AMERICAN CERAMIC SOCIETY

bulletin

emerging ceramics & glass technology

SEPTEMBER 2020

Commercially scalable, single-step polymer-derived reaction bonding synthesis of refractory ceramics

Plus–
ACerS Annual Meeting & awards issue

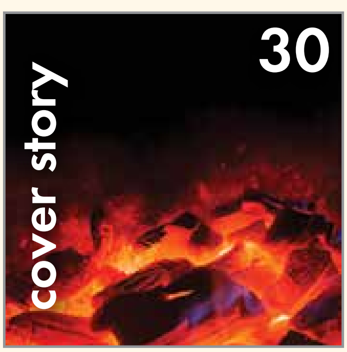
New issue inside:

Virtual Glass Summary recap | Ion-conducting ceramic markets | Upcoming January meetings

contents

September 2020 • Vol. 99 No.7

feature articles



department

columns

meeting

resources

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September 2020 • Vol. 99 No.7

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As seen on *Ceramic Tech Today*...

Credit: Pikist

Modeling teaches old dogs new tricks: Viscosity predictions from dilatometry and DSC

Determining viscosity of a glass through experiment is a slow and expensive process. In two recent papers published in JACerS, Penn State professor John Mauro and his colleagues show how it can be predicted much easier by using dilatometry and DSC to calculate parameters for a glass viscosity model that was proposed in 2009.

Read more at www.ceramics.org/viscositymodeling

Also see our ACerS journals...

The sound absorption performance of the highly porous silica ceramics prepared using freeze casting method
By Z. Du, D. Yao, Y. Xia, et al.
Journal of the American Ceramic Society

Preparation of high-strength lightweight alumina with plant-derived pore using corn stalk as pore-forming agent
By X. Li, Y. Li, S. Li, et al.
International Journal of Applied Ceramic Technology

Direct ink writing of hierarchical porous alumina-stabilized emulsions: Rheology and printability
By S. S. L. Chan, M. L. Sesso, and G. V. Franks
Journal of the American Ceramic Society

Effect of pore former (saw dust) characteristics on the properties of sub-micron range low-cost ceramic membranes
By S. Chakraborty, R. Uppaluri, and C. Das
International Journal of Ceramic Engineering & Science

Read more at www.ceramics.org/journals

American Ceramic Society Bulletin covers news and activities of the Society and its members, includes items of interest to the ceramics community, and provides the most current information concerning all aspects of ceramic technology, including R&D, manufacturing, engineering, and marketing. The American Ceramic Society is not responsible for the accuracy of information in the editorial, articles, and advertising sections of this publication. Readers should independently evaluate the accuracy of any statement in the editorial, articles, and advertising sections of this publication. *American Ceramic Society Bulletin* (ISSN No. 0002-7812). ©2020. Printed in the United States of America. *ACerS Bulletin* is published monthly, except for February, July, and November, as a "dual-media" magazine in print and electronic formats (www.ceramics.org). Editorial and Subscription Offices: 550 Polaris Parkway, Suite 510, Westerville, OH 43082-7045. Subscription included with The American Ceramic Society membership. Nonmember print subscription rates, including online access: United States and Canada, 1 year $135; international, 1 year $150.* Rates include shipping charges. International Remail Service is standard outside of the United States and Canada. *International nonmembers also may elect to receive an electronic-only, email delivery subscription for $100. Single issues, January–October/November: member $6 per issue; nonmember $15 per issue. December issue (*ceramicSOURCE*): member $20, nonmember $40. Postage/handling for single issues: United States and Canada, $3 per item; United States and Canada Expedited (UPS 2nd day air), $8 per item; International Standard, $6 per item.

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ACSBA7, Vol. 99, No. 7, pp 1– 68. All feature articles are covered in Current Contents.

How effective is that mask? Depends on what materials it is made of

Across the world, the COVID–19 pandemic rages on.

The SARS–CoV–2 virus is not magically disappearing, and with cases once again on the rise in many locations, it looks like this new reality of shutdowns and stay-at-home orders is going to continue for much longer than many people originally anticipated.

With that in mind, more people are shopping online for reusable cloth face masks that they can wear when they must to go out in public, in accordance with CDC guidelines.

When it comes to face masks that are functional, the gold standard is the N95, so named because its nonwoven polypropylene fibers can filter out an incredible 95% of airborne stuff, including viruses, from the air we breathe.

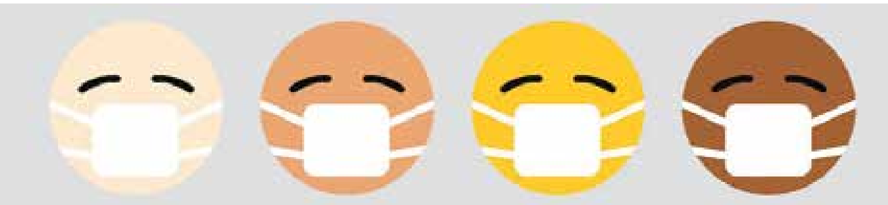
What makes N95 respirator mask so effective, and what made them originally so revolutionary, is how well they fit—snug enough to filter nearly all the air you breath—yet how breathable they are to wear. Surgical masks are often made of the same material but provide a less snug fit, so they are generally less efficient than N95 masks.

The nonwoven polypropylene fibers of the material form a tangled web that traps even tiny particles effectively, a property called filter efficiency, yet it contains big enough pores that the wearer can breathe easily.

That breathability factor is measured by the pressure drop, and it is another important consideration for an effective face mask. If breathing creates a large differential in pressure between the two sides of a mask material, it has a high pressure drop, and breathing is more difficult.

But N95 respirators are being reserved for medical workers. So current guidelines indicate general members of the public wear cloth-based masks instead.

Unfortunately, despite many individuals, companies, and businesses offering face masks for sale, a large proportion of these products provide little or



Credit: visuals; Unsplash

How efficient are homemade face masks? Surprisingly, results from a recent paper show many common household materials can be fashioned into face masks that are just as efficient if not more efficient than surgical masks.

no information about what material they are made of, how many layers they contain, or other important factors to help people determine if the masks are actually effective and comfortable to wear.

Many websites are selling masks made of lightweight cotton materials, which while incredibly breathable, have relatively low filter efficiency. They are better than nothing, but studies seem to indicate they only block about 20% of small particles (study results widely vary here, depending on the type of material, its thickness, and the testing procedures).

Research shows the material is an important consideration for an effective mask, as not all materials are created equal in both measures—the smaller pore size of high-filter efficiency materials often means they have a high pressure drop and thus are difficult to breathe through.

So it is an optimal combination of filter efficiency and pressure drop that makes a face mask effective and comfortable. Fortunately, a study published in *Nano Letters* in early June offers more complete data on the performance of an array of common materials.

Using a modified version of the testing protocol used to certify N95 masks, the researchers compared the performance of a range of household materials, both synthetic and natural—cotton, nylon, polyester, silk, and paper (cellulose)—compared to nonwoven polypropylene, the material of N95 and surgical masks.

The team measured filter efficiency and pressure drop of the various materials, combining those measures into a single measure called a filtration quality factor—a sort of scoring system to assess how efficient and breathable each material would be as a face mask.

The team's relatively strict testing criteria showed a perhaps surprisingly low efficiency of nearly all tested materials compared to N95 masks. Even surgical masks, sourced from two different manufacturers, showed relatively low scores.

Although most of the materials tested could not compare to the filtration quality of N95 masks—the exception being copy paper, which despite its high efficiency has an incredibly high pressure drop, and it also would not hold up well in the humid environment created by breathing—the results show that many common household materials can be fashioned into face masks that are just as efficient if not more efficient than surgical masks.

And layering multiple different materials together may offer the most effective solution when making homemade face masks.

"Cotton, polyester, and polypropylene multilayered structures can meet or even exceed the efficiency of materials used in some medical face masks," the authors write in the paper. "However, the exact number of layers, basis weight, and thread-count of material will need to be considered in addition to the fluid resistance and performance under breathing."

Table 1. Evaluation of reference and common materials' filtration properties

Material	Initial filtration efficiency	Initial pressure drop (Pa)	Filter quality factor (k/Pa)
Meltblown polypropylene (N95)	95.94%	9.0	162.7
Meltblown polypropylene (surgical mask 1)	33.06%	34.3	5.0
Meltblown polypropylene (surgical mask 2)	18.81%	16.3	5.5
Spunbond polypropylene	6.15%	1.6	16.9
Cotton, pillow cover	5.04%	4.5	5.4
Cotton, T-shirt	21.62%	14.5	7.4
Cotton, sweater	25.88%	17.0	7.6
Polyester baby wrap	17.50%	12.3	6.8
Silk napkin	4.77%	7.3	2.8
Nylon exercise pants	23.33%	244.0	0.4
Paper towel	10.41%	11.0	4.3
Tissue paper	20.2%	19.0	5.1
Copy paper	99.85%	1883.6	1.5

Notably, the team's results with a spunbond polypropylene fabric commonly found in households had the highest filter quality factor next to N95 masks. "While not as common as cotton, polypropylene spunbond is an inexpensive material that can be found in hobby fabric shops, some reusable bags, mattress covers, hygiene products, and disposable work wear," the authors write.

This material is in the same family of materials used to make N95 and surgical masks—although instead of being spunbond, the materials in N95 and surgical masks are meltblown, a manufacturing difference that results in finer and noncontinuous fibers.

Interestingly, the study also showed simply rubbing the spunbond polypropylene material for 30 seconds with a latex glove provides enough electrostatic charge on the surface of the material to essentially double the material's filtration efficiency for about an hour.

This finding is not entirely unexpected, however, as surface charge is another known reason N95 masks are so effective.

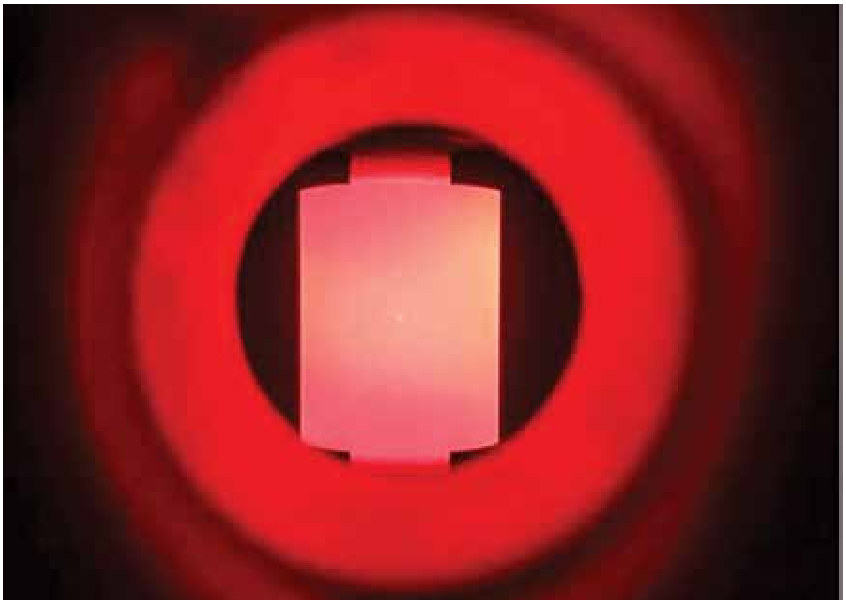
Although the study's data show relatively low overall filter efficiency for these various household materials, that is likely partly attributed to the high bar set by their stringent testing criteria (although the study disclosures do state several authors have potential competing financial interests via their involvement with a company called 4C Air Inc.).

It is important to note here that reported filter efficiency and other mask measures widely vary from study to study, depending on the testing protocol and other factors. But despite this variability, it seems like using a tightly woven fabric and incorporating multiple different materials, combined with a snug fit around your mouth and nose, make for a sufficiently effective mask.

The paper, published in *Nano Letters*, is "Household materials selection for homemade cloth face coverings and their filtration efficiency enhancement with triboelectric charging" (DOI: 10.1021/acs.nanolett.0c02211). ■

Corporate partner news

Online summer school: Electric and magnetic field-assisted processing of inorganic materials



Forschungszentrum Jülich is holding a free online summer school on electric and magnetic field-assisted processing of inorganic materials from Sept. 14–16, 2020. Register by September 1 via email to fieldsmatter@fz-juelich.de.

Rising e-waste and a deficit of recycling

Millions of tons of electrical and electronic equipment are discarded every year, and many companies that claim to "recycle" these materials are actually exporting the e-waste to developing countries instead, where it is often dumped improperly in the ground or burned, releasing toxic pollutants into the environment and negatively affecting the health of workers.

Prior to this year, the most recent statistics for global e-waste came from a 2017 report that estimated almost 45 million metric tonnes (Mt) of e-waste was generated worldwide in 2016. The report predicted e-waste would increase to 52.2 million Mt by 2021.

Last month, a new report was released, and its statistics are sobering—global e-waste amounts already passed 53 million Mt in 2019 alone.

Tracking e-waste: The Global E-waste Statistics Partnership

The 2017 report and recent 2020 report were both published by the Global E-waste Statistics Partnership (GESP), a collaboration between the International Telecommunication Union (ITU), United Nations University (UNU), and International Solid Waste Association (ISWA).

Founded in 2017, GESP aims to monitor development of e-waste over time and to help countries produce e-waste statistics in an internationally standardized way.

The partnership's first big project was the 2017 *Global E-waste Monitor* report referenced above, which published in December 2017. The report was a follow-up to the UNU's Sustainable Cycles Programme's 2014 *Global E-waste Monitor* report.

In June 2019, GESP launched globalewaste.org, an open source portal that visualizes e-waste data and statistics globally, by region and by country. In a UNU press release on the launch, ISWA president Antonis Mavropoulo said, "We hope that this new initiative will further stimulate the on-going efforts to tackle the e-waste challenge and drive resource recovery policies and activities towards a circular economy in the IT industry."

E-waste continues to grow rapidly as recycling systems lag far behind. What can be done to combat this problem?

The new 2020 *Global E-waste Monitor* report released this month marks the completion of the third big project by GESP, and the statistics contained within the report are sobering.

2020 Global E-waste Monitor: Surging waste faces a deficit of recycling

The 2020 report reveals that a record 53.6 million Mt of e-waste were generated worldwide last year, a 21% increase in five years. By 2030, this amount is expected to reach 74 million Mt—almost a doubling in just 16 years.

And yet only 17.4% of this waste was officially documented as properly collected and recycled, a statistic that indicates "recycling activities are not keeping pace with the global growth of e-waste," the report says.

Why is e-waste growing so rapidly? The report says the growing amount is mainly fueled by higher consumption rates of electrical and electronic equipment, short life cycles, and few repair options. And though Asia generated the highest quantity of e-waste in 2019 at 24.9 million Mt, Europe ranked first worldwide in terms of e-waste generation per capita at 16.2 kg.

On a positive note, the number of countries that have adopted a national e-waste policy, legislation, or regulation has increased from 61 to 78 since 2014. Unfortunately, "regulatory advances in some regions are slow, enforcement is poor, and policy, legislation, or regulation does not yet stimulate the collection and proper management of e-waste due to lack of investment and political motivation," the report says.

So what can be done to combat the amount of e-waste and improve recycling? One of the most important and effective approaches is to raise awareness of the problem. The report mentions several initiatives that GESP is pursuing, such as organizing workshops on e-waste statistics in various countries.

GESP is not the only organization carefully tracking and combating the e-waste problem. One nonprofit called the Basel Action Network has launched some notable initiatives, including running an e-Trash Transparency Project that holds unethical e-waste recycling companies accountable and establishing an e-Stewards Program to encourage socially and environmentally conscious behavior. ■

Ion-conducting ceramics: Global markets

By Margareth Gagliardi

The global market for technical ceramics is estimated to be valued at \$96 billion in 2020 and projected to expand at a compounded annual growth rate (CAGR) of 7.4% through the next five years. Currently, ion-conducting ceramics (ICCs) occupy a very small share of this market—\$167 million in 2019—but are projected to have very healthy growth through 2025, rising at a CAGR of 13.1% to reach \$338 million.

ICCs are a group of materials characterized by distinct properties related to their capability of conducting positive and negative ions. The most common ion-conducting ceramics are based on fluorite-type oxides, phosphates, perovskites, and garnet-type oxides. Some of these materials have been engineered to have ionic conductivity close to those of liquids.

BCC Research has identified three main sectors in which ICCs find current and potential applications: energy, sensors and instrumentation, and chemical/petrochemical/environmental.

- **Energy:** Applications within the energy sector currently account for the largest share of the market, at an estimated 80.3% of the total in 2020. Within this segment, ion-conducting ceramics are being used primarily for fabrication of fuel cell and battery components.
- **Sensors and instrumentation:** The sensors and instrumentation sector represents a smaller share at 17.5% of the total market. This segment has been expanding at a 6.9% CAGR since 2018, mainly driven by the use of ICCs for production of gas sensors.
- **Chemical/petrochemical/environmental:** This sector is the smallest, accounting for an estimated 2.2% of the total market. Currently, the main application for these ceramics is in the fabrication of membranes for various processes, but these processes are for the most part still in the development stage.

During the 2000–2019 period, the number of global patent applications and patents issued rose at a CAGR of 8.4%, and since 2010 the CAGR has been running at 9.8%, indicating that interest in the development of ICCs is expanding at a generally healthy rate.

The U.S. is the largest consumer of ICCs, with revenue of \$71 million in 2019 (42.5% of the market). The Asia Pacific region represents the second-largest market, with revenue of \$52 million (31.1%). Europe comes in third with revenues of \$34 million (20.4%).

About the author

Margareth Gagliardi is a research analyst for BCC Research. Contact Gagliardi at analysts@bccresearch.com.

Resource

M. Gagliardi, "Ion-conducting ceramics: Global markets" BCC Research Report CHM127A, August 2020. www.bccresearch.com. ■

Table 1. Technological milestones for ion-conducting ceramics

Period	Description
Early 1830s	Michael Faraday (London, U.K.) discovered that ion transport occurs not only in liquid electrolytes but also in certain types of solid materials.
1839	During an expedition in Russia, Gustav Rose (Berlin, Germany) discovered a $CaTiO_3$- based mineral in the Ural Mountains. The mineral was named "perovskite" after the Russian mineralogist Lev Aleksevich von Perovski.
1897	The German chemist Walther Nernst discovered that zirconia doped with a small amount of yttria is capable of conducting oxygen ions.
1950s	Seminal research was performed on crystalline materials that exhibited ionic conductivity at high temperatures. Research related to perovskite materials also took off.
1964	Compagnie Generale d'Electricité (Paris, France) developed a perovskite-based solid electrolyte for fuel cells.
1967	Prof. Takehiko Takahashi at Nagoya University in Japan introduced the term "solid state ionics" to define the behavior of solid electrolytes.
1970	General Electric (New York, NY) was issued a U.S. patent for the development of an electrolytic capacitor using a ion-conducting ceramic based on beta alumina.
1971	Exxon Research Engineering (Linden, NJ) developed oxide perovskite-based cathode catalysts for electrochemical cells used to convert alcohols into ketones.
1975	Hitachi (Tokyo, Japan) manufactured the first gas sensors based on oxide perovskites.
1977	Researchers at Sandia National Laboratories (Albuquerque, NM) reported the development of $LiAlSiO_4$ glass ceramic for use as solid electrolyte.
1980	DuPont (Wilmington, DE) was awarded a U.S. patent for a sodium-gadolinium-silicon oxide glass-ceramic formulation capable of transporting sodium ions and suitable as solid electrolyte for batteries and other electrochemical devices.
1994	Oxide-ion conducting ceramics based on perovskite lanthanum-gallium oxide were introduced.
2000 and beyond	The number of R&D activities related to ion-conducing ceramics has been growing very rapidly driven in particular by the need of creating new generations of devices that are more environmentally friendly.

SOCIETY, DIVISION, SECTION, AND CHAPTER NEWS

Corporate Partner news

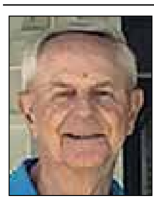
ACerS extends a warm welcome to all our new members. Please contact us with any questions you may have regarding your membership.

Our newest Corporate Partner is:

– Cerion Nanomaterials

ACerS thanks its Corporate Partners for supporting the industry and encourages members to support them. Visit the ACerS Corporate Membership webpage for a complete listing of corporate partners. ■

Volunteer Spotlight



Stett

ACerS Volunteer Spotlight profiles a member who demonstrates outstanding service to the Society.

Mark Stett received his B.S. in ceramic engineering from Alfred University, and he received his M.S. and Ph.D. in ceramic engineering from the University of California, Berkeley. He worked for 32 years in R&D with Kaiser Refractories/National Refractories and has now been retired for 19 years.

Stett became an ACerS member in 1962 and Fellow in 1996. He served on the Refractory Ceramics Division executive committee and as Division chair in 2000. Additionally, he has served on the Allen Award Committee since 1992.

His awards include the St. Louis Section Planje Award in 2001 and the ASTM Award of Merit in 1998. He was involved with UNITECR as well, serving as the program chair for New Orleans in 1997 and as Executive Board chair for Orlando in 2005. He was named a UNITECR Distinguished Life Member in 2005.

"Mark has done so much for the Refractory Ceramics Division, and I could always count on his counsel. We are grateful for his commitment to the Alfred Allen Award Committee for the past 28 years," says Dana Goski, ACerS president-elect and Allied Mineral Products vice president of research and development.

We extend our deep appreciation to Stett for his service to our Society! ■

Names in the news

Malara

Megan Malara was selected as the 2020–2021 TMS/MRS Congressional Science and Engineering Fellow. Malara will serve a one-year term working as a special legislative assistant on the staff of a member of Congress or congressional committee.

Members—Would you like to be included in the* Bulletin's *Names in the News? Please send a current head shot along with the link to the article to mmartin@ceramics.org. The deadline is the 30th of each month. ■

Help ACerS help you

This fall, ACerS will conduct a membership satisfaction and needs assessment survey. The survey results will help serve as a guide for strategically planning ACerS future. All members are encouraged to complete the survey to help us better serve you. Please watch for it in your inbox in September. ■

In memoriam

Louis Domingues

Henry C. Graham

Ralph Rose

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

Annual Business Meeting news

ACerS Annual Meeting will be a virtual event this year, and so will the Annual ACerS Business Meeting. Please plan to attend from the comfort of your own home or office. President Ohji will report on the state of the Society, new officers and board members will be inducted, and we will have time for questions and comments from members. The meeting will take place in early October. Full details will be provided in the coming weeks. ■

AWARDS AND DEADLINES

The Navrotsky Award for Experimental Thermodynamics of Solids

Awarded biennially to an author who made the most innovative contribution to experimental thermodynamics of solids technical literature during the two calendar years prior to selection (2019 and 2020). The award is presented at ACerS Annual Meeting at MS&T, where the recipient delivers a talk on the work cited for the award. Nominations must be received by **Jan. 15, 2021**. For more information, visit https://ceramics.org/awards/navrotsky-award. ■

ACerS/BSD Ceramographic Competition

The Roland B. Snow Award is presented to the Best of Show winner of the 2020 Ceramographic Exhibit & Competition organized by the ACerS Basic Science Division. This unique poster competition will be held online with entries displayed and judged at http://bit.ly/RolandBSnowAward. Winning entries are featured on the back covers of the *Journal of the American Ceramic Society*. ■

STUDENTS AND OUTREACH

Compete in Material Advantage student contests

Join fellow Material Advantage student members from around the world by competing in student contests, including

- **Undergraduate student speaking and poster contests**

Submit entries for the MA Undergraduate Student Speaking Contest and the Undergraduate Student Poster Contest by **Sept. 7, 2020**.

- **Graduate student poster contest**

Submit entries for the Graduate Student Poster Contest by **Aug. 31, 2020**.

