AMERICAN CERAMIC SOCIETY

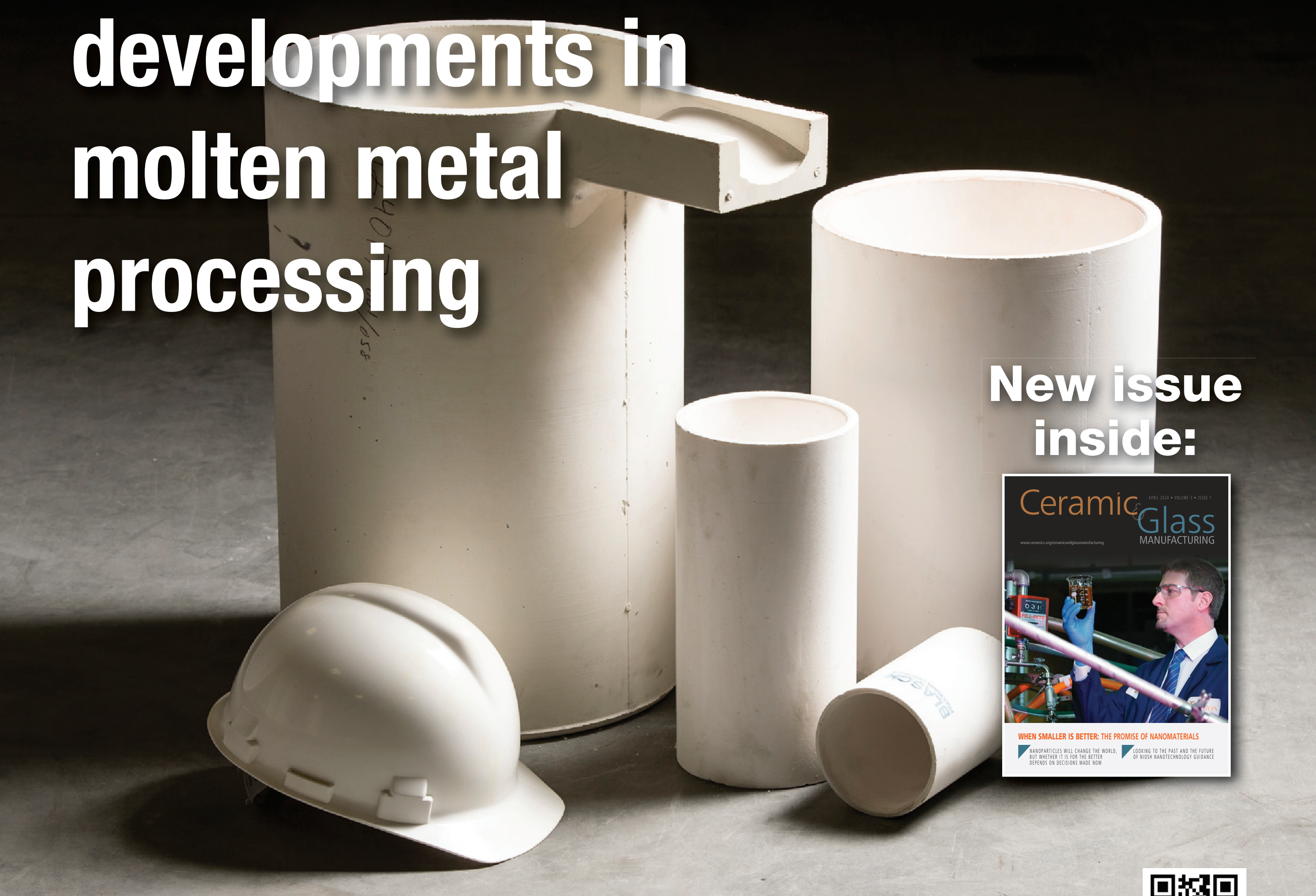
bulletin

emerging ceramics & glass technology

APRIL 2024

Ceramic crucibles:

Market drivers and novel developments in molten metal processing



Ceramic casting cores | Ultrahigh-density carbon–carbon composites | Inside AACCM

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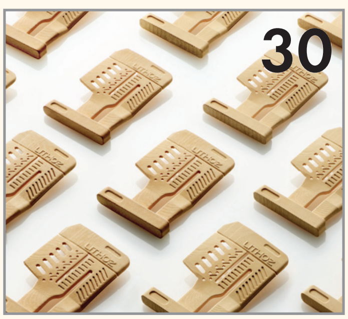

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Cover image

High-performance ProCaster ceramic crucibles by Blasch Precision Ceramics. These crucibles are engineered for coreless induction furnaces up to 5,000-pound capacity. *Credit: Blasch Precision Ceramics*

AMERICAN CERAMIC SOCIETY
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As seen on *Ceramic Tech Today*...

Credit: andersfloor, Pixabay

Building with nature: Fungi show promise as green construction material

More and more companies and organizations are considering the potential of mycelium, the root-like structure of most fungi, as a green construction material. This CTT spotlights several recent innovations in this area.

Read more at www.ceramics.org/fungi-construction

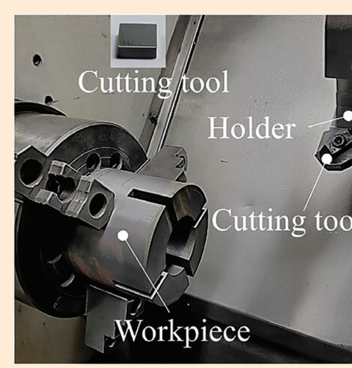
Also see our ACerS journals...

Topical Collection: Ceramics to improve manufacturing

The latest ACerS Topical Collection highlights the use of contemporary research techniques to address the expanding needs for better performance and improved manufacturability. Learn more about this collection on page 34 in the "Journal Highlights" column. https://bit.ly/April2024-CeramicManufacturing

Featured articles in this collection:

Cutting performance and wear characteristics of Si_3N_4–SiCw–HfB_2 ceramic cutting tools in turning of ductile cast iron
By Q. K. Gu, R. P. Liu, Z. W. Chen, et al.
Journal of the American Ceramic Society



Recent progress in carbide-based composite materials fabricated by laser additive manufacturing processes
By H. Ebrahimnezhad-Khaljiri and A. Ghadi
Journal of the American Ceramic Society

Use of alumina dispersant in alumina-spinel castable: Comparison between in situ and preformed spinels
By S. Kumar and R. Sarkar
International Journal of Applied Ceramic Technology

Read more at www.ceramics.org/journals

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ACSBA7, Vol. 103, No. 3, pp. 1–64. All feature articles are covered in Current Contents.

news & trends

New supply chain strategies aim to secure access to critical resources

Supply chains have been top of mind for governments during the last few years as the COVID-19 pandemic, extreme weather events, and war impacted the global transport of goods. And only a few weeks into 2024, supply chains are again grabbing headlines as hundreds of ships detour an extra 4,000 miles around Africa to avoid drone and missile attacks in the Suez Canal.

In response to these global transport disruptions, many governments are implementing new programs to ensure continued and secure access to critical resources, including several in the past few months. Learn about some of these recently implemented programs in the sections below.

US: Dozens of new actions aim to strengthen domestic supply chains

In November 2023, the White House issued a fact sheet announcing almost 30 new actions the Biden–Harris administration is taking to strengthen U.S. supply chains.

Included in these actions is the creation of the Council on Supply Chain Resilience. This Cabinet-level council, co-chaired by the National Security Advisor and National Economic Advisor, formalizes and expands on the Supply Chain Disruptions Task Force, which was created in 2021 to resolve short-term supply and demand discontinuities.

The Council on Supply Chain Resilience brings together more than a dozen of the nation's top federal officials directly involved in industrial policy. One of the Council's tasks will be to conduct a quadrennial supply chain review. The first review, due by Dec. 31, 2024, will update criteria on industries, sectors, and products defined as critical to national and economic security.

In addition to the Council, several new Centers to monitor existing and emerging supply chain risks were announced. For example, the Department of Commerce's Supply Chain Center is designed to be the analytic engine for supply chain resilience policy action within the U.S. government. It will integrate industry expertise and data analytics to develop innovative supply chain risk assessment tools.

On the other hand, the Department of Homeland Security's Supply Chain Resilience Center will collaborate with the private sector to better secure U.S. supply chains. The Center plans to host at least two table-top exercises in 2024 to test the resiliency of critical cross-border supply chains with other U.S. federal agencies, foreign governments, and industry partners.

Also coming up in 2024 is the new Supply Chain Data and Analytics Summit, convened by the Department of Commerce. In addition to gathering expert input on supply chain risk assessment models and tools, the summit will assess data availability, utility, and limitations and consider actions to improve data flows.

EU: Critical Raw Materials Act aims to reduce reliance on China

In November 2023, the European Council and the European Parliament reached a provisional agreement on the Critical Raw Materials Act.

Proposed by the European Commission in March 2023, the Critical Raw Materials Act is one of the flagship legislative initiatives of the Green Deal Industrial Plan, which was announced in February 2023. It aims to reduce reliance on China for the minerals essential to emerging green and digital technologies.

The provisional agreement kept the overall objectives of the original proposal but strengthened several elements, for example, by adding aluminum to the list of strategic raw materials. The act is expected to be finalized and go into effect in early 2024.

UK: Critical Imports and Supply Chains Strategy aims to secure flow of critical imports

On Jan. 17, 2024, the U.K. government announced the launch of its new Critical Imports and Supply Chains Strategy.

This strategy builds on several recent programs, specifically the Integrated Review Refresh, advanced manufacturing plan, and the semiconductors, batteries, and critical minerals strategies. It sets out how the U.K. government will work with business and international partners across five priorities to enable the efficient and reliable flow of critical imports.

1. Making the U.K. government a center of excellence for supply chain analysis and risk assessment.
2. Removing critical import barriers to support the U.K.'s business-friendly environment.
3. Building the U.K.'s response to global supply chain shocks.
4. Ensuring the U.K. can adapt to long-term trends.
5. Expanding collaboration between government, business, and academia.

To achieve these priorities, the U.K. government will establish the Critical Imports Council, which will give companies and government officials a platform through which to collaboratively identify import risks and develop action plans. ■

Corporate Partner news

HWI and Calderys bring an extended portfolio of high-temperature solutions to customers

In February 2023, Calderys and HWI were united under single ownership and became the Calderys Group. The new Group began a program to share technologies, transferring a selection of Calderys solutions in the Americas to HWI and bringing a selection of HWI products to EMEA and APAC. https://calderys.com/news-media

Lithoz joins Japanese technology network for high-performance 3D-printed ceramics

Japanese ceramic companies AS ONE, Mitsui Kinzoku, and Yugyōkuen Ceramics chose Lithoz as a key partner in driving growth and advancement in the Japanese additive manufacturing community. As initiative leader, AS ONE will work with Mitsui Kinzoku and Yugyōkuen Ceramics as contract manufacturers and Lithoz as technology provider. https://lithoz.com/en/press-events

McDanel announces name change to support expansion of material capabilities

McDanel transitioned its name from McDanel Advanced Ceramic Technologies to McDanel Advanced Material Technologies. This decision is aligned with McDanel's strategic plan to expand its technology portfolio, historically focused on high-purity tubular advanced ceramics, to include a broader range of material technologies. https://www.prnewswire.com/news-releases

Saint-Gobain certified 'Top Employer Global' for ninth year

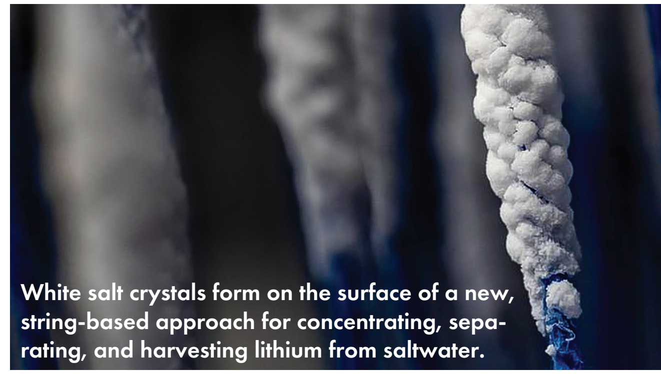
Saint-Gobain was awarded the "Top Employer Global" certification for the ninth consecutive year. Only 17 companies globally hold this international certification. Among the 20 criteria analyzed by the Top Employers Institute, Saint-Gobain made significant progress in the past year on 13 of them, with eight showing an increase of 3% or more. https://www.saint-gobain.com/en/press/press-releases ■

String-based extraction could revolutionize lithium production

With demand for certain minerals increasing as more countries transition to an electrified economy, focusing only on the largest deposits of minerals is no longer a sustainable approach.

Lithium is at the center of these efforts to diversify critical mineral supply chains. In the past decade, numerous groups worked to develop techniques that can extract lithium from sources with low concentrations, such as oilfield brines and seawater. These techniques are based on various processes, including adsorption, ion-exchange, electrodialysis, and solvent-extraction. But they face some major barriers in terms of selectivity, energy and chemical uses, and high cost.

In September 2023, researchers at Princeton University, along with colleagues at the University of Maryland, published a paper describing a new passive method for fast and selective extraction of lithium from saltwater. Their method uses a set of porous, twisted cellulose fibers that have a water-loving core and a water-repelling surface. When the ends are dipped in a saltwater solution, the water travels up the strings through capillary action and then quickly evaporates. The evaporated water leaves behind salt ions, such as sodium and lithium. As water continues to evaporate, the salts become increasingly concentrated and form crystals that can be harvested.



White salt crystals form on the surface of a new, string-based approach for concentrating, separating, and harvesting lithium from saltwater.

Credit: Bumper DeJesus, Andlinger Center for Energy and the Environment

Due to the different physical properties of sodium and lithium, the salts reach their saturation points at different locations along the twisted fibers. Sodium, with low solubility, crystallizes near the bottom, while highly soluble lithium crystallizes near the top. This natural separation allows the lithium and sodium to be collected individually, a feat that otherwise would require the use of more chemicals.

Though currently only a lab-scale process, the researchers estimate that the method, if advanced to industrial scale, could accelerate the evaporation process by more than 20 times compared to traditional evaporation ponds. It could also cut the amount of land needed by more than 90% of current operations.

The paper, published in *Nature Water*, is “Spatially separated crystallization for selective lithium extraction from saline water” (DOI: 10.1038/s44221-023-00131-3). ■

Doug Thurman
Guest columnist

AACCM: Expanding the market for manufactured ceramic components

The ceramics industry has seen a lot of changes over the last 30 years, with many new applications for advanced ceramics driving extensive market growth since the early 1990s. This steady stream of new applications has served to counter the impact of increasing international competition.

The Association of American Ceramic Component Manufacturers (AACCM) was formed in 1992 by 18 charter member companies to expand the market for manufactured ceramic components. They aimed to achieve this goal by enhancing the processes and product quality of advanced ceramics, as well as by increasing public and industry education and awareness of ceramic applications.

Most of these initial member companies were manufacturers with a primary focus on engineered or advanced ceramics, and that remains the case today. Additionally, much like today, the original members ranged in size from small, closely held companies to very large conglomerates within the ceramics industry.

I believe AACCM has played a role in industry growth and in the competitive strength of U.S. manufacturers, in large part by providing a noncompetitive forum for industry peers to discuss and address common challenges. Importantly, many of the companies send operational personnel to AACCM meetings, in addition to senior executives and technical directors. This format provides a unique opportunity for operational leaders to network because these team members are not typically part of most professional society meetings.

Today's AACCM membership consists of 18 companies, the same as at the Association's inception. However, while several of the original founding member companies remain active in AACCM and continue as stand-alone entities, many of the founding member companies have since been acquired or are otherwise not around anymore. Instead, several early-stage entities bring an entrepreneurial perspective with a desire to use the organization to stay closer to the front edge of technological innovation in both materials and applications.

The activities of AACCM shifted somewhat in recent years. This shift is driven in part by the present composition of the organization but also by all that is happening in technical development right now. With new applications for ceramics in areas such as energy, medical technology, transportation, and defense, AACCM responded by creating and strengthening relationships and tie-ins with leading U.S. materials science universities. The goal is to facilitate technology adoption and improve talent recruitment for member companies. This goal is in addition to the day-to-day membership benefits of referring businesses to each other, discussing and mitigating common threats to the industry, and combining marketing resources at trade shows.

I believe there is no question that AACCM members benefit most from our live meetings and conferences, which we do every year at either a major U.S. research university or national laboratory. This format is desirable not just because of what we learn from the faculty presentations but also from the interactive aspects of the day.

For instance, beginning a few years ago, AACCM added a component where each member company gives a brief presentation to the students, highlighting what they do and the interesting markets they serve, often with large societal benefit. This portion of the day not only provides a great recruiting forum but also helps build interest in materials science in general and ceramics in particular. This initiative dovetails nicely with similar programs at The American Ceramic Society focused on the middle school and high school levels.

In the last two years, AACCM worked to get back on its feet following the hiatus in live meetings in 2020 and 2021 due to the COVID-19 pandemic. We started back up with conferences in the spring of 2022 at Clemson University's Advanced Materials Research Lab. Most recently, in the fall of 2023, we had another interesting and informative program put on by Alfred University, in concert with Alfred's Center for Advanced Ceramic Technology. In 2024, we have another great program in the works, with more details on location and agenda being announced ahead of our meeting at the Ceramics Expo this April in Novi, Mich.

Learn more about AACCM and the work being done by its member companies at https://aaccm.org. ■

About the author

Doug Thurman is past president (2022–2023) of AACCM and president of Sunrock Ceramics Company (Broadview, Ill.). Contact Thurman at dthurman@sunrockceramics.com.

In memory of Jeffery Brundage, AACCM president

Jeffery (Jeff) Brundage, current president of AACCM as of January 2024, died peacefully early in the morning of Feb. 10, 2024, at the age of 71. He was a member of AACCM since its inception and long-time ACerS member.

Brundage supported the ceramics industry in past positions with ILC Space Systems (Clearlake, Texas); General Ceramics National Beryllia Division, now American Beryllia Inc. (Haskel, N.J.); and Superior Technical Ceramics (St. Albans, Vt.). He started his own business, Critical Services LLC (Swanton, Vt.), and served as CEO of Lamda Advanced Materials LLC (Alfred, N.Y.) at the time of his death.

Brundage made many dear friends during his 40 years solving challenges within the ceramics industry. He will be deeply missed. ■

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS Corporate Partners

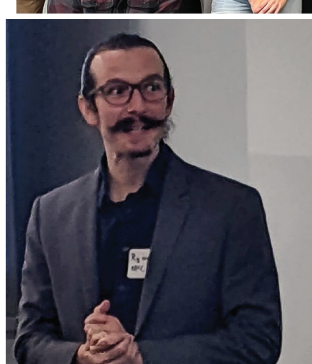
ACerS is pleased to welcome its newest Corporate Partners:

bcc Research | GLEEBLE A VPG Brand | Institute of Refractories Engineers

To learn about the benefits of ACerS Corporate Partnership, contact Marcus Fish, industry relations director, at (614) 794-5894 or mfish@ceramics.org. ■

ACerS Southern and Northern California Sections welcome ACerS President Rajendra Bordia for campus visits

ACerS Northern California Section members gathered to welcome Bordia to the UC Davis campus.



ACerS Southern California Section chair Ryan McCarty welcomed members to the presentation given by Bordia.

ACerS President Rajendra Bordia visited the Southern California Section members at the University of California, Irvine campus on Friday, Jan. 19, 2024, and the Northern California Section members at the University of California, Davis campus on Monday, Jan. 22, 2024. Bordia gave a presentation in which he shared his plans for the Society. Each day concluded with lab tours and dinner. ■

FOR MORE INFORMATION:

ceramics.org

ACerS International Italy, Germany, and Spain Chapters co-host happy hour at ICACC 2024

Members of the ACerS International Italy Chapter pose for a photo during the Chapter-organized happy hour at ICACC 2024.

ACerS International Italy, Germany, and Spain Chapters co-hosted a happy hour for Chapter members during the 48th International Conference and Expo on Advanced Ceramics and Composites in Daytona Beach, Fla. Members who attended the happy hour socialized and networked with fellow Chapter colleagues. ACerS past president Sanjay Mathur (2022–2023) and current president Rajendra Bordia also attended the gathering to meet and network with Chapter members from around the world. ■

www.ceramics.org/ceramictechtoday

Meet the Strategic Planning for Emerging Opportunities Committee

The Strategic Planning for Emerging Opportunities (SPEO) Committee comprises the leaders of ACerS principal committees and Society member groups, such as the President's Council of Student Advisors, the Young Professionals Network (YPN), and technical interest groups, and several members-at-large. The Committee is responsible for identifying emerging opportunities that the Society should consider as part of its strategic planning process.

ACerS Board of Directors develops ACerS long- and short-term strategy, which, in turn, is implemented through the Society's committees and member groups. Thus, SPEO serves an important role, complementary to the Board, in setting and achieving the Society's strategic direction.

