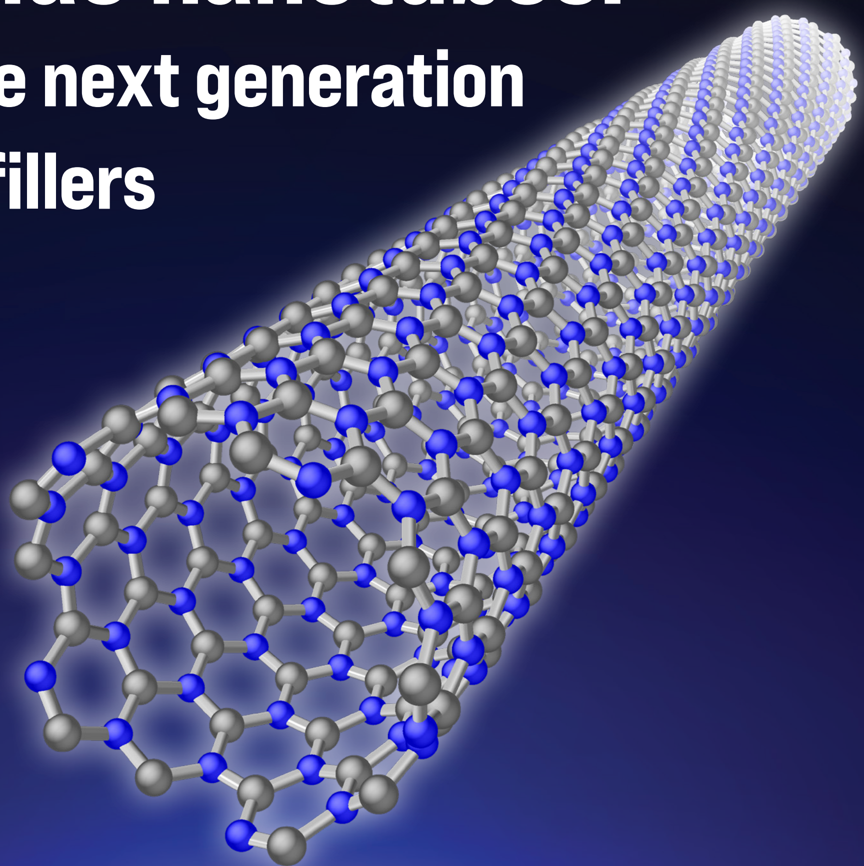
AMERICAN CERAMIC SOCIETY
bulletin
emerging ceramics & glass technology
JANUARY/FEBRUARY 2026

Boron nitride nanotubes:
Developing the next generation of functional fillers

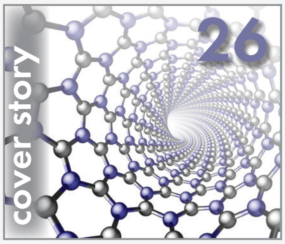


Celebrating engineered ceramics | Federal FY26 budget proposals | Meet ACerS president

contents

January/February 2026 • Vol. 105 No.1

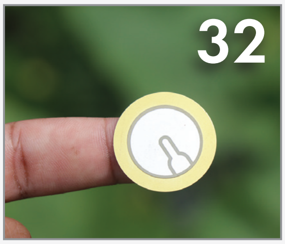
feature articles



Boron nitride nanotubes: Developing the next generation of functional fillers

Despite synthesis and scale-up challenges slowing commercial adoption, recent breakthroughs have enabled boron nitride nanotubes to now stand at the cusp of transforming the advanced materials landscape.

by Erika Brown, Evan A. Doud, and Carl Aune



From discovery to design: Evolution of piezoceramic fabrication methods for application-specific performance

While early piezoelectric developments relied on discovery-driven processes, this article highlights current efforts that embrace a more intentional, design-driven methodology.

by Ender Suvacı, Nesli Yürük, Victor Tinti, Jason Nikkel, Rasmus Lou-Moeller, Claire Bantignies, and Thomas Kelley

Tradition and transformation in architectural glass

At Fa. I. Edelkoort & Zn in The Hague, Netherlands, several recent innovations allowed the glass studio to enter a new era of artistic and technical exploration while staying true to its classical roots.

by Vlad Mitskevich

Indium oxide semiconductors for low-power AI systems

Semiconductor Energy Laboratory Chairman and CEO Shunpei Yamazaki and colleagues developed indium oxide-based semiconductors to replace silicon electronics. An excerpt from their open-access paper elaborates on this development.

by Lisa McDonald

ACerS Mentor Programs: 'Engineering' connections to support the next generation of ceramic and glass scientists 45

The ACerS Mentor Programs equip participants with the insight, tools, and connections necessary to make a lasting impact in their future career.

Hear from Rishabh Kundu and Peter McGinnis about their experience as a student–industry professional pair in the ACerS Mentor Programs.

Cover image: Background: Successful girl / Shutterstock; Nanotube: Epic Advanced Materials

departments

News & Trends 4
ACerS Spotlight 12
Research Briefs 22
Ceramics in Manufacturing . . . 24

industry

Business and Market View 8
Aerospace ceramics: Global markets to 2029
by BCC Publishing Staff

Industry Perspectives 9
Engineered ceramics support the past, present, and future of aerospace ambitions
by Elizabeth Opila

Industry Insights 10
Innovations in access and technology secure clean water around the world
by David Holthaus

columns

Letter from the Editor 3
International Day of Ceramics: Celebrating the importance of ceramics in modern society
by Lisa McDonald

Meet ACerS President 21
Mario Affatigato (2025–2026)
by Lisa McDonald

Journal Highlights 44
Manufacturing considerations for the next generation of engineered ceramics
by Brittney Hauke

Deciphering the Discipline 52
Ceramics in medicine: Engineering materials that heal
by Priya Kushram

meetings

Upcoming meetings 46

resources

Calendar 47
Classified advertising 49
Ad index 51

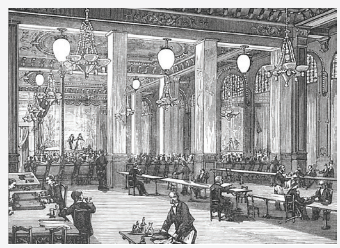
AMERICAN CERAMIC SOCIETY
bulletin

online
www.ceramics.org

January/February 2026 • Vol. 105 No.1

http://bit.ly/acerstwitter http://bit.ly/acerslink http://bit.ly/acersfb

As seen on *Ceramic Tech Today*...



Credit: Wikimedia (Public domain)

Yablochkov candles: The short-lived ceramic spark in the City of Light

The Yablochkov candle is an early type of electric arc lamp that, despite only having short-lived commercial success, helped lay the foundation for the ubiquitous electric lighting we enjoy today.

Read more at https://ceramics.org/yablochkov

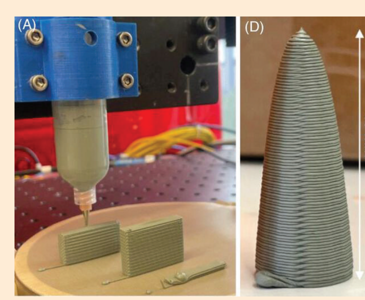
Also see our ACerS journals...

3D-printed SiC-microfiber-reinforced polymer-derived ceramic with high strength at elevated temperature
By B. G. Compton, P. P. Bui, S. K. Romberg, et al.
Journal of the American Ceramic Society

Contact point geometry governs structural buildup at rest in Portland cement–limestone blends
By L. Michel, A. Sanner, F. Zunino, et al.
Journal of the American Ceramic Society

Silica-assisted cold sintering of diopside for sustainable cementitious composites
By W. Huang, J. Yang, B. Li, et al.
Journal of the American Ceramic Society

Silazane-based zinc-filled coating system for corrosion protection of steel in humid and salt water containing environments
By J.-F. Wendel, N. Matthée, S. Schafföner, and G. Motz
Journal of the American Ceramic Society



Credit: Compton et al., *JACerS*

Journal of the American Ceramic Society · International Journal of Applied Ceramic Technology · International Journal of Applied Glass Science · International Journal of Ceramic Engineering & Science

Read more at https://ceramics.org/journals

American Ceramic Society Bulletin is the membership magazine of The American Ceramic Society. It covers news and activities of the Society and its members and provides the most current information concerning all aspects of ceramic science and technology, including R&D, manufacturing, engineering, and marketing. *American Ceramic Society Bulletin* is published monthly, except for February, July, and November. Subscription included with The American Ceramic Society membership. Institutional subscription rates can be found online at www.ceramics.org or by contacting customer service at customerservice@ceramics.org.

The American Ceramic Society is not responsible for the accuracy of information in the editorial, articles, and advertising sections of this publication. Readers should independently evaluate the accuracy of any statement in these sections. Publication of articles does not constitute endorsement, acceptance, or approval of the data, opinions, or conclusions of the authors on the part of the Society or its editors.

POSTMASTER: Please send address changes to American Ceramic Society Bulletin, 470 Olde Worthington Road, Suite 200, Westerville, OH 43082-8985. Periodical postage paid at Westerville, Ohio, and additional mailing offices. Allow six weeks for address changes.

American Ceramic Society Bulletin. ISSN (Print): 0002-7812; ISSN (Online): 1945-2705. ©2026. Printed in the United States of America.

ACSBA7, Vol. 105, No. 1, pp. 1–52. All feature articles are covered in Current Contents.

International Day of Ceramics: Celebrating the importance of ceramics in modern society

Dear ACerS members and readers,

Since ancient times, ceramics have played a foundational role in the evolution of human society. Sun-dried clay bricks were used to construct permanent living structures in early agricultural settlements, from the circular dwellings in Jericho to the monumental adobe architecture in Peru. As civilizations developed writing systems, clay tablets served as the medium for recording the characteristic wedge-shaped cuneiform scripts.

Advancing into the Bronze Age, refractories are perhaps one of the earliest demonstrations of advanced ceramic applications, with fire-resistant clay kilns and furnaces supporting the emerging metalworking sector. The ability to perform high-temperature firing processes also opened the door to creating new ceramic forms, such the delicate Chinese porcelain that became the envy and inspiration for the European ceramics industry.

The development of microscale imaging techniques and technologies in the 20th century set the stage for a new era of engineered ceramics. Now, we see ceramics used in everything from artificial tissue scaffolding to radiation-resistant coatings to emerging quantum computing systems.

Despite their transformative influence on our world, ceramics often receive less recognition than other materials. This relative obscurity is due to several factors. For one, materials science is often left out of primary and secondary school education, and even at the university level, few degree programs exist that focus explicitly on ceramic engineering. Furthermore, ceramics are typically embedded within larger systems and devices, so their presence in everyday life is hidden from the casual observer.

The ceramics industry offers incredible opportunities for innovation in everything from healthcare to renewable energy, so it is important to show the public that ceramics represent not just our historical past but the building blocks of our technological future. To this end, the international ceramics community will celebrate the International Day of Ceramics on **March 12, 2026**.

This global initiative, which was originally proposed by the Japan Fine Ceramics Association, was announced publicly last year. It aims to celebrate and promote the vital role ceramics play in our modern world. This year will be the first official celebration of the initiative, and the International Ceramic Federation is overseeing the global coordination of this event.

The ceramics industry offers incredible opportunities for innovation in everything from healthcare to renewable energy, so it is important to show the public that ceramics represent not just our historical past but the building blocks of our technological future.

We invite industry partners, academic institutions, and the public to participate in planning and celebrating this important initiative. Together we can show the world the importance of ceramic science and engineering. ■

Best wishes,
Lisa McDonald
Editor, *ACerS Bulletin*

International Day of Ceramics logo contest

As part of the preparations for this year's International Day of Ceramics, the International Ceramic Federation hosted a contest to determine the event's official logo. The design by Maximilian Munz of the Austrian Ceramic Society inspired the official logo (shown above).

Learn more about the International Day of Ceramics at www.ceramicsday.org. To get involved in the North American celebrations for this International Day, contact Marcus Fish, director of development at the Ceramic & Glass Industry Foundation, at mfish@ceramics.org.

news & trends

Federal budget 2026—Science agencies brace for possible steep funding cuts

By Helen Widman

The Trump administration is back in Washington, D.C., for a second term and aims to make significant changes across the federal budget, including considerable reductions to science agencies such as the National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), and National Institutes of Health (NIH). In contrast, the House and the Senate have not been so ready to suggest such significant cuts, with Senate appropriators seeking near-level funding for many science agencies.

At the time this article was finalized in early December 2025, the U.S. government had just reopened after the longest shutdown in U.S. history (43 days). This reopening is only temporary, however, and the current short-term continuing resolution will expire on Jan. 30, 2026, unless the full fiscal year 2026 budget is passed by that date.

A few highlights from the proposals:

Department of Defense

The DOD's research, development, test, and evaluation (RDT&E) accounts dropped to $143 billion in 2025, a decrease of nearly 6% from 2024. This year, the White House, House, and Senate appropriators are requesting a 0.4% decrease, a 4% increase, and a 1% decrease, respectively.

While the White House provided a specific aggregate number for the Science and Technology portfolio in its budget request—$19.2 billion, or 10% below the enacted fiscal year 2025 level of $21.3 billion—neither the House nor Senate version did. That is because funding related to Budget Activity 6.3, Advanced Technology Development, was not reported as an aggregate number this year but rather piecemeal through specific programs to be funded through this budget code. For example, House appropriators requested approximately $13 billion for missile defense and space programs to augment and integrate in support of the Golden Dome effort and more than $2.6 billion for hypersonics programs.

As of November 2025, Senate appropriators still had not passed their version of the DOD Appropriations Act, though they did pass the related National Defense Authorization Act (NDAA), which authorizes spending levels and policy outlines for the DOD. The Senate version of NDAA does not include the SAFE Research Act, however, a measure in the House version that would prohibit awarding federal funds to researchers affiliated with a "hostile foreign entity."

National Science Foundation

After requesting a 12% increase to the National Science Foundation in 2025, the White House is now requesting a 57% decrease in funding for 2026, with House and Senate appropriators recommending 23% and 1% decreases, respectively.

In March 2025, the Trump administration announced their intent to eliminate $234 million from NSF's Major Research Equipment and Facilities Construction budget, which represents a 2.6% decrease

Table 1. FY26 budget proposals ($ in millions)*

	DOD S&T total	NSF	DOE Office of Science	NIST	NASA (science)	NIH
FY25 appropriation	21,300	9,060	8,240	1,157	7,334	48,301
White House	19,200 (-10%)	3,903 (-57%)	7,092 (-14%)	833 (-28%)	3,908 (-47%)	28,860 (-40%)
House	N/A	7,000 (-23%)	8,400 (+2%)	1,007 (-13%)	6,000 (-18%)	47,845 (-1%)
Senate	N/A	9,000 (-1%)	N/A	1,197 (+4%)	7,300 (-1%)	48,701 (+1%)

*Data from the American Institute of Physics FYI "Federal Science Budget Tracker."

to NSF's 2024 topline fiscal year budget of $9 billion, if successful. This decrease, combined with the White House's significant request of cutting the overall NSF budget to $3.9 billion, would move NSF in the opposite direction of doubling its $9 billion budget to $18.9 billion by 2027—an authorization set by the CHIPS and Science Act of 2022.

On the other hand, the near-level request by Senate appropriators reflects their interest in protecting certain programs related to women and underrepresented minorities in NSF's STEM Education Directorate. However, the White House is requesting to reallocate the STEM Education Directorate to NSF's Research and Related Activities account, which would likely result in less funding for STEM education overall because it places the funding into a larger pot without guaranteed provisions for specific programs.

Both House and Senate appropriators expressed interest in having NSF continue to advance the U.S. as a leader in artificial intelligence, with House appropriators commending NSF on their National Artificial Intelligence Research Resource Pilot Program, a two-year initiative that launched in 2024.

Department of Energy

The White House requested $45.1 billion for the DOE, which is a decrease of 10% from 2025's enacted amount. House appropriators requested $48.7 billion, which is higher than the White House but still less than the enacted amount of $50.1 billion. At the time this article was finalized, Senate appropriators had not finalized their proposed budget for the DOE.

Office of Science

The White House requested a decrease of 14% to the Office of Science while House appropriators requested a slight increase of 2%.They called this funding a "high priority," stating that the private sector is unlikely to fund noncommercial research.

Applied energy

The White House requested only $888 million (a 74% decrease) for the Office of Energy Efficiency and Renewable Energy and includes eliminating funding for solar and wind initiatives. House appropriators proposed nearly a 50% decrease in funding for the Office as well.

Along with these proposed cuts, the Trump administration recently renamed the National Renewable Energy Laboratory to the National Laboratory of the Rockies. A December 2025 press release about the change claims this decision "reflects the Trump Administration's broader vision for the lab's applied energy research."

Regarding the Office of Nuclear Energy, the White House requested $1.370 billion, or a 19% decrease from the enacted total of $1.685 billion in 2025, with the stated aim of reducing "nonessential research." House appropriators requested $1.9 billion for this Office.

National Nuclear Security Administration

House appropriators requested $25.3 billion in funding for the NNSA, while the White House requested $30 billion, as well as $4.8 billion in mandatory funding to be provided to NNSA through the congressional budget reconciliation process. The White House's request would be a 24.5% increase from the 2025 enacted amount of $24.1 billion.

National Institute of Standards and Technology

NIST is slated to experience a decrease in funding again, with the White House requesting a 28% decrease and House appropriators requesting a 13% decrease. On the other hand, Senate appropriators requested a 4% increase. The White House and House appropriators are both requesting a 17% decrease to NIST research programs specifically, while Senate appropriators propose a flat rate (excluding earmarks).

Also of note is President Trump's request to reduce or eliminate laboratory programs on atomic spectroscopy and biophysics, do away with "low-priority" workforce development initiatives in exploratory measurement science, and put an end to the greenhouse gas measurements program. The White House and House appropriators both propose a flat rate for NIST facility construction while Senate appropriators propose a 46% increase.

Contrary to years prior, NIST did not receive any funds for earmarked projects on top of its annual budget in 2025; however, House and Senate appropriators are requesting an additional $273 million and $149 million, respectively, under NIST's Scientific and Technical Research and Service programs for fiscal year 2026. Senate appropriators also earmarked $258 million under NIST research facilities.

National Aeronautics and Space Administration

The White House proposed a steep cut of 47% to NASA's Science Mission Directorate budget, with House appropriators requesting an 18% decrease and Senate appropriators requesting a near flat level. These proposals reflect a redirection in funding allocated toward human space exploration, which received requests for an increase across all three entities.

The overall significant decrease in NASA funding will lead to the cancellation of 40 or more missions, including the Mars Sample Return Mission, of which funding was a point of contention between the House and Senate in 2024.

Senate Democrats in the Commerce, Science, and Transportation Committee also published a report in October 2025 stating that NASA was directed to start spending their fiscal year 2026 budget over the summer by White House Office of Management and Budget Director Russell Vought. While NASA leadership denied the claim, Senate Democrats still cited safety concerns due to the significant budget cuts.

National Institutes of Health

The White House requested a 40% decrease to the NIH, but both Senate and House appropriators rejected this deep cut by requesting near-level funding. Senate appropriators requested no change from the 2025 enacted levels for the Advanced Projects Agency for Health, but the White House and House both requested a decrease of 37%.

The Trump administration also requested the restructuring of NIH into eight institutes, consolidating at least five current institutes into one. Both the Senate and House proposals rejected this request, with the Senate proposal including a reminder that 24 of NIH's 27 institutes and centers were established with statute and that "ample notice" should be communicated to the House and Senate before significant changes are made.

For more information on the federal budget, visit the American Institute of Physics FYI "Federal Science Budget Tracker" at https://ww2.aip.org/fyi/budget-tracker. ■

Corporate Partner news

Bullen Ultrasonics receives US patent

Bullen Ultrasonics was recently issued U.S. Patent No. 12,294,172 B2 for an innovative electrical connection system. The patent was awarded to inventors Bradley Jeffries, senior design engineer, and Eric Norton, research and early innovation manager. Read more: https://www.bullentech.com/news

Capital Refractories subsidiary is acquired by Siemens Energy

Siemens Energy acquired Capital Injection Ceramics Limited (CIC), a subsidiary of Capital Refractories (CRL). This acquisition allows CRL to streamline their portfolio and focus on advancing their monolithic business. CIC will operate as a subsidiary of Siemens Energy with the same staff in place to ensure a seamless transition. Read more: https://www.capital-refractories.com/news-events

GE Aerospace to invest £19 million in upgrades to Wales site

As part of a larger company-wide initiative, GE Aerospace will invest £19 million (US$25.4 million) to update its Wales site, which is home to its global maintenance, repair, and overhaul operations. The modernization will include updates to roof space, building cladding, insulation, and glazing installations. Read more: https://www.geaerospace.com/news

Imerys site in France opens its doors for the community and stakeholders

Imerys acquired the Saint-Bauzile diatomite site in France in January 2025, and in October, the company hosted a two-day experience there for community members and stakeholders. The event gave an overview of Imerys' activities, expertise, and sustainable growth strategy and included tours of the facility and site. Read more: https://www.imerys.com/news

Schunk welcomes Chinese delegation in November visit

German-based technology company Schunk Group welcomed six Chinese delegates at their Heuchelheim site. Representing one of the most important markets for Schunk, the Chinese delegates received a factory tour and look inside the laboratory. Read more: https://www.schunk-group.com/en/news-events ■

Aerospace ceramics: Global markets to 2029

The global market for aerospace ceramics was valued at $5.3 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 8.0% to reach $8.2 billion by the end of 2029.

According to the International Energy Agency, the aviation industry was responsible for 2.5% of global carbon emissions in 2023. To achieve net-zero emissions, this sector must undergo transformation driven by the push for greener aviation materials and technologies, sustainability mandates, and environmental regulations.

Aerospace ceramics are one way to improve the sustainability of the aviation industry. These advanced materials exhibit superior thermal and electrical performance and lightweight properties, leading to enhanced aircraft performance, including fuel efficiency, greater speed, range, and payload capacity. They are primarily found in thermal protection shields, engine and exhaust systems, and structures for aircraft.

