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AMERICAN CERAMIC SOCIETY

bulletin

emerging ceramics & glass technology

AUGUST 2021

Materials for electronics:

Where they come from, where they go

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As seen on *Ceramic Tech Today*...

Credit: Apple

Video: Glass-ceramic covers newest generation of iPhones

Gorilla Glass is the go-to cover screen material for many big phone brands. The recently released iPhone 12 and iPhone 12 Pro, however, use a new glass-ceramic material called Ceramic Shield developed by Apple and Corning.

Read more at www.ceramics.org/CeramicShield

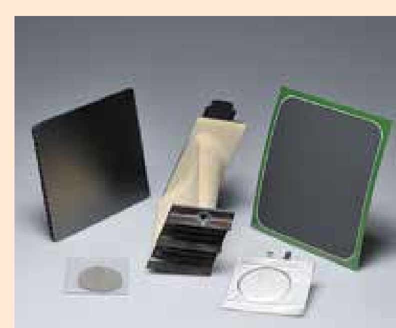
Also see our ACerS journals...

Topical Collection: Energy Harvesting and Storage

Articles on piezoelectric, thermoelectric, solar, and energy storage technologies
International Journal of Ceramics Engineering & Science

Development of magnetic recyclable spinel photocatalysts with enhanced sunlight-driven degradation of industrial dyes

By T. Tangcharoen, J. T-Thienprasert, and C. Kongmark
Journal of the American Ceramic Society



Two-step preparation of fly ash-based composites for microwave absorption

By B. Zhu, Y. Tian, L. Liang, et al.
Journal of the American Ceramic Society

Polarity-induced grain growth of gadolinium-doped ceria under field-assisted sintering technology/spark plasma sintering (FAST/SPS) conditions

By S. K. Sistla, T. P. Mishra, Y. Deng, et al.
International Journal of Ceramic Engineering & Science

Journal of the American Ceramic Society | International Journal of Applied Ceramic Technology | International Journal of Applied Glass Science | 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). ©2021. 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. 100, No. 6, pp 1– 48. All feature articles are covered in Current Contents.

A decade of discovery: A review of MXenes, the family of 2D transition metal carbides and nitrides

Example of a V_2CT_x MXene.

Credit: Armin VahidMohammadi, Drexel University

MXenes are a family of 2D transition metal carbides, nitrides, and carbonitrides that are made by selectively etching MAX phases. Originally discovered in 2011 by two groups of researchers at Drexel University, it wasn't until 2017 that the MXene "gold rush" began and researchers started identifying new MXenes at an unprecedented rate.

There are currently more than 30 different experimentally made MXenes and more than 100 theoretically predicted MXenes, including those with in-plane and out-of-plane ordering of metal atoms. These materials have a wide variety of applications, from use in water treatment and environmental remediation to bone regeneration and ultrahigh-temperature ceramics. With such a broad playing field, it can be difficult to know what research on MXenes has taken place—which is why a new review article published in *Science* is such a valuable resource.

The senior author of the new paper is Yury Gogotsi, Distinguished University and Charles T. and Ruth M. Bach Professor in the Department of Materials Science and

Engineering at Drexel University. He wrote the paper along with Drexel research assistant professor Armin VahidMohammadi and Linköping University professor Johanna Rosén.

The three researchers wrote the review article as a way to mark the 10^{th} anniversary of the discovery of these materials. In addition to discussing the fundamentals of MXenes, they give the article a future focus by including ways to overcome the hype accompanying new discoveries, as well as ways to address challenges related to synthesis, scale-up, and commercialization of these materials.

Below are a few highlights from the 14-page review.

MXene applications

MXenes are mainly metallic conductors that, as stated above, are being explored for use in a wide variety of applications. The review article goes into detail on some of the main applications, including the following.

Optical and electronic applications

Low sheet resistance and good transparency in the visible light range make thin films of the MXene titanium carbide ($Ti_3C_2T_x$) promising for optoelectronic applications where flexible, transparent, conductive electrodes are required, such as solar cells, liquid crystal displays, and organic light-emitting diodes.

MXenes also serve well in gas sensors because of their metallic core channels and surface functional groups, which allow the material to strongly adsorb and thereby detect volatile organic compounds and nonpolar gases, such as ammonia, ethanol, and acetone, at room temperature.

MXenes can serve in electromagnetic interference shielding applications as well thanks to their high metallic conductivity and abundant free electrons. The high conductivity and solution processability of $Ti_3C_2T_x$ has helped it attract attention for microwave absorbance and terahertz shielding, as well as wireless communication, antennas, and radio frequency identification tags.

Energy storage, harvesting, and electrocatalysis

Use of MXenes for electrochemical energy storage, such as lithium-ion batteries and supercapacitors, was an early area of interest. Two reasons that MXenes have so much potential for this application area are: 1) the transition metal core layers in MXenes facilitate rapid electron transport through the electrode, enabling charge storage at ultrahigh rates; and 2) a transition metal oxide-like surface provides redox-active sites for pseudocapacitive charge storage.

Biomedical and environmental applications

Biocompatibility and low cytotoxicity of most MXene compositions, such as $Ti_3C_2T_x$, Nb_2CT_x, and $Ta_4C_3T_x$, as well as their plasmon resonance and high photothermal conversion efficiency in the near-infrared and infrared range make these materials

Corporate Partner News

Lithoz CEO wins 'Big Five Award' 2021 in additive manufacturing

Johannes Homa and his company, Lithoz GmbH, were recently awarded the "Big Five Award of Additive Manufacturing 2021." The Institute for Toolless Fabrication (IwF GmbH) awards this prize each year in association with the FH Aachen in Germany to celebrate long-term and defining contributions to the additive manufacturing industry. Lithoz has created a range of 3D printers for various applications, including medical, industrial, and dental, and also developed ceramic printing materials to suit different needs. Professor Andreas Gebhardt of IwF GmbH described the award as being a recognition of both Homa's and Lithoz's achievements in the "journey of an idea from the laboratory to the top of the world market." 100

promising for cancer theranostics, i.e., the combination of using one radioactive drug to identify (diagnose) and a second radioactive drug to deliver therapy to treat the main tumor and any metastatic tumors.

MXenes also have higher resistance to biofouling and accumulation of microorganisms such as bacteria compared with graphene oxide, so researchers have explored using MXenes as filtration and desalination membranes and as implantable devices.

One of the most exciting possible biomedical applications is to use MXenes to build wearable dialysis systems ("artificial kidneys"), which would free millions of people from having to use stationary dialysis machines and could save lives of people where there is no access to dialysis facilities.

Future research

The authors acknowledge there are still many challenges that must be addressed to unleash the full potential of MXenes.

"Efficient, scalable, and cost-effective etching techniques and delamination routes need to be developed for MXenes beyond $Ti_3C_2T_x$," they write. In addition, "Nitride MXenes have been predicted to have a variety of attractive properties, from ferromagnetism to higher conductivity than carbides or semiconducting properties. However, only a few nitrides have been made."

Considering how much MXenes have to offer, the researchers "expect to see the pinnacle of MXene research in the next few years with wide commercialization and use of these materials," they write in an email.

They conclude the paper by identifying some specific areas ripe for exploration, for example:

- Considering how MXenes complement properties of other 2D materials and how they can be used as building blocks to create hybrid materials and structures.
- Establishing methods and protocols to improve the chemical stability of MXenes.
- Facilitating scale-up and large-volume manufacturing of MXenes by better understanding the role of precursor structure and stoichiometry, as well as the etchant composition and postprocessing treatments on synthesis and properties.
- Exploring alternative synthesis methods, such as by using chemical or physical vapor deposition methods or by starting from non-aluminum-based MAX phases.

The paper, published in *Science*, is "The world of two-dimensional carbides and nitrides (MXenes)" (DOI: 10.1126/science.abf1581). 100

By Lisa McDonald

Into the Bulletin Archives—A look back at our 100 years in print

Since May 1922, the *ACerS Bulletin* has served the ACerS community, providing them updates on member news, Division meetings, and the latest research in ceramics and glass.

In celebration of Volume 100 this year, the *Bulletin* editorial team is running a special column in each issue of the 2021 *Bulletin* that looks at the history of the *Bulletin* by decade. This issue highlights the 1970s.

We hope you enjoy following the journey of the *Bulletin* from its early years to today. As an ACerS member, you have access to all 100 years of the *Bulletin* on the *Bulletin Archive Online* at https://bulletin-archive.ceramics.org. 100

Into the *Bulletin* Archives—1970s

Starting in September 1969, the National Institute of Ceramic Engineers (NICE) began publishing its newsletter in the *Bulletin*. The NICE Newsletter appeared regularly in the *Bulletin* throughout the 1970s and 1980s, providing updates on NICE activities much like the *Bulletin* did for the Society.

Credit: *ACerS Bulletin* (June 1978) Vol. 57 Iss. 6, p. 615

The first time an ACerS Annual Meeting included a poster session was in 1978, during the 80th Annual Meeting in Detroit, Michigan.

1970s

HERITAGE QUIZ

1. Who has held continuous membership in the Society for the longest period of time?
2. What were the original dues for Charter Members, Members and Associate Members?
3. Which two former presidents of the Society played varsity football for Ohio State University?
4. What was the third school of ceramic engineering to be established and who was the original head of the department?
5. Where was the first high school program established to study ceramic technology?

Credit: *ACerS Bulletin* (December 1975) Vol. 54 Iss. 12, p. 1085

The "Our Ceramic Heritage" column, published in 1975–1976, featured a quiz at the end of each edition. Answers for this December 1975 quiz can be found in the January 1976 issue.

The NICE Newsletter at times included commentaries on various subjects, such as a discussion about ethics in ceramic engineering and science by Alfred R. Cooper of Case Western Reserve University, Ohio.

> "While the evidence accumulates that we are in a unique period of time when the effects of our technology can produce long-term deleterious, and even fatal, effects to our planet, engineers and scientists whose objective, unbiased thinking and detailed knowledge could provide the best chance for preservation may be discouraged from addressing the problem within the area of their competence. ... The Ethics Committee needs a variety of thoughtful contributions as to what the appropriate posture of the National Institute of Ceramic Engineers should be with regard to this and other questions of ethics within our profession."
>
> –*ACerS Bulletin, Vol. 56., Iss. 4., April 1977 (pp. 444–446)*

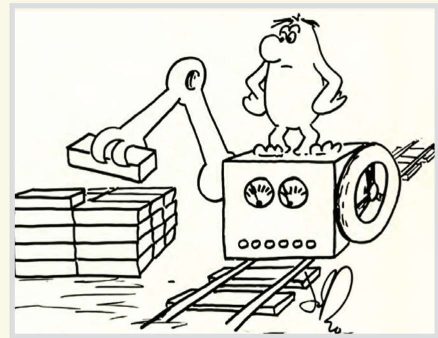
In 1975–1976, the Society participated in celebrating the bicentennial of the United States through "Our Ceramic Heritage," a theme chosen by the Committee on Programs and Meetings for the 78th Annual Meeting in Cincinnati, Ohio. In the June 1975 issue, ACerS president Ralston Russell, Jr. explains that this theme "stems from the Society's recent diamond anniversary, and the fact that many of our younger or newer members have had little exposure to ceramic history and their ceramic heritage."

Starting in July 1975 and running through December 1976, the *Bulletin* featured an "Our Ceramic Heritage" section that showcased important global discoveries and researchers in the ceramics and glass field, as well as history of the Society. A few of the many interesting facts covered in the column include

- First technical society in ceramics: "Although the United States Potter's Association can be considered an antecedent, the National Brick Manufacturers' Association [organized in 1886] is recognized as the first technical society of national scope in the field of ceramics." (July 1975, p. 681)
- Early ceramic-focused journals: "The earliest journal of record published in America, relative to ceramics, was the *Crockery Journal*, the first volume of which was issued in November, 1874. … The first publication of the American Ceramic Society appeared in 1899 as the *Transactions of the American Ceramic Society*." (September 1975, p. 803) More details on *Transactions* appear in the September 1976 issue (p. 805).
- Early Society activities: "The first activity undertaken by the Society was the translation of 'The Collected Works of Herman August Seger,' [a German chemist] which was published in 1902." (January 1976, p. 159)

The agenda for the Bicentennial Session of the 78th Annual Meeting appeared in the April 1976 issue. James I. Mueller, chairman of the History and Archives Committee and ACerS president in 1981, wrote the final column in December 1976 and closed with "So, as we say, 'Auld Lang Syne,' to 1976 and to the Bicentennial, we trust that continued efforts will be made to contribute to 'Our Ceramic Heritage.'"

The Society added one Division and slightly modified the name of another during the 1970s. The Society added the Cement Division in 1971. The June 1971 issue explains that the move to establish such a Division goes back to January 1969, when Geoffrey J. C. Frohnsdorff met with the Society's Committee on Programs and Meetings to develop the Society symposium on cements for the 72nd Annual Meeting. Besides the addition of Cement, the White Wares Division adopted the single-word spelling of "Whitewares" starting in January 1974; no reason for this change is given.



Credit: *ACerS Bulletin* (October 1973) Vol. 52 Iss. 10, p. 729

James Johnson, former ACerS president and Distinguished Life Member, drew cartoons for the President's Page in the *Bulletin* during his 1973–1974 term.

DIVISIONS OF THE SOCIETY

During the 1970s, the Society had 11 Divisions.

- Basic Science
- **Cement (New)**
- Ceramic-Metal Systems
- Design
- Electronics
- Glass
- Materials and Equipment
- Nuclear
- Refractories
- Structural Clay Products
- Whitewares (spelling modified in 1974)

Electronic waste and the future of recycling

By Arpita Mukherjee and Clara Mouawad

Increasing levels of battery and other electronic waste (e-waste), and their illegal and unsafe treatment or disposal, pose significant harm to the environment and human health. Fortunately, recycling technologies are gaining traction across a variety of industries.

BCC offers two ways for you to learn about the future of recycling, through their full-length report and their free podcast called "You Should Know This."

Highlights from the report

Batteries and other e-waste are the fastest growing municipal waste stream worldwide, accounting for 70% of the hazardous toxins in landfills and illegal dump sites. The amount of e-waste was estimated to total 61.1 million metric tons globally in 2019 and is expected to grow at a compound annual growth rate of 9.0% to surpass 83.1 million metric tons by 2024.

The recycling of battery and other e-waste generally uses two types of facilities:

Manual/physical recycling processes

- Advantages: Processes are independent of the scale of pyrolysis and hydrothermal processes, and they recover materials in the reusable form.
- Disadvantages: Requires a thorough knowledge of the battery composition and their chemistries, plus breaching e-devices and extracting their materials is difficult to scale.

Chemical recycling processes

Hydrometallurgical process (chemical leaching)

- Advantages: Offers a less energy-intensive alternative and lower capital costs than other chemically treated processes.
- Disadvantages: Slow and time consuming.

Pyrometallurgy process

- Advantages: Exists at an industrial scale, is highly effective in recovering materials, and is usually eco-friendly.
- Disadvantages: Facilities are capital intensive, high inefficiency in plastic recovery, and the process of smelting produces hazardous emissions.

Highlights from the podcast

In a May 2021 episode, BCC content specialist Clara Mouawad talks with Shaye DiPasquale, publicist for TerraCycle (Trenton, New Jersey), a social enterprise set on "eliminating the idea of waste."

Mouawad: ***What is one aspect of recycling that you've found is constantly surprising people when they are just getting into recycling?***

Table 1. Hazardous materials in batteries and other types of e-waste

E-waste	Possible hazardous content
Batteries	Lead, lithium, cadmium, mercury, nickel, cobalt, manganese
Printed circuit boards	Lead, beryllium, antimony, brominated flame retardants (BFRs)
Cathode ray tubes	Lead, antimony, mercury, phosphor
Liquid crystal displays	Mercury
Plastics	Phthalate plasticizer, BFRs
Rubber	Phthalate plasticizer, BFRs
Electrical wiring	Phthalate plasticizer, BFRs, lead
Cooling systems	Ozone depleting substances
Fluorescent lamps	Mercury, phosphorous, flame retardants
Thermostat	Mercury
External electric cables	BFRs, plasticizers
Electrolyte capacitors	Glycol, other unknown substances

DiPasquale: *So this is a big one for me personally because it's definitely something I was guilty of. The term that we have is called 'wish'cycling. This is when you are placing something into your blue bin with the hope that it will be recycled.*

It's a great thought in theory, but unfortunately it does a lot more harm than it does good. If you are not aware if that item can be recycled, but you've put it in that blue bin, it's now going to make its way from that recycling truck to the facility, … and it's going to go through those systems that are geared toward recycling very particular items, and more than likely it is going to clog, stall, jam machinery.

If by chance somebody who works at one of the facilities sees it in there beforehand, they may have to slow or shut down the process so they can remove it before the rest of it starts moving. … It's great that it's not going to jam the machinery, but the facility might not have the manpower to sit there and sort what should be from what shouldn't be … so that whole bin now could end up just being sent immediately to the landfill.