Monica Ferraris
2023–24
Chair and president-elect
Politecnico Di Torino, Italy

Claire Xiong
2022–25
Member
Boise State University

Mario Affatigato
2023–24
President-elect nominee
Coe College

Surojit Gupta
2022–25
Member
University of North Dakota

David Poerschke
2018–24
Publications Committee chair
University of Minnesota

Olivier Guillon
2023–26
Member
Forschungszentrum Jülich GmbH, Germany

Jessica Rimsza
2022–24
Meetings Committee chair
Sandia National Laboratories

Alessandro De Zanet
2023–24
Young Professionals Network co-chair
Leonardo Labs, Italy

Lisa Rueschhoff
2020–24
Member Services Committee chair
Air Force Research Laboratory

Theresa Davey
2023–24
DEI Subcommittee chair
Bangor University, UK

Clive Randall
2021–2024
Member
Pennsylvania State University

Michael Thuis
2023–24
President's Council of Student Advisors, chair
Northwestern University

MEMBER HIGHLIGHTS

Volunteer Spotlight: Jie Zhang

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

Jie Zhang is principal investigator at Shenyang National Laboratory for Materials Science in the Institute of Metal Research, Chinese Academy of Sciences. She received a Ph.D. in materials science from the Graduate School of Chinese Academy of Sciences.

Zhang's research is focused on advanced ceramics and coatings for extreme environment applications. She is dedicated to the fundamental understanding and practical development of novel ceramics and coatings in severe environments.

Zhang was recently recognized as an ACerS Global Ambassador for her work with the Engineering Ceramics Division. She serves as chair-elect of ECD as well as program chair of ICACC 2024.

We extend our deep appreciation to Zhang for her service to our Society! ■

FOR MORE INFORMATION:

ceramics.org/members

more MEMBER HIGHLIGHTS

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.

Aldo R. Boccaccini, FACerS, head of the Institute of Biomaterials at the University of Erlangen-Nuremberg, started his two-year tenure as president of the Federation of European Materials Societies (FEMS) in January 2024. He has been a FEMS Board member since 2016, representing the German Materials Society (DGM). ■

ACerStudent Engagement: Brittney Hauke

Brittney Hauke is a Ph.D. candidate at The Pennsylvania State University and chair of the Communications Committee for the ACerS President's Council of Student Advisors (PCSA). Hauke has attended various ACerS conferences, including the Glass & Optical Division Annual Meeting and ACerS Annual Meeting at MS&T, and says she feels supported by the community that ACerS student membership offers.

"Being a student member of ACerS has given me the opportunity to present my research and network amongst my peers at amazing conferences such as GOMD. I have also been able to improve my leadership skills by working in the President's Council of Student Advisors as the current Communications Committee chair."

You can take advantage of these opportunities as well by becoming a student member of ACerS. Visit https://ceramics.org/members/membership-types to learn more. ■

Ceramic Tech Chat: David Jensen

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 third Wednesday of each month.

In the February 2024 episode of Ceramic Tech Chat, **David Jensen**, sample coordinator and glaze production scheduler at Ludowici Roof Tile, describes the advantages of and his work on clay roof tile, shares how he became interested in the history of Ludowici, and explains how that interest led to the discovery of a glass slide collection created by ACerS founder Edward Orton Jr.

Check out a preview from his episode, which features Jensen explaining how he discovered the Orton glass slide collection.

"I had been looking through a book on the Centennial of The American Ceramic Society, and on one page an image jumped out to me because I recognized this photo of our company's former tile plant in Chicago, and the only other time I had seen this very photo was in a book published in 1910 that had contained many other photos of our other tile plants from that time. … I looked in the back of the book and it listed that particular photo as being property of The American Ceramic Society. So, I contacted the Society and asked if we'd be able to view or digitize any of the images. And after going and viewing them, we realized it wasn't just one or two photos. It was a collection of around 800 photos that Edward Orton, Jr. had taken during his time as secretary for the Society."

Listen to Jensen's whole interview—and all our other Ceramic Tech Chat episodes—at https://ceramictechchat.ceramics.org/974767. ■

IN MEMORIAM

Jeff Brundage

Günter Petzow

Jack Simon

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

AWARDS AND DEADLINES

Nomination deadlines for Division awards: May 15, May 30, July 1, or July 31

Contact: **Vicki Evans | vevans@ceramics.org**

Division	Award	Deadline	Contacts	Description
GOMD	**Alfred R. Cooper Scholars**	May 15	Steve Martin swmartin@iastate.edu	Recognizes undergraduate students who demonstrated excellence in research, engineering, and/or study in glass science or technology.
ED	**Edward C. Henry**	May 30	Aiping Chen apchen@lanl.gov	Recognizes an outstanding paper reporting original work in the *Journal of the American Ceramic Society* or the *Bulletin* during the previous calendar year on a subject related to electronic ceramics.
ED	**Lewis C. Hoffman Scholarship**	May 30	Aiping Chen apchen@lanl.gov	Recognizes academic interest and excellence among undergraduate students in ceramics/materials science and engineering.
ECD	**Bridge Building Award**	July 1	Jie Zhang jiezhang@imr.ac.cn	Recognizes individuals outside of the United States who have made outstanding contributions to engineering ceramics.
ECD	**Global Young Investigator**	July 1	Amjad Almansour amjad.s.almansour @nasa.gov	Recognizes the outstanding young ceramic engineer or scientist whose achievements have been significant to the profession and to the general welfare of the community around the globe. Nominations are open to candidates from industry, academia, or government-funded laboratories around the world.
ECD	**James I. Mueller Lecture**	July 1	Young-Wook Kim ywkim@uos.ac.kr	Recognizes the enormous contributions of James I. Mueller to the Engineering Ceramics Division and to the field of engineering ceramics. This award aims to recognize the accomplishments of individuals who have made similar contributions.
ECD	**Jubilee Global Diversity Award**	July 1	Michael Halbig michael.c.halbig @nasa.gov	Recognizes exceptional early- to mid-career professionals who are women and/or underrepresented minorities (i.e., based on race, ethnicity, nationality and/or geographic location) in the area of ceramic science and engineering.
EMSD	**Outstanding Student Researcher**	July 31	Charmayne Lonergan clonergan@mst.edu	Recognizes exemplary student research related to the mission of ACerS Energy Materials and Systems Division.

FOR MORE INFORMATION:

ceramics.org/members/awards

CERAMICANDGLASSINDUSTRY FOUNDATION

Introducing the new Ceramic and Glass Career Center

The Ceramic and Glass Industry Foundation (CGIF) is proud to present a newly updated Ceramic and Glass Career Center.

The Center is the ideal place for job seekers and employers in the ceramics and glass community to search for their next best opportunity or candidate. The updated site includes new resources and features for both job seekers and employers.

Job seekers can use the site to apply for jobs, upload their resume, and get job alerts so they do not miss out on desired roles. Employers can use the site to post jobs, manage their apps, and search for resumes.

"The CGIF is thrilled to launch the new Ceramic and Glass Career Center, which will directly link job seekers with employers in the ceramics and glass industries," says Marcus Fish, CGIF director of development and industry relations. "The site will also enable CGIF to support the next generation of ceramic and glass professionals, while providing a dedicated space for employers to find new talent."

ACerS Corporate Partners can post jobs for free on the Career Center. To learn more about the benefits of becoming an ACerS Corporate Partner, contact Fish at mfish@ceramics.org.

Help CGIF create more resources like the Ceramic and Glass Career Center to support the next generation of ceramic and glass professionals by visiting ceramics.org/donate. ■

Global abrasive market: Materials, products, and applications

By BCC Publishing Staff

The global market for abrasives was valued at $55.0 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 5.1% to reach $74.0 billion by 2028.

The abrasive industry consists of two segments (Table 1): companies and industries that manufacture or refine abrasive grains, and companies and industries that use these grains to manufacture products for grinding, cutting, or polishing. The users of abrasive grains far outnumber those that manufacture the grains.

Materials are classified for their abrasive nature on a relative scale that was initially developed by German mineralogist Friedrich Mohs in 1812. The Mohs Scale of Hardness has since been expanded to include both natural and synthetic materials (Table 2).

Table 2. Mohs Scale of Hardness including both natural and synthetic materials

Mohs hardness	Materials
0–1	Lithium, sodium, potassium
1	Talc
1–2	Graphite, lead, barium, tin
2	Calcium, sulfur, hexagonal boron nitride
2–3	Gold, silver, aluminum, zinc, lignite, magnesium
3	Copper, antimony, arsenic
3–4	Zinc sulfide
4	Fluorite, nickel, iron
4–5	Platinum, steel
5	Cobalt, zirconium, tooth enamel
5–6	Beryllium, molybdenum, anatase, garnet
6	Titanium, manganese, uranium, sand, silica, cerium oxide
6–7	Glass, pyrites, silicon, rutile, pumice, hematite, magnetite
7	Quartz, vanadium
7–8	Tungsten, hardened steel (steel shots), pinel, zirconium silicate, emery
8	Topaz, cubic zirconia
8–9	Silicon nitride, chromium
9	Corundum
9–10	Silicon carbide, tungsten carbide, boron, cubic boron nitride, boron carbide
10	Diamond

Many ceramic materials are used as abrasives. For example, conventional abrasives include fused alumina and silicon carbide, and these abrasives are among the most widely used and least expensive. Super abrasives, such as diamond or cubic boron nitride, can grind 100 times more parts than a conventional abrasive. However, they cost more than 50 times as much as their conventional abrasive counterparts.

The means by which abrasives are used in applications determines the nature of the abrasive tool. Broadly, the tools are classified as

- **Loose abrasive grains:** Used "as is" in powder or grain form. For surface cleaning, oil and rust removal, and macro cleaning.
- **Bonded abrasives**: Abrasive is firmly retained in a matrix called the "bond." For macro and bulk-level material removal.
- **Coated abrasives**: Thin layer of abrasive grain is attached to a backing material, such as paper or cloth. For material removal and finishing.
- **Nonwoven abrasives**: Abrasive is embedded into a network of highly conformable fibers. For finer finishing and macro polishing.
- **Polishing products**: Slurries or pastes that are applied by buffing or polishing wheels. To develop gloss, reflection, aesthetics, or high-technology products with microscopic tolerance requirements or metallography.

Table 1. Global market for abrasives, by type, through 2028 ($ millions)

Abrasive type	2022	2023	2028	CAGR % (2023–2028)
Grains	27,448.5	28,967.7	37,681.5	5.4
Products	27,528.7	28,867.7	36,332.1	4.7
Total	54,977.2	57,835.4	74,013.6	5.1

Various factors must be considered when choosing an abrasive for a specific purpose. For example,

- **Friability**: Determines how fast the abrasive material disintegrates in operation, and as such informs when the material should be replaced.
- **Hardness**: Determines whether the abrasive will grind, cut, or polish the material.
- **Shape**: Determines the type of abrasive action. For example, angular abrasives are best for grinding and are used for stripping corrosion and rust. Meanwhile, round abrasives provide a peening effect and can remove mill scale or thin factory coatings.
- **Size**: Determines cleaning rate and surface finish. Coarser particles remove materials quickly but create a rougher surface. Finer particles remove materials slowly but create a more polished surface.

About the author

BCC Publishing Staff provides comprehensive analyses of global market sizing, forecasting, and industry intelligence, covering markets where advances in science and technology are improving the quality, standard, and sustainability of businesses, economies, and lives. Contact the staff at Helia.Jalili@bccresearch.com.

Resource

BCC Publishing Staff, "Global abrasive market: Materials, products, and applications," BCC Research Report AVM033E, October 2023. https://bit.ly/BCC-October-2023-abrasives ■

New frontiers in space travel: A review of ultrahigh-temperature ceramic properties and processes

The stars have guided and inspired humanity for thousands of years, but it is only within the last century that people made the leap from Earth-based observations to outer space travel. Ceramic materials played a central role in this momentous transition, and they will continue to serve as essential components in aeronautic and astronautic technologies as we travel faster and further into space.

Ultrahigh-temperature ceramics (UHTCs) are a promising class of materials for such applications. These refractory ceramics have the formulation M–X, where M is an early transition metal (groups 4–5 of the periodic table) and X is either a boron, carbon, or nitrogen. They have very high melting temperatures (>3,000°C) as well as other useful thermomechanical properties.

UHTCs were first reported in the late 19th century, but it was the U.S.–Soviet Union space race in the mid-20th century that kicked off systematic study of these materials. UHTCs are now used in various commercial applications, such as the Hall-Héroult aluminum production process and boiling water nuclear reactors. Researchers expect UHTCs will expand into other extreme environment applications, including hypersonics and space travel.

Considering this potential, "we believe that it is timely to provide a focused perspective on the relation among atomic-scale fundamentals, oxidation behavior, processing parameters, and future opportunities for scientific advancement of UHTCs for use in extreme environment applications," researchers write in a new paper.

ACerS member Babak Anasori, Reilly Rising Star Associate Professor of Materials and Mechanical Engineering at Purdue University, is senior author on the new paper. He wrote the paper with his students Brian C. Wyatt and Srinivasa Kartik Nemani along with ACerS Fellows Gregory E. Hilmas (Missouri University of Science and Technology) and Elizabeth J. Opila (University of Virginia).

Highlights from their 18-page review paper, which is the first article on UHTCs published in *Nature Reviews Materials*, are given in the following sections.

Credit: SpaceX, Wikimedia (CC0 1.0)

First stage of the SpaceX Falcon 9 rocket successfully landing on an autonomous spaceport drone ship in April 2016. Ultrahigh-temperature ceramics are expected to play a key role in future aerospace technologies, for example, as shielding on the leading edges of hypersonic vehicles.

UHTC bonding fundamentals

The authors begin the review by diving into the structural characteristics of UHTCs, specifically the bonding structure.

There are three main chemical bonds at play in UHTCs: transition metal to boron/carbon/nitrogen (M–X), transition metal to transition metal (M–M), and nonmetal to nonmetal (X–X).

This mixture of ionic, covalent, and metallic bonds within one system can greatly impact the stability of the cubic (carbide or nitride) or hexagonal (diboride) crystal structure, depending on the ratio of each bond type. But in general, "the ionic character of ionic and covalent M–X bonds and the reduction of the number of antibonding M states are the dominant contributors to the stability that support increased melting temperatures in UHTC systems," the authors write.

Research News

Engineers 3D print the electromagnets at the heart of many electronics

Massachusetts Institute of Technology researchers modified a multimaterial 3D printer so it could produce 3D solenoids in one step. Solenoids are electromagnets formed by a coil of wire wrapped around a magnetic core. They are a fundamental building block of many electronics. The modified 3D printer created the solenoids by layering ultrathin coils of three different materials. The solenoids were able to withstand twice as much electric current and generate a magnetic field that was three times larger than other 3D-printed devices. For more information, visit https://news.mit.edu ■

Researchers discover 2D waveguides

The U.S. Naval Research Laboratory, in collaboration with Kansas State University, created slab waveguides based on 2D hexagonal boron nitride. The research was motivated by challenges with optically measuring 2D transition metal dichalcogenides (TMDs). When laser light is focused on TMDs, particles known as excitons are generated. Most excitons emit light out of the TMD's plane; however, elusive "dark" excitons exist in some TMDs and emit in the TMD's plane. The new slab waveguides capture the light from the dark excitons, providing a way to study them optically. For more information, visit https://www.nrl.navy.mil/Media/News. ■

High-temperature oxidation behavior of UHTCs

High-temperature applications of UHTCs typically involve high speeds and corrosive conditions as well. Such environments increase the possibility of chemical reactions taking place, such as oxidation. Understanding the mechanisms that drive oxidation can help researchers design more chemically resistant UHTCs.

In general, UHTCs have a thin native oxide scale that prevents oxidation of the material in ambient conditions. However, as temperature increases, both the M and X components in UHTC systems continuously form oxides species past the native oxide, which affects the mechanical and thermal integrity of UHTCs.

The authors provide detailed descriptions of the different oxide species that form in several UHTCs. Overall, transition metal diborides demonstrate superior oxidation behavior compared with transition metal carbides and nitrides, and thus are preferred for hypersonic and space exploration applications.

UHTC synthesis and additives

The authors turn their attention to UHTC synthesis in the paper's third section. While there are multiple approaches to synthesizing UHTCs, including solid-state reactive synthesis and solution-derived synthesis processes, the final UHTC's quality is most influenced by two key characteristics of the starting powders: particle size and impurity content.

The authors note that sintering UHTCs to full density in their monolithic forms is difficult due to the strong covalent nature of the M–X bonds. As such, additives in the form of alloying or doping can help promote densification, as well as provide structural and functional enhancements.

The most common additives used can be classified into three types: 3D particles, fibers, and lower-dimensional materials. The authors overview the pros and cons of each additive type.

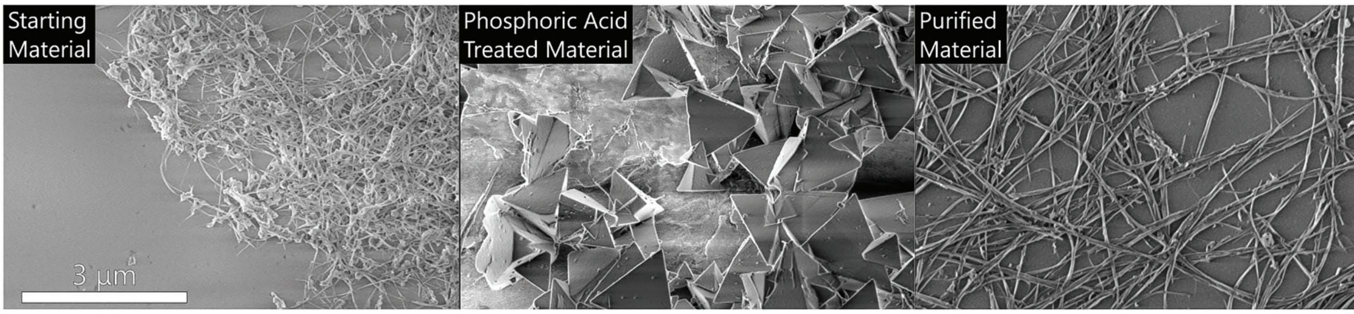
Future perspectives

In addition to research on traditional UHTC synthesis and manufacturing methods, some novel techniques are being used to develop UHTCs, including 3D printing, machine learning and modeling, high-entropy composition design, and 2D fabrication (e.g., MXenes).

This research on both traditional and novel manufacturing methods "will help the development of new UHTC materials to see humanity into the next era of technological breakthroughs in extreme environment scenarios," the authors conclude.

The paper, published in *Nature Reviews Materials*, is "Ultra-high temperature ceramics for extreme environments" (DOI: 10.1038/s41578-023-00619-0). ■

Purifying nanomaterials in bulk: New acid etching method rids boron nitride nanotubes of impurities



Credit: Marti group, Rice University

Scanning electron microscopy images, from left, of the starting material, after phosphoric acid treatment, and final purified boron nitride nanotubes.

Researchers at Rice University described a new wet-thermal etching method that rids boron nitride nanotubes (BNNTs) of impurities.

BNNTs are an emerging class of nanomaterials for which scalable synthesis methods are yet to be developed. Because of their chemical inertness, BNNTs require high temperatures and/or pressures to be synthesized in bulk. This extreme processing environment results in the formation of non-nanotube boron structures, such as amorphous boron, hexagonal boron nitride, boron nitride cages, and other less ordered boron nitride materials.

Researchers have explored various processes to eliminate the unwanted boron nitride forms, including chemical etching, functionalization, and physical separation techniques. While several methods can effectively remove amorphous boron, the other forms are more chemically similar to BNNTs and thereby more difficult to remove.

To date, wet-thermal etching is the most effective method for removing these other forms by targeting morphological differences. While the cylindrical structure of BNNTs allows for seamless connections between the atoms, hexagonal boron nitride and boron nitride cages contain unconnected atoms, which makes them more susceptible to reaction with external stimuli.

In the new study, the Rice University researchers used a phosphoric/hydrochloric acid solution for wet-thermal etching. As explained in a Rice University press release, this choice was inspired by a 2013 study at The Pennsylvania State University that showed phosphoric acid acted as a boron nitride wetting agent.

The Rice University researchers believed this wetting property may allow them to selectively remove the unwanted boron nitride forms. But upon heating the boron nitride nanomaterials in solution, they were surprised to see a pyramid structure had formed.

This observation indicated a chemical reaction had taken place, against the researchers' initial assumptions. So, they revised their hypothesis and conducted more experiments to tune the reaction to destroy only the unwanted boron nitride forms.

Their final process resulted in mass yields of up to 29% purified nanotubes, which is significantly greater than the 5% achieved with conventional steam etching setups. However, they note this result is highly dependent on the concentration of impurities in the starting material.

The paper, published in *Chemistry of Materials*, is "Reactivity of boron nitride nanomaterials with phosphoric acid and its application in the purification of boron nitride nanotubes" (DOI: 10.1021/acs.chemmater.3c01424). ■

Ultraviolet light-sensitive tape allows for easier and less damaging transfer of 2D materials

Researchers at Kyushu University and Japanese company Nitto Denko developed a tape with an adhesive force tunable through ultraviolet light illumination, which may be an ideal solution for mass graphene transfer.

