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emerging ceramics & glass technology

SEPTEMBER 2022

Additive manufacturing of yttria-stabilized zirconia and lithium silicate electroceramics for energy applications

New issue inside:

ACerS Awards of 2022 | 3D printing a nuclear future | Single-step ceramics AM

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Lithography-based 3D-printed yttria fully stabilized zirconia (8 mol % YSZ) immediately after printing with residue slurry, still on the parts surface. *Credit: John Zaengle*

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As seen on *Ceramic Tech Today*...

Credit: NASA's James Webb Space Telescope, Flickr (CC BY 2.0)

Cosmos creation—exploring formation of ceramic materials in space

The universe contains many complex chemistries and phenomena yet to be discovered or explained. Two recent studies offer a glimpse into how some ceramic materials may form in space.

Read more at www.ceramics.org/cosmos-creation

Also see our ACerS journals...

Research, standards & data needs for industrialization of ceramic direct ink writing
By A. J. Allen, I. Levin, and R. A. Maier
International Journal of Ceramic Engineering & Science

Electromechanical properties of paper-derived potassium sodium niobate piezoelectric ceramics
By L. Wahl, J. G. Maier, S. Schmiedeke, et al.
Journal of the American Ceramic Society

Martian regolith—Ti_6Al_4V composites via additive manufacturing
By A. Afrouzian, K. D. Traxel, A. Bandyopadhyay
International Journal of Applied Ceramic Technology

Improved additive manufacturing of silicon carbide parts via pressureless electric field-assisted sintering
By A. Bratten, R. Chen, J. Rittenhouse, et al.
International Journal of Applied Ceramic Technology

Influence of the dispersant on the parts quality in slurry-based binder jetting of SiC ceramics
By S. Diener, H. Schubert, A. Held, et al.
Journal of the American Ceramic Society

Read more at www.ceramics.org/journals

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ACSBA7, Vol. 101, No. 7, pp 1– 72. All feature articles are covered in Current Contents.

On sustainability … A grain of humility

To the editor:

As scientists, we are trained to address the vital challenges of mankind. We believe that we will advance the well-being of people by providing available resources, warmth, communication, and mobility, and for this reason we chose this profession.

Some of us work on application-oriented problems to provide answers to societal needs, or at least needs society is convinced it needs. Other scientists solve basic scientific challenges, either for the thrill of challenging discovery or to lay the groundwork for new approaches to solving application-related questions.

Therefore, it seems natural that we consider ourselves vital in solving mankind's quest for ever-lasting sustainability.

Two worries come to mind.

1. We may have read the "Limits of growth," published 50 years ago by D. H. Meadows et. al.[1] We also may have read the last report of the International Panel on Climate Change.[2] Why, then, if scientists are educated about the limits of our planet's resources and the futile combat to keep the problem at bay, do we still expect ourselves to be the true heroes?
2. If our politicians are correct that we need at least 2% of economic growth (in China, the number was said to be 9%) to keep going, then we are certainly worried about our laws of thermodynamics and about our simple mathematical understanding that an exponential function is prone to hit a ceiling in a confined sample. Right?

The answer to these worries is rather simple: Scientists will not provide the solution to an unsolvable, ill-posed problem. In traveling from international conference to international conference, meeting in new fancy hotels, we may have an enormous carbon footprint and may be a part of the problem ourselves.

So, what to do?

Science is not the complete answer to the world's most pressing quest for eternal sustainability. It is, however, a key junction to connect economic models to reality and can provide a reality check for the latter.

If we had guts, we would confess to a grain of humility and would say we can assist to reduce the imbalance between resources and mankind's abuse of resources, but the problem is a socio-political one in the end. As Mahatma Gandhi put it in 1992, "The world has enough for everyone's needs, but not everyone's greed."

More so, if we would accept that every nation and every human being is entitled to the same energy consumption and same mineral resources, we would realize all that's required is *a grain of humility and a generous share of empathy*.

This knowledge may not increase our research dollars; possibly we should even reduce our own carbon footprint to retain some credibility.

Does that sound rough and awfully inconvenient?

