the new ACerS Corporate Partnership program to an attendee at the ICACC Expo in Daytona Beach.**

"As the saying goes, 'the more you put into something, the more you get out of it,'" continues Thompson. "By engaging with the Society through conferences, trade shows, advertising, sponsorships, etc., the more connected you become with ACerS and its 11,000 plus members."

Response has been very positive so far, according to Thompson. "I spoke with a lot of companies at the recent ICACC show in Daytona Beach, and there was a lot of interest in the new program."

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

## National Academy of Inventors names four ACerS members Fellow

**Delbert Day** (Missouri University of Science and Technology), **Richard Riman** (Rutgers, The State University of New Jersey), **Mrityunjay Singh** (Ohio Aerospace Institute), and **Anil Virkar** (University of Utah) will be inducted as NAI Fellows at a ceremony in Boston on April 6, 2017. ■

## IOM3 awards Boccaccini group Pfeil Award

The Institute of Materials, Minerals and Mining (IOM3) awarded **Aldo Boccaccini** and his coauthors its 2016 Pfeil Award for the paper "Electrophoretic deposition of nanostructured $TiO_2$/alginate and $TiO_2$-bioactive glass/alginate composite coatings on stainless steel," published in the journal *Advances in Applied Ceramics* (Vol. 113). Boccaccini is professor at University of Erlangen-Nuremberg, Germany. ■

# St. Louis Section/RCD 53rd Annual Symposium: March 29-30, 2017

The St. Louis Section and the Refractory Ceramics Division of ACerS will sponsor the 53rd Annual Symposium on the theme "Real World Applications of Refractory Testing" on March 29–30, with a kickoff event on Tuesday, March 28. The meeting will be at the Hilton St. Louis Airport Hotel, St. Louis, Mo. Program cochairs are Ashley Hampton of Vesuvius and Brian Rayner of the Orton Ceramic Foundation.

A block of rooms has been set aside for March 27–31 at the Hilton (314-426-5500). To receive the $110 rate, mention St. Louis Section of The American Ceramic Society, or SLC, when making reservations. Make online reservations at Bit.ly/SLCSymposium. Hotel reservation deadline is **February 27**. For more information, contact Patty Smith at 573-341-6265 or psmith@mst.edu.

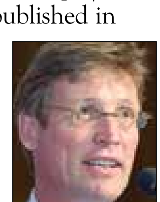
### Awards to be presented

**Alfred W. Allen Award**

A.G. Tomba Martinez of Materials Science and Technology Research Institute (INTEMA), Argentina, A.P. Luz, M.A.L. Braulio, and V.C. Pandolfelli of Federal University of São Carlos, Brazil, will receive the Alfred W. Allen Award for their paper, "$Al_2O_3$-based binders for corrosion resistance optimization of $Al_2O_3$-$MgAl_2O_4$ and $Al_2O_3$-MgO refractory castables." The paper was published in *Ceramics International* 41 (2015) 9947-9956.

**T.J. Planje–St. Louis Refractories Award**

Andreas Buhr of Almatis GmbH (Frankfurt, Germany), global technical director refractories will receive the T.J. Planje–St. Louis Refractories Award.



Buhr

March 28, 2017

5:00 p.m. Kickoff event – Gateway Arch riverboat cruise of the Mississippi

March 29, 2017

7:15 a.m. Registration and coffee

8:00 a.m. Welcome and introductions
**St. Louis Section chairman**
*Bill Davis*, Harbison Walker International
**Refractory Ceramics Division chair**
*Josh Pelletier*, Kerneos Inc.
**Co-program coordinators**
*Ashley Hampton*, Vesuvius
*Brian Rayner*, The Edward Orton Jr. Ceramic Foundation

8:15 a.m. Morning technical sessions

1:00 p.m. Afternoon sessions and presentation of the T.J. Planje St. Louis Refractories Award to **Andreas Buhr**, Almatis GmbH, Germany

4:45 p.m. RCD annual members meeting

5-7 p.m. Exposition and cocktail hour

7:00 p.m. Dinner

March 30, 2017

6:30 a.m. Refractory Ceramics Division (RCD) breakfast meeting

8:15 a.m. Morning technical sessions and presentation of the 2016 Alfred W. Allen Award winner "Reflections on refractory materials and their evaluation" **Victor C. Pandolfelli**, Federal University of São Carlos, Brazil

12:00 p.m. Questions and discussion

12:30 p.m. St. Louis Section officer business meeting ■

## Students and outreach

### ACerS 'Next Top Demo' competition!

Show off your demonstration skills in ACerS Next Top Demo Competition, organized by ACerS President's Council of Student Advisors. This virtual competition is a new opportunity to educate the public while advertising the community outreach that you and your peers already perform. Get your fellow students together and submit a video conducting a ceramic and/or glass outreach demonstration. Visit www.ceramics.org/pcsademo to submit videos. Deadline for submissions is **April 28, 2017.** ■

### Refractories scholarship opportunity for students

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

### Grad students—Put yourself on the path to success!

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

GGRN aims to help graduate students

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

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

### Grad students—Basic Science Division GEMS awards at MS&T17

Sponsored by ACerS Basic Science Division, the annual Graduate Excellence in Materials Science (GEMS) awards recognize the outstanding achievements of up to 10 graduate students in materials science and engineering. The award is open to graduate students making oral presentations in any symposium at MS&T17. Enter the competition at www.matscitech.org and submit your paper by **March 15, 2017.** ■

## Awards and deadlines

### Electronics Division's best student presentations of EMA 2017

Electronics Division presented awards during the January 2017 EMA meeting in Orlando, Fla. Congratulations to the following students!

#### Best student poster presentations

First place: **Tassie Andersen**, Northwestern University, *Evolution of brownmillerite structure in $SrCoO_{2.5}$ under varying molecular beam epitaxy growth conditions*

Second place: **William Huddleston**, Case Western Reserve University, *Sintered cathodes for all-solid-state structural lithium-ion batteries*

Third place: **Kevin Pachuta**, Case Western Reserve University, *Characterization of solution-based exfoliated nanosheets*

#### Best student oral presentations

First place

**Ching-Yen Tang**, University of Illinois at Urbana Champaign, *In situ X-ray photoelectron and Auger electron spectroscopic characterization of reaction mechanisms during Li-ion cycling of CuO electrodes*

Second place

**Ran Gao**, University of California, Berkeley, *Ferroelectricity in epitaxial $Pb_{1+\delta}ZrO_3$ thin films*

Third place

**Xiaorui Tong**, West Virginia University, *Kinetic Poisson-Cahn model of defect segregation near grain boundaries during thermal annealing in oxygen-conducting solid electrolytes* ■

### GOMD and Electronics Division awards with May 15 deadlines

While January 15 was the deadline for most award nominations, three prestigious Society and Division awards have a **May 15, 2017** deadline. Visit www.ceramics.org/awards for eligibility details. Contact Erica Zimmerman at ezimmerman@ceramics.org with any questions.

#### Glass & Optical Materials: Alfred R. Cooper Scholars Award

This award recognizes undergraduate students who have demonstrated excellence in research, engineering, and/or study in glass science or technology. The recipient receives a plaque, $500, and a free MS&T registration.

CERAMIC AND GLASS INDUSTRY FOUNDATION

## The Ceramic and Glass Industry Foundation receives $50,000 grant from Corning Incorporated Foundation

The Ceramic and Glass Industry Foundation (CGIF) has been awarded a $50,000 grant from the Corning Incorporated Foundation to support the CGIF's student outreach programs to increase awareness of ceramic and glass materials science among middle school and high school students in the United States.

The Corning Incorporated Foundation grant specifically will support distribution of the CGIF's Materials Science Classroom Kits, which introduce students to the basic classes of materials (ceramics, glass, composites, metals, and polymers) through fun and interactive lessons. The kits include nine materials science lessons—five teacher demonstrations and four student labs. Six of the lessons focus specifically on ceramic and glass materials.

Accompanying each kit is *The Magic of Ceramics*, a book that introduces the nontechnical reader to the many exciting applications of ceramics. The book describes how ceramic materials function, while teaching key scientific concepts like atomic structure, color, and the electromagnetic spectrum. *The Magic of Ceramics* contains numerous illustrations of ways that ceramics make advanced products possible, and also addresses newer areas in ceramics, such as nanotechnology.

With the backing of the Corning Incorporated Foundation, the CGIF will focus its outreach efforts on middle schools and high schools located in areas of the United States where Corning Incorporated operates, which include approximately 165 middle schools and high schools in 17 target communities. The primary objective is to get kits and books into the hands of educators who are excited to teach materials science to their students.

ACerS individual members and Corporate Partners are encouraged also to sponsor Materials Science Classroom Kits. The CGIF currently has a wait-list of nearly 60 middle and high schools who have requested a kit to use in their classrooms but do not have the resources to purchase a kit on their own. If you are interested in supporting the Foundation's mission to introduce young people to the world of ceramic and glass materials through kit sponsorship, visit www.ceramics.org/donateakit.

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

### Electronics: Edward C. Henry Award

This award is given annually to an outstanding paper reporting original work in the *Journal of the American Ceramic Society* or the *ACerS Bulletin* during the previous calendar year on a subject related to electronic ceramics. The author(s) receive a plaque and $500 (split between authors).

### Electronics: Lewis C. Hoffman Scholarship

This $2,000 tuition award encourages academic interest and excellence among undergraduate students in the area of ceramics/materials science and engineering. The 2017 essay topic is "Low dimensional structures and properties in electronic ceramics." ■

## Ultrathin aluminum oxide layer boosts performance of garnet ceramic solid-state batteries

Researchers at the University of Maryland have designed a way to insert an ultrathin layer of aluminum oxide within solid-state batteries that incorporate garnet ceramic materials, decreasing the batteries' impedance by 300-fold and allowing the energy to flow.

Garnet ceramic electrolytes create high impedance (resistance) between the garnet and the electrodes in solid-state batteries, limiting current flow.

"This is a revolutionary advancement in the field of solid-state batteries—particularly in light of recent battery fires, from Boeing 787s to hoverboards to Samsung smartphones," Liangbing Hu, associate professor of materials science and engineering and one of the corresponding authors of the paper, says in a University of Maryland press release. "Our garnet-based solid-state battery is a triple threat, solving the typical problems that trouble existing lithium-ion batteries: safety, performance, and cost."

The other corresponding author on the paper is Eric Wachsman, ACerS member and Fellow and director of the University of Maryland Energy Research Center and William L. Crentz Centennial Chair in Energy Research, who recently put ceramic materials in the public eye in a segment on *CBS This Morning*.

To solve the impedance problem, the team used atomic layer deposition to squeeze an ultrathin film of aluminum oxide between the battery's lithium anode and garnet electrolyte LLCZN ($Li_7La_{2.75}Ca_{0.25}Zr_{1.75}Nb_{0.25}O_{12}$).

The oxide addition decreased impedance at room temperature from 1,710$\Omega \bullet cm^2$ to 1$\Omega \bullet cm^2$, "effectively negating the lithium metal/garnet interfacial impedance," the authors write in the paper's abstract.

The authors go on to explain that their experimental and computational results indicate that the oxide coating "enables wetting of metallic lithium in contact with the garnet electrolyte surface and the lithiated-alumina interface allows effective lithium ion transport between the lithium metal anode and garnet electrolyte."

And the researchers themselves are not the only ones who realize the impact of their work.

"The work effectively solves the lithium metal–solid electrolyte interface resistance problem, which has been a major barrier to the development of a robust solid-state battery technology," UCLA materials science and engineering professor Bruce Dunn, who was not involved in the research, says in the press release.

The paper, published in *Nature Materials*, is "Negating interfacial impedance in garnet-based solid-state Li metal batteries" (DOI: 10.1038/nmat4821). ■



**A new method could boost the performance of solid-state batteries.**




**Transmission electron microscopy image of an improved two-phase ceramic membrane that separates hydrogen. Proton and electron conduction phases are marked in color: barium cerate doped with europium oxide (BCEO) and cerium doped with yttrium and europium oxide (CYO).**

## Ceramic hydrogen separation membrane doubles flow rate, could enable clean energy

Researchers at Forschungszentrum Jülich in Germany have developed a significantly improved stable ceramic hydrogen separation membrane that can enable a hydrogen flow rate that is nearly double that of other separation membranes.

To bypass the limitations of individual materials, the researchers explored two-phase membranes based on perovskite and fluorite. Their membrane mixes together barium cerate doped with europium oxide (BCEO) and cerium doped with yttrium and europium oxide (CYO).

"The individual grains are only a thousandth of a millimeter in size and exhibit both ionic and electronic conductivity," lead author Mariya Ivanova says a Jülich press release.

The two-phase $BaCe_{0.8}Eu_{0.2}O_{3-\delta}$:$Ce_{0.8}Y_{0.2}O_{2-\delta}$ membrane, just 500 µm-thick, allows hydrogen protons and electrons to separately pass through the membrane. Protons occupy crystal lattice vacancies in the ceramic membrane and are driven through the membrane by pressure differences and temperature, the researchers explain.

"They dock onto a hydrogen ion and

jump in the direction of the lower pressure to the next hydrogen ion, from vacancy to vacancy, until they form elementary hydrogen again on the other side," Ivanova says in the release. "The electrons are transported through the second component of the ceramic and ensure that charge equalization occurs."

The ceramic membrane also functions at lower temperatures of 600°C–700°C, although the research is preliminary. So far, the team has only fabricated and tested a small membrane, measuring about the size of a 10-cent coin—so there is much more work to be done.

"It is still too early to be thinking about an industrial application," Ivanova says. "We will continue to conduct research, searching for a suitable material with a high flow rate and stability as well as low costs. The next step will be to increase component size to make it fit for industrial application."