Rules for each contest as well as where to send entries can be found at www.matscitech.org/students. For more information, contact Yolanda Natividad at ynatividad@ceramics.org. ■

2020 PCSA Humanitarian Pitch Competition

The President's Council of Student Advisors is hosting the Humanitarian Pitch Competition for students to pitch ideas to a panel of judges about how they can address a challenge a community is experiencing by using their material engineering background.

Students may put together a team of up to four participants, and both undergraduate and graduate students are eligible to participate. Visit www.ceramics.org/pitchcomp for further details. Submit abstracts by **Sept. 1, 2020**. ■

Upcoming ACerS webinars—mark your calendars

September 3: Constructing PowerPoint presentations

Are you planning on giving an oral presentation at an upcoming meeting? The webinar "From dull data to neat narrative: Constructing PowerPoint presentations through story framing and slide design" will familiarize you with the basics of creating a good PowerPoint presentation, including both composing the research story and crafting the slides. Register to attend this webinar scheduled for **Sept. 3, 11 a.m. Eastern Time** by visiting www.ceramics.org/webinars.

October 21: Application process

Are you planning to apply for a scholarship or award? **Save the date of Oct. 21, 11 a.m. Eastern Time** for an ACerS webinar on the topic of the ever-elusive application process.

Be sure to visit the ACerS Webinar Archives to view recordings of past webinars. ■

Give GGRN a 'like' on Facebook!

Whether you are an ACerS Global Graduate Researcher Network (GGRN) member or not, we invite you to join us on Facebook at www.facebook.com/acersgrads to stay up to date with ACerS news, opportunities, competitions, career development tips and tricks, and more.

If you are not a current GGRN member but are a graduate student whose work includes ceramics or glass, be sure to stop by www.ceramics.org/ggrn to join GGRN today. ■

CERAMICANDGLASSINDUSTRY
FOUNDATION

CGIF distributes 2019 “Gratitude Report”

The Ceramic and Glass Industry Foundation is pleased to share its 2019 annual report. In honor of the Foundation’s 5-year anniversary (2014–2019), we titled the publication “Gratitude Report” to show our immense appreciation for all of those who have donated to support our endeavors. We know the growth of our outreach programs would not be possible without our donors, thus we offer our Gratitude Report to show what YOU have done with your gifts of support.

Our mission of inspiring and training the next generation of ceramic and glass professionals is being fulfilled every day because of our donors. In fact, since 2014, our donors have enabled us to distribute over 1,000 of our Materials Science Classroom Kits to teachers around the country and the world.

Read more about what your donations have done for the CGIF at http://foundation.ceramics.org/2019Report. As always, we truly appreciate your gifts of support.

If you would like to provide a gift to the CGIF to support our work, please contact Marcus Fish at mfish@ceramics.org or 614-794-5863. You may also donate online at https://foundation.ceramics.org/give. ■

2014–2019 Five Years of Giving to Champion the Future of our Industry

foundation.ceramics.org/give

research briefs

Ceramic Faraday rotators improve optical isolator performance

Credit: Akio Ikesue

Prototype of an optical isolator using terbium yttrium oxide ceramic (right) in comparison with a commercial optical isolator based on terbium gallium garnet single crystal (left).

FACerS Akio Ikesue and colleagues created high-performing transparent ceramics that could improve the performance of optical isolators.

An optical isolator, or optical diode, is an optical component that allows transmission of light in only one direction. It typically is used to prevent back-reflected light into an optical oscillator, such as a laser cavity, and a single solid-state laser system generally contains multiple isolators (anywhere from two to 10).

Traditional optical isolators are based on the Faraday effect, which is the rotation of a light beam's plane of polarization caused by a magnetic field. The rotation occurs in a transparent paramagnetic or ferrimagnetic material called a Faraday rotator.

Currently, Faraday rotators are made using single crystals, typically terbium gallium garnet ($Tb_3Ga_5O_{12}$, TGG). Ikesue and his colleagues wanted to see if a transparent ceramic could be used instead.

They focused on terbium-based ceramics because the Verdet constant—which indicates the ability of a material to polarize light—is determined dominantly by the occupancy of terbium ions. In a paper published in 2017, Ikesue and his colleagues explain that various investigations revealed the most promising crystal structure to boost terbium ion occupancy is bixbyite (Re_2O_3, where Re is a lanthanide rare-earth element). However, using lanthanide rare-earth oxides as an optical material is, in a traditional view, inconceivable.

"The melting point of lanthanide rare-earth oxide is around 2,400°C, and it is very difficult to melt and solidify," Ikesue explains. "Even if melting and solidification are possible, there is a phase transition point below the melting point in all lanthanide elements. Therefore, a large stress is induced in the material when it is produced, causing the material to break or crack. Also, a large stress associated with the phase transition remains inside the materials, and it cannot be used as an optical material."

Ikesue says ceramic fabrication processes do not require melting, so there are less problems producing lanthanide rare-earth oxides this way than as single crystals. Unfortunately, high temperatures are still required to make these oxides fully dense and transparent, and the sintering temperature always exceeds the phase transition point around 1,500°C.

Research News

Battery breakthrough gives boost to electric flight and long-range electric cars

Researchers at Lawrence Berkeley National Laboratory, in collaboration with Carnegie Mellon University, reported a new class of soft, solid electrolytes—made from both polymers and ceramics—that suppress dendrites in that early nucleation stage, before they can propagate and cause the battery to fail. Key to the design of these new electrolytes was the use of soft polymers of intrinsic microporosity, whose pores were filled with nanosized ceramic particles. In tests, continuously smooth growth of lithium was observed, in contrast to conventional electrolytes, which showed telltale signs of the early stages of dendritic growth. For more information, visit https://newscenter.lbl.gov.

Cementing the future: Unraveling the centuries-old processes behind cement production

Researchers from Oklahoma State University, Princeton University, and Argonne National Laboratory used complementary imaging methods to continuously monitor changes in Portland cement as it hardened so they could understand the process. They drew a number of broad conclusions from the accumulated 3D images and measurements of particle composition. For instance, while both micron-scale and nano-scale particles exhibit uneven growth and dissolution on their surfaces, larger particles tended to accumulate minerals containing heavier elements, while the surfaces of smaller particles mostly exhibited mineral dissolution. For more information, visit https://www.anl.gov/news.

"Therefore, no one has ever succeeded in synthesizing this material even with ceramic technology," Ikesue says.

Until recently, that is.

In the 2017 paper, Ikesue and his colleagues described their success creating terbium yttrium oxide (TYO) and binary terbium oxide (TO) ceramics using vacuum sintering and hot isostatic press treatment. They published another paper in 2019 improving on the process and describing TYO and TO properties, including the following.

High Verdet constants

The Verdet constants of $(Tb_{0.6}Y_{0.4})_2O_3$ and Tb_2O_3 are 2.5 and 4 times that of TGG, respectively, meaning they can better polarize light. This fact means smaller magnets can be used to surround the Faraday rotator, thus encouraging device miniaturization.

High extinction ratio

In telecommunications, extinction ratio describes the efficiency with which transmitted optical power is modulated over fiber-optic transport.

Compared to the extinction ratio of TGG (35 dB), TYO and TO had extinction ratios of 42 dB and 47 dB, respectively, meaning they are more efficient at transmitting light.

Low insertion loss

Insertion loss describes the optical loss that occurs inside the Faraday rotator medium when polarized in a strong magnetic field.

TYO and TO showed comparable insertion loss to TGG. In addition, TYO had a laser damage threshold of 18 J/cm^2, which is about twice that of TGG single crystal, meaning TYO ceramics are less likely to suffer optical damage when used with a high-powered laser.

Ikesue says when they first began developing TYO and TO ceramics, they provided some Faraday rotator prototypes to their end users for evaluation. At the same time, they exhibited a very small and compact optical isolator device at the SPIE Photonics West conference in San Francisco. From these experiences, they found a large demand for the device, so they started selling it as a new product from the beginning of this year.

Ikesue says he and his colleagues succeeded in their research because of their willingness to look past conventional wisdom.

"We doubt past theoretical views and technologies and tried to know the truth of natural science with a pioneering spirit," he says.

The 2017 paper, published in *Optics Letters*, is "Polycrystalline $(Tb_{\chi}Y_{1-\chi})_2O_3$ Faraday rotator" (DOI: 10.1364/OL.42.004399)

The open-access 2019 paper, published in *Materials*, is "Total performance of magneto-optical ceramics with a Bixbyite structure" (DOI: 10.3390/ma12030421).

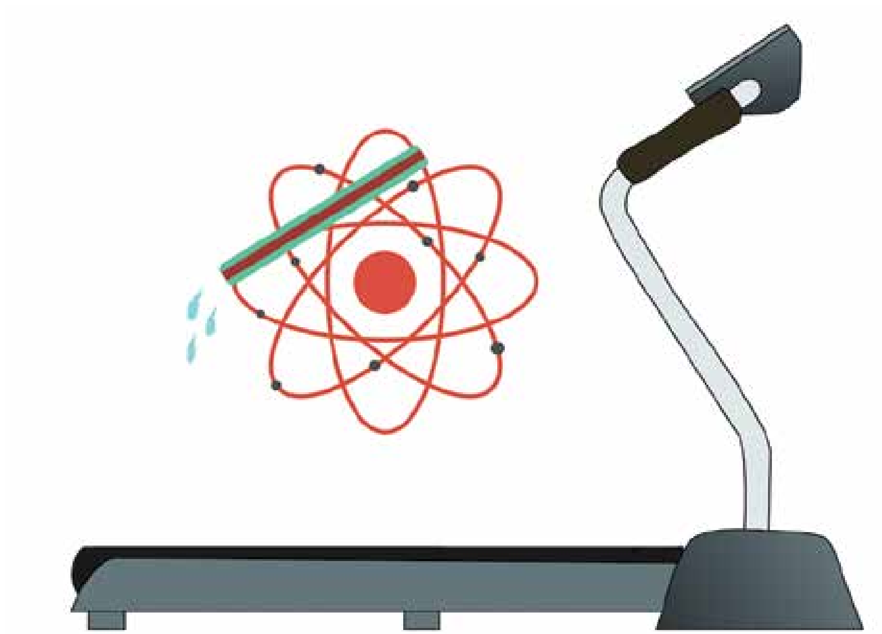
Grain boundary diffusion of cations is faster but not easier

Researchers at RWTH Aachen University in Germany explored the grain boundary diffusion behavior of cations in certain metal oxides and found though the diffusion is faster along the boundary than in the bulk, it is not necessarily easier.

In oxygen-ion conducting metal oxides, the mechanisms governing diffusion of negatively charged oxygen ions (anions) generally receive much more attention than the mechanisms governing diffusion of positively charged metal ions (cations) because of the anions' role in conductivity.

"It is the oxide ions that are highly mobile, providing the dominant contribution to the electrical conductivity," explains Roger De Souza, professor at RWTH Aachen University, in an email. "The [metal] cations, in contrast, are far less mobile, and their contribution to the overall conductivity is negligible."

However, though cations' role in conductivity is small, "The diffusion of the cations is nevertheless important for long-term processes, or processes at very high temperatures: sintering, grain growth, interdiffusion, creep, phase formation, and kinetic unmixing," De Souza adds.


Credit: ACerS

A faster process is not necessarily easier, as grain boundary diffusion of cations in certain metal oxides goes to show.

Research on cation diffusion has found that, unlike anions, cations tend to diffuse faster along grain boundaries, i.e., the interfaces between grains of differing crystal orientations in polycrystalline structures. This finding may be surprising to students who associate grain boundaries with decreased conductivity—but remember, conductivity mainly depends on the anions, not the cations.

"The transport of oxide ions across boundaries is indeed hindered," De Souza says. "For the cations, diffusion experiments ... show that grain boundaries provide a fast path for the very slow cations."

Currently, most knowledge concerning fast diffusion of cations along grain boundaries comes from studies on metals, not ceramics. And this fact cannot be overlooked due to an inherent difference between metal and ceramic grain boundaries.

In metals, the grain boundaries are locally electroneutral, meaning they hold no charge. Ceramic grain boundaries, however, generally become electrostatically charged, which causes the adjacent bulk areas to develop space-charge layers (SCLs), i.e., areas that are structurally part of the bulk but electrically part of the grain boundary.

SCLs can drastically alter the concentration of point defects in that area, such as the number of oxygen and cation vacancies, which naturally affects ion diffusion. And yet surprisingly, there are no studies to date investigating the effect of SCLs on cation diffusion in fluorite (and some perovskite) oxides.

"It was a big surprise to us that the presence of SCLs has not been invoked so far, [especially because the presence of them are widely accepted]," De Souza says. So, he and doctoral candidate Jana Parras decided to investigate the effect of SCLs themselves.

To investigate how grain boundaries and SCLs affect cation diffusion, Parras and De Souza attacked the problem with a two-step, continuum-level approach, in which point-defect distributions were calculated before cation diffusion was allowed to occur.

Using this approach, they ran numerous diffusion simulations for both fluorite and perovskite oxides and varied four parameters over a range of temperatures: percent of oxygen vacancies in the bulk, standard chemical potential of the oxygen vacancies, and number densities of core sites for oxygen vacancies and acceptor dopants.

Among their findings, the most important one had to do with activation enthalpy, i.e., the amount of energy necessary to initiate diffusion.

They found that although cations diffuse faster along the grain boundary than in the bulk, the activation enthalpy for grain-boundary diffusion can approach, or even equal, the activation enthalpy for bulk diffusion. In other words, even though diffusion along the grain boundary was faster, it took the same amount of energy to occur.

"If in the past you found [equal activation enthalpy] experimentally, it was considered to be unphysical. You had done something wrong in your experiments. And for metals, I would agree," De Souza says. "But for oxides, we have now shown that it is not unphysical. In fact, we have shown that there is a solid physical basis for such behavior."

De Souza says they are now pursuing two further avenues of research, one computational and one experimental, to investigate the diffusion mechanism more. And this time, they have an additional tool to help them out—based on the information in this study, Parras and De Souza derived an empirical relationship that predicts the grain-boundary diffusivity using knowledge of space-charge parameters and bulk diffusivity.

The paper, published in *Acta Materialia*, is "Grain-boundary diffusion of cations in fluorite-type oxides is faster but not always easier" (DOI: 10.1016/j.actamat.2020.05.022). ■

Nickel-manganese-aluminum cathodes for lithium-ion batteries

University of Texas at Austin researchers led by Cockrell Family Regents Chair in Engineering and director of the Texas Materials Institute Arumugam Manthiram showed the potential of cobalt-free lithium-ion batteries in recent research.

Cobalt is a key ingredient in lithium-ion batteries, specifically ones with cathodes made from nickel-cobalt-manganese (NCM) or nickel-cobalt-aluminum (NCA). Cobalt stabilizes the cathode by compensating for the charge when lithium ions arrive or depart during cycling.

Over the past decade, lithium-ion batteries with NCM and NCA cathodes solidified their status as the battery of choice for power tools and electric vehicles because of their high energy density, i.e., the amount of energy stored per unit volume. However, increasing demand for electric vehicles—in addition to increased calls for ethical mining of cobalt—are expected to result in shortages of cobalt in the long term, leading companies to begin seriously considering alternative batteries that are cobalt-free.

Ideally, a cobalt-free battery would have energy density equivalent or better than the NCM and NCA batteries because it would allow a car to go longer between charges. And theoretically, a cobalt-free nickel-based battery would be a good way to achieve that because nickel provides high energy density.

Unfortunately, nickel is unstable by itself and requires other elements to stabilize the cathode. And only cobalt, aluminum, and manganese appear to stabilize it without severe side effects.

"While elements such as magnesium, zirconium and titanium are routinely introduced in commercial high-Ni layered oxides for performance tuning ... optimal amounts are typically very small, sometimes down to ppm levels, as detriments often coincide with benefits," the UT Austin researchers write in a recent perspective article. "Large usage can give rise to substantial structural defects (for example, cation mixing), lattice distortion and impurities, severely worsening electro-chemical properties."

In the perspective article, the researchers discuss several important design considerations for high-nickel layered oxide cathodes and make an interesting suggestion—if aluminum and manganese are known to stabilize nickel well, as evidenced by NCM and NCA batteries, why not create a nickel-based cathode that ditches cobalt and combines aluminum and manganese instead?

In a new paper, Manthiram, postdoctoral fellow Wangda Li, and graduate student Steven Lee explored the potential of lithium-ion batteries featuring nickel-manganese-aluminum (NMA) cathodes, a combination that "strikingly" has not been reported to their knowledge.

They compared the composition NMA-89 (nickel content 89%) to NMC-89, NCA-89, and aluminum-magnesium codoped NMC (NMCAM-89) and made several notable findings.

Lower specific capacity, higher average voltage

Despite a marginally lower specific capacity, i.e., amount of charge stored per unit volume, NMA-89 showed a higher average voltage of nearly 40 mV more than NMC-89.

Credit: Michael Movchin and Felix Müller, Wikimedia (CC BY-SA 3.0)

Could electric vehicles be powered by cobalt-free batteries in the future?

Fast discharging performance

Rate capability, or the rate a battery charges/discharges, is another key performance metric in addition to energy density. And the fast-discharging performance of NMA-89 is very similar to that of NMC-89 and NCA-89.

Comparable retained capacity

After 100 cycles at a charge/discharge rate of 1/3, i.e., every 3 hours, NMA-89 retained 90% of its original capacity, which falls right in line with NMCAM-89 (93%), NMC-89 (91%), and NCA-89 (88%).

In the conclusion, the researchers note electrochemical characterization in this study is only preliminary. "…future work is needed to fully understand the benefits and detriments of Mn-Al cosubstitution in high-Ni layered oxides in the absence of [cobalt]," they write.

In an email, Manthiram says they are in the process of analyzing the electrodes after 1,000 cycles with state-of-the-art characterization techniques to better understand materials behavior in the battery during repeated cycling. In addition, they are carrying out further studies to refine the compositions and scale-up the production process. Details on how they plan to bring the technology to market can be seen in the university press release.

The paper, published in *Advanced Materials*, is "High- nickel NMA: A cobalt- free alternative to NMC and NCA cathodes for lithium-ion batteries" (DOI: 10.1002/adma.202002718). ■

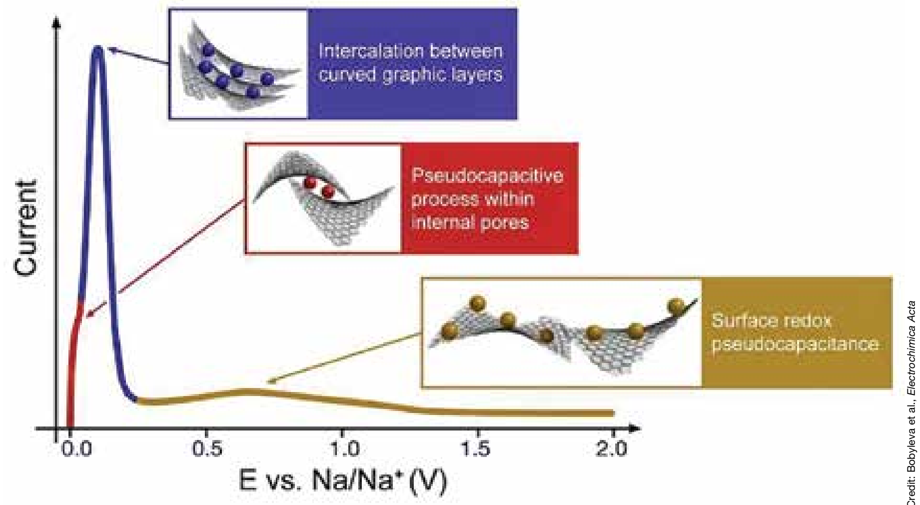


Illustration of proposed three-stage charge storage mechanism for hard carbon anodes.

"Three-stage" model for charge storage in hard carbon anodes gains support

Researchers at Lomonosov Moscow State University, Skolkovo Institute of Science and Technology, and Tokyo University of Science gave support for the "three-stage" model of charge storage in hard carbon anodes in their recent paper.

Hard carbon is the material most often used for the anode in sodium-ion batteries. Na-ion batteries are analogous to Li-ion batteries, but instead of lithium ions moving between the cathode and anode, sodium ions do so instead. The two batteries have similar electrochemical characteristics, but Na-ion batteries cost less to produce because Na-ion batteries do not require cobalt in the cathode and sodium is more abundant than lithium.

However, there is a key difference between Na-ion and Li-ion batteries. Sodium ions are much bigger than lithium ions, so the material typically used for the anode in Li-ion batteries—graphite—cannot be used for Na-ion batteries because the sodium ions cannot intercalate, i.e., be inserted, into the graphite structure. Thus, hard carbon is used instead.

Hard carbon refers to carbons arranged in such a way that they are nongraphitizable, i.e., they cannot be cleanly separated into thin, separate layers of graphite. The disordered structure provides spaces large enough for sodium ions to intercalate.

Intercalation is not the only way charge is stored in anodes, however. Another important charge storage mechanism to consider is adsorption.

Adsorption refers to adhesion of ions on the surface of the anode material. (In contrast to intercalation, which refers to insertion of ions within the bulk.) Compared to batteries in which intercalation is the main charge storage mechanism, batteries that store charge through adsorption (known as supercapacitors) demonstrate low specific energy density and high self-discharge rate.

In Li-ion batteries, intercalation is the main charge storage mechanism in graphite anodes. But in Na-ion batteries, the relationship between intercalation and adsorption in hard carbon anodes remains an open question.

In an email, Oleg Drozhzhin, senior research scientist at the Skoltech Center for Energy Science and Technology and Lomonosov Moscow State University, explains several of the main views currently held on hard carbon charge storage mechanisms.

"The most popular and old one is 'intercalation-adsorption' (i.e., intercalation between curved graphitic layers within the sloping voltage region and adsorption at low-voltage plateau)," he says. "Another model, named 'adsorption-intercalation,' supposed Na+ adsorption at the surface or defects sites with further intercalation within the low-voltage plateau."

Several alternative models—such as "adsorption-filling" and three- or four-stage models—also exist, but Drozhzhin says determining which model is correct is difficult.

"...hard carbon is an extremely complex object for studying. As it does not possess long-range ordering, usual methods such as X-ray diffraction or transmission microscopy could not reveal the type of electrochemical process," he says.

Drozhzhin says several sophisticated methods have provided some insight into the mechanisms, such as the work of Clare Grey's group at the University of Cambridge using solid-state nuclear magnetic resonance, but "at the moment there is no method that could definitely determine the charge storage mechanism in hard carbon." As such, "The existence of several opinions on a complex subject is the best way to understand the nature of things," he says.

Based on this premise, Drozhzhin and colleagues decided to conduct their own study on the charge storage mechanisms in hard carbon. And in the recently published paper on their research, they propose a model that differs from the currently most popular view.

In their study, they used linear sweep voltammetry to analyze the pseudocapacitive behavior of hard carbon. (Pseudocapacitance refers to adsorption with certain chemical interactions allowing charge transfer.) And based on their findings, they agree that a three-stage "adsorption-intercalation-adsorption" process first suggested by Bommier et al. in 2015 is a good model for interaction between sodium ions and the hard carbon anode.

"First, pseudocapacitive-type reaction between Na+ and carbon open surface occurs at high potentials," they write in the paper. "After the surface is filled, intercalation of Na+ between pseudographitic layers takes place, which is evidenced by low b-values (close to 0.5)."

"Finally, another type of pseudocapacitive-type process is observed at very low (~20 mV) potentials. ... Under the theory of open and internal porosity, this third process can be considered as pseudocapacitive Na+ filling within internal pores, since this type of electrochemical reaction may occur only after filling the bulk volume of the material with Na+," they conclude.