So, I think it's really important for people to … head to your municipality's website and see if you can get their dos and don'ts of what is recyclable."

About the authors

Arpita Mukherjee and Clara Mouawad are analyst and content specialist, respectively, at BCC Research. Contact them at info@bccresearch.com.

Resources

A. Mukherjee, "Battery and Other E-waste Recycling" BCC Research Report FCB051A, August 2020. www.bccresearch.com

C. Mouawad, "The Future of Recycling with TerraCycle," *You Should Know This*, 27 May 2021 (S2E36). www.bccresearch.com/market-podcast

acers spotlight

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS corporate partners

ACerS is pleased to welcome its newest Corporate Partners:

– The Henry Brick Co

To learn about the benefits of ACerS corporate partnership, contact Kevin Thompson, membership director, at (614) 794-5894 or kthompson@ceramics.org.

Remembering Sheldon Wiederhorn, pioneer of fracture mechanics

Sheldon (Shelley) Wiederhorn, FACerS, ACerS Distinguished Life Member and pioneer of fracture mechanics, passed from this life on June 3, 2021, at the age of 88.

Wiederhorn grew up in Bronx, N.Y., the son of immigrants. He earned his B.S. in chemical engineering from Columbia University in 1956, where he was a member of the men's swim team. By 1960 he had earned M.S. and Ph.D. degrees in chemical engineering from the University of Illinois at Urbana-Champaign.

His first job was with E.I. Du Pont De Nemours & Co., where his research interests turned toward the study of the mechanical behavior of ceramic materials. After three years, he joined the National Bureau of Standards, now National Institute of Standards and Technology, to lead research on the mechanical behavior of glasses and ceramic materials. He stayed at NIST for the rest of his working and emeritus career, comprising a tenure of more than 50 years.

Wiederhorn is best known for the experiments he developed to characterize subcritical crack growth in glasses and the influence of water on crack propagation. His 1970 paper, "Stress corrosion and static fatigue of glass"[1] with L.H. Bolz, is considered one of the most important papers in the glass literature corpus, earning more than 1,000 citations during his lifetime.

However, his work went far beyond slow crack growth in glasses. "He was famous for reliability analyses in general, extending them to structural ceramics such as silicon nitride and silicon carbide. This included direct tension creep rupture testing with extraordinary microstructural analyses by Nancy Tighe and Bernard Hockey," says George Quinn, a NIST colleague.

Arthur Heuer, Distinguished University Professor emeritus at Case Western Reserve University, adds, "His work stimulated the use of fracture mechanics in the field of ceramics. At the time, that discipline was being invented by scientists interested in brittle fracture of materials. Shelley picked up on it and applied fracture mechanics principles to estimate reliability of brittle materials, and that methodology is still in use today."

Wiederhorn joined ACerS in 1960 and belonged to the Basic Science, Engineering Ceramics, and Glass and Optical Materials Divisions. He served 15 years as editor of the *Journal of the American Ceramic Society* and on the ACerS Board of Directors from 2005–2008. He was elevated to ACerS Fellow in 1970 and was recognized by the Society's members with the Ross Coffin Purdy Award (1971), Jeppson Award (1994), and Edward Orton, Jr. Memorial Lecture (2013). In 1998, the Society bestowed upon him its highest honor of Distinguished Life Member.

Other honors include election to the National Academy of Engineering in 1991 and the World Academy of Ceramics in 2010. He was recognized by NIST and the U.S. Department of Commerce with numerous awards.

The Society made a donation in his memory to the Ceramic and Glass Industry Foundation to help the next generation be inspired and guided by his example.

Wiederhorn is survived by a son and daughter and their families.

[1] S.M. Wiederhorn and L.H. Bolz, "Stress corrosion and static fatigue of glass," *J. Am. Ceram. Soc.*, 1970, Vol. 52, No. 10, pp. 543–548.

Oleg Mazurin—Russian glass scientist and SciGlass founder

Oleg Vsevolodovich Mazurin, a world-renowned Russian glass scientist, died in May 2021 at the age of 93.

He was awarded ACerS Honorary Membership during the 2019 International Congress on Glass with the Annual Meeting of the Glass & Optical Materials Division in Boston, Mass.

Mazurin grew up in the U.S.S.R. and earned his M.S. in glass technology followed by a Ph.D. in chemistry in 1962 from the Lensovet Leningrad Institute of Technology. From there he led glass research groups at the I.V. Grebenshchikov Institute of Silicate Chemistry, Academy of Sciences USSR as head of the Laboratory of Glass Chemistry and head of the Laboratory of Physical and Chemical Properties of Glass. He was chief editor of *Fizika I Khimiya Stekla* (*Glass Physics and Chemistry*) and regional editor of the *Journal of Non-Crystalline Solids*.

As a researcher, he made significant contributions to the understanding of phase separation in glass, viscosity in the nearly solid range, viscoelastic and structural relaxation and the glass transition range, and electrical conductivity and glass-to-metal seals. He was the first to accurately draw the immiscibility diagram in the Na_2O–B_2O_3–SiO_2 system.

His interest in unlocking the secrets driving thermophysical properties of glasses led to Mazurin collecting and curating composition and property data on a wide range of glass compositions, which was compiled into the Handbook of Glass Data,[1] considered by many to be the most comprehensive source of glass property data.

With the emergence of the internet, Mazurin led the development of the SciGlass Information System,[2] which contains data from the Handbook and new data, along with built-in modeling tools. Today SciGlass contains property data on more than 425,000 glass compositions.

Mazurin was well-known and respected in his homeland and throughout the world. "He led the organization of the XV International Congress on Glass in Leningrad in July 1989, a first for the Soviet bloc, which brought many in the international glass community behind the Iron Curtain for the first time," recalls Arun Varshneya, Alfred University professor emeritus.

Credit: Natalia Vedishcheva

Mazurin with his daughter and grandson

As the Iron Curtain gave way, Mazurin was able to travel more freely and was a welcome guest in every glass community around the world, and especially at Alfred University, where he had a special relationship with the students and faculty.

[1] O.V. Mazurin, M.V. Streltsina, T.P. Shvaiko-Shvaikovskaya, *Handbook of Glass Data*, Elsevier, Amsterdam: 1983.

[2] SciGlass Information System, https://github.com/epam/SciGlass (accessed 21 June 2021).

more SOCIETY DIVISION SECTION CHAPTER NEWS

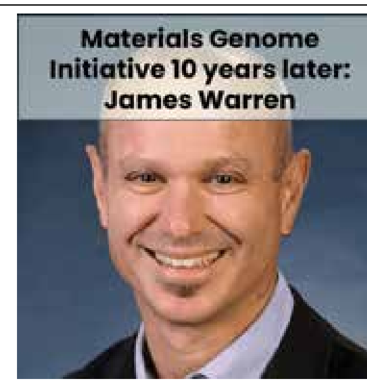
ACerS Diversity & Inclusion Member Community—fostering a culture of inclusivity welcome to all

Coordinated by ACerS Diversity & Inclusion Subcommittee, the ACerS Diversity & Inclusion Member Community offers a place for ACerS members to collaboratively work toward developing a diverse, inclusive, and equitable organization for ceramics and glass professionals.

To join the D&I Member Community, log into your membership account at www.ceramics.org and navigate to the Member Community platform by choosing the Member Community link in the main menu.

Together we can foster a diverse, inclusive, and equitable environment for everyone in the ceramics and glass community. We hope you will join! Learn more about the D&I Member Community at www.ceramics.org/d&i-member-community. 100

Ceramic Tech Chat: James Warren



Hosted by ACerS Bulletin editors, Ceramic Tech Chat talks with ACerS members to learn about their unique and personal stories of how they found their way to careers in ceramics. New episodes publish the second Wednesday of each month.

In the June episode of Ceramic Tech Chat, James Warren, director of the Materials Genome Program at the National Institute of Standards and Technology, expands on the interview he gave in the June/July 2021 issue of the *Bulletin* on the Materials Genome Initiative, which celebrates its 10th anniversary this year.

Check out a preview from his episode, which features Warren discussing how they determined the scope of the MGI when writing the original white paper.

> *"We didn't want to put too much of a scope on this. In fact, we really understood that materials really did span anything that's made out of atoms, basically. There is a challenge of knowing sort of when to stop. But we did really view the materials development continuum was going from discovery of new materials all the way out to deployment and manufactured products, even, in principle, to service. ... So we were trying to work across government and across all these technical research, you know, TRLs [technology readiness levels], to have something that everybody could be in the MGI umbrella. So we didn't draw a lot of boundaries."*

Listen to Warren's whole interview—and all of our other Ceramic Tech Chat episodes—at http://ceramictechchat.ceramics.org/974767. 100

FOR MORE INFORMATION:

ceramics.org

Frontiers of Ceramics & Glass Webinar Series

MONDAY, AUGUST 23
2–3 P.M. EASTERN TIME

Title: *Rheometer Testing to Evaluate Extrusion Behavior*

PRESENTER:
JOHN SANDERS – Clemson University

Free to ACerS members

Hosted by: Structural Clay Division

Names in the news

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.

Varshneya

Arun Varshneya, FACerS, ACerS Distinguished Life Member and professor emeritus from Alfred University, will receive the Gold Medal award, the highest honor bestowed annually by the Case Alumni Association, in recognition of professional achievement and scientific leadership.

Haile

Sossina Haile, FACerS, the Walter P. Murphy Professor of Materials Science and Engineering at the McCormick School of Engineering at Northwestern University, was awarded the Ver Steeg Distinguished Research Fellowship Award. The Ver Steeg Fellowship supports research and scholarship by tenured Northwestern professors.

Sundaram

S.K. Sundaram, FACerS, the Inamori Professor of Materials Science & Engineering at Alfred University, was elected to the to the ASM 2021 Class of Fellows for distinguished contributions in the field of materials science and engineering.

Handwerker

Carol Handwerker, FACerS, professor at Purdue University, was named MRS Fellows for national leadership across the field of electronic materials packaging, from structure evolution in ceramics to lead-free solder replacements, and for leadership in sustainability in materials selection and materials education. 100

IN MEMORIAM

Robert Brill

Frederick Dynys

Ramon Iles

Oleg Mazurin

Robert (Bob) Ruh

George J Sundy

Sheldon Wiederhorn

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

more SOCIETY DIVISION SECTION CHAPTER NEWS

ACerS Washington DC/Maryland/Northern Virginia sponsors ACerS Annual Meeting at MS&T registration scholarships

The Washington, D.C./Northern Virginia/Maryland Section of ACerS will provide Annual Meeting at MS&T conference registration payments for five graduate students and one young professional. Applicants must reside within the section. The application deadline is **July 31, 2021**.

Eligibility

- Enrolled student or young professional within five years of graduation.
- Must be based within the section geographic limits.
- Must have an active ACerS membership.

Application instructions

Submit the following via email to dcmdnova.acers@gmail.com:

- Subject line: "Conference Attendance for MS&T21"
- One page resume (university, major, and graduation date)
  - o Students: Major must be materials science or other related field
  - o Young professionals: Illustrate that your current role is related to materials science.
- Cover letter with no more than 250 words, include interest statement
  - o Students: Highlight your expectations for the conference
  - o Young professionals: Highlight your expectations for the conference. Include any events you plan to support at the conference.

Please reach out to the section leadership at dcmdnova.acers@gmail.com with any questions. 100

AWARDS AND DEADLINES

Society Awards	Nomination Deadline	Contacts
Darshana and Arun Varshneya Frontiers of Glass Lectures	Sept. 1, 2021	Erica Zimmerman ezimmerman@ceramics.org
ACerS Fellow	Sept. 2, 2021	Erica Zimmerman ezimmerman@ceramics.org

2022 Class of Fellows nominations: Deadline Sept. 2, 2021

Nominees for the 2022 Class of Society Fellows shall be persons of good reputation who have reached their 35th birthday and who have been members of the Society at least five years continuously. Visit http://bit.ly/SocietyFellows to download the nomination form.

Submit nomination materials electronically or by mail. If submitting electronically, send to Erica Zimmerman at ezimmerman@ceramics.org. Electronic nominations are preferred. 100

Do you qualify for Emeritus member status?

If you will be 65 years old (or older) by **Dec. 31, 2021**, and will have 35 years of continuous membership in ACerS, you are eligible for Emeritus status. Note that both criteria must be met. Emeritus members enjoy waived membership dues and reduced meeting registration rates. To verify your eligibility, contact Erica Zimmerman at ezimmerman@ceramics.org. 100

FOR MORE INFORMATION:

ceramics.org/members/awards

Volunteer spotlight

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

Goetschius

Kathryn Goetschius received her bachelor's and master's degree in glass engineering and science from Alfred University. She also obtained a Ph.D. in materials science from Missouri University of Science and Technology under the mentorship of Richard K. Brow. She is currently a research project lead in the Product Innovation Group at Guardian Glass.

Goetschius has been a member of ACerS in the Glass & Optical Materials Division since 2007. She is in her second year as a co-chair of the ACerS Young Professionals Network and serves on the Education and Professional Development Council and Strategic Planning & Emerging Opportunities Committee. She chaired the selection committee for the Du-Co Ceramics Young Professional Award and participates as a representative on the ACerS Strategic Planning Industry focused team.

We extend our deep appreciation to Goetschius for her service to our Society!

ACerS welcomes new Eastern Tennessee Section

ACerS is pleased to announce that the Board of Directors recently approved a petition to establish the Eastern Tennessee Section of ACerS. As a local source of ceramic and glass industry education, information, and interaction, ACerS Sections bring the Society's vast resources directly to our members.

Officers of the new section are:

- Chair: **James Hemrick**, Oak Ridge National Laboratory
- Secretary: **Kenneth Kane**, Oak Ridge National Laboratory
- Treasurer: **Ryan Ginder**, University of Tennessee Knoxville

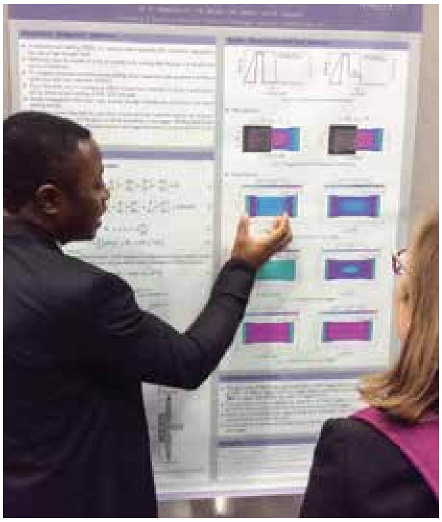
Welcome to the newest ACerS Section!

Description
The Frontiers of Glass Science and the Frontiers of Glass Technology lectures are designed to encourage scientific and technical dialogue in glass topics of significance that define new horizons, highlight new research concepts, or demonstrate the potential to develop products and processes for the benefit of humankind.
Fellow is awarded for outstanding contributions to the ceramic arts or sciences, either through broad and productive scholarship in ceramic science and technology, by conspicuous achievement in ceramic industry, or by outstanding service to the Society.

MS&T21 registration for ACerS Distinguished Life and Senior, Emeritus members

ACerS is again offering complimentary MS&T21 registration for Distinguished Life Members and reduced registration for Senior and Emeritus members. These special offers are only available through ACerS and are not offered on the MS&T registration site. Registration forms are available at https://bit.ly/DLM-Emeritus-SeniorMSTREG and should be submitted by **Sept. 30, 2021**, to Erica Zimmerman at ezimmerman@ceramics.org.

STUDENTS AND OUTREACH



Student opportunities at MS&T21

Here is your chance to work on expanding your speaking, artistic, and physical skills—all at ACerS Annual Meeting at MS&T21 in Columbus, Ohio. Be sure to sign up for the following student contests:

- Undergraduate student speaking contest
- Humanitarian pitch competition
- Undergraduate student poster contest
- Graduate student poster contest
- Ceramic mug drop contest
- Ceramic disc golf contest

For more information on any of the contests and additional student activities available at MS&T, visit www.matscitech.org/students or contact Yolanda Natividad at ynatividad@ceramics.org. 100

PCSA Humanitarian Pitch Competition at MS&T21

The ACerS President's Council of Student Advisors (PCSA) is hosting the 3rd Annual Humanitarian Pitch Competition for you to pitch your ideas to a panel of judges about how you can address a challenge that a community is experiencing. This year's theme will be "Use materials knowledge to address a health related humanitarian issue locally or abroad."

You may put together a team of up to four participants to develop a solution to a real-world problem using materials science. Both undergraduate and graduate students are eligible to participate. Visit www.ceramics.org/pitchcomp for further details and be sure to submit your abstracts by **Sept. 10, 2021.** 100

Graduate Excellence in Materials Science—GEMS Award

The Basic Science Division organizes the annual GEMS awards to recognize the outstanding achievements of graduate students in materials science and engineering. The award is open to all graduate students who are making an oral presentation in any symposium or session at the Materials Science and Technology (MS&T) meeting.