Read more in the open-access paper, published in *Scientific Reports*: "Hydrogen separation through tailored dual phase membranes with nominal composition $BaCe_{0.8}Eu_{0.2}O_{3-\delta}:Ce_{0.8}Y_{0.2}O_{2-\delta}$ at intermediate temperatures"(DOI: 10.1038/srep34773). ■

## Synthesis technique integrates 2-D materials into supercapacitors that can charge electronics in seconds, last for decades

Researchers at the University of Central Florida (Orlando, Fla.) have developed a technique to incorporate 2-D materials into thin and flexible supercapacitor nanostructures that rapidly provide sufficient power and remain stable after countless charging cycles.

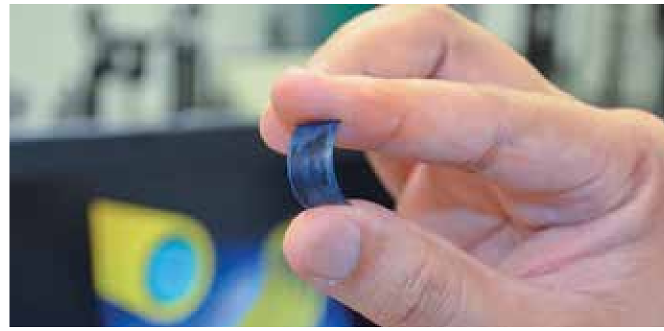
"If they were to replace the batteries with these supercapacitors, you could charge your mobile phone in a few seconds and you wouldn't need to charge it again for over a week," said Nitin Choudhary, a postdoctoral associate who conducted much of the research, in a UCF news release.

The UCF researchers' 2-D materials of choice are transition metal dichalcogenides, semiconductor materials with properties that make the materials well-suited for various electronic applications.

To incorporate the 2-D materials into supercapacitors, the team devised a technique to coat transition metal dichalcogenide layers onto thin nanowires, creating core-shell structures. The core structures provide conductivity, while the shells yield high energy and power densities—so that the combined structures hold sufficient power yet still charge and discharge rapidly.

"There have been problems in the way people incorporate these 2-D materials into the existing systems—that's been a bottleneck in the field," principal investigator and assistant professor Yeonwoong "Eric" Jung says in the news release. "We developed a simple chemical synthesis approach so we can very nicely integrate the existing materials with the 2-D materials."

And although simple, the team's synthesis approach is highly effective.


Credit: University of Central Florida

**Researchers at the University of Central Florida have developed a method to fabricate thin, flexible supercapacitors from 2-D materials.**

While lithium-ion batteries significantly degrade and thus ultimately fail at less than 1,500 charging cycles, recent supercapacitors have stretched the cycles to a few thousand. But the UCF researchers' new core-shell supercapacitors can recharge 30,000 times without degrading, according to the news release.

Because this is such a major advance, the team is now working to patent the fabrication process. "It's not ready for commercialization," Jung says in the release. "But this is a proof-of-concept demonstration and our studies show there are very high impacts for many technologies."

The paper, published in *ACS Nano*, is "High-performance one-body core/shell nanowire supercapacitor enabled by conformal growth of capacitive 2D WS2 layers" (DOI: 10.1021/acsnano.6b06111). ■

# advances in nanomaterials

## Nothing silly about super-sensors made of 'Silly Putty' and graphene

A group out of Trinity College Dublin in Ireland have mixed graphene with homemade "Silly Putty" to make a composite with very cool properties.

In a video available at youtu.be/2aGixN9Vzhk, Trinity College physics professor and lead scientist Jonathon Coleman explains, "When you took the composite... and you squashed it or deformed it in any way, its electrical resistance would change dramatically," which would make it useful as an electromechanical sensor. The researchers found it has a "sensitivity factor of up to 500—hundreds of times better than a strain sensor," according to Coleman.

How sensitive is that? Reports assert it can sense footsteps of a spider walking across it.

While arachnid zookeepers and researchers may rejoice at having found a sensor that will keep the little monsters from making a jailbreak, there are practical applications in the biomedical arena that could be disruptive.

For example, in the video Coleman's group shows that pulse and blood pressure can be monitored easily by placing the material over the carotid artery and measuring the electromechanical response. While there are plenty of existing techniques, Coleman notes that the ability to measure blood pressure continuously is a breakthrough.

So why does it work? The sensitivity results from a sharp increase in resistance with applied strain. The resistance decays very slowly compared to the rate at which stress relaxes. The paper explains, "We interpret this behavior as the strain rapidly deforming the network and breaking nanosheet–nanosheet connections, thus increasing the resistance."

In addition, the researchers hypothesize that the nanosheets themselves have some mobility. "This network relaxation can be thought of as a self-healing process," although they note that the deformation is not fully reversible. Eventually, the material will lose sensitivity.

Credit: AMBER, Trinity College Dublin

**Trinity College Dublin researcher Johnny Coleman investigates G-Putty, but his son Oisin prefers Silly Putty.**

Nonetheless, the upside potential of this super-simple composite is huge.

"It shows the power of nanomaterials—a small amount of nano can turn something ordinary into something extraordinary," Coleman modestly concludes in the video.

The paper, published in *Science*, is "Sensitive electromechanical sensors using viscoelastic graphene-polymer nano composites" (DOI: 10.1126/science.aag2879). ■

## Graphene goes 3-D to build porous geometries that are stronger and lighter than steel

Although 2-D materials such as graphene have unsurpassed strength and a whole host of properties that make them potentially revolutionary, the difficulties of integrating 2-D materials into 3-D structures has hindered any potential revolution thus far.

But engineers at the Massachusetts Institute of Technology (Cambridge, Mass.) have figured out the key to building strong yet light 3-D structures from graphene.

Using pressure and heat, the team compressed 2-D graphene flakes into 3-D structures with a large surface area in a small volume. Then, using atomistic computational modeling, the scientists built robust simulations of the material's gyroid structure, accounting for individual atoms within those structures.

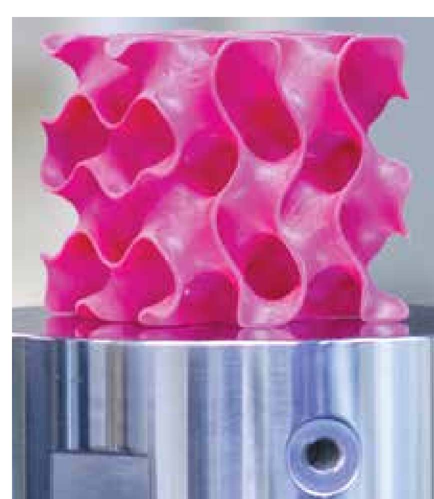
These simulations showed that, with an optimized structure, porous graphene geometries could have 10 times the strength yet just 5% the density of steel.

To confirm their simulations, the engineers 3-D-printed much larger models of these geometries out of plastic, varying the wall thickness, so that they could experimentally test the structures.

Hear more from the engineers themselves and see how the structures held up in a short MIT video available at youtu.be/VIcZdc42F0g.

And the concept is not limited to graphene. "You could either use the real graphene material or use the geometry we discovered with other materials, like polymers or metals," Markus Buehler—senior author on the new research, head of MIT's Department of Civil and Environmental Engineering, and McAfee Professor of Engineering—says in an MIT press release. "You can replace the material itself with anything. The geometry is the dominant factor. It's something that has the potential to transfer to many things."

The open-access paper, published in *Science Advances*, is "The mechanics and design of a lightweight three-dimensional graphene assembly" (DOI: 10.1126/sciadv.1601536). ■



Credit: Melanie Gonick; MIT

**3-D-printed gyroid models such as this one were used to test the strength and mechanical properties of a new lightweight material.**

## Big data offers bigger potential to bolster manufacturing efficiency and productivity

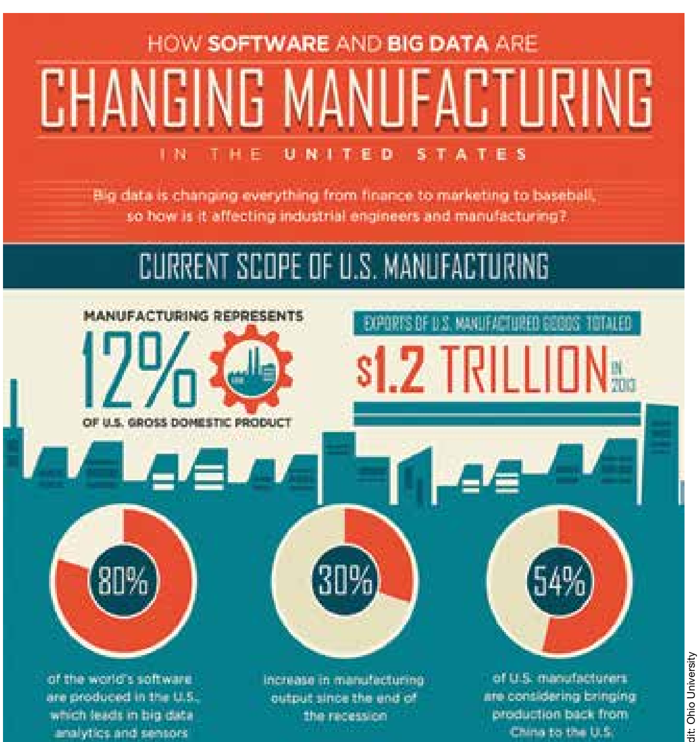
While big data's role in research may be more familiar to most, research is not the only place where big data has potential.

Because analysis of big data offers the ability to comprehensively assess many nuanced variables at once, it is particularly well suited for complex processes such as manufacturing.

According to an article from McKinsey & Company, a management consulting firm, "In manufacturing, operations managers can use advanced analytics to take a deep dive into historical process data, identify patterns and relationships among discrete process steps and inputs, and then optimize the factors that prove to have the greatest effect on yield."

In other words, collecting and analyzing big data in manufacturing can increase efficiency by saving time and money. Even voices from some of the biggest names in manufacturing agree that big data is key to boosting production and making manufacturing competitive.

In fact, combining big data with flexibility in manufacturing can increase productivity by 30% and decrease development and assembly costs by 50%, according to a news story from Ohio University. The university recently created an infographic that provides several more figures about big data in manufacturing. The full infographic is available at bit.ly/2k7UfCL.




**This infographic, created by researchers at Ohio University, provides a visual representation of figures about big data in manufacturing. The full infographic is available at bit.ly/2k7UfCL.**

Big data can increase productivity and decrease manufacturing costs in several different ways, including product development and manufacturing processes.

Designing, building, and testing prototypes is time- and labor-intensive—but using big data can enable modeling and simulations that inform smarter prototype design and even reduce the number of prototypes a company builds and tests.

Plus, data analytics can help manufacturing facilities run more efficiently by monitoring equipment and processes, offering the potential to sense and predict problems before they occur.

The results can drive rapid, optimized product development and prevent costly downtime, ultimately boosting productivity.

"The big data era has only just emerged, but the practice of advanced analytics is grounded in years of mathematical research and scientific application," according to the McKinsey & Company article. "It can be a critical tool for realizing improvements in yield, particularly in any manufacturing environment in which process complexity, process variability, and capacity restraints are present." ■

## Sintering technique processes ultrafine nanocrystalline spinel

Nanocrystalline ceramics can have extraordinarily high hardness.

Classic size–effect relationships predict that decreasing grain size will increase hardness, but the phenomenon is only observed when ceramics are pore-free—a condition difficult to achieve because elimination of porosity at final stages of sintering is linked to grain growth.

However, by further understanding the dependence between densification and grain growth, the Nanoceramics Thermochemistry Laboratory at the University of California, Davis—led by ACerS member Ricardo Castro—has circumvented this problem to devise a new process to fabricate fully dense ceramic parts with virtually no grain growth.

The method produced transparent nanocrystalline magnesium aluminate ($MgAl_2O_4$) spinel with grain sizes of 7 nm and a record-breaking Vickers hardness of 28.4 GPa—even harder than sapphire.

"Magnesium aluminate spinel is the primary material of choice for stringent optical and transparent armors, with a combination of high hardness, light weight, and broadband optical properties that exceed that of competing materials, such as sapphire and AlON," Castro says. "However, high processing costs of truly dense spinel ceramics limits their market."

Densification slows down at the final stage of sintering because pores become highly stable. Castro's group managed to break this stability by using pressure-assisted sintering with a punch designed to deform when the system reaches the final stage of sintering.

This spark plasma sintering (SPS) process, named deformable punch spark plasma sintering (DP-SPS), uses the high heating rates of SPS. However, uniaxial pressures from SPS are not enough to induce full densification without some level of grain growth, which can form grains larger than 10 nm.

Therefore, the team used a complaint punch to transfer transversal momentum to the grains, shifting contact angles—where pores and grain boundaries meet—and breaking the pores' stability cages. The result is fully dense ceramics with unprecedentedly small grain sizes.

"Our results show that we can lower the sintering temperature to below 800°C, using nanoparticles as a starting material and a deformable punch in the die set that helps achieve full densification with minimal—truly minimal—grain growth," Castro adds. "The method removes residual porosity, which is critical for optical applications, by sliding the grains instead of growing them during sintering. This means very small grains that are mostly limited by initial grain size rather than by processing conditions."

Using a controlled chemical synthesis method, the UC Davis team densified nanopowders with 4-nm grain sizes into spinel samples with 7-nm grain sizes. The highly transparent


Credit: Nanoceramics Thermochemistry Laboratory

**A sample of transparent nanocrystalline spinel developed at University of California, Davis.**

## Research News

### Crystal structure holds promise for optoelectronic devices

A Florida State University (Tallahassee, Fla.) research team has discovered a crystal structure of organic-inorganic hybrid materials that could open the door to new applications for optoelectronic devices like LEDs and lasers. The team used a class of crystalline materials called organometal halide perovskites to assemble 1-D structures. The team found a way to put these pieces together in a chain, which is surrounded by organic pieces to form a core-shell type wire. Millions of the organic-coated wires then stack together to form a crystalline bundle with interesting optical properties—it is highly photoluminescent, which scientists can manipulate moving forward as they use it for different technologies. For more information, visit www.news.fsu.edu.