After graphene is synthesized, it must be transferred from the production chamber onto various target substrates for application. However, current transfer methods tend to degrade the graphene's quality. For example, thin polymer support layers are regularly used to transfer graphene grown through chemical vapor deposition. After transfer, the support layer is removed, usually through dissolution with organic solvents. This process leaves behind residues on the graphene's surface plus limits the choice of target substrates (i.e., no flexible plastics).

The new ultraviolet light-sensitive tape avoids these disadvantages. To use this tape, it is first attached to as-grown graphene and then illuminated with ultraviolet light. The light hardens the adhesive layer while also weakening the graphene–adhesive interaction, setting the stage for the graphene's eventual release. The tape/graphene stack is detached from the original substrate by electrochemical delamination and then washed with deionized water. Next, the stack is placed on the new substrate and baked at 90°C. Finally, the tape is peeled off the stack at 80°C, leaving behind monolayer graphene.

Analysis of the graphene via optical microscopy revealed a pristine product without damages or contamination. But many defects were observed in the areas that missed being illuminated, "demonstrating the efficient control of adhesive force by UV light," the researchers write.

They used the ultraviolet light-sensitive tape to transfer both small and large amounts of graphene, from millimeter-sized areas up to wafer scales. They note that once the graphene is attached to the tape, it can be easily cut into different sizes and shapes before the graphene is released.

The ultraviolet light-sensitive tape transfer method is not only applicable to graphene. The researchers also transferred semiconducting transition metal dichalcogenides and multilayer hexagonal boron nitride using this method, though the adhesive composition needed to be modified to ensure proper attachment and release of different materials.

To date, the researchers have successfully transferred graphene wafers up to 10 cm in diameter. They are working to expand the size of the ultraviolet light-sensitive tape to the scale needed for manufacturers. Plus, they aim to improve stability of the 2D materials on the ultraviolet light-sensitive tapes so the tapes can be distributed to other end users, such as scientists at different institutions, with the materials already attached.

The open-access paper, published in *Nature Electronics*, is “Ready-to-transfer two-dimensional materials using tunable adhesive force tapes” (DOI: 10.1038/s41928-024-01121-3). ■

Optimized tape casting process creates LZO thin films for use as solid-state electrolytes

Researchers in Argentina and Spain developed a new forming route to obtain lithium metazirconate (LZO) films for use as electrolytes in solid-state batteries.

LZO has been investigated as a nanocoating in both traditional and solid-state lithium-ion batteries. Its use has resulted in batteries with enhanced cyclability and capacity retention.

Because of these great results, several studies investigated the use of LZO as a solid-state electrolyte itself, rather than as just a coating. However, to date, all electrochemical testing on LZO for this application was performed on sintered, pressed LZO discs. In application, LZO solid-state electrolytes would be formed as thin, flat, and dense sheets.

To fabricate LZO in the form of a sheet, the well-known tape casting technique is a good option. Tape casting involves forming thin and flat sheets, with a large area and thicknesses below 500 μm, from a suspension of a ceramic or metallic powder in water or nonaqueous solvents. However, despite the versatility and simplicity of this process, researchers have not studied or optimized its use to cast thin LZO sheets.

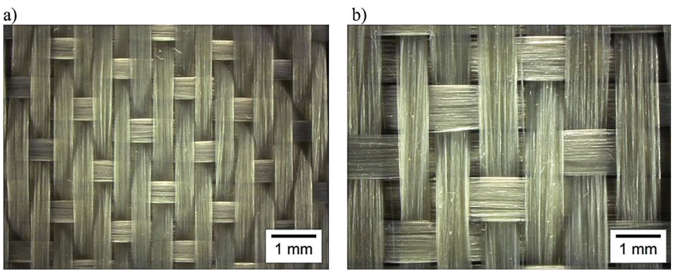
In February 2023, researchers from several centers and universities in Argentina published a paper describing how they fabricated highly dense LZO bodies using an optimized aqueous slip casting technique. Based on this experience, they partnered with researchers from Instituto de Cerámica y Vidrio in Spain to develop an aqueous forming route to obtain LZO films by tape casting. The results of this collaboration are reported in a paper published in August 2023.

Using knowledge from their earlier study, as well as data gathered from slip cast samples created for the new study, the researchers created optimized LZO suspensions for use in the tape casting process. They made a few changes compared to the slip casting process. For example, they added an acrylic binder agent to improve flexibility and green strength of the thin sheets. They also applied a slower heating speed during the thermal densification step to prevent sheets from cracking during debinding.

Thanks to these optimized parameters, the researchers successfully created homogeneous, sintered, defect-free LZO tapes with thickness values close to 500 μm, bulk densities equal to about 81% of the theoretical density, and only superficial shrinkage of 19.9–22.6% after thermal treatment.

The paper, published in *Journal of the European Ceramic Society*, is “Aqueous tape casting of lithium metazirconate (Li_2ZrO_3) thin sheets” (DOI: 10.1016/j.jeurceramsoc.2023.07.050). ■

Tradeoffs of creating all-oxide CMCs from fiber bundles with higher filament counts



Investigated Nextel 610 fiber fabrics: a) DF-11-1500-8HS and b) DF-13-4500-5HS.

Researchers in Germany explored the tradeoffs that come with creating all-oxide ceramic matrix composites (CMCs) from fiber bundles with higher filament counts.

It is easier to control fiber morphology and microstructure when extruded fiber bundles have a relatively low filament count. As such, the highest filament count conventionally is fiber bundles with 1,500 denier. Recently, though, 3M Co. started offering oxide fiber bundles with 4,500 denier. These bundles, called Nextel 610, are relatively priced about 36% less than the standard bundles with 1,500 denier. Plus, a version of the Nextel 610 fiber bundles weaved in a 5 harness-satin pattern instead of the traditional 8 harness-satin pattern is even more affordable, costing about 60% less than the standard bundles.

Some preliminary tests on these new fiber bundles demonstrated noticeable differences in the fiber morphology and bundle strength. More tests are needed to determine to what extent this cost reduction impairs the fibers' mechanical properties.

In a recent paper, the German researches compared the mechanical performance of all-oxide CMCs that use the Nextel fiber fabric weaved in a 5 harness-satin pattern (DF-13-4500-5HS) as reinforcement to ones that use the standard Nextel fiber fabric (DF-11-1500-8HS). The CMCs featuring the new DF-13-4500-5HS fabric exhibited lower strength under different types of mechanical loading compared to the standard CMC with DF-11-1500-8HS fabric. Specifically, when mechanical load was applied in the direction of the reinforcing fibers, the strength of the higher-denier fabric was about 15% lower. For off-axis properties, the strength of the higher-denier fabric was about 10% lower.

On the other hand, the higher-denier fabric can reduce the cost of raw materials by up to 60%. Additionally, the increased thickness of the higher-denier fabric means fewer layers are needed to obtain the desired component thickness. Fewer layers can lead to a labor time reduction of about 33% during critical processing steps, such as fiber infiltration, stacking, and shaping of all-oxide CMCs.

The open-access paper, published in *Open Ceramics*, is "The use of bundles with higher filament count for cost reduction of high-strength oxide ceramic composites" (DOI: 10.1016/j.oceram.2023.100389). ■

ceramics in energy

Protecting solar panels from hail—the thicker the glass, the better

Researchers from Vellore Institute of Technology and Waaree Energies Ltd. in India and City University of Hong Kong explored the role that front glass thickness in solar panels plays in improved hail resistance.

They used photovoltaic modules with three different thicknesses of front glass (2.8 mm, 3.2 mm, and 4 mm). Investigations were carried out following the guidelines prescribed by the IEC 61215–2:2016 and IS 14286:2019 standards for size, weight, and speed of hailstones.

- Hailstone size: 25–55 mm
- Hailstone weight: 7.5–80 gm
- Hailstone speed: 23–34 m/s.

At least three rounds of hail tests were completed on each module, with 11 hailstones being shot each round. After each round, the modules were analyzed for performance, insulation, wet leakage current, electric power output, and microcracks.

Results showed that while hail reduces the power output, having a thicker glass panel greatly reduces this effect. The thickest panel (4 mm) only lost 1.1% power output, in contrast to a reduction of 21.8% and 11.74% for the 2.8-mm and 3.2-mm-thick panels, respectively.

The 2.8-mm and 3.2-mm-thick panels also showed severe cracks at the point of impact, and both only survived the first impact of the 45-mm hailstone without the glass breaking. In contrast, the 4-mm-thick panel withstood impact from the 55-mm hailstone, though it did experience some microcracks, which could lead to electrical separation that makes a section of the cell inactive.

Finally, the 4-mm-thick panel experienced the smallest reduction in wet leakage current resistance, with the value dropping by only 27.23% compared to the 2.8-mm (55.25%) and 3.2-mm (46.81%) panels.

Currently, 3.2 mm is the standard thickness for glass front panels in commercial photovoltaic modules. Based on these results, for hail-prone zones, "the installer should go for photovoltaic modules with a front glass thickness of 4 mm to reduce or nullify the hail damage," the researchers write.

Credit: National Renewable Energy Laboratory

A solar panel that sustained damage during a hailstorm. If solar energy is to be a reliable source of energy, the resistance of photovoltaic modules to hail damage must be improved.

The paper, published in *Renewable Energy*, is "Analysis of the hail impacts on the performance of commercially available photovoltaic modules of varying front glass thickness" (DOI: 10.1016/j.renene.2022.12.061). ■

Recycling green technology: Microwave radiation facilitates deconstruction and reuse of solar panels

Microwaves can anneal semiconductor materials faster and more selectively. But this processing method can also affect the final mechanical and electrical properties of a semiconductor device. For example, researchers at Macquarie University and the University of New South Wales in Australia demonstrated that solar panel components fabricated via microwave annealing can be more easily deconstructed and reused.

They used modified kitchen microwaves to anneal the thin silicon layer in a solar panel. The microwave radiation selectively heated just the silicon and not the other materials around it, leading to several beneficial outcomes. For example, because everything except the silicon remained at room temperature, chemical substances within the oven walls did not flake off, as they do in conventional thermal annealing. As such, "there is less contamination," says lead author Binesh Puthen Veettil, senior lecturer in the School of Engineering at Macquarie University, in a Macquarie press release.

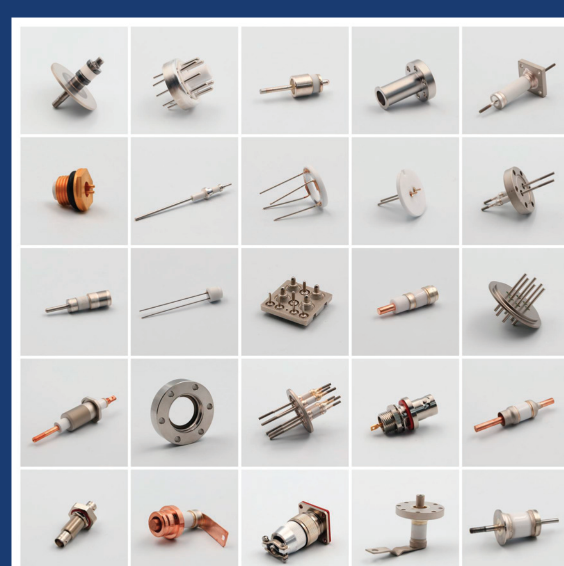
More importantly, however, was the recycling benefit. Solar panels feature a plastic (ethylene vinyl acetate) coating that protects the silicon plate from moisture and contamination. Unfortunately, this coating sticks to the toughened glass on top of the panel. To remove the plastic, the whole panel is smashed, heat treated, and washed in harsh chemicals. This process not only devalues or destroys many of the materials that could be reused from the solar panel, but it is also expensive. As such, dumping solar panels in a landfill is often the more economical option.

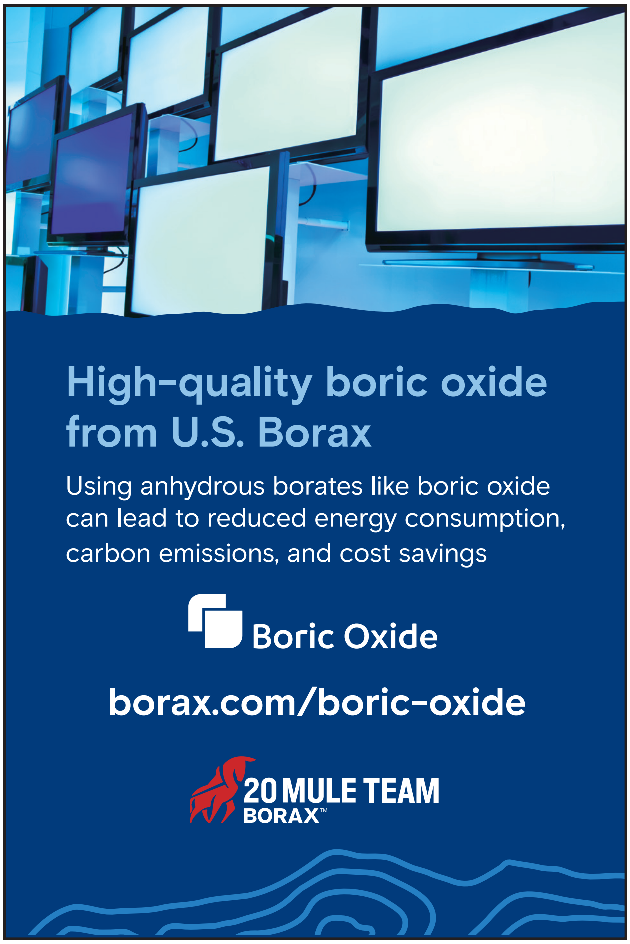
In contrast, during microwave annealing, the microwave radiation softens the plastic. This softening allows the plastic to be peeled off mechanically without destroying the glass.

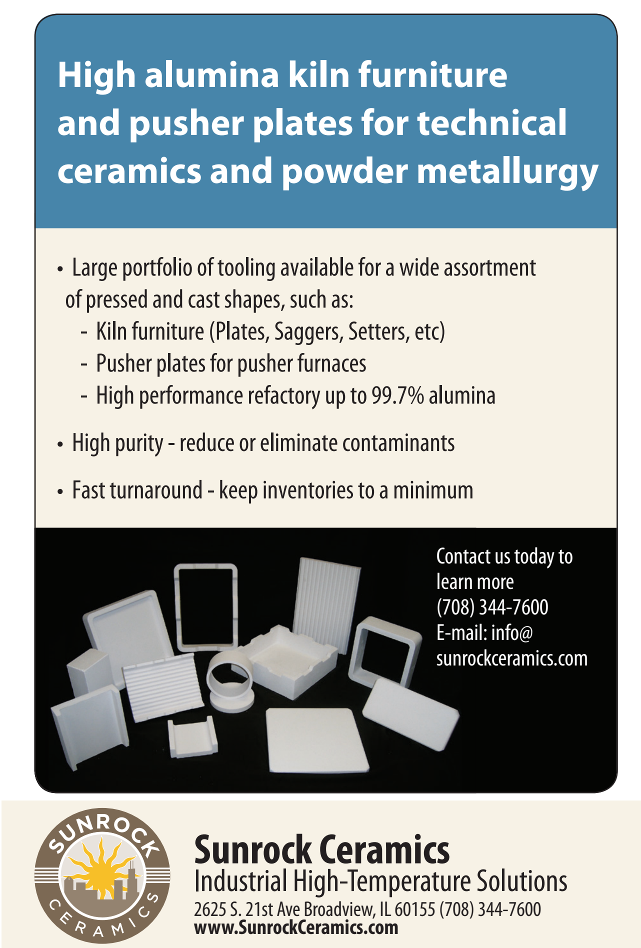
"If you can reuse the glass, the recycling will pay for itself," says Veettil in a *Cosmos* article.

In the Macquarie press release, the researchers note that the microwave-annealed solar cells were also more efficient at converting sunlight to electricity than the conventionally annealed cells. The reason for this efficiency was not clear, however, so new experiments are underway to answer that question.

The paper, published in *Applied Physics Letters*, is "Microwave annealing of silicon solar cells" (DOI: 10.1063/5.0127896). ■







ceramics in the environment

Reducing environmental impacts of MXene synthesis: Life cycle assessment and production guide offer tips

ACerS member Babak Anasori helped lead two studies that can help reduce the environmental impacts of MXene synthesis.

MXenes are a family of 2D transition metal carbides, nitrides, and carbonitrides that demonstrate a wide range of chemical and structural diversity. Since their discovery in 2011, MXenes have found usage in many sectors. Yet the environmental impacts of MXene synthesis have not been assessed systematically.

In April 2023, Anasori and University of Alabama professor Mark Elliot led a "cradle-to-gate" life cycle assessment (LCA) of $Ti_3C_2T_x$ MXene production, starting with raw material extraction and covering through manufacturing. They specifically evaluated $Ti_3C_2T_x$ MXenes produced as a coating layer for communications satellites' electromagnetic interference (EMI) shielding because "it is a well-known platform that requires EMI shielding and for which the detailed data required for LCA were available," they explain.

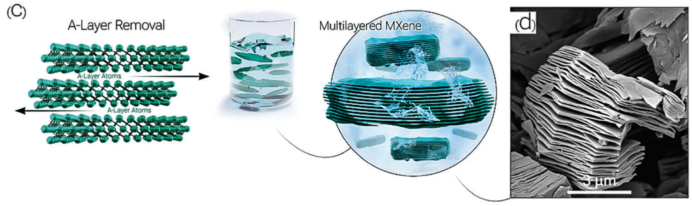
As MXenes are not yet employed for industrial-scale EMI shielding applications, they evaluated two laboratory-scale sizes of MXene synthesis in this study: a small lab scale (19.2 g per batch) and a large lab scale (800 g per batch). They curated inventory data from their own lab notes as well as various published studies on laboratory-scale syntheses of MXenes.

The results of their LCA, which they state "is the first report on the LCA of any MXene composition," suggests that electricity consumption plays the most important role in the environmental impacts of $Ti_3C_2T_x$ MXene synthesis in the laboratory. Based on this result, they suggested that methods to reduce energy consumption during MXene synthesis would be the best way to reduce the process's environmental impact, such as shortening synthesis time.

However, "A screening-level LCA may not accurately predict the environmental burdens by a direct scale-up because scaling up can introduce additional uncertainties," the researchers add. "Therefore, higher reaction yields, the recycling of reagents, and more efficient equipment are expected to reduce the associated environmental impact and energy required for the unit mass of $Ti_3C_2T_x$ MXenes produced at the industrial scale."

In May 2023, Anasori and colleagues from Indiana University–Purdue University Indianapolis and the University of Pennsylvania published an open-access, systematic guide for synthesizing high-quality MXenes that can be consistently reproduced. In addition to establishing a better understanding of various experimental conditions, their optimal stepwise synthesis process "holds the potential to be scaled to manufacturing levels," they write.

The April 2023 open-access paper, published in *Advanced Materials*, is "Life cycle assessment of $Ti_3C_2T_x$ MXene synthesis" (DOI: 10.1002/adma.202300422).



Credit: Firouzjaei et al., *Advanced Materials* [CC BY-NC 4.0]

Schematic representation of the production of $Ti_3C_2T_x$ MXenes on a small scale for potential industrial use. The steps shown above include the removal of A-layer atoms (aluminum) through selective etching in the topochemical production of MXene, leaving behind stacked MXene flakes.

The May 2023 open-access paper, published in *Small Methods*, is "Step-by-step guide for synthesis and delamination of $Ti_3C_2T_x$ MXene" (DOI: 10.1002/smtd.202300030). ■

Waste glass as packaging material for high-power automotive lighting applications

Researchers at SungKyunKwan University and Korea Photonics Technology Institute demonstrated how waste glass can be used as packaging material for white light-emitting diodes (WLEDs) in headlamps and side turn lamps of automobiles.

Current commercial WLEDs consist of a blue LED chip (indium gallium nitride) and yellow phosphor (cerium-doped yttrium aluminate garnet, YAG:Ce^{3+}) mixed with a silicon or organic resin. However, when used in high-power applications, such as automobile lighting, the resin used to package the phosphor can become damaged by the heat.