In the future, Drozhzhin says there are several aspects of anode materials for Na-ion batteries they wish to explore further, including

- **Safety issues**, particularly the process of sodium dendrite formation during long-term cycling;
- **Self-discharge**, particularly the rate of charge loss at different states of charge; and
- **Full cells**, particularly which cathode materials combine best with hard carbon anodes.

The paper, published in *Electrochimica Acta*, is "Unveiling pseudocapacitive behavior of hard carbon anode materials for sodium-ion batteries" (DOI: 10.1016/j.electacta.2020.136647). ■

Boron nitride destroys ‘forever’ chemicals

Researchers at Rice University were surprised to discover that boron nitride serves as an efficient photocatalyst for degrading per- and polyfluoroalkyl (PFAS) chemicals.

PFAS are a group of more than 4,700 manmade chemicals containing linked chains of carbon and fluorine. The first PFAS were invented in the late 1930s, and two in particular—perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS)—quickly gained widespread application in a variety of consumer products, including nonstick cookware like Teflon.

Yet as PFAS became a staple in many consumer products, studies showing the negative environmental and health impacts of these chemicals began to grow as well. The United States Congress recently doubled down on the dangers of PFAS, but unfortunately, even if use of PFAS is limited in the future, there still exists the problem of PFAS already in the environment.

PFAS are known as “forever” chemicals because, once created, they are notoriously difficult to break down. This stability means these chemicals stick around far after PFAS-containing products are sent to the dump. And they do not stick around only in the environment—more than 97% of people living in the U.S. have a detectable amount of PFAS in their blood.

To date, incineration is considered the most effective way to dispose of PFAS waste. However, this method is not very cost effective, cannot be used to remove PFAS in water supplies, and may actually do more to spread PFAS than to break it down.

In recent years, researchers started investigating the potential of photocatalytic degradation to remove PFAS from water supplies. In photocatalytic degradation, a material called a photocatalyst uses energy from light to accelerate a chemical reaction that breaks down the reacting substance.

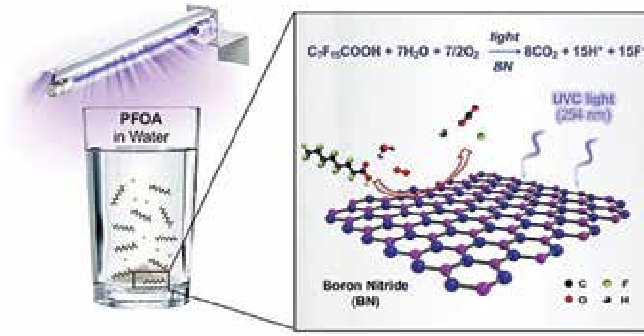
Traditionally, photocatalytic degradation of PFAS was not widely pursued because of the limited ability of common semiconductor materials to break the carbon–fluorine bonds in aqueous systems. However, some materials—indium oxide (In_2O_3), gallium oxide (Ga_2O_3), and titanium dioxide (TiO_2) in particular—degrade some PFAS quite well under ultraviolet light.

There is much room to improve on photocatalytic degradation of PFAS, and the Rice University researchers, led by William M. McCardell Professor in Chemical Engineering Michael Wong, looked to do so by identifying new photocatalyst materials.

In their search for a photocatalyst, the researchers used ultraviolet light with a wavelength of 254 nanometers to investigate the photocatalytic properties of various materials. This wavelength should be too long to activate boron nitride, which is why they used boron nitride as a control group in experiments.

While none of the experimental groups performed well, boron nitride did.

“Here’s the observation,” Wong explains in a Rice University press release. “You take a flask of water that contains some



Credit: Michael Wong, Rice University

An illustration of the boron nitride-based photocatalysis reaction that destroys the pollutant PFOA in water.

PFOA, you throw in your [boron nitride] powder, and you seal it up. That’s it. You don’t need to add any hydrogen or purge it with oxygen. … You expose that to ultraviolet light, specifically to UV-C light with a wavelength of 254 nanometers, come back in four hours, and 99% of the PFOA has been transformed into fluoride, carbon dioxide and hydrogen.”

The researchers were confused and decided to hold off on publishing the results until they could offer a plausible explanation for the observations—an explanation that ended up centering around atomic defects.

“We concluded that our material does absorb the 254-nanometer light, and it’s because of atomic defects in our powder,” Wong says. “The defects change the bandgap. They shrink it enough [lower the energy requirement] for the powder to absorb just enough light to create the reactive oxidizing species that chew up the PFOA.”

More experimentation will be needed to confirm the explanation. But one thing is for certain—boron nitride can destroy other PFAS as well, specifically GenX.

GenX is a PFAS that was widely used to replace PFOA when that chemical was banned. More studies are suggesting that GenX could be just as big an environmental problem as PFOA, but unfortunately, there so far has been no success in using catalysts to degrade GenX.

When Wong and colleagues tested the ability of boron nitride to degrade GenX, the results were not as good as with PFOA—two hours exposure only led to about 20% of the GenX being destroyed—but Wong says the team has ideas about how to improve the catalyst for GenX.

“The research has been fun, a true team effort,” Wong says. “We’ve filed patents on this, and [the Rice-based Nanosystems Engineering Research Center for Nanotechnology-Enabled Water Treatment] interest in further testing and development of the technology is a big vote of confidence.”

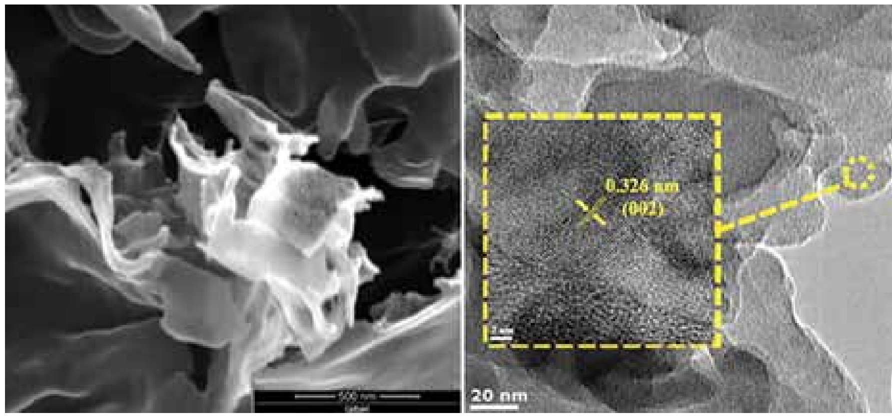
The paper, published in *Environmental Science & Technology Letters*, is “Efficient photocatalytic PFOA degradation over boron nitride” (DOI: 10.1021/acs.estlett.0c00434).

Photocatalysis techniques for destroying antibiotic resistant bacteria and genes

Rice University researchers developed two "trap-and-zap" strategies for removing antibiotic resistant bacteria and antibiotic resistance genes from wastewater.

Antibiotic resistant bacteria are bacteria with the ability to defeat drugs designed to kill them. Such bacteria have become an increasingly concerning problem around the world due in part to overprescription and inappropriate prescription of antibiotics, practices which lead to bacteria developing resistance.

The agricultural sector is particularly notorious for its use of antibiotics. A 2014 report by the U.S. Food and Drug Administration revealed an estimated 80% of antibiotics sold in the U.S. are used in animals. These antibiotics are primarily meant to promote growth and prevent infection, but 70%–90% of antibiotics administered are excreted in urine and stool instead—and then widely dispersed into the environment through fertilizer, groundwater, and surface runoff.



Credit: Alvarez Research Group

(Left) Scanning electron micrograph showing the mesoporous structure of molecular-imprinted graphitic carbon nitride nanosheets. (Right) Transmission electron micrograph showing the sheet's edge and its crystalline structure.

Once in the environment, these antibiotics interact with bacteria and lead to growth of antibiotic resistant bacteria (ARB) and antibiotic resistance genes (ARGs), i.e., small pieces of DNA that carry genetic instructions for resistance from one germ to another. And often, these ARB and ARGs then end up in our water supply.

Water treatment systems are designed to filter out ARB and ARGs to ensure the water people drink is safe. However, though conventional systems such as chlorination are moderately effective in removing ARB, they are relatively ineffective at removing ARGs.

Thus, developing new treatment systems that effectively destroy ARGs is an active area of research.

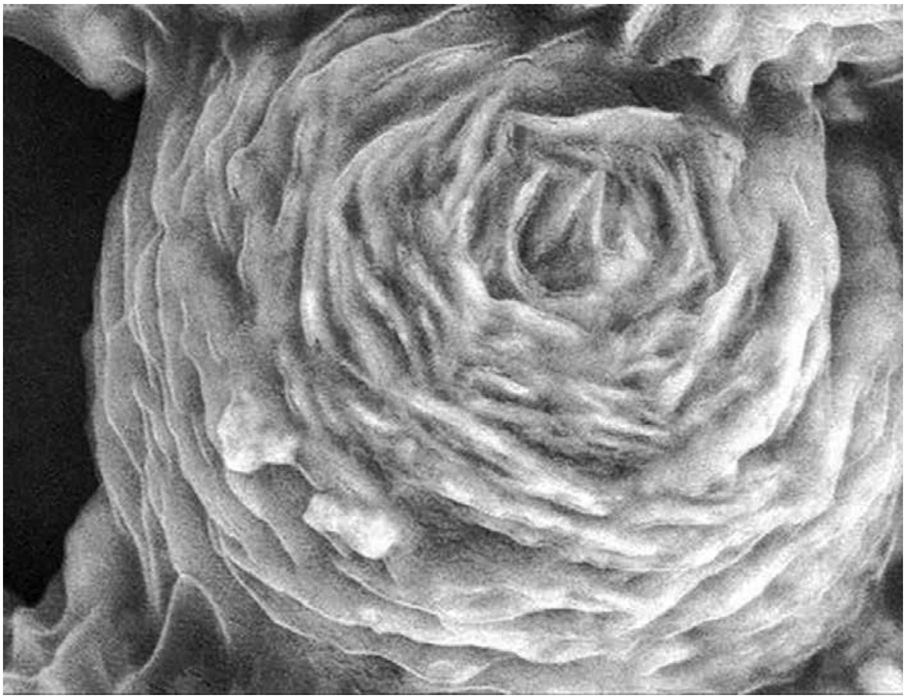
In recent papers published in March and July, Rice University researchers led by George R. Brown Professor of Engineering Pedro J.J. Alvarez are investigating degrading ARGs through photocatalysis.

Photocatalysis is the acceleration of a light-based chemical reaction in the presence of a catalyst. The acceleration is due mainly to the catalyst material, upon absorbing ultraviolet light, generating special oxygen-containing molecules called "reactive oxygen species" (ROS) that play a large role in photocatalytic degradation.

Molecular imprinting bolsters "trap-and-zap" degradation

In the March paper, they looked to address a challenge that comes from using graphitic carbon nitride, an earth-abundant and metal-free photocatalyst, in photocatalysis processes to rid wastewater treatment plant effluent of ARGs.

"...degradation of ARGs by pristine or modified C_3N_4 can be adversely affected in [wastewater treatment plant] effluent, where soluble microbial product and natural organic matter compete with less abundant target contaminants (or ARGs in



Credit: Deyi Li, Tongji University

Scanning electron micrograph showing a nitrogen-doped reduced graphene oxide shell around layered bismuth–oxygen–carbon nanoplates. The microsphere traps and zaps antibiotic resistant bacteria and the resistance genes they release.

this case) for photogenerated ROS," the researchers write.

In other words, reaction of graphitic carbon nitride with substances other than ARGs results in fewer ARGs being degraded.

If graphitic carbon nitride could be directed to react only with ARGs, then the rate of ARG degradation would improve. So the researchers looked to achieve this result by using a technique called molecular imprinting.

Molecular imprinting is known as a "lock and key" technique. A material is imprinted with template-shaped cavities ("locks") to which only certain molecules ("keys") can attach. Once the molecules attach, they are trapped in place and degraded through reaction with ROS.

The researchers found when they molecularly imprinted graphitic carbon nitride nanosheets, photocatalytic removal of the plasmid-encoded ARG $bla_{\mathrm{NDM-1}}$ was 37 times faster than with bare graphitic carbon nitride.

"This trap-and-zap strategy significantly enhances removal of the eDNA [environmental DNA] gene, clearly outperforming commercial photocatalysts," Alvarez says in a Rice press release.

The paper, published in *Environmental Science & Technology*, is "Selective adsorption and photocatalytic degradation of extracellular antibiotic resistance genes by molecularly-imprinted graphitic carbon nitride" (DOI: 10.1021/acs.est.9b06926).

Improved "wrap, trap, and zap" process for destroying ARGs

In the July paper, the researchers again used a "trap-and-zap" strategy to improve photocatalysis-induced degradation. But instead of using molecular imprinting to improve ARG adsorption, the researchers instead added a "wrap" step to the "trap-and-zap" strategy.

The researchers originally showed the potential of a "wrap, trap, and zap" strategy in 2014, when they wrapped nanosheet-assembled bismuth–oxygen–carbon microspheres in reduced graphene oxide to increase ROS production.

"However, while enhanced ROS generation may improve disinfection, a higher rate of cells lysis [disintegration] increases the release of eARGs," they write in the recent paper.

In other words, though more ROS were produced, ARB did not strongly attach to the microspheres. So, when the ARB degraded, the resulting ARGs spread into the environment rather than degrading as well.

To fix this problem, the researchers postulated that doping the reduced graphene oxide with nitrogen may improve ARB adhesion to the microspheres. And that is exactly what they found.

"The NRGO [nitrogen-doped reduced graphene oxide] shell increased the photocatalyst's affinity toward the antibiotic resistant plasmid through π-π stacking and hydrogen-bond interfacial interactions, improving degradation of eARGs [environmental ARGs]," they write in the paper.

In addition, the NRGO shell served as a protective layer for the microspheres, "preventing photocorrosion under irradiation, thereby increasing the photocatalyst's lifetime," they add.

The paper, published in *Water Research*, is "Hierarchical $Bi_2O_2CO_3$ wrapped with modified graphene oxide for adsorption-enhanced photocatalytic inactivation of antibiotic resistant bacteria and resistance genes" (DOI: 10.1016/j.watres.2020.116157). ■

Honoring the ACerS Awards Class of 2020

Over its long history, The American Ceramic Society has established a tradition of awards to recognize its members' outstanding contributions and accomplishments and to create career benchmarks for aspiring young scientists, engineers, and business leaders.

The most prestigious of ACerS awards is Distinguished Life Member designation, a recognition bestowed upon only two or three members each year. In 2020, three individuals will receive DLM honors: Richard Brow, Alexandra Navrotsky, and Mrityunjay Singh.

The Society will elevate 23 members to Fellow and recognize many more outstanding members with various Society, Division, and Class awards will honor the awardees during a virtual celebration on Oct. 5, 2020.

2020 DISTINGUISHED LIFE MEMBERS

Richard Brow

As a high school senior growing up in upstate New York, Richard Brow thought he would become an attorney. But plans changed after he was accepted to Alfred University.

A solid performance on an entrance exam to Alfred University led to a small scholarship, and because he liked math, he settled on being a math major. However, his father noticed that enrollment in the New York State College of Ceramics at Alfred University would allow them to pay in-state, public university tuition rather than private tuition. So he convinced his son to enroll as a double major in mathematics and ceramic engineering.

It was an excellent plan until Brow took "mud lab" in his freshman year.

"It was so much fun and so interesting that the math thing went out the door, and my 'accidental' ceramic engineering career started," says Brow. He credits professors William Lacourse at AU and Helmut Schaeffer at University of Erlangen (Germany) with introducing him to the mysteries of glass, and he has been a self-described "glass geek" ever since.

Unable to find a job during the recession of the early 1980s, Brow enrolled at Penn State, where he earned a Ph.D. From there he went to work at Sandia National Laboratory for 12 years.

"That was really where I got involved in The American Ceramic Society and started building up my network of colleagues," Brow says.

There was no plan to become an academic, but he got to know professor Delbert Day (also a DLM) when Day spent a sabbatical year in Brow's lab at Sandia. One thing led to another, and eventually Brow joined Day on the faculty at Missouri University of Science & Technology, where he is now Curator's Professor of Ceramic Engineering.

The surprise was to discover how satisfying the role is.

"It's fun. It's fun working with students. ...What I know is new to them. And then they help me find something new, show me things that are new to me," he says

The Society provided Brow a professional entrée to the industry very early in his career. His first talk was at the Glass Division meeting in Bedford Springs in Pennsylvania, and his first publication appeared in the *Journal of the American Ceramic Society*. At the suggestion of professor Joseph Simmons, Brow volunteered to be part of the conference program organizing committee.

By volunteering to plan a meeting, "you had the opportunity to invite the people you wanted to meet," says Brow. "It was just a marvelous opportunity to meet people. You never know who's going to give you that idea or that opportunity on which you can build your own career."

Brow has served the Society in various capacities, including the Board of Directors and Society president. During his presidency, he helped found the Ceramic and Glass Industry Foundation.

What drives his volunteering? Nothing fancy, it turns out.

"I wanted to talk to people. I wanted meet people. I wanted to share ideas and pick their brain. That's how all that started for me," he says. But, over the years, the character of the relationships changed.

"The great value [of the Society] is being part of a community. At some point you stop talking about non-bridging oxygens and start talking about your kids going off to college. These people have always been there, and maybe that's the most valuable thing I've gotten out of The American Ceramic Society. Now much more than colleagues, they are friends," he says

"It's an accidental career! It just started because I was interested in glass and wanted to talk to people with a similar interest."

Alexandra Navrotsky

Many students enter their first thermodynamics course reluctantly, finding the topic dense and a bit obscure. Alexandra Navrotsky, however, had quite a different take.

"Everybody was saying how hard it is [thermodynamics]. I said, 'Hard? It's just tremendously logical,'" Navrotsky says.

Navrotsky originally entered the University of Chicago thinking she would become an organic chemist. However, after sitting in on a graduate-level physical organic chemistry course that discussed using isotopes and isotope effects to study organic reactions, "the stuff seemed so logical that about three weeks into the ten-week course, I registered for it," she says.

Navrotsky continued on to earn her B.S., M.S., and Ph.D. in physical chemistry from UChicago. By that point she knew she wanted to be a faculty member, and so she pursued postdoctoral work in Germany and at The Pennsylvania State University before joining the faculty in chemistry at Arizona State University in 1969.

Over the course of her career, Navrotsky moved several times, to Princeton University in 1985 and then the University of California, Davis, in 1997. In 2019, she returned to Arizona State to lead the new Navrotsky Eyring Center for Materials of the Universe, which brings together researchers in an interdisciplinary collaboration to study materials and their applications from theoretical, computational, observational, and experimental approaches. Through these experiences, she conducted enough research to publish more than 900 scientific papers, and she developed, applied, and commercialized numerous unique high temperature calorimetric techniques and instruments.

Navrotsky became involved with ACerS during her initial time at Arizona State when she submitted a paper to one of the ACerS meetings. The research concerned the thermodynamics behind color changes in transition metal oxides, but instead of being placed in the basic science section, Navrotsky's talk was assigned to the whitewares section.

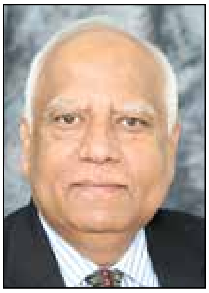
"Here I was, under 30 years old, giving a talk to a bunch of people who build bathtubs and toilets, the majority of whom were males in their late 50s," she says. "It was a funny talk because they couldn't care less about the basic science, and I couldn't care less about their products."

Navrotsky later joined ACerS Basic Science Division and over the years received numerous Society awards, including Ross Coffin Purdy Award (1995), Nuclear & Technology Division Best Paper Award (2001), Spriggs Phase Equilibria Award (2005), and the W. David Kingery Award (2016). In 2018, she helped establish a new award, the Navrotsky Award for Experimental Thermodynamics of Solids, which was awarded for the first time in 2019.

Navrotsky says what she likes about ACerS is that it is a relatively small society. "Some of the other societies ... have gotten so huge that they've all but lost any sort of personal touch, but ACerS still has that" she says.

"I've certainly very much enjoyed my connections to ACerS and the meetings, and I'm honored by all of the honors that ACerS has given me, including the Distinguished Life Member," she says.

Mrityunjay Singh



As a child growing up in India, 500 miles south of New Delhi, Mrityunjay (Jay) Singh lived in a rural village that lacked heat and where the modern comforts of electricity only arrived when he was a teenager.

Working on the family farm, Singh showed an aptitude for science and eventually earned a master's of science in physical chemistry from Gorakhpur University in Gorakhpur, India, in 1980, and went on to earn a Ph.D. in metallurgical engineering from the Indian Institute of Technology at Banaras Hindu University in 1983.

That education launched a career in the research of high-temperature materials and ceramics that included work with the world's leading space agency, technology used by some of the world's largest corporations, and collaborations with universities and laboratories around the globe.

After postdoctoral work at Louisiana State University and Rensselaer Polytechnic Institute, he went to work in 1991 at the NASA Lewis Research Center, now the NASA Glenn Research Center, working on the development of affordable, fiber-reinforced ceramic matrix composites. It was there one of his most memorable professional achievements occurred.

After the tragic accident of the space shuttle Columbia in February 2003, NASA was looking for ways to repair the reinforced carbon-carbon components of the shuttle's thermal protection system. Singh and his group developed a refractory adhesive for on-orbit repair of damaged components, a first-of-a-kind material that could survive more than 1,650°C plasma temperatures. The space shuttle program returned to flight in July 2005.

He is currently chief scientist at the Ohio Aerospace Institute in Cleveland.

Singh's membership in the Society dates to the 1980s, when literature searches for his postdoctoral work led him to the *Journal of the American Ceramic Society*. He first volunteered with the Society in 1996 as a member of the Engineering Ceramics Division Awards Committee.

His many professional volunteer activities include serving as president of The American Ceramic Society in 2015–2016.

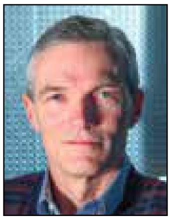
As president, Singh worked to strengthen the Society's relationships with corporations and its outreach to international members and professional organizations.

"This is a truly global Society," he said. "So we have to have members from all over the world being recognized."

He also focused on fostering relationships with the volunteers who offer their time and expertise to the Society. He helped start recognition programs such as the Global Ambassador award to recognize them. "That's the key," he said. "Volunteer recruitment, retention, and recognition—those three factors are so important."

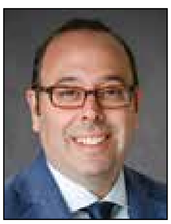
His leadership and involvement in the Society's mission has been a way for him to give back. "Professionally, being involved in the Society and having a role getting new programs started, trying to mentor young people, getting students supported, as well as young professionals and even senior professionals, has been gratifying," he said. ■

The 2020 Class of Fellows



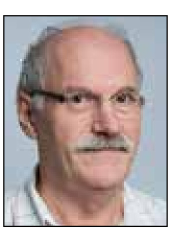
Barnett

Scott Barnett is professor of materials science and engineering at Northwestern University in Evanston, Ill. He received his Ph.D. in metallurgy from the University of Illinois at Urbana-Champaign. He has served on the Program Committee of the International Symposium on Solid Oxide Cells: Materials, Science and Technology, at the annual ICACC meeting.



Brinkman

Kyle Brinkman is chair of the Department of Materials Science and Engineering at Clemson University in Clemson, S.C. Brinkman received his Ph.D. in materials science from the Swiss Federal Institute of Technology in Lausanne, Switzerland. Brinkman is vice chair of the Energy Materials and Systems Division of ACerS, and was vice chair and secretary of the dissolved Nuclear and Environmental Technology Division.