### Probing ways to turn cement's weakness to strength

Rice University (Houston, Texas) researchers are a step closer to understanding why plasticity at small scales lets concrete constantly adjust to stress, even after hardening. The scientists performed an atom-level computer analysis of tobermorite, a naturally occurring crystalline analog to the calcium-silicate-hydrate that makes up cement, to see how it uses dislocations to relieve stress. The models showed that defect-free tobermorite deformed easily as water molecules caught between layers helped them glide past each other. But in particles with screw defects, the layers only glided so far before being locked into place by tooth-like core dislocations. That effectively passed the buck to the next layer, which glided until caught, and so on, relieving the stress without cracking. For more information, visit www.news.rice.edu.

sample can be used as strike face materials for transparent armor system and other applications that require transparency and high hardness.

The team measured an increase in hardness from 17.2 to 28.4 GPa—surpassing sapphire hardness—when it refined grain sizes from 188 to 7 nm, following a square-root function of grain size.

"The hardness for the nanospinel is higher than sapphire for any given plane, while being equally transparent," Castro says. "Combined with the fact that the spinels are isotropic due to their cubic structure, in terms of shock resistance this nanospinel can offer better performance for sure."

This behavior can be explained by a quasi-plasticity model that assumes load-induced deformation in ceramics is accommodated by grain shearing, which breaks (and reforms) bonds at grain boundary regions. Therefore, there is a correlation between strength of grain boundaries, their networking area, and room temperature macro-mechanical behavior.

Correspondingly, an increased grain boundary network (small grains) should lead to more efficient intergranular cracking deflection, macroscopically representing an increase in hardness.

From this perspective, there should be no expected low grain size limit, except for when grains are so extremely small that there is loss of long-range ordering and the material is mostly amorphous.

DP-SPS has finally allowed production of such small-grained samples to prove this concept, suggesting contrary data are likely related to impurities and residual porosities.

Although tests mostly involved DP-SPS in spinel densification, the team suggests there is no reason to believe this method is exclusive to spinel densification. As long as deformation of the punch is set to occur at the ceramic's final stages of sintering, the method can likely eliminate residual porosity as well.

The UC Davis team also successfully tested the technique for $BaTiO_3$, suggesting the rise of a new generation of nanoceramics with truly nanoscale sizes (<10 nm) that may unveil the full potential of nanoceramics without porosity interference.

Moreover, while the process can allow densification of nanograined ceramics, it can also help densify micrograined samples—in particular those difficult to sinter to full densities.

"With this unprecedented sizes and fully dense samples, we can finally assess the nano-effects with great reliability, without interfering porosity. We have tested the compliant punch in other oxides now—achieving fully dense nanocrystalline samples is not exclusive for $MgAl_2O_4$. So, testing magnetic behavior, electric behavior, conductivity etc. can now be done without the inconvenience of contaminations, cracks, and other common sample problems in nanoceramics."

"The secret is the compliant punch," Castro says. "While at this point we are focused on the science behind this, I'm positive this can be scaled up. Once one can make thin nano-spinel discs, cutting them with a laser will be much easier than cutting sapphire due to its isotropic properties. Moreover, with higher hardness than sapphire, this can be a scratch-free surface that largely surpasses Gorilla Glass and sapphire for display applications as well."

The paper, published in *Materials Letters*, is "Colossal grain boundary strengthening in ultrafine nanocrystalline oxides" (DOI: 10.1016/j.matlet.2016.10.035).

This work was sponsored by NSF DMR Ceramics, 160978. ■



### Why ferroelectric crystals exhibit strong piezoelectric responses

An international team of scientists led by Pennsylvania State University (University Park, Pa.) may have solved the 30-year-old riddle of why certain ferroelectric crystals exhibit extremely strong piezoelectric responses. Previous research on a relaxor-ferroelectric solid solution suggested that polar nanoregions contributed to its high piezoelectricity. The Penn State team performed experiments at ultralow cryogenic temperatures to determine if this theory was correct. Using phase-field modeling, the researchers showed that the significant enhancement in piezoelectricity originated from the polar nanoregions and demonstrated how the polar nanoregions help generate ultrahigh responses. For more information, visit www.mri.psu.edu.

## Magnetic ink prints self-healing devices that fix themselves in mere milliseconds

Engineers at the University of California, San Diego have developed a magnetic ink that can be used to print batteries, circuits, and other devices that, if broken or damaged, can heal themselves in a matter of milliseconds.

The team developed the self-healing ink by loading it with neodymium microparticles, which are magnetic, and carbon black, which they added for its electrochemical properties.

Although the microparticles' individual magnetic fields would otherwise cancel each other out, the engineers found that if they printed the ink in the presence of an external magnetic field, the microparticles orient themselves so that the device has two separate poles at either end.

That way, if the device is damaged, the two broken ends are attracted to one another, healing the device with no external forces, catalysts, or intervention.

Credit: JacobsSchoolNews; YouTube

**A newly developed ink for printing electronic devices can self-heal itself with the help of magnetic nanoparticles.**

According to the researchers, devices printed with the new ink can self-heal gaps as wide as 3 mm and can self-heal in about 50 milliseconds, an impressive achievement in both distance and time when it comes to self-healing materials.

To show the versatility of such a self-healing ink, the team has printed batteries, electrochemical sensors, and wearable, textile-based electrical circuits so far.

According to a UCSD news release, "For example, nanoengineers printed a self-healing circuit on the sleeve of a T-shirt and connected it with an LED light and a coin battery.  The researchers then cut the circuit and the fabric it was printed on. At that point, the LED turned off. But then within a few seconds it started turning back on as the two sides of the circuit came together again and healed themselves, restoring conductivity."

A video showing a few examples of the team's self-healing devices is available at youtu.be/BYU0dKeuno0.

"Our work holds considerable promise for widespread practical applications for long-lasting printed electronic devices," says Joseph Wang, director of the Center for Wearable Sensors and chair of the nanoengineering department at UC San Diego.

The open-access paper, printed in *Science Advances*, is "All-printed magnetically self-healing electrochemical devices" (DOI: 10.1126/sciadv.1601465). ■

## Research News

### Milestone in graphene production produces functional OLEDs

For the first time, Fraunhofer Institute (Dresden, Germany) researchers along with with partners from industry and research have produced functional OLED electrodes from graphene. In a steel vacuum chamber, the scientists heated a wafer plate of high-purity copper to about 800ºC and then supplied a mixture of methane and hydrogen to initiate a chemical reaction. In just a few minutes, the methane dissolves in the copper and forms carbon atoms, which spread on the surface. After cooling, a carrier polymer is placed on the graphene and the copper plate is etched away, leaving an OLED electrode. Due to their flexibility, the graphene electrodes are ideal for touch screens. For more information, visit www.fraunhofer.de/en/press.

### Lighting up ultrathin transition metal dichalcogenide films

Ludwig Maximilian University (Munich, Germany) researchers have developed a method for rapid and efficient characterization of thin-film semiconductors made up of transition metal dichalcogenides. Recent studies of these materials have led to inconsistent values for the degree of valley polarization. With the aid of a newly developed polarimetric method and using monolayers of molybdenum disulfide as a model system, LMU researchers have now clarified the reasons for these discrepancies: Response to polarized light is sensitive to the quality of the crystals, and can thus vary significantly within the same crystal. The new method can be applied to other monolayer semiconductors and systems made up of several different materials. For more information, visit www.en.uni-muenchen.de/news.

## Sea sponges resist buckling by building optimally engineered glass toothpicks

Orange puffball sea sponges (*Tethya aurantia*) extract silica from seawater to build glass spicules, called strongyloxea, which provide internal structural support to these otherwise squishy creatures.

Orange puffball sponges have evolved bundles of toothpick-shaped spicules that help the sponge maintain its shape.

But how can squishy sponges maintain their structural integrity with only thin filaments made of glass?

Brown University researchers Haneesh Kesari and Michael Monn have taken a closer look at orange puffball spicules and found that they have evolved a precisely engineered design that provides the structures with maximal strength.

The researchers' close examination of orange puffball sponges showed that their monolithic, axially symmetric, tapered silica spicules—which are about 35 μm thick and just 2 mm long—are "remarkably uniform," according to the authors.

While examining the spicules, the Brown researchers noticed that in addition to their uniformity, the structures had an unmistakable toothpick-like shape—thicker in the middle and tapered at the ends.

Why, the team wondered, would the sponges use such tapered structures rather than simple columns?

Kesari and Monn found their answer in an engineering theory devised by German scientist Thomas Clausen in 1851. Clausen thought that a column structure that was tapered at the ends would be most resistant to buckling, the primary failure mechanism in slender structures—and he was right. Calculations show that a Clausen column is 33% more resistant to buckling than a cylinder and 18% more resistant than an ellipse.

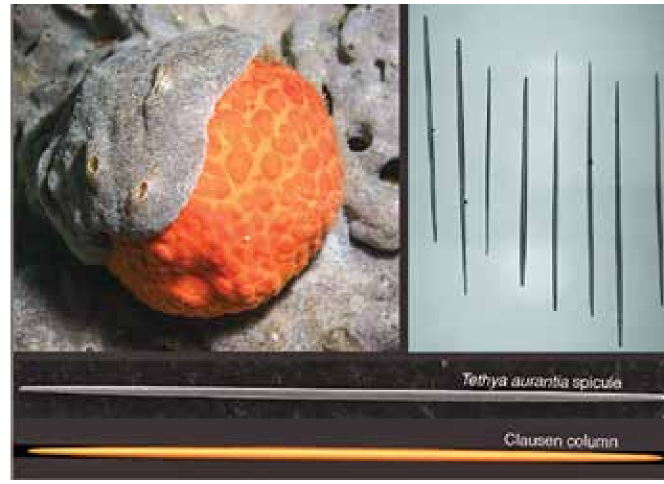
So the design of the orange puffball sponge's spicules provide them with resistance to buckling, despite the fact that they are made of glass.

"We use a structural mechanics model to better understand the function of the strongyloxea spicules within the sponge and to show that they are well tuned for performing that load bearing function," Monn explains via email.

Clausen column structures have been historically difficult to engineer via traditional manufacturing, which is why most architectural designs incorporate simple columns instead. "However, 3-D printing and other digital manufacturing techniques could totally shift this balance and allow for practical designs that leverage optimal shapes like the Clausen column," Monn notes in the email.

According to Monn, optimized Clausen columns might be able to improve and strengthen nanoscale and microscale truss materials in particular.

"High-resolution 3-D printing has allowed us to design the interior of components so they don't need to be solid," Monn explains. "This makes the materials' specific stiffness and strength much higher by replacing solid material with a nanoscale or microscale truss lattice. But the downside is that you introduce a new and important failure mode—truss element buckling."



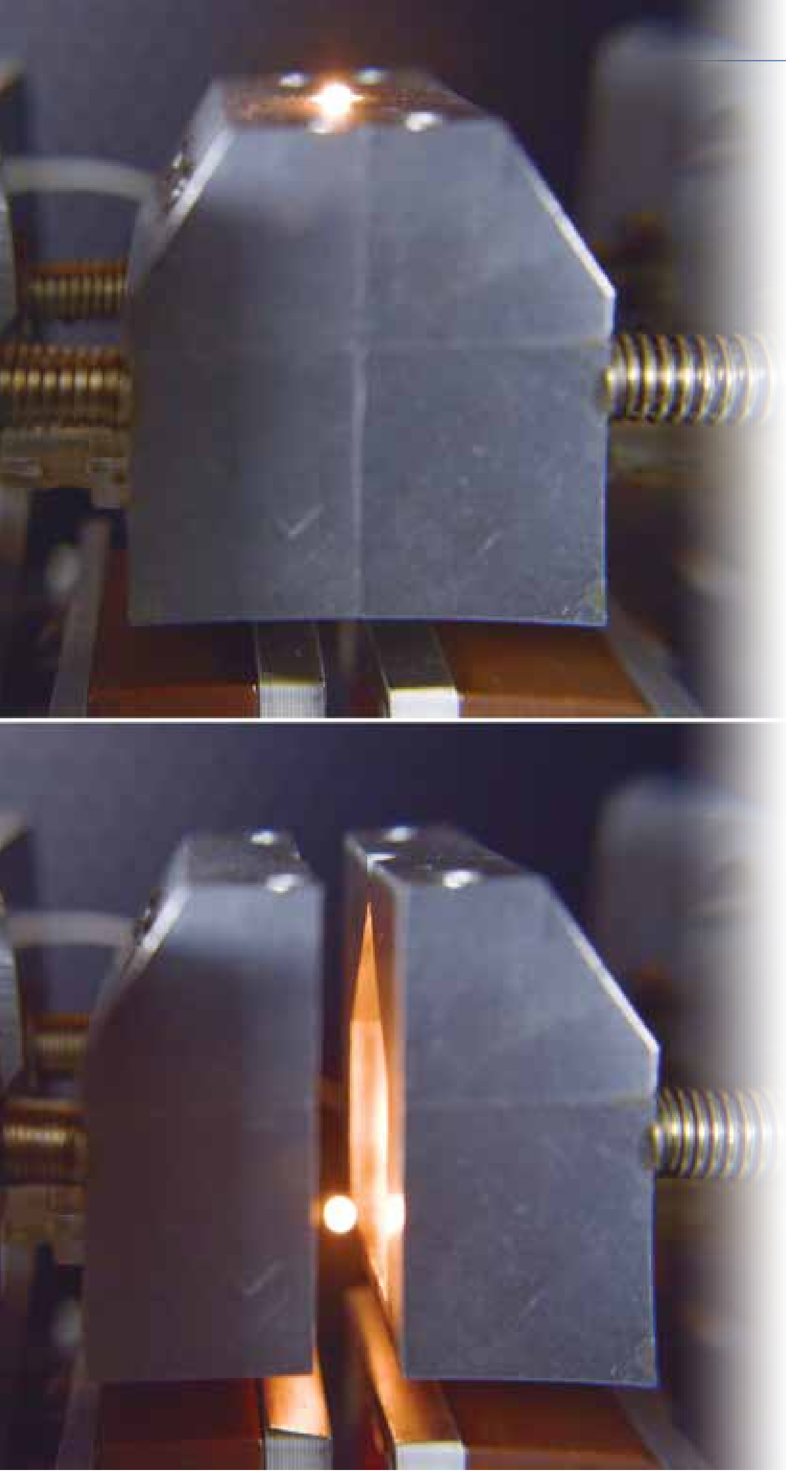

**The odd shape of tiny structural rods found in a species of sea sponges turns out to be optimal for resistance to buckling.**

And because Clausen columns are optimized to resist buckling, this small structural change could help make such truss structures even stronger.