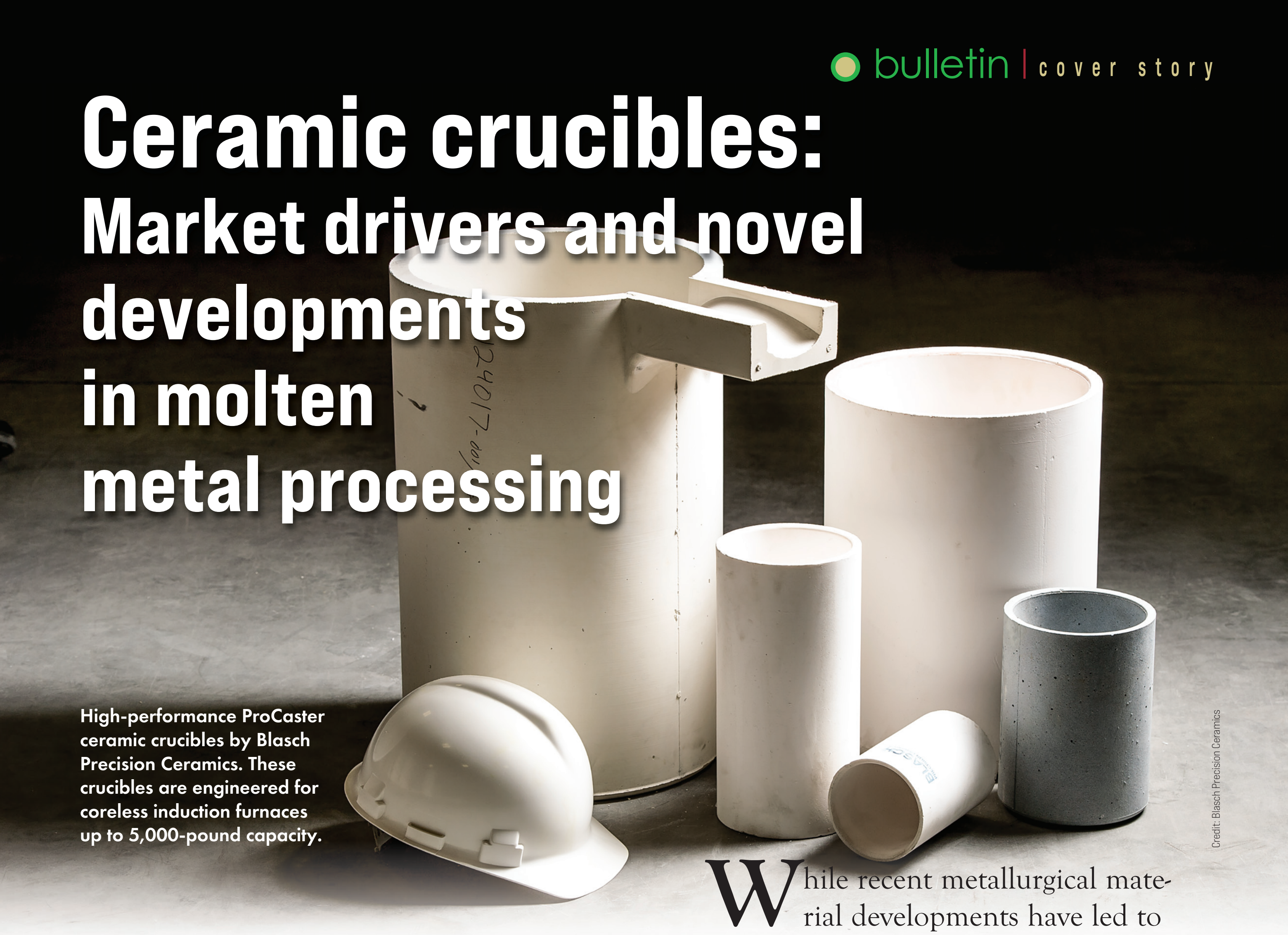
Phosphor in glass (PiG) is considered an attractive option for replacing the resin. PiG is a simple mixture of phosphor with glass powder that is sintered at temperatures of less than 800°C. Replacing the resin with glass improves the thermal and chemical stability of the WLED while maintaining the color conversion efficiency of the conventional phosphors.

In the recent study, the researchers explored whether waste glass could be used to prepare PiGs for application in WLEDs. They do not identify the specific waste glass used, except to say it was initially in the form of a cylinder and could not be used for its original purpose due to fracture, failure, and/or scratches. Energy dispersive spectroscopy revealed the glass contained silicon, calcium, sodium, oxygen, and potassium as main components.

The waste glass was mixed with one of two phosphors, either yellow YAG:Ce^{3+} or amber europium-doped calcium-stabilized alpha-SiAlON. A blue-chip package test revealed that the yellow phosphor-based PiG matched the commercial WLED standards for use in automobile headlamps, while the amber phosphor-based PiG could be used for side turn lamps.

The open-access paper, published in *Scientific Reports*, is "Fabrication of phosphor in glass using waste glass for automotive lighting application" (DOI: 10.1038/s41598-023-27685-2). ■

Ceramic crucibles: Market drivers and novel developments in molten metal processing



High-performance ProCaster ceramic crucibles by Blasch Precision Ceramics. These crucibles are engineered for coreless induction furnaces up to 5,000-pound capacity.

Credit: Blasch Precision Ceramics

By Rehan Afzal and Keith J. DeCarlo

A new generation of novel ceramic crucibles meet the performance needs of extreme processing environments while remaining reasonably priced.

While recent metallurgical material developments have led to advanced metals with improved properties, they have also impacted the processing environment. Specifically, when these metals are molten at high temperatures (>1,700°C in some applications), they are more corrosive to the containment equipment than previous compositions.[1]

Ceramics are the traditional materials used to contain molten metals. The oldest existing examples of crucibles come from the late neolithic and early bronze ages and are made of clay formed into simple cup-like geometries.[2] This rudimentary form evolved into the traditional crucible geometry seen today.

Low-cost ceramic materials, such as cordierite or fireclay, used to be the main materials used for molten metal containment. But with the increasingly corrosive and high-temperature environments found in today's advanced molten metals processing, manufacturers are starting to adopt higher-cost ceramics, such as alumina, zirconia, magnesia, and mullite, that can withstand higher temperatures, more heat cycles, and provide a higher level of corrosion resistance.

However, manufacturing costs are increasing across all industries due to both raw material and labor market trends.[3] As a result, customers looking to buy containment equipment

Figure 1. Corrosion testing of high alumina fireclay and alumina crucibles containing (a) cast iron, (b) 304 stainless steel, (c) 400 nickel, and (d) 6061 aluminum.

for both traditional (e.g., cast iron and steel) and advanced (e.g., lithium alloy) molten metal processing are backing out of sales for the more expensive ceramic products and instead are sourcing lower-performing but less costly products to remain within budgets.

In the future, it is likely that some molten metal processing environments will become even more corrosive and higher temperature. The development and manufacture of lithium alloys for the battery market will be a main driver of this trend, for example, along with other high-performance ferrous and nonferrous alloys. As such, manufacturers will no longer be able to make do with the lower-performing ceramic products. Therefore, it is necessary that a new generation of novel ceramic materials be developed that can meet the performance needs of extreme processing environments while remaining reasonably priced.

Meeting the demands of today's industries: Development of a high-alumina fireclay material

The market for ceramic crucibles is highly demanding because premature failure can result in substantial production issues and monetary losses. Thus, manufacturers require these ceramics to have robust thermal and chemical properties to ensure that processes are maintained with minimal downtime. Some of these processes include, but are not limited to, aerospace casting, automotive casting, die casting, continuous casting, investment casting, atomization, and alloy production.

The ceramic of choice for containment purposes varies depending on the final metal product. Molten metals that are ferrous, nonferrous, acidic, or alkaline come with different containment requirements. Ceramics used in these various cases include alumina, mullite, fused silica, and zirconia, among many others.

Recent advancements in molten metal processing have driven demand for larger and more intricate geometries than traditional cup-shaped crucibles. Traditional crucibles could hold one pound of molten metal, but now there are crucibles that can retain more than 8,000 pounds of molten metal while also sporting unique features, such as spouts or induction heating functionality. Some of these unique design features are difficult to fabricate with traditional slip cast, dry pressing, or even extrusion manufacturing processes. As such, the final price of the ceramic increases and subsequently reduces the customer's interest.

To improve a crucible's thermal and chemical properties while keeping cost low, Blasch Precision Ceramics developed a novel super duty high-alumina fireclay material. Because the overall cost of fireclay raw materials is significantly less than alumina, silicon carbide, zirconia, and other higher-cost ceramics, the development of a robust but low-cost novel ceramic material was possible.

Porosity, thermal shock resistance, and three-point bending modulus of rupture are three critical mechanical properties to ensure a customer's processes do not stall during operation. Through thorough development testing, Blasch Precision Ceramics fine-tuned the novel high-alumina fireclay material to perform better in each of these areas than the competing super duty fireclay bricks currently used in the market.

Furthermore, the Blasch Precision Ceramics' high-alumina fireclay material demonstrates similar or better corrosion resistance and nonwetting attributes when compared to higher-cost materials for both ferrous and nonferrous metals (Figure 1). Details of the testing process to determine these properties are described in the sidebar, "Internal 'cup-brick' testing for corrosion resistance and nonwettability."

The corrosion resistance and nonwetting attributes, coupled with the ability to form complex geometries, makes the Blasch Precision Ceramics' high-alumina fireclay material a very attractive candidate for customers that require a robust crucible that can operate in harsh environments at a lower price point.

Application spotlight: Use of ceramics for aluminum–lithium alloy manufacture

The demand for lithium alloys is increasing rapidly with the increasing electrification of everyday life.[2] Lithium alloys offer increased energy densities and efficiencies compared to other battery materials, which is what makes them desirable.

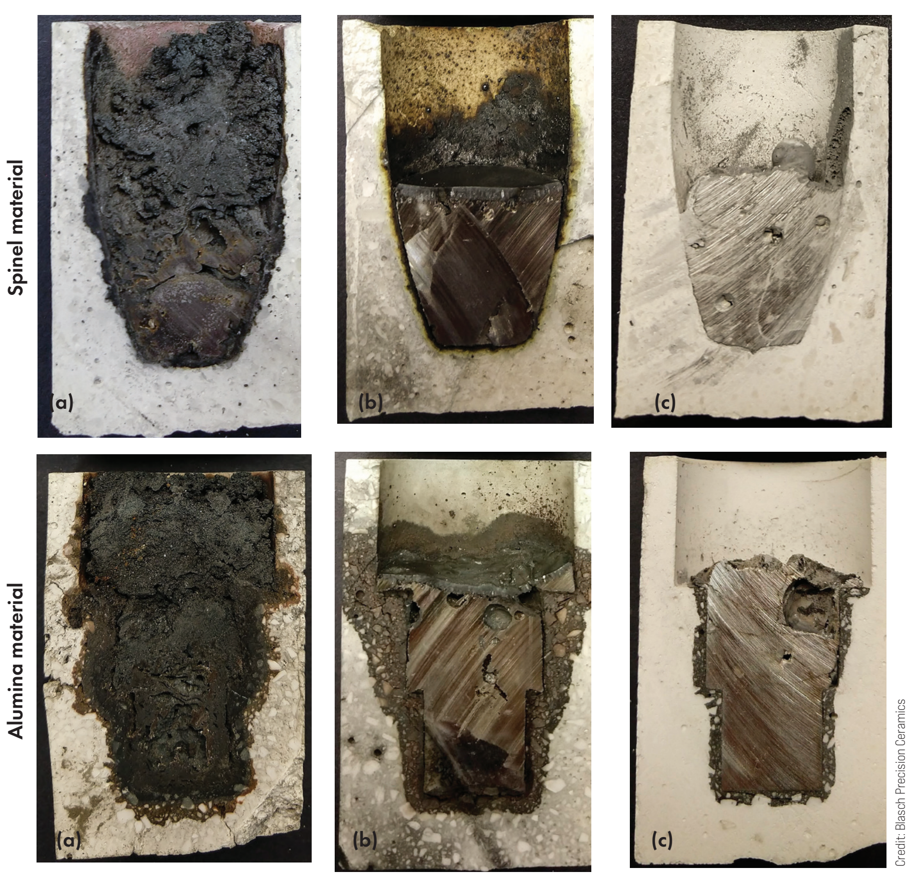


Figure 2. Internal "cup-brick" corrosion testing of magnesia alumina spinel and alumina refractory crucibles containing (a) 304 stainless steel, (b) 400 nickel, and (c) 6061 aluminum. 6061 aluminum is an Al–Mg alloy with a relatively basic pH. It is not as basic as Al-Li alloys, but it is a good starting point for corrosion and nonwetting testing of basic pH materials.

Energy storage devices, such as portable electronics, grid-scale energy storage, and now transportation with the forthcoming of electric vehicles, are the primary applications for lithium alloys. The global market for energy storage devices is projected to grow five times larger during the next decade from its current size of approximately $120 billion in 2019.[4]

Depending on the industry, lithium is alloyed with various other metals to enhance desired properties as well as reduce its reactivity, as lithium is an alkali metal. The aerospace industry specifically uses aluminum–lithium alloys to manufacture structural components for aircraft. In the 1950s, researchers discovered that lithium alloyed with aluminum greatly decreases the density of the aluminum while increasing the elastic modulus.[5] So, the use of aluminum–lithium alloys in aircraft can greatly increase the vehicle's structural rigidity while decreasing its overall weight and improving its fuel efficiency.

Safety is of the utmost importance in the aerospace industry, so there are tight regulations to avoid impurities in the materials used in planes. Vacuum induction furnaces are often used to ensure aluminum–lithium alloy production remains as pure as possible. Additionally, processing the alloy in a vacuum reduces exposure to moisture and air, which prevents unwanted reactions from occurring with the lithium.

But unlike typical induction furnaces, vacuum induction furnaces can complicate the geometries for the ceramic crucibles used within. This situation presents a challenge when considering the ceramic material that is typically used for holding aluminum–lithium alloys during processing.

Lithium-containing alloys are usually highly basic pH, which is problematic for traditional refractory materials (e.g., clays, alumina, mullite, silica) that have low corrosion resistance to basic pH environments. Therefore, magnesia is the refractory of choice due to its high corrosion resistance to basic pH environments.

However, magnesia is hygroscopic, which means it tends to absorb moisture from the environment. This property greatly hinders refractory manufacturers from casting magnesia into different shapes, so magnesia is typically sold as an unshaped refractory that must be environmentally controlled. If magnesia is shaped, it is done so via dry pressing, which limits shape complexity and thus the ability to make an effective magnesia crucible for use in vacuum induction furnaces for aerospace component manufacture.

To create a crucible with corrosion resistance similar to magnesia but with the ability to be formed into complex shapes, researchers have synthesized new materials that contain magnesia as a component with varying success. Least successful are the materials that incorporate magnesia directly rather than as a compound. In this case, magnesia remains hygroscopic, which hinders aqueous casting techniques and therefore storability and complex shape formation.

In contrast, when magnesia is incorporated as magnesia alumina spinel, the final material typically is not hygroscopic, depending on the synthesis technique used and final stoichiometry. So, it can be formed into complex geometries without any specialized storage needs. Furthermore, spinel can exhibit similar basic pH corrosion resistance compared to magnesia, again depending on synthesis technique and final stoichiometry.

Internal testing of a spinel refractory developed by Blasch Precision Ceramics demonstrated the newly developed material has excellent nonwetting attributes. Additionally, internal "cup-brick" corrosion testing (see sidebar for details) showed it demonstrated minimal corrosion against a variety of molten metal alloys compared to an alumina refractory also manufactured by Blasch Precision Ceramics (Figure 2).

Besides Blasch Precision Ceramics' new magnesia alumina spinel, the development of even more ceramic materials that are resistant to basic pH environments, can withstand high temperatures, and can be manufactured into complex shapes will allow industry to expand into even higher-temperature melts and more corrosive alloys. Ultimately, industry will be able to further advance new technologies for aerospace, energy, and defense markets, plus many more.

Conclusions

Crucible technology has rapidly evolved in recent years due the high demand for better performing metals and, subsequently, refractory ceramic products that can improve metallic purity while lasting longer in service. The need for crucibles that can withstand extremely corrosive and high-temperature environments while remaining reasonably priced is a primary driver of the refractory ceramics market today.

Blasch Precision Ceramics is meeting the demand for high-performing and low-cost crucibles with the development of ceramic materials for use in both traditional (e.g., cast iron and steel) and advanced (e.g., aluminum–lithium alloys) molten metal processes. In the former case, Blasch Precision Ceramics' novel high-alumina fireclay material has costs similar to traditional cordierite and fireclay materials but with the thermal and chemical performance of alumina, mullite, and zirconia materials. In the latter case, Blasch Precision Ceramics' magnesia alumina spinel circumvents the manufacturing issues with traditional magnesia while demonstrating similar corrosion resistance to basic pH environments.

Processes and technologies that employ crucibles will continue to advance as they have for the past thousands of years. Blasch Precision Ceramics stands ready to help meet the demand as industry evolves to process molten metals in increasingly corrosive and higher-temperature environments.

Internal "cup-brick" testing for corrosion resistance and nonwettability

Internal "cup-brick" testing consists of filling a 3 inch x 2 inch x 2 inch ceramic crucible with 15 cm^3 of a chosen molten metal alloy. After filling, the samples are fired to a soak temperature above the melting temperature of the metal being tested. The "cup-brick" is held at the respective soak temperature for 20 hours and then allowed to cool to room temperature, after which it is sectioned in half and qualitatively observed for corrosion.

Corrosion is determined based on the interaction between the metallic and the ceramic, seen as the darkened portions along the ceramic–metallic interfaces in Figures 1 and 2. Meanwhile, the ceramic's nonwetting attributes are demonstrated as the depth of the darkened portions, where a thin line demonstrates good nonwetting attributes and a deep penetration into the bulk ceramic demonstrates metallic wetting. ■

About the authors

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3D-printed ceramics in investment casting: Rewriting the rules for efficient casting core production

Credit: Lithoz

By Alice Elt and Peter Schneider

Harnessing Lithoz's ultraprecise lithography-based ceramic manufacturing 3D printing technology to fabricate ceramic casting cores allows for the creation of precise and complex metal components for aerospace applications.

Investment casting is an integral part of manufacturing metal components in the aerospace industry.

In this process, a wax pattern is "invested" (coated) with a refractory ceramic material. After the ceramic coating dries and hardens, the wax is melted out and leaves behind a cavity that is subsequently filled with molten metal. Once the metal cools and solidifies, the ceramic cast is removed from the metal, leaving behind a complex and highly accurate component.

To achieve even more intricate parts, sacrificial casting cores are employed in the investment casting process to produce intricate inner channels in the final component. These channels reduce the component's weight and allow for internal cooling in application.

Ceramics are the standard material used for casting cores. Ceramic cores maintain their integrity and shape even at very high temperatures, ensuring mechanical strength and ultimately delivering a dimensionally accurate, high-quality casting result.

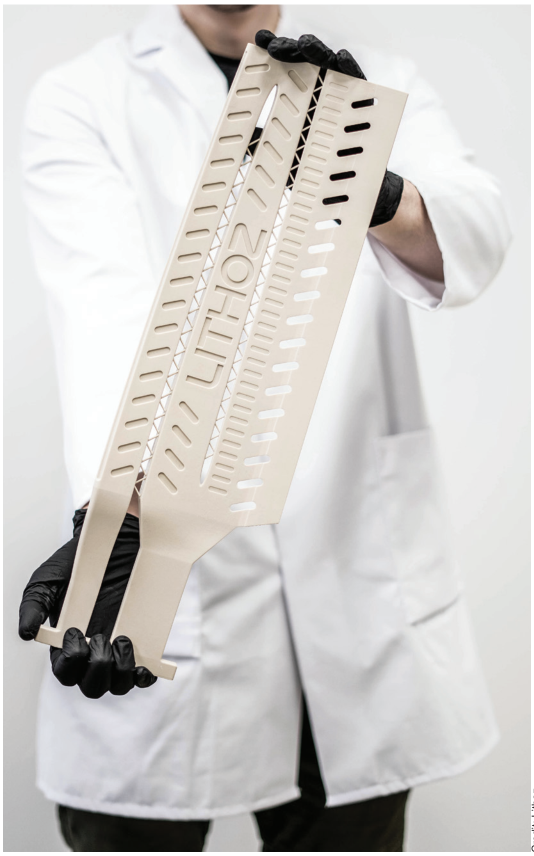
When ceramic casting cores are combined with the design freedom of Lithoz's lithography-based ceramic manufacturing (LCM) 3D printing technology, it is possible to rapidly manufacture ever more complex and efficient cores—opening the door to previously unimaginable applications in aerospace.

Ceramics for investment casting

Silica-based ceramics are the main choice for casting cores because of their lack of chemical reactivity with most metals. Reactions between the core and the molten metal could lead to defects or compromised structural integrity in the final part, but use of silica helps avoids this outcome.