In addition to their abstract submissions, students also must submit a nomination packet to John Blendell, chair of the GEMS Award selection committee, by **Aug. 15, 2021.** For further details regarding the GEMS award and what to include in your nomination packet, visit the GEMS award page at www.ceramics.org/gems. 100

Ceramographic competition and Roland B. Snow award

The Roland B. Snow award is presented to the Best of Show winner of the Ceramographic Exhibit & Competition, an annual poster exhibit to promote the use of microscopy and microanalysis as tools in the scientific investigation of ceramic materials. The competition is held during the ACerS Annual Meeting at MS&T and entries are prominently displayed in the convention center. For deadlines and submission requirements, visit the Ceramographic Competition page at www.ceramics.org/roland_b_snow_award. 100

FOR MORE INFORMATION:

www.ceramics.org/students

ACerS GGRN for young ceramic and glass researchers

Put yourself on the path toward post-graduate success with ACerS Global Graduate Researcher Network. GGRN is an ACerS network that addresses the professional and career development needs of graduate-level research students who have a primary interest in ceramics and glass.

GGRN aims to help graduate students

- Engage with ACerS,
- Build a network of peers and contacts within the ceramic and glass community, and
- Have access to professional development tools.

Are you a current graduate student who could benefit from additional networking within the ceramic and glass community? Visit www.ceramics.org/ggrn to learn what GGRN can do for you or contact Yolanda Natividad at ynatividad@ceramics.org. 100

CERAMICANDGLASSINDUSTRY FOUNDATION

Your help is needed for ACerS Student Travel Fund

As a member of the ceramic and glass materials community, you know how important it is for students to attend ACerS meetings. These undergraduate and graduate students are working to launch their professional careers, and they benefit greatly from presenting their research, attending lectures, and meeting with peers and mentors face-to-face.

That is why The American Ceramic Society created the ACerS Student Travel Fund last year. The fund provides financial support for undergraduate and graduate student attendance at ACerS meetings. But with the worldwide pandemic, we have not yet been able to use the fund to help students.

With our return to in-person meetings this year, now is the time for you to help your younger colleagues. Your gift to the Student Travel Fund will give students opportunities to supplement their education and deepen their understanding of ceramic and glass science. And you will help them begin to create their own personal network of trusted mentors and friends in our community.

Please support the next generation of ceramic and glass professionals by giving online at www.ceramics.org/donate. With your gift, we can help more students attend ACerS meetings and become lifelong members of our ceramic and glass materials community. 100

Developing MAX phase materials for next-generation nuclear power plants

MAX phase is the term for layered ceramic materials with the general formula $M_{n+1}AX_n$, where M is a transition metal (toward the left-hand side of the periodic table), A is a metalloid (edging into the left-hand transition metals and heavy metals), and X is carbon or nitrogen.

With their unique layered structures, MAX phases offer a beneficial mixture of properties, such as the machinability and electrical conductivity of metals with the high temperature and corrosion properties of ceramics. The radiation tolerance of MAX phases is of particular interest because it makes these materials ideal candidates for use in next-generation nuclear power technologies.

Many irradiation studies focus on the titanium-based MAX phases due to their ability to retain crystallinity at high radiation doses. However, instabilities in these materials under proton irradiation mean they may have limited applicability in high-temperature reactors.

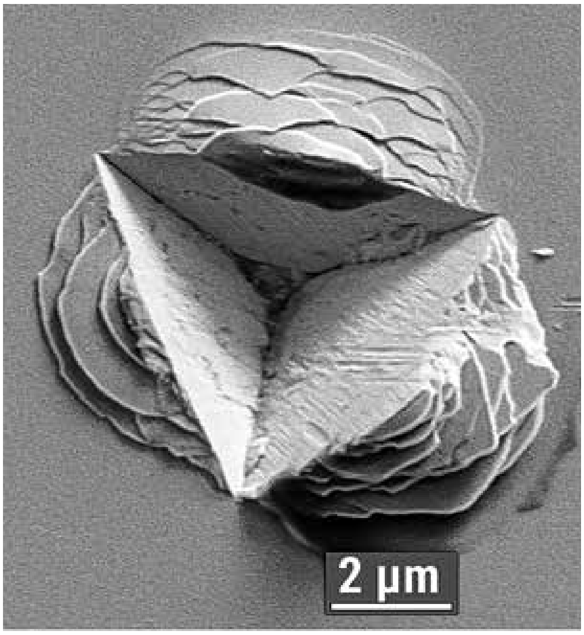
Ternary carbides within the Cr–Al–C system are an alternative MAX phase that offers a couple important advantages: It can be produced at relatively low temperatures, and the material can be first deposited in amorphous form then crystallized in air without any deterioration. But to date, there are limited radiation studies on this system.

Two recent papers published in 2020 and 2021, respectively, look at irradiation of the Cr–Al–C system. Both papers synthesized Cr_2AlC films using magnetron sputtering, but the sputtering conditions of the two studies differed.

The authors of the 2020 article, led by researchers at Fudan University in China, deposited the film on alumina substrates at 600°C, resulting in highly crystalline Cr_2AlC. They then irradiated the samples with 100 keV helium ions, disrupting the Cr_2AlC structure and causing it to form a new one. Upon annealing, the material returned to the original crystal structure.

In contrast to the 2020 article, the authors of the second paper, who are from Austria and the United Kingdom, aimed to investigate how the material would behave under irradiation if it was not fully crystalline. As such, the authors "deviate from the pure MAX phase concept by synthesizing a dual-phase material with the Cr_2AlC MAX phase as matrix and an amorphous phase of the same local chemistry, as the secondary phase."

The authors synthesized a film with both nanocrystalline MAX phases and amorphous grain boundaries of the same composition. When irradiated with 300 keV xenon ions, some implantation occurred in the crystalline phase, but the bulk of the xenon implanted into the amorphous grain boundaries.



Secondary electron micrograph showing a Cr_2AlC film after nano-impact testing.

This finding is substantial because it indicates that nanocrystalline grain sizes are effective sinks for radiation induced defects, which also helps to prevent full amorphization of the MAX phase. With minimal effects on the crystallite structure and lattice parameters, this dual microstructure should retain structural integrity after irradiation to a larger degree.

The 2020 paper, published in *Journal of the American Ceramic Society*, is "Annealing effects on the structure and hardness of helium-irradiated Cr_2AlC thin films" (DOI: 10.1111/jace.17469).

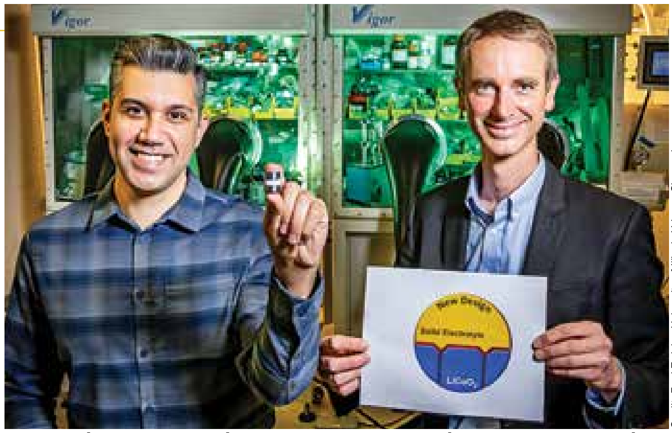
The 2021 open-access paper, published in *Science Advances*, is "Deviating from the pure MAX phase concept: Radiation-tolerant nanostructured dual-phase Cr_2AlC" (DOI: 10.1126/sciadv.abf6771).

Of course, there are many other MAX phases to be explored beyond the titanium and Cr–Al–C systems. Texas A&M researchers recently described a new computational tool to evaluate the suitability of different MAX phases for high-temperature applications.

Density functional theory, a physics-based mathematical model frequently used to explain materials phenomena, struggles to evaluate the properties of MAX phases at different temperatures. To speed up the time it takes to model oxidation of different MAX phases at high temperatures, some studies demonstrated that augmenting density functional calculations with machine learning and experimentally acquired information can quickly and accurately improve predictions.

The Texas A&M researchers augmented density functional calculations using an emerging machine learning method called sure independence screening and sparsifying operator in combination with a computational thermodynamics technique called grand-canonical linear programming. The high-throughput predictions given by the machine-learning-based model for several MAX phases—Ti_2SiC, Ti_2AlC, and Cr_2AlC—compared well with values determined via oxidation experiments, thus establishing "the generality of the scheme ... [and] strength of our framework."

The open-access paper, published in *npj Computational Materials*, is "High-throughput reaction engineering to assess the oxidation stability of MAX phases" (DOI: 10.1038/s41524-020-00464-7).



Credit: Fred Zwicky, University of Illinois Urbana–Champaign

Materials science and engineering researchers Beniamin Zahiri, left, and Paul Braun led a team that developed new battery electrodes made of strategically arranged materials in an effort to drive better solid-state battery technologies.

Lining up for better performance: Researchers tailor interfaces in solid-state batteries

In a recent paper, researchers at the University of Illinois Urbana–Champaign and Xerion Advanced Battery Corporation (Kettering, Ohio) investigated the role of interface crystallography and morphology on the performance of solid-state batteries.

"Currently, solid-state battery electrodes contain materials with a large diversity of surface atom arrangements. This leads to a seemingly infinite number of electrode-solid electrolyte contact interface possibilities, all with different levels of chemical reactivity," Beniamin Zahiri, UIUC postdoctoral research associate, explains in a UIUC press release. These reactions can affect interfacial stability, which can cause voltage loss and reduce power-generating ability, leading to poor battery performance.

To mitigate these interfacial reactions, many scientists have considered incorporating a thin coating material in between the electrodes and electrolyte to stabilize the interface, with some successes. However, coatings face some disadvantages, such as impeding fundamental study of the impact of crystallography and morphology at the interface. In recent years, development of a new family of halide-based solid electrolytes has enabled the possibility of studying the interface without the need for coatings.

The researchers used electrodeposition to create several dense, crystallographically oriented lithium cobalt oxide (LCO) and sodium cobalt oxide (NCO) cathodes. They paired the cathodes with four different solid electrolytes (three halide and one sulfide) so they could understand, "and ultimately exploit," the role that interface morphology and crystallography play in solid-state battery performance.

They found that the dense cathodes demonstrated a linear relationship between capacity fade and interfacial resistance—thus revealing a direct impact of interface crystallography and morphology on solid-state battery performance. In contrast, conventional composite cathodes with random crystallographic orientation and a larger interfacial area led to unpredictable behavior.

The paper, published in *Nature Materials*, is "Revealing the role of the cathode–electrolyte interface on solid-state batteries" (DOI: 10.1038/s41563-021-01016-0).

Bifunctional composite bioceramic hydrogel shows promise for treating skin cancer

Studies show that repeated and severe sunburns can increase risk of skin cancer later in life. An international team of researchers developed a bifunctional composite bioceramic hydrogel for treating melanoma, the deadliest form of skin cancer.

Researchers from several institutions in China, along with colleagues from Sabancı University in Turkey and Queensland University of Technology in Australia, developed a new bifunctional composite bioceramic hydrogel for treating melanoma via a minimally invasive technique called photothermal treatment.

Melanoma is considered the deadliest form of skin cancer because it typically spreads to other areas of the body if left untreated. Treatment commonly involves combining chemotherapy or radiotherapy with surgical removal of the affected tissue or organ.

"However, incomplete surgical resection usually causes recurrence, and the refractory wounds left by the surgery are hard to self-heal, even prone to secondary injury due to infection. Consequently, there are pressing needs to develop multifunctional biomaterials with simultaneous tumor-killing and skin tissue regeneration capability for desirable therapeutic efficacy," the researchers explain in the open-access paper.

Photothermal therapy has received much attention due to its "high selectivity, minimal invasiveness, and no systemic effect compared with traditional chemotherapy/radiotherapy." In this treatment, molecules called photothermal agents are placed in the tumor tissue and are heated by electromagnetic radiation to kill cancer cells.

Development of new photothermal agents is an ongoing area of research, yet to date the photothermal agents investigated for melanoma treatment have suffered drawbacks such as limited bioactivity and acute inflammation, limiting further clinical applications of this treatment.

The researchers note that a photothermal agent with good biocompatibility and high efficiency of photothermal conversion in addition to a wound repair effect would be ideal for melanoma treatment. To achieve all of these properties, the researchers suggest manganese-doped silicate bioceramics may be a good starting point for exploration.

"Silicate bioceramics offer a great prospect in the field of tissue engineering including skin, bone, and cartilage regeneration," they write. "Moreover, the manganese (Mn) element plays a vital role in extracellular matrix synthesis and shows great potential in bone tissue regeneration … [and] could endow silicate bioceramics with excellent photothermal performance. Consequently, it is reasonable to speculate that Mn-doped silicate biomaterials can possess both tumor-killing and wound healing capabilities, which offer high potential for melanoma therapy and wound healing."

However, applying bioceramic powders directly for wound healing is difficult due to high pH at wound sites, nonuniform distribution, and potential cytotoxicity caused by excessive metal ions, among other challenges. Fortunately, "To solve these problems, an appropriate wound dressing biomaterial could be used to load the bioceramic powders."

In their study, the researchers loaded manganese-doped calcium silicate nanowires into sodium alginate hydrogel, a material widely used in wound dressing and other tissue engineering fields. They used this bifunctional composite bioceramic hydrogel (which they termed MCSA) for postoperative treatment of malignant melanoma in mice.

In vivo photothermal therapy using the laser-irradiated bifunctional composite bioceramic hydrogels significantly inhibited skin melanoma tumor growth, and the wounds gradually healed without obvious tumor recurrence within 14 days. Of the tumor cells that did remain, most were apoptotic, i.e., undergoing cell death.

"According to the results above, the conjecture could be confirmed that tumor cells were eradicated by the photothermal therapy in the early treatment stage, and then skin defects induced by skin tumors were stimulated and repaired with the MCSA hydrogels," the researchers write.

Thus, "The results showed that the developed bifunctional MCSA hydrogels would be an excellent candidate for integrative melanoma photothermal therapy and wound healing processes," they conclude.

The open-access paper, published in *Research*, is "Manganese-doped calcium silicate nanowire composite hydrogels for melanoma treatment and wound healing" (DOI: 10.34133/2021/9780943). 100

research briefs

Rare borate structural unit appears to enhance functionality of nonlinear optical materials

A team led by researchers in China and the United States explored arranging borate in the linear BO_2 configuration to enhance functionality of borate-based nonlinear optics.

Alkali and/or alkaline earth metal borates (A-borates) are frequently used in nonlinear optics because of their high transmittance at nanometer wavelengths combined with higher damage threshold. However, as researchers push to create ever smaller optical devices, they are running into a problem with the current A-borates.

"…compounds with a higher absorption edge energy (lower wavelength), larger birefringence, and larger nonlinear optical coefficient are required to enable smaller optical devices leading to new uses and increased efficiency in industrial and scientific applications," the researchers write in the open-access paper. However, almost all of the current A-borates contain borate in the traditional triangular BO_3 and tetrahedral BO_4 unit structures—structures that do not allow the A-borates to achieve such enhanced functionality.

The researchers argue that exploring borates arranged in other structural configurations will allow design of nonlinear optical materials with enhanced functionality. So they chose to explore A-borates containing the rare linear BO_2 structural units, which have only been observed in apatite-type $A_{10}(PO4)_{6-x-y}(SiO_4)_x(BO_4)_y(BO_2)$ and $Gd_4(BO_2)O_5F$ to date.

Using a high-temperature solution method in an open system, they fabricated single crystals of $K_5Ba_2(B_{10}O_{17})_2(BO_2)$ containing BO_2, BO_3, and BO_4 units. They characterized the structure by using density functional theory-based nuclear magnetic resonance spectroscopy; infrared spectrum measurements and vibrational modes calculations further confirmed the borate structure.

They calculated that $K_5Ba_2(B_{10}O_{17})_2(BO_2)$ has a birefringence of 0.062@1064 nm, which is near the maximum threshold (~0.07@1064 nm) of A-borates comprising only BO_3 and BO_4 units. Despite the relatively high value, the researchers felt the birefringence enhancement was small for a material containing BO_2 units "due to the low density (1/21) of the boron sites."

They postulated that a borate with a high density of BO_2 units would have a larger birefringence, and they tested this hypothesis by investigating a theoretical structural model of $K(BO_2)$, a structure comprising solely BO_2 units. They calculated that $K(BO_2)$ would theoretically have a birefringence of 0.18@1064 nm—a value larger than any previously reported A-borate, including $Ca(BO_2)_2$, which contains borate in only the BO_3 unit structure and has a birefringence of 0.124@1064 nm.