Types of aerospace ceramics:

- **Ceramic matrix composites** (CMCs) are a class of engineered ceramics composed of ceramic fibers embedded in a ceramic matrix. They offer enhanced damage tolerance compared to traditional bulk ceramics because when cracks propagate through the matrix, they are deflected by the fiber reinforcement, preventing sudden failure. CMCs are increasingly used in turbine blades, combustor liners, and thermal protection systems, and they accounted for 62.6% of the market for aerospace ceramics in 2023.
- **Oxide ceramics**, particularly alumina and zirconia, are integral to aerospace applications due to their superior electrical insulation properties, corrosion resistance, and mechanical strength. These ceramics are preferred materials in barrier coatings for gas turbines and jet engines, where they protect components from the extremely hot and oxidizing environment.
- **Nonoxide ceramics** have exceptional endurance to harsh environments, especially in reducing and vacuum environments, where oxide ceramics may deteriorate because of phase change. Moreover, they exhibit a higher strength-to-weight ratio than most metals, making them ideal for lightweight aerospace structures.

Aerospace researchers are also developing components with ultrahigh-temperature ceramics (UHTCs). These transition metal carbides, nitrides, and borides are distinguished by their exceptional oxidation ablation resistance and melting points above 3,000°C. However, some of the materials used in UHTCs are sourced from limited suppliers, making international collaboration and trade vital to the supply chain's functioning.

The market for aerospace ceramics is segmented into structural, thermal, and electrical applications. While structural applications hold the largest market share (57.2% in 2023), thermal applications are expected to grow fastest, driven by the demand for ceramics material that exhibits heat conductivity, thermal shock resistance, and phase stability. Meanwhile, the rising demand for electric aircraft is driving the growth of electrical aerospace ceramic applications (Table 1).

North America is the largest revenue-generating market for aerospace ceramics, accounting for 48% of the global aerospace ceramics market in 2023. This market dominance is due to North America being home to major aerospace original equipment manufacturers such as Boeing, Lockheed Martin, Northrop Grumman, and RTX Corp. The presence of advanced ceramic material suppliers such as CoorsTek, Applied Ceramics, Ceramco, and Advanced Ceramic Materials further strengthens North America's position in aerospace ceramics innovation.

Table 1. Global market for aerospace ceramics, by application, through 2029 ($ millions)

Application	2023	2024	2029	CAGR % (2024–2029)
Structural	3,056.5	3,201.2	4,641.7	7.7
Thermal	1,508.7	1,615.3	2,603.5	10.0
Electrical	777.5	793.5	994.4	4.6
Total	5,342.7	5,610.0	8,239.6	8.0

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 utkantha.srivastava@bccresearch.com.

Resource

BCC Publishing Staff, "Aerospace ceramics: Global markets to 2029," BCC Research Report AVM218B, April 2025. https://bit.ly/April-2025-aerospace-ceramics ■

By Elizabeth Opila
Guest columnist

Engineered ceramics support the past, present, and future of aerospace ambitions

Engineered ceramics play key roles in aerospace applications, from structural components to protective coatings that can withstand the high-temperature, reactive environments.

Perhaps the earliest success of ceramics in aerospace applications was the use of yttria-stabilized zirconia (YSZ) as thermal barrier coatings (TBCs) on nickel-based superalloys for turbine engine applications. These coatings, which initially were used on stationary components such as combustors as early as the 1960s, allowed higher operating temperatures and increased engine efficiencies due to YSZ having low thermal conductivity.

The coatings were adapted for rotating turbine blades around 1990, and improved coating properties were achieved by utilizing electron beam physical vapor deposition in the early 2000s. Further efforts for TBC development include using surface coatings of gadolinium zirconate to mitigate reactions with ingested siliceous debris.

While TBCs are widely employed in commercial aviation, further increases in engine operating temperature are not possible with the current materials systems due to loss of precipitation strengthening and increased creep rates of the alloy, as well as phase instability and sintering of the YSZ. Instead, engine companies have turned to development of higher temperature material systems such as silicon carbide (SiC)-based ceramic matrix composites (CMCs) with environmental barrier coatings (EBCs).

CMCs for aeroturbine applications are composed of SiC fibers coated with a thin boron nitride layer, woven or laid up and infiltrated with chemically vapor deposited SiC and/or molten silicon to form the matrix. The boron nitride interphase is key to the toughness of these composites due to two energy-absorbing processes: i) cracks deflect around the fibers and ii) the boron nitride allows fiber pullout as cracks open.

Development of current state-of-the art SiC-based composites began around 1990; they were first inserted into the GE-Safran LEAP engine in 2016. This long development cycle led to the oft quoted 2001 study, "Will Pigs Fly Before Ceramics Do?"

Environmental barrier coating development proceeded in tandem with that of SiC CMCs. EBCs are required to limit volatilization of the silica that forms on CMCs when exposed to high-temperature water vapor present in combustion environments. Current EBCs are composed of rare earth disilicates desirable for chemical and thermal expansion compatibility with the underlying composites. Multicomponent rare earth silicates are an active area of research to further reduce thermal conductivity and to mitigate reactions with ingested siliceous debris.

NASA's Space Shuttle (1981–2011) also relied on ceramics for thermal protection during orbital reentry. The shuttle's underside was covered with silica tiles (94 vol.% air) coated with a black borosilicate glass to increase emissivity for more rapid cooling. The leading edge and nose of the space shuttle were subjected to higher temperatures (up to 1,650°C) during reentry and were thus made of a higher temperature material system: carbon fiber-reinforced carbon composite with a surface conversion layer of SiC. Because the thermal expansion of carbon and SiC differ, cracks in the SiC occurred on cooling from processing temperatures. A sodium silicate glass was applied to the surface that melted during reentry, flowed into the cracks, and mitigated oxidation of the underlying carbon composite.

The space shuttle flew at hypersonic speeds during reentry and was intentionally designed as a blunt-bodied vehicle to promote shock wave formation far from the vehicle, limiting surface heating. Future, more maneuverable hypersonic vehicles must have sharp leading edges, which will result in shock wave formation closer to the vehicle and significantly higher surface heating. Ultrahigh-temperature ceramics (UHTCs) are proposed for these leading-edge applications.

UHTCs have been under development since the 1960s and primarily consist of early transition metal borides, carbides, and nitrides. The most widely studied composition is ZrB_2–20 vol.% SiC, which oxidizes under reentry relevant conditions to form columnar ZrO_2 and a borosilicate glass. At higher Mach numbers and temperatures, the borosilicate glass is expected to vaporize.

Studies over the last five decades have resulted in improved processing and mechanical properties for UHTCs as well as improved understanding of oxidation mechanisms; nevertheless, rapid oxidation remains a challenge. Many studies are underway to identify alternative compositions, including high-entropy UHTCs and UHTC composites that might surmount this challenge.

Engineered ceramics have helped support our advancement of aeroturbine technologies and explorations of space since the earliest days. The development of new compositions and composites will continue to be a grand ambition for the application of ceramics in aerospace.

About the author

Elizabeth Opila is Rolls-Royce Commonwealth Professor of Engineering and director of the Rolls Royce University Technology Center on Advanced Material Systems at the University of Virginia. Prior to joining the university, she was a materials engineer at NASA-Glenn Research Center for 19 years. Contact Opila at opila@virginia.edu. ■

By David Holthaus
Industry reporter

Innovations in access and technology secure clean water around the world

Food, water, and shelter—the basic necessities of life—are scarce for millions of people around the world. Yet even when these resources are technically obtainable, they may not be available in a format that supports healthy living.

Approximately 115 million people worldwide depend on untreated surface water for their daily needs, and more than 2 billion lack a safely managed source of water.[1] Contaminated water can cause cholera, dysentery, hepatitis, and other life-threatening diseases, which could be prevented with essential sanitation.

Water filters that make use of ceramic materials have advanced to the point that they can purify water to be almost 100% bacteria-free. But poor communities are not typically viewed as markets for expensive, highly engineered products. That leaves millions of people essentially on their own.

"Marginalized peoples are not looked at as customers," says Ian Nettleship, associate professor of mechanical and materials science at the University of Pittsburgh, in an interview. "Supply chains generally don't get into marginalized communities. As a consequence, there were no filters on the market they could buy because they're all too expensive."

As a materials scientist, Nettleship knew he could do something to address this need. His solution was to train residents in impoverished communities to make low-cost ceramic water filters using locally sourced materials.

"What we do, along with other groups who are involved in this initiative, is establish small-scale filter factories in marginalized communities to fight waterborne diseases," he says.

Starting with local clay, sometimes at an old or existing brickyard, a combustible material like sawdust is mixed in and then a pot-shaped container is formed using a hand-operated press. When the filter is fired, the sawdust burns out, leaving small cracks and pores that are large enough to allow water to pass through but too small for bacteria. The final touch is a small amount of colloidal silver, which is known to exhibit antimicrobial properties, applied to both the inside and outside of the filter.

The result is a passive device made of native materials and using no electricity. The filter fits into a five-gallon plastic bucket fitted with a lid and a spigot that can store the clean water. To use it, one only needs to pour contaminated water in the top. The filters will produce water that is 99.9% free of bacteria.

In 2023, Nettleship became president of Ceramic Water Filter Solutions (CWFS), a Pennsylvania-based not-for-profit organization that has standardized this method of producing affordable, reliable water filters. Since 2013, the organization has worked with residents in Mexico, Nepal, and Nigeria (Figure 1). In Nepal alone, CWFS has placed about 4,000 filters in poor, remote communities, serving about 30,000 people, Nettleship says.

The technology the group brings to the communities is a return to the origins of modern ceramic water filters, which were first deployed in London in the 1800s to counter outbreaks of cholera and typhoid. At that time, drinking water from the Thames was contaminated with raw sewage, so epidemics of waterborne diseases were common. John Doulton and his son Henry (of English fine china and pottery fame) invented the ceramic water filter to remove bacteria from London's drinking water. The Doulton water filter brand lives on today, part of the portfolio of products of Fairey Industrial Ceramics (Newcastle-Under-Lyme, U.K.).[2]

As ceramic manufacturing advanced, so did the quality of water filters as refinements in pore size and structure improved their reliability. In the 20th century, the addition of silver particles to inhibit bacterial growth on the filter's surface was a major innovation.

Credit: CDO Nepal

Figure 1. A young girl in Nepal drinks water cleaned using ceramic water filters (container to the left).

The 21st century has seen an evolution in the use of nanomaterials to improve antibacterial and adsorptive performance. These leaps in technology have been significant, as the expansion of urban areas, a growing global population, and the pace of industrialization have introduced pollutants such as heavy metals and dyes into water streams that pose greater challenges for securing potable water.

Graphene and graphene oxide derivatives have demonstrated high performance as water purification membranes.[3] A relatively new class of 2D nanomaterials, MXenes, has also shown potential for broad applications in water treatment and other environmental remediation activities due to their structure, high surface area, and environmentally friendly characteristics.[4]

Among the businesses specializing in ceramic water filters are

- **Ceramic Filters Co. Inc.**, based in Brooklyn, Mich. This company started in 1989 as an importer for a British ceramics manufacturer and then split off as a freestanding company. It markets the AquaCera brand of water filtration products.

- **Fairey Industrial Ceramics**, in addition to the Doulton brand, also markets the British Berkefeld brand of ceramic filters.
- **Katadyn Products Inc.**, based in Kemptthal, Switzerland. This company offers filtration products under several brands, including Micropur and Optimus, and is probably best known for its portable filters used by hikers and other outdoor enthusiasts.

These companies and others, as well as engineers and researchers, have developed technologies that keep pace with the need for clean water around the world.

For Nettleship, innovation is not necessarily about advancing technology but expanding who has access to it. To successfully increase the impact of ceramic water filtration systems, he and his colleagues at Ceramic Water Filter Solutions must adapt to a variety of local conditions and teach new skills to uneducated populations. They must also find ways to keep the process affordable so local residents can continue making filters after the CWFS team goes home.

"The material is going to be different everywhere you go because you're locally sourcing it," he said. "So, the innovation has to come in how you quickly adapt to different clays in different regions and how you create an affordable process to stand up a small-scale factory. These innovations are more related to entrepreneurial skills."

By innovating in that way, Ceramic Water Filter Solutions can continue expanding the use of an age-old technology that is still addressing the challenges of today's world.

About the author

David Holthaus is an award-winning journalist based in Cincinnati, Ohio, who covers business and technology. Contact Holthaus at dholthaus@ceramics.org.

References

[1]"Drinking-water," World Health Organization. Published 13 Sept. 2023. https://www.who.int/news-room/fact-sheets/detail/drinking-water

[2]"Our Brands," Doulton. https://doulton.com/en-us/pages/our-brands

[3]M. Sun and J. Li, "Graphene oxide membranes: Functional structures, preparation and environmental applications," *Nano Today* 2018, **20**: 121–137.

[4]Rasool et al., "Water treatment and environmental remediation applications of two-dimensional metal carbides (MXenes)," *Materials Today* 2019, **30**: 80–102.

*All references verified as of Nov. 19, 2025. ■

acers spotlight

SOCIETY
DIVISION
SECTION
CHAPTER
NEWS

ACerS leaders for 2025–2026

ACerS is pleased to introduce the 2025–2026 Society leadership. New officers and directors were installed at the 127th Annual Business Meeting on Sept. 29, 2025, during ACerS Annual Meeting at MS&T25 in Columbus, Ohio.

Back row, from left: Christopher Berndt, Dileep Singh, Rodney Trice, Todd Steyer, Yiquan Wu, and Palani Balaya. Front row, from left: Ruyan Guo, Klaus-Markus Peters, Mario Affatigato, Monica Ferraris, Shibin Jiang, and Mark Mecklenborg. Not pictured: Yutai Katoh, Alexandra Navrotsky, and Stephen Freiman.

Society officers and directors

Executive Committee

President
Mario Affatigato
Fran Allison and Francis Halpin
Professor of Physics
Coe College
Cedar Rapids, Iowa

President-elect
Shibin Jiang
President and CEO
AdValue Photonics Inc.
Tucson, Ariz.

Past President
Monica Ferraris
Full professor of science and technology of materials
Politecnico di Torino
Turin, Italy

Treasurer
Klaus-Markus Peters
Director of engineering
Fireline Inc.
Youngstown, Ohio

Secretary
Mark Mecklenborg
Executive director
The American Ceramic Society
Westerville, Ohio

Board of Directors (new)

Palani Balaya
Associate professor
National University of Singapore
Singapore

Yutai Katoh
Director of the Materials Science and Technology Division
Oak Ridge National Laboratory
Oak Ridge, Tenn.

Yiquan Wu
Inamori Professor
Alfred University
Alfred, N.Y.

FOR MORE INFORMATION:

ceramics.org/spotlight

Board of Directors (returning)

Christopher C. Berndt
University Distinguished Professor
Swinburne University of Technology
Melbourne, Australia

Ruyan Guo
Robert E. Clarke Endowed Professor of Electrical and Computer Engineering
The University of Texas at San Antonio
San Antonio, Texas

Rodney Trice
Professor
Purdue University
Lafayette, In.

Alexandra Navrotsky
Regents Professor
Director of the Navrotsky Eyring Center for Materials of the Universe
Arizona State University
Tempe, Ariz.

Todd Steyer
Chief engineer for materials and manufacturing R&D
The Boeing Company Huntington Beach, Calif.

Dileep Singh
Senior scientist and group leader
Applied Materials Division
Argonne National Laboratory
Argonne, Ill.

Parliamentarian
Stephen Freiman
Freiman Consulting Inc.
Potomac, Md.

Student member
Jack Hoffler
Graduate student
North Carolina State University
Raleigh, N.C.

ACerS 127th Annual Business Meeting: Updates on the Society

The American Ceramic Society held its 127th Annual Business Meeting on Monday, Sept. 29, during ACerS Annual Meeting at MS&T25 in Columbus, Ohio. This meeting provides a platform for ACerS leadership to report on the state of the Society.

During this year's business meeting, outgoing ACerS President Monica Ferraris summarized the Society's 2024–2025 accomplishments, including initial successes with implementing the 2025–2028 strategic plan, a two-year extension of funding from the Department of Defense for the ACerS–USACA "Professional Development for Hypersonic Materials" program, and cementing the Society's continued partnership with Wiley on the four ACerS journals. Then, Treasurer Daniel Tipsord reported that the Society experienced an increase in its net assets this year, which means increased financial stability for the Society.

New officers were sworn-in, and outgoing officers were recognized and thanked for their service. Incoming President Mario Affatigato outlined his vision and goals for this year as president (see details on page 21), which will focus on three "Fs": finances, fulfillment, and the future.

Outgoing ACerS President Monica Ferraris, left, passes the ceremonial ceramic gavel to incoming ACerS President Mario Affatigato during the Annual Board Meeting on Sept. 29, 2025.

The Annual Awards Banquet took place that night at the Hyatt Regency Columbus. This year's awardees included 12 members elevated to Fellow Status and two members awarded the distinction of Distinguished Life Member: John E. Marra and Subhash H. Risbud.

In addition to the Annual Business Meeting, other events that provide updates on different parts of the Society took place during MS&T, including meetings of the Board of Directors, Division executive committee and business meetings, and meetings of ACerS working committees and subcommittees. The Society's student leadership group, the President's Council of Student Advisors, also held its annual meeting. This year, the PCSA includes 46 students from 29 universities, representing seven countries.

View pictures from ACerS 127th Annual Business Meeting at https://bit.ly/MST25-Columbus. ACerS 128th Annual Meeting at MS&T26 will take place Oct. 4–7, 2026, in Pittsburgh, Pa. ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

ACerS International United Arab Emirates Chapter takes part in first UAE Doctoral Sprint Competition

Khalifa University, in collaboration with ACerS International United Arab Emirates Chapter, successfully hosted the first UAE Doctoral Sprint Competition, an event celebrating the creativity, innovation, and research excellence of doctoral students across the United Arab Emirates.

ACerS International United Arab Emirates Chapter members and Khalifa University students at the inaugural UAE Doctoral Sprint Competition on Oct. 8, 2025.

The competition, held on Oct. 8, 2025, provided a dynamic platform for Ph.D. candidates to present the novelty and impact of their thesis research in just 150 seconds. This fast-paced format challenged participants to communicate their ideas with clarity, precision, and enthusiasm. Several ACerS student members and volunteers helped ensure the smooth execution of the program.

Following overwhelming response and participation from researchers in numerous countries, the UAE Chapter plans to organize the next Doctoral Sprint Competition in a hybrid format. ■

ACerS International Spain Chapter co-hosts 'New Horizons in Multifunctional Ceramic and Glass Materials'

On Oct. 7 and 8, 2025, ACerS International Spain Chapter and Nanomaterials and Nanotechnology Research Center (CINN) co-hosted "New Horizons in Multifunctional Ceramic and Glass Materials." This event provided researchers, students, and professionals from the industrial sector a forum to address the most current challenges in the development of new interfaces in multifunctional ceramic and glass materials.

Around 30 people attended the in-person event, which began on Tuesday with a workshop in the auditorium of the Spanish National Research Council delegation in Asturias. Distinguished experts in the field of ceramic materials participated, covering topics ranging from the preparation and characterization of new materials to their applications in key areas such as energy, biomedicine, and electronics.

On Wednesday, a visit was made to the facilities of the CINN Multifunctional Materials Development Unit in Sotrondio. There, attendees learned firsthand about some of the cutting-edge technologies used by CINN for the industrial-scale production of multifunctional ceramic materials, most notably the largest hybrid hot-press/spark plasma sintering unit built to date. ■

Event attendees at the workshop on Tuesday.

Members of ACerS International Spain Chapter and Nanomaterials and Nanotechnology Research Center during the "New Horizons in Multifunctional Ceramic and Glass Materials" event.

Event attendees visiting the CINN Multifunctional Materials Development Unit facilities.

Extended hypersonic workshop series launches successfully in Washington, DC

ACerS and the United States Advanced Ceramics Association (USACA) kicked off their newly extended "Professional Development for Hypersonic Materials" program with a successful workshop on Oct. 29, 2025, at USACA's headquarters in Washington, D.C. The event marks the first of 18 workshops to be delivered over the next two years, following the Department of Defense's recent commitment to a two-year funding extension for this critical training initiative.

Twenty-four professionals from academia, industry, and government contractors gathered for the intensive full-day workshop, which focused on ultrahigh-temperature ceramics and composite materials for hypersonic applications. The program, led by Purdue University Professor Rodney Trice, delivered eight comprehensive modules covering everything from the history of hypersonic flight to cutting-edge developments in thermal protection systems.

Participant feedback was overwhelmingly positive, with attendees particularly praising the depth and breadth of information provided. The intimate group size fostered an interactive learning environment where participants could pose questions throughout the day. Many noted the value of the extensive references and lecture materials provided, which will serve as lasting resources for their work in hypersonic materials development.

Trice will deliver another iteration of this comprehensive course virtually on Jan. 6–7, 2026. Interested professionals can register at https://ceramics.org/course/virtual-hypersonic-workshop-2026. ■

CHECK OUT THESE RECENT ADDITIONS TO THE ACERS WEBINAR ARCHIVE:

RESOURCE UTILIZATION ON EARTH AND BEYOND: VALORIZATION OF MINING WASTE AND IN-SITU RESOURCE UTILIZATION
Original air date: Oct. 20, 2025
Hosted by: Cements Division
Featured speaker: Hee-Jeong Kim

MACABRE MATERIALS ACROSS TIME: FROM TOXIC PIGMENTS TO MANIC ALCHEMISTS
Original air date: Oct. 31, 2025
Hosted by: Washington, D.C./Maryland/Virginia Section
Featured speakers: Celia S. Chari

ACerS members can view these webinars and other past recordings by visiting the ACerS Webinar Library at https://ceramics.org/education/webinars.

MEMBER HIGHLIGHTS

IN MEMORIAM

Steve Feller
Martin Liverman
Carl McMurtry
Inna Talmy

FOR MORE INFORMATION:

ceramics.org/membership

Volunteer Spotlight: Dachamir Hotza and Ashutosh Kumar Dubey

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

Dachamir Hotza is full professor at the Federal University of Santa Catarina (UFSC) in Brazil. He received his bachelor's and master's degrees in chemical and mechanical engineering from UFSC and his Ph.D. in materials engineering from Hamburg University of Technology, Germany. He has held visiting research appointments at the University of Aveiro (Portugal), the University of Limoges (France), the University of Queensland (Australia), and the University of California, Davis (U.S.).

Hotza's research and outreach efforts focus on sustainable ceramic and cementitious materials, waste valorization, and circular economy strategies—linking scientific innovation with global environmental responsibility.