Yes, but as researchers we are still needed on two fronts.

1. Apply our understanding and application-oriented research to power toward sustainability.
2. Persevere on basic research as, in the end, true innovations may stem from goal-oriented basic science where—with an open eye—we discuss new phenomena desperately needed for lasting sustainability.

But we also have responsibility as educated citizens, communicators, and teachers. Specifically,

1. Discuss the biggest challenge of this planet in your colleague's circles, in your community, and with other groups, and pledge to limit your carbon footprint by reducing your mobility, heating/cooling, consumption, etc. For example, forfeiting an international return flight from Los Angeles to London reduces carbon footprint by 2.9 tonnes, the equivalent of more than the carbon footprint of an Indian or Brazilian citizen per year.
2. Get vital interest groups into the discussion. For example, why are high-school students forming powerful interest groups while undergraduate and postgraduate students are only slain with our demands to study lecture notes? Why are they not standing up as they did some decades ago?

In the end, the path is blatantly clear: Scientists need to move society onto a straight—but rocky and long—path to sustainability. The alternative is a path that is convenient only for a short distance and leads to the wide-spread disaster you may read about in other documents.

Beyond the simple suggestions, here are some recommendations.

- Read the three references provided.
- Embrace "A grain of humility and a generous share of empathy."
- "Come on!"[3]

Sincerely,

Jürgen Rödel, FACerS
Technische Universität Darmstadt, Germany
Roedel@ceramics.tu-darmstadt.de

References

[1]Donella H. Meadows, Dennis L. Meadows, Jorgen Randers and William W. Behrens III, "The limits to growth," Potomac Associates (1972)

[2]Intergovernmental Panel on Climate Change, "Climate change 2022—Impacts, adaptation, and vulnerability," IPCC website www.ipcc.ch

[3]Ernst Ulrich von Weizsäcker, Anders Wijkman, "Come on! Capitalism, short-termism, population, and the destruction of the planet," Springer, New York (2018)

news & trends

CHIPS+ nears the finish line after two plus years of discussion

House Speaker Nancy Pelosi (center, purple jacket) held a bill enrollment ceremony for the CHIPS and Science Act on July 29, 2022, a day after its passage in the U.S. House of Representatives.

Credit: Nancy Pelosi, YouTube

On July 28, 2022, the United States House of Representatives approved the CHIPS and Science Act of 2022, sending the legislation to President Joe Biden for his signature.

This act, colloquially called CHIPS+, is the culmination of months-long negotiations between the House and Senate to reconcile their America COMPETES Act of 2022 and U.S. Innovation and Competition Act (USICA), respectively. Congress negotiators ultimately agreed to pull out and pass a narrow set of science provisions as CHIPS+ while they continue debating the more controversial provisions of COMPETES and USICA.

The $52 billion for semiconductor R&D and manufacturing is likely the most talked about provision of CHIPS+. This money will fund programs established under the Creating Helpful Incentives to Produce Semiconductors for America (CHIPS) Act, which passed as part of the fiscal year 2021 National Defense Authorization Act.

The passage of CHIPS program funding is great news for the state of Ohio, where semiconductor chip manufacturer Intel announced plans to build a manufacturing mega-site near the state's capital. Recently, Intel delayed a groundbreaking ceremony for its $20 billion project citing the lack of CHIPS funding. However, following passage of CHIPS+ by the House, Intel CEO Pat Gelsinger announced the company is ready to move "full speed ahead" on the project.

Also included in CHIPS+ is a framework for the National Science Foundation's new Directorate for Technology, Innovation, and Partnerships (TIP). The TIP directorate was officially endorsed in the final fiscal year 2022 funding package, but the mission and scope of the directorate remained unclear due to differing visions in the House and Senate. CHIPS+ merges these frameworks, requiring the TIP directorate to focus on not more than five "societal, national, and geostrategic challenges" and not more than 10 "key technology focus areas," with each list subject to periodic revision.