Calas

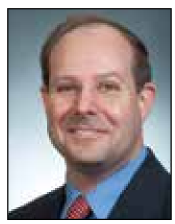
Georges Calas is professor (emeritus) of mineralogy at Sorbonne Université (Paris) and senior member of the University Institute of France. He received a Science Doctorate in mineralogy from the University of Paris. Calas is associate editor of the *Journal of the American Ceramic Society*.

Du

Jincheng Du is professor of materials science and engineering at the University of North Texas in Denton, Texas. He received his Ph.D. in ceramics from Alfred University. Du is the current chair of the Glass & Optical Materials Division and previously served as secretary, vice chair, and chair-elect. Du is currently an editor of the *Journal of the American Ceramic Society*.

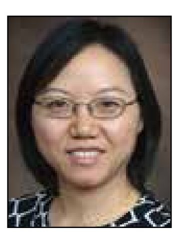
Feeser

Richard Feeser is President Emeritus of Superior Technical Ceramics in St. Albans, Vt. Freeser earned his B.S. in ceramic engineering from Virginia Polytechnic Institute. Freeser was a founding trustee of the Ceramic & Glass Industry Foundation of the Society when it formed in 2014, and served as chair from 2018–2019.



Halbig

Michael C. Halbig is senior materials research engineer and tech lead for Additive Manufacturing / Joining & Integration of Composite Materials at the NASA Glenn Research Center in Cleveland, Ohio. He has an M.S. in materials science and engineering from Case Western Reserve University. Halbig is associate editor for the *International Journal of Applied Ceramic Technology* and current trustee and past chair of the Engineering Ceramics Division. Halbig has served on several Society- and Division-level committees.



Huang

Liping Huang is professor of materials science and engineering and associate dean for Research and Graduate Programs in the School of Engineering at Rensselaer Polytechnic Institute in Troy, N.Y. She obtained her Ph.D. from the University of Illinois at Urbana-Champaign. She served as the secretary, vice chair, chair-elect, and chair of ACerS Glass & Optical Materials Division in 2015–2019. She is currently an associate editor of *International Journal of Ceramic Engineering & Science* and an editor of *Journal of Non-Crystalline Solids*.

Frances Mazze Hurwitz is senior materials research engineer at NASA Glenn Research Center in Cleveland, Ohio. She has a Ph.D. in macromolecular science from Case Western Reserve University. Hurwitz is a member of ACerS Engineering Ceramics and Basic Science Divisions, has served as an organizer of the Thermal Protection Materials Symposia, and has chaired numerous sessions at ACerS conferences.

Hurwitz

Jackson

Marie Jackson is research associate professor in the Department of Geology and Geophysics at the University of Utah in Salt Lake City, Utah. She received a Ph.D. in earth sciences from Johns Hopkins University. Jackson is currently secretary of the Art, Archaeology and Conservation Science Division.

Jung

Steven Jung is chief technology officer of the specialty glass and ceramics company Mo-Sci Corporation in Rolla, Mo., and adjunct professor of material science and engineering at Missouri University of Science and Technology. Jung earned a Ph.D. in materials science and engineering from Missouri S&T. He was the founding chair of the newly formed Bioceramics Division and on the leadership team for the Manufacturing Division.

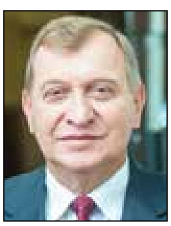
Lambert

Matthew Lambert is manager of special projects for Allied Mineral Products in Columbus, Ohio. He graduated from The Ohio State University with a B.S. in ceramic engineering and a M.S. in materials science. He is a member and former chair of the Refractory Ceramics Division and currently the treasurer of ACerS Central Ohio Section. He is also active in the UNITECR 2021 planning committee and a peer reviewer for the *International Journal of Ceramic Engineering & Science*.

The 2020 Class of Fellows (continued)

Li

Jing-Feng Li is Changjiang Scholar Distinguished professor at the School of Materials Science and Engineering at Tsinghua University in Beijing, China, and serves as deputy director of the Tsinghua University-Toyota Research Center. He received a Ph.D. in materials science and engineering from Tohoku University in Japan. He has received several awards, from the Japan Institute of Metals, the Chinese Ceramic Society, the National Natural Science Foundation of China, and the *Journal of the American Ceramic Society* Loyalty Award.

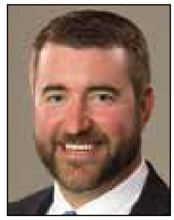


Lis

Jerzy Lis is vice rector and professor of materials science and chemical technology at AGH University of Science and Technology in Krakow, Poland. Lis received his Ph.D. and D. Sci. at AGH UST. Lis' accomplishments include the "Building Bridge Award" of the Engineering Ceramics Division (2019), head of the Nomination Committee of the ACerS Spriggs Phase Equilibria Award, invited speaker of many ACerS organized conferences and other ceramic symposia, and reviewer for the *Journal of the American Ceramic Society*.

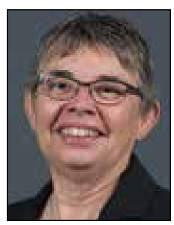
Maria

Jon-Paul Maria is professor of materials science and engineering at The Pennsylvania State University and professor emeritus at North Carolina State University, where he spent 15 years serving on the materials science and engineering faculty. He received his Ph.D. from Penn State in ceramic science. Maria's research group, J.-P. Maria Group, pursues new materials discovery, property engineering, advances in synthesis science, and new integration strategies to merge diverse materials.



Pelletier

Josh Pelletier is North American Sales Manager for Refractory Producers at Imerys. He received his B.S. in ceramic and materials engineering and M.B.A in international business from Clemson University. Pelletier has served as chair of the Refractory Ceramics Division and is a champion for student outreach, partnering with RCD and PCSA for STEM demo kits and volunteering at Materials Camp. Pelletier currently serves on ACerS Committee on Society Awards and the Committee on Meetings and Programs.



Reidmeyer

Mary R. Reidmeyer is teaching professor emeritus at the Missouri University of Science and Technology in Rolla, Mo. Reidmeyer received her Ph.D. from the University of Missouri-Rolla studying technical glasses after working in the refractories industry. Reidmeyer has been recognized by Missouri S&T with several honors and awards for teaching and service. She remains active with ACerS St. Louis Section, where she served as an officer for two rotations. In 2019, she received the Greaves-Walker Lifetime Service Award.

Seal

Sudipta Seal is University Distinguished Professor, Trustee Chair, and UCF Pegasus Professor at the University of Central Florida. He joined UCF after postdoctoral work at Lawrence Berkeley National Laboratory and the University of California, Berkeley. At UCF, he pioneered nanostructured cerium oxide and other metal/oxide ceramic (micro to nano), discovered its antioxidant properties, and applied it in various biomedical problems. Seal received the 2002 Office of Naval Research Young Investigator Award.

Subhash

Ghatu Subhash is the Newton C. Ebaugh Professor and UF Research Foundation Professor of Mechanical and Aerospace Engineering at University of Florida in Gainesville, Fla. He obtained his M.S. and Ph.D. degrees from the University of California, San Diego, and conducted post-doctoral research at the California Institute of Technology. Subhash is editor-in-chief of *Mechanics of Materials* and served as associate editor for the *Journal of the American Ceramic Society*. He is associated with the Engineering Ceramics Division and is a member of the Organizing Committee on Armor Ceramics at ICACC.

Swab

Jeffrey J. Swab is senior ceramic engineer and team leader with the U.S. Army Research Laboratory at Aberdeen Proving Grounds, Md. He received his Ph.D. in materials science and engineering from the State University of New York–Stony Brook. Swab is a member of the Engineering Ceramics Division and the Glass & Optical Materials Division. He is one of the original architects and lead organizers of the Armor Ceramics Symposium held in conjunction with ICACC meetings. In 2011, he received the ECD Global Star award.

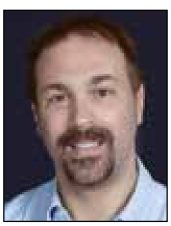
Tan

Xiaoli Tan is professor of materials science and engineering at Iowa State University in Ames, Iowa. He received his Ph.D. in materials science and engineering from University of Illinois at Urbana-Champaign. Tan is a committee member of the Electronics Division and has co-organized nine symposia at MS&T and EMA meetings, and serves as an associate editor for the *Journal of the American Ceramic Society*.

Society Awards

Tatami

Junichi Tatami is professor in the Graduate School of Environment and Information Sciences at Yokohama National University in Japan. He received a Ph.D. in science and engineering of ceramics from Tokyo Institute of Technology in Japan. Tatami is a member of the Engineering Ceramics Division and has received numerous awards, including ACerS Richard M. Fulrath Award and Global Star Award. He organized symposia at many international conferences, including MS&T, ICACC, PACRIM, HTCMC, GFMAT, and CMCEE.



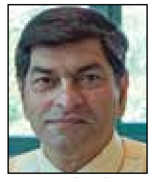
Ubic

Rick Ubic is professor at Boise State University in the Micron School of Materials Science & Engineering. He earned his Ph.D. in engineering materials from Sheffield University in the U.K. Ubic received the ACerS 2003 Edward C. Henry Best Paper Award and the 2004 Robert L. Coble Award for Young Scholars. He served as an officer in ACerS Electronics Division from 2014–2019 and as program chair of the EMA meeting in 2017 and 2018. Ubic also serves on the Publications Committee and chaired the Spriggs Phase Equilibria Award Subcommittee.

Wu

Yiquan Wu is professor in the Department of Materials Sciences and Ceramics at New York State College of Ceramics at Alfred University. Wu has a Ph.D. in materials from Imperial College London in the U.K. Wu is a member of ACerS Basic Science Division, Engineering Ceramics Division, and Glass & Optical Materials Division. He served as president of the ACerS Ceramics Education Council and currently serves as the vice chair of ACerS Basic Science Division. He is an editor of the *Journal of the American Ceramic Society* and associate editor of the *International Journal of Ceramic Engineering & Science*. ■

W. DAVID KINGERY AWARD recognizes distinguished lifelong achievements involving multidisplinary and global contributions to ceramic technology, science, education, and art.



Risbud

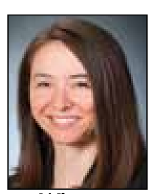
Subhash Risbud is Distinguished Professor of Materials Science and Engineering at the University of California, Davis. He has actively collaborated with colleagues worldwide on projects ranging from photonics-electronics engineering to biotechnology, nanoscience, and computer modeling to environmental effects on human health. Risbud has worked on quantum dots in glasses, sol-gel processing, and structural probes for amorphous solids. His current interests include nanoporous ceramics for energy applications, creation of architected pores in glass and ceramic powders, and the study of fluid flow in through nanochannel tubes formed by spark plasma sintered and electrophoretically deposited ceramic materials.

JOHN JEPPSON AWARD recognizes distinguished scientific, technical, or engineering achievements.

Fu

Zhengyi Fu is a Fellow of ACerS, an academician of the World Academy of Ceramics, and editor-in-chief of *Ceramics International*. His research focuses on multifunctional ceramics and ceramic-based composites, structural/functional integrative composites, novel materials structure and properties, in-situ reaction synthesis and processing, fast and ultrafast sintering, bioprocess-inspired synthesis, and fabrication.

ROBERT L. COBLE AWARD FOR YOUNG SCHOLARS recognizes an outstanding scientist who is conducting research in academia, in industry, or at a government-funded laboratory.



Wiesner

Valerie L. Wiesner is research materials engineer in the Advanced Materials and Processing Branch at NASA Langley Research Center in Hampton, Va. Her current research efforts focus on developing ceramic materials for applications in extreme environments, ranging from hypersonic flight to lunar and planetary surface operations. She serves as chair-elect of ACerS Engineering Ceramics Division and is a member of the Strategic Planning and Emerging Opportunities and Member Services Committees. She has also served as vice chair of the Northeast Ohio Section and chaired the 44th ICACC.

Corporate Environmental Achievement Award

The Corporate Environmental Achievement Award (CEAA) was established to recognize and honor a single outstanding environmental achievement made by an ACerS corporate member in the field of ceramics.

The award recognizes **Central Glass and Ceramics Research Institute (CGCRI) Khurja Centre** (India) for their research and development of glass, ceramic, and related materials that maximize the economic, environmental, and societal benefit to industry.

Central Glass and Ceramics Research Institute also undertakes advanced R&D projects, which are internationally competitive, and public-private partnership projects sponsored by private/public sector enterprises to provide technical advisory and infrastructural services like project engineering, testing and evaluation, training and education, and dissemination of scientific information to the public domain. ■

Society Awards (continued)

ROSS COFFIN PURDY AWARD recognizes authors who made the most valuable contribution to ceramic technical literature in 2018.

Ultrahigh piezoelectricity in ferroelectric ceramics by design

Published in: *Nature Materials* 2018; 17: 349–354

Chen

Long-Qing Chen is the Donald W. Hamer Professor of Materials Science and Engineering, professor of mathematics, and professor of engineering science and mechanics at The Pennsylvania State University, State College, Pa.

Chen

Zibin Chen is research fellow at University of Sydney, New South Wales, Australia.

Cheng

Zhenxiang Cheng is theme leader for the multiferroic materials program and professor at the Institution for Superconducting and Electronic Materials in the Australian Institute for Innovative Materials at University of Wollongong, New South Wales, Australia.

Li

Fei Li is professor at Xi'an Jiaotong University, Shaanxi, China.

Huang

Qianwei Huang is a doctoral candidate in the School of Aerospace, Mechanical and Mechatronic Engineering at the University of Sydney, New South Wales, Australia.

Liao

Xiaozhou Liao is professor in the School of Aerospace, Mechanical and Mechatronic Engineering at the University of Sydney, New South Wales, Australia.

Li

ChunChun Li is associate professor of information science and engineering at Guilin University of Technology, Guangxi, China.

Lin

Dabin Lin is professor at Xi'an Technological University, Shaanxi, China.

Shrout

Thomas R. Shrout is professor emeritus of materials science and engineering at The Pennsylvania State University, State College, Pa.

Wang

Jianli Wang is professor in the College of Physics at Jilin University in Changchun, China, and senior visiting fellow at University of New South Wales Canberra, Australia.

Xu

Zhuo Xu is professor in the School of Electronic Science and Engineering at Xi'an Jiaotong University, Shaanxi, China.

Zhang

Shujun Zhang is professor at the Institution for Superconducting and Electronic Materials in the Australian Institute for Innovative Materials at University of Wollongong, New South Wales, Australia.

RICHARD AND PATRICIA SPRIGGS PHASE EQUILIBRIA AWARD honors authors who made the most valuable contribution to phase stability relationships in ceramic-based systems literature in 2019.

Thermodynamics and crystallization kinetics of REEs in $CaO–SiO_2–Ce_2O_3$ system

Published in: *J Am Ceram Soc.* 2019; 103: 2845–2858

Du

Yu Du is a doctoral candidate at the University of Science and Technology Beijing, China.

Gao

Jintao Gao is an associate professor, at State Key Laboratory of Advanced Metallurgy, University of Science and Technology Beijing, China.

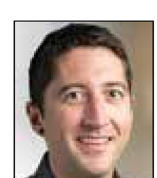
Guo

Zhancheng Guo is director of State Key Laboratory of Advanced Metallurgy, University of Science and Technology Beijing, China.

Lan

Xi Lan is a doctoral candidate in the State Key Laboratory of Advanced Metallurgy at the University of Science and Technology Beijing, China.

MORGAN MEDAL AND GLOBAL DISTINGUISHED DOCTORAL DISSERTATION AWARD recognizes a distinguished doctoral dissertation in the ceramics and glass discipline.



Talley

Kevin R. Talley is post-doctoral researcher at the National Renewable Energy Laboratory in Golden, Co. His main research is the search for new or improved piezoelectric and ferroelectric nitride ceramics, but he is also working to advancing thin-film nitride synthesis processes and to apply data tools to combinatorial experimentation.

MEDAL FOR LEADERSHIP IN THE ADVANCEMENT OF CERAMIC TECHNOLOGY

MEDAL FOR LEADERSHIP IN THE ADVANCEMENT OF CERAMIC TECHNOLOGY recognizes individuals who have made substantial contributions to the success of their organization and expanded the frontiers of the ceramics industry through leadership.

Swartz

Scott L. Swartz is chief technology officer and co-founder of Nexceris in Lewis Center, Ohio. He was principal investigator on multiple Nexceris projects related to sensors, catalysts, and solid oxide fuel cells. He manages Nexceris projects related to SOFC technology development, leads government business development activities, manages the growth of Nexceris' intellectual property portfolio, and provides technical leadership and vision to the company. He organized a symposium on Advances in Solid Oxide Fuel Cell Technology at MS&T 2018.

Zhang

Long Zhang, is professor of materials sciences at the Chinese Academy of Sciences (CAS), deputy director, Shanghai Institute of Optics and Fine Mechanics (CAS), and Head, Key Lab. of Materials for High-Power Laser (CAS).

DU-CO CERAMICS YOUNG PROFESSIONAL AWARD

DU-CO CERAMICS YOUNG PROFESSIONAL AWARD is given to a young professional member of ACerS who demonstrates exceptional leadership and service to ACerS.

Wiesner

Valerie L. Wiesner is research materials engineer in the Advanced Materials and Processing Branch at NASA Langley Research Center in Hampton, Va. She serves as chair-elect of ACerS Engineering Ceramics Division and is a member of the Strategic Planning and Emerging Opportunities and Member Services Committees. She also served as vice chair of the Northeast Ohio Section and chaired the 44th ICACC. ■

RISHI RAJ MEDAL FOR INNOVATION AND COMMERCIALIZATION

RISHI RAJ MEDAL FOR INNOVATION AND COMMERCIALIZATION is awarded annually to recognize one individual whose innovation lies at the cusp of commercialization in a field related, at least in part, to ceramics and glass.

Beall

George Beall is a Corporate Fellow in Corning's Research Group. He received a Ph.D. at the Massachusetts Institute of Technology in 1962. Beall has worked on a variety of successful innovations including the discovery of glass-ceramic materials used in Corning products such as Macor® machineable glass-ceramics, Pyroceram® commercial tableware, and Visions® cookware and environmental products. ■

ECERS-ACERS JOINT AWARD

The European Ceramic Society-American Ceramic Society Joint Award recognizes individuals who foster international cooperation between The American Ceramic Society and the European Ceramic Society, in demonstration of both organizations' commitment to work together to better serve the international ceramics community..

Leriche

Anne Leriche is professor at Polytechnic University Hauts-de-France, and she was director of Laboratoire des Matériaux Céramiques et Procédés Associés (LMCPA) from 1999 to 2016. The research carried out by the laboratory focuses mainly on bioceramics for bone substitutes, piezoelectric ceramics, and functionalized coatings by sol-gel and hydrothermal methods. She has served as board member of the Belgian Ceramic Society, president of the French Ceramic Society (nine years), president of the European Ceramic Society (two years), and president of the JECS Trust (three years). During her ECerS presidency, she initiated contacts with ACerS (which were finalized by the signing of a MOU) and she contributed to setting up the January Winter Workshop. ■

Corporate Technical Achievement Award

The Corporate Technical Achievement award recognizes a single outstanding technical achievement made by an ACerS corporate member in the field of ceramics.

CORNING

The award recognizes **Corning Incorporated** for the development of Corning® DuraTrap® GC filters.

DuraTrap GC filters, which have a unique microstructure and are made from cordierite, a magnesium aluminosilicate, are Corning's newest automotive exhaust filters. These filters trap microscopic particles of exhaust-borne carbon soot and ash, ranging in size from about 10 nanometers to several hundred nanometers.

The introduction of particulate filters in gasoline vehicles is an important engineering advancement for clean-vehicle technology as gasoline vehicles grow in popularity. Corning will continue to leverage its expertise in ceramic science and extrusion manufacturing technology to develop market-leading emissions control solutions that help their customers meet future emission standards and enable cleaner air worldwide. ■

Class Awards

ACerS/EPDC ARTHUR FREDERICK GREAVES-WALKER LIFETIME SERVICE AWARD recognizes an individual who has rendered outstanding service to the ceramic engineering profession and who, by life and career, has exemplified the aims, ideals, and purpose of the former National Institute of Ceramic Engineers.


Richardson

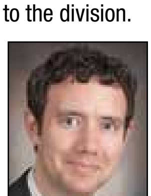
Kathleen A. Richardson is Pegasus Professor of Optics and Materials Science and Engineering and Florida Photonics Center of Excellence (FPCE) Professor at CREOL/College of Optics and Photonics at the University of Central Florida, where she runs the Glass Processing and Characterization Laboratory.

EPDC OUTSTANDING EDUCATOR AWARD recognizes truly outstanding work and creativity in teaching, directing student research, or general educational process of ceramic educators.


Quinn

George D. Quinn is guest researcher at the National Institute of Standards and Technology in Gaithersburg, Md. He received a B.S. in mechanical engineering from Northeastern University. Quinn is a member of ACerS Basic Science Division and became a Fellow in 2001. He received the Global Ambassador Award in 2020. He has been teaching the short course on Mechanical Properties of Ceramics and Glasses since 2011. ■

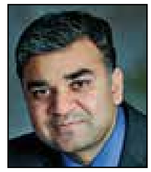
ENERGY MATERIALS AND SYSTEMS DIVISION D.T. RANKIN AWARD in memory of Tom Rankin recognizes a member of the former Nuclear & Environmental Technology Division who has demonstrated exemplary service to the division.


Fox

Kevin M. Fox is principal engineer in the Environmental Stewardship Directorate of the Savannah River National Laboratory (SRNL).

Richard M. Fulrath Symposium and Awards

promote technical and personal friendships between Japanese and American ceramic engineers and scientists.


Priya

US Academic
Shashank Priya
Energy harvesting materials and devices

is professor in materials science and engineering at The Pennsylvania State University. His research focuses in the areas related to multifunctional materials, energy harvesting, and bio inspired systems. Priya was lead organizer of the 3rd Annual Energy Harvesting Society Meeting, and he also served on the organizing committee for Materials Challenges in Alternative & Renewable Energy 2020 combined with the 4th Annual Energy Harvesting Society Meeting. He is past chair of ACerS Electronics Division and a member of the ACerS Energy Task Force. Priya was associate editor of the *Journal of the American Ceramic Society* from 2010–2012.


Gorzkowski

US Industrial
Edward Gorzkowski
Bulk nanostructured ceramics using novel processing techniques

is branch head (acting) of the Multifunctional Materials Branch at the U.S. Naval Research Laboratory in Washington, D.C. His research interests include piezoelectric materials for sensor and actuator applications; processing of dielectric and ferroelectric materials; unique processing methods to create bulk nanostructured ceramics; and structural applications such as hypersonics, thermal barrier coatings, and magnetic/dielectric devices. Gorzkowski is a member of ACerS Electronics (secretary elect), Basic Science, and Engineering Ceramics Divisions as well as a founding member and co-chair of the Washington, D.C., Maryland, and Northern Virginia Section. He is also on the ACerS Book Subcommittee and received the 2015 Du-Co Young Professionals Award and a 2018 Best Paper award for the *Journal of the American Ceramic Society*.

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Yamada

Japan Academic
Tomoaki Yamada
Bottom-up growth design and property control for dielectric thin films and nanostructures

is associate professor in the Department of Energy Engineering at the Nagoya University, Japan, and visiting associate professor of the Materials Research Center for Element Strategy at the Tokyo Institute of Technology, Japan. His research group specializes in functional dielectric, piezoelectric, and ferroelectric thin films and nanostructures, especially with a focus on their bottom-up growth design using physical vapor deposition techniques, and their property control. He is a member of ACerS Electronics Division.


Kobayashi

Japan Industrial
Takeshi Kobayashi
Novel design and fabrication of piezoelectric MEMS and their application to IoT

is team leader of the Sensing System Research Center in the National Institute of Advance Industrial Science and Technology, Tsukuba, Japan. His research interests include piezoelectric MEMS and their application to IoT system. Kobayashi developed a 2D-strain mapping MEMS-based ultrathin PZT/Si array sheet for structural health monitoring of bridges. He also developed a piezoelectric MEMS vibration sensor for pump monitoring and chicken health monitoring. He has just started to develop ultrathin piezoelectric MEMS for acoustic and haptics devices.