Hotza has been instrumental in fostering collaboration among ceramic researchers across the Americas. For example, he is co-organizer of the Pan-American Ceramics Congress and currently director of communications of the Brazilian Ceramic Association. At the 69th Brazilian Ceramics Congress, he and his team, in collaboration with the European Ceramic Society, led activities that further strengthened the connection between ACerS and the Brazilian ceramics community.

Hotza is an ACerS Fellow, only the fourth Brazilian to receive this honor. His primary affiliation within ACerS is the Engineering Ceramics Division, but he also contributes to the Basic Science Division and the Global Young and Early Career Professionals Network through mentoring activities. Hotza has played a leading role in expanding international collaboration, most notably through the establishment and active coordination of the ACerS International Brazil Chapter.

Ashutosh Kumar Dubey is associate professor and head of the Department of Ceramic Engineering at Indian Institute of Technology Varanasi (IIT BHU). He received his M.S. in materials science and technology from IIT BHU and his Ph.D. in materials science and engineering from Indian Institute of Technology Kanpur. Following his doctoral studies, Dubey was awarded the prestigious Japan Society for the Promotion of Science Postdoctoral Fellowship at the Nagoya Institute of Technology, Japan. He later served as a postdoctoral research associate at the same institute and as a visiting scholar at The University of Texas at San Antonio before joining IIT BHU in 2015.

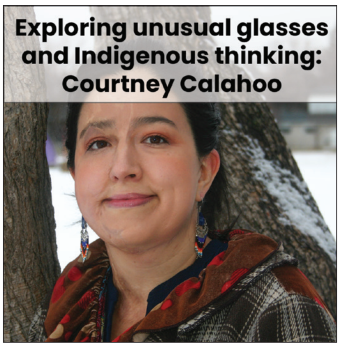
Dubey has made pioneering contributions to materials for orthopedic applications. His research currently focuses on piezoelectric biomaterials, particularly electric field and surface charge-mediated biocompatibility of ceramics, piezoelectric biomaterials for self-powered medical devices, and nanoporous and functionally graded ceramics for orthopedic applications.

Dubey is an active member of the Bioceramics Division, serving as secretary (2023–2024), vice chair (2024–2025), and now chair-elect (2025–2026). He is also an associate editor of *International Journal of Applied Ceramic Technology*.

We extend our deep appreciation to Hotza and Dubey for their service to our Society! ■

Ceramic Tech Chat: Courtney Calahoo

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.



In the October 2025 episode of Ceramic Tech Chat, Courtney Calahoo, research and development team lead at Genics, shares her journey to working on dissolvable glasses, describes some of her current projects, and provides examples of how Indigenous knowledge can benefit scientific research.

Check out a preview from her episode, where she talks about the overlap between Indigenous knowledge and glass science.

"I was reading about how Inuit process muskox horn into their tools, and the description of how they did it just struck me so much as being similar to how a glassblower would be doing it. It made me realize that the people that are living in the Arctic, they were materials scientists. It made me feel that there's sort of a missed opportunity where we could put maybe even a fraction of the same interest or effort into investigating how Indigenous materials scientists worked with their materials, how they chose their materials."

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

ACerStudent Engagement: Jordan Sweeney and Julia Esakoff

Jordan Sweeney and **Julia Esakoff** are third- and second-year Ph.D. students, respectively, in materials science at Colorado School of Mines. Sweeney's research focuses on conversion cathodes for next-generation ion batteries while Esakoff's research focuses on ferroelectric nitride thin films for nonvolatile memory.

Sweeney and Esakoff are both outreach chairs for Mines' Keramos Chapter as well as delegates for ACerS President's Council of Student Advisors. Through Keramos, Sweeney and Esakoff helped run a one-day Materials Adventure camp in October 2025 for high school students along with Ryan McGinnis, another PCSA delegate. Esakoff oversaw a microelectronics demonstration that involved coating silicon in copper while Sweeney showed the students a computer chip and battery electrode in the scanning electron microscope. The students then looked at the coated silicon in the profilometer, which gave them hands-on experience with analyzing materials.

"These outreach events always remind me why I love what I do," says Sweeney.

Congratulations to Sweeney and Esakoff on the successful event!

Group picture of everyone who participated in the Materials Adventure camp: high school students, Mines student volunteers, and faculty supervisor Kim Scott.

All students can gain valuable skills and experiences like Downing and Yeo through ACerS student membership. Learn more at https://ceramics.org/membership/join. ■

AWARDS AND DEADLINES

Nomination deadlines for Division awards: Jan. 15, 21, 31, or March 1, 2026

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

Division	Award	Deadline	Description
MFG	John E. Marquis Memorial Award	January 15	Recognizes the author(s) of a paper on research, engineering, or plant practices relating to manufacturing in ceramics and glass, published in the prior calendar year in a publication of the Society, that is judged to be of greatest value to the members and to the industry.
GOMD	Norbert J. Kriedl	January 21	Recognizes a young engineer or materials scientist who has conducted excellent research in glass science. Nominations are open to all degree-seeking graduate students (M.S. or Ph.D.) or those who have graduated within a 12-month period of the annual GOMD meeting.
GOMD	George W. Morey	January 21	Recognizes new and original work in the field of glass science and technology. The criterion for winning the award is excellence in publication of work, either experimental or theoretical, done by an individual.
GOMD	L. David Pye Glass Hall of Fame	January 21	Recognizes an individual's lifetime of dedication, vision, and accomplishments in advancing the fields of glass science, glass engineering, and glass art.
GOMD	Stookey Lecture	January 21	Recognizes an individual's lifetime of innovative exploratory work or noteworthy contributions to outstanding research on new materials, phenomena, or processes involving glass that have commercial significance or the potential for commercial impact.
GOMD	Varshneya-Mauro-Jain Guru-Chela Travel Fund	January 21	Seeks to encourage two technical presentations by a teacher and their student either individually or jointly at a GOMD meeting.
BIO	Young Scholar	January 31	Recognizes excellence in research among current degree-seeking graduate students and postdoctoral research associates.
BIO	Global Young Bioceramicist	January 31	Recognizes a young ceramic engineer or materials scientist who has made significant contributions to the area of bioceramics for human healthcare around the globe.
BIO	Larry L. Hench Lifetime Achievement	January 31	Recognizes an individual's lifetime dedication, vision, and accomplishments in advancing the field of bioceramics, particularly toward innovation in the field and contribution of that innovation to the translation of technology toward clinical use.
BIO	Tadashi Kokubo	January 31	Recognizes an individual's outstanding achievements in the field of bioceramics research and development.
CEMENTS	Early Career	January 31	Recognizes an outstanding early career scientist who is conducting research in the field of cement and concrete in academia, industry, or a government-funded laboratory.
BSD	Early Discovery	March 1	Recognizes an early career member of ACerS who has demonstrated a contribution to basic ceramic and glass science.

FOR MORE INFORMATION:

ceramics.org/awards

Last call for 2026 Society award nominations

ACerS recognizes outstanding achievements of its Corporate Partners, individual members, and authors during the Annual Awards Banquet at ACerS Annual Meeting. Society award nominations for 2026 are due **March 1, 2026**. View all Society awards and submit your nominations at https://ceramics.org/career-development/awards. Contact Erica Zimmerman, executive office manager, at ezimmerman@ceramics.org with questions. ■

ECD Best Poster winners from ICACC 2025

The Engineering Ceramics Division announced Best Poster winners from ICACC 2025, held last January in Daytona Beach, Fla. The awards will be presented during the plenary session at ICACC 2026. Congratulations to the authors of these award-winning posters!

2025 Best Poster awards (presenter name in bold)

First place: *Creation of the RbI–*SrI_2 *phase diagram to facilitate scintillator scale-up*—**Megan A. Gillespie**, K. S. Pestovich, M. Zhuravleva, C. Melcher, L. Stand, and E. van Loef; University of Tennessee, Knoxville, and Radiation Monitoring Devices Inc., Mass.

Second place (tie): *Prediction of size dependency of strength scatter in ceramics using extreme value statistics for defect distribution*—**Taiyo Maeda**, T. Osada, and S. Ozaki; National Institute for Materials Science Research Center for Structural Materials and Yokohama National University, Japan

Second place (tie): *Building a composite cathode for sulfidic solid-state Na-ion batteries via infiltration method*—**Leticia Trezecik Silvano**, T. Schubert, V. Knoblauch, and P. Kaya; Institute for Materials Research Aalen, Germany

Trustee awards (presenter name in bold)

Processing of Nb/Ta–Al_2O_3 *composites by FAST/SPS and investigation of 3D-microstructure*—**Gregory Kallien**, B. Kraft, G. Schell, and S. Wagner; Karlsruhe Institute for Applied Materials, Germany

Processing and characterization of carbon dots: Phyllosilicate composites—M.A. Escobal, **Gisele Laure Lecomte-Nana,** J. Duclere, C. Peyratout, and R.T. Candidato Jr; University of Limoges, ENSCI, Science of Ceramic Processes and Surface Treatments Laboratory, and Mindanao State University–Iligan Institute of Technology, France

Investigating durability of 8YSZ via wear and erosion testing for lunar applications—**Ashley Tirado Pujols,** Z. Stein, C. Wohl, V.L. Wiesner, and S. Raghavan; Embry-Riddle Aeronautical University, Fla., and NASA Langley Research Center, Va.

Combined effects of displacement damage and transmutation on the thermal diffusivity of CVD-SiC—**Keshav Vasudeva,** A. Wylie, K. Woller, M. P. Short, and S. E. Ferry; Massachusetts Institute of Technology, Mass. ■

2024–2025 Global ambassador awardees

The Global Ambassador Program recognizes dedicated ACerS volunteers worldwide who demonstrate exceptional leadership and/or service that benefits the Society, its members, and the global ceramics and glass community. ACerS 2024–2025 President Monica Ferraris selected the following volunteers for the Global Ambassador Award:

- **Enrico Bernardo,** University of Padova, Italy
- **Thomas Fischer,** University of Cologne, Germany
- **B. Reeja Jayan,** Carnegie Mellon University, Pa.
- **Wei Ji,** Wuhan University of Technology, China
- **B.Venkata Manoj Kumar,** Indian Institute of Technology, India
- **Dong (Lilly) Liu,** University of Oxford, U.K.
- **Peter Mechnich,** German Aerospace Center DLR, Germany
- **Elisa Moretti,** Ca' Foscari University of Venice, Italy
- **Yuki Nakashima,** National Institute of Advanced Industrial Science and Technology, Japan
- **Nina Obradovic,** Missouri University of Science and Technology, Mo.
- **Ungyu Paik,** Hanyang University, Republic of Korea
- **Martin Schwentenwein,** Lithoz GmbH, Austria
- **Junichi Tatami,** Yokohama National University, Japan
- **Alberto Vomiero,** University of Venezia, Italy
- **Douglas Wolfe,** The Pennsylvania State University, Pa. ■

Inside brickmaking: A virtual field trip at Belden Brick

The Ceramic and Glass Industry Foundation (CGIF) recently partnered with Belden Brick to host a virtual field trip that gave teachers and students around the world an inside look at how bricks are made. Led by plant manager Scott Gerber, the tour walked through each stage of the brickmaking process at Belden Brick's Plant 6, from raw material to finished product.

Gerber began by showcasing the fireclay and shale used to form bricks. By adding water and precisely mixing the clay and shale powders, it is compacted in a vacuum pug mill and pushed through an extruder. A long column of green brick emerges and is cut to shape, allowing Belden Brick to create a wide range of customized designs for its customers. The tour continued through the drying, firing, and glazing stages, giving participants a firsthand look at the craftsmanship and precision involved in brick production.

As Gerber described, brickmaking is a highly coordinated process that depends on many parts working together at once. Each employee has their own type of job and technical and educational background and plays a critical role in keeping the operation running smoothly, much like an orchestra, where every instrument must perform in harmony to create the final piece. Teachers found this behind-the-scenes access especially valuable, with several commenting that their students loved seeing the factory line, the glazed bricks, and the full production workflow, experiences that they would not have been able to have otherwise.

While Gerber walked the audience through the plant, CGIF Program Manager Nathan McIlwaine guided the experience behind the screen, fielding questions from curious students and passing them along to Gerber in real time. Questions such as "How hot does the kiln get?" and "Can you make bricks any color?" sparked moments of discovery, turning the tour into a truly interactive experience rather than just a lesson.

Students and teachers were not just learning how bricks are made; they were discovering the people and possibilities behind them. For example, Gerber shared how his 35-year career at Belden Brick started while he was still a student at Kent State University in Ohio. What began as a part-time college job turned into a lifelong profession when Gerber joined the company full time after graduation.

Gerber's enthusiasm for his craft brought the industry to life. Many viewers began to see materials science not as an abstract field but as a world full of creativity, innovation, and fulfilling career opportunities. One teacher shared that the tour "exposed my students to jobs in our backyard," while another noted how much students appreciated hearing about "job satisfaction, pride in work, and the various job opportunities" available in manufacturing.

By the end of the event, the impact was clear. Participants' favorable opinions of materials science rose by 12%, their awareness of career paths increased by 33%, and teachers felt 10% more confident introducing these ideas in their classrooms, according to a post-event survey.

CERAMIC AND GLASS INDUSTRY FOUNDATION

CGIF Program Manager Nathan McIlwaine (left) guides the conversation as Belden Brick Plant Manager Scott Gerber (right) answers students' questions during the virtual field trip.

The Belden Brick Virtual Field Trip took place Oct. 29, 2025. The recording is available on ACerS YouTube channel.

An example of the custom brick shapes and colors that Belden Brick can make for their customers.

More than 1,000 students from four countries and 20 U.S. states participated in the live virtual experience, representing grade levels from kindergarten through college.

View the recording of the virtual field trip at https://www.youtube.cowwwwwwwqPMknlxpqWBYgMEE.

Help us continue to empower the next generation of ceramic and glass professionals by giving now at https://ceramics.org/donate. ■

Meet ACerS President Mario Affatigato

By Lisa McDonald

> "There are still so many opportunities for growth, for optimism."

Almost everyone has someone who left an indelible impact on their life. While we seldom can repay this kindness to the original benefactor, we can create a positive ripple effect throughout society by paying it forward to others.

When Mario Affatigato, ACerS president for 2025–2026, first heard about Coe College during a college fair at his high school in Venezuela, he could not imagine the central role this institution would come to play in his personal and professional life. But the seeds were soon planted after arriving in Cedar Rapids, Iowa, to pursue a bachelor's in physics, where he met the late, indomitable Steve "Doc" Feller.

Feller specialized in conducting physics-oriented glass research, particularly using nuclear magnetic resonance. He was still in the early years of establishing Coe's now well-known physics undergraduate research program, but Affatigato says he immediately "dove into that world" and began to learn about the role that glass plays in our lives as well as glass structure.

Affatigato's interest in glass continued in graduate school at Vanderbilt University, where his advisor gave him the freedom to study light scattering from rough glass surfaces. After graduation, he had the fortune to return to Coe as a professor and establish his own glass research group. This decision was driven largely by his own "very good experience" as a Coe student and the feeling that "I could perhaps contribute to making that experience available to other undergrads."

Affatigato focuses his research on areas with strong applications but remaining fundamental questions. For example, some of his students investigate the structure–property relationships governing electronic conductivity in glasses, which is useful for particle detection and battery applications, while others study the factors behind surface hydrophobicity, which is useful for application in water-repellent windshields. His group also uses laser levitation to synthesize difficult-to-make glasses.

Affatigato's involvement in The American Ceramic Society started at Coe as well, when he attended the Glass & Optical Division Meeting in Tucson, Ariz., during his undergraduate studies. He became a member of the Society after returning to Coe as a professor and slowly started taking on larger and larger volunteer roles, culminating this year as ACerS president.

While students may believe that volunteering at this level requires them to do "something extraordinary," Affatigato emphasizes that they simply need to start small and serve "in the best sense of the word."

"The opportunities will follow because people appreciate the service that you provided," he says.

Affatigato says his priorities for this year will be guided by three "Fs": finances, fulfillment, and the future. These goals will be accomplished through specialized task forces, such as those aimed at improving the Young Professionals Network and evaluating how to handle artificial intelligence, as well as initiatives such as an innovation fund to finance ideas that promise a return on investment. In this way, the Society can "remain active, healthy, literally a great flag bearer for the world of ceramics and glass globally," he says.

Affatigato acknowledges there will undoubtedly be new challenges to tackle in 2026. However, "There are still so many opportunities for growth, for optimism, and that's what my goals are all about: helping find these opportunities and make them possible for our members," he says. ■

In memory of Steve Feller

Steve Feller died on Nov. 19, 2025, after taking ill at the Society of Physics Students conference in Denver, Colo. The family requests that donations be made to the Coe College Physics Research Fund to "pay forward" the opportunities for future generations of students.

Beyond the standard: Extra steps may be required for surface preparation of ferroelectric samples

In a recent paper, researchers from Friedrich-Alexander University of Erlangen-Nürnberg (FAU Erlangen-Nürnberg) in Germany and the Center for Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV) in Mexico showed that more attention should be paid to the mechanical polishing and heat treatment steps used to prepare ferroelectric and piezoelectric samples for surface-sensitive probing techniques.

Neamul Hayet Khansur, previously at FAU Erlangen-Nürnberg and now assistant professor in the Department of Materials Science and Engineering at Case Western Reserve University, explains in an email that the genesis of this publication came about from a casual discussion with Angélica María Benítez-Castro, first author and joint Ph.D. student at FAU Erlangen-Nürnberg and CINVESTAV.

"While preparing ceramic samples for her Ph.D. project, Angélica observed that the X-ray diffraction patterns varied significantly depending on the surface finishing quality, such as using 15-micron grinding steps or fine colloidal polishing," Khansur says. "Moreover, the grinding and polishing-induced effects could not be minimized even after heating the samples above 600°C for more than four hours."

"This effect was particularly pronounced in samples with an average cubic structure in their as-processed states," he continues. "Based on this initial observation, she began developing and exploring further experimental steps to investigate this phenomenon."

Benítez-Castro worked with several professors as well as university technicians to develop and test some hypotheses that could explain the phenomenon. In an email, she gives a special thanks to Eva Springer, a technician at FAU Erlangen-Nürnberg, who helped her assure reproducibility of the experiments.

The results of these efforts are reported in the recent paper, which uses the polycrystalline piezoceramic sodium bismuth titanate–barium titanate (NBT–6BT) as a model system.

The authors drew two main conclusions about ferroelectric and piezoelectric sample preparation from this experiment:

Rough grinding induces new secondary phases: While grinding was supposed to help remove the sintering-induced chemical changes on the NBT–6BT surface, rough grinding with 15 μm-grit silicon carbide abrasive paper instead resulted in the formation of new secondary phases. Specifically,

- Rough grinding increased the propensity of the chemically changed surface to degrade into a bismuth-rich phase with a pyrochlore structure within the outermost portion of the surface (~1.13 μm).
- Rough grinding triggered a relaxor-to-ferroelectric phase transition, resulting in the formation of a phase-modulated structure that extended about 24 μm into the surface.

The authors attribute the formation of these phases to a combination of factors, including frictional force, local heating, and cooling media. However, further polishing with fine-grained diamond suspensions (9, 6, 3, and 1 μm) helped smooth out the mechanically induced damage and reveal the pseudocubic phase of the unmodified NBT–6BT.

Roughly polished surfaces are less stable than finely polished surfaces: Comparison of X-ray diffraction patterns for roughly and finely polished NBT–6BT samples were notably different, which the authors argue provide insight into the phase stability of the samples' respective surfaces. Specifically, "The [roughly polished] 15 μm samples exhibited the formation of secondary phases when subjected to O_2 and N_2 environments, while [finely polished] OP-S showed a small trace of a new formed phase in N_2 only, inferring that the 15 μm crystal structure appears to be more unstable," they write.

Considering these findings, scientists should pay closer attention to their sample preparation methodologies so it "mitigates the surface damage and reveals intrinsic properties, thereby enhancing structural stability," the authors conclude.

The paper, published in *Ceramics International*, is "Mechanically induced surface damage and resulting thermal instability in polycrystalline $0.94Na_{1/2}Bi_{1/2}TiO_3$–$0.06BaTiO_3$" (DOI: 10.1016/j.ceramint.2025.06.175). ■

Materials in the news

New low-temp fuel cell could transform hydrogen power

Kyushu University researchers developed scandium-doped oxide materials that enable efficient proton transport at just 300°C. Currently, solid oxide fuel cells require extremely high temperatures of around 700-800°C to function properly. This innovation overcomes the long-standing trade-off between adding more dopants and maintaining fast ion movement, providing a promising path toward affordable, intermediate-temperature solid oxide fuel cells. For more information, visit https://www.kyushu-u.ac.jp/en/researches/view/346.

X-rays reveal how intense lasers tear buckyballs apart

Researchers led by Max Planck Institute for Nuclear Physics and Max Planck Institute for the Physics of Complex Systems used intense X-rays to capture a buckminsterfullerene molecule as it expanded, split, and shed electrons under strong laser fields. Detailed scattering measurements showed how the molecule behaves at low, medium, and high laser intensities. Notably, some predicted oscillations never appeared, pointing to missing physics in current models. For more information, visit https://www.mpi-hd.mpg.de/mpi/en/public-relations/news.

3D-printed glass photonic crystals achieve nearly 100% visual light reflectance

A team of researchers from China, Denmark, and Singapore successfully fabricated glass structures with periodicities as small as 260 nm using two-photon polymerization. These structures, in addition to demonstrating an advancement in submicroscale glass processing, also exhibited breakthrough nanoscale light manipulation properties.

An organic–inorganic hybrid resin dubbed Glass-Nano, created by the authors, was the basis for this innovation. The resin contains an acryloxy-propyl polyoctahedral silsesquioxanes cage mixture as the silicon precursor. The multibranched acrylate groups in this mixture can be directly polymerized, dispersing the silicon elements throughout the polymer structure upon curing.

Two cross-linkers were also added to the resin: bisphenol A ethoxylate diacrylate, to increase the refractive index, and pentaerythritol triacrylate, to promote polymerization and enhance the mechanical properties of the printed structures. Toluene was used as a solvent to dissolve the polymerization initiator.

Two-photon polymerization of the resin resulted in glass photonic crystals with a low refractive index. The structures were then sintered in air at 650°C to remove all the organic components and convert the remaining material into silica glass.