In addition to these provisions, CHIPS+ sets aggressive growth targets for the topline budgets of NSF, NIST, and the DOE Office of Science, as well as for certain major programs within each agency. An FYI article describes out how the funding will be distributed among these agencies. Notably, in contrast to the semiconductor funds, the agency funds are only "authorizations," meaning Congress is not obligated to provide the money and will decide whether to meet the targets on a year-by-year basis.

Further details on the CHIPS+ provisions can be seen on the House Committee on Science, Space, & Technology website at https://science.house.gov/chipsandscienceact. ■

Minerals Security Partnership advances multinational commitment to bolstering critical mineral supply chains

A new Minerals Security Partnership was announced during the annual Prospectors & Developers Association of Canada convention in mid-June 2022.

The Minerals Security Partnership is a multinational partnership initiative that aims to ensure critical minerals are "produced, processed, and recycled in a manner that supports the ability of countries to realize the full economic development benefit of their geological endowments," according to a U.S. Department of State media note.

The new Minerals Security Partnership announced in mid-June 2022 includes Australia, Canada, Finland, France, Germany, Japan, South Korea, Sweden, the United Kingdom, the United States, and the European Commission.

Credit: Under Secretary for Economic Growth, Energy, and the Environment, Twitter

The 11 participants in the new partnership are Australia, Canada, Finland, France, Germany, Japan, South Korea, Sweden, the United Kingdom, the United States, and the European Commission. Together they plan to "catalyze investment from governments and the private sector for strategic opportunities … that adhere to the highest environmental, social, and governance standards," the media note says.

In recent days, several Indian news sites reported there are growing concerns in India over being left out of the new partnership.

"India relies heavily on China for [heavy rare earth elements], which is one of the leading producers with an estimated 70 percent of the global production," reports New Delhi-based news site *WION*. "Hence, there is a lot at stake for India."

According to *The Indian Express*, the Union Finance Ministry reportedly communicated with the Ministry of External Affairs to explore the possibility of New Delhi joining the 11-member group.

While India traditionally has remained an outlier to such initiatives, the Indian government has ambitious plans to improve India's standing in various advanced technological areas, for example, renewable energy, decarbonization efforts, and semiconductor production. Additionally, in May 2022, India and the U.S. launched a new joint initiative on critical and emerging technologies following a bilateral meeting during the Quad Leaders' Tokyo Summit 2022. ■

Corporate Partner news

Lithoz wins Licensing Executive Society International Innovation Award in "Small Enterprises" category

Lithoz GmbH, global market leader in ceramic 3D printing, was selected as the winner of the 2022 Licensing Executives Society International Innovation Award in the "Small Enterprises" category.

The goal of the LESI Innovation Award is to highlight recent studies in innovations and licensing, as well as recognize outstandingly innovative approaches in licensing technology that lead to long-term market innovations and a leading market position.

Speaking on behalf of the LESI Innovation Trends Committee about Lithoz's win, André Gorius stated that "the submission, with its solid invention value creation process, impressive collaborative teamwork and partnership strategy, and clear identification of roadblocks along the whole value chain, aligned perfectly with our focus on the best way to detect and manage trends in innovation." ■

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DGG centennial celebrated at International Congress on Glass

By Thomas Jüngling

The 26th International Congress on Glass, held July 3–8, 2022, in Berlin, Germany, was hosted by nonprofit glass association Deutsche Glastechnische Gesellschaft e.V. (DGG).

The Congress included the 13th International Congress on Advances in Fusion and Processing of Glass and the 95th Annual Meeting of DGG. In addition, the United Nations International Year of Glass (IYOG) and the DGG centennial anniversary were celebrated, and DGG received a commemorative plague and glass memento from The American Ceramic Society.

This Congress was the first opportunity for glass experts from around the world to meet and share their latest experience on glass science and technology, plus develop new collaborations and refresh old ones, since the 25th ICG in 2019, which was hosted by ACerS Glass & Optical Materials Division in Boston, Mass.

More than 870 participants from 37 countries attended the Congress, which offered a strong and vibrant scientific and technical program with 456 lectures and 131 posters in 38 technical sessions structured in nine symposia. Topics covered at the Congress included chemistry and structure of glasses, glass physics, properties and characterization, computational glass science, sustainable glass production, glass forming, post-processing and quality control, recycling and raw materials, emerging glass applications and application-related challenges, culture and heritage, education, and FunGlass.