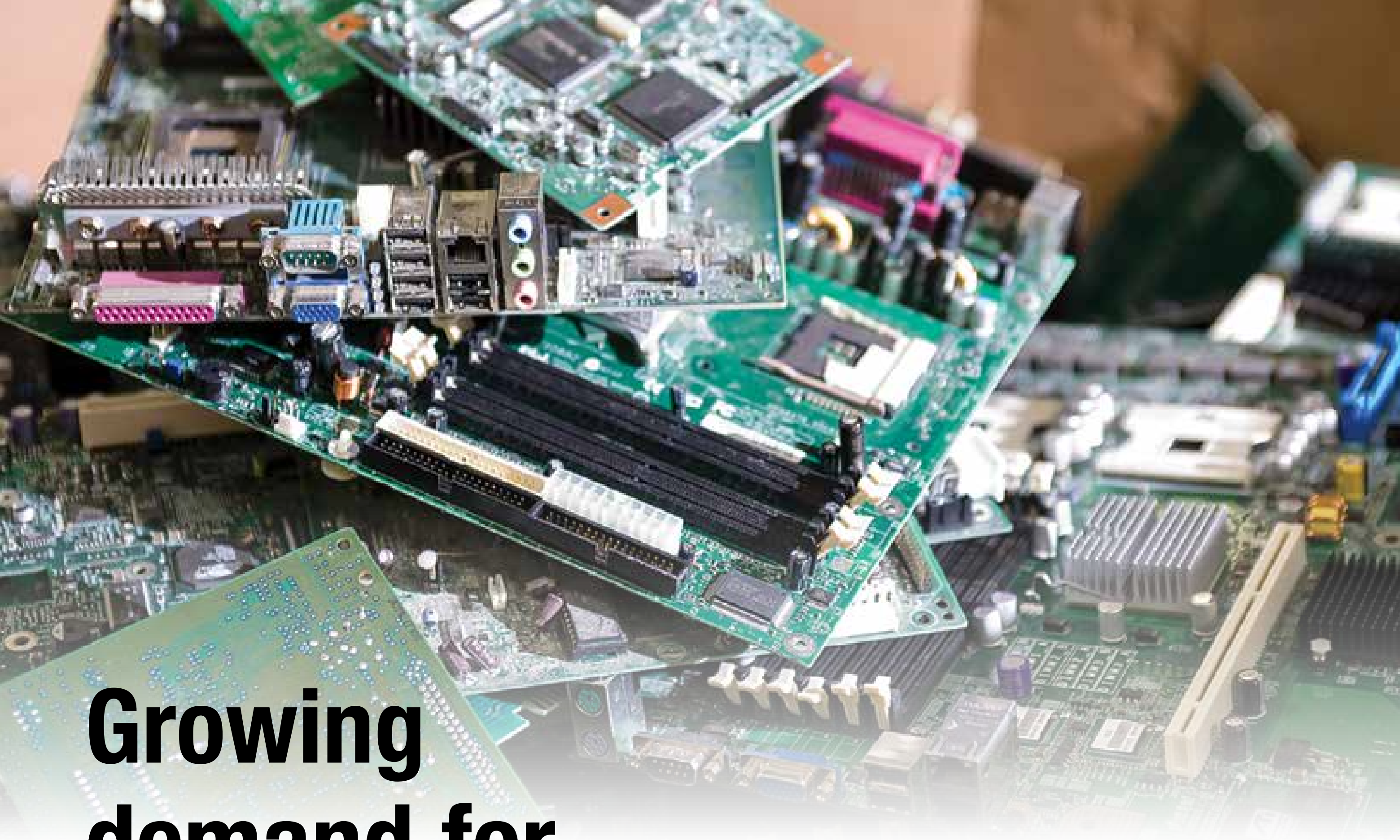
"The predicted birefringence in $K(BO_2)$ would lead to higher-efficiency beam splitting in light polarization processes across telecommunications and scientific instrumentation applications and provide enhanced ability to create and control polarized light," the researchers write. In addition, "The BO_2 functionality could enable optical capabilities, specifically in the rarely accessible deep UV range, and thus sets a target for synthetic crystal growth."

The open-access paper, published in *Nature Communications*, is "Expanding the chemistry of borates with functional $[BO_2]^-$ anions" (DOI: 10.1038/s41467-021-22835-4).

Research News

Underground fiber optic sensors record sounds of COVID lockdown, reopening

Researchers at The Pennsylvania State University used sound signals captured by underground fiber-optic sensors to understand how COVID measures impacted human activities from March–June 2020. By listening to small changes in vibrations at the surface, they found construction activity and vehicle traffic recovered sooner than pedestrian traffic. For more information, visit https://news.psu.edu.



Growing demand for electronics… and ceramic components

By Patty McKenzie

When people outside the industry think of ceramics, they most likely do not think of electronics. But in fact, ceramics are an important component in many of the electronics used today.

The size of the global electronics ceramics market is expected to reach almost $16 billion by 2026,[1] driven by rising demand for phones, tablets, and other e-products that are a part of everyday life. Ceramics are often used as the "package" for microchips or integrated circuits because of their excellent thermal conductivity and resistance to chemical erosion.

While the proliferation of electronics has benefited people worldwide with unprecedented access to information, education, healthcare, and financial services, the current rate of growth and consumption of resources is not sustainable. Faster, smarter, more feature-rich devices are released with ever-growing frequency, replacing their older model counterparts. But what happens to the estimated 54 million tons of electronics that are discarded every year?

Estimates for global recycling rates for electronics range from 15–30%. These rates mean the vast majority of electronics are instead accumulating in closets, offices, basements, and landfills, where the potential for reuse or recycling remains largely untapped. It is estimated that the value of reusable resources from discarded electronics is more than $55 billion each year.[2] In addition to sacrificing the value that could be gained from those products, it depletes the limited supply of resources necessary to produce those products.

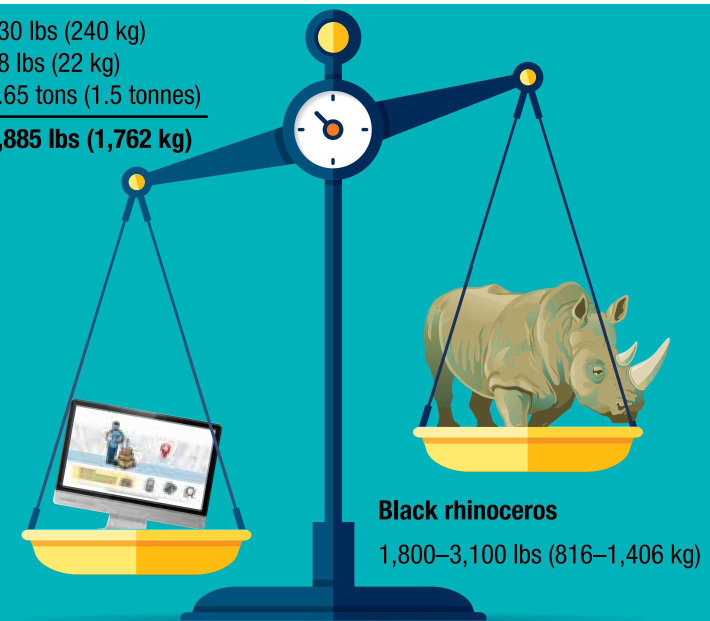
The new movement toward a circular economy is a more sustainable model. A circular economy maximizes the value of products throughout their life cycles. Recycling plays an important role, but extending the useful life of products takes center stage because of the greater environmental benefits of reuse—particularly so when it comes to electronics. The manufacturing process for a laptop accounts for as much as 70% of the total energy the laptop will consume throughout its entire lifecycle.[3] A United Nations University study[4] found that manufacturing a single computer and screen used 530 pounds of fossil fuels, 48 pounds of chemicals, and 1.65 tons of water. With so much invested in the production, lengthening the lifespan of electronic products only makes sense. The good news is that repaired and refurbished electronics can perform as new if loaded with updated software and drivers, and the lifespan can easily be doubled, or even tripled.

When reuse in no longer a viable option, a circular economy maximizes value by harvesting parts and components that can be used in future repairs, or even to manufacture entirely different products. And when harvesting options have been exhausted, materials recovery is the next step. Many different precious metals and other elements can be successfully recovered and reintroduced into the manufacturing stream, reducing the demand for limited supplies of natural resources.

Ceramics are one of the few materials that are not recoverable at this time. As part of the circuit board, they are sent to a smelter for precious metal recovery, but the ceramics themselves are not recovered during this process. As new technologies and uses for recovered materials develop, a more circular economy for electronics will continue to emerge.

Every individual, business, and municipality has a part to play in sustainable management of used electronics. To ensure the electronics you no longer use are properly sanitized of data and follow the circular economy model of reuse–recovery, entrust them to an R2 Certified facility. R2 Facilities undergo comprehensive annual audits to ensure they are following the best practices established in the R2 Standard. Learn more about R2 and sustainable management of electronics at https://sustainableelectronics.org.

Fossil fuels	530 lbs (240 kg)
Chemicals	48 lbs (22 kg)
Water	1.65 tons (1.5 tonnes)
Total	**3,885 lbs (1,762 kg)**



The amount of resources it takes to manufacture a single computer and screen weighs more than a black rhinoceros.

About the author

Patty McKenzie is director of education and outreach for Sustainable Electronics Recycling International. Contact McKenzie at patty@sustainable-electronics.org.

References

[1]ReportLinker, "Global Electronic Ceramics Market By Material, By Application, By End User, By Region, Industry Analysis and Forecast, 2020–2026," https://www.globenewswire.com/news-release/2020/12/23/2150169/0/en/Global-Electronic-Ceramics-Market-By-Material-By-Application-By-End-User-By-Region-Industry-Analysis-and-Forecast-2020-2026.html

[2]V. Forti, "Global electronic waste up 21% in five years, and recycling isn't keeping up," *The Conversation*, published 10 July 2020, https://theconversation.com/global-electronic-waste-up-21-in-five-years-and-recycling-isnt-keeping-up-141997

[3]L. Deng, C. W. Babbitt, and E. D. Williams, "Economic-balance hybrid LCA extended with uncertainty analysis: case study of a laptop computer," *Journal of Cleaner Production* **19**(11), 2011: 1198–1206. https://doi.org/10.1016/j.jclepro.2011.03.004

[4]R. Kuehr and E. Williams, "Computers and the environment: understanding and managing their impacts," Springer Dordrecht Heidelberg New York London: Kluwer/Springer, 2003. http://collections.unu.edu/view/UNU:5657 100

R2 Standard—a call to action

The R2 Standard was developed in response to the growing challenges surrounding safe and sustainable management of used and end-of-life electronics. In 2005, the U.S. Environmental Protection Agency convened a multistakeholder process to create a voluntary, market-based mechanism for ensuring best practices in electronics recycling. What emerged from that process was the "Responsible Recycling practices for Use in Accredited Certifications Programs" (R2) Practices. First published in 2008, the R2 Standard set the industry bar for responsible electronics recycling.

A revision to the Standard (R2:2013) was released in 2013, with greater emphasis on testing and repair of used electronics. The positive impact of R2:2013 was twofold. In addition to the environmental benefits of extending the life of reusable products, responsible reuse has provided tremendous social benefits by helping to bridge the digital divide around the world through making affordable used devices accessible to people without the resources to purchase new products.

The most recent version of the Standard, R2v3, released in 2020, goes even further in raising the global bar with enhanced requirements for data security, traceability, downstream accountability, legal compliance, and environmental health and safety.

The R2 Standard continues to grow worldwide, with almost 1,000 R2 Certified facilities operating in 32 countries.

Sustainable Electronics Recycling International (SERI) is a 501(c)3 nonprofit organization and is responsible for the development and oversight of the R2 Standard. Through the R2 Certification Program and other initiatives, SERI works to create a world where electronic products are reused and recycled in a way that promotes resource preservation, the well-being of the natural environment, and the health and safety of workers and communities. Learn more about R2 and sustainable management of electronics at www.seriR2.org.

A global semiconductor shortage highlights a troubling trend: A small and shrinking number of the world's computer chips are made in the US

By Carol Handwerker

The global semiconductor shortage is driven by a combination of short-term and long-term factors both on the supply and demand side. FACerS Carol Handwerker takes a look at some of these factors.

President Joe Biden's executive order calling for a review of supply chains for critical products[1] put a spotlight on the decades-long decline in U.S. semiconductor manufacturing capacity. Semiconductors are the logic and memory chips used in computers, phones, vehicles, and appliances. The U.S. share of global semiconductor fabrication is only 12%, down from 37% in 1990, according to the Semiconductor Industry Association.[2]

It might not seem important that 88% of the semiconductor chips used by U.S. industries, including the automotive and defense industries, are fabricated outside the U.S. However, three issues make where they are made critical to the U.S. as the global leader in electronics: lower capability, high global demand, and limited investment.

Lower capability

The increasing reliance by U.S. chip companies on international partners to fabricate the chips they design reflects the United States' diminished capability. U.S. semiconductor companies have 47% of the global chip sales market, but only 12% are manufactured in the U.S. Meeting expectations for ever faster and smarter electronics requires chip design innovation, which, in turn, is dependent on the most advanced fabrication technologies available.

Advances in semiconductor fabrication are based on the number of transistors, the smallest of a chip's electronic components, per square millimeter. The most advanced semiconductor fabrication technologies and facilities, known as fabs, are labeled as 5 nanometers, or millionths of a millimeter. The number refers to the process rather than any particular chip feature. Generally, the smaller the nanometer rating, the more transistors per square millimeter, though it's a complicated picture with many variables.[3]

The highest transistor densities are about 100 million per square millimeter.

Taiwan and Samsung in South Korea are developing 3 nanometer fabs while the U.S. does not yet have a 7 nanometer fab. Intel has announced that its 7 nanometer fab won't be ready for production until late 2022 or early 2023.[4] This leaves the U.S. without the means to make the most advanced chips.

High global demand

With the pandemic, demand for cell phones, laptops and other work-at-home devices and increased use of the internet have put pressure on fabs to increase the number of chips they are delivering for these products. The global automotive industry predicted that demand for cars would fall during the pandemic, so it reduced its orders for semiconductors chips used in vehicle safety, control, emissions, and driver information systems. The auto industry has restarted production but is now faced with a shortage of semiconductor chips.[5]

Recently, eight state governors asked Biden to redouble efforts "to urge wafer and semiconductor companies to expand production capacity and/or temporarily reallocate a modest portion of their current production to auto-grade wafer production." This "modest" reallocation cannot be done without causing shortages elsewhere. And it cannot be done quickly. For example, Taiwanese semiconductor giant TSMC has reported a six month lead time from placing an order to delivery, and producing a chip is estimated to take up to three months.

Limited federal investment

The governments of Taiwan, South Korea, Singapore and China each invest tens of billions of dollars each year in their semiconductor industries and it shows. These investments include not just the facilities themselves but also the R&D and tool development necessary to move to the next generation of fabs. Such incentives in the U.S. remain minimal.

TSMC plans to invest US$25–28 billion this year in fabs alone and has promised to invest $12 billion for a fab in Arizona. To put this in perspective, the Arizona TSMC fab is expected to start processing 20,000 wafers a month, compared with the 1,000,000 wafers in existing TSMC facilities in Taiwan and China.

Biden's executive order about supply chains is an important step in determining the investments needed to improve the prospects for the U.S. semiconductor industry.

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Recommendations from the Biden-Harris Administration's 100-day supply chain review

By Lisa McDonald

On Feb. 24, 2021, President Joe Biden signed an executive order[a] requiring a 100-day review of the global supply chains in key industries. The action was spurred in part by the global semiconductor shortage, which began shortly after lockdowns were enacted in response to the coronavirus pandemic in spring 2020.

On June 8, the White House announced key findings from the 250-page review,[b] which assessed the supply chains for four critical products: semiconductor manufacturing and advanced packaging; large capacity batteries, such as those for electric vehicles; critical minerals and materials; and pharmaceuticals and active pharmaceutical ingredients.

The review identified eight cross-cutting risks that encompass most of the identified threats to semiconductor supply chains.

1. Fragile supply chains.
2. Malicious supply chain disruptions.
3. Use of obsolete and generations-old semiconductors and related challenges for continued profitability of companies in the supply chain.
4. Customer concentration and geopolitical factors.
5. Electronics production network effects.
6. Human capital gaps.
7. IP theft.
8. Challenges in capturing the benefits of innovation and aligning private and public interests.

The review included seven policy recommendations to address the current semiconductor shortage and the risks identified.

1. Promote investment, transparency, and collaboration, in partnership with industry, to address the semiconductor shortage.
2. Fund the Creating Helpful Incentives for Production of Semiconductors (CHIPS) for America provisions in the Fiscal Year 2021 National Defense Authorization Act (NDAA).
3. Strengthen the domestic semiconductor manufacturing ecosystem.
4. Support manufacturers, particularly small and medium-size businesses.
5. Build a diverse and accessible talent pipeline for jobs in the semiconductor industry.
6. Engage with allies and partners on semiconductor supply chain resilience.
7. Protect U.S. technological advantage in semiconductor manufacturing and advanced packaging.