Sintering resulted in an about 4.9-fold reduction per linear dimension and about 118-fold shrinkage in volume. This heat-induced shrinkage allowed for the submicroscale dimensions to be achieved while retaining high resolution of the printed structures.

Optical testing of the 3D-printed glass photonic crystals showed that they exhibit nearly 100% reflectance in the visible spectrum, depending on the size of the features, which is much higher than the reflectance typically observed from similar structures in low–refractive index materials. Achieving such a high reflectance was possible thanks to both the large number of repeat units (>20) and extremely high degree of structural uniformity that this fabrication method and novel hybrid resin allow.

The open-access paper, published in *Science Advances*, is "Nanoscale 3D printing of glass photonic crystals with near-unity reflectance in the visible spectrum" (DOI: 10.1126/sciadv.adv0267). ■

Engineered imperfections supercharge graphene's power

Researchers from the University of Nottingham, the University of Warwick, and Diamond Light Source developed a graphene synthesis technique that deliberately incorporates structural defects to enhance performance. Their single-step approach uses a molecule called azupyrene, which has a shape that closely resembles the desired defect type. Adjusting the temperature during the growth phase allowed the researchers to control how many defects appear. For more information, visit https://www.nottingham.ac.uk/news/pressreleases/listing.aspx. ■

Ultrasonication of diazonium salts results in stable water-repellent glass coatings

Researchers led by Curtin University investigated a novel coating method for water-repellent glass based on diazonium salts.

Hydrophobic windshield coatings typically are created using a dual-layer sol-gel process. This process involves the chemical reaction of alkoxysilanes with water, which results in the formation of fluorinated silanes and other organic molecules. The Si–O–Si bonds in these molecules provide the coating's water-repellent properties, but they are also susceptible to hydrolysis (reactions with water) under certain conditions. If these molecules undergo hydrolysis, the water-repellent properties can diminish and lead to degradation of the coating over time.

Diazonium salts are high-energy materials that are commonly employed to grow covalently bonded thin films on conductive surfaces. This process involves electrochemical reduction of the diazonium group, generating aryl radicals that react with the surface to form controllable polymeric films.

Traditionally, electrons for the reduction reaction have been supplied using electrodes, an approach that does not work for electrically insulating surfaces, such as glass. So, the authors of the recent study decided to explore using ultrasound-induced cavitation as an alternative electron source.

As they explain in the paper, "Cavitation involves the formation of microbubbles in a liquid under the influence of sound waves. When these bubbles collapse, they generate localized high temperatures and pressures, creating conditions suitable for initiating chemical reactions that are otherwise difficult to achieve."

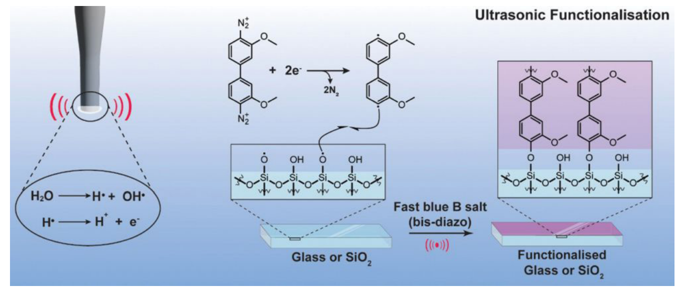
For example, water splitting may be triggered by the bubble collapse, producing hydrogen and hydroxyl radicals. The hydrogen radicals can be spontaneously reduced to protons, "which may serve as a source of electrons for reducing diazonium salts," the authors write.

They attempted this ultrasound-driven reduction of diazonium salts on soda lime silicate glass surfaces. The process resulted in the formation of a thin organic polymeric film on the glass surface, which was bonded via Si–O–C bonds rather than the more hydrolysis-prone Si–O–Si bonds seen in the sol-gel approach.

Because of the more stable bonding structure, this water-repellent coating is "ideal for real-world applications where reliability and durability are key…[such as] clearer windshields in heavy rain, self-cleaning skyscraper windows, and solar panels that stay dust-free," says first author Tiexin Li, research associate at Curtin University, in a press release.

In addition, the researchers discovered an unexpected benefit of the modified glass beyond its water-repellent properties—the ability to attract bacteria, fungi, and algae.

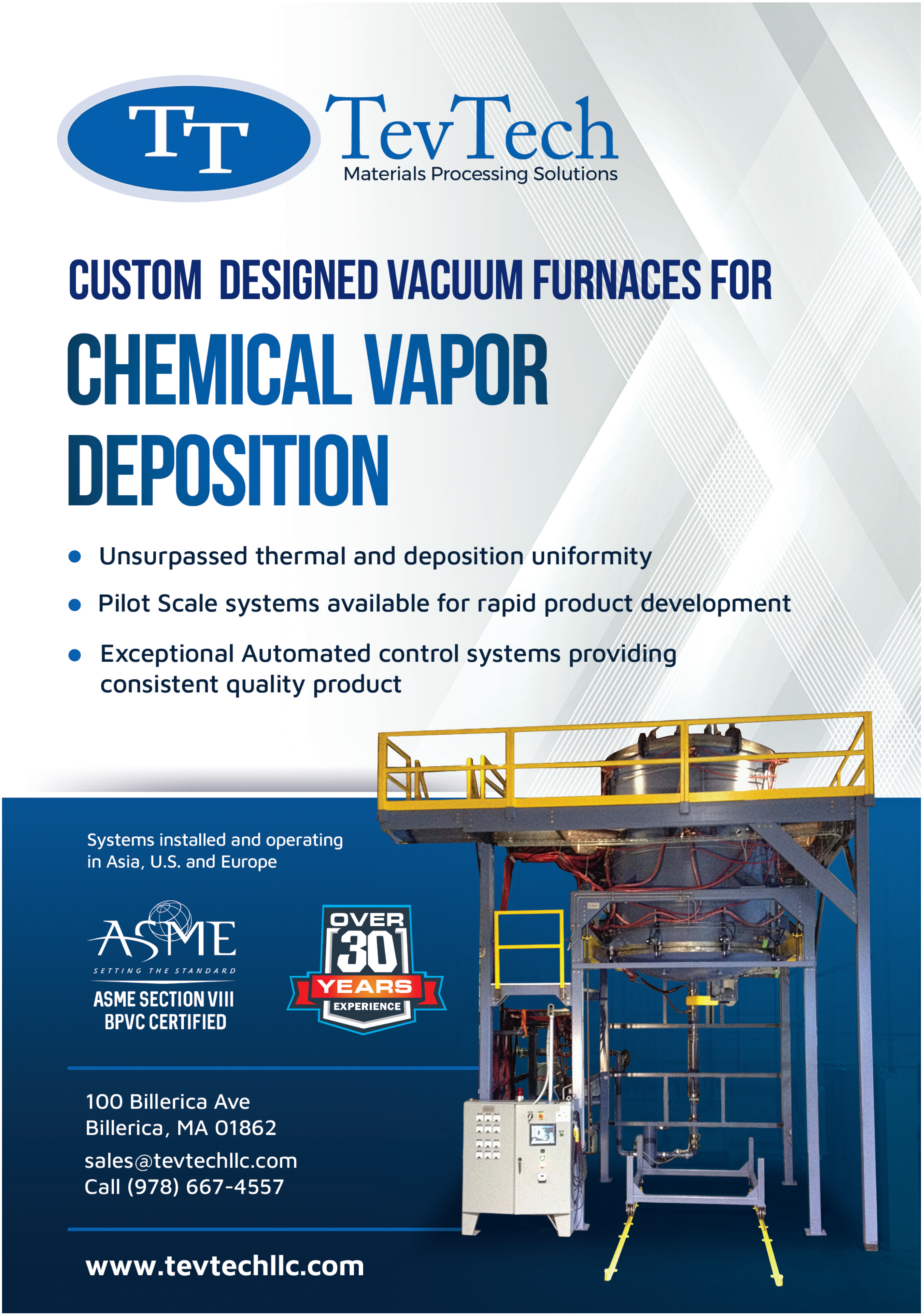
"This [behavior] is very exciting as we can tailor glass properties for specific uses … For example, the coated glass can help bind yeast in brewing, capture bacteria in wastewater filtration systems, or act as a chemical barrier to microorganisms in air filters," says second author Zane Datson, faculty member in the School of Molecular and Life Sciences at Curtin University, in the press release.

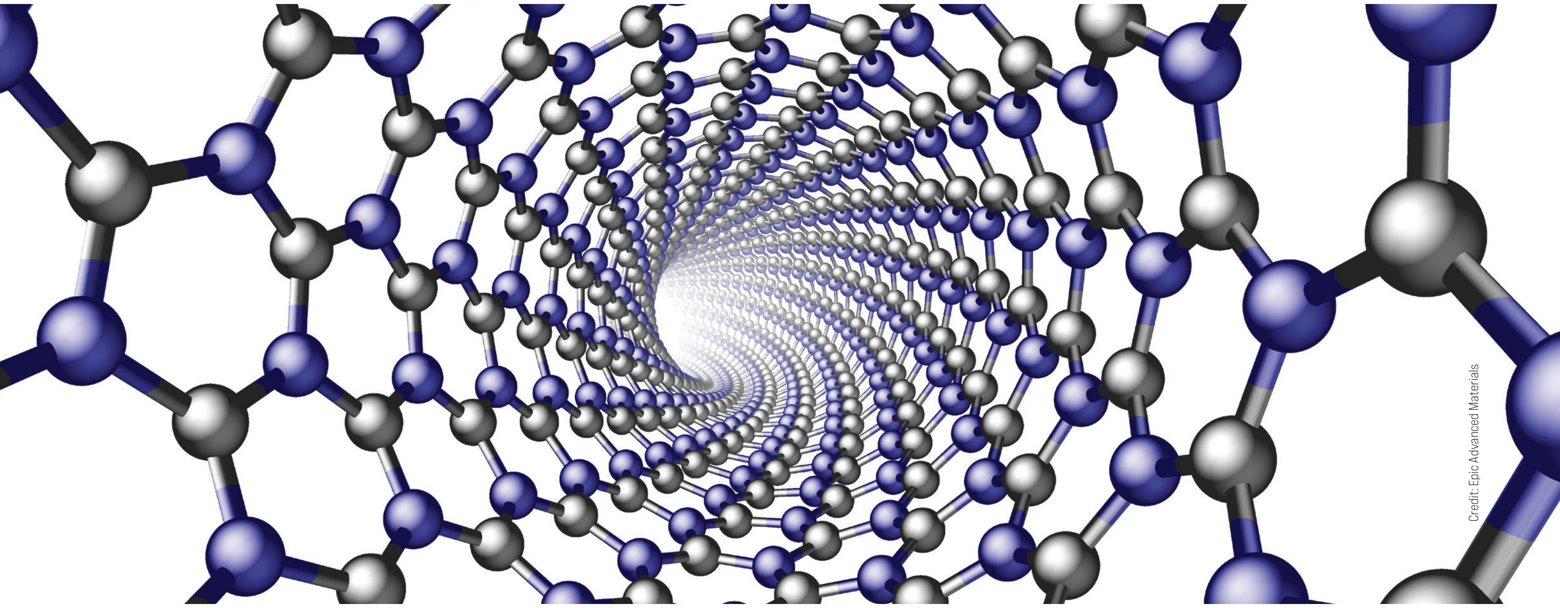


Schematic of the ultrasonic fabrication of diazonium films on glass.

The researchers are now seeking industry partners to test and scale up the technology, particularly in the automotive, construction, and environmental sectors.

The open-access paper, published in *Advanced Functional Materials*, is "Sonochemical functionalization of glass" (DOI: 10.1002/adfm.202420485). ■


TT
TevTech
Materials Processing Solutions
CUSTOM DESIGNED VACUUM FURNACES FOR
CHEMICAL VAPOR DEPOSITION
• Unsurpassed thermal and deposition uniformity
• Pilot Scale systems available for rapid product development
• Exceptional Automated control systems providing consistent quality product
Systems installed and operating in Asia, U.S. and Europe
ASME
SETTING THE STANDARD
ASME SECTION VIII BPVC CERTIFIED
OVER 30 YEARS EXPERIENCE
100 Billerica Ave
Billerica, MA 01862
sales@tevtechllc.com
Call (978) 667-4557
www.tevtechllc.com



Rendering of the atomic structure of boron nitride nanotubes. Blue and grey atoms represent nitrogen and boron, respectively.

Boron nitride nanotubes: Developing the next generation of functional fillers

By Erika Brown, Evan A. Doud, and Carl Aune

The rapid advancement of industrial and technological innovations has demanded simultaneous innovation in the materials landscape to meet these emergent needs. Yet many base materials are already utilized at or near their theoretical performance limits.

To overcome this seemingly immutable barrier, functional fillers have emerged as a promising method to drive innovations in established material systems. Filler materials can modify existing composites to enhance the properties of the overall system thanks to their own exceptional properties, which can include superb mechanical strength, extreme chemical and oxidative resistance, variable thermal conductivity, and tunable electrical conductivity.

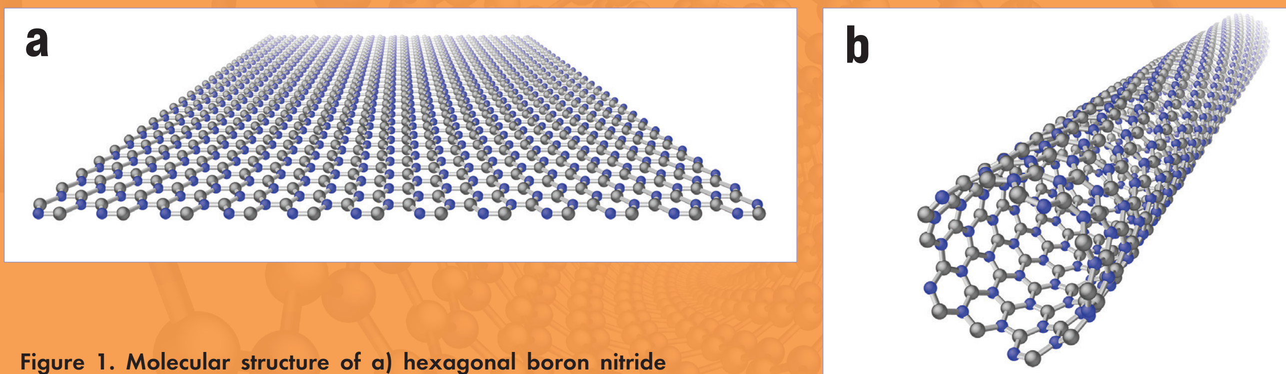
Traditional fillers typically have dimensions on the micrometer scale, including talc, glass fibers, and carbon black. However, many of these microfillers require high loading levels (up to 50 wt.%) and suffer from effects due to interfacial matrix mismatch or decreased matrix interaction.

Nanofillers are an emerging category of filler materials with at least one dimension on the nanometer scale. They are powerful alternatives to microfillers due to their extremely high surface-to-volume ratio, which allows for much stronger interfacial interaction with the matrix material. This improved interaction between filler and matrix leads to significant mechanical, thermal, or barrier property enhancements and are achievable at loading levels of only 1–5 wt.% or lower.

In addition to enhanced properties, the reduced loading level of nanofillers enables retention of many of the desirable properties inherent to the host matrix, such as processability and toughness. These lower loading levels also avoid excessive weight or density increases, which can make the overall material unusable in tailored applications. An additional advantage of the low weight loading is economic—it leads to lightweighting and minimizing cost of the final product while delivering optimized properties for the overall composite material.

The choice of nanofiller depends on the desired balance of mechanical, thermal, electrical, and barrier properties. Currently, several nanofillers are commonly used within the materials industry to create high-performance materials:

- **Graphene** is inherently a 2D nanofiller, as it exists as a sheet structure composed of just one or a few atomic layers.



Credit: Epic Advanced Materials

Figure 1. Molecular structure of a) hexagonal boron nitride and b) boron nitride nanotubes. Blue and grey atoms represent nitrogen and boron, respectively.

Hexagonal boron nitride (hBN) can be exfoliated or synthesized to similar dimensions. Both graphene and hBN offer enhanced mechanical strength and thermal conductivity.

- **Nanoclays**, which are 2D silicate platelets, excel primarily as barrier enhancers that impede gas and liquid permeation and enhance flame retardancy.
- **Metal oxide nanoparticles** are typically 0D, meaning all their physical dimensions are on the nanometer scale. They are utilized for specific functionalities, such as ultraviolet absorption and catalytic or electronic activity.

The 2D platelets and 0D nanoparticles listed above are currently the most common morphologies of nanofillers. However, 1D tubular morphologies, i.e., nanotubes, have emerged as prime candidates for highly functional nanofillers.

Like other nanofillers, 1D tubular morphologies have an extremely high surface-to-volume ratio. But a distinct benefit of 1D nanofillers lies in their balance between high surface area and low effective dosing rates. In other words, a small number of long tubes can bridge the entire matrix, forming a continuous network for electrical current, heat transfer, or mechanical stress transfer more easily than stacked 2D flakes or dispersed 0D spheres.

Evidence of carbon nanotubes (CNTs) has been found in certain historical steels and pottery coatings, but the first intentional synthesis of CNTs was demonstrated by Iijima et al. in 1991.[1] This discovery marked a pivotal moment in nanoscience.

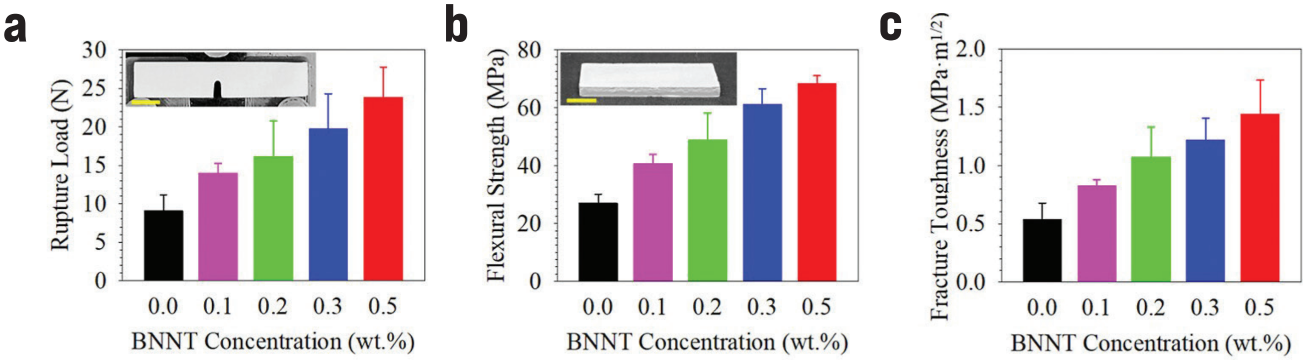
The structure of CNTs is typically described as a 2D graphene nanosheet cut into a ribbon and rolled into a 1D tube. While this description effectively communicates their hexagonal lattice structure, it is misleading because CNTs are typically synthesized from the bottom up using gaseous precursor materials. Structurally, CNTs can be synthesized as either single-walled carbon nanotubes (consisting of a single seamless graphene cylinder) or as multiwalled carbon nanotubes (concentric cylinders of graphene separated by less than 1 nm).

CNTs were initially explored for use in electronics as transistors, a potential application rooted in their electrically conductive properties. Their application remained limited to niche markets for many years, but in the past decade, advancements in synthesis techniques, particularly large-scale chemical vapor deposition and the optimization of metal catalysts, enabled their mass production at a manageable cost. CNTs are now routinely used as nanofillers to create products ranging from electrically conductive plastics in electronics and automotive parts to mechanically reinforced materials in textiles, solar panels, and high-performance sports equipment, resulting in an annual market volume measured in tens of thousands of tons.

Recently, boron nitride nanotubes (BNNTs) have garnered interest as a highly functional nanofiller. Just as the structure of CNTs can be imagined as rolled graphene sheets, the structure of BNNTs can be similarly imagined as rolled nanosheets of hBN (Figure 1), consisting of alternating boron and nitrogen atoms in a hexagonal lattice.[2]

BNNTs were originally synthesized by Chopra at al. in 1995,[3] who predicted their creation based on the structural similarities of graphene and hBN. But even though the initial discovery of BNNTs followed only a few years after CNTs, there has been a distinct difference in the trajectory of scale up and industrial adoption of these materials. The market globally for CNTs has reached tens of thousands of tons annually, while BNNTs are only on the scale of tens of kilograms.

This article will shine a light on the factors driving the growth trajectory of BNNTs and describe the recent breakthroughs that enable BNNTs to now stand at the cusp of transforming the advanced materials landscape.



Credit: Anjum et al., *ACS Appl. Eng. Mater.* (Republished with permission)

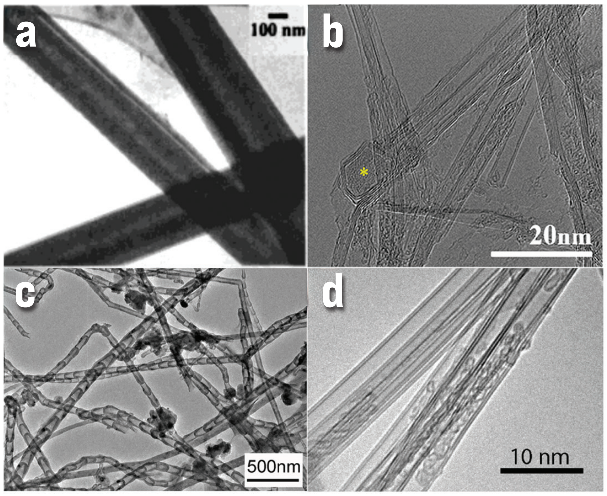
Figure 2. Example of how boron nitride nanotubes at low concentrations can increase the mechanical properties of ceramic matrix composites, in this case a 100% silica ceramic system.[5]

Structure–property relationships of BNNTs

Because of their structural similarity, both BNNTs and CNTs share several key properties. Both have a Young's modulus of more than 1 TPa, making them excellent additives for ceramics and polymers to enhance bulk material mechanical properties.[4] For example, in a 100% silica ceramic matrix system, Anjum et al. showed that mechanical properties could be doubled or tripled through the addition of less than 0.5 wt.% of BNNTs (Figure 2).[5] Similar success with using BNNTs as reinforcing agents has been achieved in other matrix systems.[6]

In contrast to these mechanical similarities, BNNTs and CNTs exhibit significantly different electronic properties. Unlike the purely covalent bonds between the carbon atoms in graphite, graphene, and CNTs, the boron–nitrogen bond in hBN and BNNTs possesses a partial ionic character. This critical chemical difference theoretically promises a fundamentally insulating material, in contrast to the conductive nature of CNTs.[4]

Furthermore, while the chirality angle of a CNT dictates its electronic properties (either metallic or semiconducting depending on the specific atomic symmetry), the theoretical expectation for BNNTs was that it would serve as a robust electrical insulator regardless of the tube's chirality or geometric dimensions.