The program was put together by Congress president Joachim Deubener and program chair Lothar Wondraczek with the support of the session organizers and partners in the ICG Technical Committees. DGG is grateful for the excellent contributions and support by the international glass community. The conference was complemented by an exhibition area, where 11 companies displayed their product offerings.

During the opening ceremony, Heinz Kaiser, president of nonprofit research association Hüttentechnische Vereinigung der Deutschen Glasindustrie e.V. (HVG), gave a brief review of DGG history. The founders of the predecessor organization of HVG founded DGG in 1922 with the goal to enable networking between technical and scientific glass experts and, as a result, to further optimize the glass manufacturing process. The intention proved to be sustainable and continues to be relevant for the successful future of glass science and technology.

The Congress graciously provided SCHOTT AG the opportunity to present its Otto Schott Research Award to two ACerS members: Alicia Durán (second right), FACerS, research professor for the Spanish Research Council, and Daniel Neuville (third left), senior research director at the Institut de Physique du Globe de Paris at University of Paris.

Credit: Bedenkzeitfotografie, DGG

The following awards were presented during the opening ceremony and award session.

Otto Schott Research Award

The introduction was given by Matthias Müller, chairman of the Ernst-Abbe Fund.

Awardees: Alicia Durán and Daniel Neuville

ICG President's Award

Awardee: Alicia Durán

ICG Vittorio Gottardi Prize

Awardee 2020: Juejun Hu

Awardee 2021: Emma Barney

Awardee 2022: Julian Jones

W.A. Weyl Award

Awardee: Anoop Krishnan

DGG Awards

Adolf-Dietzel Industriepreis awardee: René Limbach

Goldener Gehlhoff Ring awardee: Ralf Müller

ICG held a well-attended Technical Committee Meeting and the annual meetings of the Steering Committee, Council of the Technical Committees, as well as the Council Meeting.

Initiated by Lothar Wondraczek, ICG and the IYOG Executive Committee sponsored an "IYOG Glass Future Fellow" program, which enabled 17 young international scientists to participate and display their research by presenting posters.

Social events provided excellent networking opportunities. The welcome reception was sponsored by glass manufacturer SORG, which is celebrating its 150th anniversary this year. During the dinner banquet, the international glass community celebrated the centennial of DGG. In addition to SORG, the companies SCHOTT, Nippon Electric Glass, AGC, soulbottles, Ardagh Glass, and GS Group of Companies also sponsored this event, contributing to its success.

During the closing ceremony, Joachim Deubener thanked all participants, presenters, exhibitors, sponsors, and the organization team. He then handed over the baton to the organizers of the next ICG Congress.

The 27th International Congress on Glass will be hosted by the Central Glass and Ceramic Research Institute in Kolkata, India, Jan. 20–24, 2025.

About the author

Thomas Jüngling is managing director at DGG and HVG in Offenbach am Main, Germany. Contact Jüngling at juengling@hvg-dgg.de. ■

How additive manufacturing is settling into the mainstream

By Helia Jalili

This article first published in the *Society of Vacuum Coaters Bulletin*, Fall/Winter 2021. Condensed and republished with permission.

The global market for 3D printing, or additive manufacturing, was valued at more than $15.6 billion in 2020 and is forecasted to reach more than $54 billion by 2026, growing at a compound annual growth rate (CAGR) of 23.7%.