The open-access paper, published in *Scientific Reports*, is "A new structure-property connection in the skeletal elements of the marine sponge *Tethya aurantia* that guards against buckling instability" (DOI: 10.1038/srep39547). ■

# Hot matters—

## Experimental methods for high-temperature property measurement



A laser-heated sample being dropped into a calorimeter.

By Alexandra Navrotsky and Sergey V. Ushakov

Experimental methods for measuring high-temperature properties of refractory ceramics will provide data to engineer new materials for extreme service applications.

Concepts of "heat" and "temperature" pervade our thinking and language. We know intuitively that "hot" is fast and "cold" is slow. A "hot topic" also can be "cool." We live in a narrow range of temperatures between the freezing and boiling points of water. Since early in human history, we have endeavored to harness fire to inhabit a comfortable temperature environment, to cook our food, and to make new metal and ceramic materials using high-temperature processing.

Yet an exact definition of "high-temperature" remains elusive. The temperature of the sun's surface and of the boundary of the earth's iron–nickel inner core is around 5,500°C. Temperatures of millions of degrees are achieved in stars, in nuclear explosions, and in experiments on inertial confinement fusion. Temperatures above the melting and softening points of steel and glass represent high-temperature for most people, and traditionally the term 'refractories' is reserved for materials that can be used for containment of metal and silicate melts.

The calculation of phase diagrams method (CalPhaD)[1] was developed from endeavors in alloy modeling and now is a cornerstone of the integrated computational materials engineering (ICME) approach, providing inputs for simulating phase and microstructure evolution and mechanical properties with phase field techniques and finite-element methods. ICME has demonstrated remarkable achievements in accelerated development of new alloys.[2] However, with superalloys reaching their high-temperature limits for required applications,[3]

## Capsule summary

### AN OPPORTUNITY FOR CERAMIC MATERIALS

Although measurement and modeling techniques have accelerated development of superalloys, these materials are reaching their high-temperature limits. Ceramic materials offer unprecedented higher-temperature capabilities, but lack experimentally measured thermodynamic property data.

### INSIDE THIS ARTICLE

We review recent developments in experimental methods that can provide data for high-temperature properties of refractory ceramics, including thermal analysis and the laser flash method; high-temperature calorimetry; and X-ray and neutron diffraction.

### BIG, BOLD, AND HOT

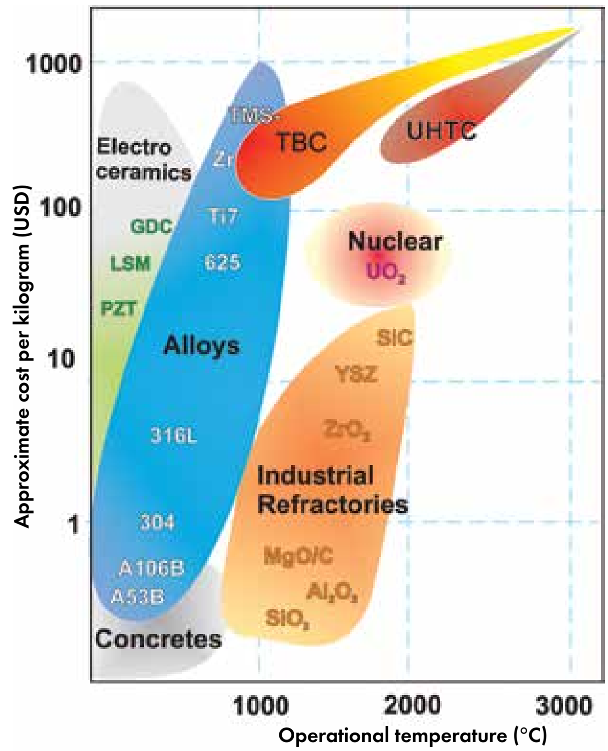
Recent advances have made high-temperature property research more available and sustainable than ever before. Using newly acquired thermodynamic data, computational design has an incredible potential to develop new ceramic materials.


strong impetus exists to extend ICME to ceramic materials, which require experimentally measured high-temperature thermodynamic properties. As with any technology, the applications are stretching beyond the original development purpose. However, once successfully implemented, ICME has potential to affect all categories of refractory ceramics, as shown in Figure 1 and described briefly below.

## Major classes of refractories

Ceramic thermal barrier coatings (TBC) on metal alloys enable higher operating temperatures and prevent melting and high-temperature oxidation. In addition to high melting temperatures, TBCs are required to have low thermal conductivity and low oxygen permeability. However, lower thermal expansion of ceramic materials than of metals poses a problem of delamination during heating–cooling cycles.

Coatings for gas-turbine blades in jet engines are probably the most studied class of TBCs.[3] Current coatings use tetragonal yttria-stabilized zirconia (YSZ) deposited in a columnar structure to avoid delamination. In addition, an engineered $Al_2O_3$-based bonding layer between the alloy and coating provides adhesion. Coatings with lower thermal conductivities at high temperatures, such as $La_2Zr_2O_7$, have been explored[4] to increase operating temperature and, thus, improve engine efficiency. Resilience of the coatings to interaction with silicate particles in the atmosphere or from the ground during takeoff and landing is a major concern and constitutes another research direction. Radiation cooling is the most efficient way to dissipate heat at high temperatures, thus, high emissivity is highly desirable.




Credit: Alexandra Navrotsky and Sergey V. Ushakov

**Figure 1. Operation temperature versus cost for major categories of ceramics and alloys.**

Ultra-high-temperature ceramics (UHTCs) are under development for control- and propulsion-related surfaces of hypersonic vehicles.[3] An ideal UHTC is lightweight and has a high melting temperature. SiC composites have been used for blunt aerodynamic surfaces of space shuttles, which heat to 1,500°C upon atmospheric re-entry. Sharp leading edges can provide better aerodynamic characteristics, although they can reach temperatures in excess of 2,000°C. Therefore, carbides and borides of hafnium, tantalum, and zirconium—with melting temperatures that exceed 3,000°C—are key constituents for new UHTC ceramics and impose requirements different from coatings. As with coatings on metals, their function is to protect underlying ceramics from oxidation by air or high-temperature water vapor formed during fuel combustion. Melting temperatures of constituents of UHTCs are higher than for oxides (Figure 2). For internal surfaces that cannot be cooled by radiation, high thermal conductivity may be desired to reduce thermal gradients and allow heat dissipation in other parts of the vehicle.

Uranium oxide ($UO_2$) is the main nuclear fuel used throughout the world. Researchers have spent hundreds of person-years studying its high-temperature thermophysical properties and have developed many novel experimental techniques. In pressurized and boiling water reactors, $UO_2$ is used in the form of pellets that are ~1 cm in diameter inside zircaloy tubes filled with helium gas. Composition and microstructure of the fuel changes during burnup because new atomic species are formed by fission and because of the steep thermal gradient during operation (from 1,400°C in the center of the pellet to 400°C at the rim). Reaction of zirconium with steam at temperatures greater than 1,200°C to produce zirconia and hydrogen has been the source of catastrophic explosions in nuclear reactor accidents involving loss of coolant.

There is now great interest in finding new fuels and fuel assemblies that are more accident tolerant, including uranium carbides and nitrides. Multilayer encapsulation of fuel spheres in layers of materials with high thermal conductivity,

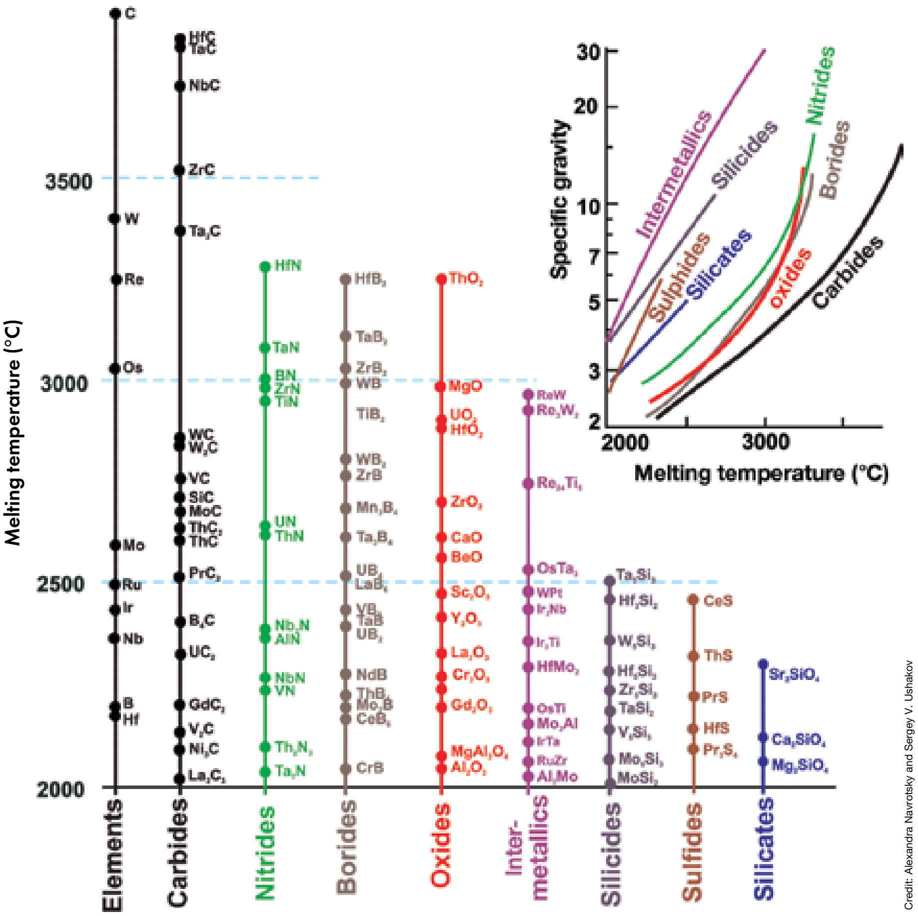



**Figure 2. Compounds with melting temperatures higher than 2,000°C and specific gravity–melting temperature envelope.[7]**

such as SiC and graphite, is proposed to aid heat exchange and provide better stability in operation and direct disposal of spent fuel. ICME application to nuclear fuels is the most advanced, with an extensive and growing set of experimental data and ab initio calculations on thermodynamic and thermophysical properties of $UO_2$ and its solid solutions, facilitating CalPhaD[1] and phase field[2] modeling.

Concrete and industrial refractories used for metal and glass manufacturing to a large extent use as-mined, chemically unprocessed, and relatively cheap mixtures. Thermal stability and mechanical properties of the concrete are defined mostly by cements holding together sand, gravel, and crushed rock. Portland cements, the most common type used around the world, are mostly composed of $Ca_2SiO_5$ and $Ca_2SiO_4$ synthesized at temperatures higher than 1,400°C. Calcium aluminate cements are used in construction concretes and in castable refractories, blurring the line between these categories. Oxides of aluminum, silicon, magnesium, calcium, titanium, zirconium, and chromium, and carbides and nitrides of titanium, boron, and silicon are the major constituents of common refractories. Further, oxide/graphite refractories are used to avoid wetting by silicate slags and to increase thermal conductivity.

Refractories used to be disposed as landfill after removal from service, so the cost to produce refractories was a major concern in design and manufacturing. Energy conservation and recycling requirements as well as developments in hot repair and in situ fabrication technologies, may lead to feasibility of using high-performance, more expensive formulations. Industrial refractories used at high temperatures require strength, dimensional stability, and high or low thermal conductivity, with evolving microstructure under conditions of sharp thermal gradients and in contact with silicate slags and metal melts of complex compositions.

Modeling capabilities promise to streamline development of new high-temperature materials and facilitate improvements of existing ones by reducing the cost and time required for screening and by focusing experimental efforts in the most promising directions. Data on surface energies, enthalpy, heat capacity, and molar volumes as a function of temperature are required as thermodynamic inputs. Success of the ICME approach for alloys development[2] is to a large extent because of availability of these data for metals, leveraged by application of CalPhaD modeling. Fusion enthalpies have been measured for all metals and many alloys, often using various experimental techniques.[5,6]

However, even melting temperatures of key refractory oxides are being corrected by up to hundreds of degrees (e.g., MgO),[7] heats of fusion are often unknown, and thermodynamic data for complex ternary and multicomponent oxide systems are far less complete than for metals. What follows are some examples of recent developments in experimental methods that can provide missing data. More detailed accounts of the research mentioned can be found in several reviews[7–9] and the references therein.

## Temperature measurement

Resistance and thermocouple thermometry is well developed and used ubiquitously. Seebeck voltage is standardized to 1,820°C for B-type Pt-Rh thermocouples, and W-Re thermocouples can be used to 2,800°C in inert conditions. Reaction with measured samples, aging, and evaporation of thermocouples makes contactless temperature measurement preferable for many applications. Often it is the only feasible method available, such as for oxidizing conditions in excess of 1,800°C, liquid metals, or levitated samples.