Credit: a) Shelimov and Moskovits, *Chemistry of Materials* (Republished with permission); b) Kim et al., *Scientific Reports* (CC BY 4.0); c) Li et al., *Nanoscale Research Letters* (CC BY 2.0); d) Fathalizadeh et al., *Nano Letters* (Republished with permission)

Figure 3. Transmission electron microscopy micrographs of different boron nitride nanotube morphologies produced through various methods: a) chemical vapor deposition,[8] b) laser ablation,[9] c) ball milling,[10] and d) thermal plasma.[11]

That expectation was due to the partially ionic bond in BNNTs forcing a wide bandgap, removing any property dependence on the chirality angle. This guaranteed electronic stability was a core scientific driver guiding early BNNT research, as it offered the possibility of a robust nanostructure without the electronic conductivity of CNTs. Many experimental studies have since confirmed these expectations.[7]

BNNT synthesis methods

Early synthesis methods for BNNTs mirrored those from the pioneering phase of CNT research, primarily relying on high-energy techniques, such as arc discharge. While these methods can yield large quantities of high-quality CNTs, synthesizing BNNTs using these methods often results in short tubes with high levels of impurities, such as unreacted precursor materials, nontubular BN structures, and metallic components (which are included as catalysts to contend with the thermally stable and insulative nature of the precursor materials).

Various methods of BNNT synthesis have emerged as research and technology have progressed (Figure 3):[8–14]

Chemical vapor deposition

This widely used method for CNT production has been adapted for BNNTs. It involves introducing volatile precursors (often containing boron and nitrogen, such as borazine) into a reaction chamber where they decompose on a heated substrate. Metal catalyst nanoparticles on the substrate act as nucleation points for tube growth. The main differences between chemical vapor deposition and other methods are the former's reliance on a catalyst and substrate for controlled growth. The need for a catalyst leads to challenges in purifying the final BNNT product, as trace metals can impact the electrically insulating properties.

Laser ablation/evaporation

This high-energy technique uses an intense pulsed laser beam to instantaneously vaporize a solid target (typically hBN or a boron metal mixture). The resulting boron and nitrogen vapor condenses in a relatively cool, inert gas environment to form nanotubes. The rapid and extreme conditions lead to a product with high crystallinity and structural quality. This technique has a low yield, which is fine for fundamental research needing small batches of high-purity material but challenging for industrial scale-up due to the intense energy and slow kinetics of tube formation.

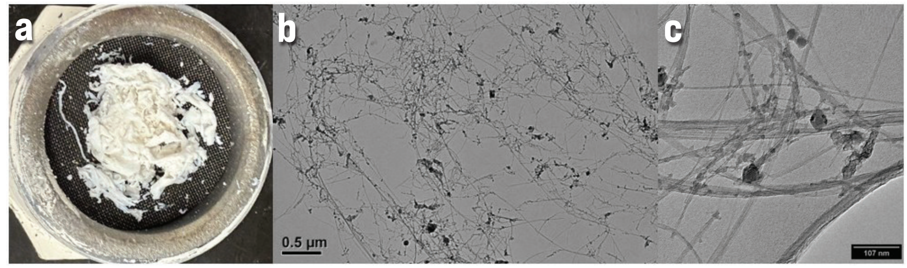
Ball milling and annealing

This two-step synthesis process starts with mechanical processing. High-energy ball milling grinds hBN powder into nanosized fragments with structural defects. These fragments are then subjected to a high-temperature annealing step (within a furnace) so the boron and nitrogen atoms can reorganize into tube structures. This method is often the simplest and lowest-cost approach. However, it can produce BNNTs that are short, with a higher rate of surface defects, and with a wide distribution of diameters because the initial fragmentation is less controlled than other methods.

Thermal plasma methods

These methods are the most promising for large-scale commercialization. They involve injecting precursors into an extremely hot plasma torch (often generated by an inductive coil). The plasma, reaching temperatures of 5,700°C or higher, rapidly dissociates the precursors into highly reactive boron and nitrogen species, which then quickly reassociate and cool to form long, high-quality BNNTs. This method can have high energy requirements and can leave unreacted feedstock, which requires purification.

Of these methods, a thermal plasma technique called enhanced pressure inductively coupled plasma shows significant promise for overcoming many of the limitations traditionally faced in BNNT production (Figure 4). This technique, which was originally developed at Lawrence Berkeley National Laboratory and is currently licensed and practiced by Epic Advanced Materials, does not use a metal catalyst.[15] So, purification of the plasma-generated BNNTs can result in higher yields of quality tubes, as the processes used to remove metal impurities are often harsh and can generate defects in the nanotubes. Furthermore, this method has been developed to offer high production rates with aspect ratios of more than 2,000:1. Such high production rates offer the possibility of expansion into commercial uses for these materials, which have traditionally been limited to research applications due to their low rates of production.



Credit: Epic Advanced Materials

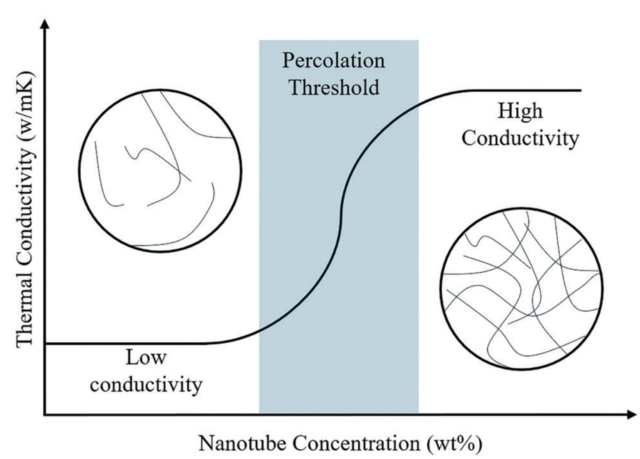
Figure 4. (a) Image of bulk boron nitride nanotube material from Epic Advanced Materials. (b,c) Transmission electron microscopy image showing boron nitride nanotube structure as well as the presence of some impurities of boron and hBN.

Applications for BNNT fillers

Thermal interface materials (TIMs) are crucial for effective thermal management in electronics; however, the base polymer or grease matrices inherently suffer from poor thermal conductivity. Fillers are essential to boost heat transfer by creating continuous pathways of high thermal conductivity materials to facilitate heat flow.

The ideal filler particles for TIMs optimize the balance between achieving extremely high thermal conductivity, maintaining necessary electrical insulation, and ensuring sufficient mechanical performance. Metallic particle fillers can often lead to reduced dielectric properties undesirable for many applications and are electrically conductive, which risks short circuits. On the other hand, many existing ceramic thermal management fillers require high loading levels (from 20–50 wt.%) to achieve improvements in thermal properties, which can affect the cost, weight, and viscosity of the TIM material. So, while the resultant composite may obtain effective heat transfer properties, it can result in significant negative alteration of the original properties (e.g., Young's modulus, tensile strength) of the matrix materials. Carbon-based fillers (e.g., graphene, CNTs) offer exceptional conductivity and light weight but are usually electrically conductive; they also face challenges with poor dispersion and high cost. Ultimately, the primary challenge is the trade-off: Materials with the highest thermal conductivity are often also electrically conductive, while maintaining electrical safety forces a reliance on less conductive ceramics.

Due to their high aspect ratio, nanotubes typically have a low percolation threshold, i.e., the additive percentage at which a large change in the thermal or electrical conductivity of the bulk material is observed. As seen in Figure 5, percolation is dependent on both the concentration of particles within a matrix as well as the aspect ratio of the particles. While spherical particles can eventually form a percolation network, they require



Credit: Epic Advanced Materials

Figure 5. Percolation occurs as a network of interconnected particles forms within the matrix. Controlling the particle aspect ratio and loading allows for tunable thermal properties.

far higher concentrations than particles that are elongated. Nanotubes are essentially 1D structures, with their length orders of magnitude larger than their width, leading to bridging between networks of particles at low loadings. The low percolation threshold allows for selective tuning of thermal properties in nanotube systems while benefiting from improved mechanical properties.

Percolation in composite systems with an aspect ratio of 2,000:1 typically occurs at 1–3 wt.% additive concentration. If particles are added at a lower concentration, minimal effect on the thermal conductivity is observed. For higher loading levels, significant improvements in thermal conductivity and decreases in the coefficient of thermal expansion can be achieved.

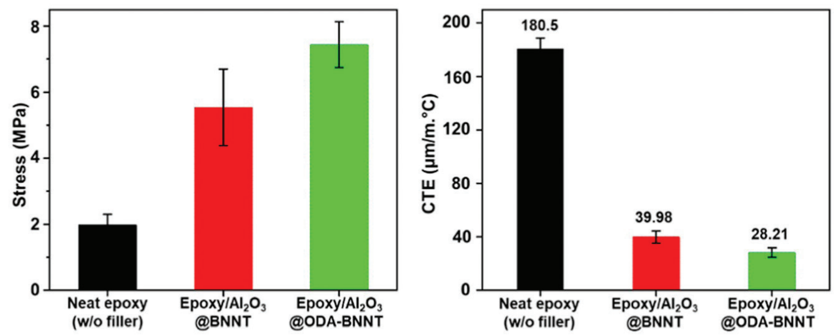


Figure 6. Hybrid filler strategies, such as modifying alumina particles with protruding boron nitride nanotubes, provide additional benefits in thermal conductivity and coefficient of thermal expansion.[16]

To overcome the traditional trade-off between thermal and mechanical properties, researchers frequently employ hybrid filler strategies, combining particles of different shapes or sizes to create a more robust, highly conductive 3D network at a lower required loading percentage. For example, Hanif et al. modified alumina particles to include BNNTs protruding from the surface of the ceramic particles.[16] Adding BNNTs at loading levels of just 1 wt.% yielded enhancement over the effect of ceramic additive systems, increasing thermal conductivity and decreasing the coefficient of thermal expansion (Figure 6).

The integration of BNNTs into ceramic and composite systems can also enhance their ablation resistance due to the inherent high thermal stability and chemically nonreactive behavior of BNNTs in high-temperature, oxidizing environments. BNNTs can resist oxidation in air at temperatures of more than 850°C (CNTs only resist oxidation up to about 400°C). In a system of hybrid composite materials, Reyes et al. showed that BNNTs enhanced the survivability of the composites under exposure to a hot jet test.[17] Weight loss was lowered by 14% and the flexural modulus was increased by 55%. In addition, the formation of crystalline oxides was observed, likely serving as a protective layer that shields the underlying material from the flame's direct heat and erosive forces.

Advanced technological applications have also benefited from BNNT fillers. For example, early interest in BNNT technology was led by NASA research on applications in aerospace and extreme environments.[18] Boron has an exceptionally high neutron capture cross section owing to the significant percentage of boron-10 present, whose nucleus can readily accept a neutron. The ability of BNNTs to absorb neutron radiation, combined with high thermal oxidative stability and mechanical strength, makes them ideal materials for certain aerospace applications, suchc as spacesuits and spacecraft. BNNTs also show superior performance in hydrogen storage, exhibiting enhanced binding strength at ambient temperature compared to CNTs, which is crucial for advancing clean energy applications.[19]

In the biomedical field, BNNT's low reactivity and lack of cytotoxic properties make them suitable platforms for applications such as drug delivery, gene delivery, and neutron capture therapy; they also show potential for enhancing the properties of implants and dental resins. The catalyst-free synthesis of pressurized vapor/condenser BNNTs is particularly important for these biomedical uses, eliminating trace metal concerns introduced by the catalysts. In a National Institute of Health study, the addition of BNNTs to dental resin increased the compression strength of the composite by 46% and improved interfacial bonding and fracture resistance.[20] In another study, Bohns et al. showed that the addition of BNNTs to dental sealants improved therapeutic bioactivity.[21]

Challenges and solutions to BNNT adoption

Based on the positive results reported in the literature and the ongoing improvements to production rates, it seems a foregone conclusion that BNNTs will spread in popularity and utility within industry. But another challenge remains before BNNTs can be widely used in large-scale production: They must be fully dispersed in a manner that preserves their high aspect ratios and avoids agglomeration or flocculation of the particles.

While their chemical nonreactivity and hydro- and oleophobic properties are a boon as an additive, these properties also complicate the dispersal of BNNTs into a variety of mediums. Unless care is taken to optimize the surface energies between the nanoparticles and the matrix, the tubes can tend toward states that minimize the energy difference. This behavior will cause agglomeration of the particles into bundles, or worse, the tubes can curl in on themselves, preferring to interact with the surface of other tubes preferentially over the matrix material.

In the former case, properties can still be imparted to the composite, but the effective mass fraction of the nanotubes will appear lower, as the tubes will operate in bundles rather than individualized particles. For the latter, much of the benefit of the particles will be lost as their aspect ratio decreases significantly. These challenges with dispersion may explain some of the wide ranges of tube fractions reported throughout literature, as poorly dispersed tubes will require a higher dosing rate to obtain target material properties.

Poor dispersibility and matrix mismatch are not challenges unique to BNNTs. Many filler materials, whether they are nano-, micro-, or macroscale, suffer from these challenges, which results in poor performance of the overall composite.

One way to combat these limitations is to provide additional surface functionalization to the filler material. This strategy incorporates chemistries or other modifications to increase compatibility with the host matrix system, thus increasing dispersibility and positive matrix interactions within the composite.

Functionalization of a filler material is most often achieved through a chemical reaction to covalently bond other groups to the filler's surface or through the reliance on noncovalent interactions to closely associate other materials to the filler's surface. In the case of BNNTs, the boron–nitrogen bond can be cleaved to produce reactive boron and nitrogen sites that can undergo further chemical treatment, resulting in covalent linkages to groups or materials that can enhance matrix interactions. The partial ionic nature of the boron–nitrogen bond as well as the electronic orbital structure can similarly be leveraged to noncovalently bind chemical species that also induce positive matrix interactions.

A new era of fundamental functional fillers

BNNTs are at the cusp of transforming the advanced materials landscape, offering a compelling blend of properties that surpass the limitations of conventional fillers and even their structural analog, CNTs. While synthesis and scale-up challenges have slowed their commercial adoption compared to the meteoric rise of CNTs, recent breakthroughs—notably the development of high-aspect-ratio, catalyst-free plasma production methods such as those at Epic Advanced Materials—are rapidly closing this gap, enabling large-scale availability.

As production scales and costs fall, BNNTs are poised to move beyond niche research applications to become a mainstream filler driving the next generation of lightweight, multifunctional, and high-stability composite materials.

About the authors

Erika Brown, Evan A. Doud, and Carl Aune are director of product development, lead research chemist, and director of business development, respectively, at Epic Advanced Materials (Thousand Oaks, Calif.). Contact Aune at carl.aune@epicbnnt.com.

References

[1]S. Iijima, "Helical microtubules of graphitic carbon," *Nature* 1991, **354**: 56–58.

[2]J. Zhang et al., "Atomically thin hexagonal boron nitride and its heterostructures," *Advanced Materials* 2021, **33**(6): 2000769.

[3]N. G. Chopra et al., "Boron nitride nanotubes," *Science* 1995, **269**(5226): 966–967.

[4]L. Liu, Y. P. Feng, and Z. X. Shen, "Structural and electronic properties of h-BN," *Physical Review* B 2003, **68**(10): 104102.

[5]N. Anjum et al. "Boron nitride nanotubes toughen silica ceramics," *ACS Appl. Eng. Mater.* 2024, **2**(3): 735–746.

[6]W.-L. Wang et al., "Microstructure and mechanical properties of alumina ceramics reinforced by boron nitride nanotubes," *J. Eur. Ceram. Soc.* 2011, **31**(13): 2277– 2284.

[7]J.-W. Ren et al., "Core-shell engineered boron nitride nanotubes for enhancing dielectric properties of epoxy composites," *Materials & Design* 2025, **253**: 113942.

EPIC™ ADVANCED MATERIALS: Founding and future goals

Epic Advanced Materials, founded in 2019 in Thousand Oaks, Calif., is an advanced manufacturing company specializing in nanomaterials, with a focus on boron nitride nanotubes (BNNTs) and ultrahigh-temperature ceramics. The company leverages proprietary artificial intelligence-driven synthesis and process optimization to scale production of high-performance nanomaterials. Its BNNT products, known for exceptional thermal stability and electrical insulation, serve as additives across aerospace, defense, electronics, and composite applications to enhance durability, strength, and overall material performance. ■

[8]K. B. Shelimov and M. Moskovits, "Composite nanostructures based on template-grown boron nitride nanotubules," *Chemistry of Materials* 2000, **12**(1): 250–254.

[9]J. H. Kim et al., "Dual growth mode of boron nitride nanotubes in high temperature pressure laser ablation," *Scientific Reports* 2019, **9**: 15674.

[10]L. Li et al., "Mechanically activated catalyst mixing for high-yield boron nitride nanotube growth," *Nanoscale Research Letters* 2012, **7**: 417.

[11]A. Fathalizadeh et al., "Scaled synthesis of boron nitride nanotubes, nanoribbons, and nanococoons using direct feedstock injection into an extended-pressure, inductively-coupled thermal plasma," *Nano Letters* 2014, **14**(8), 4881–4886.

[12]J. J. Velázquez-Salazar et al., "Synthesis and state of art characterization of BN bamboo-like nanotubes: Evidence of a root growth mechanism catalyzed by Fe," *Chemical Physics Letters* 2005, **416**(4–6): 342–348.

[13]T. Xu et al., "Advances in synthesis and applications of boron nitride nanotubes: A review," *Chemical Engineering Journal* 2022, **431**(3): 134118.

[14]S. Kalay et al., "Synthesis of boron nitride nanotubes and their applications," *Beilstein Journal of Nanotechnology* 2015, **6**(1): 84–102.

[15]"Method and device to synthesize boron nitride nanotubes and related nanoparticles," United States Patent US9394632B2. Granted 19 July 2016. https://patents.google.com/patent/US9394632

[16]Z. Hanif et al., "Protruding boron nitride nanotubes on the Al_2O_3 surface enabled by tannic acid-assisted modification to fabricate a thermal conductive epoxy/Al_2O_3 composite," *ACS Omega* 2024, **9**(37): 38946–38956.

[17]A. N. Reyes et al., "Supersonic hot jet ablative testing and analysis of boron nitride nanotube hybrid composites," *Composites Part B: Engineering* 2024, **284**: 111684.

[18]A. L. Tiano et al., "Boron nitride nanotube: Synthesis and applications," *Proceedings of SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring* 2014, **9060**: 906006.

[19]J. FN Dethan et al., "Deformation behaviors of hydrogen filled boron nitride and boron nitride - carbon nanotubes: Molecular dynamics simulations of proposed materials for hydrogen storage, gas sensing, and radiation shielding," *International Journal of Hydrogen Energy* 2024, **57**: 746–758.

[20]M. Patadia et al., "Enhancing the performance of dental composites with nanomaterial reinforcements via stereolithographic additive manufacturing," *Discover Nano* 2025, **20**(1): 149.

[21]F. R. Bohns et al., "Boron nitride nanotubes as filler for resin-based dental sealants," *Scientific Reports* 2019, **9**: 7710.

*All references verified as of Nov. 13, 2025. ■

Credit: Pixel Enforcer / Shutterstock

From discovery to design: Evolution of piezoceramic fabrication methods for application-specific performance

By Ender Suvacı, Nesli Yürük, Victor Tinti, Jason Nikkel, Rasmus Lou-Moeller, Claire Bantignies, and Thomas Kelley

In 1880, Jacques and Pierre Curie discovered that applying pressure to certain crystals such as quartz, zinc blende (sphalerite), and tourmaline can generate an electric charge.[1] By the 1910s, this phenomenon—called piezoelectricity—was widely recognized as an intrinsic property of some solids.

The term "piezoelectricity" is derived from the Greek word *piezein*, meaning "to press," and refers to the generation of electricity in response to mechanical stress.[1] In the early 1940s, barium titanate ($BaTiO_3$, or BT) was identified as the first perovskite material to demonstrate piezoelectricity, exhibiting a piezoelectric coefficient (d_{33}) of 86 pC/N. By the 1950s, lead-based piezoelectric materials, typically lead zirconate titanate (PZT), became widely used due to their high piezoelectric coefficients (d_{33} of about 600 pC/N for PZT).[2]

Also in the 1950s, reports on alkaline niobates, such as $(K_{0.5}Na_{0.5})NbO_3$ (KNN), identified them as another class of lead-free materials besides BT. They were not widely studied at the time due to PZT's superior performance, but increasing concerns about lead's toxicity in the mid-20th century shifted focus to the development of lead-free piezoelectric materials.

The work of Jaeger and Egerton in 1962 is often cited as the start of the specific effort to find a PZT replacement,[3] and it was built on earlier foundational materials such as BT and KNN. But a major resurgence and fueling of interest in lead-free piezoceramics came later with a highly impactful paper by Saito et al. in 2004,[4] which demonstrated that a combination of compositional and microstructural design could yield lead-free piezoceramics with properties comparable to PZT (d_{33} up to 416 pC/N for textured KNN piezoceramics).

As this brief history demonstrates, there has been a shift in the field of piezoelectricity regarding how piezoelectric materials are discovered and designed. Historically, advancements relied heavily on serendipitous material discoveries and empirical optimization. But recent developments use computational modeling, high-throughput synthesis, and advanced characterization techniques to design materials with specific properties.

This paradigm shift enables researchers to bypass lengthy trial-and-error processes, thereby accelerating the development of novel piezoelectric materials with enhanced performance for specific applications, such as high-sensitivity sensors or high-power transducers. Accordingly, this article aims to provide an overview of the evolution of piezoceramics and piezoceramic fabrication methods for application-specific performance.

Piezoceramic composition, powder synthesis, and crystal texture

Classic piezoceramic materials

Classic piezoceramics are typically lead based and are widely employed in sensor, actuator, and transducer applications. PZT is the most popular piezoceramic due to its high electromechanical coupling factor, high Curie temperature, and wide range of dielectric constants, as well as its ease of fabrication.