Examples of advances in 3D printers, materials, and software that create thriving emerging markets include

- **3D microfabrication**. This process involves fabricating miniature structures on micrometer scales and smaller using 3D printing. The main technologies used in 3D microfabrication include microstereolithography, microlaser sintering, and electrochemical deposition. Two-photon polymerization is used for 3D fabrication at the nanoscale. 3D microfabrication often is used to create new designs for electronics, but it is also used to produce medical devices.
- **4D printing**. The process whereby a 3D-printed object transforms itself post-production into another structure through the influence of an external stimulus such as light or heat. 4D printing is still in its infancy, but researchers are working on its implementation in various applications, such as self-repairing architecture and preventive medicine devices.
- **Sustainable 3D printing materials**. One of the most widely used 3D printing materials, polylactic acid, is a bioplastic derived from renewable materials such as corn, sugarcane, or tapioca. New environmentally friendly 3D printing materials coming to market are made from recycled plastics or various biodegradable materials. Plus, various plant-based filaments are being developed, such as from soy and seaweed.
- **Food technology**. At present, 3D-printed food is associated in many peoples' minds with sugary desserts like chocolates and sweets. However, some startups are developing 3D-printed meat and fish products that mimic the taste, texture, and even smell of the real thing but with 3D-printable and plant-based materials.
- **Fashion**. Footwear with 3D-printed components (e.g., uppers, lowers, and insoles) has gone relatively mainstream, generating estimated revenues of $1.5 billion for shoe manufacturers in 2020. Further use of 3D printing technology in this sector could lead to sustainable, zero-waste fashion.

North America had the largest share of the additive manufacturing market in 2020 with a value of $6.5 billion, which is forecasted to grow at a CAGR of 21.5% to reach almost $21 billion by 2026. Europe held the second-largest market share with $4.6 billion. Although Asia had a slightly smaller market share at $3.7 billion, their forecasted CAGR of 27.5% will position them as the second-largest market shareholder by 2026 with $16 billion.

About the author

Helia Jalili is director of research–science and technology at BCC Research. She has a Ph.D. in materials physics and more than 15 years of R&D experience with functional materials for energy applications, spintronics, superconductivity, and additive manufacturing. Contact Jalili at Helia.Jalili@bccresearch.com.

Resource

H. Jalili, "Market watch: How additive manufacturing is settling into the mainstream," *Society of Vacuum Coaters Bulletin* Fall/Winter 2021. https://www.svc.org/Publications/SVC-Bulletin.cfm

Further readings

"Advanced materials for 3D printing: technologies and global markets" BCC Research Report AVM101D, August 2022. https://bit.ly/3SpqFpi

"Additive manufacturing in powder metallurgy: global markets" BCC Research Report AVM231A, July 2022. https://bit.ly/3Jpa6WF

"3D printed medical devices" BCC Research Report IFT173B, January 2022. https://bit.ly/3Spr5vS

"Global markets for 3D printing" BCC Research Report MFG074B, October 2021. https://bit.ly/3zrjk00

View more materials reports at www.bccresearch.com/collections/materials. ■

Table 2. Additive manufacturing technologies and materials

Process/Technology	Polymers	Metals	Ceramics	Composites
Powder bed fusion				
Selective laser sintering	✓	✓	✓	✓
Direct metal laser sintering		✓		
Electron beam melting		✓		
Selective heat sintering	✓			
Selective laser melting		✓		
Vat polymerization				
Stereolithography	✓			✓
Digital light processing	✓			
Material extrusion				
Fused deposition modeling	✓			
Inkjet printing				
Material and binder jetting	✓	✓	✓	✓
Directed energy deposition				
Laser metal deposition		✓		✓
Electron beam additive manufacturing		✓		
Ion fusion formation		✓		
Laser powder forming		✓		
Laminated object manufacturing	✓	✓	✓	✓
Ultrasonic consolidation		✓		

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS Corporate Partner

ACerS is pleased to welcome its newest Corporate Partner.

Sapphire Corporate Partner

SIERRA SPACE

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

Dayton/Cincinnati/Northern Kentucky Section welcomes new leadership

Congratulations and welcome to the new members of the Dayton/Cincinnati/Northern Kentucky leadership.

Chair: **Chenggang Chen**, University of Dayton Research Institute

Secretary: **John Drazin,** Air Force Research Laboratory

Treasurer: **Stephanie Chapman**, Fusite Division of Emerson Electric

Welcome to the newest ACerS Section! ■

Italy Chapter helps organize first in-person event since start of COVID-19 pandemic

Members of the ACerS Italy Chapter and POLITO's Glance Group and Advanced Joining Technologies Group collaborated with the Research Group on Ceramic Matrix Composite Materials and the CNRS LCTS Lab to organize the first Italian-French in-person event since the start of the COVID-19 pandemic.