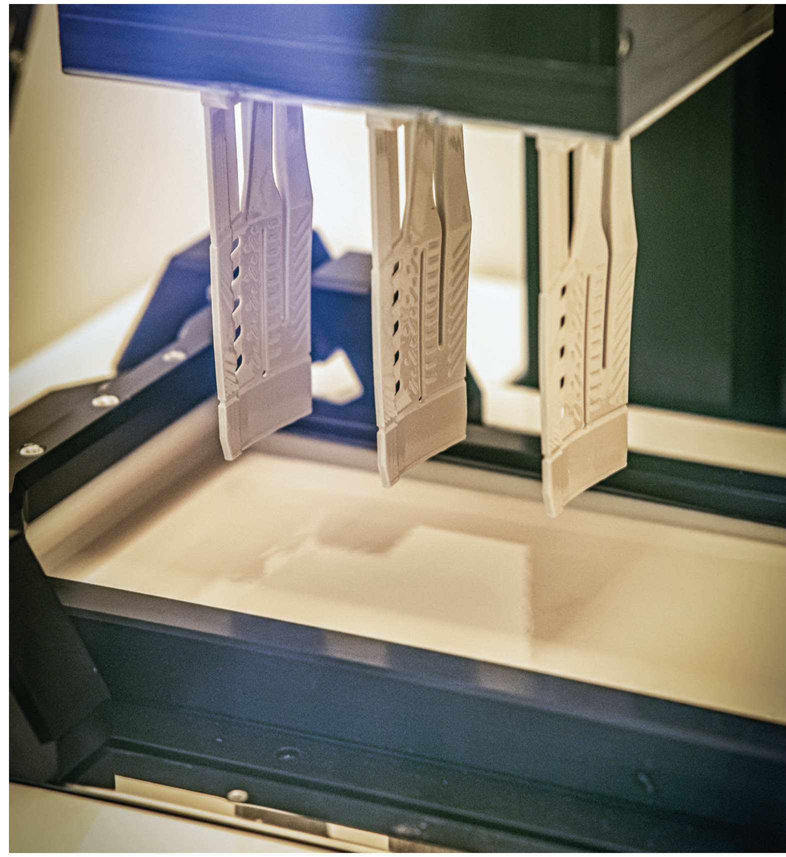
However, silica-based ceramics will react with chemical leaching agents used in the investment casting process. Thanks to this reaction, any leftover ceramic material can be easily dissolved, leaving a residue-free casted part.

Lithoz's LithaCore 450 is a ceramic material precisely tailored by Lithoz to meet the challenges of producing increasingly fine structures in casting cores for investment casting (Figure 1). Based on silica with additions of alumina and zircon, this material has a very low coefficient of thermal expansion, a high porosity, and outstanding surface quality (roughness average < 3 μm), ensuring that internal channels in the final part have a smooth finish and good leachability.



Credit: Lithoz

Figure 1. Example of a 3D-printed ceramic casting core made of Lithoz's LithaCore 450.



Credit: Lithoz

Figure 2. Lithoz's lithography-based ceramic manufacturing 3D printing technology enables the manufacture of far more durable and intricate ceramic casting cores.

3D-printed ceramic cores

While ceramics offer many advantages in the production of casting cores from a materials perspective, investment casting requires absolute accuracy and reliable repeatability. As demand for more complex components in the aerospace industry grows, the combinations of metals with traditional casting methods are simply unable to achieve the level of detail needed for the part's internal structure.

Lithoz's LCM 3D printing technology can produce ceramic casting cores with highly complex designs,[1] with intricate structural features as precise as 100 µm. (Figure 2). This capability unlocks new possibilities for design innovation in aerospace, optimizing the performance and efficiency of parts.

3D printing as a technology for producing investment casting cores also significantly reduces lead times. Conventional methods for fabricating cores are often very time-consuming, requiring multiple steps and tools. By using 3D printing to streamline the production process and directly print the cores, parts can be produced and improved far more rapidly, enabling a quicker turnaround.

Conclusion

3D-printed ceramics present an innovative and effective solution for producing intricately structured cores for investment casting. This geometrical freedom, together with the superb properties of ceramics, opens the door to manufacture far more precise and complex metal components for current and emerging aerospace applications.

With more than a decade of experience, Lithoz offers the LCM 3D printing technology, LithaCore ceramic material, and technical know-how to entirely streamline the production process of casting cores for investment casting and produce more efficient cores than ever before.

About the authors

Alice Elt is public relations manager and Peter Schneider is head of application engineering at Lithoz (Vienna, Austria). Contact Elt at aelt@lithoz.com.

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Advancing a new era for aerospace:

Ultrahigh-density carbon–carbon composites through safe and affordable FAST processing

By Edward J. A. Pope

Field assisted sintering technology developed by materials research and development company MATECH produces a new class of ultrahigh-density carbon–carbon composites for next-generation aerospace applications.

Since their first demonstration in 1958, carbon–carbon composites are now commonly used in defense and aerospace applications.

Carbon–carbon composites are thermally stable composites composed of carbon fibers and matrix phases. These materials, which are classified as a "critical technology" by the U.S. Department of Defense, are used in ballistic nosetips; rocket motors; and reentry materials, such as heat shields and aeroshells.

Current carbon–carbon composites are typically created through a polymer infiltration and pyrolysis process and have somewhat low bulk densities around 1.60 g/cc. Carbon–carbon composites with higher bulk densities are desirable because this property equates to improved performance in other areas, including higher hardness, higher thermal conductivity, and greater mechanical erosion and abrasion resistance.

Higher bulk densities of about 1.95 g/cc can be achieved using the hot isostatic pressure impregnation carbonization (HIPIC) process. But this process, developed decades ago to fabricate nosetips for intercontinental ballistic missiles, is considered dangerous, very expensive, and difficult to implement.

Materials research and development company MATECH (Westlake Village, Calif.) recently developed a patent-pending technology for making an entirely new class of ultrahigh-density (UHD) carbon–carbon composites. This development extends MATECH's prior work on the densification of SiC/SiC and C/SiC ceramic matrix composites using field assisted sintering technology (FAST).[1,2]

The new FAST process achieves UHD carbon–carbon composites with bulk densities greater than 2.20 g/cc. Not only are these bulk densities higher than those achieved with the HIPIC process, but MATECH's technology is also safe, affordable, and easy to implement.

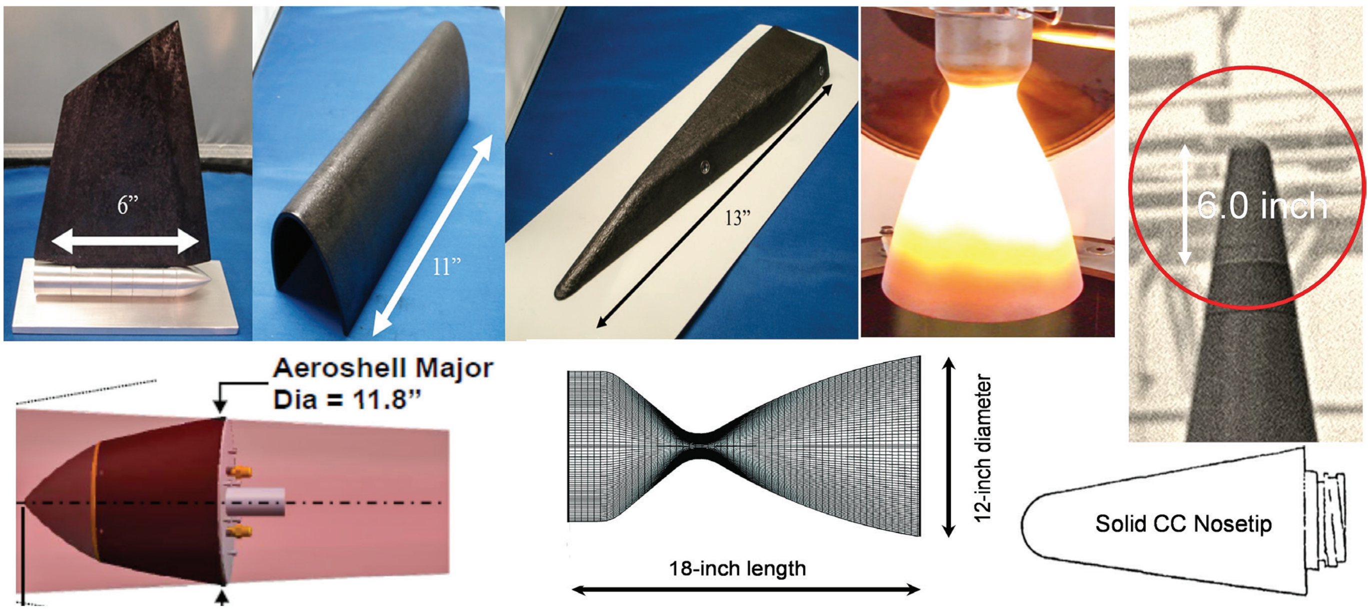

Figure 1. Pictured are example components that can be manufactured by MATECH's FAST ultrahigh-density carbon–carbon processing technology. Clockwise from top left: control fin, rounded leading edge, strake leading edge, thin wall thrust nozzle, solid intercontinental ballistic missile nosetip, integrated composite nozzle and exit cone schematic, and thin wall hollow nosetip.

MATECH's FAST densification process can be performed in only 10 minutes, which means the technology is readily scalable to create UHD carbon–carbon composites for use as ballistic nosetips, rocket nozzles, and leading edges of aircraft, among other components (Figure 1). Even larger components, such as hypersonic aeroshells, are feasible with larger equipment. MATECH is in close contact with global equipment manufacturers and service providers to manufacture parts in the 2.0-meter x 1.0-meter size range, prompted by a specific customer requirement.

In addition to the economic and safety benefits of MATECH's FAST densification process, the resulting UHD carbon–carbon composites offer several performance benefits beyond higher bulk density. For example, modeling predicts ablation resistance 20 times higher than conventional carbon–carbon composites and five times higher than HIPIC carbon–carbon composites. A higher ablation resistance means the shape of the nose tip or leading edge is retained much longer, thereby maintaining its aerodynamic predictability. Lower ablation resistance, on the other hand, leads to severe shape changes that make aerodynamic behavior less predictable.[3,4]

Additionally, extensive fiber pull-out upon fracture has been documented by optical fractography (see Figure 2). This behavior can lead to a 20-times increase in toughness of a composite prior to ultimate failure compared with a monolithic material of comparable composition.

As society advances toward a new era for aerospace, MATECH's FAST technology will help realize these lofty goals.

About the author

Edward J. A. Pope is CEO of materials research and development company MATECH (Westlake Village, Calif.). Contact Pope at ed@matechgsm.com.

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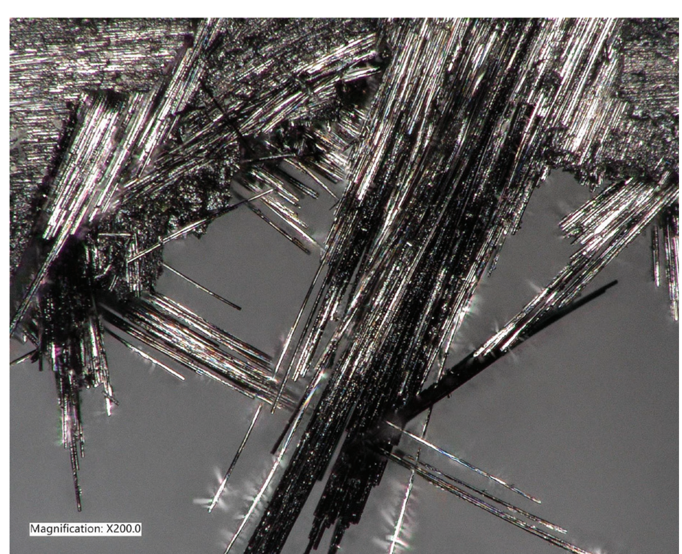


Figure 2. Optical fractography of extensive fiber pull-out in MATECH's FAST-densified carbon–carbon composites.

Jonathon Foreman
ACerS journals managing editor

Ceramics to improve manufacturing

With superior mechanical, thermal, and chemical properties compared to other types of materials, ceramics have been used as tooling, containers, insulation, and more for manufacturing for more than a century. For example, the high hardness of carbides and diamond make them excellent materials for cutting tools, while the high-temperature mechanical and chemical stability of corundum and mullite lead to their use as containers and insulation in smelting and other extreme processing environments.

Even with these well-established applications, research continues to enhance the desirable properties and minimize the limitations. The American Ceramic Society is a leading publisher of articles encompassing all aspects of ceramics for manufacturing, from new materials to performance testing to manufacturing of end products. We have assembled a topical collection of recent articles highlighting the use of contemporary research techniques to address the expanding needs for better performance and improved manufacturability.

The articles in this collection fall generally into three categories:

1) Studies on cutting tools, including explorations of materials, structures, fabrication techniques, and use of modeling and simulation.
2) Materials for refractories, including new raw materials and their effects on processing and performance, along with applying advanced characterization methods to refractory raw materials.
3) Processing parameters for grinding media and the effects of conditions and additives on performance.

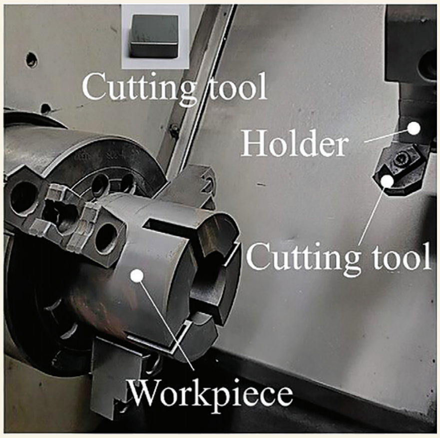
Exemplifying the types of articles included in the first category is "Enhancing cutting performance of Ti(C,N)-based cermet tools on nodular cast iron by incorporating high-entropy carbide." Nodular cast iron is an excellent material for mechanical components, such as gears and camshafts, but it is difficult to machine due to poor thermal conduction. Materials with high hardness, toughness, and wear resistance are needed to form tools with the cutting efficiency needed to minimize heat transfer.

High-entropy materials contain multiple metallic elements of varying atomic sizes that appear to be stabilized by highly disordered structures. This stability improves mechanical and thermal properties, including hardness and toughness. The authors of the article found that tools that incorporate high-entropy carbides had, for the most part, higher hardness, toughness, strength, and thermal conductivity. The tool with the best properties had a tool life that was nearly double the baseline tool without the high-entropy carbides.

Regarding articles in the second category, refractory manufacturers and researchers are highly focused on reducing energy consumption, not only in the manufacturing of their products but also for their customers during usage. Refractory parts feature intricate compositions, comprising coarse and fine refractory particles, binders, additives, and more.

Calcium aluminate cements (CACs), which are widely used as binders in refractories, require substantial amounts of natural resources and energy to produce while emitting high amounts of CO_2. The article "Design, characterization, and incorporation of geopolymer binders in refractory ceramic compositions" compared kaolin-based geopolymer and nanosilica-containing liquids formulations to CACs. While their initial results showed limited success, one geopolymer binder formulation demonstrated potential as an alternative to CAC.

The articles in the third and final category, among the most important parameters that manufacturers need to consider for grinding media are wear and cost. Excessive wear on grinding media both drives up cost and introduces impurities, which is particularly important when processing materials into powders for downstream use.



Setup for testing the cutting performance and wear characteristics of Si_3N_4–SiC_w–HfB_2 ceramic cutting tools.

In the article "Processing of alumina grinding media using scandia as a sintering aid," the authors focused on improving wear to produce media for high-purity fine powders. Though scandia is a relatively expensive material, the performance improvements and potential longevity from reduced wear can easily justify the added cost. Fortunately, the authors found sufficient gains by adding between 0.01 wt.% and 0.1 wt.% scandia.

The topical collection "Ceramics to Improve Manufacturing" can be found on the ACerS Publication Central hub at https://ceramics.onlinelibrary.wiley.com. Click on the "Collections" menu and select "Topical Collections" from the drop down. You will see this collection along with others created over the past few years. You can also directly access this collection using the link https://bit.ly/April2024-CeramicManufacturing. ■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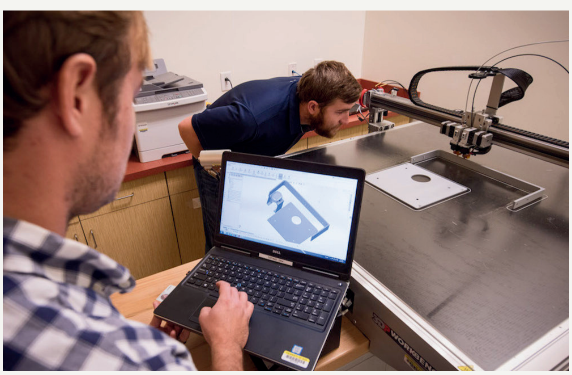

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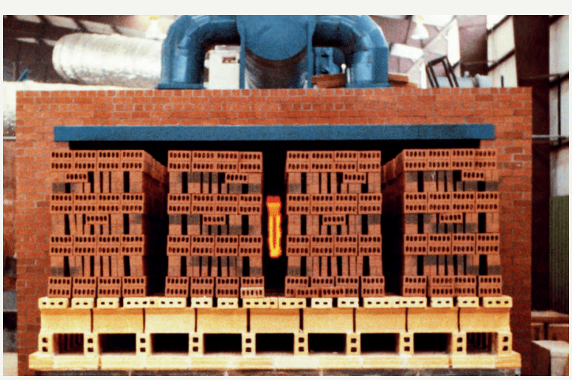

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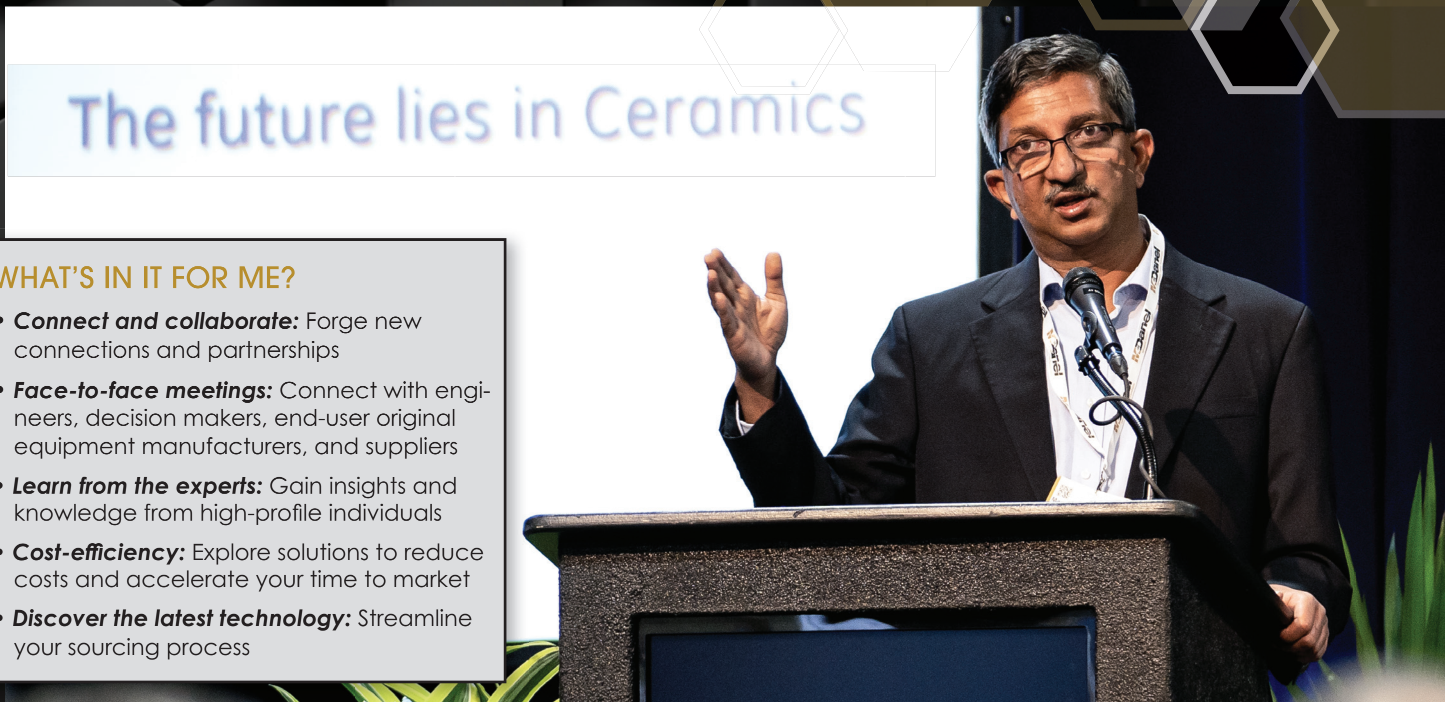

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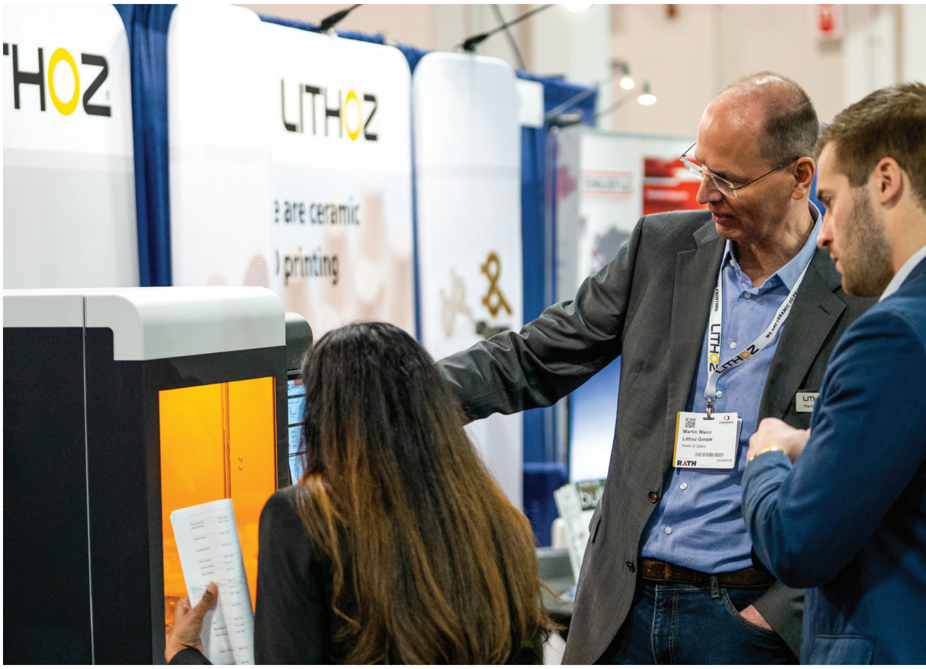
Topics for 2024 include: Innovation in ceramic materials, 3D printing, supply chain sustainability, piezoelectric ceramics, workforce and talent development, advanced ceramic innovations in aerospace and electronics, and next-generation solid-state batteries.