Despite their popularity, the manufacturing and use of lead-based systems are hazardous to both human health and the environment. Although the European Union's Restriction on Hazardous Substances (RoHS) directive restricts the use of lead in many applications, piezoceramics currently are exempt. However, if a lead-free piezoceramic device is developed that demonstrates comparable performance to PZT-based systems, RoHS regulations may be extended to restrict the use of lead in piezoceramics as well.

As noted in the introduction, barium titanate was discovered in the early 1940s. Although it exhibits a relatively low piezoelectric coefficient and Curie temperature ($T_c \approx 120°C$), manufacturers prefer BT for capacitor applications because of its high permittivity, reasonable electromechanical coupling coefficients, and simple processing.[5]

Potassium sodium niobate-based piezoceramics are considered promising candidates to replace PZT due to their comparable piezoelectric properties to lead-based systems and considerable electromechanical coupling factors. But currently, their performance remains below that of PZT for some applications.[5]

Sodium bismuth titanate-based piezoceramics have also gained attention due to their large remnant polarization ($P_r \approx 38\ \mu C/cm^2$). Nevertheless, they present certain drawbacks, for example, they are difficult to polarize due to high electrical conductivity and a large coercive field.[5]

Advances in powder synthesis

Several methods are used to produce piezoceramic powders, namely solid-state reactions, sol–gel processes, co-precipitation, and hydrothermal/solvothermal methods.

Solid-state processing is the most widely used method due to its relative simplicity, scalability, and inexpensive nature. But this approach requires high sintering temperatures and may cause stoichiometric deviations due to elemental evaporation.

The sol–gel process is another widely used route for producing ABO_3-type perovskite structures. In this wet-chemical method, a colloidal or polymeric solution is first formed and then transformed into a gel, which contains both liquid and solid phases. This multiphase medium enables effective microstructural control. Nevertheless, major drawbacks of the sol–gel process are limited scalability and high cost of precursors.

Co-precipitation is another wet-chemical method. In this approach, liquid precursors are mixed in stoichiometric proportions and then reacted with chemical agents, such as hydroxides and oxalates, to form precipitates. This method is advantageous because it can be used to produce ultrafine homogenous particles, as well as reduce the sintering temperature and improve the electrical properties of the final product.[5] But one major drawback is that the ultrafine particles formed during precipitation tend to agglomerate or aggregate. Also, in most cases, the precipitating phase needs to be calcined to obtain the target phase. This calcination step makes particle shape and size control very difficult, particularly for nanosized particles.

Hydrothermal and solvothermal methods are also important synthesis routes. Both techniques involve reactions in an autoclave under high vapor pressure, using precursors that are soluble in the selected solvent. While hydrothermal synthesis is limited to aqueous solutions, solvothermal synthesis can be performed in any solvent system. Both methods enable the production of dense and homogenous ceramics at lower sintering temperatures, as well as control over particle size and morphology. However, it can be difficult to control the phase purity of complex compositions, such KNN.[5]

Compositional tuning: MPB and dopants

Adjusting the piezoceramic's chemical composition is one of the most effective ways to improve its electrical, mechanical, and thermal properties, as it allows precise control over both the crystal structure and the microstructure. Two main strategies for compositional tuning are generally used: creating morphotropic phase boundaries (MPB) and adding dopants.

The MPB is a special composition region where two different crystal phases, such as rhombohedral and tetragonal, coexist in equivalent free energies. At this boundary, the variation in crystal symmetry allows for more polarization directions and subsequently easier dipole reorientation, resulting in a higher piezoelectric response. In PZT, an MPB occurs near the 52:48 zirconium:titanium ratio, leading to the maximum piezoelectric coefficient.

In contrast to MPB, dopants are foreign ions added in small amounts to modify the sintering behavior, microstructure, and electrical properties of the host material. For instance, copper oxide lowers the sintering temperature of KNN and improves density, while lithium ions fill A-site vacancies and increase the piezoelectric coefficient. Combining MPB design with proper dopant addition is an effective strategy to optimize piezoelectric ceramics for specific applications.[5]

Texturing techniques for enhanced properties

The electrical properties of piezoceramics depend on their crystallographic orientation. Single-crystal materials exhibit high anisotropy, i.e., directionally dependent properties, due to their homogeneous crystal structure. On the other hand, the usually random orientation of grains in polycrystalline materials leads to lower electrical performance compared to single crystals. Single-crystal structures are difficult and expensive to produce, however, making them impractical for industrial-scale applications.[6]

To reproduce the direction-dependent properties of single crystals in polycrystalline materials, researchers developed the method of crystallographic texturing to engineer anisotropy. In this method, grains in polycrystalline materials are oriented along specific crystallographic planes to achieve the desired properties based on application requirements.

Textured ceramics can be prepared by the templated grain growth (TGG) method, which involves adding seed or template particles into a fine-grained matrix (Figure 1). During sintering, these template particles grow preferentially and promote texture formation. At first, the templates are randomly distributed, but they align during the forming process, such as tape casting.[7]

The growth of template particles depends on their thermal and crystallographic compatibility with the matrix. For effective texture formation, the template particles and the matrix should have similar crystal structures, and the lattice mismatch

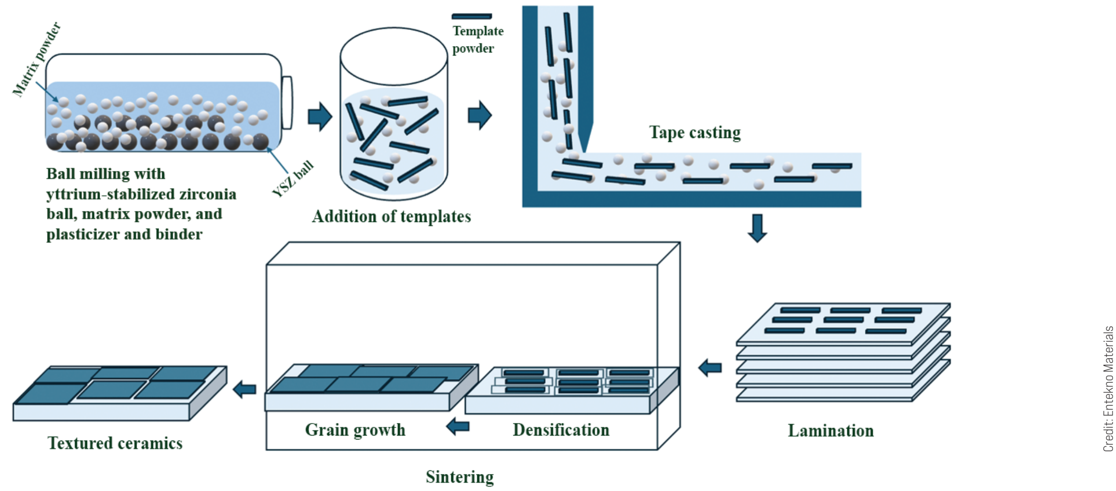


Figure 1. Schematic showing how textured ceramics are manufactured via a templated grain growth process.

between them should be less than 15%. The template particles should also have a suitable shape and aspect ratio, such as whisker, blade, or platelet forms, so that they can be aligned under shear forces during forming.

Reactive templated grain growth (RTGG) is a modified version of the TGG process. In this method, template particles are added to a matrix composed of complementary reactant precursor powders. During high-temperature processing, the matrix powders undergo an in-situ chemical reaction, and the final ceramic phase nucleates and grows epitaxially directly onto the surfaces of the prealigned, reactive template particles. The desired texture is thus developed simultaneously with the formation of the bulk phase.

To determine the degree of texture and texture quality of the textured ceramic, different techniques including the XRD-based Lotgering factor and pole diagrams, scanning electron or transmission electron microscope-based orientation imaging microscopy, and stereology can be used (Figure 2). Among these methods, the Lotgering factor is most commonly used because it relates the degree of texture to the intensity of specific diffraction peaks. However, other techniques should be used as well to quantify texture quality.

Ultimately, both TGG and RTGG are potentially cost-effective methods for engineering polycrystalline ceramics with single-crystal-like anisotropy, leading to remarkable improvements in piezoelectric and dielectric properties.

Manufacturing evolution: From bulk ceramics to complex architectures

The main convention for industrial manufacturing of bulk ceramic materials is solid-state processing. This method includes stoichiometric solid batching of precursor oxides or carbonates, reacting, spray drying, forming, sintering, and machining to a final bulk component.

Numerous variables can affect and govern each step of this process, leading to nontrivial developmental periods for each. As a result, most developed and commercially available piezoceramics are site specific and are not easily translatable via technology transfer, even between sister sites within individual corporations.

Of these steps, batching, calcination, and sintering are among the most critical. To effectively sinter a ceramic component, first it must be batched to very high stoichiometric precision, sufficiently reacted (calcined), and then pressed into a green ceramic of adequate density. To achieve this process at industrial scale, binding additives are added to the calcined ceramic, spray dried into a free-flowing granular state, and then pressed into compacts, either near net shape of the final component or into a geometry that is readily machinable (cylindrical or rectangular prisms). These compacts are then sintered to densify, react, and coarsen the ceramic. Finally, sintered ceramics can be machined into many conventional geometries, including but not limited to rings, disks, lenses, plates, and wedges.

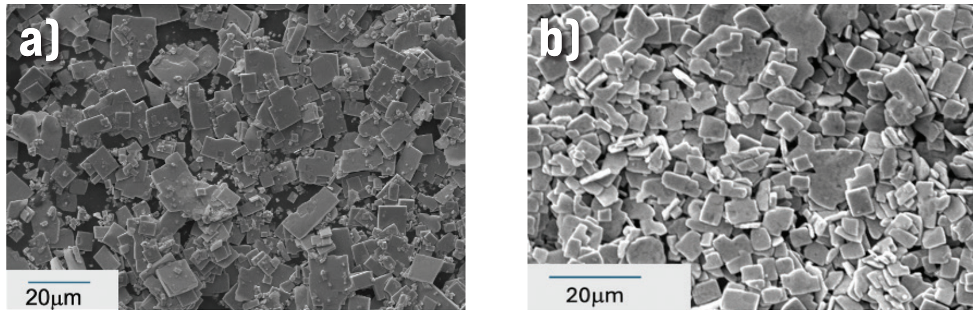
Tape casting: Slurry formation and capabilities

Tape casting remains a cornerstone technique for producing thin, uniform ceramic layers. It begins with the preparation of a well-dispersed slurry containing ceramic powder, organic binders, plasticizers, and solvents.[8] The slurry is cast onto a moving carrier substrate using a doctor blade, forming a continuous green tape with controlled thickness. After drying, these tapes can be laminated and shaped prior to sintering. This method is particularly suited for the mass production of large-area components due to its speed, scalability, and reliability.

Piezoceramic tapes produced via tape casting are used in applications such as multilayer actuators, piezoelectric sensors, and ultrasonic transducers. Additionally, due to the controlled shear stresses applied during the casting process, tape casting can induce preferred alignment of anisotropic crystallites, such as seed crystals or plate-like templates.[9] This alignment allows for textured ceramics with enhanced electromechanical properties.

Co-firing and multilayer structures

Co-firing integrates multiple ceramic and electrode layers into a monolithic structure through a single sintering step. As such, this process allows the fabrication of multilayer actuators and complex devices with embedded functionalities. Careful



Credit: Entekno Materials

Figure 2. Scanning electron microscope micrographs of a) $(Na_{0.5}Bi_{0.5})TiO_3$ and b) $BaTiO_3$ platelets, which are used as templates in templated grain growth.

matching of thermal and mechanical properties between the ceramic and electrode materials is critical to prevent delamination or cracking during sintering. When optimized, co-firing achieves intimate integration between electrodes and the active piezoceramic layers, reducing the overall device volume and minimizing interface-related losses.[10]

Multilayer structures are employed to enhance performance beyond the limitations of bulk piezoceramics. In bulk actuators, the electric field is applied across the full thickness, requiring high voltages and limiting the stroke (i.e., the maximum distance an actuator can travel in a given direction). By stacking many thin ceramic layers separated by electrodes, the stroke is amplified while operating at low driving voltages. The piezoceramic stroke ΔL is proportional to the number of layers n:

$$\Delta L = n \cdot d_{33} \cdot V$$

where d_{33} is the piezoelectric coefficient and V is the applied voltage. This configuration enables compact, high-force actuators, which are used in precision motion devices for robotics, medicals devices, and adaptive optics.

Additive manufacturing

Additive manufacturing (AM) has introduced new design freedom to piezoceramic fabrication. Techniques such as direct ink writing and digital light processing enable layer-by-layer construction of complex, 3D architectures that are difficult (or impossible) to achieve with conventional methods.[11] These approaches support graded compositions, internal channels, and intricate geometries, expanding the potential of piezoceramics for advanced applications such as biomedical implants and acoustofluidics.

Widespread industrial adoption of AM techniques remains limited, however, due to challenges including the successful fabrication of high-density and defect-free sintered parts, maintaining precise dimensional accuracy, and optimizing printable piezoceramic formulations. Furthermore, production speeds remain slower than traditional processes, and scalability is an ongoing barrier. Overcoming these limitations will be key to unlocking AM's full potential for next-generation piezoceramic devices.

Constraints and challenges

In industrial piezoceramic manufacturing, the most typical reason for scrapping a part is, and will always be, chips and cracks. Due to the brittle nature of ceramics, chipping and cracking during processing and handling of ceramic materials is a perennial problem and is generally accepted as a cost of doing business.

Aside from this challenge, and other complications inherent to ceramic manufacturing (e.g., lapping, core drilling, round grinding, lens forming, and dicing), more complex challenges are encountered when attempting to fabricate elaborate ceramic components. For example, many piezo-components rely on complex electrode configurations (e.g., patterned, wrap-around, quadrant, hemispheric, or striped electrodes), which generally place electronically active materials in contact with electronically inactive materials. These interfaces can generate large stresses within the material and constrain components due to fatigue, crack formation at the interface during poling or under drive, and depressed material properties due to mechanical clamping.

Furthermore, it is not trivial to pole these components because unique poling fixtures need to be designed on a case-by-case basis, and manufacturers must account for the indirect piezoelectric effect (i.e., the piezoelectric material undergoes mechanical strain when an electric field is applied across it). For small-scale sampling, these challenges are usually surmountable. However, when scaled to full industrial production, these challenges quickly become significant constraints resulting in very high scrap rates and low reproducibility rates.

Other challenges arise from the natural complexity of ceramics processing. For example, most ceramic manufacturers are aware of humidity effects on production. These effects are generally observed during very humid seasons.

Industrial scalability and reproducibility

Expanding materials synthesis capabilities from laboratory scale to industrial production requires several considerations. Obvious examples include the availability of equipment for weighing raw materials, such as milling machines and furnaces, but some considerations are more subtle, such as the availability of materials from dual sources, machinability, and compatibility with electrodes.

Currently, the value-chain and production apparatus are built up mainly around PZT ceramics. Novel materials such as lead-free piezoceramics that fit the PZT production route will have an advantage because of simplified upscaling. However, materials sensitive to contamination may need a separate production line even if the production route is the same as PZT.

Other factors that must be considered when developing new piezoceramic compositions include poling voltage, which

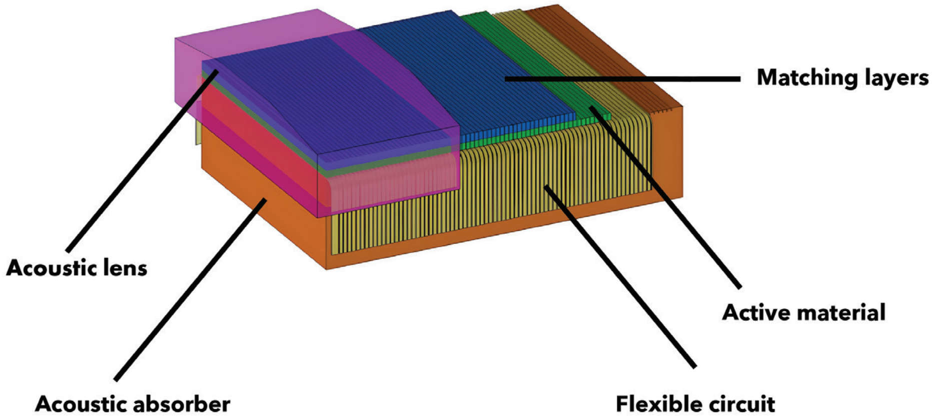


Figure 3. Cross-sectional view of an ultrasound transducer.

usually determines the thickness limit for a piezoceramic component. The material may also exhibit behavior that does not scale, for example, sinterability. It may also be sensitive to temperature gradients during the heat processing steps, which may lead to gradients in the chemical composition, porosity, and grain size, among other characteristics.

Application-driven optimization: Medical imaging and therapeutic ultrasound devices

Medical ultrasound transducers

Ultrasound medical imaging is a safe, accessible, and affordable diagnostic technique compared to alternatives such as MRI, CT scans, and X-rays. This technique uses high-frequency sound waves to create detailed images of internal body structures, and it is widely used across various medical fields, including clinical diagnostics for obstetrics and pregnancy, cardiology, vascular assessments, and veterinary applications.

Ultrasound systems typically operate at frequencies between 1 and 20 MHz, though some specialized applications for superficial or small animal imaging reach up to 40 MHz. Most ultrasound transducers used in radiology feature multiple elements, ranging roughly from 60 to 250 for 1D arrays and even more for 2D matrix arrays, which enable 3D imaging.[12]

Key acoustic properties essential for enhancing ultrasound imaging include signal sensitivity, bandwidth, and beam profile in relation to penetration depth. High signal sensitivity correlates with greater penetration depth, while a broad bandwidth is crucial for improved image resolution. In many cases, high directivity is also mandatory to increase the field of view, particularly for cardiac imaging. These parameters can be optimized through both the geometrical specifications of the array, tailored to the specific application, and the multimaterial design of the transducer.

Figure 3 illustrates the cross-sectional view of an ultrasound transducer. The core component is the active material, which generates ultrasound waves via the piezoelectric effect. Currently, the most commonly used piezoelectric materials in medical ultrasound transducers are PZT ceramics and lead magnesium niobate–lead titanate (PMN–PT)-based single crystals. To prevent interference between sound waves, an acoustic absorber is attached to the back of the piezoceramic material. Matching layers are then affixed to the front of the transducer to match the acoustic impedance of the piezoceramic with that of the target tissue.[13]

Given that piezoceramics have an acoustic impedance of approximately 20–30 MRayls and the human body is around 1.5 MRayls, the matching layers are designed to achieve an average value of 6–7 MRayls. Typically, multiple layers are employed to attain an equivalent impedance within this desired range and to enhance the transmission of sound waves. Finally, a biocompatible acoustic lens is used to geometrically focalize ultrasounds in one direction and for an encapsulation purpose.

The volume of piezoelectric ceramics used for medical imaging applications is relatively small compared to, for instance, those used in the automotive industry. Consequently, the properties most sought after and emphasized for medical imaging ultrasound applications differ. Specifically, these applications require "soft" piezoelectric ceramics, characterized by the properties detailed below, in contrast to "hard" piezoelectric ceramics used for applications such as sonar or power. The main properties targeted are

- A high electromechanical coupling coefficient in bar mode or thickness mode,
- A high dielectric constant, and
- A low mechanical quality factor.

Single crystal PMN–PT is currently the most efficient piezomaterial for ultrasound medical imaging because it exhibits the highest electromechanical coupling coefficient in bar mode and the lowest mechanical quality factor compared to regular PZT ceramics.[14] It has been implemented in commercial premium ultrasound imaging probes for many years.

While the European Union RoHS directive regarding lead in products currently exempts transducers for ultrasound imaging, its renewal is pending for 2027. Different lead-free systems being explored for medical ultrasound imaging include BT, KNN, and barium calcium titanate zirconate

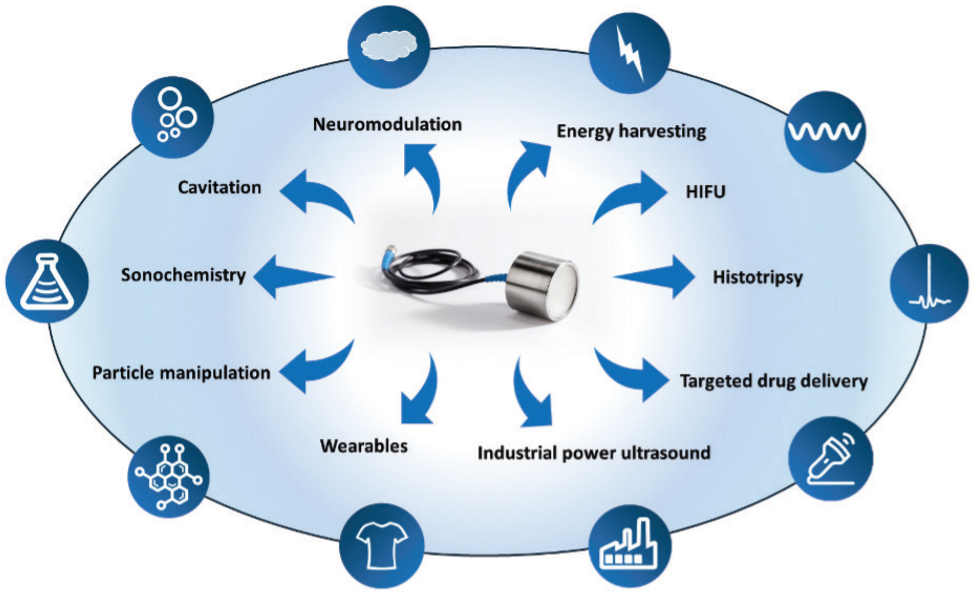


Figure 4. Emerging therapeutic and other ultrasonic applications, which drive developments in piezoceramic materials.

($Ba_{0.85}Ca_{0.15}Ti_{0.90}Zr_{0.10}$, BCTZ).[15] These materials have not yet matched the imaging performance of PZT-based probes in multielement arrays, and relevant publications remain scarce.[16] But ongoing advancements in the piezoelectric field and improvements in upscaling the manufacture of lead-free piezoelectric materials are highly encouraging for finding a future solution.