Radiation thermometry is used to define the International Temperature Scale above the freezing temperature of silver (961.78°C). The theoretical basis for radiation thermometry is Planck's law describing the temperature dependence of spectral radiance of a blackbody, namely an abstract object that does not reflect light and emits only thermal radiation:

$$B_\nu(T) = \frac{2h\nu^3/c^2)}{(\exp(h\nu/kT)-1)}$$

where $T$ is absolute temperature; $\upsilon$ frequency of radiation; and h, k, and c constants (Planck's, Boltzmann's, and speed of light, respectively).

Emissivity ($\varepsilon$) is the ratio of spectral radiance of the actual material to radiance of a blackbody at the same temperature. In traditional single-color pyrometry, apparent temperature is obtained from a single intensity value registered on a narrow preselected band (ensured by a red filter in disappearing filament pyrometry). Geometry close to that of a blackbody cavity is sought in the experimental arrangement to ensure $\varepsilon \approx 1$.

In the simplest case, the pyrometer can be aimed inside the crucible through a small orifice. Even in these ideal conditions, researchers must account for absorption by windows along the observation path, and any changes caused by absorption or emission, such as by generated vapors, will affect accuracy of the measurements.

When blackbody cavity geometry is not possible, emissivity has to be measured or estimated for single-band pyrometry. In general, $\varepsilon$ changes with wavelength, temperature, observation angle, and surface roughness, and, thus, estimation of emissivity is the major source of uncertainty. Emissivity can be obtained from reflectivity ($R$), and, if the object is not transparent for the chosen wavelength, then $\varepsilon = (1 - R)$. A Pyrolaser instrument (Pyrometer Instrument Co., Windsor, N.J.) measures emissivity at 865 nm in situ from the power of projected and reflected laser beams.[10]

Two-color pyrometry measures intensity of radiation on two spectral bands, assuming emissivity is identical at the chosen wavelengths. Temperature is derived from the ratio of intensities rather than their absolute values. However, any differences in effective emissivities between chosen wavelengths will have a large effect on accuracy of the measurements. Luckily, at temperatures greater than the reach of Pt-Rh thermocouples, emitted radiation can be registered in the visible range (Figure 3), for which sensors and optics represent well-developed technology.

Spectropyrometers, which use all the measured intensities for calculation of surface temperature, often are used in research and have been available commercially for more than a decade.[11] When spectral responsivity and linearity corrections have been established through calibration, the programmed algorithms of data processing can be applied to derive a temperature value from the entire spectrum. The possibility to adapt conventional and high-speed complementary metal–oxide semiconductor cameras for 2-D and stereoscopic pyrometry was demonstrated recently.[12] Although it is unlikely that radiation thermometry will ever reach accuracies of resistance and thermocouple contact measurements, the possibility of routine measurement of surface temperatures with uncertainties of ±5°C using spectropyrometry and in situ emissivity methods is a big advancement.

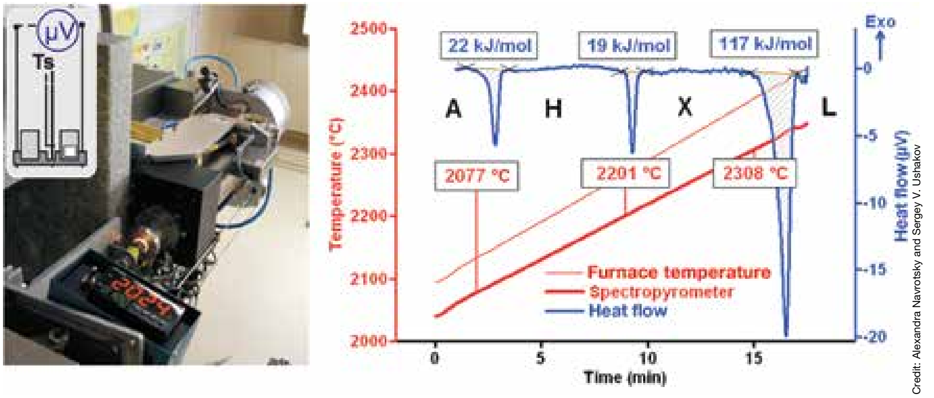



**Figure 4. Modified high-temperature differential thermal analyzer (left) and heat flow trace (right) of $Nd_2O_3$ showing premelting phase transformations and melting (baseline subtracted).**

## Thermal analysis and laser flash method

Methods of differential thermal analysis (DTA) and differential scanning calorimetry (DSC) take their root in measurement of sample temperature heating or cooling. Heat flow traces in DTA and DSC correspond to differences in temperature between a sample and an empty reference crucible. The methodology is well developed and widely used for biological materials, polymers,

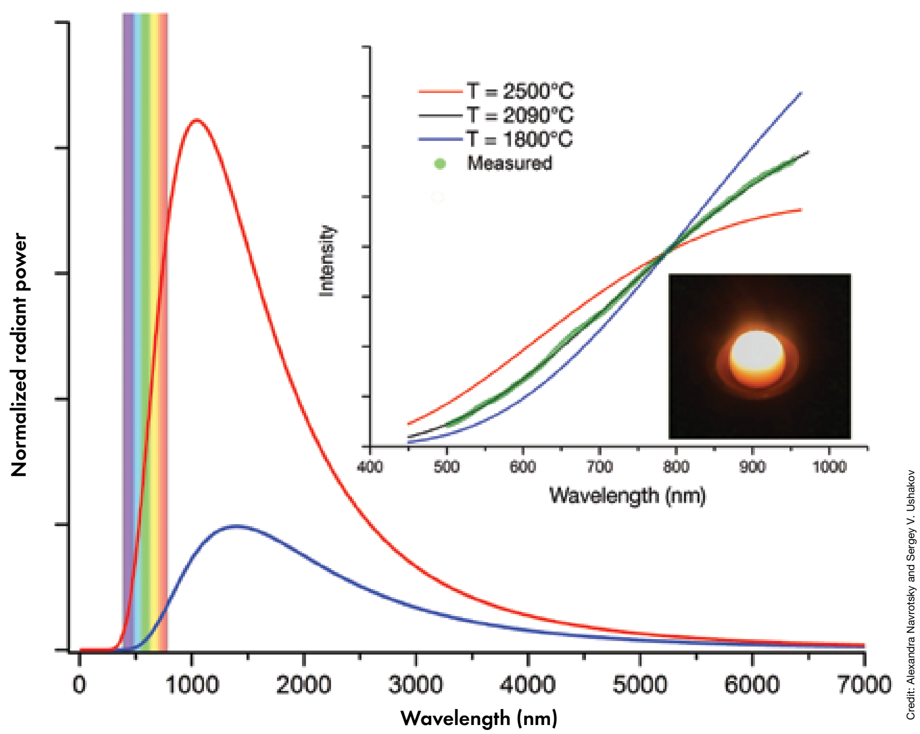



**Figure 3. Theoretical spectra of blackbody radiation at 1,800°C and 2,500°C. Emissivity-independent fit of surface temperature of levitated bead from spectropyrometer is shown on the inset.**

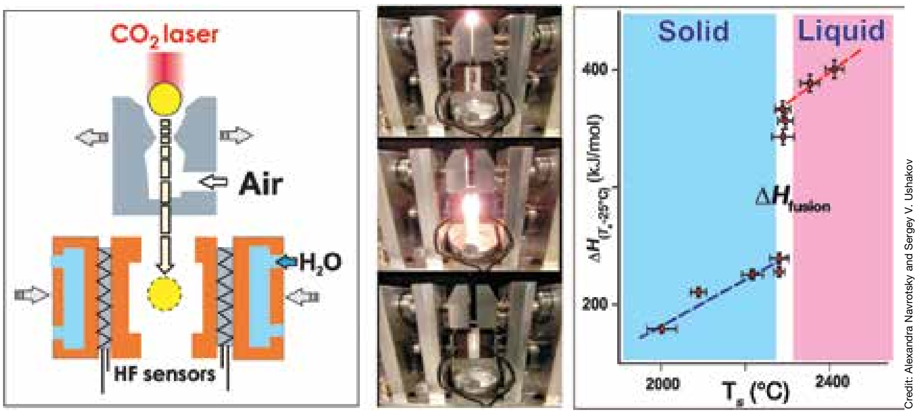



**Figure 5. Drop-n-catch calorimeter schematic, operation and enthalpy versus temperature curve for $Al_2O_3$. Diameter of sample beads is 2.5–3 mm.**

and ceramics up to 1,600°C with Pt-Rh thermocouples for temperature measurement. For the higher temperature range, DTA for operation to 2,400°C with W-Re thermocouples is available from several manufacturers. Nevertheless, the method generally was not used to quantify heat effects above 1,600°C because of fast aging of W-Re thermocouples affecting temperature calibration and the absence of standards for fusion enthalpy above the melting temperature of $Al_2O_3$ (2,054°C).

Recently, the Thermochemistry Laboratory at the University of California, Davis further explored the DTA method for its potential to provide the means to fill missing data on fusion and phase transition enthalpies above 1,600°C. A Setaram (Caluire, France) Setsys 2400 DTA equipped with graphite furnace and W-WRe sensor was modified to allow operation to 2,500°C and measurement of sample temperature by radiation thermometry (Figure 4). Enthalpies of phase transitions in $HfO_2$ and $La_2O_3$ and fusion enthalpies of $La_2Zr_2O_7$, $LaAlO_3$, and $La_2O_3$ were measured successfully on samples sealed in tungsten crucibles to prevent reactions with carbon present in the furnace.[7] The recent independent measurement of fusion enthalpy of $Y_2O_3$ allows high-temperature sensitivity calibration, which extends DTA capabilities to provide thermodynamic data above 2,000°C.[13]

The laser flash method heats a disk-shaped sample by laser pulses on one side while tracing temperature rise on the opposite side. Many companies offer flash instruments for measurements up to 2,800°C. Originally the method was demonstrated to yield thermal diffusivity and heat capacity, which allows calculations of thermal conductivity.[14] However, it is currently used almost exclusively for thermal diffusivity measurements. This is because heat capacity determination with laser flash requires a reference standard with the same surface emissivity as the sample or requires coating the sample and standard to provide identical emissivity, which is not required for thermal diffusivity measurements.

A common practice is to measure thermal diffusivity with a laser flash method and obtain heat capacity values from scanning calorimetry or estimate values from available reference data or theoretical considerations. Applications of the laser flash method for high-temperature heat-capacity measurements should be explored further using advances in radiation thermometry discussed above.

## High-temperature calorimetry

Levitation calorimetry on metals using magnetic levitation and inductive heating has been practiced by several groups, and fusion enthalpies of platinum, palladium, molybdenum, neodymium, and 10 other metals were measured by 1975.[6] These data, in addition to more recent independent measurements of heat contents by pulse heating,[8] provide a reliable foundation for computational engineering of alloys.

Multiple compilations of thermodynamic data often refer to a single source when it comes to heat content of refractory oxides above 2,000°C.[15] In this work, samples that weigh tens of grams were suspended in a graphite furnace and dropped into an ice-water calorimeter.[15] Drop calorimetry also was used to measure heat content and fusion enthalpy on $UO_2$ samples sealed in tungsten containers.[16] However, no experimental measurements of fusion enthalpies of fusion of high-melting oxides, such as $HfO_2$ and $ZrO_2$, have been reported. The most recent assessments of thermodynamic functions for rare-earth oxides for calculations of phase diagrams is based on a single, sparingly described measurement of $Y_2O_3$ fusion enthalpy.[13]

A new technique for ultra-high-temperature drop calorimetry on ceramic samples was recently developed at UC, Davis (Figure 5). In this method, called drop-n-catch (DnC) calorimetry, samples are laser heated in a splittable nozzle aerodynamic levitator and dropped into a calorimeter at room temperature. The step in enthalpy versus temperature curve gives the heat of fusion.[17] DnC was validated by measuring fusion enthalpy of $Al_2O_3$ and now is used in combination with DTA for enthalpy measurements of fusion and phase transitions of rare-earth oxides.

Surface energies, perhaps an abstract concept for ceramic engineers, however, invariably come into play in models of mechanical properties and microstructure development. Thus, it is no surprise that surface and interfacial energies of metals and alloys are studied much more comprehensively than for ceramic materials. Thermodynamically, surface energy can be defined as a reversible work to create the new surface and interfacial energy as a sum of surface energies minus work of adhesion required to separate the interface. These figures are required as inputs for modeling of nucleation and fracture, in which new interfaces and surfaces are created—and of the sintering process in which they are eliminated.

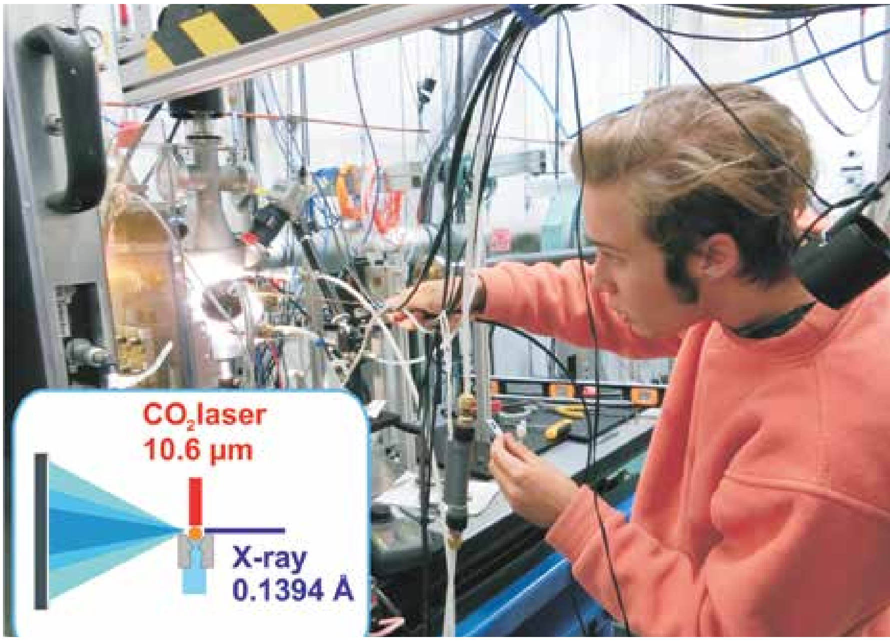
High-temperature oxide melt solution calorimetry has been used for half a century for measurements of enthalpies of formation of refractory compounds, which are not easily dissolved in acids.[9] In the past 20 years, it also became instrumental for measurements of surface energies of key refractory oxides: $Al_2O_3$, $TiO_2$, $ZrO_2$, $HfO_2$, MgO, and $Y_2O_3$.[9] The method is elegant in its simplicity—single-phase samples of various surface areas are dissolved in a sodium molybdate ($3Na_2O$-$4MoO_3$) or lead borate ($2PbO$-$B_2O_3$) melt at 700°C or 800°C. When the surface area is the only variable in the experiments, linear dependence of heat effects on surface area is observed and absolute value of the slope corresponds to surface energy.