As part of the review announcement, the White House said it will establish a Supply Chain Disruptions Task Force to address supply chain challenges in key sectors where "a mismatch between supply and demand has been evident." The task force will focus on "homebuilding and construction, semiconductors, transportation, and agriculture and food" and will be led by the secretaries of commerce, agriculture, and transportation.

[a]White House, "Executive Order on America's Supply Chains," February 24, 2021. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains

[b]White House, "Building resilient supply chains, revitalizing American Manufacturing, and fostering broad-based growth: 100-day reviews under Executive Order 14017," June 2021. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

From landfill to raw material:
Obtaining high-quality recycled cullet to avoid glass manufacturing problems

By Jacques van Putten

Netherlands-based cullet inspection company Flexty B.V. explains the benefits of using recycled glass in manufacturing and describes their approach to the cullet inspection process.

This article was originally presented at the 81st Conference on Glass Problems in Columbus, Ohio.[a] The 82nd Conference on Glass Problems will take place Nov. 1–4, 2021, in Columbus. Learn more at http://glassproblemsconference.org.

[a]J. van Putten, *Ceramic Transactions* Volume 269, 81st Conference on Glass Problems, pp. 93–99

Recycled glass over the years has evolved from waste to a sustainable raw material for the glass manufacturing industry. In many areas, recycled glass is the main component of the batch entering the melter.

The increased use of recycled glass introduced a variety of new quality and process challenges, not only in the manufacturing of container glass but also other glasses like float, lighting, and insulation fiberglass. The development of standardized audit methods to inspect recycled glass improved the cullet quality in a way that it can be used without the past problems.

This paper gives a short overview of the historic development of cullet usage in the Netherlands, a description of the recycling process, and a look at inspection methods developed to improve cullet quality. The execution of the inspection process by Flexty B.V. (Vlaardingen, the Netherlands) will be discussed, as well as the benefits for the glass industry, with an example of how cullet quality improved over time.

History of glass recycling in the Netherlands

The use of recycled glass in the glass industry dates back to ancient times,[1] but in the beginning, the process mainly involved internal scrap material. In the Netherlands, it was not until the 1970s that the use of externally generated cullet became more and more common.[1]

During the early years, companies needed a lot of advertising and promotion to collect glass for recycling instead of sending it to landfill. In the early 1970s, companies collected, broke, sieved, and manually cleaned glass for reuse.[1]

When first introduced in the melting process, this recycled cullet created a completely new set of problems in the glass industry.

Credit: O-I Manufacturing

Figure 1. Examples of cullet-related inclusions, from left to right: pottery, silicon sphere, and glass-ceramics.[6]

New kinds of inclusions, spontaneous seeds, blister flurries, and color mismatches occurred (Figure 1). These issues were mainly caused by inhomogeneous color distribution in the mixed cullet, and contamination of the cullet with metals, ceramics, stones, organic materials, paper, and plastics. As a result, new products could consist of up to a maximum of 20% recycled cullet to ensure proper glass quality was achieved.[2]

A secondary problem occurred because the flue gas composition changed, resulting in different emissions of CO_2, SO_x and NO_x.[3] More furnaces also experienced glass leaks through the melter bottom as a result of the metal pollution in the cullet. Additionally, the life of many furnaces was shorter than expected as a result of increased carryover from the fine particles in the cullet.

To combat these problems, the Dutch glass industry teamed up with recycling companies and the Netherlands Organization for Applied Scientific Research (TNO with Prof. Dr. Ir. Ruud Beerkens) to develop measurement methods to quantify the cullet quality. TNO also helped with the development of measuring methods for the composition of the flue gases.[4]

The Dutch government also recognized the importance of recycling glass and started to provide grants for the development of the glass recycling processes.[1] As a result of quick developments and investments, the use of recycled cullet went up to 80% for all of the one-way glass packaging bottles and jars in the Netherlands.[1]

Glass plants in Europe now use between 30–85% of recycled cullet, depending on availability of the external cullet and glass color produced.[2] This recycling rate prevents more than 400,000 tons of residual waste going to landfill every year. For the glass industry, the increased recycling resulted in lowering the use of raw materials and improving the energy efficiency of glass manufacturing.

In the 1990s, successful trials produced glass made from 100% color-separated recycled cullet in green and amber. However, due to the low availability of high-quality, one-color cullet, this process could not be sustained.[5]

The recycling process

The raw cullet as collected from consumers and industry is contaminated with a lot of waste, such as plastic bags, plastic bottles, bottle caps, metals, china, and pottery. Also, materials that in appearance look similar to glass, like glass-ceramic cookware, are considered contamination because these materials do not melt completely in container glass melters and cause inclusions, among other issues. The total amount of these contaminants reached values of up to 50 kg per ton of glass.

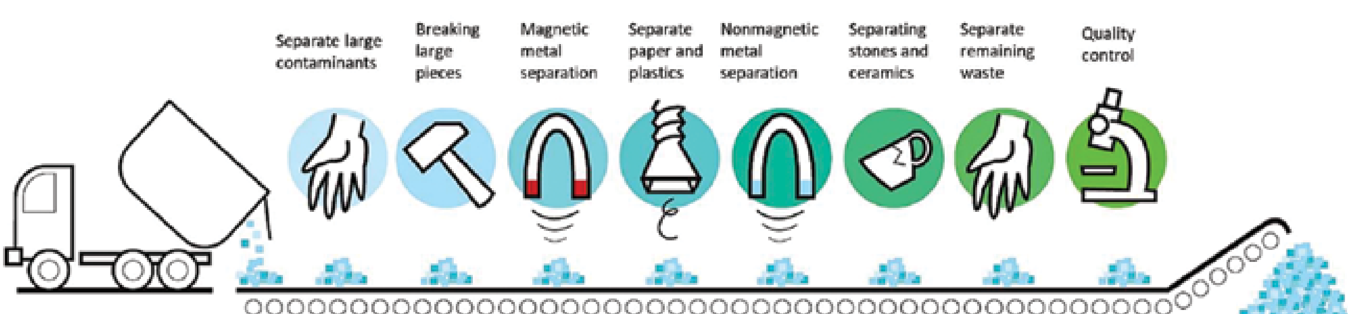
With state-of-the-art technology involved in the recycling and refinement process (Figure 2), the raw cullet can be treated and cleaned into usable cullet for the glass melting process, with low amounts of contamination. For example, less than 15–25 grams/ton of pottery and china contamination, and less than 2 grams/ton of (non)ferrous metal contamination.

The success of recycling container glass led to the recycling of other glass types, such as windowpanes and car windshields. In addition, there are other innovative developments, such as 1) specialized machines for glass recycling developed by companies like Binder, Red Wave, Morgenson, and many others to separate contaminants like stones and nonferrous/nonmagnetic metals from the cullet stream; and 2) more environmentally friendly labels and prints used on bottles and jars.[2]

These developments all resulted in Europe having many countries that collect over 80% of the glass packaging sold, separated from the overall household waste stream.

The major advantages of using recycled glass are

- The reduction of landfill;



Credit: VGN Website

Figure 2. Typical recycling process.[1]

a)

b)

Credit: Flexty B.V.

Figure 3. (a) Result of color distribution inspection and (b) Result of findings from contamination.

- Improved energy efficiency (on a verage, a 2.5% energy efficiency increase for every 10% of cullet replacing raw materials);
- Possible increase of specific pull by using recycled cullet;
- Improved image of glass as a recyclable material, reducing the use of natural resources; and
- Reduction of greenhouse gas emissions.

The inspection process

Why is a reliable, reproducible inspection process required?

A well-known saying states "garbage in, garbage out," so it is imperative that the cullet used as a raw material is of excellent quality. Although the high temperatures in the glass melting furnace can take care of some of the recycled cullet quality issues, it cannot "dissolve" them completely. So, each glass manufacturer will have its own quality control for the incoming recycled glass, with corresponding specifications the cullet has to meet like their raw materials. Also, the glass recycling companies will have their own quality checks and specifications.

To support both glass manufacturing industry and cullet processing companies, researchers developed methods, supported by R&R studies, in the past 50 years that make it possible for batches as large as 1,500 metric tons to be measured and inspected, providing reliable quality information about the processed cullet.

The method adopted by Flexty B.V., an independent company that performs cullet inspections for both the glass manufacturers and the recycling companies, was developed in collaboration with Owens-Illinois, Inc. (Perrysburg, Ohio), a leading manufacturer of glass packaging products. Most of the time our standard method is used, with some minor adjustments, because of the proven reliability of the test results. However, with our experience and expertise, we also work together with our customers to further develop and improve the inspection method.

What does a Flexty B.V. inspection process look like?

At the time of the inspection, the inspector should see through the eyes of the customer. In other words, besides the assessment of the recycled cullet quality, the cullet storage area is audited as well. The glass storage bins, boxes, or compartments are therefore critically examined. For example, an inspector will consider questions like

- What do the floors and walls of a compartment look like, are they damaged?
- Are there any holes in the containment walls that could cause cross contamination between batches?
- Is there a lot of dirt/waste found near the cullet piles? What could possibly be blown in by the wind?

More critical questions are asked for a more thorough examination.

When it comes to inspecting the lot, the inspector will walk over the entire lot looking for

- The color distribution and homogeneity of the lot,
- Cullet size distribution and homogeneity of the batch, and
- Contamination on the batch itself.

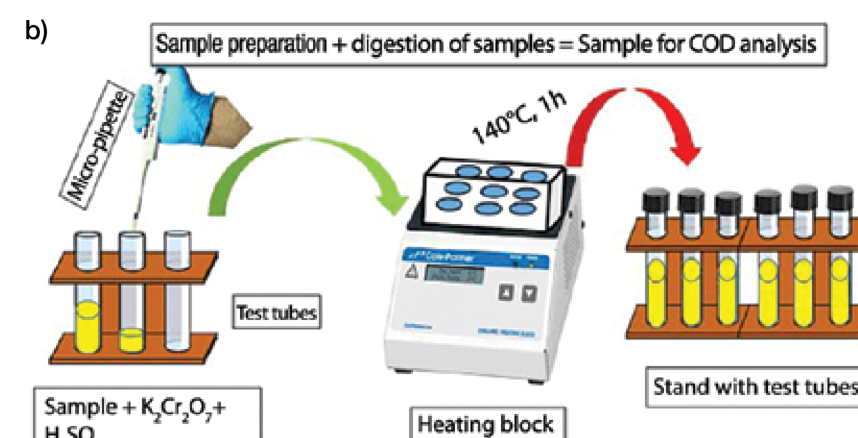
The inspector collects all found contaminants and takes photographs of the contamination and other anomalies found and adds these to the final report.

How is the sampling done?

The operating procedure states the exact size of the samples to be taken from the lot. The samples are usually collected as a percentage of the lot size or as a pre-

a)

b)



Credit: Flexty B.V.

Figure 4. (a) Glass melting test and (b) chemical oxygen demand measurements

determined weight. The inspector will put out sample buckets across the entire batch.

When filling the buckets, the inspector will first remove three large scoops of glass from the surface of the batch and only fill the buckets from scoop four and onwards. In this way, the samples are taken from within the lot and not directly from the surface. Then a shovel truck will dig out a significant amount of material from the middle of the batch or lot, and final samples will be taken from a deeper place inside the batch.

The inspection of the samples is performed in a fully equipped truck, which functions as a mobile inspection laboratory. In the laboratory, the glass is transported by a frequency-controlled vibrating chute on a frequency-controlled conveyor belt. This process creates a single layer of glass fragments so any contamination can be collected with optimal efficiency. All contaminations are collected, weighed per type, and converted to a weight per ton for the report. Then the total sample is thoroughly mixed and resampled for an extensive sieve and color distribution analysis (Figure 3).

All findings are recorded in the inspection report. Pictures of all findings are added to the report. The inspector will immediately print out the report and hand it over to the customer if the customer is the cullet processing company. That same day, the report will be emailed to all parties involved, the glass manufacturer, and the cullet supplier.

In addition to the onsite inspection, chemical oxygen demand measurements and loss on ignition determination can be performed to determine the level of organic contamination (Figure 4). Because of the high carbon content, this organic contamination can cause seeds, blisters, and even coloring issues during the manufacturing process of new glass. The amount of cullet fines has increased significantly in the last years, and especially organic contamination is an issue in this fine cullet.

All specifications on stone, color, fines, metals, and organics were developed over many years, based on the issues found in the glass melting process.

Improvements in cullet quality

By inspecting the recycled glass, the glass melting process will benefit enormously from improved energy efficiency and glass quality. Also, the recycling companies will benefit because their outgoing materials will have an improved quality, and the materials are not expected to cause process issues for the customers because any possible quality issues were caught onsite.

Because of the cullet audits at the supplier's site before shipping cullet to the manufacturers, the trend of the supplied cullet quality at the glass manufacturers improved significantly in the past 10 years. The graphs in Figure 5 report on the cullet quality improvements (5a) and rejection rates (5b) of cullet deliveries of the Ardagh Group (Dublin, Ireland) over the past 10 years.[7]

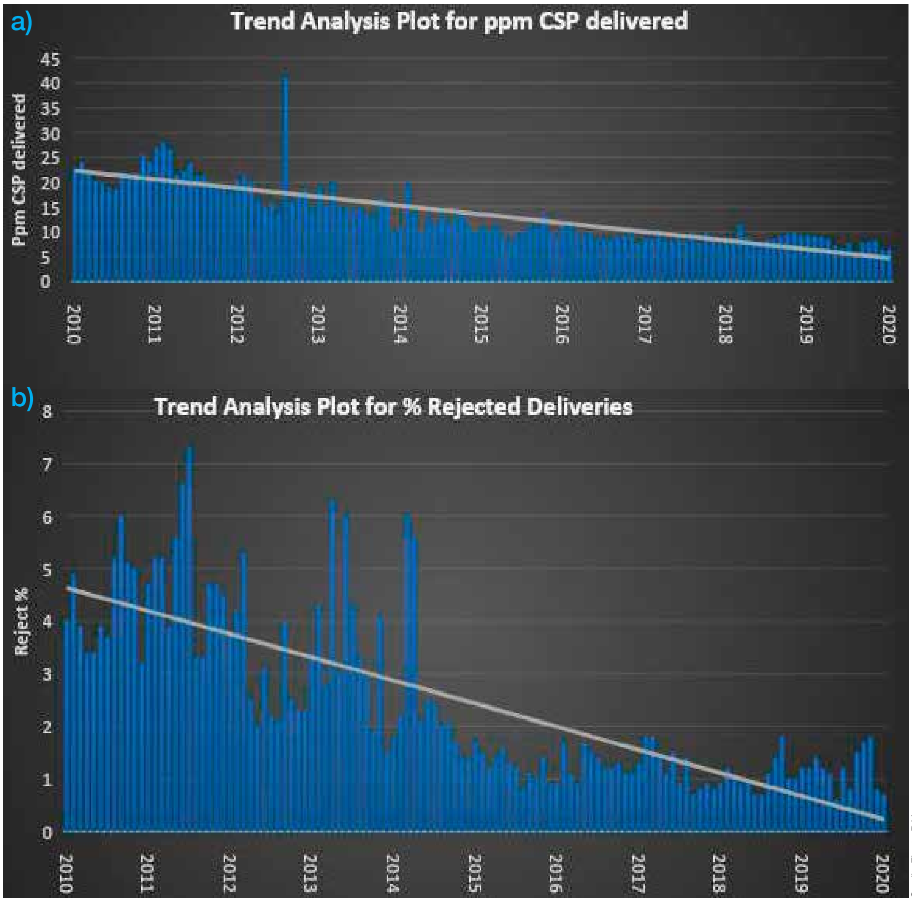


Figure 5. (a) Trend on cullet quality improvements and (b) Trend on cullet batch rejection rates for the Ardagh Group.

Further developments

In recent years, glass-ceramics became more of a problem in the recycling and glass manufacturing process, causing a decline in the use of processed external cullet.

Glass-ceramic products are very popular with consumers, and because of their appearance, the consumer recycles these products the same way as their glass packaging materials. However, because the glass-ceramics industry is developing more heat-resistant products, these materials will not melt in the packaging glass melting furnaces, causing not only inclusions in the containers but sometimes also machine stops, reducing the efficiency of the production process.

Flexty B.V. is working together with the glass-ceramics industry to determine what the possibilities are to detect and separate these types of glass from the soda–lime glass so that recycled glass remains the number one raw material for the glass industry.

Conclusions

There are several advantages of using recycled glass, such as higher energy efficiency, less landfill, less use of natural resources, and lowering of flue gas emissions. However, the recycled glass needs to be of a quality so that it does not introduce problems during the glass manufacturing process. Therefore, the recycled glass needs to be intensely inspected before shipping as well as randomly on arrival.