High-intensity focused ultrasound for therapeutic applications

Therapeutic ultrasound has risen to prominence over the last decade. It works by using ultrasonic beams delivered via different modalities to elicit a physical effect, such as a thermal gradient for tissue ablation or a mechanical force for targeted drug delivery. It can also induce phenomenon such as cavitation, which can be harnessed for sonochemistry (enhanced chemical reactions) or histotripsy (tissue destruction).

High-intensity focused ultrasound (HIFU) is a common modality for delivering ultrasonic beams in therapeutic ultrasound devices.[17,18] It requires frequencies in the range 100 kHz to 5 MHz to deliver focused ultrasonic beams that effectively heat the targeted tissue.

The large form factor and geometrically curved radiating surfaces typical of single-element HIFU devices make these piezoceramics complex to produce. Another challenge is that modern HIFU devices can operate at well over 100 W,[19] and at this level of acoustic output, a small loss in efficiency can lead to a massive drop in operational performance. Producing 100 W acoustic output with a transducer at 90% efficiency generates 11 J/s of dissipated energy, which usually manifests as heating within the device. Assuming this heating is concentrated around internal components, notably the piezoelectric element, a piezoceramic disc at 1 MHz and 60 mm diameter may weigh about 44 grams, which combined with a specific heat capacity of around 440 J/kg°C leads to a temperature rise of more than 1.3°C per second, assuming minimal heat dissipation. If a 20°C temperature rise is acceptable within operating limits, then a reduction in efficiency to 80% reduces run time from 34 seconds to 15 seconds. Thermal stability is therefore another key driver for future piezoceramic development.

Future directions for piezoceramic development

Piezoceramic materials, while essential for sensors, actuators, and energy harvesting, face three primary challenges: the toxicity of lead-based systems and the materials' inherent brittleness and temperature sensitivity. These challenges, in addition to the increasing demand for piezoceramics with higher efficiency, guide research and development of next-generation piezoelectric systems.

While developing high-performance lead-free alternatives is a major focus of current research efforts, studies focused on advancing additive manufacturing methods to create complex, miniaturized components are growing as well. A key material strategy involves developing textured piezoceramics to significantly boost piezoelectric performance and improve the sensitivity of sensors and performances of actuators and transducers.

These innovations will enable expanded applications of piezoceramics in fields such as high-temperature environments, flexible wearable electronics, advanced medical devices, and next-generation Internet of Things sensors (Figure 4). Furthermore, materials targeted at specific applications may be useful for other purposes, for example, the crossover between medical therapeutics and underwater acoustics (both HIFU systems and long-range sonar benefit from piezoceramics with ability to produce high power outputs).

While early piezoelectric developments relied on discovery-driven processes, this article highlights current efforts that embrace a more intentional, design-driven methodology. With the cross-seeding of ideas and innovations across industries leading to the uncovering of ever greater numbers of applications for piezoceramics, we see high-performance piezoceramics as a key market trend in the coming years.

Acknowledgments

The authors would like to acknowledge the financial support by Eureka via Eurostars program for the Life-MedU project.

About the authors

Ender Suvacı is professor of materials science at Eskişehir Technical University and chief technology officers at Entekno Materials Corp. (Eskisehir, Türkiye). Nesli Yürük is R&D specialist at Entekno Materials Corp. Victor Tinti, Jason Nikkel, and Rasmus Lou-Moeller are project engineer, development engineer, and director of engineering, respectively, at CTS Denmark A/S (Kvistgaard, Denmark). Claire Bantignies is deputy director of active probe manufacturing at Vermon SA (Tours, France). Thomas Kelley is sensors manager at Precision Acoustics Ltd. (Dorchester, U.K.). Contact Suvacı at esuvaci@eskisehir.edu.tr or esuvaci@enteknomaterials.com.

References

[1]C. Shee, S. Banerjee, R. Alagirusamy, and S. W. Ali, "Deployment of piezoelectric transducers for diverse technical applications: A comprehensive review," *Results in Engineering* 2025, **25**: 103881.

[2]S. Trolier-McKinstry, S. Zhang, A. J. Bell, and X. Tan, "High-performance piezoelectric crystals, ceramics, and films," *Annual Review of Materials Research* 2018, **48**(1): 191–217.

[3]R. E. Jaeger and L. Egerton, "Hot pressing of potassium-sodium niobates," *Journal of the American Ceramic Society* 1962, **45**(5): 209–213.

[4]Y. Saito et al., "Lead-free piezoceramics," *Nature* 2004, **432**(7013): 84–87.

[5]A. Khorsand Zak, S. T. Yazdi, M. E. Abrishami, and A. M. Hashim,. "A review on piezoelectric ceramics and nanostructures: Fundamentals and fabrications," *Journal of the Australian Ceramic Society* 2024, **60**(3): 723–753.

[6]R. L. Walton et al., "Tailoring particle alignment and grain orientation during tape casting and templated grain growth," *Journal of the American Ceramic Society* 2019, **102**(5): 2405–2414.

[7]G. L. Messing et al., "Templated grain growth of textured piezoelectric ceramics," *Critical Reviews in Solid State and Materials Sciences* 2004, **29**(2): 45–96.

[8]R. E. Mistler and E. R. Twiname, *Tape Casting: Theory and Practice*. Wiley, 2000.

[9]A.D. Moriana and S. Zhang, "Lead-free textured piezoceramics using tape casting: A review," *Journal of Materiomics* 2018, **4**(4): 277–303.

[10]H. Yang et al., "Mass production of multi-layer piezoelectric composite and their energy harvesting properties," *Ceramics International* 2022, **48**(18): 26129–26136.

[11]S. Bhandari et al., "A review on additive manufacturing of piezoelectric ceramics: From feedstock development to properties of sintered parts," *Mater. Sci. Eng. R: Reports* 2025, **162**: 100877.

[12]A. Fenster, G. Parraga, and J. Bax, "Three-dimensional ultrasound scanning," *Interface Focus* 2011, **1**(4): 503–519.

[13]M. Ali, D. Magee, and U. Dasgupta, "White paper: Signal processing overview of ultrasound systems for medical imaging," Texas Instruments, November 2008: SPRAB12. https://www.k-space.org/ymk/sprab12.pdf

[14]Z. Zhang et al., "Design and comparison of PMN–PT single crystals and PZT ceramics based medical phased array ultrasonic transducer," *Sensors and Actuators A: Physical* 2018, **283**: 273–281.

[15]J. Rödel et al., "Transferring lead-free piezoelectric ceramics into application," *Journal of the European Ceramic Society* 2015, **35**(6): 1659–1681.

[16]E. Ringgaard et al., "Lead-free piezoelectric transducers," *IEEE Trans. Ultrason. Ferroelectr. Freq. Control* 2024, **71**(1): 3–15.

[17]X. Bai et al., "Design and manufacturing technologies of focused piezoelectric ultrasound transducers for biomedical applications," *International Journal of Extreme Manufacturing* 2024, **6**(6): 062001.

[18]M. Lafond, A. Payne, and C. Lafon, "Therapeutic ultrasound transducer technology and monitoring techniques: A review with clinical examples," *International journal of Hyperthermia* 2024, **41**(1): 2389288.

[19]"HIFU transducers," Precision Acoustics Ltd. https://www.acoustics.co.uk/product/hifu-transducers

*All references verified as of Dec. 8, 2025. ■

Tradition and transformation in architectural glass

By Vlad Mitskevich

Example of a decorated glass door created using the new stained-glass painting technique.

Glass has captivated artists, architects, and craftsmen for centuries, not only for its practical uses but also for its aesthetic possibilities. From Gothic cathedrals to Art Nouveau mansions, decorative glass plays a vital role in architectural design.

Traditional techniques for imbuing glass with decorative designs and colors, such as sandblasting, engraving, and stained-glass painting, continue to be cherished for their precision and intricate patterns. However, as technology and creativity evolve, new approaches push the boundaries of what can be done with glass.

At Fa. I. Edelkoort & Zn in The Hague, Netherlands, several generations of glassworkers have used time-honored decorating techniques to design glass for more than a century. But several recent innovations allowed the studio to enter a new era of artistic and technical exploration while staying true to its classical roots.

Traditional decorating techniques and applications

While glass is typically formed in a molten state using glassblowing, kiln casting, and other hot glass working processes, decorating usually occurs after the glass has cooled and solidified. Below is an overview of the decorating techniques most commonly used in the modern decorative glass industry.

- **Stained-glass painting** (medieval origins): Classical method involving powdered paints applied in layers, each of which must be burned in a kiln to fix before the next is applied.
- **Engraving** (ancient origins, refined in the 18th to 19th centuries): Either hand-engraved or machine-assisted, this technique produces sharp, elegant lines ideal for inscriptions and memorials.
- **Etching** (mid-19th century): Comprises techniques that use acidic, caustic, or abrasive substances to produce intricate patterns or motifs on the surface of glass.
- **Airbrushing** (developed 1870s, popularized in the 20th century): Involves using a small, hand-held instrument connected to a canister of compressed air to spray paint in a controlled way. It allows for smooth gradients and precise coloration, and so artists and illustrators often use airbrushing to create a high level of realism.
- **Sandblasting** (early 20th century): A method of carving or frosting the surface of glass by propelling abrasive materials at high velocities using compressed air. Often used for transom windows, signage, and decorative mirrors.
- **Fusing** (late 20th century): Combines different types of glass into one cohesive piece through high-temperature heating.

It is not uncommon for decorative glass manufacturers to use several of these techniques in parallel to design unique and complex decorative glass pieces. But at Fa. I. Edelkoort & Zn, I developed a novel glass fusing method that provides my team with an enhanced way to integrate the older techniques with new technologies.

Fa. I. Edelkoort & Zn: A legacy of Dutch glass craftsmanship

Founded in 1925 by Izak Edelkoort in The Hague, Netherlands, Fa. I. Edelkoort & Zn was a family business handed down first to Jacobus Edelkoort in 1946, who expanded the company's reach, and then to Jacques Edelkoort in 1978, who modernized its operations and embraced contemporary techniques.

In 1995, glass artist Vlad Mitskevich joined the company and later took over after Jacques Edelkoort's retirement. Under his guidance, the studio adopted several innovative decorating techniques that the small, creative team uses alongside traditional practices to bolster their glass craftsmanship. ■

Credit: Vlad Mitskevich

Izak Edelkoort stands in front of his workshop in The Hague during the 1930s.

Credit: Vlad Mitskevich

Vlad Mitskevich stands in front of the same building in September 2025. The company has remained in the same location for its century of existence.

Fused glass images withstand environmental exposure

The novel glass fusing method was inspired by the rising demand for durable and aesthetically pleasing outdoor glass memorials in the 1990s. While experimenting with airbrushed images fired in a kiln, I found traditional glass paints could not withstand outdoor exposure. Stained glass artworks typically are installed indoors or behind protective glazing, which prevents direct contact with the elements. Without such protection, painted images will fade, peel, or erode just like regular paint.

Credit: Vlad Mitskevich

Figure 1. Memorial created using the novel glass fusing method.

To improve the durability of colored memorials, I had an idea: Why not fuse two layers of glass with the image encapsulated between them? Initial tests showed promise, but air bubbles trapped between the sheets during firing led to visual distortions. So, I embarked on six years of independent experimentation to overcome this challenge.

At first, relatively small sheets (~100 × 100 mm) were successfully fused, but with bigger sizes, the results were inconsistent. I continued testing, changing variables such as firing time and temperature with each attempt, until I achieved consistently flawless results.

The outcome was a new fused-glass product that resists air pockets, delamination, weathering, and discoloration due to weather, chemicals, and ultraviolet radiation. Notably, this product is not laminated glass. Instead, the image becomes an integral, inseparable part of the solid glass structure with no layers or adhesives—allowing it to be effectively guaranteed for life.

A major advantage of the method is its environmental friendliness: no tape, foil, or adhesives are required, and it can be executed using conventional glass machinery without special equipment.

With this development, the technical challenges of painting and airbrushing were solved. But the next question was how to bring photography into the fusing process. The only option was to rely on ceramic transfers, but most suppliers offered poor image resolution or restricted sizes (usually no larger than A3). After considerable trial and error, a reliable supplier was found, allowing for sharp, large-format imagery (up to 1,000 × 700 mm) to be incorporated into the fused panels (Figure 1).

This technique shows great promise for memorial applications, especially as an alternative to ceramic photo plaques. While ceramic photos are durable, they are still just a surface treatment that can wear over time. Meanwhile, fused photographic glass offers several benefits:

- Full protection from environmental damage.
- Minimal 4-mm-thick profile (Figure 2).
- Custom shapes and sizes.
- Greater visual refinement and permanence.

While the memorial plaques that inspired this innovation are an obvious application of the new glass fusing technique, additional uses include glass information panels for swimming pools, where ceramic tiles or foil graphics often degrade due to moisture, as well as larger panels for hotel logos, signage, or decorative wall features. Beyond these uses, the material is also suited for architectural applications, such as building decoration panels and other facing elements.

Answering concerns about cost

Currently, the new fused glass method is entirely handmade and performed in a small-scale artisan workshop, which makes it relatively costly compared to other decorating techniques. However, it is important to remember that historically, even ceramic tiles were once handmade and expensive until industrial processes evolved to make them widely available.

Similarly, the fused-glass method is still less than 10 years old. With time, development, and industrial partnerships, there is every reason to believe it could follow the same trajectory—from artisanal to accessible. Innovation often starts in the artist's studio, not the factory. What is handcrafted today may be automated tomorrow.

Breakthrough in stained-glass painting

In addition to the new glass fusing method, I developed a complementary innovation in the realm of stained-glass painting.

Traditionally, this form of painting is a highly specialized craft requiring expensive tools and a strict layering process. Artists must apply powdered paint in stages, burning each layer in a kiln before proceeding to the next. This process prevents the fragile powder from smudging or detaching but drastically slows down the workflow.

I experimented with different additives that could hold the paint together and burn cleanly in the kiln without compromising the image. After prolonged testing, I succeeded in creating a liquid compound that transforms powdered glass paint into a medium resembling watercolor or acrylic. This new medium eliminated the need for expensive brushes or intermediate firings.

With this method, artists can complete detailed glass paintings in a single session, requiring only one final kiln firing to fix the image permanently. The technique greatly reduces costs, speeds up production, and broadens creative possibilities.

This technique is also useful in glass door manufacturing (Figure 3). A decorated glass door can be painted and sent directly for hardening because the heat used for tempering the glass is the same as that needed to fix the paint. This beneficial property of the technique opens new avenues for durable, decorative, and cost-effective glass doors.

A call to collaboration

The fused glass and stained-glass painting techniques are mature and field-tested technologies. The small artisan studio is now actively seeking partnerships with manufacturers, architects, and designers to scale up these innovations and bring them into broader use.

From historic roots to future possibilities, Fa. I. Edelkoort & Zn exemplifies how tradition and innovation can not only coexist but also elevate each other to new heights.

About the author

Vladislav Mitskevich is owner of Fa. I. Edelkoort & Zn in The Hague, Netherlands. Contact Mitskevich at vmvlad17@gmail.com. ■

Credit: Vlad Mitskevich

Figure 2. Side view showing the thinness of the fused glass.

Credit: Vlad Mitskevich

Figure 3. This decorated glass door, created using the new stained-glass painting technique, brings to life the picture of company founder Izak Edelkoort standing in front of his workshop in The Hague.

Credit: ACerS

Shunpei Yamazaki, second from right, shows off a replica of the first 300-mm oxide semiconductor wafer during the 2024 Rustum Roy Lecture at ACerS Annual Meeting at MS&T in Pittsburgh, Pa. Standing with him, from left to right, is ACerS Fellow and session chair Young-Wook Kim, ACerS Past President Rajendra Bordia (2023–2024), and ACerS Distinguished Life Member Mritunjay Singh.

Yamazaki will present the Mrityunjay Singh Bridge Building Award lecture on oxide semiconductor developments during the Golden Jubilee Celebration of the 50th International Conference and Expo on Advanced Ceramics and Composites in Daytona Beach, Fla.

Indium oxide semiconductors for low-power AI systems

By Lisa McDonald

The world's digital data volume is expanding rapidly, driven by the adoption of big data and artificial intelligence-based systems. With this expansion, the energy required to operate data centers is also increasing. As a result, scientists and engineers must develop new computer components and paradigms that can enable both high processing speeds and low power consumption. In October 2024, Semiconductor Energy Laboratory Chairman and CEO Shunpei Yamazaki delivered the Rustum Roy Lecture at ACerS Annual Meeting on the development of indium oxide-based semiconductors to replace silicon electronics. In July 2025, he and his colleagues published an open-access paper—excerpted below—that elaborates on this development.

Oxide ceramic large-scale integration device for putting the brakes on global boiling accelerated by artificial intelligence age computers

Climate change caused by global boiling, which is a factor in natural disasters, is a serious social problem.

One of the factors that could be considered a cause of global boiling is the rapid progress and widespread use of artificial intelligence (AI). Thus, hardware in the era of AI, such as servers, requires both high processing speed and low power consumption as a measure against global boiling.

One oxide semiconductor material, indium gallium zinc oxide (IGZO), was first synthesized in the world by N. Kimizuka in 1985, and its use as a semiconductor device was reported in 1987.[1] Furthermore, in 1991, research results relating to the phase diagram for the In_2O_3–Ga_2ZnO_4–ZnO system were published.[2] Subsequently, in 2004, field-effect transistor (FET) characteristics using amorphous IGZO were reported.[3] We discovered *c*-axis aligned crystalline IGZO (CAAC-IGZO) in 2009.[4,5]

Research on oxide semiconductor materials continued even after the discovery of IGZO. In particular, crystal indium oxide with higher mobility than IGZO has attracted attention in recent years. We first proposed single crystal indium oxide and its application in large-scale integration in 2011 and have since continued to investigate its uses.

As reported at the 70th Annual IEEE International Electron Devices Meeting,[6] we developed a 3-Mbit dynamic random-access memory (DRAM) device that includes crystal indium oxide. This DRAM is monolithically stacked over a silicon complementary metal oxide semiconductor and includes vertical capacitors and vertical channel FETs (channel hole diameter: 60 nm) over the vertical capacitors. According to high-speed verification, the DRAM operated normally even with a read time of 5 nanoseconds (2.0 V) and a write time of 5.5 nanoseconds (1.9 V).

In comparison with conventional vertical channel FETs that contain IGZO as a channel material, the vertical channel FETs that contain crystal indium oxide exhibited an on-state current that was higher by 8.3-fold. Furthermore, an 81% reduction in read time and an 89% reduction in write time were estimated when the gate electrode line was pulled up to be away from the source electrode to reduce the parasitic capacitance; that is, the read/write time was shortened due to the optimization of the vertical channel FET structure by including crystal indium oxide as a channel material in place of IGZO.

According to the retention measurement results, a pass ratio of 99% was maintained at 125°C even after a retention time of 100 seconds, which is 1,563 times longer than the general DRAM refresh time of 64 milliseconds. Thus, reductions in the refresh frequency and standby power are expected. This DRAM structure has potential for application into high-bandwidth memory that is die-stacked DRAM, the demand of which is increasing for AI.

Another application example is our analog AI system, in which oxide semiconductor FETs are monolithically stacked over silicon FETs.[7] This analog AI system utilizes the subthreshold region of the silicon FETs for multiply–accumulate operations in the current mode.

Because a slight fluctuation in voltage in the subthreshold region causes a crucial fluctuation in the output current, the analog memory requires extremely high retention characteristics. Considering this context, an oxide semiconductor FET that enables a 10^{17} on/off ratio is regarded as a suitable device for analog AI systems. Our fabricated chip retains higher than 90% classification accuracy even after five hours have passed, which means that this chip achieves better data retention characteristics.

General analog AI systems consume a large amount of power in digital-to-analog (DA) and analog-to-digital (AD) conversion. In contrast, our fabricated system adopts a setup of executing analog computing in multilayer networks without AD conversion to reduce the number of times of DA/AD conversions and the number of data path circuits, resulting in reducing the power consumed by DA/AD conversion. Owing to this configuration, this system succeeded in executing the MNIST handwritten digit classification task with a low energy of 1.1 nJ/classification and an accuracy of 91.6% without a weight refresh for as long as five hours. This analog AI system has potential comparable to a human brain in the ultimate form of a low-energy device.

As a display with oxide semiconductor FETs, we fabricated a high-resolution, high-luminance (3,207 ppi and 15,000 cd/m^2) augmented/virtual reality display system with 1.50 inches diagonally.[8] This display system has a stacked-layer structure that includes a silicon circuit as the bottom layer, an oxide semiconductor pixel circuit layer over the silicon circuit, and an organic electroluminescence layer as the uppermost layer.[9]

Powerchip Semiconductor Manufacturing Corporation (PSMC), a Taiwanese company, successfully fabricated a 12-inch (300-mm) wafer based on our technology for application in augmented/virtual reality. PSMC is now addressing the commercialization of augmented/virtual reality systems by adopting our technology for the first time in the world.

In conclusion, our oxide semiconductor device technology can help reduce the power consumed by AI, which could be a key to solving global boiling.

References

[1] N. Kimizuka and T. Mohri, "Compound having a hexagonal layer structure represented by $InGaZn_2O_5$ and its manufacturing method," Japanese Patent JPS63239117A. Granted 5 Oct. 1988. https://patents.google.com/patent/JPS63239117A

[2] M. Nakamura, N. Kimizuka, and T. Mohri, "The phase relations in the In_2O_3–Ga_2ZnO_4–ZnO system at 1350°C," *Journal of Solid State Chemistry* 1991, **93**(2): 298–315.

[3] K. Nomura et al., "Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors," *Nature* 2004, **432**: 488–492.

[4] S. Yamazaki et al., "Semiconductor device," Japanese Patent JP5172918B2. Granted 27 March 2013. https://patents.google.com/patent/JP5172918B2

[5] S. Yamazaki et al, "Transistor and display device comprising oxide semiconductor layer," United States Patent US9935202. Granted 3 April 2018. https://patents.google.com/patent/US9935202B2

[6] S. Miyata et al., "Vertical-channel crystalline In_2O_3 FET with a pulled-up gate, monolithically stacked on Si CMOS, achieving 112.2 µA/µm on-state current," 70th *IEEE Int Electron Devices Meeting* 2024.

[7] K. Tsuda et al., "A 1.1-nJ/classification true analog current computing on multilayer neural network with crystalline-IGZO/Si-CMOS monolithic stack technology," *IEEE Journal of the Electron Devices Society* 2024, **12**: 594–604.