Visitors can register for a free pass that grants entry to the exhibition area, where exhibitors will spotlight the newest advancements and technologies shaping the future of advanced ceramics. The entire supply chain will be represented, with notable companies such as ERG Aerospace, Fiven, GeoCorp, ALTEO, McDanel, Bosch, Rath, Schott, and American Elements. ■



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- 3D Printing with Hydroxyapatite

Day 2 – Wednesday, May 1

FOCUS: INNOVATION AND MANUFACTURING

- Solving the Workforce and Talent Development Crisis in Ceramics and Glass
- Innovation in Ceramic Materials for Microelectronics
- Manufacturing Advanced Ceramic Parts for Aerospace and Electronics
- Piezoelectric Ceramics—From Bulk to Thin Film and BTO

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Overcoming ceramic challenges at the 48th ICACC in Daytona Beach

Students and speakers who participated in the IGNITE MSE programming at ICACC 2024. The programming included lectures by guest speakers on topics of professional development, several networking games, a luncheon with industry members, and a poster session where students could discuss the broader impacts of science in their research and other scholarly activities.

(All photos credit: ACerS)

The 48th International Conference and Expo on Advanced Ceramics and Composites (ICACC 2024) welcomed more than 800 people, including nearly 200 students, from 28 countries to Daytona Beach, Fla., from Jan. 28–Feb. 2, 2024. This year's conference included 19 symposia; five focused sessions; and a special focused session on diversity, entrepreneurship, and commercialization.

During the opening plenary session on Monday, Engineering Ceramics Division chair Young-Wook Kim welcomed everyone to the conference and presented the Jubilee Global Diversity Award and Global Young Investigator Award. Student poster awards from 2023 were also announced and presented, along with the Global Star Awards. Conference chair Jie Zhang shared the good news that nearly 900 abstracts were accepted for ICACC 2024.

The following sections contain some highlights from ICACC 2024.

Attendees got to talk with ceramic and glass materials and equipment suppliers in the vendor exposition hall.

Award and plenary lectures

Ghatu Subhash of the University of Florida focused the Mueller Award lecture on mechanism-based approaches for understanding the impact behavior of ceramics. He described how he used peak shifts in Raman spectroscopy under high pressures to simulate the effects of shockwaves on the nanosecond scale. Results for various ceramic materials were compared with molecular dynamics simulations.

Kiyoshi Shimamura, group leader in the Optical Single Crystals Group at National Institute for Materials Science in Japan, focused the Bridge Building Award lecture on the use of single crystals in electro-optical applications. He discussed early work in single crystals and then described more recent developments, including his research on using crushed single-crystal materials in high-intensity white-light LEDs.

Elżbieta Pamuła of AGH University of Science and Technology gave the first plenary lecture on multifunctional biomaterials for bone tissue regeneration and treatment. She described her development of a coated silicate framework that encases active cells, which reduced the required treatment dosage but retained consistent delivery over time.

Judith Jeevarajan, vice president and executive director of the Electrochemical Safety Research Institute at UL Research Institutes, gave the second plenary lecture on ways to mitigate thermal runaway propagation between lithium-ion battery cells. She and her colleagues tested various containers and materials used to separate individual cells in modern battery packs to determine the best combination to prevent heat transfer between cells.

ICACC 2024 program chair Jie Zhang, left, and Engineering Ceramics Division chair Young-Wook Kim, right, welcomed everyone to the conference.

Student highlights from ICACC 2024

IGNITE MSE saw its successful return at ICACC 2024. This special student professional development event, which initially launched alongside ACerS Annual Meeting at MS&T23, consisted of talks on professional development, several networking games, a luncheon with industry members, and a poster session.

Additionally, Wiley hosted a journal writing workshop for young researchers.

View more images from the conference on ACerS Flickr page at https://bit.ly/ICACC-2024. The 49th ICACC will take place Jan. 26–31, 2025, in Daytona Beach, Fla. ■

EMA 2024 debuts in Denver

(All photos credit: ACerS)

ACerS members had the chance to meet and talk to ACerSpresident Rajendra Bordia (second from left) during EMA 2024.

Traditionally held in Orlando, Fla., the Electronic Materials and Applications Conference took place this year in Denver, Colo., from Feb. 13–16, 2024. The decision to move EMA 2024 to Denver was met with widespread approval from attendees.

EMA is coorganized by ACerS' Electronics Division and Basic Science Division. For EMA 2024, Electronics Division organizers were Mina Yoon of Oak Ridge National Laboratory and Matjaz Spreitzer of Josef Stefan Institute in Slovenia. Basic Science Division organizers were Fei Peng of Clemson University and Klaus Van Benthem of the University of California, Davis.

Attendance was up from last year's conference, with more than 330 attendees coming from 22 countries. Below are some highlights from EMA 2024.

Plenary lectures

Heli Jantunen, Distinguished Professor of Technical Physics at the University of Oulu, Finland, delivered the first plenary lecture on the transformative potential of ultralow-permittivity materials in enabling sub-THz telecommunication. Her lecture provided a comprehensive overview of the advantages offered by these materials as well as current commercial availability.

Heli Jantunen of the University of Oulu presented the first plenary lecture of EMA 2024 on Wednesday morning on the topic of ultralow-permittivity dielectrics for sub-THz telecommunication.

Wayne D. Kaplan, Distinguished Karl Stoll Chair in Advanced Materials at Technion – Israel Institute of Technology, delivered the second plenary lecture on the role of grain boundaries in shaping microstructures and influencing material properties. The heart of Kaplan's lecture was a nuanced exploration of the mechanisms underlying grain boundary motion during sintering.

EMA welcomes significant student turnout

Of the more than 330 attendees at the conference, 105 were students, meaning they accounted for nearly a third of all attendees. In comparison, EMA 2023 welcomed only 40 students.

The Colorado School of Mines, located in Golden, Colo., played a big part in enabling more students to attend the meeting. Aside from being located close to the conference hotel, the Colorado School of Mines sponsored the opening networking reception.

In collaboration with the Ceramic and Glass Industry Foundation, EMA 2024 hosted IGNITE MSE, a professional development series for students happening at select ACerS conferences. An industry luncheon welcomed professionals from Intel, CoorsTek, National Renewable Energy Laboratory, U.S. Naval Research Laboratory, Johns Mansfield, Platt Engineering Solutions, and Colorado School of Mines to talk to students about their jobs. Following lunch, students participated in networking games and heard invited talks on various topics of professional development in ceramic and glass materials science.

In addition to IGNITE MSE, the conference featured a student poster session and young professional reception to help students foster their networks and nurture professional communities among their peers.

EMA 2024 Basic Science Division organizer Fei Peng, right, presented EMA 2024 plenary lecturer Wayne D. Kaplan with a certificate of appreciation after his talk on microstructure engineering of grain boundaries.

Check out more images from EMA 2024 on ACerS Flickr page at https://bit.ly/EMA-2024.

EMA 2025 will take place in Denver, Colo., again next year from Feb. 25–27, 2025. ■

The American Ceramic Society
www.ceramics.org

UPCOMING DATES

GOLDEN NUGGET LAS VEGAS HOTEL & CASINO, LAS VEGAS, NEV.

Join ACerS Glass & Optical Materials Division for a program featuring six symposia involving glass. The conference will provide an open forum for glass scientists and engineers from around the world to present and exchange findings on recent advances related to glass science and technology.

HOTEL BONAVENTURE, MONTREAL, QC, CANADA

The theme for the 10th International Congress on Ceramics will be "Enabling a better world through ceramic and glass materials."

DAVID L. LAWRENCE CONVENTION CENTER, PITTSBURGH, PA.

The Materials Science & Technology (MS&T) technical meeting and exhibition series is a long-standing, recognized forum for fostering technical innovation at the intersection of materials science, engineering, and application. At MS&T, you can learn from those who are on the cutting edge of their disciplines, share your work with the leading minds in your field, and build the valuable cross-disciplinary collaborations unique to this conference series.

HYATT REGENCY VANCOUVER, VANCOUVER, BRITISH COLUMBIA, CANADA

Join us in Vancouver, British Columbia, Canada, for the 16th Pacific Rim Conference on Ceramic and Glass Technology and the Glass & Optical Materials Division Meeting (GOMD 2025).

calendar

Calendar of events

April 2024

7–11 Pan American Ceramics Congress and Ferroelectrics Meeting of Americas – Hilton Panama, Panama City, Panama; https://ceramics.org/PACCFMAs-2024

9–12 ceramitec 2024 – Munich, Germany; https://ceramitec.com/de/muenchen

10–12 ➡ Smart Additive Manufac-turing, Design & Evaluation (Smart MADE 2024) – Osaka University Nakanoshima Center, Japan; https://sites.google.com/view/smart-made-2024

14–19 ➡ Ultra-High Temperature Ceramics: Materials for Extreme Environment Applications VI – UNAHOTEL, Giardini Naxos, Messina, Italy; https://engconf.us/conferences/materials-science-including-nanotechnology/ultra-high-temperature-ceramics-materials-for-extreme-environment-applications-vi

22–24 Mineral Recycling Forum 2024 – Hilton Imperial Hotel, Dubrovnik, Croatia; http://imformed.com/get-imformed/forums/mineral-recycling-forum-2024

30–May 1 ➡ Ceramics Expo 2024 – Suburban Collection Showplace, Novi, Mich.; https://ceramics.org/event/ceramics-expo-2024

May 2024

19–23 2024 Glass & Optical Materials Division Annual Meeting – Golden Nugget Las Vegas Hotel & Casino, Las Vegas, Nev.; https://ceramics.org/gomd2024

June 2024

16–19 ➡ The 5th International Symposium on New Frontier of Advanced Silicon-Based Ceramics and Composites (ISASC-2024) – Seogwipo KAL Hotel, Jeju, Korea; https://www.isasc2024.org

17–19 ACerS 2024 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Sheraton Oklahoma City Downtown Hotel, Oklahoma City, Okla.; https://ceramics.org/clay2024

19–21 14th Advances in Cement-Based Materials – Missouri University of Science and Technology, Rolla, Mo.; https://ceramics.org/cements2024

23–27 ➡ American Conference on Neutron Scattering (ACNS 2024) – Crowne Plaza Knoxville Downtown University, Knoxville, Tenn.; https://ceramics.org/event/american-conference-on-neutron-scattering-acns-2024

July 2024

14–18 International Congress on Ceramics – Hotel Bonaventure, Montreal, Canada; https://ceramics.org/ICC10

15–19 ➡ 15th International Conference on the Structure of Non-Crystalline Materials, 15th European Glass Society Conference, and the SGT Annual Conference – Churchill College, Cambridge, U.K.; https://sgt.org/mpage/ESG15NCM15

August 2024

4–9 Gordon Research Conference – Mount Holyoke College, South Hadley, Mass.; https://ceramics.org/event/gordon-research-conference

18–22 ➡ 14th International Conference on Ceramic Materials and Components for Energy and Environmental Systems – Budapest Congress Center, Budapest, Hungary; https://akcongress.com/cmcee14

25-28 ICG Annual Meeting 2024 – Songdo Convensia, Incheon, Republic of Korea; https://ceramics.org/event/icg-annual-meeting-2024

October 2024

6–9 ACerS 126th Annual Meeting with Materials Science and Technology 2024 – David L. Lawrence Convention Center, Pittsburgh, Pa.; https://ceramics.org/mst24

May 2025

4–9 16th Pacific Rim Conference on Ceramic and Glass Technology and the Glass & Optical Materials Division Meeting – Hyatt Regency Vancouver, Vancouver, Canada; https://ceramics.org/pacrim16

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.

Ceramic & Glass MANUFACTURING

APRIL 2024 • VOLUME 5 • ISSUE 1

www.ceramics.org/ceramicandglassmanufacturing

WHEN SMALLER IS BETTER: THE PROMISE OF NANOMATERIALS

NANOPARTICLES WILL CHANGE THE WORLD, BUT WHETHER IT IS FOR THE BETTER DEPENDS ON DECISIONS MADE NOW

LOOKING TO THE PAST AND THE FUTURE OF NIOSH NANOTECHNOLOGY GUIDANCE

Center for Advanced Ceramic Technology

2024 Summer Industrial Short Courses at AU

Scientific and technological advances shape the face of industry today. Engineers, technologists, and managers need to keep up with the swift changes in the field, meaning they must be lifelong learners. Each summer, Alfred CACT seeks to increase individuals' expertise in the field of ceramics and glass through its industrial short course offerings. CACT can work with you to develop custom content that can be conducted either on campus or at your site, or join us at one of the following programs, currently accepting registrations.

Fracture Analysis & Failure Prevention of Glass and Ceramics
When: June 10 – 14, 2024
Instructors: Dr. James Varner, Professor of Ceramic Engineering Emeritus at Alfred University and Dr. Jeffrey Swab, Senior Research Scientist with the Army Research Laboratory, Aberdeen Proving Ground.

Computational Methods for Glass & Ceramics
When: July 15 – 18, 2024
Instructors: Dr. Collin Wilkinson, Assistant Professor of Glass Science at Alfred University and Rebecca Welch, Visiting Scholar at Alfred University.

For course outlines and registration details, visit:
www.alfred.edu/about/community/short-courses/

For more information visit:
www.Alfred.edu/CACT

Alfred University
OUTSIDE of ORDINARY

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Vol. 5, No. 1, pp 1–16.

INDUSTRY NEWS

JOINT VENTURE OF GERMAN TRADE FAIR COMPANIES

Two of Germany's biggest trade fair companies, Messe Düsseldorf and Deutsche Messe AG, agreed to pool their expertise in the Turkish market and will each hold a 50% share in Hannover Messe Ankiros Fuarcılık A.S. in Ankara. The venture organizes Ankiros/Turkcast, a large trade fair for the metallurgy and foundry industries, and Aluexpo, the largest aluminum trade fair for the Eurasian region. Messe Düsseldorf acquired 50% of the shares in Hannover Messe Ankiros Fuarcılık A.S., making both German trade fair companies equal business partners.

Ankiros/Turkcast is a leading Eurasian trade fair.

The Lithoz 3D printer uses laser slurry drying, or net shaping, technology.

LITHOZ, ORNL AGREE TO EXPLORE ADDITIVE MANUFACTURING TECH

Lithoz GmbH (Vienna, Austria) and Oak Ridge National Laboratory in Tennessee signed a research and development agreement to use Lithoz's 3D printing technology to explore the processing and additive manufacturing of nonoxide ceramics. The goal of the agreement is to develop technology to shape nonoxide ceramics with high-refractive indexes, such as silicon carbide, for use in extreme temperature applications and to scale up production of ultrahigh-temperature ceramic parts to an industrial level.

A HYDROGEN FIRST: MASS PRODUCTION OF A GLASS SPIRITS BOTTLE

Family-owned spirits company Bacardi (Hamilton, Bermuda) says it completed the world's first commercial production fueled by hydrogen of a glass spirits bottle. Bacardi worked with Slovenia-based glassmaker Hrastnik1860 to develop the technology that powered a glass furnace with hydrogen as its primary energy source. The trial produced 150,000 70cl glass bottles for spirits maker St. Germain. Hydrogen contributed more than 60% of the fuel for the glass furnace, cutting greenhouse gas emissions by more than 30%.

Bacardi operates production facilities in 11 countries and territories.

ReElement uses chromatographic refining equipment for separating and purifying rare earth elements. *Credit: ReElement Technologies*

PARTNERSHIP MAKES USE OF PURDUE RARE EARTHS TECHNOLOGY

Fishers, Ind.-based ReElement Technologies is partnering with Purdue University to use the university's patented rare earths technology. The technology uses ligand-assisted chromatography for separation and purification of rare earths and other critical elements from coal, coal byproducts, ores, recycled permanent magnets, and lithium-ion batteries. ReElement says the partnership will enable it to develop a domestic supply chain of critical materials for U.S. producers of recycled and ore-sourced rare earth metals.

ORNL AND CITY-OWNED POWER COMPANY COLLABORATE ON RESEARCH

EPB, a Chattanooga, Tenn.-based municipal energy and telecommunications company, and Oak Ridge National Laboratory announced a joint research effort called Collaborative for Energy Resilience and Quantum Science. It will focus on using Chattanooga's energy and communications infrastructure to develop technologies for improving the resilience and security of the national power grid and accelerating the commercialization of quantum technologies.

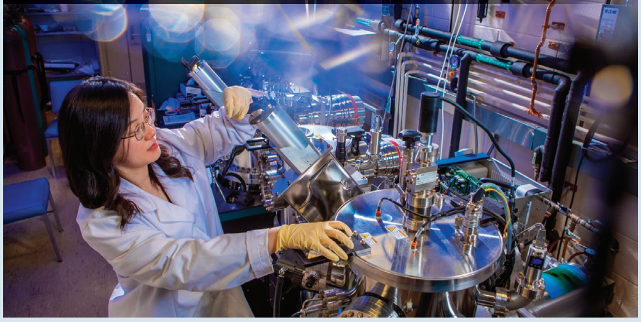
Officials of the Department of Energy, U.S. Congress, Oak Ridge National Laboratory, and the city of Chattanooga announced the joint research project on energy and quantum science. *Credit: EPB*

TRICORBRAUN ACQUIRES GERMAN GLASS MAKER

Packaging company TricorBraun acquired Bonn, Germany-based glass packaging provider Glassland. The acquisition grows the German footprint of St. Louis-based TricorBraun's glass packaging business, Vetroelite, and broadens the company's European presence. Glassland serves spirits makers and other customers in Germany and Switzerland with high-end glass bottle and closure designs. Since its founding in 1902, TricorBraun has acquired 41 packaging companies globally.

TricorBraun operates from more than 100 locations across the Americas, Europe, Asia, and Australia.

The University at Buffalo's dual-chamber thin film deposition system is used to conduct advanced semiconductor research. *Credit: Douglas Levere, University at Buffalo*



NEW YORK COLLEGE LAUNCHES CENTER FOR ADVANCED SEMICONDUCTOR TECHNOLOGIES

The University at Buffalo launched the Center for Advanced Semiconductor Technologies to continue its microelectronics and research innovation for the semiconductor industry. The center's director will be Jonathan Bird, professor and chair of the UB Department of Electrical Engineering. In October 2023, the Buffalo-Rochester-Syracuse region was designated a federal technology hub following the passing of the CHIPS and Science Act in 2022—a $280 billion effort to boost microchip research and production in the United States.

Representatives from the Jagodina, Serbia region attended Schott Pharma's groundbreaking ceremony. *Credit: Schott Pharma, Sasa Krstic*

SCHOTT BREAKS GROUND FOR PLANT IN SERBIA

Schott Pharma invested in a new production site in Jagodina, central Serbia, for pharmaceutical drug containment solutions and delivery systems. The site will produce ampoules for storing injectable drugs, including painkillers, inflammation inhibitors, and anesthetics. Other product groups might follow based on market demand, the company says. In the first phase, Schott will create 130 jobs, and 350 are planned for the expansion phase.

WHEN SMALLER IS BETTER: THE PROMISE OF NANOMATERIALS

By David Holthaus

In a world where bigger often equates to better, nanotechnology flips that on its head: smaller is superior. The relatively young science makes use of rapidly evolving research to exploit the unique properties that materials display when they are in the nanoworld, far too small to be seen by the naked eye.

A nanometer is one-billionth of a meter. Imagining something that small can be difficult, so it helps to describe this measurement in everyday terms. A sheet of paper is 100,000 nanometers thick. A human hair is about 80,000 nanometers wide. One inch equals 25.4 million nanometers.

Nanomaterials can come in different sizes and shapes, as long as at least one dimension is on the nanoscale (< 100 nm). For example, nanoparticles and quantum dots have all their dimensions on the nanoscale, while nanorods and nanofibers are confined to the nanoscale in two dimensions but can be longer in the third.

Some trace the advent of nanotechnology to a groundbreaking lecture in 1959 by Nobel Prize-winning physicist Richard Feynman at the California Institute of Technology.

"Atoms on a small scale behave like nothing on a large scale, for they satisfy the laws of quantum mechanics," he said during the lecture. "So, as we go down and fiddle around with the atoms down there, we are working with different laws, and we can expect to do different things. We can manufacture in different ways."