Sato

Japan Industrial
Hiroshi Sato
Development of co-fired all solid state lithium ion battery with multilayer ceramic technology

is section head of Technology & Intellectual Property HQ at TDK Corporation, Japan. He has been working on co-fired all solid-state lithium ion battery using multilayer technology for 15 years. ■

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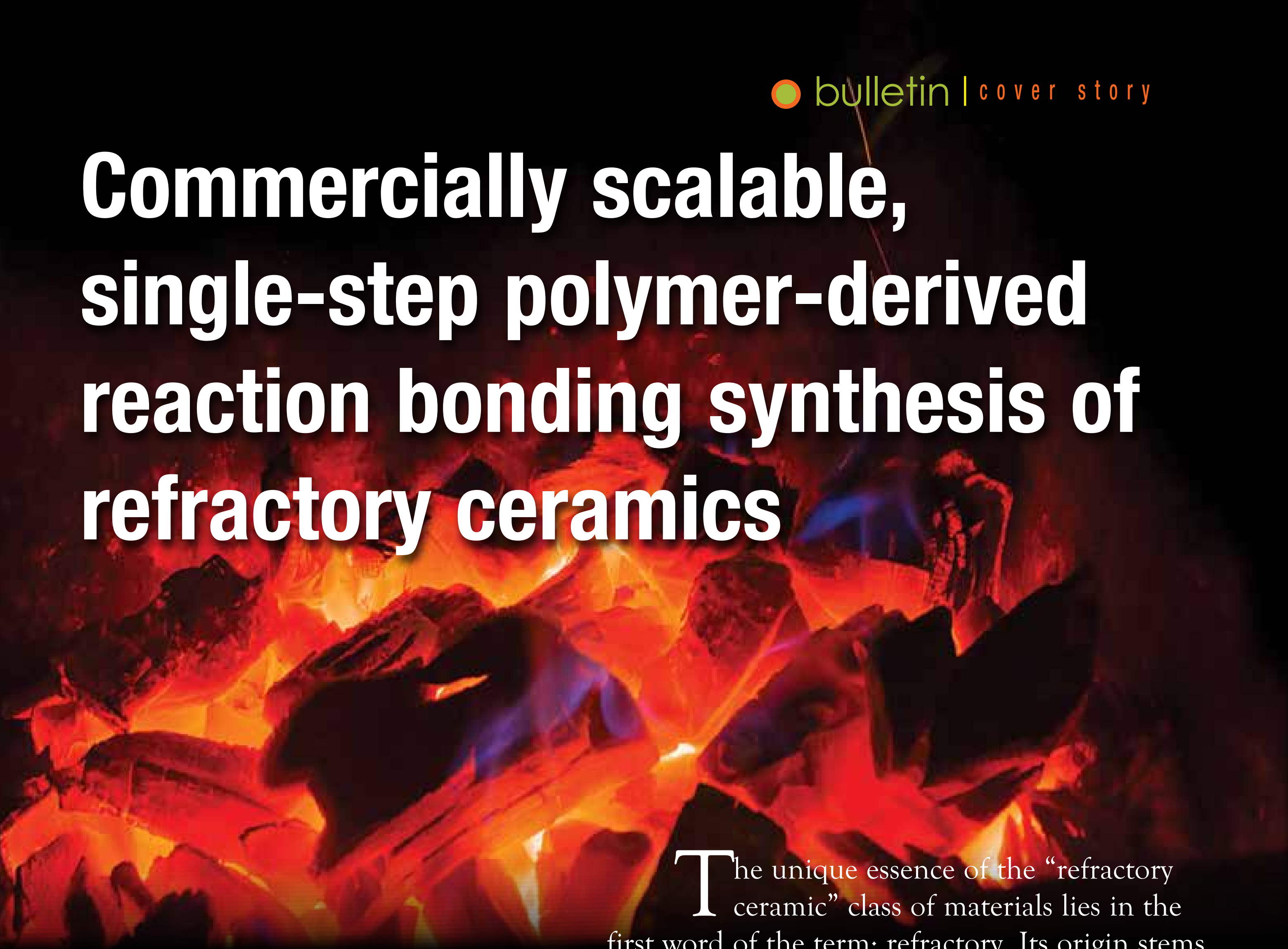


Commercially scalable, single-step polymer-derived reaction bonding synthesis of refractory ceramics

By Boris Dyatkin and Matthew Laskoski

The U.S. Naval Research Laboratory reports on its polymer-derived ceramics synthesis approach, which relies on blends of metals and monomer resins to synthesize near net shape refractory metal carbides, borides, and nitrides using a single-step in situ reaction bonding method.

The unique essence of the "refractory ceramic" class of materials lies in the first word of the term: refractory. Its origin stems from the Latin *refractarius*, which, directly translated, means "stubborn."

This stubbornness most commonly applies to behavior of materials in extreme thermal environments. Refractory ceramics melt at very high temperatures of over 2,500°C.[1] However, these materials often demonstrate stubbornness in multiple categories. They are among the hardest available engineering materials, and they also readily withstand corrosion, whether by caustic chemicals or oxidizing air molecules at elevated temperatures. Many of these "stubborn" materials also readily deflect or absorb ionizing or neutron radiation from nuclear fuels.

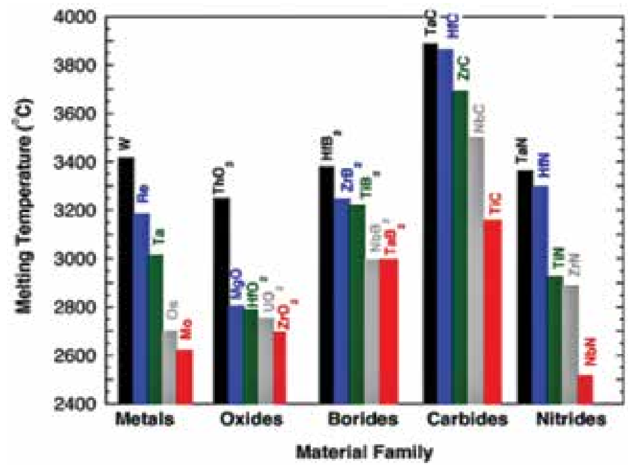
As our technological demands grow, the harsh environments that these ceramics must readily withstand will shift from obscure extremes hypothesized for future generations of applications and into regularly experienced conditions that will require materials engineering solutions. Transoceanic passenger flights that complete their journeys in less than an hour will need engines that withstand supersonic air flows and heats of combustion. Multiple-use space vehicles that ferry astronauts back and forth between Cape Canaveral and the International Space Station will demand heat shields that endure fiery re-entries. Our thirst for rare earth minerals and oil will require deployment of drill bits and cutting tools that—without breaking—pierce miles of Earth's crust. Refractory ceramics stand out as a material solution that demonstrate required performance and endurance in the face of these challenging environments.

Binary, covalently bonded, nonoxide ceramics that incorporate transition metal Group IV and V elements from the periodic table offer the optimal combination of refractory properties. These ceramics include metal carbides, metal borides, metal nitrides, and metal silicides. They have attracted interest since the middle of the 20th century, but their use and development has proceeded intermittently in fits and starts since then.

Their bond strengths ensure that the melting points of these refractory materials fall in the 2,500–3,900°C range (Figure 1). While these ceramics adopt a broad range of cubic, hexagonal, and rhombohedral structures, their close-packed lattices ensure these materials maintain excellent strength and hardness of well over 200 GPa. Absence of weakly bonded oxygen in these materials also strengthens the materials' resistance to oxidation. Finally, the covalent nature of bonding behavior in many of these ceramic polymorphs facilitates electronically conductive behavior and even thermoelectric properties.[2]

Although such a wide array of useful properties in such a broad material family is incredibly attractive, several important roadblocks have, to date, precluded their implementation in many perfectly suited engineering systems. Economic and efficient manufacturing stands as the biggest challenge these materials face. Metal carbide powders, for example, are produced via carbothermal reduction of metal oxides and graphite at over 2,000°C. Subsequently, hot pressure sintering compacts those powders into dense monoliths—again, at 2,000°C—and while under over 1 GPa applied pressure. These compaction systems require significant energy inputs to operate, are unwieldy and unsafe, and cannot handle high throughput capabilities. Moreover, weeks of tooling often follows the sintering process in order to carve compacted formless monoliths into engineering parts with precise geometries and sharp angles.

Recent insights into spark plasma sintering have implemented pulsed electric current through ceramic greenbodies to efficiently and rapidly compact them into ceramics.[3] These approaches reduce lead times, yet remain at a small scale: to date, they cannot produce vehicle-scale heat shields or engine cowls. Polymer-derived approaches, which compact metalorganic molecules into desired shapes and carbonize and pyrolyze them into ceramics, can yield ceramics at much lower temperatures (1,000–1,400°C).[4] However, available chemistries primarily limit this pathway to polysilanes (or similar molecules) that can only yield silicon-based ceramics (e.g., SiC, Si_3N_4, SiO_2). If other ceramics, such as titanium- or hafnium-based refractory composites are desired, silica formers, metal salts or oxides, and copolymers with oxygen groups must be included in the preceramic blend. All of these pathways embed chemical impurities in the resulting ceramic composite and inhibit their mechanical and thermal properties.



Credit: Fahrenholtz, W.G., Hilmas, G.E., Talmy, I. G. and Zaykoski, J. A. (2007) "Refractory Diborides of Zirconium and Hafnium," *Journal of the American Ceramic Society*, 90: 1347–1364. DOI:10.1111/j.1551-2916.2007.01583.x.

Figure 1. A comparison of the melting temperatures of the most refractory members of several classes of materials. Several borides, carbides, and nitrides have melting temperatures above 3,000°C and are considered ultrahigh-temperature ceramics.

High-char resin: Key to novel polymer-derived refractory ceramics

In 1993, the United States Naval Research Laboratory (NRL) leveraged its longtime research into phthalonitriles, which are thermosets that cure at low temperatures and remain thermally stable at high temperatures,[5] to develop a novel acetylenic monomer resin.[6]

This thermoset is 1,2,4,5 tetrakis(phenylethynyl)benzene ("TPEB"), which is a meltable aromatic polymer that contains solely carbon and hydrogen atoms: $C_{38}H_{22}$. While it is a powder in a neat stage and melts in the 170–200°C range, this resin rapidly cures at 225–250°C and increases its viscosity from about 0.15 Pa·s to over 250,000 Pa·s. Furthermore, as it is heated to over 700°C, TPEB chars but retains a very high carbon yield of over 85%.[7] This polymer has, subsequently, become the carbon source and key functional ingredient in a novel polymer-derived ceramic process.[8]

NRL's ceramics fabrication approach (shown in Figure 2) blends together this resin with powders of metals or metal hydrides to yield the two-component homogeneous powder. The subsequent process step then compacts this preceramic into a desired preceramic greenbody shape. This step requires a conventional hand-powered hydraulic Carver press and applied loads of 130 MPa or less.

Depending on the application demands, a broad variety of die configurations—e.g., discs, panels, spheres, cones—guide the form factors and geometries of resulting shapes. NRL has synthesized samples as small as 6 mm diameter discs that were 1 mm thick and as large as 15 cm by 15 cm panels that were over 10 mm thick. The process elastically scales with requested dimensions and is viable for production of even larger components. On the flipside, if the processing requires a powder product, this approach delivers the microscale ceramic powders as well.

In the next step of processing, the greenbodies are placed in a tube or box furnace with flowing inert (argon) gas and are heated up to 1,400–1,500°C. As the TPEB resin cures at 250°C, its exceptionally high viscosity firmly locks and embeds the metal particles in a cross-linked rigid carbon matrix. Subsequently, unlike other polymer-derived processes that rely on thermoplastic carbon sources, no material phase separation or flow occurs in these greenbodies.

As the material transitions through the 600–750°C thermal processing range, polymer charring removes hydrogens and volatile hydrocarbons from the

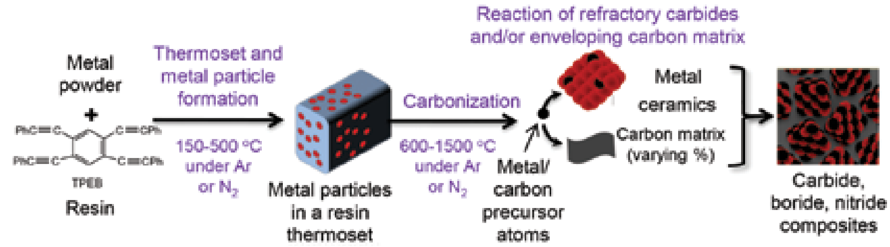


Image credit: Boris Dyatkin and Matthew Laskoski

Figure 2. Schematic of polymer-derived ceramics synthesis process that implements TPEB resin with a high char yield in a low-temperature, pressureless synthesis route to deliver metal carbides, metal nitrides, and metal borides.

material matrix. Owing to the strong triple bonds in the acetylenic TPEB material, the resin retains a larger mass fraction of its carbon than comparable thermosets during the char process. This carbon, subsequently, reaction bonds with the metals in the 1,000–1,500°C temperature range to form metal carbides. To date, NRL has used it to synthesize titanium carbide (TiC),[9] silicon carbide (SiC),[10] tantalum carbide (TaC),[11] and tungsten carbide (WC).[12] However, practically any transition metal can be incorporated into this process to yield a corresponding metal carbide.[8]

This single-step polymer-derived ceramics process offers several important fundamental advantages. Most importantly, both the cost and processing time are significantly lower than comparable refractory carbide manufacturing techniques; the procedure does not require high temperature sintering and completes end-to-end manufacture in less than 48 hours. The material ingredients are cheap and readily accessible. Metal powders can remain in the micron size and do not require extensive chemical purification, surface treatment, or cleaning prior to use. The polymer precursor can be readily synthesized in large quantities in conventional industrial processing centers. The precursor blending process uses a ball mill, but it does not require excessive grinding and can upscale for simultaneous blending of pounds of preceramic powders. The temperature that facilitates this reaction bonding is 600 degrees lower than that employed in conventional methods and can produce over 75% in energy cost savings.

The reaction bonding process that nucleates metal ceramics from blends of metal atoms and carbons is a rapid kinetic process that has neither a high activation barrier nor a self-igniting exothermic runaway step. The initial preceramics (Figure 3A) convert to the fully densified refractory monoliths (Figure 3B) in a near net shape process. The reaction bonding step negligibly shrinks the solids (< 8% volumetric decrease) and retains the geometric features, such as sharp edges, that had been preset in the greenbodies. The material surface morphology (Figure 3C) shows a homogeneous structure without phase separation or microscale cracking. Leftover free carbon homogenously disperses throughout the ceramic matrix and does not agglomerate into macroscale, structurally weak aggregate phases.

Low temperature processing offers another vital benefit that eludes conventionally sintered ceramics. While high-temperature compaction facilitates densification kinetics and accelerates pore closure in greenbodies, the same processes coarsen crystalline grains of ceramics.[13] Owing to the Hall-Petch effect, resulting dense ceramic monoliths with macroscale grains lose their hardness and strength advantages and become extremely brittle.[14] Moreover, pressureless densification of some ceramics, such as boron carbide (B_4C), decomposes the ceramic structure into weak constituents above 2,100°C.[15] Low-temperature nucleation of metal ceramic grains from reaction bonded metal and carbon atoms yield nanocrystallites that are narrower than 100 nm across with tight distributions. Moreover, the free carbon polymer byproducts further inhibit grain coarsening.[16]

Image credit: Boris Dyatkin and Matthew Laskoski

Figure 3. (A) Photograph of a 40 mm diameter preceramic greenbody of boron and TPEB. (B) Photograph of aforementioned greenbody following its conversion into a B_4C monolith at 1,450°C. (C) Electron microscopy analysis of the surface morphology of the B_4C ceramic surface.

Versatile routes to novel refractory ceramic nanostructures

Metal carbides are the most intuitive product of the polymer-derived route that reaction bonds metals with the carbon char of the TPEB resin. However, this approach facilitates the formation of other metal ceramics and multiceramic compositions.

Slight modification to the process that yields nanocrystalline titanium carbide (X-ray diffraction data shown in Figure 4A) converts the resulting product into nanocrystalline titanium nitride (TiN). Introduction of nitrogen-rich functional groups into the TPEB structure and execution of the high-temperature synthesis step under flowing nitrogen (N_2) gas (as opposed to argon) yields this refractory ceramic (Figure 4B). Moreover, use of the original, carbon-rich TPEB polymer and N_2 gas delivers a core-shell structure; the resulting ceramic monoliths demonstrate a rigid carbide core and a homogeneous nitride shell that envelops it. NRL has implemented this approach to synthesize niobium carbide/nitride composites (Figure 4C). The interface between the two ceramics is strain-free and seamlessly transitions from one refractory material into another.

The viscous nature of the post-cured TPEB thermoset enables it to function as a binder in an approach that produces a different class of refractory metal ceramics. Preceramic mixtures that include a transition metal, such as zirconium or titanium, blended with boron metal and a small fraction of TPEB yield metal boride monoliths. Zirconium boride (ZrB/ZrB_2) (shown in Figure 4D) or titanium diboride (TiB_2) are examples of these products. In this pathway, the small mass fraction of TPEB embeds the homogeneous blend of boron and the transition metal particles in close physical contact (to ensure high yield), retains the preceramic near net shape, and forms the free carbon matrix in the formed ceramic (to control grain growth).

Thermal, electronic, and mechanical properties

In addition to low cost and a high degree of customization of synthesis products and resulting material chemistry, the polymer-derived refractory process delivers ceramic composites with different fundamental properties. Subsequently, different refractory carbides, nitrides, or borides can address different technology demands and offer a broad range of breakthrough performances in diverse applications.

To date, engineering studies have evaluated the oxidative stabilities of polymer-derived metal carbides in high-temperature environments, assessed their electronic and superconductive capabilities, and evaluated the influence of their composite structure on their mechanical strength.

One of the hallmark features of refractory carbides are their thermal stabilities and resistance to oxidation at high temperatures. Several polymer-derived ceramics, including titanium carbide (Figure 5A) and silicon carbide (Figure 5B), were heated up to 1,300°C under flowing air in a TGA experiment to assess their performance.

Both TiC and SiC remain stable up to approximately 400°C. Above that temperature, they undergo an exothermic process that peaks at 635°C. Between 400°C and 700°C, due to oxidation of the free carbon and differences in the ceramic structure, TiC loses 0.5% of its mass while SiC loses 8.5% weight percent. Although TiC increases its mass by 21 wt.% during its high-temperature oxidation, no further material erosion of SiC occurs between 700°C and 1,000°C. Further heating up to 1,300°C yields a very slow uptake of weight (~3.5%), which suggests oxidation of the SiC on the surface and the formation of a SiO_2 barrier coating. A similar titania coating forms on the surface of the TiC ceramic. Upon cooling and reheating back up to 1,400°C, neither material changes their respective masses. This finding underscores the impenetrability of the resulting barrier coating on each material.

Unlike electronically insulating oxide ceramics, metal carbides have tunable electronic transport properties. Depending on the chemical composition and temperature, metal carbides may perform as semiconductors, exhibit metallic-like conductivity, and even demonstrate superconducting capabilities. Polymer-derived ceramics, which feature customized nanocrystalline grains and free carbon inclusions, equally show a range of these behaviors.

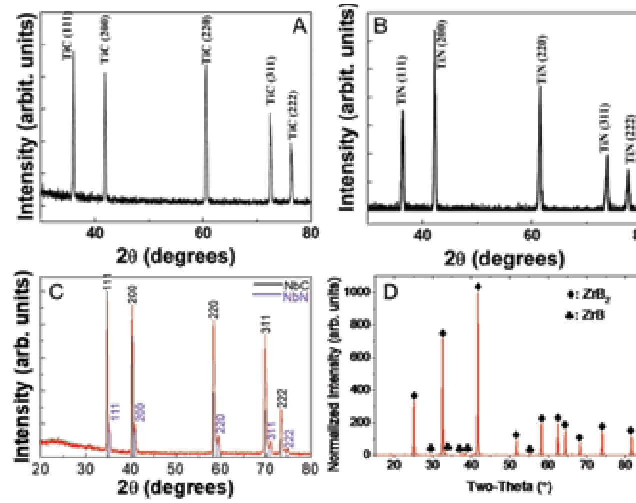


Figure 4. X-ray diffraction analysis of (A) crystal structure polymer-derived TiC ceramic, (B) polymer-derived titanium nitride produced using nearly identical approach, (C) core-shell NbC core/NbN shell, and (D) zirconium boride synthesized from blend of zirconium hydride, boron, and TPEB powder. Source of (A) and (B): T. M. Keller, et al.[9]

Credit: (A,B) T.M. Keller et al., The Journal of Physical Chemistry C; (C,D) Boris Dyatkin and Matthew Laskoski

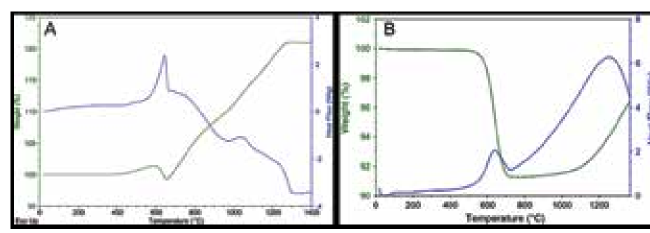


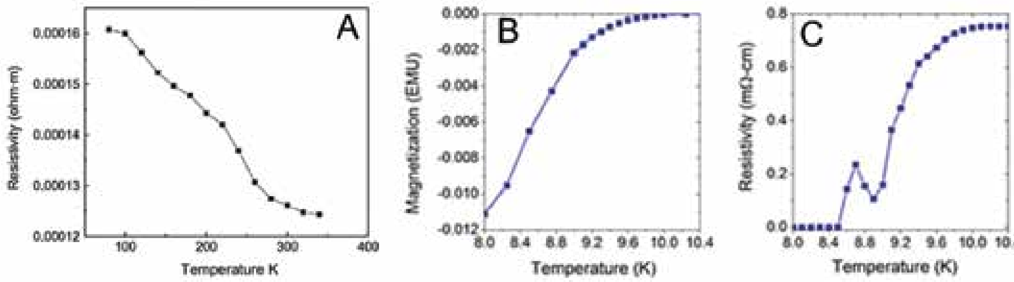
Figure 5. Oxidative study of (A) TiC ceramic and (B) SiC ceramic up to 1,400°C. Source of (A): T. M. Keller et al.[9]; (B): T.M. Keller et al.[10]

Credit: (A) T. M. Keller et al.,[9] *The Journal of Physical Chemistry C*; (B) T.M. Keller et al.[10], *J Mater Sci*

Figure 6A shows the temperature-dependent resistivity of silicon carbide. Acting like a semiconductor, its conductivity increases at higher temperatures. It demonstrates a measured bandgap of 0.1 eV, and various defects and lattice deformations in the material matrix all uniquely and significantly influence the electronic structure and densities of states.