Refractory oxides can manifest a strikingly large variation in surface energy between various polymorphs. For example, surface energy for $ZrO_2$ changes from 0.5 J/m$^2$ for the amorphous phase to above 3 J/m$^2$ for the monoclinic phase. High-temperature phases of given oxides generally have lower surface energies, thus, amorphous and high-temperature polymorphs are thermodynamically stabilized at high surface areas. A familiar example is the stable amorphous $Al_2O_3$ layer that forms on the surface of aluminum-containing alloys (and is used as a starting layer for TBC engineering).

Surface energies are increasingly calculated from first principles. However, with ceramic materials representing more variation in bulk and surface structures and types of defects, experimental benchmarks are essential. Novel approaches to evaluate surface energy from heat evolved on coarsening in DSC and from enthalpy of water adsorption have been developed and validated against the values measured by solution calorimetry.[18]

## X-ray and neutron diffraction

Powder X-ray diffractometry (XRD) has become an indispensable workhorse of materials characterization at all steps of ceramic development and manufacturing. In part, this is because of an accumulated collection of more than 170,000 entries of structural data for inorganic compounds and automated routines for whole profile Rietveld analysis, allowing quantification of phase contents and crystallite sizes. High-temperature powder XRD provides data on thermal expansion and volume change on phase transition, which are required for thermodynamic modeling. XRD also can be used for in situ phase diagram determination, especially at high temperatures, because of fast equilibration.




Credit: Alexandra Navrotsky and Sergey V. Ushakov

**Figure 6. Aerodynamic levitator at Argonne Photon Source (beamline 6-ID-D) for in situ high-temperature diffraction on ceramic materials. Matthew Fyhrie (UC Davis) is loading the oxide sphere in the levitator chamber with an air pick.**

For powder XRD at temperatures lower than 1,700°C, Pt-Rh thermocouples and ceramic holders or $Al_2O_3$ capillaries[19] at synchrotron sources can be used for measurements in variable atmospheres. For diffraction experiments at temperatures higher than 2,000°C, traditional measurements are limited to inert atmospheres using W-Re thermocouples and tungsten, molybdenum, or ruthenium sample holders or wires, which often also serve as heaters. Because of high thermal expansion of metal holders, the quality of diffraction data at temperatures in excess of 2,000°C is rarely suitable for structure determination.

High-temperature structures have been determined successfully from neutron diffractometry using a large volume of sample encapsulated in a container. Neutrons have the advantage over X-rays in that they are much more sensitive to light elements, including oxygen and hydrogen. However, because of scarcity of neutron sources around the world and complexity of measurements, such determinations have been limited until recently. For example, among rare-earth sesquioxides, high-temperature structures have been determined only for $La_2O_3$ and $Nd_2O_3$. However, this field is growing because much smaller sample sizes are now required for neutron diffractometry and facilities are becoming much more user-friendly.

Aerodynamic levitators with laser heating have been used for more than a decade at synchrotron and neutron sources worldwide to study structures of oxide melts.[7,20] These operational instruments also can provide high-temperature diffraction data on solids. In levitation experiments, a sample is suspended in a gas flow and heated by a $CO_2$ laser beam, and surface temperature is measured with radiation thermometry (Figure 6). Samples are usually prepared by laser melting of powders, in which case spheroids are formed by surface tension of the melt. Diffraction is obtained from the top of the bead levitated in a shallow conical nozzle. The technique can obtain high-energy synchrotron diffraction patterns in 0.1 s, while tens of minutes of collection time are required for neutron diffraction.[4]

Because the levitating sample is heated from the top and cooled from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the bottom by gas flow, thermal gradients in the diffracted volume are unavoidable. They are larger for solid samples than for melts because of the absence of thermal conduction inside the sample by convective flows, and can reach 150°C. Despite such problems, the first applications of the method resolved some lingering questions on structure and thermal expansion of refractory oxides, such as high-temperature phase transformations in $Y_2O_3$ and $Yb_2O_3$, and thermal expansion of YSZ and $La_2Zr_2O_7$ to melting temperatures.[4,7] The method now is used to measure thermal expansion and volume changes on phase transformation in rare-earth oxides, which are critical for CalPhaD modeling of oxide systems with rare earths.

The unique advantages of levitation are elimination of sample reaction with container or support material and flexibility in choice of atmosphere. UHTC formulations for flight-related applications should be capable to sustain high-temperature exposure to oxygen in conditions of hypersonic flow. In-depth understanding of high-temperature interaction with water vapor is critical for propulsion-related UHTC formulations and for design of protective coatings for nuclear applications. Diffraction on levitated, laser-heated samples in variable environments at synchrotron and neutron user facilities provides versatile new tools for high-temperature research. It can provide high-temperature thermophysical data (thermal expansion and volume change on phase transitions) and, potentially, kinetic data on high-temperature oxidation reactions and transformations.

Most high-temperature thermodynamic and thermophysical data on refractory oxides were obtained during the Cold War era using ad hoc instrumentation in specialized laboratories. The current availability of synchrotron and neutron user facilities, turnkey lasers, high-temperature DTA, and commercial calorimeters now make high-temperature research sustainable in university settings. When required basic thermodynamic inputs are available, computational materials design has potential to speed up the "lab-to-fab" cycle for materials development. It is our hope that such developments will be fruitful, and our current students will witness civilian supersonic flights, manned landings on Mars and other regions of the solar system, and improvements in technology for sustainability on Earth that older generations could only dream of.

Think big, bold, and hot!

## Acknowledgements

High-temperature experiments on rare-earth oxides at UC Davis were supported by National Science Foundation Award DMR-1506229. Use of the Advanced Photon Source (APS, beamline 6-ID-D), a DOE Office of Science user facility operated by Argonne National Laboratory, was supported by DOE Contract No. DE-ACO2-06CH11357.

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## References

[1]B. Sundman, U.R. Kattner, C. Sigli, M. Stratmann, R. Le Tellier, M. Palumbo, and S.G. Fries, "The Open Calphad thermodynamic software interface," *Comput. Mater. Sci.*, **125**, 188–96 (2016).

[2]M. F. Horstemeyer, *Integrated computational materials engineering (ICME) for metals: Using multiscale modeling to invigorate engineering design with science*, Wiley, New York, 2012.

[3]N.P. Padture, "Advanced structural ceramics in aerospace propulsion," *Nat. Mater.*, **15** [8] 804–809 (2016).

[4]S.V. Ushakov, A. Navrotsky, R.J.K. Weber, and J.C. Neuefeind, "Structure and thermal expansion of YSZ and $La_2Zr_2O_7$ above 1500°C from neutron diffraction on levitated samples," *J. Am. Ceram. Soc.*, **98** [10] 3381–88 (2015).

[5]T. Huepf, C. Cagran, and G. Pottlacher, "Thermophysical properties of 22 pure metals in the solid and liquid state—The pulse-heating data collection," *EPJ Web Conf.*, 15 01018 (2011).

[6]M.G. Frohberg, "Thirty years of levitation melting calorimetry—A balance," *Thermochim. Acta*, **337** [1–2] 7–17 (1999).

[7]S.V. Ushakov and A. Navrotsky, "Experimental approaches to the thermodynamics of ceramics above 1500°C," *J. Am. Ceram. Soc.*, **95**, 1463–82 (2012).

[8]W. Schroeer and G. Pottlacher, "Estimation of critical data and phase diagrams of pure molten metals," *High Temp.-High Pressures*, **43** [2–3] 201–15 (2014).

[9]A. Navrotsky, "Progress and new directions in calorimetry: A 2014 perspective," *J. Am. Ceram. Soc.*, **97** [11] 3349–59 (2014).

[10]E.S. Cameron, "Laser assisted remote temperature measurement"; pp. 155–62 in *Optomechanical design of laser transmitters and receivers*, SPIE Proceedings, Vol. 1044, 1989.

[11]R.A. Felice, "The spectropyrometer—A practical multi-wavelength pyrometer," *AIP Conference Proceedings*, **684** [Pt. 2] 711–16 (2003).

[12]M. Jakob, P. Lehnen, P. Adomeit, and S. Pischinger, "Development and application of a stereoscopic 3-color high-speed ratio-pyrometry," *Combust. Flame*, **161** [11] 2825–41 (2014).

[13]D. Kapush, S. Ushakov, A. Navrotsky, Q.-J. Hong, H. Liu, and A. van de Walle, "A combined experimental and theoretical study of enthalpy of phase transition and fusion of yttria above 2000°C using 'drop-n-catch' calorimetry and first-principles calculation," *Acta Mater.*, **124**, 204–209 (2017).

[14]W.J. Parker, R.J. Jenkins, C.P. Butler, and G.L. Abbott, "Flash method of determining thermal diffusivity, heat capacity, and thermal conductivity," *J. Appl. Phys.*, **32** [9] 1679–84 (1961).

[15]C D. Pears, "The thermal properties of twenty-six solid materials to 5000 DegF. or their destruction temperatures"; pp. 420 pp. in *Technical Documentary Report*, Vol. ASD-TDR-62-765. Southern Research Institute, Birmingham, Alabama, 1963.

[16]R.A. Hein, P.N. Flagella, and J.B. Conway, "High-temperature enthalpy and heat of fusion of uranium dioxide," *J. Am. Ceram. Soc.*, **51**, 291–92 (1968).

[17]S.V. Ushakov, A. Shvarev, T. Alexeev, D. Kapush, and A. Navrotsky, "Drop—and—catch (DnC) calorimetry using aerodynamic levitation and laser heating," *J. Am. Ceram. Soc.* (approved for publication Oct. 24, 2016), in press.).

[18]S. Hayun, T. Roehling, S.V. Ushakov, and R.H.R. Castro, "Experimental methodologies for assessing the surface energy of highly hygroscopic materials: The case of nanocrystalline magnesia," *J. Phys. Chem. C*, **115**, 23929–35 (2011).

[19]R.P. Haggerty, P. Sarin, Z. D. Apostolov, P.E. Driemeyer, and W.M. Kriven, "Thermal expansion of $HfO_2$ and $ZrO_2$," *J. Am. Ceram. Soc.*, **97** [7] 2213–22 (2014).

[20]J.K.R. Weber, C.J. Benmore, L.B. Skinner, and J.B. Parise, "Measurements of liquid and glass structures using aerodynamic levitation and in-situ high-energy X-ray and neutron scattering," *J. Non-Cryst. Solids*, **383**, 49–51 (2014). ■

# Ceramic reactive membranes made of Magneli-phase titanium oxide decrease operating expenses and increase efficiency in water-treatment plants

**by Robert Sterner and Jay Huang**

Start-up company Magneli Materials has developed a new manufacturing process to produce industrial quantities of Magneli-phase titanium dioxide, an electrically conductive ceramic with industrial processing applications.

Arne Magneli was one of the pioneers of crystallography. Magneli established the study of transition-metal suboxides and shear-plane dislocations, paving the way for discovery of conducting titanates and pervoskites.

Beginning in the 1940s, Magneli examined a variety of transition-metal oxides to determine why the materials were lubricious and electrically conductive, when they should have been neither. These early studies focused on tungsten and molybdenum suboxides, and later work included titanium and vanadium suboxides.

Magneli discovered that, similar to graphite and (later) graphene, each material's crystalline structure featured dislocation planes that accounted for the material's electrical conductivity and lubricious properties. These materials now are called Magneli-phase materials. Magneli-phase suboxides of titanium are ceramic materials that have a graphitelike crystalline structure. These materials have individually identifiable X-ray diffraction spectra and are not simply doped $TiO_2$ or casual mixtures of $TiO_x$. Magneli-phase titanium suboxides are a range of distinct compounds with a general formula of $Ti_nO_{2n-1}$ ($n$ = 4–10), such as $Ti_4O_7$, $Ti_5O_9$, and $Ti_6O_{11}$.

## Key properties of Magneli-phase materials

The structure of Magneli-phase titanium oxides are based on, but distinguishable from, the rutile $TiO_2$ crystal structure and are all triclinic.

Magneli-phase crystals consist of $TiO_2$ octahedra blocks that share edges and corners to form a slab, which repeats in two dimensions. In $Ti_nO_{2n-1}$, every $n^{th}$ layer has an oxygen deficiency, which leads to shear planes in the crystal structure. This shear plane occurs at $n$ spacing in the octahedral layers. Higher $n$ values have greater shear-plane intervals.

$Ti_4O_7$ is by far the best known and most studied Magneli-phase material. It is the most reduced Magneli-phase material, with a rutile form of $TiO_2$ with every eighth oxygen removed. $Ti_4O_7$ has the highest number of shear planes occurring at the shortest spacing of these

## Capsule summary

**BACKGROUND**

Magneli-phase titanium oxide is an electrically conductive ceramic with potential applications in many areas of industrial processing. Although the material's advantages have been known for about 30 years, the existing manufacturing process was expensive and produced low-quality material.