At the atomic level, Feynman said, scientists will see "new kinds of forces, new kinds of possibilities, and new kinds of effects." But, he noted, "The problems of manufacture and reproduction of materials will be quite different."

FROM RESEARCH TO APPLICATION

Although Feynman's lecture was delivered nearly 65 years ago, it was in the 21st century that the promise of nanotechnology began to materialize in many industrial sectors, including medicine, energy, information technology, and environmental science. That is when researchers and manufacturers gained the tools and techniques necessary to image and manipulate materials on the nanoscale.

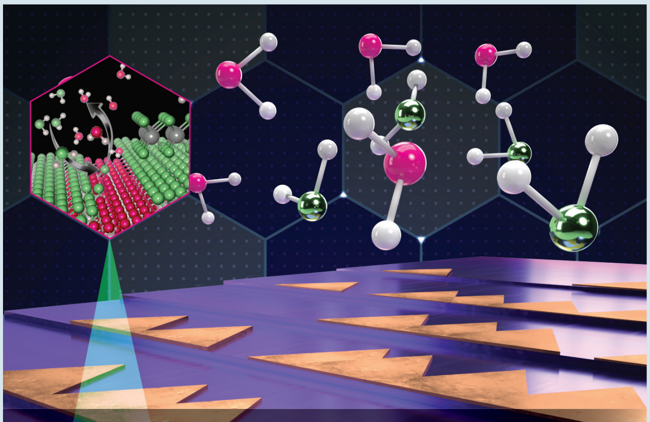
Nanomaterials allow for products to be made lighter, stronger, more durable, more reactive, and/or more conductive, among other properties. For example, nanoscale additives in personal body armor can make it lighter yet more protective. Nanoscale films on glass can make eyeglasses, computer screens, and cameras more water-repellent, anti-reflective, and self-cleaning. Nanoengineered materials in cars are found in high-power, rechargeable battery systems; thermoelectric materials for temperature control; and tires that improve fuel mileage. Nanostructured ceramic coatings improve wear resistance for machine parts, while nanoscale lubricants and engine oils can extend the lifetimes of moving parts in everything from power tools to industrial machinery.

In the United States, the National Nanotechnology Initiative (NNI) was launched in 2000, bringing together more than 30 federal departments, independent agencies, and commissions to work together on understanding and controlling matter on the nanoscale. Its main areas of focus include leveraging nanotechnology to improve water sustainability, sensors, and electronics.

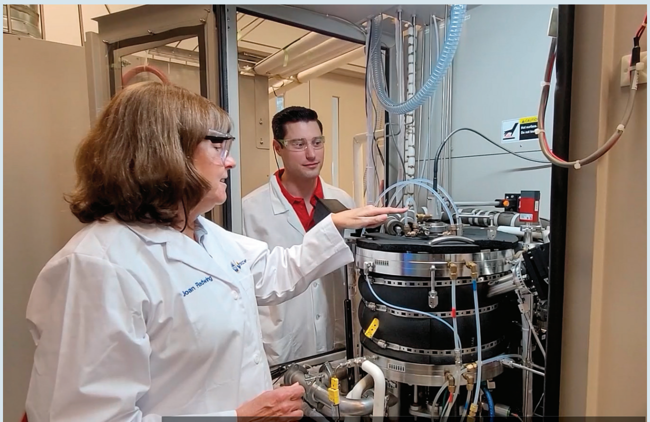
The NNI coordinates investments in nanoscale research and development across the U.S. government. Cumulatively, the participating government agencies and departments have invested more than

A nanomaterial sample from a large-scale reactor in Cerion's industrial-scale manufacturing facility. *Credit: Cerion*


A large-scale reactor mixes nanomaterial product at Cerion's manufacturing plant. *Credit: Cerion*



Atomic-scale steps on sapphire substrates enable crystal alignment of 2D materials, reducing defects and improving electronic device performance. *Credit: Jennifer M. McCann, Penn State*



Joan Redwing, left, leads research at Penn State's 2D Crystal Consortium-Materials Innovation Platform lab. *Credit: Seana Wood, Penn State*

$38 billion over the past 20 years to realize the potential of nanoscience, the agency says.

One company that produces nanomaterials is Cerion, a Rochester, N.Y.-based firm that designs, scales, and manufactures metal, metal oxide, and other ceramic nanomaterials for companies that are developing products and systems that will use them.

"We're one of the oldest and one of the largest in the United States for manufacturing nanomaterials," says CEO Landon Mertz. "We're about 16 years old now, which, at least in our industry, makes us a dinosaur. It's still a very young industry."

Although Cerion was founded in 2007, its history goes back much farther to Rochester-based photography pioneer Eastman Kodak Company, which developed the precipitation-based manufacturing processes for fabricating materials used in photographic film emulsions. Building on that work, Cerion researchers developed processes to create and scale up nanomaterials to satisfy customer specifications.

Some of the main challenges in the nanomaterials industry include being able to rapidly design custom materials specific to a product or system while preserving the material's technical attributes during scale-up and manufacturing. Plus, they must accomplish these goals in a cost-efficient manner.

Landon Mertz

Some manufacturers may customize off-the-shelf materials or invest in bringing nanomaterial expertise in-house, but this approach can be costly. Cerion focuses on designing and scaling nanomaterials to meet specific customer needs.

"We provide product development teams and commercialization teams with access to advanced expertise in precision design, scale-up, and manufacturing so that our customers can get access to nanomaterials at commercial scale," Mertz says.

In its earlier years, Cerion scientists saw demand for nanomaterials that can modify the refractive index in glass for use in mobile phone displays, television displays, and augmented reality. But over the last few years, Mertz says the demand in the ceramics market has shifted toward powders.

"What you tend to see is somebody's making a part that is either wholly or partially comprised of a nanomaterial that then gets incorporated into a larger system," he says.

Nanomaterials are a general-purpose technology, Mertz says, a technology that can be implemented across the entire economy throughout a wide range of industries.

"We tend to see demand across almost every major industrial sector, but it tends to be on the higher-value end of the spectrum," he says.

In the ceramics sector, the biomedical field is the most explored, as ceramic nanoparticles are considered good carriers for drugs, genes, proteins, and imaging agents, according to researchers at Jamia Hamdard University in New Delhi, India. They say nanoparticles have been successfully used as drug delivery systems against bacterial infections, glaucoma, and, most widely, cancer.

NEXT-GENERATION ELECTRONICS

The field of 2D materials is where some of the most leading-edge nanomaterials research is conducted today. 2D materials are a class of nanomaterials that are merely one or several atoms thick, but they have properties that include being exceptionally strong, lightweight, flexible, and excellent conductors of heat and electricity.

At The Pennsylvania State University's Materials Research Institute, Joshua Robinson and his team are working on creating 2D materials for applications in next-generation electronics beyond silicon for digital circuits and flexible electronics, as well as developing novel coating technologies and functionalities enabled by 2D materials.

"The 2D materials we focus on are made on a flat surface and grown over very large areas," Robinson says. "We can make these so that they're compatible with the standard electronics industry. Our aim is to manufacture them in a way that is useful for folks like Intel that are working hard on next-generation transistors and things like that."

Graphene, a 2D material consisting of carbon atoms arranged in a honeycomb-like structure, is made by researchers in Penn State's 2D Crystal Consortium-Materials Innovation Platform lab using a small furnace that heats elements to 2,400°C. Graphene is very strong but also super thin, which allows electrons to move much faster through it than they can through silicon, the basis of today's computer chips.

Replacing silicon with graphene may allow computers to transmit information much faster than they already do and make them even more energy efficient. But before they can be manufactured at industrial scale, they must be produced and perfected in places such as Robinson's lab.

Although the focus of Robinson's lab currently is semiconductors, there are many other applications for their research.

"There's use of these materials in things like catalysis and hydrogen evolution for energy," he says. "There's also materials for photovoltaics, like solar cells."

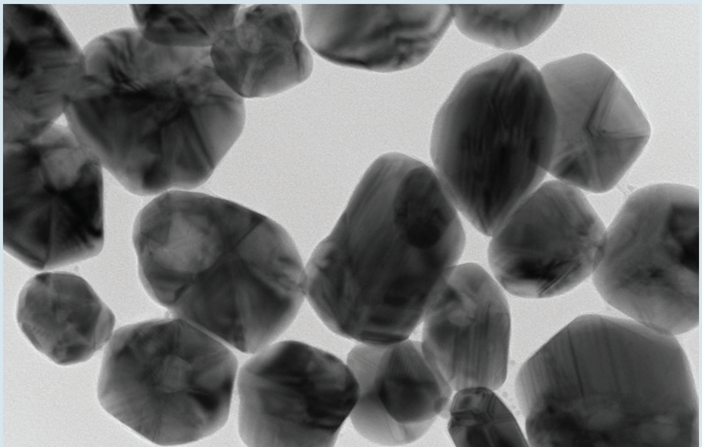
EUROPE'S INVESTMENT IN GRAPHENE

Graphene was first isolated in 2004 by two researchers at the University of Manchester, U.K. Since then, research on this ultrathin and ultrastrong material has exploded, and it can be found in commercial products including lithium-ion batteries, motorcycle helmets, and lubricants in high-power electronics.

Several groups in Europe are leading the charge on graphene research. For example, the University of Manchester now houses the National Graphene Institute and the Graphene Engineering Innovation Centre. A team of scientists there in January 2024 announced they had received a 3-million-euro investment to help them develop a lithium-free energy storage solution.

Additionally, in 2013, the European Union formed a consortium of industry and academic partners called The Graphene Flagship. The initiative was one of three established by the European Commission to investigate major, long-term scientific and technological challenges. The others are a project on the human brain and one on quantum technologies.

The effort was initially funded with one billion euros from the European Commission and focused largely on academic research. It gradually evolved to industry-led projects using the research gained from its initial work, says Patrik Johannson, director of the Graphene Flagship.



An electron microscopy image of silver nanoparticles. *Credit: Cerion*

"Our overall vision over these years has been 'from lab to fab[rication],'" he says.

Research conducted through the Flagship has led to 83 patents, and 17 spin-off companies have been generated from it, according to the consortium's latest annual report. So far, the Flagship has convened 11 industry-led projects that are focused on real-world applications.

The Flagship's industry partners include Fiat-Chrysler (Amsterdam, Netherlands), which is working on a dashboard for vehicles that will feature conductive patterns, sensors, and other devices based on graphene. Sweden-based energy giant ABB is working on a maintenance-free circuit breaker that would replace grease in drive mechanisms with self-lubricating graphene. And aerospace company Lufthansa is working on a project to improve air filtration systems in aircraft using graphene foams.

The versatility of graphene and its potential to be used in such a broad range of applications led to the European Union's effort, Johannson says. But he notes the cost of the material varies depending on its application.

"Do you want it to be for wafer production? Or do you want it as a filler in concrete? You can imagine that's quite different," he says.

The costs of nanomaterials may adjust as their applications become more accepted in the marketplace, says Cerion's Mertz.

"The way we need to look at it is how do we get more volume into the marketplace, which helps bring some fixed costs down," he says. "The people that tend to adopt new technologies need some kind of new leading-edge performance. And they are willing to pay for it. You're first to market. Over time, as you ramp up volumes, you're able to make these materials more mass-market."

Significant challenges remain in converting research lab findings to industrial applications and in scaling up production, which includes controlling for cost. Other challenges, particularly with biomedical materials, include gathering long-term information on their safety. And standards for the industry are still under development, making it difficult to develop regulatory guidelines.

But thanks to more than two decades of basic research, investment, and application, it is almost certain that these challenges will be overcome, allowing nanotechnology to improve and even revolutionize many more technology and industry sectors.

Nobel Prize winners in nanoscience

By David Holthaus

Over the last decade-plus, the Royal Swedish Academy of Sciences has awarded several Nobel Prizes for groundbreaking research in nanomaterials.

In 2023, the Nobel Prize in Chemistry was awarded to a trio of scientists for the discovery and development of quantum dots, nanoparticles so tiny that their size determines their properties. Quantum dots now illuminate computer monitors and television screens based on QLED technology. They also add depth to the light of some LED lamps, and biochemists and doctors use them to map biological tissue.

Physicists had long known that, in theory, size-dependent quantum effects could arise in nanoparticles, but it was considered almost impossible to design materials on that scale with precision. So, few believed this knowledge could be put to practical use. But in the early 1980s, Aleksey Yekimov, now the chief scientist at U.S. company Nanocrystals Technology (New York, N.Y.), succeeded in creating size-dependent quantum effects in colored glass. The color came from nanoparticles of copper chloride. Yekimov demonstrated that the particle size affected the color of the glass via quantum effects.

A few years later, Louis Brus of Columbia University was the first scientist to demonstrate size-dependent quantum effects in particles floating freely in a fluid. Then in 1993, Moungi Bawendi of Massachusetts Institute of Technology revolutionized the chemical production of quantum dots, resulting in a high quality that was necessary for them to be used in applications.

"They planted an important seed for nanotechnology," the Royal Swedish Academy said in awarding the coveted prize.

In 2010, the Nobel Prize in physics was awarded to two scientists at the University of Manchester in the United Kingdom who first unambiguously produced and identified the 2D material graphene. Andre Geim and Konstantin Novoselov extracted a single-atom layer of carbon from a piece of graphite using ordinary adhesive tape. Their groundbreaking work was done at a time when many believed it was impossible for such thin crystalline materials to be stable.

Today, graphene is known to be a conductor of electricity that performs as well as copper. As a conductor of heat, it outperforms all other known materials. It is almost completely transparent, yet so dense that not even helium, the smallest gas atom, can pass through it. Because of these properties, it has applications in batteries, transistors, and computer chips, among others.

NANOPARTICLES WILL CHANGE THE WORLD, BUT WHETHER IT IS FOR THE BETTER DEPENDS ON DECISIONS MADE NOW

By Kristin Omberg

Kristin Omberg is group leader of the Chemical and Biological Signatures Group at Pacific Northwest National Laboratory. This article was originally published in The Conversation and can be found at theconversation.com/us. Republished with permission.

Technologies based on nanoscale materials—for example, particles that are more than 10,000 times smaller than the period at the end of this sentence—play a growing role in our world. Carbon nanofibers strengthen airplanes and bicycle frames, silver nanoparticles make bacteria-resistant fabrics, and moisturizing nanoparticles called nanoliposomes are used in cosmetics.

Nanotechnology is also revolutionizing medicine and pushing the boundaries of human performance. If you received a COVID-19 vaccine in the United States, it contained nanoparticles.

In the future, nanotechnology may allow doctors to better treat brain diseases and disorders like cancer and dementia because nanoparticles pass easily through the blood-brain barrier.

Nanoparticles in eye drops may temporarily correct vision. And strategically implanted nanoparticles in the eyes, ears, or brain may enable night vision or hearing that's as good as a dog's. Nanoparticles could even allow people to control their smart homes and cars with their brains.

This isn't science fiction. These are all active areas of research.

But frameworks for assessing the safety and ethics of nanoparticles have not kept pace with research. As a chemist working in bioscience, I am worried by this limited oversight. Without updated frameworks, it's hard to tell whether nanotechnology will make the world a better place.

NANO—WHAT AND WHY?

Any particle or material between 1 and 100 nanometers in one dimension can be classified as "nano." The period at the end of this sentence is 1,000,000 nanometers, and a human hair is about 100,000 nm in diameter. Both are much too large to be considered "nano." A single coronavirus is about 100 nanometers in diameter, and soot particles from forest fires can be as small as 10 nanometers in diameter—two examples of naturally occurring nanoparticles.

Nanoparticles can also be produced in a laboratory. The adenovirus vectors, nanolipoparticles and mRNA used in COVID-19 vaccines are engineered nanoparticles. The zinc oxide and titanium dioxide used in sheer mineral sunscreens are also engineered nanoparticles, as is the carbon nanofiber in airplanes and bicycle frames.

Nanoparticles are useful because they have different properties than larger materials, even when they have the same chemical composition. For example, large particles of zinc oxide cannot be dissolved in water and are used as pigment in white paint.

Nanoscale zinc oxide is also used in sunscreen, where it looks nearly transparent but reflects sunlight away from your skin to prevent sunburn.

Nanoscale zinc oxide also exhibits antifungal and antibacterial properties that could be useful for making antimicrobial surfaces, but the reason for its antimicrobial properties is not completely understood.

And therein lies the problem. While many scientists are interested in exploiting the positive properties of nanomaterials, my colleagues and I are concerned that scientists still don't know enough about their behavior.

NANOTECHNOLOGY SAFETY

Nanoparticles are attractive to biomedical researchers because they can slip through cell membranes. The antimicrobial properties of nanoscale zinc oxide are probably related to their ability to cross bacterial cell membranes. But these nanoparticles can cross human cell membranes as well.

In the United States, zinc oxide is "generally recognized as safe and effective" by the Food and Drug Administration for products like sunscreen because it's unlikely—in sunscreen—to be toxic to humans.

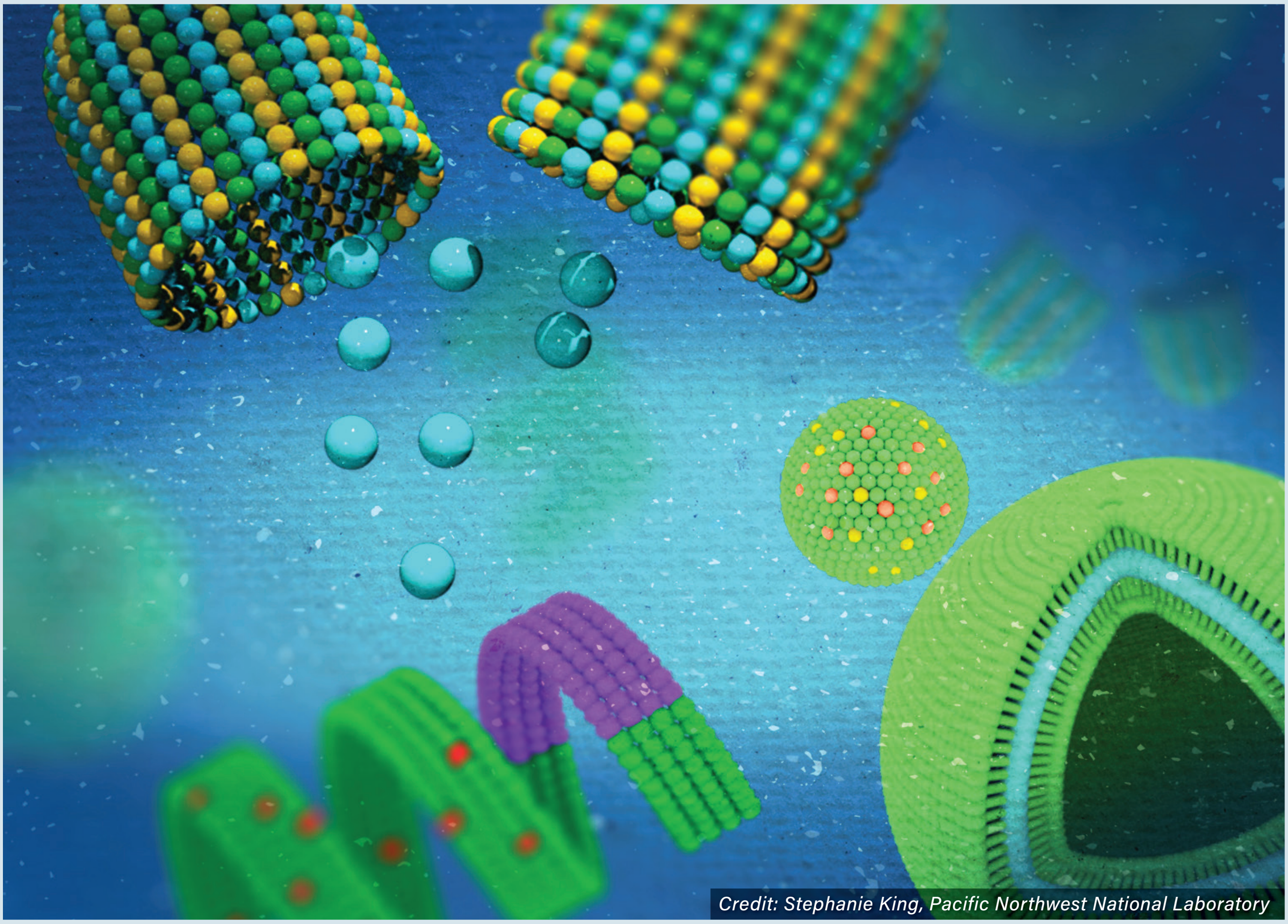
However, although scientists understand the health effects of large particles of zinc oxide fairly well, they don't fully understand the health effects of nanoscale zinc oxide. Laboratory studies using human cells have produced conflicting results, ranging from inflammation to cell death.

I'm a big believer in sunscreen. But I also worry about the environmental effects of particles that are known to cross cell membranes.

Hundreds of tons of nano-zinc oxide are produced each year, and it doesn't degrade easily. If we don't understand its behavior better, there's no way to predict whether it will eventually become a problem—though increasing evidence suggests nano-zinc oxide from sunscreen is damaging coral reefs.