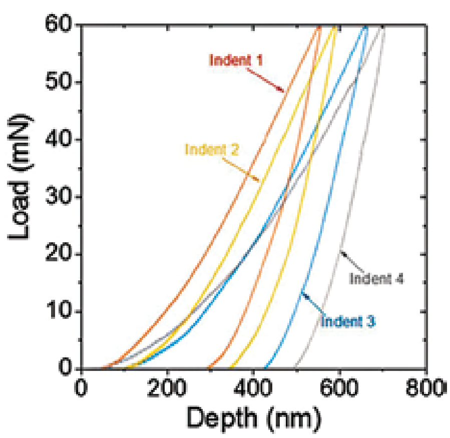
Temperature-dependent magnetization measurements of polymer-derived tantalum carbide (Figure 6B) highlight the superconducting electronic properties of these ceramics at low temperatures. Diamagnetism onset highlights the transition of the polymer-derived ceramic monolith into the superconducting state that occurs at a temperature of T_c ~ 10 K. Resistivity measurements (Figure 6C) further confirm this value. The metal-to-carbon ratio in the precursor blend controls the final stoichiometry of the resulting tantalum carbide and customizes the ratio of TaC to Ta_2C. Since the latter does not exhibit superconducting properties, the polymer-derived ceramic is important for synthesis of materials that demonstrate desired electron transport behavior.

The aforementioned polymer charring process leaves behind microscale pores in resulting ceramic monoliths. These voids contribute to noticeable porosity fractions in the resulting composites, which demonstrate 65–75% densification. Arguably, the polymer-derived single-step approach yields particle-based reaction bonded composite rather than a sintered ceramic monolith. Hardness measurements of TaC highlight this difference. Microscale Vickers hardness values reveal hardness of approximately 143 H_v (1.40 GPa) for tantalum carbide, whereas fully densified TaC typically shows H_v of 1600 (15.7 GPa). Nonetheless, nanoindentation measurements (Figure 7), with values that range between 7 and 15 GPa, exhibit local hardness nearly equal to that of fully densified TaC ceramic. Future processing optimization strategies will aim to densify materials with polymer infiltration and pyrolysis, reaction bonding with metals, and other commercially scalable densification pathways that will reconcile microscale and



Credit: (A) T.M. Keller et al.[10]; J Mater Sci; (B,C) M. Kolel-Veetil et al.[11]; Journal of Materials Research

Figure 6. (A) Plot of electrical resistivity as a function of temperature of a solid SiC monolithic disk (2.54 cm in diameter, 0.5 cm thick). (B) Zero field-cooled magnetization versus temperature and (C) resistivity versus temperature of the TaC-nanoparticle comprising pellet. Source of (A): T.M. Keller et al.[10]; (B) and (C): M. Kolel-Veetil et al.[11]



Credit: M. Kolel-Veetil et al.[11]; Journal of Materials Research

Figure 7. Nanoindentation curves of TaC-containing pellet as a function of depth of indentation. Source: M. Kolel-Veetil et al.[11]

nanoscale hardness of resulting refractory ceramic composites.

Future materials development

The Advanced Materials section of the Chemistry division at NRL is steadily delivering reports of novel additions to refractory ceramics synthesized via the low cost, single-step polymer-derived pressureless synthesis route, and this trend will continue into the future. Subsequent efforts will provide more insights into the metastable material matrix of charred polymer interspersed with metal atoms, the nature of the chemical reaction bonding between metals, and the kinetics of metal carbide nucleation and their subsequent grain growth at low temperatures. Finally, process improvements and capabilities to additively manufacture these materials will improve their commercial scalability and viability in a broader range of applications.

Looking ahead, the research will focus on the unique ability of this synthesis process to incorporate heterogeneous phases into the ceramic preform and leverage various reinforcement approaches to improve the fundamental material properties of resulting refractory composites. In addition to aforementioned metal carbide/metal nitride heterostructures, which had featured seamless junctions between different ceramic phases, previous efforts had successfully embedded macroscale secondary materials into the preceramic matrices.

Figure 8A shows a silicon carbide disc with chopped carbon fibers, which are several microns thick and about 5 mm long, homogeneously dispersed throughout the monolith. Electron microscopy analysis (Figure 8B) confirms stable interfaces between nanocrystalline metal carbide and graphitic fibers. No microscale fractures or macroscale voids form at junctions of these materials, and the two phases adhere to each other to form properly reinforced ceramic composites.

Other forms of reinforcement may further tune the structure from the bottom up and incorporate multiple phases into the ceramic matrix at the nanoscale level. Multiphase metals, secondary ceramics, and carbon nanostructures can be incorporated into the preceramic blend and reaction bond with the bulk refractory ceramic constituents during synthesis.[17] Subsequently, the nanostructure of the bulk ceramic changes and adopts new fundamental chemical, electronic, and structural properties.

This approach provides a unique capability for resulting ceramic composites to overcome current capabilities of bulk ceramics. State-of-the-art refractory metal carbides, nitrides, and borides have finite performance limits that are bound by their respective intrinsic structures. Top-down reinforcement strategies that incorporate additions during high-temperature sintering cannot replicate the degree of homogeneity and seamless bonding that the bottom-up, polymer-derived approach can deliver.

These research efforts will allow the polymer-derived refractory ceramic route to deliver high-performance engineering materials that overcome existing limitations. Despite showcasing high melting points, most ultrahigh-temperature ceramics are prone to failure from thermal shock during conditions of extreme thermal gradients.[18] Under high dynamic mechanical stresses, many mechanically strong and extremely hard carbides develop soft amorphous shear bands, which are as weak as the graphite in a pencil, and retain only a mere fraction of their former strength.[19] Nanoscale reinforcements may, among other factors, facilitate efficient thermal conductivity, increase lattice ductility, and pin dislocations in order to preclude their propagation through ceramic grains.

Commercialization of technology

Since 2017, NRL had partnered with Nanoarmor, LLC, which is a California-based startup that aims to develop and commercialize NRL's polymer-derived ceramic technology. Since then, the two entities have completed several joint development efforts that advanced the technology readiness level of the ceramics, optimized and scaled up key elements of the production process, and identified essential supply line elements that control manufacturing cost and lead times. Nanoarmor has licensed NRL's ceramics technology in order to accomplish these goals.

A core mission of the United States Research Laboratory is the transition of research breakthroughs from basic laboratory studies into targeted applied developments. In turn, these transition efforts advance the readiness level of the technology, scale up manufacturing, and, by leveraging the capabilities of commercial entities, allow the United States Navy and the Department of Defense to integrate novel technology solutions into its fleet and related operations. The Advanced Materials Section has a strong track record of transitioning its material breakthroughs, particularly in the areas of phthalonitrile composites that withstand high temperatures, into the hands of the warfighter. In addition to delivering important fundamental insights into polymer-derived reaction bonding of refractory carbides and formation of composites, the ongoing ceramics effort stands to benefit both the commercial and military enterprise.

Conclusions

Polymer-derived ceramics synthesis route that implements a high-char thermosetting resin offers a rapid and inexpensive capability to pressurelessly synthesize metal carbides, metal borides, and metal nitrides. The near net shape process, which requires temperatures below 1,500°C, reaction bonds precursors into refractory ceramics with high purities and nanocrystalline grains. The preceramic blend composition tunes the chemistry of the resulting ceramic matrix and allows bottom-up incorporation of reinforcements and structural modifiers. In turn, these control the nanoscale architecture of the resulting material and take advantage of multiphase refractory ceramic composites in order to tailor oxidative stability, mechanical strength, and electronic properties of resulting ceramic structures. The versatility and commercial viability of the process enables it to solve numerous engineering challenges and enable the use of ultrahigh temperature ceramics in a broad range of applications.

Acknowledgements

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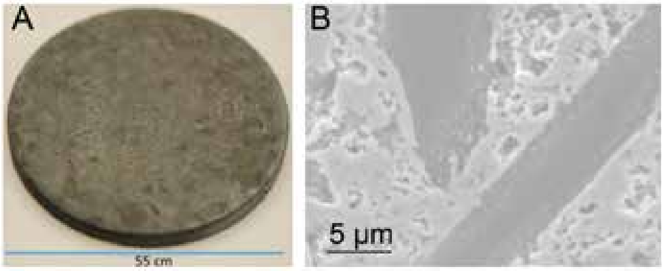

Credit: Boris Dyatkin and Matthew Laskoski

Figure 8. (A) SiC ceramic composite reinforced with chopped carbon fibers. (B) SEM of fiber-ceramic interface.

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(Credit all images: ACerS)

Virtual Glass Summit 2020—ACerS first virtual conference welcomes high attendance and variety of glass topics

ACerS first virtual conference, the Virtual Glass Summit, took place Aug. 3–5, 2020. The meeting serves in lieu of the Glass & Optical Material Division's Annual Meeting, which traditionally takes place in May but was canceled due to COVID-19.

Following the decision to cancel the in-person annual GOMD meeting, GOMD chair Jincheng Du and program chairs Jessica Rimsza (Sandia National Laboratories) and Delia Brauer (Friedrich Schiller University) worked tirelessly to see the idea of a virtual alternative realized.

"Importantly, we all did not want to see the researchers in the glass community miss a year to present due to the pandemic," Du says. "The impact can be especially large for the young researchers, who will miss a precious opportunity to attend a conference or make a presentation."

The Virtual Glass Summit welcomed 250 attendees from 13 countries, including 93 students. The agenda included 102 technical talks, four award lectures, and two social events.

Compared to in-person meetings, the ratio of attendees-to-presenters was markedly higher. "At our live meetings, we typically find that only about 15% to 20% of the attendees are not presenting. In this case, greater than 50% of the attendees were not presenting," ACerS executive director Mark Mecklenborg says. "I think this is a very positive achievement of the Virtual Glass Summit."

The four award lectures this year covered a wide variety of glass topics, including

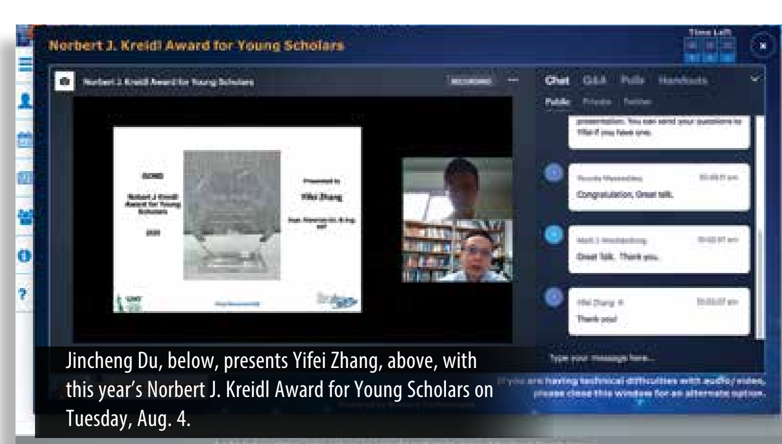
- Bio-inspired materials, particularly synthetic bone. Presented by Antoni Pawel Tomsia, Stookey Lecture of Discovery recipient and senior scientist emeritus at Lawrence Berkeley National Laboratory.
- Phase change materials for optical data storage. Presented by Yifei Zhang, Norbert J. Kreidl Award for Young Scholars recipient and Ph.D. candidate at the Massachusetts Institute of Technology.
- Optical fibers, including the different types of glasses used and applications beyond telecommunications. Presented by Younès Messaddeq, Varshneya Glass Technology Lecture Award recipient and professor at Université Laval (Quebec City, Canada).
- Batch melting thermodynamics and kinetics. Presented by Reinhard Conradt, David Pye Lifetime Achievement Award recipient and retired professor from RWTH Aachen University (Aachen, Germany).

The various sessions and presentations, like the award lectures, also covered a wide variety of topics. However, the use of simulations, particularly first principle calculations, was mentioned time and again across these different areas.

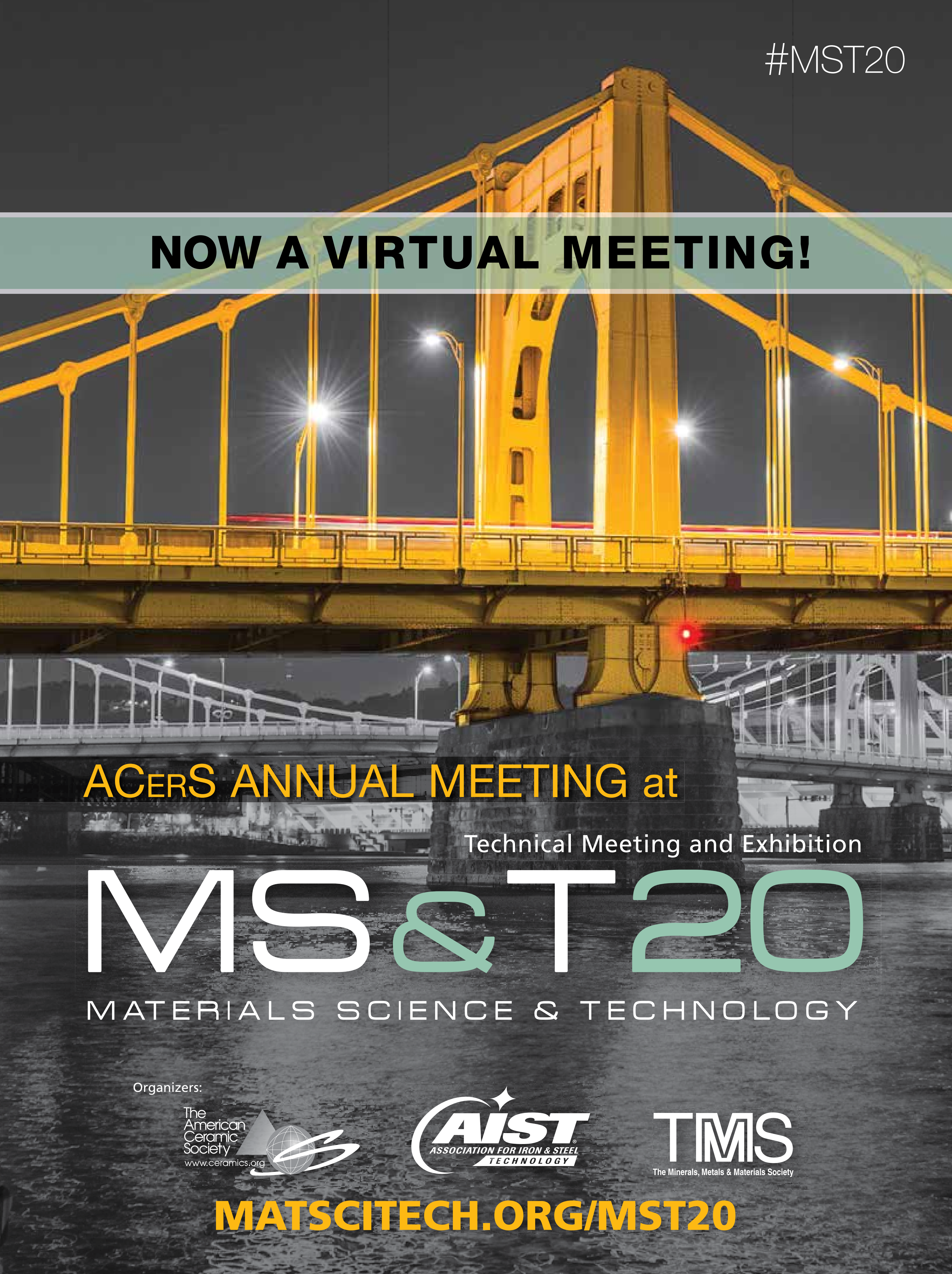
"Overall, together with dedicated and supportive ACerS staffs, we are pleased and proud to deliver the first virtual conference of our society," Du says.

Recordings from all the presentations will be available to all attendees until May 31, 2021, through the conference site. In addition, the 14th Pacific Rim Conference on Ceramic and Glass Technology including GOMD Annual Meeting is scheduled to take place that month as well from May 23–28 in Vancouver, British Columbia, Canada.

Attendees, session chairs, and ACerS Staff celebrate a successful Virtual Glass Summit during the virtual happy hour on Wednesday, Aug. 5.



Jincheng Du, below, presents Yifei Zhang, above, with this year's Norbert J. Kreidl Award for Young Scholars on Tuesday, Aug. 4.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TECHNICAL PROGRAM

Tuesday, September 29, 2020

SESSION 1 10 – 11:15 a.m.

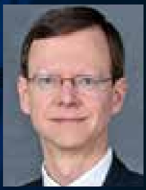
10 – 10:15 a.m. **Keynote session**
Welcome remarks


Freitag

10:15 –11:15 a.m.
Douglas Freitag. USACA
The state of manufacturing advanced ceramics and what gaps remain

SESSION 2 11:15 a.m. – 12: 15 p.m.

Testing, Quality, and Health & Safety


Jeter

11:15 – 11:45 a.m.
J. Douglas Jeter, Harrop Industries
OSHA's top 10 citations in 2019 and how you can avoid them in 2020


Thornton

11:45 a.m. – 12:15 p.m.
Tony Thornton, Micromeritics Instruments Corp.
Powder characterization for ceramic processing using ASTM test methods

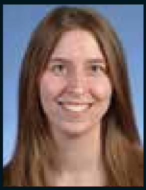
12:15 – 12:30 p.m. **30-minute break**

SESSION 3 12:45 – 3:45 p.m.

Ceramic Processing


Walker

12:45 – 1:15 p.m.
William Walker, Tenneco Powertrain
Making sense of failure modes and effects analysis

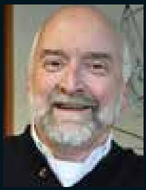

Hoel

1:15 – 1:45 p.m.
Cathleen Hoel, G.E. Research
Practical considerations for ceramic additive manufacturing

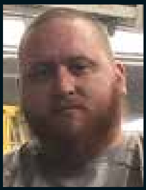

O'Brien

1:45 – 2:15 p.m.
David O'Brien, SINTX Technologies, Inc.
Key steps in successfully manufacturing silicon nitride

2:15 – 2:30 p.m. **15-minute break**


Carty

2:30 – 3 p.m.
Bill Carty, Alfred University
A comprehensive approach to ceramic forming using specific volume diagrams: examples with extrusion

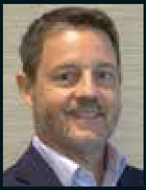

Bradburry

3 – 3:30 p.m.
Marc Bradburry, Bradburry Innovation Group
3D printing: The tool you're missing

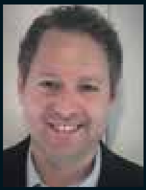
3:30 – 3:45 p.m. **15-minute break**

SESSION 4 3:45 – 4:45 p.m.

Raw Materials


Creedon

3:45 – 4:15 p.m.
Matt Creedon, Washington Mills
Electrofusion of mullite ceramics


Snyder

4:15 – 4:45 p.m.
Mark Snyder, Almatis
Alumina: A raw material that is (almost) always behind the scenes

Calendar of events

September 2020

29 Ceramic Manufacturing Solutions Conference – VIRTUAL ONLY EVENT; www.ceramics.org/CMSC

October 2020

4–8 ACerS 122nd Annual Meeting with Materials Science & Technology 2020 – Virtual Event Only; www.matscitech.org

12–13 Fluorine Forum 2020 Grand Hotel Huis ter Duin (Noordwijk), Amsterdam; http://imformed.com/get-imformed/forums/fluorine-forum-2020-revised

20–23 ➡ International Research Conference on Structure and thermodynamics of Oxides/carbides/nitrides/borides at High Temperature (STOHT)- Arizona State University, Ariz.; https://mccormacklab.engineering.ucdavis.edu/events/structure-and-thermodynamics-oxidescarbidesnitridesborides-high-temperatures-stoht2020

26–30 ➡ 81st Conference on Glass Problems (GPC2020) – Virtual Event Only; https://glassproblemsconference.org

November 2020

8–13 7th Int. Conference on Electrophoretic Deposition (EPD 2020) – Santa Fe, New Mexico; http://www.engconf.org/conferences/materials-science-including-nanotechnology/electrophoretic-deposition-vii-fundamental-and-applications

29–Dec 3 2020 MRS Fall Meeting & Exhibit – Boston, Mass. – Virtual Event Only; www.mrs.org/fall2020

January 2021

20–22 Electronic Materials and Applications (EMA2021) – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla.; www.ceramics.org/ema2021

24–29 45th International Conference and Expo on Advanced Ceramics and Composites (ICACC2021) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; www.ceramics.org/icacc2021

March 2021

15–17 China Refractory Minerals Forum 2021 – InterContinental Dalian, Liaoning, China; http://imformed.com/get-imformed/forums/china-refractory-minerals-forum-2020

24–29 ➡ 2nd Global Forum on Smart Additive Manufacturing, Design and Evaluation (SmartMADE) – Osaka University, Nakanoshima Center, Japan; http://jwri.osaka-u.ac.jp/~conf/Smart-MADE2020

27–31 ➡ The Int'l Conference on Sintering 2022 – Nagaragwa Convention Center, Gifu, Japan; https://www.sintering2021.org

April 2021

25–30 ➡ International Congress on Ceramics (ICC8) – Bexco, Busan, Korea; www.iccs.org

May 2021

3–5 6th Ceramics Expo – I-X Center, Cleveland, Ohio.; https://ceramics.org/event/6th-ceramics-expo

16–19 ➡ Ultra-high Temperature Ceramics: Materials for Extreme Environment Applications V – The Lodge at Snowbird, Snowbird, Utah; http://bit.ly/5thUHTC

17–20 China Ceramitec 2021-Messe München, Germany; https://www.ceramitec.com/en

23–28 14th Pacific Rim Conference on Ceramic and Glass Technology (PACRIM 14) – Hyatt Regency Vancouver, Vancouver, British Columbia, Canada; www.ceramics.org/PACRIM14

June 2021

28–30 MagForum 2021: Magnesium Minerals and Markets Conference – Grand Hotel Huis ter Duin, Noordwijk, Amsterdam; http://imformed.com/get-imformed/forums/magforum-2020

September 2021

14–17 20th Biennial Worldwide Congress Unified International Technical Conference on Refractories – Hilton Chicago, Chicago, Ill.; www.ceramics.org

October 2021

17–21 ACerS 123rd Annual Meeting with Materials Science & Technology 2021 – Greater Columbus Convention Center, Columbus, Ohio; www.ceramics.org

January 2022

20–22 46th International Conference and Expo on Advanced Ceramics and Composites (ICACC2022) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; 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.

denotes Corporate partner

SEPTEMBER 2020 • VOLUME 1 • ISSUE 4

Ceramic & Glass MANUFACTURING

www.ceramics.org/ceramicandglassmanufacturing

LEARNING TO FLY: HOW TRAINING AND WORKFORCE DEVELOPMENT ARE CHANGING IN THE ERA OF COVID-19

FLEXIBILITY MATTERS: HIGH PURITY, THIN, FLEXIBLE ALUMINA RIBBON CERAMIC

APPLICATION NOTE: BULK BAG WEIGH BATCHING CONTROLS COMPENSATE FOR TERRA COTTA INGREDIENT VARIATIONS

CONTENTS

Ceramic & Glass MANUFACTURING

Vol. 1, No. 4

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INDUSTRY NEWS

CORNING EXPANDS GLASS VIAL MANUFACTURING WITH HHS GRANT

Corning Inc. announced it will receive $204 million from the Biomedical Advanced Research and Development Authority (BARDA), part of the Office of the Assistant Secretary for Preparedness and Response at the U.S. Department of Health and Human Services. Under the agreement, Corning will substantially expand its domestic manufacturing capacity of Corning Valor Glass vials to support COVID-19 vaccinations and treatments. Corning will provide priority access to designated BARDA vaccine and drug development partners. The investment will enable Corning to accelerate the scale up of glass tubing and vial manufacturing at three U.S. facilities in Big Flats, N.Y.; Durham, N.C.; and Vineland, N.J.


Corning will expand production at three facilities.

ARDAGH GROUP SEES INCREASED DEMAND FOR GLASS MILK BOTTLES

Ardagh Group, Glass-North America and Stanpac are providing glass milk bottles to meet increased demand during the coronavirus pandemic. Dairy delivery companies are seeing a surge in demand for glass milk bottles. Ardagh manufactures the American-made glass milk bottles that Stanpac supplies to regional dairy brands. Ardagh Group is a global supplier of recyclable metal and glass packaging and operates 56 metal and glass production facilities in 12 countries. Stanpac is a packaging manufacturer with roots in the dairy industry, providing packaging for milk, ice cream, and other food products. They also provide direct printing on glass containers for wine, beer, spirits, and food containers.