**BREAKTHROUGH**

Start-up company Magneli Materials LLC (New Canaan, Conn.) developed a novel manufacturing process for large-scale production of industrial quantities of high-quality Magneli-phase titanium oxide.

**APPLICATIONS**

In addition to developing Magneli-phase titanium oxide-coated anodes for industrial water treatment, Magneli Materials fabricated a ceramic reactive membrane that can decrease operating expenses and decrease processing times by 50% in water-treatment plants.

shear planes. The material also has the highest electrical conductivity and chemical stability among all Magneli-phase titanium suboxides. When $n \leq 3$, shear-plane accommodation of the octahedra collapses, and the crystallographic structure shifts from triclinic to monoclinic.

Magneli-phase materials have metallike electrical conductivity. They also display high corrosion resistance in aggressive acidic and basic solutions. The materials are exceptionally resistant in HF, HCl, and KOH as well as other highly oxidizing environments, and they are exceptionally stable under electrically polarized conditions that make them useful as high-performance anodes and cathodes.

In terms of electrochemical properties, Magneli-phase materials have a wide overpotential window that suppresses oxygen-gas and hydrogen-gas evolution in water. Magneli-phase materials also have exceptional catalyst retention and superior adhesion, and, thus, require less catalyst. These also are superior characteristics for high-performance anode and cathode production.

Magneli-phase materials are lubricious and have high wear resistance—similar to graphite, but with higher wear resistance. The materials also are superhydrophilic, making them particularly useful as drying agents or electrical cable coatings. In addition, the materials display high microwave absorption (stronger than silicon carbide) and, thus, can be used as waveguides and stealth coatings. Finally, the materials are photocatalytic—yet nontoxic, cost-effective, environmentally friendly, and naturally abundant—making them particularly suited for water-splitting applications.

### Commercial manufacturing of Magneli-phase titanium materials

Magneli-phase titanium materials were isolated first in the late 1970s by Peter C.S. Hayfield while working for Imperial Metals Industries, a large United Kingdom-based producer of titanium alloys. Hayfield named the material "Ebonex" after its deep blue–black color.

Ever since, Ebonex has been produced by Atraverda, a U.K. company. The company produces Ebonex via a two-step firing process, which involves first making a $TiO_2$ ceramic body using a conventional process. Then Atraverda reduces the prefired porous ceramic body in a hydrogen kiln to obtain mixed Magneli-phase titanium suboxides, which are crushed and milled to powder.

Atraverda's manufacturing process requires sophisticated equipment and processes, with separate ceramic and hydrogen-reduction production lines. The low-efficiency process is time intensive, requiring more than 50 hours for the two-fire process alone.

In addition, the hydrogen-gas kiln introduces safety issues into the process. Further, it consumes a large amount of energy—ceramic firing requires temperatures of 1,300°C, and the reduction process requires temperatures of 1,100°C—which contribute to high manufacturing costs.

Finally, materials produced with this manufacturing process are inferior quality and have low consistency because of hydrogen-gas feed flow and diffusion in porous ceramic bodies.

### Developing a novel manufacturing process

One of the key challenges to producing bulk Magneli-phase materials is to decrease manufacturing costs. Further, Magneli shear planes are prone to oxidation, during which $Ti_4O_7$ can revert to $TiO_2$ under some conditions. Shear-plane oxidation limits the forms in which $Ti_4O_7$ can be effective—nanoscale structures, such as fibers and films, are unstable because of their high surface area, and the materials are difficult to apply as plasma-sprayed coatings or physical vapor deposition films.

In response to these challenges, Magneli Materials LLC (New Canaan, Ct.) developed a manufacturing process that results in a new class of more advanced Magneli-phase materials. These materials have a crystalline structure that includes an additional metal atom, which inhibits realignment and, thus, structurally stabilizes Magneli shear planes. The new form also resists conversion to $TiO_2$ when exposed to strong oxidizing conditions.

The manufacturing process greatly expands the forms in which Magneli

Credit: Magneli Materials

**Magneli Materials $Ti_4O_7$ anodes for water-treatment, water-disinfection, electrowinning, and galvanizing industries. Plasma spray coating deposits $Ti_4O_7$ on titanium to produce the anodes.**

materials can be made, including microscale and nanoscale structure powders, plasma-sprayed coatings on low-cost substrates (e.g., titanium, aluminum, and stainless steel), high-surface-area reticulated foams, and ceramic articles. In addition, the new process makes it economical to manufacture Magneli-phase materials in high volumes and with high consistency.

Magneli Materials' manufacturing process produces Magneli-phase materials that are substantially different from conventional Magneli-phase materials, such as $Ti_4O_7$, $Ti_5O_9$, $Ti_6O_{11}$, and trademarked mixtures of these, such as Ebonex. These new Magneli-phase materials have substantially higher (>80%) $Ti_4O_7$ content. They also are structurally stabilized—so that nanopowders of the materials can be mass-produced for the first time—and are more chemically and electrochemically stable, preventing oxidation under severe environments.

Although conventional forms of Magneli-phase materials could be used as powders or ceramics for battery additives and cathodic protection, the new structurally stabilized $Ti_4O_7$ now can be used for electrowinning; coatings, such as expanded titanium mesh; tribological applications; and water treatment, including advanced oxidation. The material also can be used in new forms, including microscale and nanoscale powders; ceramic plates, tubes, and foams; and coatings on various metal substrates.

## New structures for new uses: $Ti_4O_7$ anode and ceramic membrane

Stabilized $Ti_4O_7$ has many applications in the electrochemistry industry because of the ceramic material's high corrosion resistance to acidic and basic solutions, high electrical conductivity, and high electrochemical stability. In particular, the characteristics of $Ti_4O_7$ and its high overpotential have made it a leading candidate for use in water treatment. However, to take advantage of these industrial uses, new coating processes and catalysts were needed for application of the material to suitable substrates.

Although previous production processes created $Ti_4O_7$ tubes, they did not allow for other anode architectures. Magneli Materials' production of $Ti_4O_7$ in powder form opened the ability to coat various anode shapes, which allowed the company to develop a coating process for $Ti_4O_7$ on various metal substrates, including titanium, stainless steel, and lead.

Magneli Materials' plasma-spray-coating process enables deposition of $Ti_4O_7$ on titanium, opening development of $Ti_4O_7$ anodes. The company has used this process to coat solid plates of titanium mesh that are larger than 1 m × 1 m.

$Ti_4O_7$ provides a protective coating for anodes and is electrically conductive, and Magneli Materials has conducted preliminary research on catalyst interlayers and overlayers that work with $Ti_4O_7$. The company can create several effects for various processes.

For water-treatment applications, a catalyst interlayer will extend the life of the anode and $Ti_4O_7$ coating by facilitating ion exchange while allowing full utilization of $Ti_4O_7$ and its unique water-treatment characteristics.

Using these developments, Magneli Materials has produced anodes for the water-treatment, water-disinfection, electrowinning, and galvanizing industries using a combination of $Ti_4O_7$ and various catalyst coatings.

New anodes and a new reactor structure using these anodes were tested in a pilot-scale water treatment reactor. First-generation anodes were flat plates in a stacked array. Although the material processed contaminants, these anodes enabled only low volumes of treated water and required high energy use.

Second-generation anodes using titanium mesh with a catalyst coating allowed the higher current densities needed to process hard chemical oxygen demand (COD) contaminants, which represent organic compounds in water. The new mesh anodes proved successful, but had significant energy costs with high-COD contaminants.

As a result, Magneli Materials developed a $Ti_4O_7$ ceramic reactive membrane—a 3-D reactive membrane that can filter mechanically and electrochemically.

Credit: Magneli Materials

**$Ti_4O_7$ ceramic reactive membranes efficiently filter mechanically and electrochemically. The ceramic structure of the membranes creates more contact points with the waste stream.**

The membrane has a ceramic structure that has more contact points with the waste stream, making the membrane a very efficient and low-cost method for processing hard COD. These $Ti_4O_7$ membranes can incorporate catalyst into the material, allowing development of various effects and extension of the anode life.

The $Ti_4O_7$ ceramic membrane has been successfully tested using a longevity test of 40,000 amps/$m^2$ to ensure the structure can be maintained at high current densities for long periods of time. These membranes currently are operating in four industrial waste-treatment pilot plants and have decreased operating expenses by more than 50% compared with previous systems.

## About the authors

Robert Sterner is president and Jay Huang is chief technology officer of Magneli Materials LLC. Contact Sterner at robsterner@magnelimaterials.com. For more information about the company, visit www.magnelimaterials.com. ■


# Ten years in Daytona Beach gives ICACC room to grow in size and impact

Edgar Lara-Curzio (left) presents Ronald Kerans with the James I. Mueller Memorial Award in 2007 at the first ICACC in Daytona Beach.

This year marked the 41st rendering of the International Conference on Composites and Advanced Ceramics and its 10th anniversary in Daytona Beach, Fla. After three decades in Cocoa Beach, Fla., the move was several years in the making and allowed for the growth ICACC has enjoyed over the last decade and—importantly—anticipates in the future.

The conference began humbly enough in 1977 with 37 invited talks and 90 participants. It was organized by the Ceramic-Metal Systems Division, which became the Engineering Ceramics Division in 1985. The conference also evolved, changing its name to reflect expanding technology and applications for ceramics and composites. The conference expanded in kind, and by 2005 there were 900 attendees to hear 700 presentations.

What did not expand was the size of the conference hotel in Cocoa Beach.

Complicating the space issue was a concurrent restricted meeting organized by United States Advanced Ceramics Association (USACA). Many attendees went to both meetings.

**"In the first 30 years, the conference grew from 90 to nearly 900 attendees. By 2005 the ECD leadership realized the opportunity to grow even more was there, but we needed space,"**

– Mark Mecklenborg, ACerS Director of Membership, Meetings, and Technical Publications

Two alternative sites were considered, the TradeWinds resort in St. Petersburg and the Hilton Hotel in Daytona Beach. Edgar Lara-Curzio, then chair of ECD, visited both sites on behalf of the Society.

On considering alternative locations, the Society looked for a venue with space to grow the conference, as well as anticipate the possibility of the restricted conference moving and collocating with ICACC. The Hilton's unique North Tower and South Tower construction could accommodate that possibility.

The meeting rooms in the South Tower "are sufficiently far away [from the North Tower] to address the export control restrictions of that meeting, but close enough for those who want to attend both meetings without having to spend a lot of time going from one place to another," Lara-Curzio wrote at the time in his trip report.

Then executive director Glenn Harvey wrote in a 2005 email, "Clearly, you recongnized that a location change was essential to enble the Cocoa Beach meeting to succeed, not to mention, to grow." His comment proved prescient,

A beautiful sight! Nearly 1,000 ceramic engineers and scientists networking during the plenary session coffee break.

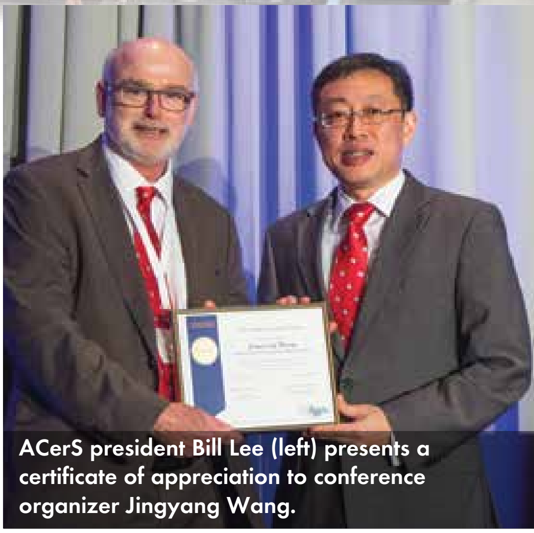
and when ICACC moved to Daytona Beach in 2007, a record-breaking 1,100 attendees were there along with nearly 80 exhibitors.

As it happened, the restricted meeting has continued to meet in Cocoa Beach, which freed space for ICACC to continue to grow. In 2007 there were 10 symposia and three focused sessions.

This year there were 15 symposia, three focused sessions, and an opening plenary session, as well as a Global Young Investigators Forum, Pacific Rim Engineering Ceramics Summit, two poster sessions, ECD business meetings, several receptions, and student events. About 1,000 attendees from 51 countries attended. In his opening remarks, lead organizer Jingyang Wang said nearly half of the attendees were from outside the United States.

Wang was pleased with the outcome of the meeting, especially programming for graduate students and young professionals. “The symposium they organized for themselves is very good, very special,” he says, referring to the Global Young Investigators Forum.

Andy Gyekenyesi, ECD chair, presents the James I. Mueller award to Trudy Kriven after her award lecture on geopolymers.



ACerS president Bill Lee (left) presents a certificate of appreciation to conference organizer Jingyang Wang.

ECD leaders discussed strategy for its future at its business meeting, which comes down to “youth, youth, youth and international, international, international,” according to ECD chair, Andy Gyekenyesi. In other words, ECD continues to have growth, growth, growth on its mind.

The Expo on Tuesday and Wednesday evening provided an opportunity for vendors to promote products and services, and a concurrent poster session provided students a chance to promote research and ideas.

Many other events took place during the week, but all with the same goal in mind—scientific dialog and exchange of ideas for the advancement of ceramic science and engineering.

Back in 2007, then *Bulletin* editor Jim Sawyer reported on the first Daytona Beach event, saying “Trading Cocoa Beach for Daytona Beach was indeed a big change, but one that leaves room for the future.”

The truth of that statement 10 years later points to the wisdom of the ECD’s leadership in 2005. ■

George Quinn (left) and Jonathan Salem (right) in a discussion over one of the many books Wiley brought for visitors to inspect and purchase.

The annual Expo provides a great opportunity for vendors to spend time with customers and helping them with their equipment needs.

The Noritake team has the right attitude!

# ELECTRONIC MATERIALS AND APPLICATIONS ATTRACTS

A poolside reception gave the field's rising researchers a chance to network and make friends with peers and mentors.