An independent cullet inspection company will provide unbiased information on the actual cullet quality, as well as provide reliable inspection reports. Also, recommendations for upgrading storage places and agreeing to a clear procedure with benefits for all parties can be achieved, and an independent inspection company can mediate the discussions and improve cooperation.

When there is more trust in cullet quality, more cullet can and will be used in the glass batch. This usage will result in lower CO_2 emissions, more efficient energy use, improved furnace life, and a green image for the glass, with less inclusions in the end product and thus better productivity and yield. Flexty B.V. is here to help you, and together we will build a better glass recycling industry from which we all can benefit while contributing to greener and more sustainable ways of manufacturing.

Figure 6. One of the Flexty inspection buses.

Credit: Flexty B.V.

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US continues exploring ways to reduce reliance on critical minerals amid COVID-19 pandemic

By Lisa McDonald

Even as the COVID-19 pandemic majorly affected industries around the world, the United States government continued researching ways to reduce reliance on foreign sources for critical minerals, as described in the annual United States Geological Survey *Mineral Commodity Summaries* report.[1]

The *Mineral Commodity Summaries* spotlights the events, trends, and issues that took place the previous year in the nonfuel mineral industry. Every August the *ACerS Bulletin* provides a look at some of the key facts covered in the report, which includes statistics on production, supply, and overall market for more than 90 minerals and raw materials.

In 2020, the estimated total value of nonfuel mineral production in the United States decreased by 2% from 2019 to $82.3 billion. The total value of industrial minerals production decreased as well, by 4% to $54.6 billion. Of this total, $27.0 billion came from construction aggregates production. Crushed stone accounted for the largest share of total U.S. nonfuel mineral production value in 2020 with 22%.

Last year saw decreases in consumption of nonfuel mineral commodities in the commercial construction, oil and gas production, steel production, and automotive and transportation industries due to the financial impacts of the global COVID-19 pandemic. For the metals sector, the aluminum, iron ore, steel, and titanium industries were particularly affected by reduced demand from manufacturing. In general, mines were not subject to COVID-19-related stay-at-home orders because they were deemed critical industries, but decreased demand from downstream industries resulted in reduced production at some operations.

The United States implemented additional import duties in 2020 for certain products that were derivatives of aluminum and steel articles. These duties continued for most countries as a result of the U.S. Department of Commerce findings in 2018 of harm to national security under section 232 of the Trade Expansion Act of 1962. Likewise, the European Union imposed additional duties on approximately $4 billion of imports from the United States while China imposed additional tariffs on approximately $77 billion of U.S. imports.

In February 2020, the U.S. Geological Survey published a new methodology[2] to evaluate the global supply of and U.S. demand for 52 mineral commodities for 2007–2016. It identified 23 mineral commodities—including aluminum, antimony, bismuth, cobalt, gallium, germanium, indium, niobium, platinum-group metals, rare-earth elements, tantalum, titanium, and tungsten—as posing the greatest supply risk for the U.S. manufacturing sector. On September 30, Executive Order 13953 was issued to address the national emergency described.[3]

The U.S. continues to rely on foreign sources for raw and processed mineral materials. In 2020, imports made up more than one-half of the U.S. apparent consumption for 46 nonfuel mineral commodities, and the U.S. was 100% net import reliant for 17 of those. Fourteen of the 17 mineral commodities with 100% net import reliance were listed as critical minerals, and 14 additional critical mineral commodities had a net import reliance greater than 50% of apparent consumption.

On the next two pages, an infographic summarizes some of the salient statistics and trends for a handful of mineral commodities that are of particular interest in the ceramic and glass industries. Readers are encouraged to access the complete USGS report at https://doi.org/10.3133/mcs2021.

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USGS MINERAL COMMODITY SUMMARIES

BAUXITE AND ALUMINA

Leading producer

Bauxite: Australia

Alumina: China

End use industries
Abrasives, cement, chemicals, proppants, refractories, slag adjuster in steel mills

Trend in global production
2.3% increase for alumina; 3.6% increase for bauxite

U.S. production
1.3 million tons of alumina

U.S. import/export
>75% net import reliance for bauxite; 49% net import reliance for alumina

World reserves
55 to 75 billion tons of bauxite

BORON

Leading producer

Turkey

End use industries
Glass, ceramics, abrasives, cleaning products, insecticides, insulation, semiconductors

Trend in global production
Cannot be calculated

U.S. production
Withheld

U.S. import/export
Net exporter

World reserves
Adequate

CEMENT

Leading producer

China

End use industries
Construction

Trend in global production
No change

U.S. production
89.0 million tons of cement; 79.0 million tons of clinker

U.S. import/export
15% net import reliance

World reserves
Raw materials are abundant

CLAYS

Leading producer

Kaolin: United States

Bentonite: United States

End use industries
Tile, sanitaryware, absorbents, drilling mud, construction, refractories, paper, absorbents

Trend in global production
1.8% decrease for bentonite; 3.8% increase for Fuller's earth; 0.7% decrease for kaolin

U.S. production
25.0 million tons (49.0% common clay; 18.8% kaolin; 17.6% bentonite; 14.5% other)

U.S. import/export
Net exporter

World reserves
Extremely large

FELDSPAR

Leading producer

Turkey

End use industries
Glass, tile, pottery

Trend in global production
No change

U.S. production
420,000 tons (marketable production)

U.S. import/export
13% net import reliance

World reserves
More than adequate

GALLIUM

Leading producer

China

End use industries
Integrated circuits, optoelectronic devices

Trend in global production
14.5% decrease

U.S. production
none (primary)

U.S. import/export
100% net import reliance

World reserves
Estimate unavailable

GRAPHITE (NATURAL)

Leading producer

China

End use industries
Brake linings, lubricants, powdered metals, refractory applications, steelmaking

Trend in global production
No change

U.S. production
none

U.S. import/export
100% net import reliance

World reserves
>800 million tons

INDIUM

Leading producer

China

End use industries
Flat-panel displays, alloys, solders, semiconductors

Trend in global production
7.0% decrease

U.S. production
none

U.S. import/export
100% net import reliance

World reserves
Estimate unavailable

IRON AND STEEL
Leading producer: China

End use industries
Construction, transportation (auto), machinery, equipment, energy

Trend in global production
6.3% decrease for pig iron; 3.2% decrease for raw steel

U.S. production
18 million tons of pig iron; 72 million tons of steel

U.S. import/export
12% net import reliance

World reserves
Not applicable

KYANITE
Leading producer: South Africa

End use industries
Refractories, abrasives, ceramic products, foundry products

Trend in global production
Cannot be calculated

U.S. production
85,000 tons

U.S. import/export
Net exporter

World reserves
Significant

LITHIUM
Leading producer: Australia

End use industries
Batteries, ceramics, glass, grease

Trend in global production
4.7% decrease

U.S. production
Withheld

U.S. import/export
>50% net import reliance

World reserves
Significant

NIOBIUM
Leading producer: Brazil

End use industries
Steel industry, aerospace alloys

Trend in global production
19.6% decrease

U.S. production
none

U.S. import/export
100% net import reliance

World reserves
More than adequate

RARE EARTHS
Leading producer: China

End use industries
Catalysts, ceramics, glass, metallurgical alloys, polishing

Trend in global production
9.1% increase

U.S. production
38,000 tons (bastnaesite and monazite concentrates)

U.S. import/export
100% net import reliance for compounds and metals; net exporter of mineral concentrates

World reserves
Relatively abundant in earth's crust, but minable concentrations less common

SODA ASH
Leading producer: United States

End use industries
Glass, chemicals, distributors, soap, detergents

Trend in global production
8.5% decrease

U.S. production
9.7 million tons

U.S. import/export
Net exporter

World reserves
Practically inexhaustible

TITANIUM DIOXIDE (PIGMENT)
Leading producer: China

End use industries
Paints, plastic, paper, catalysts, ceramics, coated textiles, floor coverings, inks, roofing granules

Trend in global production
Not available

U.S. production
1.0 million tons

U.S. import/export
Net exporter

World reserves
Estimate unavailable

YTTRIUM
Leading producer: China, Myanmar

End use industries
Abrasives, bearings and seals, high-temperature refractories, jet engine coatings, metallurgy, phosphors

Trend in global production
Not available

U.S. production
Not available

U.S. import/export
100% net import reliance

World reserves
Reserves are adequate, but worldwide issues may affect production

ZEOLITES (NATURAL)
Leading producer: China

End use industries
Animal feed, odor control, water purification, absorbent, fertilizer, pesticide

Trend in global production
0.9% increase

U.S. production
88,000 tons

U.S. import/export
Net exporter

World reserves
Estimate unavailable

By Shashank Priya and Eckhard Quandt

Penn State – American Ceramic Society – University of Kiel (PACK) Fellowship Program

Pre-COVID, the National Science Foundation (NSF) awarded funding to The Pennsylvania State University for the PACK Fellowship Program, run in collaboration with The American Ceramic Society and the University of Kiel (U Kiel), Germany. This fellowship program provides opportunities for graduate students in the United States to travel to Germany and conduct cutting-edge research on magnetic field sensing, biomedical systems, and neuromorphic computing at U Kiel.

The American Ceramic Society administers the program, managing the student selection process, international network formation and collaboration, and sustainability of the PACK Fellowship. At U Kiel, dozens of faculty and more than 50 graduate students and postdoctoral fellows support the visiting U.S. students, who conduct extensive research on materials design, nanotechnology, and surface sciences using dedicated infrastructure along with specialized equipment. This level of support provides tremendous opportunity for the U.S. students and faculty to build a partnership with an excellent cluster of scientists and engineers at U Kiel and collaborations throughout Europe.

Other objectives in this program are to widen the graduate students' horizons beyond their individual scientific projects and to extend their knowledge beyond the general approach of the graduate degree. These objectives are being pursued by activities for peer-based knowledge transfer, scheduled interdisciplinary seminars, participation at conferences, and regularly scheduled retreats. The students become acquainted with a translational research approach through lectures and workshops with guests from external companies and through the training program provided by the Center for Entrepreneurship at U Kiel.

The first cohort of students who visited U Kiel included Daniel Fortino, Penn State; Alexei Matyushov, Northeastern University; George Kotsonis, Penn State; and Ryan Thackston, University of Houston. These students received training on topics related to

PACK Fellowship and CIREP draw on diverse talents

The PACK Fellowship and CIREP workshop are more possible through the ongoing collaboration and contributions of faculty and staff at The Pennsylvania State University, University of Kiel, and The American Ceramic Society. The success of the program reflects their dedication to advancing the vision and goals of the program.

- Penn State faculty
  L.Q Chen, Robert Crane, Jian Hsu, Michael Lanagan, J.P. Maria, Shashank Priya, Clive Randall, Susan Trolier-McKinstry
- Penn State staff
  Jennifer Leedy, Katina Posney, Sadie Spicer
- University of Kiel, Germany
  Rainer Adelung, Franz Faupel, Jeffrey McCord, Eckhard Quandt, Gerhard Schmidt, Christine Selhuber-Unkel, Stephan Wulfinghoff
- The American Ceramic Society
  Marcus Fish

brain computer interfaces using magnetic sensors[1] or limit of detection and noise of magnetoelectric MEMS magnetometers.[2] The PACK students obtained first-hand insight into the alternative modes of operation of foreign research institutions and differences in scientific and work cultures. Furthermore, the visits provided the opportunity to take a first step in building an international scientific network for a future academic or professional career.

Credit: Shashank Priya

PACK mentors and students. Left to right: Phillip Durdaut, Nancy Smith, Alexei Matyushow, Eckhard Quandt, Jeffrey McCord, Christine Selhuber-Unkel, Franz Faupel, Shashank Priya.

Celebrating International Research and Education Partnerships (CIREP) workshop

In scientific research and industrial R&D activities, international partnerships greatly facilitate knowledge flow, enabling researchers to share their ideas and study complex subjects from multiple perspectives, resulting in innovative pathways for solving cross-disciplinary topics. Such partnerships provide a mechanism to break the resource limitations on expertise, facilities, funding, and talent to tackle challenging scientific problems, which further helps to maximize the outcome of individual researchers by scaling up the input in a collaborative environment.

International collaboration has proven necessary on many large and complex projects, with the European Council for Nuclear Research (CERN) and the Human Genome Project being two prime examples in the 21st century.[3] There also are promising examples of currently active projects, such as the African Coalition for Epidemic Research, Response and Training and the Partnerships for Enhanced Engagement in Research, a model of a North–South scientific collaboration during the coronavirus outbreak.

Recent statistics further show that among multiple disciplines, large teams with a background in international cooperation are often the fastest growing modes for research capabilities and output. The most striking feature is that the research outcomes are often related to number of collaborators and geographical locations.[4] For multinational enterprises, partnerships enable establishment of new opportunities for industry through participation in global value chains and access to new and emerging markets.[5]

Researchers have found that exposing students (via student exchange programs) to the international research community at a critical stage in their careers serves to establish international networks to bolster their professional development and allows them to leverage domestic and international resources for maximum benefit.[6] The American Council on Education has considered joint education an effective way of deepening ties with partners abroad, increasing mobility and building global competence among faculty and students while advancing institutional internationalization more broadly.[7]

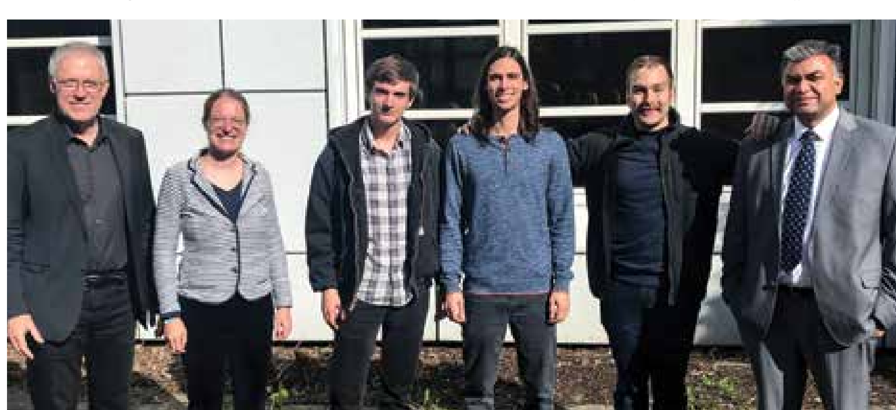
In alliance with The American Ceramic Society and Johns Hopkins

PACK research at U Kiel

Magnetic measurements have the potential to improve diagnosis and analysis of complex human diseases by supplementing established electrical measurements, such as the electroencephalography or the electrocardiography. This area is rich for interdisciplinary student training activities covering materials, signal processing, computation, and biology.

PACK Fellows at U Kiel are conducting extensive research on materials design, nanotechnology, and surface sciences for use in the emerging field of biomagnetic field sensing. Ongoing programs at U Kiel provide opportunities to systematically investigate nanocomposite and thin film composite materials that can respond to small magnetic signals emitted from brain and heart, release drugs for treating brain diseases, and provide memristive devices for neuronal systems.

Different sensor approaches are being designed and manufactured based on magnetoelectric sensors with the ability to reach a limit of detection suitable for biomagnetism, resulting in the development of closed-loop, uncooled, biomagnetic interfaces for diagnostics and immediate treatment. In addition, based upon the understanding of neural functioning, memristive controllers are being designed to provide ultralow power computation.



Credit: Shashank Priya

PACK students from first cohort with project leads. Left to right: Eckhard Quandt, Christine Selhuber-Unkel, Daniel Fortino, George Kotsonis, Ryan Thackston, Shashank Priya.

Penn State – American Ceramic Society – University of Kiel (PACK) Fellowship

University, The Pennsylvania State University is advocating the value of global collaborations in research and education. As part of this goal, one of the major outcomes of the PACK Fellowship program is the annual Celebrating International Research and Education Partnerships (CIREP) workshop.

The themes of the CIREP workshop include promoting the international relationships, sharing learnings and outcomes, identifying barriers in global engagement, and developing strategies to address them. The workshop discussions address topics such as developing uniform policies and guidelines; enhancing the impact of federally funded centers (e.g., NSF I/UCRC, ERC); establishing joint centers in partnership with multinational corporations for promoting global workforce development as well as international networking and collaboration; and providing opportunities for research and development in emerging countries. The workshop provides opportunities for discussing strategic approaches, policy, and regulations, which will play a vital role in strengthening the global partnerships.

We believe that the CIREP workshop will become a leading platform for administrators and managers to discuss the policies, models, and framework related to promotion of international partnerships.

Acknowledgement

The PACK Fellowship program is supported by NSF Award #1829573.