The meeting took place June 25, 2022, in Perugia, Italy, and featured presentations about ceramic matrix composites research and technical developments in Italy, France, and Germany. ■

Spain Chapter and Spanish Society of Materials award Alicia Durán the scientific career in glass and ceramics prize

Alicia Durán was awarded the 2022 Spanish Society of Materials–ACerS Spain Chapter prize for her scientific career in glass and ceramics during the National Materials Congress, June 28–July 1, 2022.

The awarding committee awarded the prize to Durán for her prominent research in glass, vitroceramics, and materials produced by the sol-gel route, ranging from basic and fundamental research to technological development for the glass industry. ■

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FOR MORE INFORMATION:

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Germany Chapter welcomes new leadership

Congratulations and welcome to the new members of the Germany leadership.
Chair: **Aman Bhardwaj**, University of Cologne
Vice chair: **Anna Verma**, University of Cologne
Secretary: **Ziyaad Aytuna**, University of Cologne
Treasurer: **Ruth Adam**, Institute of Inorganic Chemistry, University of Cologne
DEI officer: **Aida Raauf**, Institute of Inorganic Chemistry, University of Cologne ■

Germany Chapter celebrates summer with several outings and workshops

ACerS executive director Mark Mecklenborg, left of center (blue shirt), met with the Germany Chapter before going to Poland for ICC9 and the Ceramics in Europe Conference. The visit culminated in a wine tour in Ahrtal, Germany, on July 9, 2022.

The Germany Chapter organized the University of Cologne–German University in Cairo Joint Workshop on Ceramics in Nano-bio in Cologne, Germany, on July 7, 2022.

The Germany Chapter participated in the Trilateral Indian–German–Korean Workshop in Cologne, Germany, on June 24, 2022. President-elect Sanjay Mathur, far left, welcomes the participants.

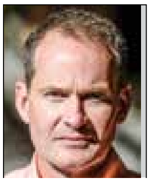
Krakow, Poland, welcomes Ceramics in Europe Conference

The opening ceremony of the Ceramics in Europe Conference included a performance by the AGH University Representative Orchestra.

The Ceramics in Europe Conference comprised three conferences in one venue: The European Ceramic Society XVII, 9th International Congress on Ceramics, and Electroceramics XVIII. Recognizing the time and budget challenges that linger with the pandemic, organizers of these three events joined together to present all three events in one venue. Ceramics in Europe took place July 10–14, 2022, in Krakow, Poland. *JACerS* editor-in-chief, William Fahrenholtz, FACerS, gave the opening plenary lecture on structure and properties of zeta-phase tantalum carbide. The European Ceramic Society conferred several awards on ACerS members, which are highlighted in the box (right). ■

Names in the news

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



John Ballato, FACerS, J. E. Sirrine Endowed Chair of Optical Fiber at Clemson University, received the 2022 William Streifer Scientific Academic Achievement Award from the IEEE Photonics Society.

Cato Laurencin, FACerS, Albert and Wilda Van Dusen Distinguished Endowed Professor of Orthopaedic Surgery at University of Connecticut, will receive the 2023 Priestley Medal, the American Chemical Society's highest honor. ■

ECerS Award Winners

Jérôme Chevalier, full professor at the National Institute of Applied Sciences (INSA–Lyon), France, received the 2022 Stuijts Award.

Bikramjit Basu, FACerS, professor at the Materials Research Center, with joint appointments in the Interdisciplinary Center for Energy Research and Center for Biosystems Science and Engineering at Indian Institute of Science, Bangalore, received the 2022 Richard Brook Award.

Ralf Riedel, FACerS, full professor in the Institute of Materials Science at the Technical University of Darmstadt, Germany, received the 2022 JECS Trust Award. ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

Ceramic Tech Chat: Katherine Faber

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

In the July episode of Ceramic Tech Chat, Katherine Faber, FACerS, Simon Ramo Professor of Materials Science at the California Institute of Technology, shares her journey to researching ceramic materials, how she got involved with studying objects of cultural heritage, and describes some of her recent projects. Check out a preview from her episode, which features Faber describing how she became involved in cultural heritage research.