[8] S. Fukuzaki et al., "High-luminance and highly reliable tandem OLED display including new intermediate connector designed for photolithography applications," *J. Soc. Inf. Display* 2024, **32**(5): 309–319.

[9] M. Kozuma et al., "OLED microdisplay with monolithically integrated CAAC-OS FET and Si CMOS achieved by two-dimensionally arranged silicon display drivers," *IEEE Journal of the Electron Devices Society* 2024, **12**: 187–194. ■

Read the full article at S. Yamazaki et al., "Oxide ceramic large-scale integration device for putting the brakes on global boiling accelerated by artificial intelligence age computers," *IJCES* 2025, 7(4): e70011.

Brittney Hauke
ACerS journals managing editor

Manufacturing considerations for the next generation of engineered ceramics

For millennia, ceramics were largely utilized in their natural form, with basic heat treatments the main process affecting their final structure and properties. But as scientific understanding of materials and manufacturing methods advanced, scientists gained the ability to design highly engineered ceramics with unique and specialized characteristics.

The advent of nanoscale imaging and advanced design capabilities in the 20th century greatly boosted the profile of engineering ceramics as a field, which The American Ceramic Society recognized in 1985 when the Ceramic-Metal Systems Division changed its name to Engineering Ceramics. That Division will now celebrate the golden jubilee of the International Conference and Expo on Advanced Ceramics and Composites later this month, and this column celebrates that milestone by showcasing articles that cover recent advances in engineering ceramics.

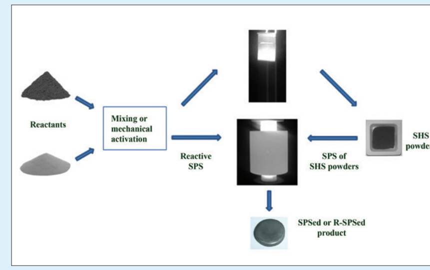
The review article "Advances in preparation techniques for high-purity silicon carbide ceramics" by Zhang et al. summarizes advancements in manufacturing techniques for high-purity silicon carbide (SiC) ceramics, which are critical for the semiconductor, aerospace, and chemical industries.[1] Specifically, the authors describe in detail the manufacturing techniques of recrystallization sintering, pressureless sintering, hot pressing sintering, spark plasma sintering, and additive manufacturing. They then compare the physical and mechanical properties of samples synthesized through these different methods, with hot pressing samples demonstrating the highest density, flexural strength, elastic modulus, and thermal conductivity.

Zhang et al. also highlight limitations of the current manufacturing techniques and suggest strategies to meet the ever-growing demand for high-purity and high-performing SiC ceramics. For example, they suggest focusing on the development of sintering strategies with zero or clean-burning additives, creating scalable and cost-effective additive manufacturing workflows, and using hybrid processes that involve a mixture of additive manufacturing and pressureless, hot pressing, or spark plasma sintering.

Another area of recent advancements relates to the eco-friendly building material called geopolymer recycled aggregate concrete (GRAC). In the review article "Preparation and properties of geopolymer recycled concrete: A review of recent developments," Li et al. evaluate the properties and carbon emissions performance of GRAC, as well as providing future research directions.[2]

GRAC was first identified in the 1970s by French researcher Davidovits. By replacing natural aggregates with recycled aggregates, GRAC can reduce the energy consumption and amount of CO_2 generated during cement production, as well as provide an avenue to use waste concrete. The authors describe the numerous advantages of GRAC when compared to ordinary Portland cement, such as its mechanical strength, durability, interfacial bonding, and chemical and high-temperature resistance. However, widespread adoption of geopolymers faces some challenges, such as the performance being highly dependent on the chemical composition of the precursor materials and the currently limited amount of long-term durability data.

Finally, the review article by Mukasyan and Rogachev, "Combustion synthesis of ultra-high temperature ceramics: Review," details combustion-based synthesis methods to produce ultrahigh-temperature ceramics (UHTCs).[3] These materials can operate at temperatures above 2,000°C,



Credit: Mukasyan et al., *ACT*

Figure 1. Spark plasma sintering routes for the fabrication of ultrahigh-temperature ceramics. Adapted from Orrù and Cao, *Materials* 2013, 6(5): 1566–1583.

which make them critical to advanced developments in the aerospace, energy, and transportation industries.

The authors discuss the types of UHTCs synthesized, ranging from simple compounds to high-entropy ceramics, as well as the two primary approaches for creating dense UHTCs (Figure 1). Future directions for UHTC research are also highlighted, including developing fiber-reinforced UHTC composites, UHTCs with complex microstructures, and doped UHTCs to enhance high-temperature performance. Modeling and other data-driven approaches will also help identify structure–property relationships.

These articles are just a few examples of the cutting-edge ceramics research being conducted and reported in ACerS journals. To read more, visit the ACerS journals homepage at https://ceramics.onlinelibrary.wiley.com.

References

[1]W. Zhang et al., "Advances in preparation techniques for high-purity silicon carbide ceramics," *Int. J. Appl. Ceram. Technol.* 2025, **22**(6): e70012.

[2]G. Li et al., "Preparation and properties of geopolymer recycled concrete: A review of recent developments," *Int. J. Appl. Ceram. Technol.* 2025, **22**(6): e70033.

[3]A. S. Mukasyan and A. S. Rogachev, "Combustion synthesis of ultra-high temperature ceramics: Review," *Int. J. Appl. Ceram. Technol.* 2025, **22**(6): e70044.

'Engineering' connections to support the next generation of ceramic and glass scientists

By Yolanda Natividad

In the ever-evolving world of materials science, mentorship can serve as the bridge between ambition and achievement for students and young professionals.

However, making these connections with seasoned scientists and engineers can be challenging for people just starting out in their career. That is why ACerS Mentor Programs are so beneficial to members of the ceramic and glass community.

ACerS Mentor Programs are designed to pair students with university and industry professionals, young faculty members with either peers or senior faculty, and emerging industry professionals with senior industry professionals. Nearly 750 individuals have been connected through these programs over the past eight years, with many mentor–mentee pairs staying connected through multiple years. That is the case for Rishabh Kundu and Peter McGinnis, a student–industry professional pair who share their experience being involved in the ACerS Mentor Programs:

Mentee's POV: Rishabh Kundu

Graduate student, ThinkEnergy Fellow, and Swanger Fellow at Case Western Reserve University

During my master's studies in Germany, I joined the ACerS Mentor Program to help reinforce and expand the bridges that I had started building during my undergraduate years. I was fortunate to be paired with Peter (Pete) B. McGinnis, a humble glass scientist who works at Owens Corning in Ohio.

From the very beginning, Pete's guidance went far beyond academic advice. When we first connected, I was at a crossroads, deciding on graduate schools in the U.S. Pete patiently listened to my priorities, goals, and reasoning, helping me see perspectives I had not considered. His calm, thoughtful approach helped me clarify what truly mattered to me and strengthened my confidence in my choices.

Through virtual meetings and in-person encounters across three countries, our mentorship quickly grew beyond the bounds of the program. When I prepared to move to the U.S., he and his wife extended kindness beyond measure, even visiting one of the apartments I was considering and sending me pictures plus their perspective before I made my decision. Pete continued to show up during holidays and milestones, even attending ACerS Annual Meeting at MS&T25 last October to see me receive the D.T. Rankin Award, despite recovering from a broken arm.

Mentors like Pete are rare. His steady encouragement, pragmatic wisdom, and genuine care have shaped not only my academic path but also how I approach some of life's uncertainties. I am deeply grateful for his mentorship and the enduring example he sets of what it truly means to give back.

Rishabh Kundu, left, stands with his ACerS mentor, Peter McGinnis, after being presented with the ACerS Energy Materials and Systems Division's D.T. Rankin Award at MS&T25. This award recognizes a member who has demonstrated exemplary service to the Division, and Kundu is the youngest-ever recipient.

Credit: Ryan Charles Eaton

Mentor's POV: Peter McGinnis

Leader of the High-Performance Glass Program at Owens Corning

Being an ACerS mentor has been a very rewarding experience, offering the chance to guide mentees through a broad spectrum of topics—from the practical to more career-focused. For example, my conversations with Rishabh have included everyday challenges faced by someone new to the U.S., such as the compatibility of personal electronics with 110 V systems, to strategic discussions about building connections with industry leaders. This variety has helped me develop flexibility in my guidance and has reminded me that mentoring is not just about professional advice—it is about supporting the whole person.

Rishabh's unique passion for ceramic science—and for life itself—makes sharing my own personal and professional experiences effortless and meaningful. His enthusiasm energizes our conversations and motivates me to grow in both my career and as a mentor. Being part of the ACerS Mentor Program has been a privilege, and I look forward to continuing my discussions with Rishabh.

It is the unique experiences that both Kundu and McGinnis have shared that allow the ACerS Mentor Programs to continue to grow and flourish. Applications to participate in the 2026 ACerS Mentor Programs are open until **Jan. 19, 2026**. Open yourself up to a new experience by applying today at https://ceramics.org/career-development/mentor-program.

About the author

Yolanda Natividad is ACerS associate director of membership and industry relations. Contact Natividad at ynatividad@ceramics.org. ■

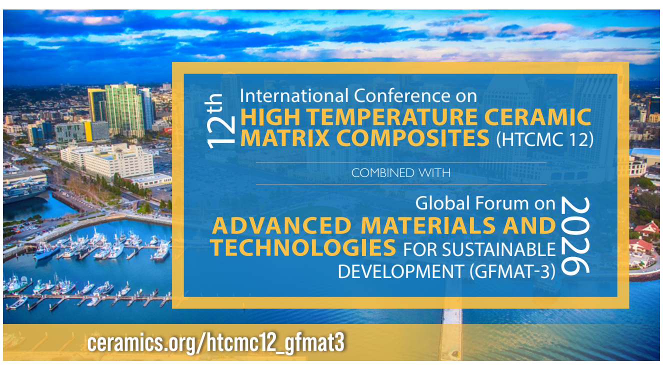
UPCOMING MEETINGS

APRIL 12–17, 2026

HYATT REGENCY BELLEVUE ON SEATTLE'S EASTSIDE,
BELLEVUE, WASH.

Six ACerS Divisions are collaborating to host the first-ever ACerS Spring Meeting in Bellevue, Wash. Each of the six Divisions will create its own programming, though collaborative sessions will take place as well. One registration fee will allow you access to all programming and events.

Register to attend!



MAY 31–JUNE 5, 2026

SHERATON SAN DIEGO HOTEL & MARINA,
SAN DIEGO, CALIF.

Join us in San Diego for the combined 12th International Conference on High Temperature Ceramic Matrix Composites and 3rd Global Forum on Advanced Materials and Technologies for Sustainable Development.

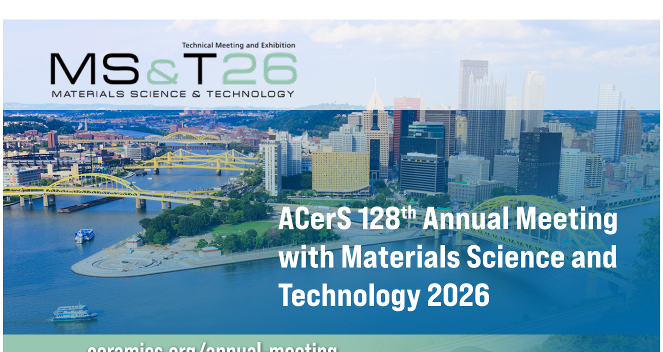
Register to attend!

JULY 12–16, 2026

HYATT REGENCY BELLEVUE ON SEATTLE'S EASTSIDE,
BELLEVUE, WASH.

Six ACerS Divisions are collaborating to host the first-ever ACerS Spring Meeting in Bellevue, Wash. Each of the six Divisions will create its own programming, though collaborative sessions will take place as well. One registration fee will allow you access to all programming and events.

Submit your abstract!



OCT. 4–7, 2026

DAVID L. LAWRENCE CONVENTION CENTER,
PITTSBURGH, PENN.

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.

Submit your abstract!

Calendar of events

January 2026

25–30 Golden Jubilee Celebration of the 50th International Conference and Expo on Advanced Ceramics and Composites – Hilton Daytona Beach Oceanfront Resort, Daytona, Fla.; https://ceramics.org/icwacc2026

29–30 ★ Mechanical Properties of Ceramics and Glass – Hilton Daytona Beach Oceanfront Resort, Daytona, Fla.; https://ceramics.org/course/quinn-mechanical-properties

February 2026

3–March 24 ★ Drying and Firing of Refractories – Virtual; https://ceramics.org/course/homeny-drying-and-firing

March 2026

3–26 ★ Survey of Raw Materials – Virtual; https://ceramics.org/course/moody-raw-materials

24–26 ➨ ceramitec 2026 – Trade Fair Center Messe, München, Germany; https://ceramics.org/event/ceramitec-2026

30–April 1 61st Annual Greater Missouri Section / Refractory Ceramics Division Symposium on Refractories – Hilton St. Louis Airport Hotel, St. Louis, Mo.; https://ceramics.org/rcd2026

31–April 2 ➨ Smart Additive Manufacturing, Design & Evaluation (Smart MADE 2026) – The University of Osaka Nakanoshima Center, Japan; https://sites.google.com/view/smartmade2026

April 2026

12 ★ Introduction to Thermal Spray Coatings: Science, Engineering, and Applications – Bellevue, Wash.; https://ceramics.org/course/berndt-intro-thermal-spray-coatings

12 ★ Fractography of Ceramics and Glass: An Introduction – Bellevue, Wash.; https://ceramics.org/course/swab-fractography

12–16 ACerS Spring Meeting — Bellevue, Wash.; http://ceramics.org/acersspring

May 2026

5–6 ➨ Ceramics Expo 2026 – Cleveland, Ohio; https://ceramics.org/event/ceramics-expo-2026

31–June 5 12th International Conference on High Temperature Ceramic Matrix Composites and Global Forum on Advanced Materials and Technologies for Sustainable Development – Sheraton San Diego Hotel & Marina, San Diego, Calif.; https://ceramics.org/htcmc12_gfmat3

June 2026

7–12 ➨ Solid State Studies in Ceramic Science Gordon Research Conference – South Hadley, Mass.; https://www.grc.org/solid-state-studies-in-ceramics-conference/2026

8–10 Structural Clay Products Division & Southwest Section Meeting 2026 – DoubleTree by Hilton Canton Downtown, Canton, Ohio; https://ceramics.org/clay2026

10–12 16th Advances in Cement-Based Materials – Miami, Fla.; https://ceramics.org/cements2026

15–25 ➨ CIMTEC 2026 – Perugia, Italy; https://ceramics.org/event/cimtec-2026

July 2026

8–10 ➨ International Conference on Self-Healing Materials – Drexel University, Philadelphia, Pa.; https://icshm2026.org

12–16 ➨ American Conference on Neutron Scattering 2026 – Detroit Marriott at the Renaissance Center, Detroit, Mich.; https://ceramics.org/acns2026

August 2026

31–Sept. 1 ➨ The International Conference on Sintering – Aachen, Germany; https://www.sintering2026.org/en

October 2026

4–7 ACerS 128th Annual Meeting with Materials Science and Technology 2026 – David L. Lawrence Convention Center, Pittsburgh, Penn.; https://ceramics.org/annual-meeting2026

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.

★ denotes a short course

The American Ceramic Society
ceramics.org

Help strengthen ACerS' presence in Wikipedia!

MONDAY, MARCH 16, 2026

WIKIPEDIA EDIT-A-THON

JOIN US FOR A DAY-LONG, VIRTUAL WIKIPEDIA EDIT-A-THON!

The event will kick off with a live video call at 9:30 a.m. Eastern Time on March 16, 2026. Participants will learn how to make impactful contributions to Wikipedia pages that mention ACerS. You'll then spend the day reviewing and editing pages at your own pace using a simple checklist and best practices guide.

>> **First 10 participants who attend and successfully complete the full checklist will receive a $100 Amazon gift card after their contributions are verified.**

Register for the ACerS Wikipedia Edit-a-Thon

Please note: This event requires participants to have an active Wikipedia account prior to the edit-a-thon.

https://forms.office.com/r/ps3juPYAhG

For questions about the Wikipedia Edit-a-Thon, please contact Kameron Haines at khaines@ceramics.org

classified advertising

Career Opportunities

Business Opportunities

Business Services

custom finishing/machining

custom/toll processing services

firing/melting/drying

maintenance/repair services

laboratory/testing services

AD INDEX

JANUARY/FEBRUARY 2026

AMERICAN CERAMIC SOCIETY
bulletin

DISPLAY ADVERTISERS

AdValue Technology	www.advaluetech.com	23
Alfred University	www.alfred.edu/CACT	Inside back cover
American Elements	www.americanelements.com	Outside back cover
Ceramitec	www.ceramitec.com	17
Deltech Inc.	www.deltechfurnaces.com	7
Harrop Industries Inc.	www.harropusa.com	Inside front cover
I Squared R Element Co., Inc.	www.isquaredrelement.com	23
Mo-Sci LLC	www.mo-sci.com	4
Paul O. Abbe	www.pauloabbe.com	15
TevTech LLC	www.tevtechllc.com	25
The American Ceramic Society	www.ceramics.org	11, 38, 48

CLASSIFIED ADVERTISERS

* Business Service advertisers

* **Bomas**	www.bomas.com	49
* **Centorr Vacuum Industries Inc.**	www.centorr.com	49, 50
Firebricks.com	www.firebricks.com	49
* **Harrop Industries Inc.**	www.harropusa.com	50
* **PremaTech Advanced Ceramics**	www.prematechac.com	49
Quality Executive Search	www.qualityexec.com	49
* **Spectrochemical Laboratories**	www.spectrochemicalme.com	50
* **Zircar Ceramics Inc.**	www.zircarceramics.com	49
* **Zircar Zirconia Inc.**	www.zircarzirconia.com	49

Advertising Sales
Mona Thiel, National Sales Director
mthiel@ceramics.org
ph: 614-794-5834

Advertising Assistant
Pam Wilson
pwilson@ceramics.org
ph: 614-794-5826

By Priya Kushram
Guest columnist

Ceramics in medicine: Engineering materials that heal

As shown in this issue's "Letter from the Editor," ceramics are an ancient material that is undergoing a quiet revolution, transforming from a natural substance passively used in pottery and brickwork into a highly engineered component that pushes the boundaries of medicine, energy, and environmental technology. Scientists and engineers have gone from simply utilizing ceramics for their inherent properties, such as hardness and heat resistance, to actively controlling a ceramic's chemical composition and structure on the atomic scale, thereby tailoring its behavior for a specific purpose.

Credit: Priya Kushram

Figure 1. A collection of 3D-printed calcium phosphate parts made by Westinghouse Distinguished Chair Professor Susmita Bose and her team.

Medicine is one sector that has greatly benefited from functional ceramic systems. Specifically, calcium phosphate ceramics, such as hydroxyapatite and tricalcium phosphate, are widely studied because their chemical composition is similar to that of natural bone mineral. This similarity allows the body to accept these so-called "bioceramics" more readily than many other materials.

Traditionally, calcium phosphates and other bioceramics were used as bone fillers or as coatings on metallic implants. While useful, their function was mainly structural. Recent breakthroughs have significantly expanded the scope of this role, however. For example, scientists are using advanced manufacturing processes to create 3D ceramic scaffolds that do much more than fill a gap. These intricate structures act as a temporary guide for the body's own healing processes.

Imagine a porous, biodegradable framework that surgeons can implant into a damaged bone to promote healing. This scaffold is not a solid block; it is filled with a network of interconnected pores and channels that allow blood vessels to grow inside, delivering oxygen and nutrients, while bone cells migrate in and begin to multiply. Over time, as the new natural bone tissue matures, the scaffold resorbs safely, leaving behind a fully regenerated bone. This approach harnesses the body's innate ability to heal itself, reducing the need for multiple surgeries.

Two key innovations are driving this progress in engineered bioceramics. The first is additive manufacturing, also known as 3D printing. Traditional ceramic manufacturing limits the shapes and internal architectures that can be created. 3D printing, however, builds objects layer by layer, allowing for the creation of patient- and defect-specific implants. Techniques such as binder jetting, extrusion, and vat photopolymerization can fabricate scaffolds that closely mimic the natural architecture of human bone. This precision enhances both the mechanical strength of the scaffold and the body's ability to integrate with it.

The second innovation is the introduction of "smart" additives. Researchers can now incorporate tiny, safe amounts of therapeutic elements, such as silver, strontium, or zinc, directly into the ceramic structure. This simple addition endows the material with powerful abilities, such as stimulating bone growth, fighting off bacterial infection, and helping control inflammation. In this way, the material shifts from being a passive placeholder to an active communicator, engaging with the surrounding tissue to guide and accelerate healing.

In our lab at Washington State University, we use various 3D printing methods to engineer advanced bioceramic materials. As shown in Figure 1, we have printed parts such as hip-stem segments, tibial inserts, bone plates, and porous blocks from calcium phosphate ceramics, demonstrating the precision with which these materials can be shaped for patient-specific defects. Beyond geometry, we tune biological performance through dopants such as zinc and silver, which support osteogenesis and help limit bacterial activity, respectively, and through natural compounds that provide additional therapeutic effects.

While degradable calcium phosphate scaffolds support tissue regeneration, dense structural ceramics remain essential for long-term load-bearing roles. Materials such as alumina and zirconia offer high wear resistance, fracture toughness, and chemical stability, making them well-suited for components such as femoral heads, dental crowns, and joint-replacement bearings. These nonresorbable ceramics complement the biological advantages of degradable systems and broaden the range of available solutions for orthopedic and dental care.

What makes today's progress in bioceramics so notable is the integration of long-standing ceramic knowledge with advanced manufacturing techniques. Traditional concepts of clay, powders, and heat now integrate with 3D printing and therapeutic additives. Whether porous and resorbable or dense and permanent, ceramics have become practical, adaptable materials for restoring tissue and supporting long-term function. Their role continues to grow as we refine how these materials interact with both mechanical demands and biological environments.

Priya Kushram is a Ph.D. candidate in mechanical and materials engineering at Washington State University. Her research in Professor Susmita Bose's group focuses on the additive manufacturing of calcium phosphate-based implants for repairing large bone defects. Outside the lab, she enjoys working out, playing board games, and trail hiking. ■


Advancing
NEW POSSIBILITIES