About the authors

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[1]http://www.sfb1261.de/index.php/en/team-en/visiting-external-students/research-visit-ryan-thackston

[2]http://www.sfb1261.de/index.php/en/team-en/visiting-external-students/research-visit-alexei-matyushov

[3]Smith, C. L., "Knowledge, networks and nations: Global scientific collaboration in the 21st century," Royal Society report on the state of global science

[4]Hsiehchen, H., Espinoza, M., and Hsieh, A., "Multinational teams and diseconomies of scale in collaborative research," *Science Advances*, 18 Sept. 2015, Vol. 1, no. 8, e1500211

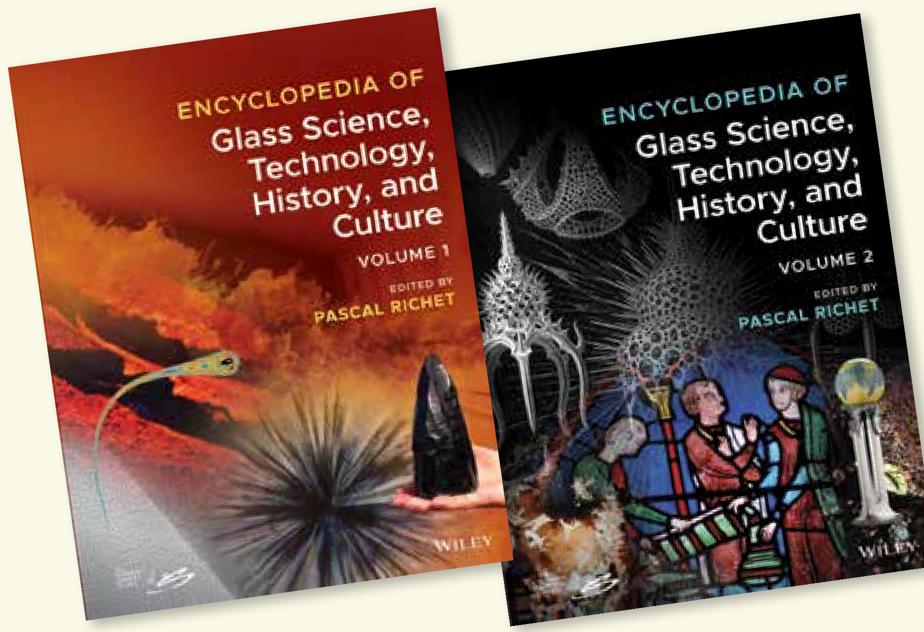
[5]Jaruzelski, B., Schwartz, K., & Staack, V. (2015). "The 2015 global innovation 1000: innovation's new world order," (Study report) http://www.strategyand.pwc.com/reports/2015-global-innovation-1000-media-report. (Accessed 3 Dec. 2016)

[6]Program Solicitation NSF 20-598: International Research Experiences for Students (IRES)

[7]Mapping Internationalization on U.S. Campuses, 2017 Edition, The American Council on Education 100

Mario Affatigato
Guest columnist

Review of *"Encyclopedia of Glass Science, Technology, History, and Culture"*



The two-volume *Encyclopedia of Glass Science, Technology, History, and Culture*, edited by Pascal Richet, is a rich compendium of information spanning a vast number of aspects of the use of glass as a material.

The two volumes cover essential information on the structure of glass and its industrial applications and also contain articles on topics as diverse as electrochemistry, glass-metal interactions, displays, natural glasses, dental glass-ceramics, and glass in architecture. The length of the articles is appropriate (on the order of 15–20 pages), providing a valuable amount of information that can be read in one sitting. The work is divided into 10 themes, namely glassmaking, the physics and (separately) the chemistry of glass, inorganic and (separately) organic glass families, history, and other individual sections on structure, transport, environmental issues, and glass and light.

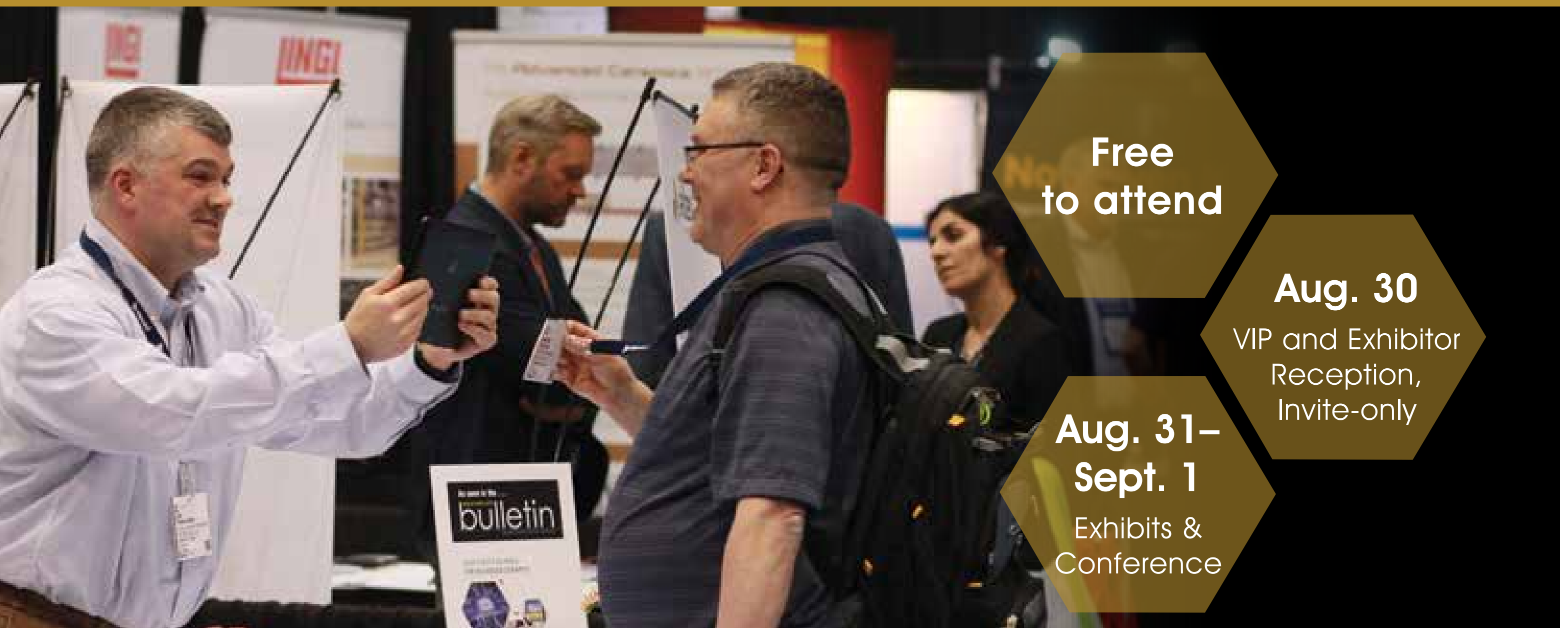
Many readers will find the content—especially many of the diagrams—quite useful in their work or even as new, additional subject matter for lectures and presentations. Among the many discussions that this reviewer found particularly interesting are the role of glass vibrations on the heat capacity at cold temperatures (I; 3.4), the coverage of radiative heat transport (I; 4.5), the presentation of corrosion of natural glasses in seawater (II; 7.3), the novel chapter on glass and the philosophy of matter in antiquity (II; 10.4), and the wonderfully illustrated chapter on biogenic silica (II, 8.1). For an academic reader who lectures on glass, the chapters on industrial processes will be quite helpful. For a student, the chapters on the basics of glass formation and structure, glass crystallization, network simulations, and the numerous articles on properties, characterization, and applications will provide a great introduction to the foundations of the field. Not to mention the fascinating piece on extraterrestrial glasses!

The authors of the articles are practitioners in the field, and the geographical distribution is impressive. Thus, the coverage of themes is excellent, and the articles tend to be written by active experts on the topic. The work is indeed encyclopedic in its topical coverage, making the volumes extremely important if not indispensable. It must be noted the printed version contains images in black and white only, while the electronic version has color figures. As many of the pictures of the historical and artistic glass are best viewed in color, the reader may want to consider this difference.

The only caveat for the reader would be the inevitable consequences of an encyclopedic work. At times, the articles can be too brief for someone seeking a more profound treatment of a topic, but this drawback can be remedied by careful use of the citations given in each article. Looking at the two volumes as a whole, the organization of the themes is logical. Still, it can result in some needed information being presented in one chapter after it is already used and discussed in a previous article. At other times, similar articles are quite apart—complex silicates are covered in the sixth chapter of Volume I, while borosilicates are in the sixth chapter of Volume II. This disconnect is inevitable in such a comprehensive work and should not be considered a negative. Instead, the reader should explore the information in this wonderful set of books as needed, looking up unknown material as it arises in relevant chapters.

***Mario Affatigato is Fran Allison and Francis Halpin Professor of Physics at Coe College in Cedar Rapids, Iowa, and editor-in-chief of the* International Journal of Applied Glass Science.**

Aug. 30–Sept. 1, 2021 Cleveland, Ohio, USA



ceramics expo—Enabling a clean, efficient and electrified future

Founding partner
The American Ceramic Society

Why should you attend the conference?

Engage with experts from across the supply chain to understand the latest developments in ceramic materials.

Learn about what's driving the market and get ahead of the curve by gaining a competitive advantage.

Transform your understanding by exploring how to become more efficient in an evolving and forward-thinking industry.

Connect with peers to form valuable business networks and collaborate on ceramic innovations of the future.

Ceramics Expo is the leading event for the advanced ceramics and glass supply chain, bringing together engineers, decision makers, and buyers from the advanced ceramics and glass supply chain and end-user OEMs. It attracts more than 2,000 visitors, 250+ exhibitors, and 30+ leading speakers to its specialist conference stages at Cleveland's The Huntington Convention Center. The event is a platform for the industry to share technical expertise in ceramics with real-world case studies, cutting-edge new technologies and materials, along with the very latest industry trends.

When ACerS came on board as a founding member of Ceramics Expo and the *Bulletin* was named as its official magazine, we could not have anticipated how fervently we would be looking forward to re-uniting in August 2021 in Cleveland, Ohio, after a year when much of life and business was put on pause.

Now, for the first time in its history, Ceramics Expo is being held at a new venue—The Huntington Convention Center—in the heart of downtown Cleveland. The large venue will enable seamless safety measures for Ceramics Expo visitors, including floor plan changes to accommodate social distancing between its 250+ exhibitors. Leaders in the ceramics and advanced materials space including NASA, McDanel Advanced Ceramic Technologies, Fiven, Kyocera, and Ferro are all signed up to attend.

"This is the largest in-person event for the global ceramics industry in 2021. We're very proud to have retained over 80 percent of our exhibitors—which is not only a testament to the resilience of the industry, but a hopeful sign that we're going to continue to grow post-COVID. We're really looking for-

CERAMICS EXPO CONFERENCE AGENDA AT-A-GLANCE

Day 1 – Sustainability and Innovation – Tuesday, Aug. 31

10:30 a.m.	Panel Discussion: Reimagining the Supply Chain: Lessons for Efficiency in the Wake of the COVID-19 Pandemic
11:55 a.m.	Panel Discussion: Towards Sustainability: Facilitating Environmentally Friendly Practices Whilst Maintaining Optimum Productivity in the Ceramics Industry
1:10 p.m.	Panel Discussion: Examining the Capabilities of Redox Flow Batteries for the Future of Energy Storage
2:30 p.m.	Panel Discussion: Understanding the Implications of Emission Control Regulations on Catalytic Conversion Technology
3:50 p.m.	Panel Discussion: Unlocking Innovation Through Closing the Gender Gap in the STEM Industry

Day 2 – Materials and Processing – Wednesday, Sept. 1

9:20 a.m.	Panel Discussion: Bridging the Gap Between Research and Development and Commercial Viability for Ceramic Additive Manufacturing
10:45 a.m.	Panel Discussion: Breaking Down the Barriers of Entry for Ceramic Matrix Composites
12:40 p.m.	Presentation: Innovations in Sintering: Improving Efficiency in Processing
1:00 p.m.	Presentation: Phase Quantification and Microstructural Analysis of Ceramics via Powder X-ray Diffraction (PXRD)
2:00 p.m.	Panel Discussion: Improving Properties of Ultra-High Temperature Ceramics for Hypersonic Applications
3:20 p.m.	Panel Discussion: Enhancing Ceramic Materials for the Advancement of 5G Technology

ward to reuniting with our peers, colleagues, friends and customers face-to-face in August," says Raymond Pietersen, event director at Ceramics Expo.

Mark Mecklenborg, ACerS executive director, adds, "With exceptional opportunities for collaboration, Ceramics Expo plays a pivotal role in gathering all the leading stakeholders in our industry. I'm thoroughly looking forward to meeting everyone in the new venue, with renewed energy and focus following the challenges of 2020."

Ceramics Expo offers unparalleled access to the latest materials specifications and capabilities as the supply chain reunites to explore the future of materials development. A pass to the free-to-attend event includes access to the exhibition hall, which displays the innovations and technologies that are changing the future of advanced ceramics and offers the opportunity to meet the entire supply chain under one roof.

Exhibitors include Fiven, Imerys, Goodfellow Corp, XJet, Corning Incorporated, Kyocera, ZEISS, and more key players in the sector.

The 2021 conference program theme "Enabling a clean, efficient and electrified future" will see more than 30 speakers tackle the most pressing industry and supply chain challenges, with experts discussing sustainability, diversity and inclusion, industrial applications, and resilience post COVID-19. The conference stage will host dynamic panel discussions on areas such as additive manufacturing, the role of ceramics in 5G, and energy storage. Speakers include eminent voices from global companies and academia, such as Northrop Grumman, Skyworks, GE Aviation, and CoorsTek, among others.

Join us in August at Ceramics Expo in Cleveland, Ohio. You can pre-register now for the free-to-attend exhibition at https://www.ceramicsexpousa.com.

Need more reasons to visit?

Source cutting-edge advanced ceramics materials and technologies from 250+ leading suppliers and manufacturers.

Understand the latest industry developments from 30+ expert speakers and game-changers.

Gain a 360° view of the ceramic materials market, including new material formulations and the future material requirements of end-user markets.

Generate valuable business connections with the Ceramics Expo B2B Matchmaking service.

Experience high-level presentations focused on the sustainability and efficiency opportunities of advanced ceramics.

Locate new solutions to technology development and implementation, cost reduction, and scaling-up of manufacturing processes.

Evaluate the use cases of the latest products and services thanks to the live demos and showcases.

Network with your peers from across the advanced ceramics value chain, from manufacturers and suppliers to major end-users from the aviation, automotive, energy, medical, and electronics sectors.

Learn the latest innovative forming processes for unique geometries and high surface area parts.

JOIN US FOR ACerS 123RD ANNUAL MEETING!

Technical Meeting and Exhibition

MS&T21

#MST21

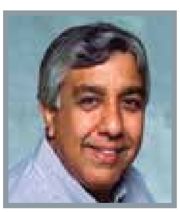
MATERIALS SCIENCE & TECHNOLOGY

OCT. 17–21, 2021

PLENARY SPEAKERS

Visit the MS&T Plenary Speakers webpage to view the complete abstracts and bios.

AIST ADOLF MARTENS MEMORIAL STEEL LECTURE



Anil K. Sachdev
Principal Technical Fellow and Lab Group Manager at GM Global Research and Development

TMS PLENARY SPEAKER

Tresa Pollock
Alcoa Professor of Materials at the University of California, Santa Barbara

ACerS EDWARD ORTON JR. MEMORIAL LECTURE

Clive Randall
Director of Materials Research Institute at The Pennsylvania State University

STUDENT ACTIVITIES

Visit the MS&T Student Activities webpage to see a complete description of all student events, including details for applying for Material Advantage chapter grants and individual travel grants.
www.matscitech.org/student

- **UNDERGRADUATE STUDENT POSTER CONTEST**
- **GRADUATE STUDENT POSTER CONTEST**
- **UNDERGRADUATE STUDENT SPEAKING CONTEST**
- **STUDENT NETWORKING MIXER**
- **ACerS STUDENT TOUR**
- **ACerS PCSA HUMANITARIAN PITCH COMPETITION**
- **CERAMIC MUG DROP CONTEST**
- **CERAMIC DISC GOLF CONTEST**
- **CAREER FAIR**
- **STUDENT AWARDS CEREMONY**
- **AIST STUDENT PLANT TOUR**
- **AIST STEEL TO STUDENTS RECRUITING RECEPTION**

HOTELS

Hotel reservation deadline: **Sept. 23, 2021**
For best availability and immediate confirmation, make your reservations online at matscitech.org/mst21.

U.S. Government Rate

Rooms are extremely limited; proof of federal government employment must be shown at check-in or higher rate will be charged. U.S. Government rate is the prevailing government rate.

Cancellation

Reservations cancelled less than 72 hours prior to Noon of scheduled arrival date will be charged one night's rate and tax.