Stevanato Group is a privately owned producer of glass packaging for pharmaceutical companies.

STEVANATO GROUP PLANS U.S. TECHNOLOGY CENTER

Italy-based Stevanato Group, a producer of pharmaceutical glass containers and drug delivery systems, plans to open its Technology Excellence Center (US TEC) in Boston in September. The center will support biopharmaceutical companies in the selection of glass primary packaging design and technology. US TEC will advise on materials science, chemistry, and engineering, focusing on container closure characterization as well as fill and finish development and optimization. Stevanato Group is one of the world's largest privately-owned designers and producers of glass primary packaging for the pharmaceutical industry.


SiO2 is based in Auburn, Ala.

SIO2 SCALES UP GLASS VIAL CAPACITY

SiO2 Materials Science announced it scaled its manufacturing capacity for glass vaccine vials ahead of schedule to 400 million doses and is on track to hit 1.2 billion capacity before the end of 2020. Experts have raised concerns about a potential shortage of glass vials needed to deliver a COVID-19 vaccine. In June, the company announced a $143 million investment from the U.S. government to accelerate the production of SiO2's primary packaging platform for storing the vaccines and therapeutics. To support the scaling of its Alabama-based manufacturing campus, SiO2 is investing an additional $160 million, adding two sites to the Auburn campus.

O-I owns five manufacturing plants in Australia and New Zealand.

O-I PLANS TO DIVEST ITS AUSTRALIA AND NEW ZEALAND UNIT

O-I Glass, Inc. agreed to sell its Australia and New Zealand business unit to Visy Industries, a privately owned packaging and resource recovery company. Gross proceeds on the sale and a related sale-leaseback agreement will approximate $947 million. O-I said the sale follows a strategic review of its global portfolio and operating structure. The review is now substantially complete, it said. O-I is the largest manufacturer of glass bottles and containers in Australia and New Zealand, with five manufacturing facilities located in Adelaide, Brisbane, Melbourne, Sydney, and Auckland, and a recycled glass processing plant in Brisbane. Headquartered in Melbourne, the business generated annual sales of $754 million.

SCHOTT ENTERS INTO MANUFACTURING AGREEMENT WITH LUMUS

SCHOTT manufactures specialty glass, glass-ceramics, and related high-tech materials.

SCHOTT, a manufacturer of optical materials and components for augmented reality (AR) waveguides, agreed to manufacture light-guide optical elements (LOEs) for Israel-based Lumus. The partnership adds a new product line to SCHOTT's offerings to the AR industry. Lumus will handle research and development on the optical design of the reflective waveguides, as well as their commercialization. SCHOTT will make them, using its production network with high-end optical glass melting in Germany, its substrate processing lines in China, and its component factory in Malaysia, where the LOE assembly line is located. SCHOTT AG is headquartered in Mainz, Germany, and is owned by the Carl Zeiss Foundation, one of the oldest private science foundations in Germany.

PUYANG REFRACTORIES GROUP WILL OPEN ITS FIRST U.S. FACILITY IN 2021

PRCO America Inc., a manufacturer of specialty refractory brick for the steel industry, plans to open its first U.S. production facility next year in Graves County, Ky., a nearly $5.5 million investment. The operation will produce custom-sized, resin-bonded, magnesia graphite refractory brick. The Kentucky Economic Development Finance Authority approved a 15-year incentive agreement with the company, providing up to $550,000 in tax incentives based on the company's investment of $5.49 million and annual targets of creation and maintenance of 32 Kentucky-resident, full-time jobs over 15 years paying an average hourly wage of $24.50, including benefits. PRCO America is a division of Puyang Refractories Group Co. The company's customers include mini-mill and integrated steel producers in the U.S., Canada, and Mexico.

COLORADO RARE EARTH PILOT PLANT IS COMMISSIONED

A rare earth and critical minerals pilot plant processing facility in Wheat Ridge, Colo., received its required permits, and its pilot plant is now being commissioned. USA Rare Earth, LLC, the funding and development partner of the Round Top Heavy Rare Earth and Critical Minerals Project in West Texas, together with Texas Mineral Resources Corp., made the announcement. The pilot plant is USA Rare Earth's second link in a U.S.-based rare-earth oxide supply chain and will draw on feedstock from the Round Top deposit. With the Round Top project, the processing facility, and the recent acquisition of a neo-magnet plant formerly owned by Hitachi, USA Rare Earth said it has a three-pronged strategy to establish a domestic supply chain for rare earth magnets used in defense applications, wind turbines, electric vehicles, smart phones, medical devices, and 5G networks.

The Round Top rare earths project is located outside El Paso, Texas.

LEARNING

HOW TRAINING AND WORKFORCE DEVELOPMENT ARE CHANGING IN THE ERA OF COVID-19

By David Holthaus

Building and maintaining a pipeline of talented and qualified workers was always a priority for manufacturers. Cultivating a skilled workforce able to adapt to changing technical needs is critical to staying competitive and continuing to grow.

Always a challenge, finding and training qualified engineers and others who can thrive in high-tech manufacturing environments became significantly more difficult over the past few months with the spread of the coronavirus SARS-CoV-2 and the COVID-19 disease around the world.

The hands-on experience so essential to training the manufacturing workforce suddenly became something to avoid as schools and workplaces closed, limits on gatherings were advised, and physical distancing became the norm.

The need for qualified talent never stopped, however, and now colleges, technical institutes, employers, and others are figuring out how to nurture the talent pipeline in the era of COVID-19.

For all of them, it's been an exercise in adapting on the fly to a problem they have never encountered before and being prepared to revise plans as conditions change.

Corning Inc. traditionally maintained a strong internship program, with 60 to 80 interns a year, composed of both graduates and undergraduates, just in its research, development, and engineering areas, says Eduardo Bascaran, the lead human resources manager for those business units.

Eduardo Bascaran
Corning Inc.

Those units also developed a co-op program, employing five students every quarter. In the spring, the co-op program came to a halt, and internship offers had to be rescinded, as they were at so many other employers.

The loss of these opportunities, even temporarily, will affect how Corning evaluates prospective employees, Bascaran says.

TO FLY

When the COVID-19 pandemic hit, Missouri S&T students designed and 3D printed face masks for local health care providers and first responders.
Credit: Missouri University of Science and Technology

"A lot of our research and development and engineering work involved hands-on experience, and general experience with processing and characterization of glasses and ceramics," Bascaran says. Without that experience, "It's more difficult to assess whether a person has the potential for hands-on work in the laboratory," he says. "We do believe this is going to have an impact. It's really a lost opportunity."

Richard Brow
Missouri S&T

While employers like Corning are becoming reconciled to new workforce conditions that changed almost overnight, engineering schools are also adjusting on the fly to new safety guidelines and requirements while trying to continue to meet the ever-evolving needs of those employers.

One of the hallmarks of the ceramics engineering program at Missouri University of Science and Technology is the hands-on experiences that both undergraduate and graduate students receive.

"They make the powders, consolidate materials, they know how to make glass," says Richard Brow, a longtime professor of ceramic engineering at Missouri S&T. "When they go off to internships or co-ops with companies, our kids are ready to contribute because they've had these experiences."

Graduates of the Bachelor of Science program in ceramic engineering typically go to work at ceramic manufacturers such as O-I or Kohler, or at companies that use ceramic materials in their products, such as GE or Caterpillar.

The laboratory experience at Missouri S&T and elsewhere had to change radically in the spring. In Brow's glass class in March, he asked graduate students to walk through the lab exercises and had them videotaped and made available to undergrads. However, "Looking at a computer screen is a heck of a lot different than putting on protective equipment and going in a furnace and pulling out molten material and making a glass," Brow says. "You need that physical experience to fully understand a process."

Improve your materials science knowledge with an ACerS short course

The American Ceramic Society offers a series of short courses online that expand on foundational topics and are geared to engineers, scientists, operations professionals, and students looking to improve their materials science knowledge. Go to www.ceramics.org/courses for details on these courses:

- Introduction to Ceramic Science, Technology, and Manufacturing
- Drying of Ceramics
- Introduction to Refractories
- Glaze Manufacturing for Industry
- Firing of Ceramics
- Fundamentals of Industrial Glass Melting Processes
- Dispersion and Rheology Control for Improved Ceramic Processing
- Statistical Process Control in Ceramic Processing
- Additive Manufacturing of High-Performance Ceramics
- Glass Corrosion
- Nucleation, Growth and Crystallization in Glasses—Fundamentals and Applications
- Sintering of Ceramics
- Introduction to Machine Learning for Materials Science

Although conditions were still evolving in late summer, Brow says Missouri S&T was planning to run labs in shifts to maintain adequate physical distancing. Students could opt out and take online versions, he says.

Colorado School of Mines also enjoys a reputation as a hands-on materials science engineering school whose graduates have received jobs in the auto industry, aerospace, refractories, semiconductors, as well as at hometown ceramics manufacturer Coorstek in Golden, Colo.

Geoff Brennecka
Colorado School of Mines

Geoff Brennecka, an associate professor and assistant director of the materials science program, is teaching a ceramics class at Mines this school year, and although things were subject to change, was moving ahead with plans to conduct labs on campus and in person.

He said the school is prioritizing the lab experiences by asking instructors to conduct lectures remotely so the labs can remain on campus.

"The hands-on lab stuff, where you really have to get in and work with the equipment that not everybody has in their kitchen or in their garage, we want to make sure as few people are on campus as feasible, so those experiences don't suffer," he says. "It's better to push those things off campus that can be done remotely. That way we can preserve the on-campus environment and experience for the things that can't be done remotely."

He plans to run the labs in shifts so fewer students are present at any one time and distancing can be maintained.

"Our great challenge now is how to we bring that experience to students under conditions that are much different than they were in February," Brow says.

It's a work in progress as conditions are changing rapidly, and school policies and procedures are stressing flexibility and change above all else.

Brennecka says he's mostly concerned about how the experience of working in teams will change as smaller lab sizes and remote, virtual learning become the norm.

Employers, he says, "are always looking for people who have demonstrated that they can work in teams and can solve problems. Those are skills that engineering students develop through the entire experience on campus. It's a much more holistic experience."

"How does the very concept of working in teams change moving forward?" he asked.

That's a question that can't be answered yet, but if virtual meetings and professional interactions become the new normal, today's students will be prepared for that, he says.

"The default is that we're all going to be using the same kinds of tools for that kind of engagement, so the students that come out of here in a couple of years, they're working in Zoom or have been doing that already for years." Brennecka says.

Brow also sees educational value in students and teachers creating virtual experiences. Creating a virtual reproduction of a lab exercise was instructional, he says. "It's an opportunity for us to provide a deeper description of the chemistry and physics that's going on," he says.

"To the kids who can't come back or who don't want to come back, we will have these elements available," he says.


Colorado School of Mines foundry and lab in pre-pandemic times.
Credit: Colorado School of Mines

Two-year technical colleges are also dealing with rapid change in how training is delivered to future manufacturing employees. Providing job-specific training remotely was already challenging, and employers are asking for it to be accelerated, says Vicki Maple, vice president of economic development and innovative workforce solutions at Central Ohio Technical College.

"One of the great changes has been: how can very specific training be delivered remotely but also in an accelerated fashion," she says.

"Before, we were looking at one-year certificates and two-year degrees," she says. "Now, we're having to look at hours and weeks where we have to deliver intense training and development programs to advance the labor force to where they need to be."

Maple, who also heads the college's Workforce Development Innovation Center, says employers are also looking for help in identifying people with leadership skills and getting them trained so their careers can advance and step up to more responsible roles at their workplaces. Her organization has provided leadership training to about 800 people just since the pandemic emerged, she says.

The pandemic and the shift to working at home actually created opportunities for professional development. At Corning, with more time available due to no commuting and fewer meetings, experts within the company were willing to volunteer their time to create training opportunities, Bascaran says.

Employees created a glass class that included 14 30-minute sessions over seven weeks that were recorded for later review. Online attendance ranged from 150 to 300 people, and 600 people attended at least one module, he says.

Corning also connected employees to other online development opportunities offered by Massachusetts Institute of Technology and other organizations.

"It was not a grand strategy, we just took advantage of the opportunity," he says.

When the time comes to return to the office, "We may continue to take advantage of those opportunities," Bascaran says.

No one knows when that time may come, but until it does, workforce professionals will continue to adapt to the ever-changing times and needs of employers.


Vicki Maple
Central Ohio Technical College

A holistic approach to developing a modern manufacturing workforce

This article was first published on the National Institute of Standards and Technology's Manufacturing Innovation blog. It was edited for length. The full version can be found at https://www.nist.gov/blogs/manufacturing-innovation-blog/holistic-approach-developing-modern-manufacturing-workforce.

By Mary Ann Pacelli

The Oregon Manufacturing Extension Partnership's (OMEP) Smart Talent methodology was launched in 2015 to help small and medium-sized manufacturers (SMMs) address workforce challenges with systematic approaches to recruitment, hiring, onboarding, and early career development.

OMEP has used the methodology with 95 organizations, in engagements ranging from 16 weeks to 18 months. It has responded to client needs by expanding the program to become an integrated holistic approach called Workforce Solutions, which includes managerial training, organizational development, and executive leadership.

Smart Talent has been adopted across the MEP National Network by Centers in Hawaii, Montana, Tennessee, and Puerto Rico. Several others are considering the methodology.

Smart Talent was developed to help manufacturers with the increasingly common—and growing—issue of finding talent to replace an aging workforce. Staffing issues often resulted in quality, productivity, and morale issues, according to OMEP consultants Paola Castaldo and Russ Gaylor.

In many cases, SMMs were trying to quickly onboard new employees for productivity's sake. They struggled with developing effective processes and the people skills required for training, often opting for hiring an experienced technical expert. Entry-level turnover was high, and tribal knowledge was difficult to translate to new employees.

The Smart Talent methodology thrived with its end-to-end approach to recruitment and training. Elements included:

• Expanding the prospect pool by rewriting job descriptions to be more attractive to tech-oriented candidates and broadening recruiting outlets.

• Moving the burden of onboard training from team leaders to the staff, which creates more of a knowledge-sharing culture and repeatable process.

• Using proven adult-learning approaches for more structured on-the-job training, which provided more clear career paths.

• Creating a learning culture in the organization.

OMEP has continued to tweak its methodology, working with its partner MEP Centers to develop new processes, apply best practices, and absorb lessons learned. Smart Talent now encompasses the entire lifecycle of an employee and scope of the company, from entry-level positions to organizational alignment. It is customizable and scalable.

Gaylor offered up a current success story in which CabDoor, a cabinet maker in Salem, Ore., was experiencing high attrition for entry-level hires, some of whom were in their first full-time job. New employees were expected to be at an 80% production level by the end of a third shift. Some of them were overwhelmed from the start.

Of those that made it through the onboarding process, only half were completing the competency test to advance to the next level of employment.

In response, OMEP and CabDoor designed a three-day bootcamp for new hires. Half of the group was on the floor learning job duties, while the other half was in a classroom setting learning about the company, its products, compliance issues, and more. The groups changed places at midday. At the end of three days, the integration of new employees was more effective, and 95% of the new hires had passed the measurement test to become eligible for the next job level.

For more information about how the Smart Talent program works, contact Mary Ann Pacelli at mary.pacelli@nist.gov or your local MEP Center.

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APPLICATION NOTE: BULK BAG WEIGH BATCHING CONTROLS COMPENSATE FOR TERRA COTTA INGREDIENT VARIATIONS

Bulk bag dischargers and pairs of flexible screw conveyors at the Gladding, McBean site. *Credit: Gladding, McBean*

Gladding, McBean (Lincoln, California) is a leading manufacturer of terra cotta products. Founded in 1875, the company mines clay from its own reserves and combines traditional methods with modern technology to create roof tiles, floor and paving tiles, clay pipe, ornamental pieces, and architectural elements for buildings.

To streamline batching and mixing of clay blends for different products, the company installed five bulk bag dischargers and five pairs of flexible screw conveyors from Flexicon to automatically deliver weighments of bulk ingredients for blending of clay compounds. The system cut dispensing and weighing time for each batch by half and reduced out-of-spec material and scrap by 95%.

COMPENSATING FOR RAW MATERIAL VARIATIONS

Clay is a natural material that varies in composition, so the company must determine the ideal ratio of ingredients for various products. "We have to ensure that what we create in the lab will translate to the final material. The only way to accomplish that is to maintain precise control of production," says Joe Parker, operations manager.

The clay is sourced from the company's nearby mine, classified, and loaded into bulk bags at the plant. Crushed, recycled ceramic material called grog is the other major component used in the manufacturing of terra cotta.

To prepare a batch, operators previously retrieved clays and grogs from bins, weighed them on a scale, and transferred them to the mixer using an open trough conveyor.

The new batching system, supplied by Flexicon Corp. (Bethlehem, Pa.), integrates bulk bag dischargers, flexible screw conveyors, and a central weigh hopper, all of which are actuated by programmable controls, also from the supplier. The system enables Gladding, McBean to vary bulk bag discharging, conveying, weighing, and mixing on a batch-by-batch basis according to recipes developed in the lab. A human machine interface (HMI) includes options for automatic or hand-mode operation, as well as setpoints, adjustments, status, start/stop, completion, and other parameters.

Once the recipe is programmed for a batch, each ingredient is conveyed by a flexible screw conveyor from a bulk bag discharger to a central weigh hopper. Load cells supporting the hopper transmit weight gain amounts to the controller, which steps down the conveyor's feed rate to dribble before stopping it once the precise batch weight is gained. The system weighs up to 30 batches per day, with improved accuracy and reduced labor.

WEIGHING IN ON BATCHING PERFORMANCE

"The versatility of the system makes it cost efficient," says Egidio Modolo, plant manager. "It's a simple, straightforward process, and an efficient way to measure and transfer clay to the blender."

He notes that no maintenance was required in the six months since installation, and that throughout discharging, conveying, and mixing, the enclosed system prevents dusting.

"We can make a small or large batch, and alter the recipe and raw materials," Parker says. "Currently, we have two different clays and three different grogs. We can change that any time."

Microscopically, clay is very abrasive, Parker adds. "It will destroy just about any equipment you use, over time. One of the reasons we chose this system was for simplicity of maintenance due to few moving parts, which should minimize downtime."

Having the system in place, Parker says, "opens up possibilities for other types of products and materials that need the same type of batching accuracy."

FLEXIBILITY MATTERS: HIGH PURITY, THIN, FLEXIBLE ALUMINA RIBBON CERAMIC

***Corning first showcased this material at the 2019 Ceramic Expo.*

By Chenggang Zhuang, Yan Wang, Ling Cai, Jody Markley, Heather Vanselous, Nikolay Zhelev, Seong-ho Seok, Lanrik Kester, and Michael Badding

Device manufacturers need innovative new materials to develop smarter, faster, and smaller next-generation electronic devices. Corning has invented a new generation of high-performance ceramic substrates in entirely new form factors that can help solve customer problems.

We demonstrate a unique process able to make high-purity, thin, continuous ceramic ribbons with a dense and fine microstructure. The thin form factor enables fast sintering rates. Across a broad composition space, materials such as zirconia, alumina, and silica can be produced.

In this paper, we introduce a high-performance alumina ribbon ceramic (>99.9 % pure, 1.4 µm fine grains, thin, flexible, and large area) and outline the ceramic's key properties; we also discuss process capabilities demonstrated on this new form factor. This product advances electronic devices with low loss, good heat management, and size miniaturization in high speed data communication (e.g., 5G/mmWave, THz), which is especially essential in unconventional curved or conformal design. The thin ceramic substrate supports nonepitaxial thin film growth, in which a sapphire-like attribute is required as well as large size, thinness, and low manufacturing cost.

FLEXIBLE ALUMINA?

If any material is thin enough, it can be flexible. But to be useful in high-tech manufacturing, ultrathin materials need to remain durable and stable in processing and end use. It's a tough problem, and Corning solved it with ceramics thin enough to be spooled on a roll.

Manufacturing of thin ceramics is very difficult due to the challenge of suitable shape control. Traditionally, thin ceramics are fabricated through a costly conventional polishing approach, which limits achievable thicknesses and wafer size. Therefore, identifying a cost-effective process capable of producing high-purity, ultrathin ceramics with good shape control would be a significant innovation for thin sheet technical ceramics.

Corning developed a novel fast sintering process, in which a continuous formed green tape is conveyed through a sintering furnace in a continuous fashion to form a continuous sintered ceramic ribbon. It is a high-temperature, short-time sintering approach, which is possible because thin ceramics can tolerate rapid heating and cooling rates. For example, compared to conventional sintering cycles, which may take many hours or even days, the new firing cycle lasts only minutes.

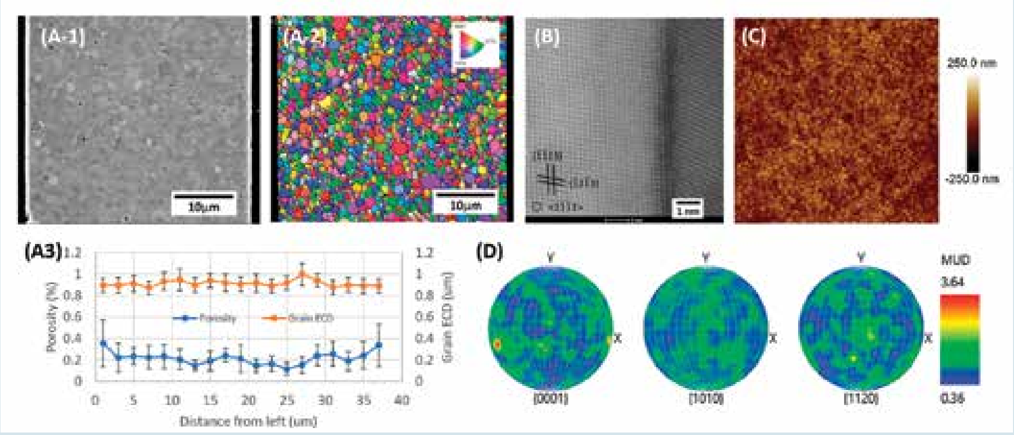

Figure 1. Microstructure of alumina ribbon ceramic. (A) SEM on grain size, porosity; (B) TEM on grain boundary; (C) Atomic force microscopy on surface roughness; (D) Pole figures on grain orientation.
Credit: Corning, Inc.

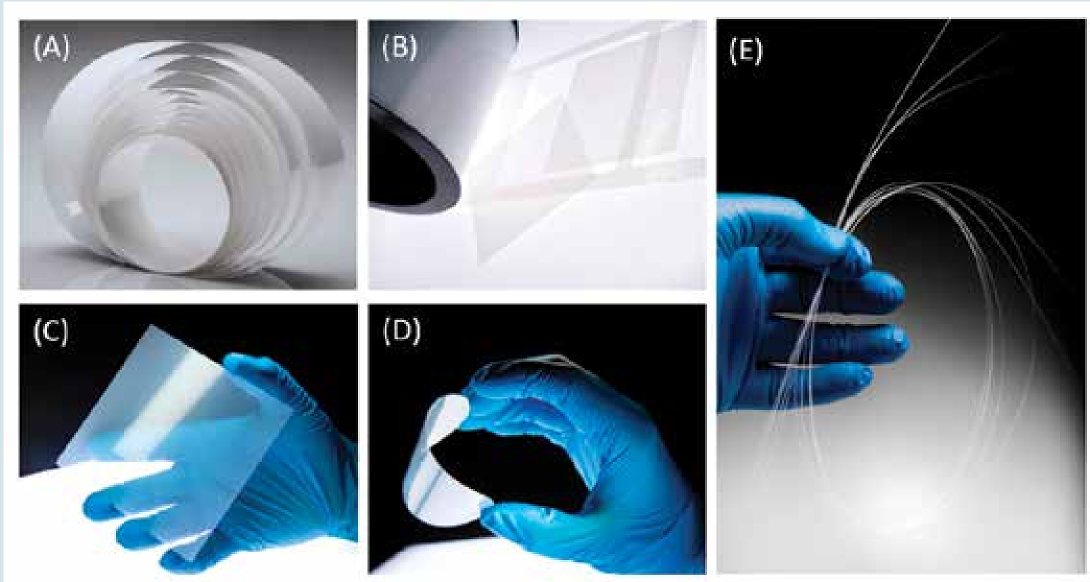

Figure 2. Different form factors of ultrathin alumina ribbon ceramic. (A-B) roll form, (C-D) sheet form/panel, and wafer (E) "cable" form/long narrow strips.
Credit: Corning, Inc.