For most, EMA begins with a close inspection of the symposia sessions and talks.

Plenary speakers Sossina Haile (left) and Neil Alford (right).

Nothing against perfect weather in Orlando, Fla., in January, but technical content was the star of this year's EMA story, from plenary session headliners, to the poster session, to the now-famous Failure Symposium, and many great technical sessions between.

The meeting, jointly organized by ACerS Basic Science Division and Electronics Division, welcomed a record 391 attendees for the eighth edition of this conference.

Plenary speakers lived up to EMA standards for excellence—good solid science told in the context of the "big picture" of applications. Sossina Haile from Northwestern University (Evanston, Ill.) presented her work using thermolysis to produce hydrogen gas, the obvious vital component to implementing a hydrogen economy. Neil Alford from Imperial College London in the United Kingdom talked about his work on masers—microwave amplification by stimulation emission of radiation.

The poster session on Wednesday night was a highlight. As a small army of judges deployed into the poster gallery, the room buzzed with everyone telling their story.

The second ACerS Winter Workshop took place concurrently. ACerS again partnered with the European Ceramic Society, which provided 15 travel grants for international students. A total of 24 students participated in Winter Workshop and were able to attend all EMA events.

Winter Workshop provided a full day of both technical and professional development sessions, as well as outstanding networking opportunities.

# RECORD NUMBER TO FLORIDA CONFERENCE

Ideas are the coin-of-the-realm for conferences. Here an attendee asks a question of Neil Alford at the Thursday plenary session.

The morning session featured experts in the field, with presentations on electroceramic technology and characterization tools. The afternoon session was a professional development opportunity, with a panel of industry leaders sharing their experiences in small group settings to foster understanding of the professional world. Talks covered a range of topics: "Ceramics Careers All Over the World," "Critical Business Knowledge for the Early-Career Engineer," and "Networking With and Without a Beer." The Winter Workshop experience concluded with a tour of the Kennedy Space Center.

Next year's Winter Workshop will be held in conjunction with the 42nd International Conference and Expo on Advanced Ceramics and Composites (ICACC18) at Daytona Beach, Fla., January 21–26. ■

Learning from your mistakes can be painful, but learning from the mistakes of others can be entertaining. Here Javier Garay tells a full audience his behind-the-scenes story at the after-conference Failure Symposium.

Ilona Jastrzebski and Adam Jastrzebski from Krakow, Poland, toured Kennedy Space Center as part of Winter Workshop. They look as though the space suit would fit.

ACerS and ECerS partnered to bring 24 students to the second Winter Workshop.

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April 23: 9 a.m. – 4:30 p.m.
April 24: 9 a.m. – 3:30 p.m.

***OSHA 10-hour industrial outreach safety workshop***
Instructor: Douglas Jeter, Verity Technical Consultants LLC
April 23: 1 – 6 p.m.
April 24: 8 a.m. – 2 p.m.

***Introduction to additive manufacturing workshop,*** *with America Makes Innovation Factory Tour, Youngstown, Ohio*
Instructor: Roger Narayan, University of North Carolina and North Carolina State University
April 23: 1 – 4:30 p.m.
April 24: 9 a.m. – 3:30 p.m.

***Lean essentials boot camp basics for manufacturing workshop***
Instructors: Samantha Kaplan, Corporate College (a division of Cuyahoga Community College), and
Tom Fazekas, Corporate College (a division of Cuyahoga Community College)
April 24: 9 a.m. – 4:30 p.m.

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## 3 ACerS booth #308 at Ceramics Expo

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Visit our booth to meet marketing and business intelligence experts Tuesday morning, April 25!

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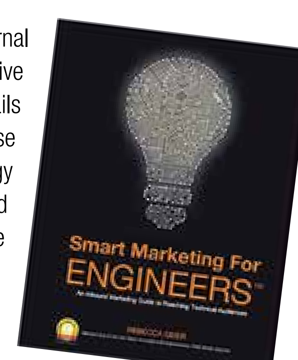
Pick up your own copy of Rebecca's hands-on book, *Smart Marketing for Engineers: An Inbound Marketing Guide to Reaching Technical Audiences.**

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# 2017 ACerS STRUCTURAL CLAY PRODUCTS DIVISION AND SOUTHWEST SECTION MEETING

## in conjunction with National Brick Research Center Meeting

**May 9-11, 2017 | Radisson Hotel | Fort Worth, Texas**

2017 marks the first time that ACerS Structural Clay Products Division, ACerS Southwest Section, and the National Brick Research Center are joining forces to put together combined annual meetings that better meet the needs of the structural clay industry. Held at the Radisson Fort Worth North at Fossil Creek, this meeting includes a full day of technical presentations, plant tours to Acme Brick (Denton) and Forterra (Mineral Wells), a companions program, a supplier's mixer, Thursday evening banquet, hospitality suite, and more!

## TENTATIVE SCHEDULE OF EVENTS

### Tuesday, May 9

| | |
|---|---|
| Registration open | Afternoon |
| Hospitality suite | Evening |

### Wednesday, May 10

| | |
|---|---|
| Registration open | Morning |
| Plant tours (Acme Brick (Denton) and Forterra (Mineral Wells)* | All Day |
| Lunch sponsored by Acme Brick | |
| Suppliers mixer reception | Evening |
| Hospitality suite | Evening |

### Thursday, May 11

| | |
|---|---|
| Technical session 1* | Morning |
| Includes Southwest Section business meeting | Lunch for all |
| Technical session 2* | Afternoon |
| Banquet (short reception preceding) | Evening |
| Hospitality suite | Evening |

### Friday, May 12

| | |
|---|---|
| NBRC member meeting | Morning |

*More details coming soon!

## HOTEL RESERVATIONS

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Reservations must be received on or before Monday, April 10,2017 based on availability.

## DIVISION AND SECTION LEADERS

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Division chair: **John Hewitt**, Interstate Brick Company

Chair-elect: **John Dowdle**, Prince Minerals, Inc.

Secretary: **Mike Walker**, National Brick Research Center

Treasurer: **Luke Odenthal**, Acme Brick Co.

### Southwest Section Leadership

Chair: **John Spence**, Acme Brick Co.

Chair-elect: **Harland Dixon**, Acme Brick Company

Vice chair: **Geoff Cogar**, J.C. Steele and Sons

Secretary: **Fred McMann**, Fives North American Combustion

Treasurer: **Glenn Holladay**, Materials & Ceramic Chemicals

# new products

### Pneumatic micro-press

The Lambient Technologies LTP-250 Micro-Press is a miniature pneumatic press for general application of heat and pressure to materials. An optional dual temperature controller allows independent control of upper and lower platens. The press has a heating temperature range of ambient to 350°C and a maximum applied force of 1,500 lbs. The platen area measures 75 mm by 75 mm. Accompanying CureView software can be used to control temperature profiles, ramps, and holds.

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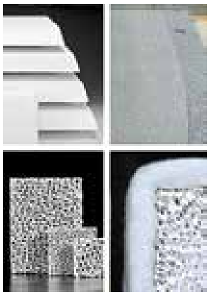

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**www.rigakuoptics.com**

### Viscometer

BYK's new Byko-visc DS viscometer rapidly calculates viscosity values and provides a direct digital readout of Krebs units, centipoise, and grams. The digital stormer maintains rotational speed at 200 rpm in compliance with ASTM D 562. Byko-visc automatically starts and stops the motor shaft rotation by lowering or raising the instrument stand. The viscometer is calibrated with NIST traceable oils. An instrument base accessory can fit quart, pint, and ½ pint containers.

**Paul N. Gardner Co. Inc.**
**(Pompano Beach, Fla.)**
**954-946-9454**
**www.gardco.com**

### Container dumper

Flexicon's new stainless or carbon steel TIP-TITE high-lift box/container dumper provides dust-free discharging. Containers are loaded at plant floor level and hydraulically seated against a discharge hood. Once the assembly is elevated and tipped, the discharge hood spout seats against a gasketed receiving ring. Opening the slide gate valve at the spout outlet allows controlled, dust-free discharge, while closing it allows partially empty boxes and containers to be returned to the plant floor.

**Flexicon Corp.**
**(Bethlehem, Pa.)**
**888-353-9426**
**www.flexicon.com**


### Glass-ceramic reference

*From Glass to Crystal–Nucleation, growth and phase separation: From research to applications* Edited by Daniel R. Neuville, Laurent Cormier, Daniel Caurant, and Lionel Montagne, with a preface by Edgar D. Zanotto (ISBN: 978-2-7598-1783-2).

The book assesses various theories on nucleation, growth, and phase separation in glassy systems; recent advances in characterization of glass-ceramics; and presents families of glass-ceramics and their applications. The book is ideal for students, lecturers, researchers, engineers, and those who are curious about the transformation of glass into hybrid glass-ceramic materials.

**EDP Sciences**
**(Les Ulis, France)**
**www.edpsciences.org**

# Calendar of events

## March 2017

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

## April 2017

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

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

## May 2017

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

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

## June 2017

**14–16** BIT's 6th Annual World Congress of Advanced Materials 2017 – Xi'an, China; www.bitcongress.com/wcam2017

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

## July 2017

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

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

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

## September 2017

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

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

## October 2017

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

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

**8–13** European Microwave Week 2017 – Nürnberg Convention Center, Nuremberg, Germany; www.eumweek.com

**18–19** 60th International Colloqium on Refractories – Eurogress, Aachen, Germany; www.ic-refractories.eu

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

## November 2017

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

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

## January 2018

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

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

## May 2018

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

## July 2018

**8–12** 15th International Conference on the Physics of Non-Crystalline Solids & 14th European Society of Glass Conference – Le Grand Large, Saint-Malo, France; www.ustverre.fr

## August 2018

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

Dates in **RED** denote new entry in this issue.

Entries in **BLUE** denote ACerS events.

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

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Victoria Christensen

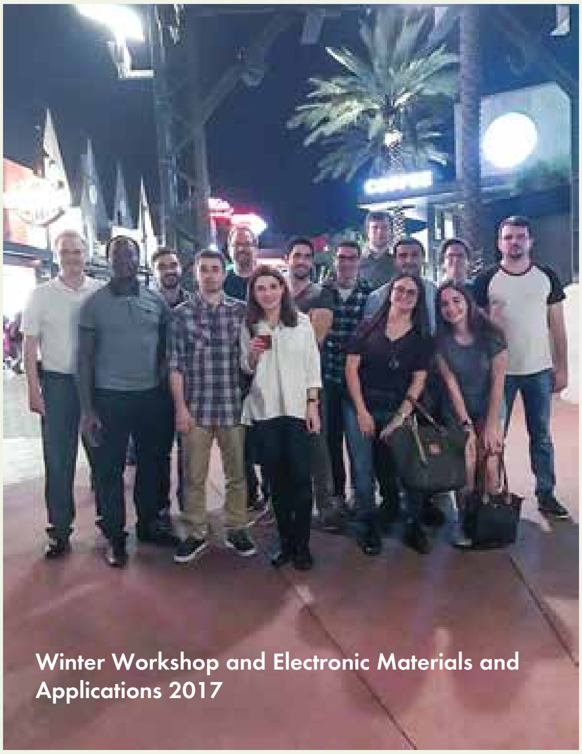
Guest columnist

# An undergraduate student perspective from Winter Workshop and Electronic Materials and Applications 2017

Arriving in sunny Orlando, Fla., for the Electronics Materials and Applications Conference and ACerS Winter Workshop was a welcome break from the snow in State College, Pa., where I am an undergraduate student at Pennsylvania State University. With little background or research experience in electronic materials, I was excited to learn about topics such as piezoelectric materials and energy harvesting applications at the meeting. EMA plenary speakers did not disappoint—each did an excellent job introducing the area of research and engaging the audience throughout the talks.

One of my favorite parts of the conference was the light-hearted, fun failure talks session. It is refreshing to hear that even people so established in their field make mistakes and learn from them. Presenters were willing to explain their mistakes and laugh about where they went wrong. I presented my research—not failures—during the EMA poster session and found it really rewarding to connect with new people. I received many good recommendations for improving or expanding upon some of my research ideas.

All of the professors, industry professionals, and graduate students I met in Florida were extremely welcoming and forthcoming with advice to an undergraduate thinking about pursuing a Ph.D. in materials science. I am thankful for this opportunity to build my network because these contacts will be my colleagues for the rest of my career. In addition to meeting professors at universities that are potential future graduate schools, I met students from all around the world at the Winter Workshop thanks to a grant from the European Ceramics Society (ECerS). Knowing people from all over Europe will open future opportunities, including collaborations and international relationships, especially when attending ECerS meetings. It is so invigorating to meet people from around the world who are interested in the same materials and technologies—it demonstrates the wide spread of the materials science community and how much we can learn from one another.



Winter Workshop and Electronic Materials and Applications 2017

Credit:

While not all the knowledge I gained from Winter Workshop technical sessions is applicable to my undergraduate research, understanding techniques and processes can inspire new ways of thinking for future projects. The workshop's professional development session was particularly helpful for illuminating post-doctoral opportunities in government positions such as national laboratories, research and development in industry, faculty positions in academia, and even possibilities of one day starting my own company. An industry presence in this portion of the workshop and in talks throughout the conference complemented the academic tone of the conference as a whole.

This meeting cemented my decision to go to graduate school to not only pursue further materials research, but to gain critical thinking skills developed during doctoral research. In addition, touring NASA's John F. Kennedy Space Center was a fun way to end the week by learning and exploring with new friends. Altogether, I enjoyed how the small size of the workshop and the conference fostered more meaningful interactions that are now friendships.

***Victoria Christensen is an undergraduate student studying materials science and engineering at Pennsylvania State University. Christensen intends to continue into graduate school to pursue a Ph.D. in ceramic–polymer composite materials for structural or aerospace applications. In her spare time, she enjoys running and volunteering for Penn State's dance marathon, an organization that benefits families affected by pediatric cancer.***