HILTON COLUMBUS (ACerS Headquarters)
$210 USD + tax

HYATT REGENCY COLUMBUS
(AIST & TMS Headquarters)
$210 USD + tax

RED ROOF INN
$169 USD + tax

DRURY INN & SUITES CONVENTION CENTER
$179 USD + tax

Rates listed above are for single or double occupancy.

ACerS LECTURES AND AWARDS

Visit the MS&T Special Events webpage to see all lectures and awards, including dates and times.

MONDAY, OCT. 18 8:10–8:55 A.M.

THE NAVROTSKY AWARD FOR EXPERIMENTAL THERMODYNAMICS OF SOLIDS

MONDAY, OCT. 18 9–10 A.M.

ACerS/EPDC ARTHUR L. FRIEDBERG CERAMIC ENGINEERING TUTORIAL AND LECTURE

Elizabeth Opila, University of Virginia, USA

MONDAY, OCT. 18 2–4:40 P.M.

ACerS RICHARD M. FULRATH AWARD SESSION

Surojit Gupta, University of North Dakota, USA

Elizabeth Paisley, Sandia National Laboratory, USA

Tsuyoshi Honma, Nagaoka University of Technology, Japan

Kenichi Okazaki, Semiconductor Energy Laboratory, Japan

Hirokazu Sasaki, Shoei Chemical, Inc., Japan

TUESDAY, OCT. 19 1–2 P.M.

ACerS FRONTIERS OF SCIENCE AND SOCIETY — RUSTUM ROY LECTURE

Alexander Michaelis, Fraunhofer Institute for Ceramic Technologies & Systems IKTS, Germany

Advanced Ceramics for Energy and Environmental Technology

TUESDAY, OCT. 19 2–4:40 P.M.

ACerS GOMD ALFRED R. COOPER AWARD SESSION COOPER DISTINGUISHED LECTURE

ACerS GOMD ALFRED R. COOPER YOUNG SCHOLAR AWARD PRESENTATION

Winners will be announced after selection by the Cooper Award Committee

WEDNESDAY, OCT. 20 1–2 P.M.

ACerS BASIC SCIENCE DIVISION ROBERT B. SOSMAN LECTURE

Wayne Kaplan, Israel Institute of Technology, Israel

Combining Atomistic and Continuum Approaches to Interfaces

SPECIAL EVENTS

Visit the MS&T Special Events web page to see all special events, including dates and times

SUNDAY, OCT. 17 3–5 P.M.

WIKIPEDIA EDIT-A-THON FOR DIVERSITY IN MATERIALS SCIENCE AND ENGINEERING

SUNDAY, OCT. 17 5–6 P.M.

MS&T WOMEN IN MATERIALS SCIENCE RECEPTION

MONDAY, OCT. 18 1–2 P.M.

ACerS 123RD ANNUAL MEMBERSHIP MEETING

MONDAY, OCT. 18 5–6 P.M.

WELCOME RECEPTION HOSTED BY THE MS&T PARTNERS

MONDAY, OCT. 18 7:30–10 P.M.

ACerS ANNUAL HONOR AND AWARDS BANQUET

MONDAY OCT. 18–THURSDAY OCT. 21
VARIOUS HOURS

ACerS BASIC SCIENCE DIVISION CERAMOGRAPHIC EXHIBIT & COMPETITION

TUESDAY, OCT. 19 VARIOUS HOURS

GENERAL POSTER SESSION WITH PRESENTERS

CALL FOR ABSTRACTS DEADLINE SEP. 6, 2021

ELECTRONIC MATERIALS AND APPLICATIONS 2022

JAN. 18–21, 2022 | DoubleTree by Hilton | Orlando, Fla., USA | ceramics.org/ema2022

ORGANIZED BY THE ACerS ELECTRONICS AND BASIC SCIENCE DIVISIONS

Electronic Materials and Applications 2022 (EMA 2022) is an international conference focused on electroceramic materials and their applications in electronic, electrochemical, electromechanical, magnetic, dielectric, biological, and optical components, devices, and systems. Jointly programmed by the Electronics Division and Basic Science Division of The American Ceramic Society, EMA 2022 will take place at the DoubleTree by Hilton Orlando at Sea World, Jan. 19–21, 2022.

EMA 2022 is designed for scientists, engineers, technologists, and students interested in basic science, engineering, and applications of electroceramic materials. Participants from across the world in academia, industry, and national laboratories exchange information and ideas on the latest developments in theory, experimental investigation, and applications of electroceramic materials.

Students are highly encouraged to participate in the meeting. Prizes will be awarded for the best oral and poster student presentations.

The technical program includes plenary talks, invited lectures, contributed papers, poster presentations, and open discussions. EMA 2022 features symposia focused on dielectric, piezoelectric, pyroelectric, magnetoelectronic, (multi)ferroic, quantum, relaxor, optoelectronic, and photonic ceramics; complex oxide thin films, heterostructures, and nanocomposites; semiconductors; superconductors; ion-conducting ceramics; 5G materials for millimeter-wave technology; and functional biological materials. Other symposia emphasize broader themes covering processing, microstructure evolution, and integration; effects of surfaces and interfaces on processing, transport, and properties; point defects, dislocations, and grain boundaries; mesoscale phenomena; and advanced characterization and computational design of electronic materials.

EMA includes several networking opportunities to facilitate collaborations for scientific and technical advances related to materials, components, devices, and systems. The Basic Science Division will again host a tutorial session in addition to the regular conference programming.

The grand finale of the meeting will again be Failure: The Greatest Teacher. We invite anyone interested to submit a brief abstract for this educational and engaging event that concludes the meeting.

Please join us in Orlando, Fla., to participate in this unique experience!

ORGANIZING COMMITTEE

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TECHNICAL PROGRAM

S1 – Characterization of Structure–Property Relationships in Functional Ceramics

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

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

S4 – Complex Oxide Thin Films and Heterostructures: From Synthesis to Strain/Interface-engineered Emergent Properties

S5 – Mesoscale Phenomena in Ferroic Nanostructures: From Patterns to Functionalities

S6 – Emerging Semiconductor Materials and Interfaces

S7 – Superconducting and Related Materials: From Basic Science to Applications

S8 – Structure–Property Relationships in Relaxor Ceramics

S9 – Ion-conducting Ceramics

S10 – Point Defects and Transport in Ceramics

S11 – Evolution of Structure and Chemistry of Grain Boundaries and Their Networks as a Function of Material Processing

S12 – 5G Materials and Applications Telecommunications

S13 – Agile Design of Electronic Materials: Aligned Computational and Experimental Approaches and Materials Informatics

S14 – Functional Materials for Biological Applications

S15 – Advanced Microelectrics

CALL FOR PAPERS ABSTRACTS DUE SEPT. 1, 2021

46TH INTERNATIONAL CONFERENCE AND EXPOSITION ON

ADVANCED CERAMICS AND COMPOSITES

ceramics.org/icacc2022

JAN. 23–28, 2022 | Hilton Daytona Beach Resort and Ocean Center | Daytona Beach, Fla., USA

We are pleased to announce that the 46th International Conference & Exposition on Advanced Ceramics & Composites (ICACC 2022) will be held from Jan. 23–28, 2022, in Daytona Beach, Fla. This conference has a strong history of being the preeminent international meeting on advanced structural and functional ceramics, composites, and other emerging ceramic materials and technologies. The Engineering Ceramics Division (ECD) of The American Ceramic Society has organized this esteemed event since 1977. Due to the high quality of technical presentations and unique networking opportunities, this event has achieved tremendous worldwide interest and has attracted active participation from ceramic researchers and developers from the global technical community thanks to the dedication and support of our membership.

We look forward to seeing you in Daytona Beach, Fla., in January 2022!

Palani Balaya
Program Chair, ICACC 2022
National University of Singapore
mpepb@nus.edu.sg

HONORARY SYMPOSIUM AND FOCUSED SESSIONS

Emergent Materials and Sustainable Manufacturing Technologies in a Global Landscape: International Symposium in Honor of Dr. Tatsuki Ohji

Special Focused Session on Diversity, Entrepreneurship, and Commercialization

11th Global Young Investigator Forum

- FS1: **Bio-Inspired, Green Processing, and Related Technologies of Advanced Materials**
- FS2: **Materials for Thermoelectrics**
- FS3: **Molecular-level Processing and Chemical Engineering of Functional Materials**
- FS4: **Ceramic/Carbon Reinforced Polymers**
- FS5: **Current Challenges in Microstructural Evolution: From Fundamentals to Engineering Applications**

SYMPOSIA

- S1: **Mechanical Behavior and Performance of Ceramics and Composites**
- S2: **Advanced Ceramic Coatings for Structural, Environmental, and Functional Applications**
- S3: **19th International Symposium on Solid Oxide Cells (SOC): Materials Science and Technology**
- S4: **Armor Ceramics – Challenges and New Developments**
- S5: **Next Generation Bioceramics and Biocomposites**
- S6: **Advanced Materials and Technologies for Rechargeable Energy Storage**
- S7: **16th International Symposium on Functional Nanomaterials and Thin Films for Sustainable Energy Harvesting, Environmental and Health Applications**
- S8: **16th International Symposium on Advanced Processing and Manufacturing Technologies for Structural and Multifunctional Materials and Systems (APMT16)**
- S9: **Porous Ceramics: Novel Developments and Applications**
- S10: **Modeling and Design of Ceramics and Composites**
- S11: **Advanced Materials and Innovative Processing Ideas for Production Root Technologies**
- S12: **On the Design of Nanolaminated Ternary Transition Metal Carbides/Nitrides (MAX Phases) and Borides (MAB Phases), Solid Solutions thereof, and 2D Counterparts (MXenes, MBenes)**
- S13: **Development and Applications of Advanced Ceramics and Composites for Nuclear Fission and Fusion Energy Systems**
- S14: **Crystalline Materials for Electrical, Optical, and Medical Applications**
- S15: **6th International Symposium on Additive Manufacturing and 3D Printing Technologies**
- S16: **Geopolymers, Inorganic Polymers, and Sustainable Materials**
- S17: **Advanced Ceramic Materials and Processing for Photonics and Energy**
- S18: **Ultrahigh-temperature Ceramics**

Calendar of events

August 2021

31–Sept 1 6th Ceramics Expo – Huntington Convention Center of Cleveland, Cleveland, Ohio; https://ceramics.org/event/6th-ceramics-expo

September 2021

5–8 ICG Annual Meeting 2021 – Songdo ConvensiA, Incheon, Korea; https://www.icg2021.org

15–16 ceramitec conference 2021 – Messe München, Munich, Germany; https://www.ceramitec.com/en/trade-fair/ceramitec-conference

20–22 Serbian Ceramic Society ACA IX conference – Serbian Academy of Sciences and Arts, Serbia, Belgrade; http://www.serbianceramicsociety.rs/index.htm

October 2021

12–15 ➡ 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

17–21 ACerS 123rd Annual Meeting with Materials Science & Technology 2021 – Greater Columbus Convention Center, Columbus, Ohio; https://ceramics.org/mst21

18–20 Flourine Forum 2021 – Pan Pacific Hanoi, Vietnam; http://imformed.com/get-imformed/forums/fluorine-forum-2020

25–27 China Refractory Minerals Forum 2021 – InterContinental, Dalian, China; http://imformed.com/get-imformed/forums/china-refractory-minerals-forum-2020

November 2021

1–4 ➡ 82nd Conference on Glass Problems – Greater Columbus Convention Center, Columbus, Ohio; http://glassproblemsconference.org

December 2021

12–17 14th Pacific Rim Conference on Ceramic and Glass Technology (PACRIM 14) – Hyatt Regency Vancouver, Vancouver, British Columbia, Canada; www.ceramics.org/PACRIM14

January 2022

18–21 Electronic Materials and Applications 2022 (EMA 2022) – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla.; https://ceramics.org/ema2022

23–28 46th International Conference and Expo on Advanced Ceramics and Composites (ICACC2022) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; https://ceramics.org/icacc2022

March 2022

15–18 17th Biennial Worldwide Congress Unified International Technical Conference on Refractories – Hilton Chicago, Chicago, Ill.; https://ceramics.org/unitecr2021

May 2022

22–26 Glass & Optical Materials Division Annual Meeting (GOMD 2022) – Hyatt Regency Baltimore, Baltimore, Md.; https://bit.ly/3ftnJqI

June 2022

22–26 ACerS 2022 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Omni Charlotte Hotel, Charlotte, N.C.; https://bit.ly/31zyfob

July 2022

10–14 International Congress on Ceramics (ICC9) – Krakow, Poland; https://ceramics.org/event/international-congress-on-ceramics-icc9

24–28 Pan American Ceramics Congress and Ferroelectrics Meeting of Americas (PACC-FMAs 2022) – Hilton Panama, Panama City, Panama; https://ceramics.org/PACCFMAs

October 2022

14–19 ACerS 124th Annual Meeting with Materials Science & Technology 2022 – David L. Lawrence Convention Center, Pittsburgh, Pa.; https://ceramics.org/event/acers-124th-annual-meeting-with-materials-science-technology-2022

July 2024

14–19 International Congress on Ceramics – Hotel Bonaventure, Montreal, Canada; www.ceramics.org

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

Entries in **BLUE** denote ACerS events.

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

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Bethany X. Rutherford

Guest columnist

Implementing ceramic materials into neuromorphic memory devices through oxide-based memristors

Today's computers are capable of processing data faster and more accurately than humans. However, their ability to efficiently store memory and data is lacking because, unlike humans, computers deal in absolutes.

Neuromorphic memory and computing is one of the latest prospects for creating next-generation computing systems as the limit of Moore's Law is being approached. First suggested in 1990,[1] neuromorphic computing is based on the idea that computers can deal in relativity like the human brain. By doing so, neuromorphic computing can eventually determine the importance of the information input into them, therefore creating more efficient computing systems that are faster and consume less energy, and potentially aiding in the advancement of artificial intelligence.

To make machines think on a more human level, the structure of the human brain needs to be taken into account. The human brain is made of a highly complex and interconnected network of neurons that communicate via electrical signals. One of the current challenges for achieving neuromorphic computing is to create hardware capable of mimicking this structure and behavior.

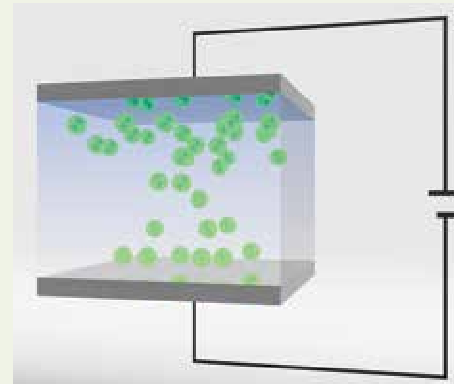
One of the proposed solutions for creating such hardware is oxide-based memristors. The term memristor is a contraction of "memory resistor" and was first theorized in 1971.[2] The device behaves similarly to a synapse—the gap between two neurons that electrical signals pass from one neuron to the other—where a ceramic oxide material is sandwiched between metal end caps. The oxide material consists of two layers (either an oxide and a doped oxygen-rich side or a bilayer of two different oxide materials), so there are essentially two resistors in series.

The inherent point defects found in ceramic materials are important for the switching properties of a memristor. The positively-charged oxygen vacancies present in the oxide material can move around and vary the border between the two layers of ceramic materials, allowing modulation of the overall resistance like a sliding scale (Figure 1).[2, 3] The adjustable resistance allows for the memristor to present a value outside of the traditional binary "0" or "1." This phenomenon is called resistive switching and is a type of electrochemical metallization.[3]

The materials used to create these computing devices are just as important as the actual hardware. Complex heterostructures are needed to take advantage of the inherent material properties of these dielectric oxides. The current challenges facing oxide-based memristors are (1) selection of optimal materials for devices, (2) lack of homogeneity of current fabrication processes, (3) compatibility with current semiconductor devices, and (4) implementation (no proposed network to date has achieved greater than 1,000 memristors in a device, which is not enough for any practical applications).[3, 4]

In terms of addressing the challenge of materials selection, researchers are looking for materials that have high dielectric constants to minimize current leakage, high thermal conductivity to minimize heating, and uniformity across the layer. In addition, the materials should be compatible with traditional semiconductor materials, require low set and reset energy pulses for increased energy efficiency, and are reliable after enduring many cycles of being switched on and off.[3]

At Los Alamos National Laboratory, we are pursuing ways to optimize the materials selection and improve the structure of the memristor. Some materials candidates being considered include hafnium oxides, titanium oxides, tantalum oxides, samarium oxides, and more complex oxides with perovskite crystal structures. Perovskites exhibit ferroelectric properties and could introduce the switching effect through polarization controlled by a Schottky barrier instead of oxygen vacancies.[5]



Credit: Bethany X. Rutherford

Figure 1. Schematic of the oxygen vacancies diffusing in the oxide materials of a memristor.

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