NANOTECHNOLOGY ETHICS

Nanoparticles' ability to cross cell membranes does make them effective in therapeutics like vaccines. Nanoparticles show promise for regenerating skeletal muscles, and they could one day treat muscular dystrophy, or the natural atrophy that comes with age.



Credit: Stephanie King, Pacific Northwest National Laboratory

But COVID-19 vaccines provide a cautionary tale—nanoparticle-enabled COVID-19 vaccines were quickly adopted by the United States and Europe, but lower-income countries had far less access due to patent protections on the vaccine and a lack of production and storage infrastructure.

Nanoparticles may also allow for human performance enhancements, ranging from better eyesight to soldiers engineered to be more effective in combat.

Without an ethical framework for their use, performance-enhancing nanotechnologies that are accessible only in certain places could deepen wealth gaps between high- and low-income countries.

EMERGING OVERSIGHT

Today, different countries treat nanoparticles differently. For example, the European Union's Scientific Committee on Consumer Safety has banned the use of nanoscale zinc oxide in aerosol sunscreens across the E.U., citing their potential to get into lung cells and, from there, move to other parts of the body. The United States has not taken similar action.

The European Union established a nanobiotechnology laboratory to study the health and environmental effects of nanoparticles.

In the United States, the National Nanotechnology Initiative, a coordinated government-sponsored research and development effort, works to bring legal and ethical experts together with scientists. They weigh the benefits and risks of nanotechnologies and disseminate information to other scientists and the public.

Overcoming the disparity in nanoparticle-enabled vaccine distribution is another issue altogether. The World Health Organization's COVAX program sought to ensure fair and equitable access to COVID-related therapeutics. Similar measures should be considered for all nanotechnology-enabled medicine so everyone can benefit.

Synthetic biology is a field that is experiencing similarly rapid growth. For the past 20 years, the nonprofit iGEM Foundation has held an annual worldwide student competition, which it uses as a platform to teach young scientists to think about the broader implications of their work.

The iGEM Foundation requires participants to consider safety, security and whether their project is "good for the world." The nanotechnology research community would benefit greatly from adopting a similar model. Nanotechnologies that change the world for the better require coordinating science and ethics to shape how they are used and controlled long after we create them.

LOOKING TO THE PAST AND THE FUTURE OF NIOSH NANOTECHNOLOGY GUIDANCE

By Jay Vietas and Lilia Chen

Jay Vietas and Lilia Chen are co-manager and coordinator, respectively, of the Nanotechnology Research Center (NTRC) and branch chief and deputy branch chief, respectively, of the Emerging Technologies Branch in the NIOSH Division of Science Integration. This article was originally published on the NIOSH Science Blog at https://blogs.cdc.gov/niosh-science-blog. Republished with permission.

The National Institute for Occupational Safety and Health (NIOSH) has been at the forefront of research on engineered nanomaterials since the early 2000s. As the NIOSH Nanotechnology Research Center (NTRC) celebrates its 20th anniversary, we look back over two decades of NIOSH NTRC published guidance to help reduce worker exposures to engineered nanomaterials (ENMs).

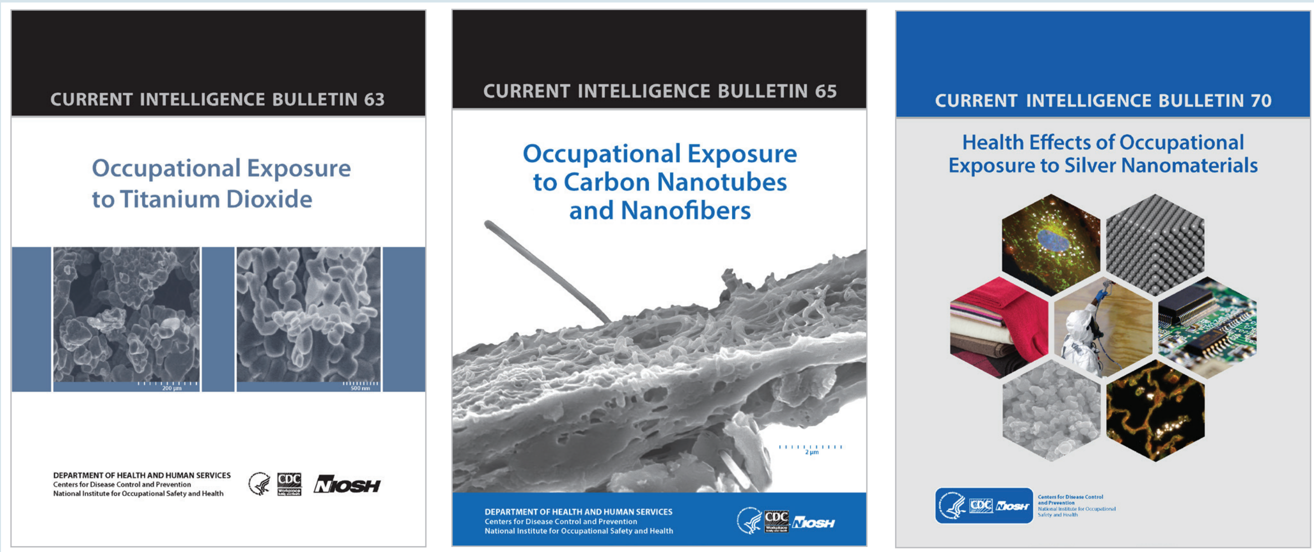
Both companies and workers use this guidance to keep workers safer. NTRC research has led to improved recommendations for controlling exposures during advanced manufacturing processes. Organizations have also used our guidance to base global standards.

Here, we reflect on how our guidance and publications have evolved through decades of research. We also discuss the needs for future research efforts.

THE NTRC STRATEGIC PLAN

In 2005, NIOSH became the first government agency to publish a strategic plan as a roadmap for nanotechnology research. This work, titled *Approaches to Safe Nanotechnology: An Information Exchange with NIOSH*, led to seminal guidance for the nanotechnology industry.

The strategic plan served multiple purposes. It offered a chance to collect safety and health concerns about nanomaterial exposures. It also outlined research needs and gave recommendations for workplace practices. International organizations and others used those workplace practices to create guidance documents. In 2009, the strategic plan was updated and published as "Approaches to safe nanotechnology: Managing the health and safety concerns associated with engineered nanomaterials."[1]



Examples of Current Intelligence Bulletins providing guidance on workplace exposure to engineered nanomaterials. *Credit: National Institute for Occupational Safety and Health*

To protect the nanotechnology workforce, NIOSH published the "Strategic Plan for NIOSH Nanotechnology Research and Guidance" in 2010.[2] Updated in 2014 and 2019, the plan currently describes the NTRC strategy into 2025.[3]

The strategic plan includes filling knowledge gaps in these priority areas:

- Researching the toxicology of available nanoparticles on the market
- Studying long-term effects of carbon nanotubes
- Developing exposure limits and control recommendations for fine and ultrafine titanium dioxide and carbon nanotubes
- Finding new nanomaterials coming into the market for mass production

ESTABLISHING WORKPLACE EXPOSURE LIMITS AND RECOMMENDATIONS

Occupational exposure limits are the "gold standard" for those working in occupational safety and health. NIOSH recommended exposure limits (RELs) are intended to prevent adverse health effects in workers from occupational inhalation exposures for up to a 10-hour shift, 40-hour work week, over a working lifetime. Researchers develop RELs from the best science available for a given material.

NIOSH was the first U.S. government agency to establish RELs for ENMs. In 2011, for the first time in its history, NIOSH released two RELs for the same chemical based on fine and ultrafine sizes. These were published in "Current Intelligence Bulletin 63: Occupational exposure to titanium dioxide."[4] Workplace guidance recommendations were also provided in this Current Intelligence Bulletin.

NIOSH also published two other ENM-related guidance documents:

- "Current Intelligence Bulletin 65: Occupational exposure to carbon nanotubes and nanofibers" (2013): https://www.cdc.gov/niosh/docs/2013-145/pdfs/2013-145.pdf
- "Current Intelligence Bulletin 70: Health effect of occupational exposure to silver nanomaterials" (2021): https://www.cdc.gov/niosh/docs/2021-112/pdfs/2021-112.pdf

TARGETED GUIDANCE FOR EMPLOYERS

In addition to exposure limits, employers need to know the best workplace practices to meet exposure targets. NIOSH has published guidance documents for these employers:

- "Medical screening and hazard surveillance for workers potentially exposed to engineered nanoparticles" offers interim guidance on controlling exposures with practical measures, conducting hazard surveillance, and using established medical surveillance methods (2009): https://www.cdc.gov/niosh/docs/2009-116/pdfs/2009-116.pdf
- "General safe practices for working with engineered nanomaterials in research laboratories" addresses ENM handling in research laboratory settings (2012): https://www.cdc.gov/niosh/docs/2012-147/pdfs/2012-147.pdf
- "Strategies for engineering controls in nanomaterial production and downstream handling processes" helps to find and describe methods for controlling ENM exposures using engineering controls (2014): https://www.cdc.gov/niosh/docs/2014-102/pdfs/2014-102.pdf
- "Building a safety program to protect the nanotechnology workforce" is targeted to small- and medium-sized businesses (2016): https://www.cdc.gov/niosh/docs/2016-102/default.html
- "Occupational exposure sampling for engineered nanomaterials" offers workplace sampling guidance for carbon nanotubes and nanofibers, silver, titanium dioxide, and other ENMs without exposure limits (2022): https://www.cdc.gov/niosh/docs/2022-153

TARGETED GUIDANCE FOR EMPLOYEES

Ultimately, NIOSH aims to protect the health of the worker. When workers understand why and how to manage their exposures, they are more likely to take actions to protect their health. NIOSH published clear, concise, one-page guidance documents specifically for workers.

For example, three NIOSH posters present safety questions workers should ask before working with nanomaterials[5] and when 3D printing with filament[6] or metal powders.[7] The posters can help workers in recognizing possible hazards. The posters include the types of controls and personal protective equipment workers could use to protect themselves.

NIOSH also published an infographic on reducing exposures when 3D printing with plastic filament.[8] It highlights easy ways to reduce exposures during fused filament fabrication, fused deposition modeling, and fused layer modeling.

LOOKING AHEAD TO THE FUTURE

NIOSH NTRC remains committed to offering research-based guidance to meet the needs of the ever-changing field of nanomaterials and related emerging technologies. Researchers recently published "Approaches to safe 3D printing: a guide for makerspace users, schools, libraries, and small business to help control exposures."[9]

Example of a one-page guidance document published by NIOSH to help workers understand why and how to manage their exposure to engineered nanomaterials. *Credit: National Institute for Occupational Safety and Health*

They are also laying the groundwork to develop additional occupational exposure limits for ENMs.

NIOSH continues to seek and gather feedback from the advanced manufacturing industry and provide guidance. The aim is to bridge knowledge gaps and make actionable recommendations. If you have input or suggestions about guidance or research needs, contact nano@cdc.gov.

You can find a full list of NIOSH nanotechnology publications at Nanotechnology Guidance and Publications.[10]

To celebrate the 20th anniversary of the Nanotechnology Research Center, the National Institute for Occupational Safety and Health will focus on nanomaterials in its 2024 science blog posts. View the NIOSH Science Blog at https://blogs.cdc.gov/niosh-science-blog.

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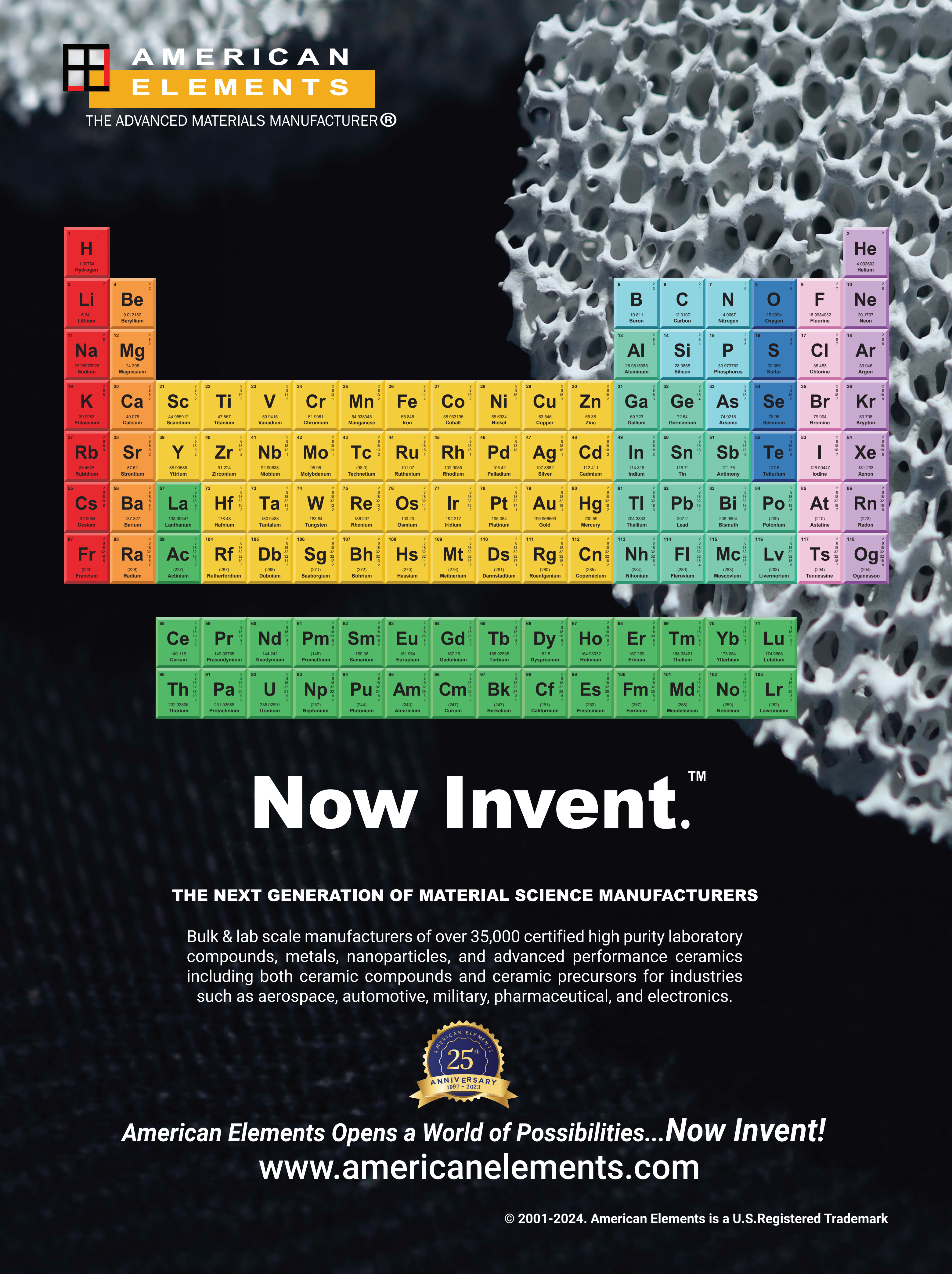
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A regular column offering the student perspective of the next generation of ceramic and glass scientists, organized by the ACerS Presidents Council of Student Advisors.

Miloš Dujović
Guest columnist

MAX phases: Opening new doorways with machinable ceramics

Ceramics are traditionally viewed as brittle materials that can be difficult to machine. However, MAX phases, which garnered interest in the 1990s as a bridge between metals and ceramics, helped fundamentally shift these traditional views.[1]

MAX phases are a family of ternary carbides and nitrides with the general formula $M_{n+1}AX_n$, where M refers to an early transition metal, A is an A-group element, and X is carbon or nitrogen.

These materials contain a highly anisotropic and nanolayered crystal structure, where strongly bonded MX octahedral layers are interleaved with weakly bonded layers of A-group element atoms (Figure 1a).[2] This structure allows MAX phases to be easily machined into complex shapes using conventional machining tools (Figure 1b), in contrast to binary transition metal carbides and nitrides.

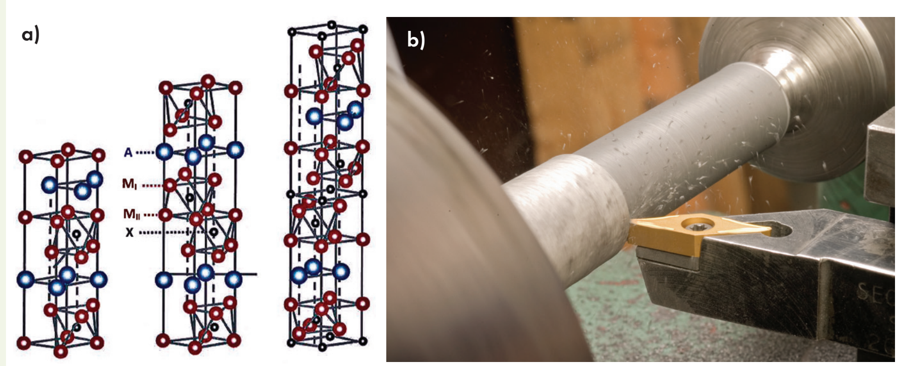

Figure 1. a) Crystal structure of 211, 312, and 413 MAX phases (left to right).[1] b) Machining of a MAX phase billet on a conventional lathe.[1]

Credit: Radovic and Barsoum, *American Ceramic Society Bulletin*

Since their discovery in the 1960s (and renewed interest in the 1990s), more than 300 different MAX phases have been synthesized. In addition to their easy machinability, MAX phases are damage tolerant, elastically stiff, good thermal and electrical conductors with low thermal expansion coefficients, and highly resistant to chemical attacks.[2] These properties make MAX phases attractive for many applications, including as pantographs for high-speed railway systems.[3,4]

Most high-speed trains are powered by electricity, which gets pulled from an overhead line via an apparatus called the pantograph mounted on the train's roof (Figure 2). The pantograph slides along the overhead line, and as the train speeds up, the pantograph slides more quickly. As such, it must have good tribological and electrical properties to ensure steady contact with the overhead line and thereby a reliable supply of electric energy.

MAX phases have successfully met these criteria to be used as materials for pantographs. Specifically, the MAX phases Ti_3SiC_2 and Ti_3AlC_2 have been tested because they possess self-lubrication properties in addition to good electrical conductivity.[3,4]

The application of MAX phases as pantographs for high-speed trains is just one example of how this class of machinable carbides and nitrides will help meet the need for new components in extreme service conditions. Other applications include gas turbine blades, braking pads, and heat exchangers.

As this class of materials combines some of the best attributes of ceramics with metal-like machinability, I believe MAX phases are a promising example of materials that are breaking traditional norms and allowing their implementation in many other branches of engineering.

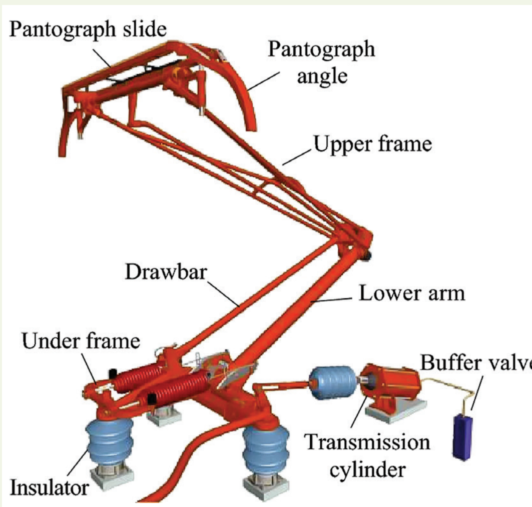

Figure 2. Schematic structure of a pantograph.[3]

Credit: Wu et al., *Railway Engineering Science* (CC BY 4.0)

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Miloš Dujović is a graduate research assistant in the Department of Materials Science and Engineering at Texas A&M University (College Station, Texas). He currently works on synthesizing and characterizing MAX phases and their 2D counterparts, MXenes. In his free time, he enjoys collecting and listening to vinyl records. ■

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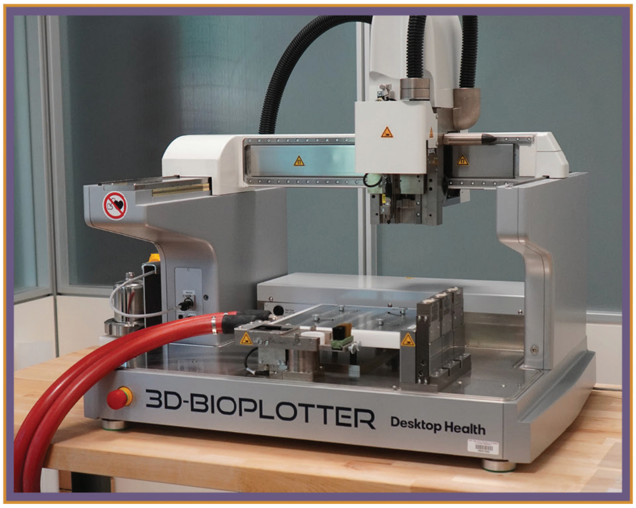

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