"During my 27-year career at Northwestern University, I spent a five-year term as department chair. During that term, I was paid a visit by a few folks from the Art Institute of Chicago. And they told me that they had received a grant to hire their very first conservation scientist. And they asked me, 'When we hire this person, although [we] have a large conservation lab filled with conservators, we are a bit concerned that that person may not have a community of scholars to interact with. Do you think you and your department might be interested in that?' And it took me about a nanosecond to say, 'Of course we would be.' ... So, through the years, this went from a partnership that was supported by the Mellon Foundation to ultimately the Northwestern University–Art Institute of Chicago Center for Scientific Studies in the Arts, where through a lot of the shared facilities at Northwestern we were able to invite other museums without laboratories to submit proposals to have some of the work done there."

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

ACerS Fellows organize 34th Annual All Iowa Glass Conference

ACerS Fellows Steve Feller and Mario Affatigato of Coe College and Steve Martin of Iowa State University organized the 34th Annual All Iowa Glass Conference on July 28, 2022. About 60 people attended, nearly all of which were students. ■

IYOG international workshop: Antifragile glass

As part of the many initiatives taking place to celebrate the UN International Year of Glass 2022, Università Ca' Foscari planned a multidisciplinary congress on glass called "Antifragile glass." This international workshop is dedicated to promoting the technological, scientific, and artistic role of glass in contemporary society.

The workshop takes place Nov. 17–19, 2022. For more information, visit https://www.antifragile.venezia.it/en/antifragile-glass. ■

IN MEMORIAM

Frank Kalman

Jon K. Tabor

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

Volunteer spotlight

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

Patel

Tulsi Patel is a National Research Council Postdoctoral Research Associate at the Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio. She received a B.S. in chemical engineering and an M.S. and Ph.D. in materials science and engineering from the University of Connecticut. She also has an M.S. in materials engineering and nanotechnology from Politecnico di Milano, Italy.

Patel has been an active member of ACerS since 2016. She is a member of the Electronics and Engineering Ceramics Divisions. She is the immediate past chair of the Dayton/Cincinnati/Northern Kentucky Section and serves as a mentor to undergraduate and graduate students through the ACerS Student Mentor Program. In the past, she volunteered for events such as the NSTA Regional Conference, MS&T Student Contests, and PCSA Winter Workshop Planning Committee. She also participated in the 2018 ECerS Electroceramics Summer School in Hasselt, Belgium.

Patel was selected for the 2022–2023 AAAS Science and Technology Policy Fellowship in the Office of the Secretary of Defense.

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

AWARDS AND DEADLINES

Attend your Division business meeting at MS&T22

Six of ACerS Divisions will hold executive and general business meetings at ACerS Annual Meeting in conjunction with MS&T22 in Pittsburgh, Pa. General business meetings will be held Monday or Tuesday in the David L. Lawrence Convention Center. Plan to attend to get the latest updates and to share your ideas with Division officers.

Monday, Oct. 10

Glass & Optical Materials Division: 11 a.m.–12 p.m.

Electronics Division: Noon–1 p.m.

Engineering Ceramics Division: Noon–1 p.m.

Energy Materials and Systems Division: 5:30–6:30 p.m.

Tuesday, Oct. 11

Basic Science Division: Noon–1 p.m.

Art, Archaeology & Conservation Science Division: TBD ■

2023 Class of Fellows nominations deadline: Jan. 15, 2023

ACerS Fellows are members who have made outstanding contributions to the ceramic arts or sciences through productive scholarship or conspicuous achievement in the industry or by outstanding service to the Society. Nominees shall be persons of good reputation who have reached their 35th birthday and who have been members of the Society at least five years continuously. Questions may be directed to Erica Zimmerman at ezimmerman@ceramics.org. ■

Do you qualify for Emeritus membership?