This novel sintering process enables several attractive product attributes, including low manufacturing cost and long lengths. Widths of up to 100 mm of spooled alumina were demonstrated for spools up to about 100 m long, and it is potentially scalable to 200 mm or 300 mm width to meet size requirements for most semiconductor wafer processes. Thickness is limited by bend stress and ranges from 20–100 µm for alumina.

MICROSTRUCTURE

Compared to conventional sintering, our process favors densification over grain growth in alumina, where high-temperature/short-time sintering enables dense and fine grain microstructures.[1–3]

Figure 1 shows microstructural data collected on the dense and fine-grained features of an alumina ribbon ceramic sample. Image analysis on the cross-sectional electron backscattering diffraction image gives a grain size of about 1.4 µm and SEM porosity of less than 0.4% at pore size of about 190 nm (> 99 % dense), which is also distributed uniformly along the thickness (Figure 1A). Transmission electron microscopy reveals clean grain boundaries with no apparent amorphous film or segregation of impurities (Figure 1B).

As a result of the fine grain, native surface roughness, Ra, retains at 30–50 nm (Figure 1C). This level surface roughness is between typical smooth surface (like glass) and rough surface (like PCB), thus favoring copper adhesion and also enabling fine line structure in metallization processes. Therefore, it should be sufficient for most application cases. Further requirements on surface smoothness (a few nanometers or even less for thin film devices) could be achieved through electropolishing or planarization. Pole figures in Figure 1D proves randomly oriented grain growth and uniform grain size distribution.

FORM FACTORS

Alumina ribbon ceramic is produced in rolls (Figure 2A) and supplied as panels or wafers with appropriate cutting (Figure 2B) either through laser or mechanical saw cutting. Figure 2C and 2D show the two most widely used geometries: 100 mm x 100 mm square panels and 100 mm diameter round wafers. The capability of alternative form factors, such as meter-long narrow ribbons, are demonstrated in Figure 2E. This format is unique to thin ribbon ceramics and could be very useful for applications requiring thin, long, and flexible substrates, such as dielec-

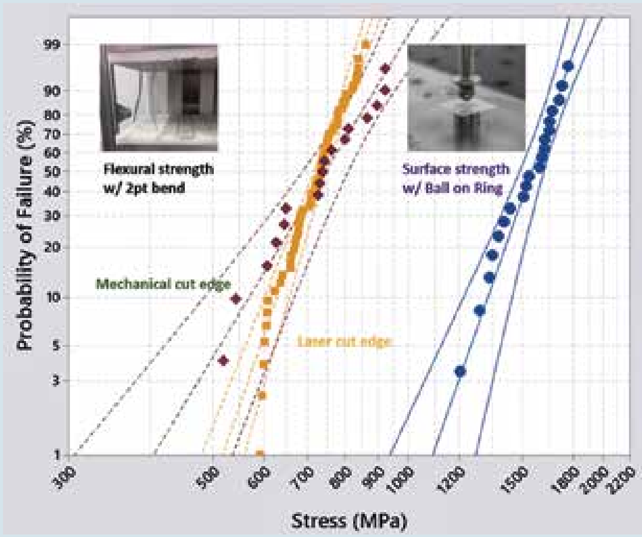

Figure 3. Surface strength with ball on ring test (blue) and flexural strength with two-point bend (laser edge [yellow] and mechanical cut edge [red]) on 40 µmt alumina ribbon ceramic. *Credit: Corning, Inc.*

tric waveguides and harsh environment sensors. The example in Figure 2E is a 1 m long strand that is 40 µm thick and 0.5 mm wide. Until now, a long-length, flexible, high-purity alumina ribbon ceramic form factor was not attainable.

MECHANICAL PROPERTIES

Benefiting from a dense and fine grain microstructure, alumina ribbon ceramic exhibits a high surface strength and edge strength, which could potentially make handling the material easier and less prone to breaking compared to conventionally ground thin-sheet ceramic. Characterizing mechanical properties on thin substrates could be challenging as the sample is too thin and flexible for conventional three- or four-point bend testing. Instead, we combined a ball-on-ring test for surface strength[4] and two-point bend test for flexural strength[5] on 40 µm alumina ribbon ceramic.

The ball-on-ring test[4] provides an "intrinsic" type surface strength measurement while surveying a very small test area, and the two-point bend test is better for evaluating process and handling flaws as it tests a larger area. Figure 3 shows Weibull plots of probability of failure against applied stress in these two different test configurations. A test set with 3 mm diameter stainless steel ball, 4 mm diameter support ring, and 8 mm x 8 mm sample was used for the ball-on-ring test at 1.2 mm/min test speed. The surface strength resulted in a Weibull B10 (10% of probability of failure) of about 1.3 GPa, corresponding to maximum flaw dimension of about 6 µm.

For two-point bend on flexural strength, two sets of samples cut with laser and mechanical saws were tested. While a Weibull B10 of about 600 MPa (and average bend strength of 720 MPa) on laser trimmed edges revealed in the plot indicates edge flaws impact strength, this strength is superior to conventional ground thin-sheet alumina (~400 MPa). Mechanically cut edges show strength about equal to laser trimmed edges with a somewhat wider distribution, indicating alumina ribbon ceramic could accommodate a conventional die cut process.

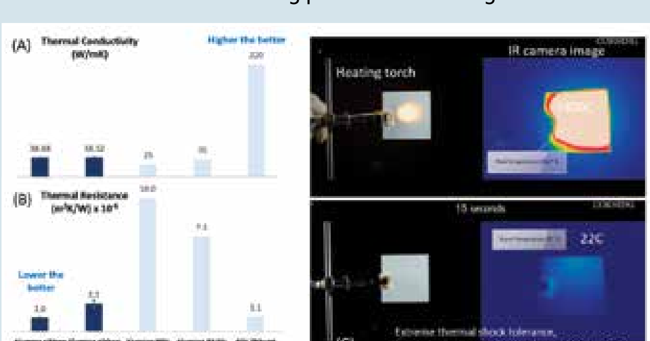

Figure 4. (A-B) Thermal conductivity and thermal resistance comparison between alumina ribbon ceramic, conventional sheet alumina, and alumina nitride; (C) Illustration of thermal shock tolerance and heat dissipation on 40 µmt alumina ribbon ceramic with a torch experiment. *Credit: Corning, Inc.*

THERMAL PROPERTIES

Many applications take advantage of alumina's good thermal properties. The thermal conductivity of Corning ribbon alumina is 36–38 W/m-K, measured by a hot disc method.[6] Due to its ultrathin thickness, the thermal resistance of 40 µmt alumina ribbon outperforms alumina ceramic of standard thicknesses of 250 µm or more, and it is comparable to a 250 µmt AlN ceramic typically used in situations in which thermal conductivity is paramount, shown in Figure 4A and 4B.

Figure 4C illustrates the extreme thermal shock tolerance and rapid heat dissipation of 40 µm thick alumina ribbon ceramic. Alumina ribbon ceramic can withstand fast local heating over 1,400°C in the center, which would break most thick ceramics as thermal stress accumulates. After removal of the heating source, the body temperature quickly drops to room temperature within 15 second. This attribute could help solve heating problems as high speed, high function integration and device miniaturization becomes an increasing demand in advanced electronics.

OPTICAL PROPERTIES

Porosity scatters light very effectively, due to the large difference in refractive index between the gas-filled pores and the alumina matrix (n_{pore}~1, $n_{alumina}$~1.76). Figure 5 plots total and diffuse transmittance and scatter ratio from UV to near IR wavelength range on a 40 µmt alumina ribbon ceramic specimen for a sample–detector distance of 15 cm. The sample shows about 80% total transmittance in the visible range with a certain level of haze, which is visually illustrated by a set of comparison at zero distance vs. 15 mm between alumina ribbon ceramic and paper underlayment in Figure 5B. Transparency increases as the spectrum moves from visible toward the infrared region.

ELECTRICAL AND DIELECTRIC PROPERTIES

Alumina is one of the best-known low loss dielectric materials for high frequency signal transmission. In Figure 6A and 6B, the dielectric constant (D_k) and dielectric loss (D_f) of alumina ribbon ceramic were measured on an Fabry-Perot open cavity[7] from 10 GHz to 60 GHz and com-

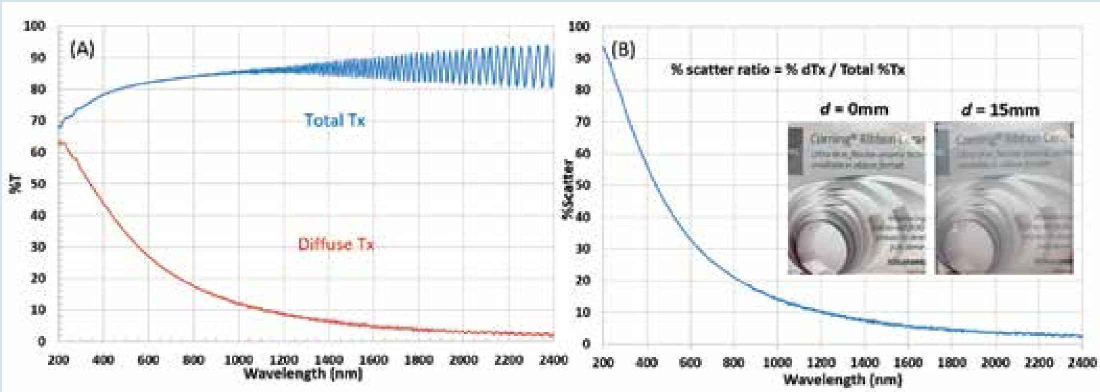

Figure 5. Transmittance and scattering curve of 40 µm thick alumina ribbon ceramic. Insert picture illustrates high translucency of alumina ribbon ceramics. *Credit: Corning, Inc.*

pared with commercial alumina ceramics (at different purity levels), fused silica, and one commercial low loss laminate. Because of its high purity and dense microstructure, alumina ribbon ceramics show remarkably low loss tangent (D_f ~ $1x10^{-4}$) across the entire test spectrum, which approaches the accuracy limit of this test method, indicating low dissipation of electromagnetic energy propagation. Coupled with high Dk of about 10, ultrathin alumina could enable device miniaturization and be attractive for a variety of RF devices, for example, compact passive devices, low loss and crosstalk waveguides, and small near-field antennae.

The loss tangent stays almost flat under a test frequency range up to 60 GHz and test temperatures up to 100°C (measured at 10 GHz on a split post resonator, Figure 6C). These properties enable device design across a wide bandwidth and application temperature range.

The DC breakdown voltage/dielectric strength of alumina ribbon ceramic was characterized and plotted in temperature and substrate thickness in Figure 6D (ASTM D149, DC voltage, oil for RT test, air for elevated temp). Alumina ribbon ceramic 40 µmt shows about 10 kV breakdown at room temperature and retains about 5 kV at elevated temperature of 300°C, with performance close to double for 80 µmt substrate at these temperatures (<300°C). These properties could be useful for miniaturization designs of power electronic devices.

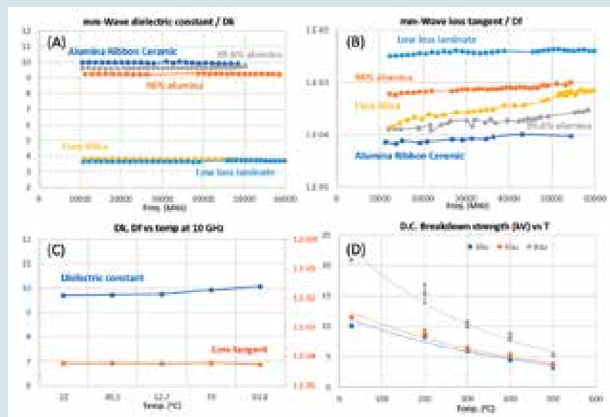

Figure 6. (A-B) Dielectric constant D_k and loss tangent D_f vs freq. on typical RF low loss materials, ceramics, fused silica and low loss laminate; (C) D_k/D_f vs Temp. at 10 GHz for alumina ribbon ceramic; (D) DC breakdown voltage (kV) vs temperature on various thicknesses of alumina ribbon ceramic. *Credit: Corning, Inc.*

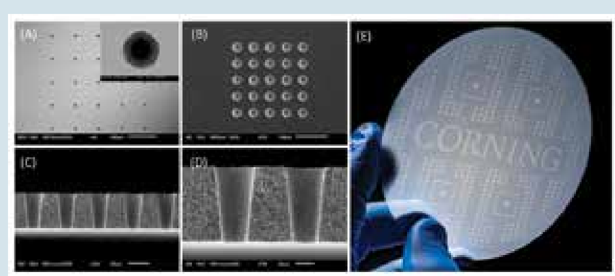

Figure 7. (A-B) 5x5 20 µm via array at different pitch (400 µm, 40 µm); (C-D) Various via cross sections; (E) Test pattern with about 25,000 40 µm size vias on a 40 µmt 4-inch alumina ribbon ceramic wafer. *Credit: Corning, Inc.*

MICROVIAS AND METALLIZATION

Microvias are holes up to 150 µm in diameter, generally laser-drilled, that connect layers in high density interconnect substrates and printed circuit boards. High quality microvia structures can be achieved directly on alumina ribbon ceramic through laser ablation, providing good thermal conductivity while maintaining thinness, which is essential for modern 3D electronics packaging design. Small via size and high via density are achievable on alumina ribbon ceramic at low aspect ratio (AR ~ 2 defined as substrate thickness/average via diameter) because of the material's thinness and good mechanical strength.

Figure 7A shows a 5 x 5 via array at 20 µm via diameter made in 40 µm thick alumina ribbon ceramic (at 400 µm center-to-center pitch), and Figure 7B (at 40 µm center-to-center pitch) corresponds to local via densities of 6 vias/mm^2 to 600 vias/mm^2. The via is taper shaped with a smooth inner wall, good edge quality, and no microcracks, as shown in Figure 7C and 7D.

Figure 7E is an example of a test via pattern constituting of about 25,000 vias at 40 µm via size and minimal 90 µm center-to-center pitch on a 40 µmt, 100 mm diameter alumina ribbon ceramic wafer.

Metal trace can be achieved by different means on alumina ribbon ceramic. Figure 8A shows a subtractive process for thin film metallization, including sputtered copper (or other metals) with a titanium adhesion layer, and a spin-coat photolithography process to define the pattern. Patterning with minimal 2 µm lines/spacings was demonstrated on 40 µmt alumina ribbon ceramic with a layer of 200 nm sputtered aluminum (SEM image of 5 µm line in Figure 8C). Although not shown here, we also achieved 1.5 µm L/S on 150 nm sputtered copper. Figure 8B shows a semi-additive process for thicker copper metallization, which uses a dry film photoresist for patterning, and the metal layer is built with electroplating process. Figure 8D shows minimal 10 μm lines/spacings achieved on 20 μm plated copper.

Microvias can be metallized either fully filled or conformal coated by choosing appropriate process parameters. Figure 8E gives CT scan images showing high quality via filling is feasible on both of 60 μm opening diameter filled via at 30 μm plated copper and 40 μm opening diameter conformally coated via with 10 μm plated copper. Figure 8F is a double side metallization test pattern with filled via by 20 μmt electroplated copper (minimal L/S: 10 μm); and Figure 8G is another example of aerosol jet printed pattern with 5 μm thick silver at 150 μm line width.

The ability of putting small and high density via and achieving fine line metallization is important to device design with high packaging density.

FLEXIBILITY AND ROLL TO ROLL PROCESSING

Thinness and flexibility enable flexible or conformal device design. Limiting bend radius is a function of thickness at a given modulus. Figure 9A plots bend stress vs. bend radius for different thickness alumina ribbon ceramic. A 17 mm bend radius on 40 μmt alumina ribbon ceramic yields 500 MPa bend stress on edge. Maximum bending should not exceed this number to avoid fracture, given its 600 MPa flexural edge strength. If using the 50% strength guideline, the recommended bending radius is 35 mm and 70 mm for 40 μmt and 80 μmt alumina ribbon ceramic, respectively, corresponding to 3-in and 6-in roller diameters. Figure 9B shows successful winding of a piece of 15 mm wide and 40 μm thick alumina ribbon ceramic strip on a 1.5-in diameter roller.

Thin flexible alumina ribbon ceramic provides a set of attractive attributes of high-performance technical ceramics; with its unique form factor, it can fit into many unique designs in a broad application space. Potential application includes low loss substrate or waveguide for high speed data communication (from RF to THz), large size flexible sensors for high temperature or harsh environment, thermal management substrate for high power devices (LEDs, VCSELs), flexible heaters, and actuators, among others.

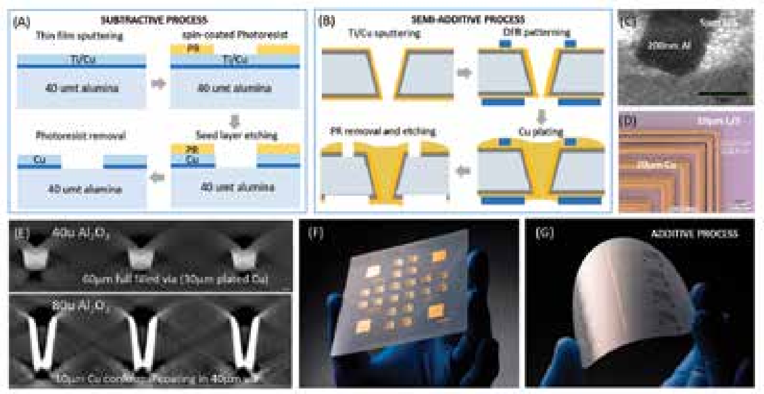

Figure 8. (A-B) Scheme of two photolithography processes for a patterned metallization layer on alumina ribbon ceramics; (C-D) Examples of pattern resolution with process A and B; (E) Via filling and conformal coating; (F) Example of direct plated copper (semi-additive process B); (G) Example of aerosol jet printing (additive process). *Credit: Corning, Inc.*

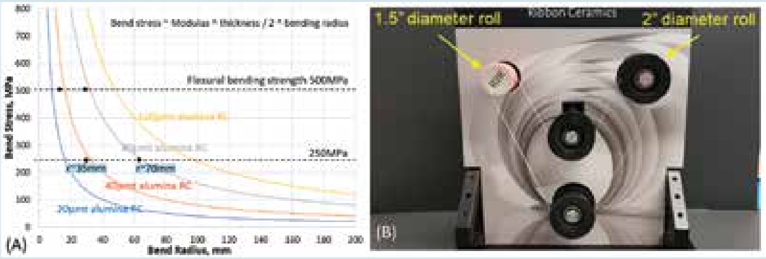

Figure 9. (A) Stress vs. bend radius over different thickness of alumina ribbon ceramic; (B) Example of conveying 40 μmt alumina ribbon ceramic. *Credit: Corning, Inc.*

It has been demonstrated that alumina ribbon ceramic is compatible to those key downstream processes. However, as a thin inorganic material, handling could be challenging with current manufacturing processes that are designed around thick substrate. Further process developments, such as temporary bonding to a carrier and/or application to a continuous roll-to-roll process, could alleviate this challenge.

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Erin Valenzuela

Guest columnist

Pre-designed microporosity within oxide-based CMCs

Oxide-based ceramic matrix composites (CMCs) are continuous fiber reinforced composites in which both fiber and matrix are comprised of oxide materials. Oxide CMCs are known for their high hardness and temperature resistance, low density, oxidation resistance, and high specific strength.[1] These properties enable them to be used in various industries, including aerospace, defense, and space exploration.

Global research groups are working to solve a range of issues with CMCs to improve their application and predictability. These issues include improving high temperature stability, creating an ideal interface between the fiber and matrix, and forming complex shapes.

The aim of my research is to raise the maximum operating temperature and strength of the overall CMC. One way to do so is to enable a weak fiber/matrix relationship by engineering microporosity into the matrix.[2] Engineered microporosity enables in-service densification if the thermal limitations are ever exceeded during use, and the finely distributed porosity within the matrix enables crack deflection close to the fiber/matrix interphase as well as matrix microcracking.[3]

There are several ways in which the microporosity can be introduced into the matrix of the CMC. A common process involves the use of a binder within the slurry processing stage. This binder acts as an aid for the impregnation of the ceramic slurry into the fabrics. During later steps in the manufacturing process, the binder can be burnt out of the matrix, leaving the desired pores where the binder once was.

For this project, phosphates were used to generate a porous matrix. Phosphates generate porosity by their formation method. A phosphate gel is created from aluminum hydroxide, phosphoric acid, and deionized water. Once the gel is applied to the fibers, the heat pressing process evaporates the water and pores are formed (Figure 1).

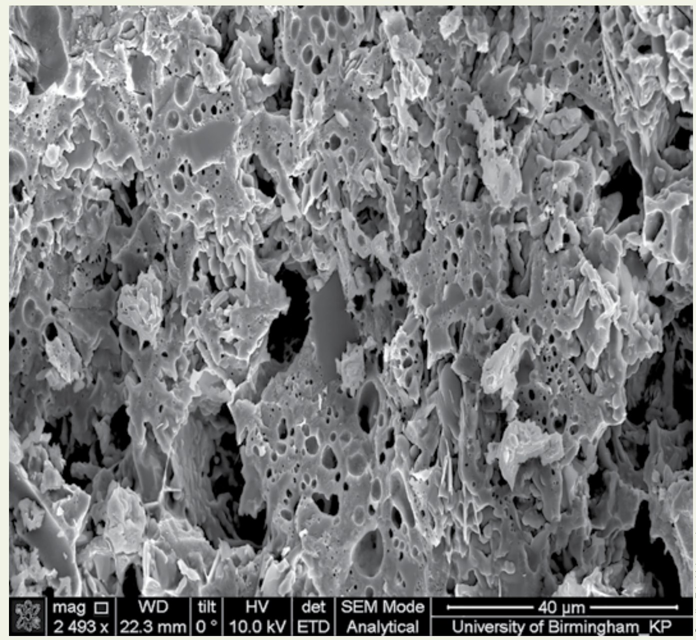

Figure 1. SEM image of phosphate matrix demonstrating porosity.

Phosphates also demonstrate other favorable properties for this project. When created at the correct molar ratio, phosphates demonstrate an average of 2% mass loss when exposed to temperatures of up to 1,500°C.[4] Phosphates can also be used to delay the process of oxidation of nonoxide materials, extending their possibility to be utilized within the CMC system. The delay of oxidation would enable oxide CMCs with the addition of a carbon body, such as carbon nanotubes, to be pushed up to 150°C further with respect to thermal exposure before oxidation begins to weaken the system.

CMCs can only ever really perform to the highest standard of the fibers used within the CMC itself. Improving the fiber/matrix relationship enables us to get the most out of the matrix and use the fibers to their full extent before reaching the limitations of the CMC. By pushing for better thermal and mechanical stability, we begin to improve the overall CMC system.

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