If you will be 65 years old (or older) by Dec. 31, 2022, and will have 35 years of continuous membership in ACerS, you are eligible for Emeritus status. Note that both criteria must be met. Emeritus members enjoy waived membership dues and reduced meeting registration rates. To verify your eligibility, contact Erica Zimmerman at ezimmerman@ceramics.org. ■

STUDENTS AND OUTREACH

FOR MORE INFORMATION:

www.ceramics.org/students

ACerS student tour to Almatis

All MS&T student registrants are invited to tour Almatis in Leetsdale, Pa., on Oct. 12, 2022, during ACerS Annual Meeting in conjunction with MS&T. Space is limited and registration is on a first come, first served basis. To register, visit www.matscitech.org/MST22 and navigate to the "Students" tab. The deadline to register is **Sept. 7, 2022**. If you have any questions, please contact Yolanda Natividad at ynatividad@ceramics.org. ■

ACerS Ceramographic Exhibit & Competition

ACerS Ceramographic Exhibit & Competition, organized by the ACerS Basic Science Division, is an annual poster exhibit that promotes the use of microscopy and microanalysis in the scientific investigation of ceramic materials. The competition is held at ACerS Annual Meeting in conjunction with MS&T, which this year takes place in Pittsburgh, Pa., **Oct. 9–12, 2022**.

The Roland B. Snow Award is presented to the Best of Show winner of the competition. Winning entries are featured on the back covers of *Journal of the American Ceramic Society*.

Learn more and apply at http://bit.ly/RolandBSnowAward. ■

Ceramic mug drop and disc golf contests at MS&T22

The Ceramic Mug Drop contest allows students to demonstrate their prowess in designing and manufacturing a ceramic mug possessing high strength, mechanical reliability, and/or aesthetics. Mugs fabricated by students from ceramic raw materials are judged (separately) on aesthetics and then by dropping them from ever-increasing heights. The mug with the highest successful drop height wins.

The Ceramic Disc Golf contest asks students to create discs from ceramic or glass materials that can withstand being thrown into a regulation disc golf basket. Each disc will be judged in the categories of farthest distance achieved and artistic merit (aesthetics). The disc that is successfully thrown into the disc golf basket from the farthest distance in the fewest number of shots will be named winner. The most aesthetically pleasing/creative disc will be recorded as "Best Looking" disc.

Both contests are sponsored by Keramos. For more information on entering, visit https://bit.ly/3OKZnad. ■

Give GGRN a 'like' on Facebook!

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

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

CERAMICANDGLASSINDUSTRY FOUNDATION

Physics professor uses Materials Science Classroom Kits to inspire students

You are 15 years old, excited for summer and sports camp with your friends. But your mom has different plans and sends you to a science camp at a local college. Moping around on your phone, daydreaming about sports camp—until the sound of breaking glass in the lab catches your attention.

This reaction is just one that Casey Schwarz witnessed during the 2019 Glass and Materials Science (GaMES) summer camp at Ursinus College in Collegetown, Pa. The breaking glass was a part of a thermal shock experiment.

"Not everybody, not (all) high schoolers know what materials sciences is, and just giving them this idea of this is a job that people get, or this is a science people can go into, I think that's important," Schwarz says.

Schwarz has not always worked with younger students, though. Originally, she planned to work in either a research lab or industry.

After earning her Ph.D. in physics at the University of Central Florida in 2012, Schwarz stayed on as a postdoc. It was then she began teaching and working with undergraduate students. Now, Schwarz works as a materials scientist and assistant professor of physics at Ursinus.

"These students are just figuring out what they want to do and what they're interested in," Schwarz says. "There are also high schoolers that are interested the same way … then how can we make this accessible to even younger students that we work with?"

Schwarz was able to expand access in the summer of 2019 after receiving a grant from the Ceramic and Glass Industry Foundation (CGIF). The grant funded the acquisition of 10 Materials Science Classroom Kits and helped Schwarz create a glass and materials science summer camp.

The GaMES camp served underrepresented 9-to-15-year-old students in the area.

"We were looking for diverse applicants, people who might not be going to any kind of summer camp, just getting kids aware of materials science at a very young age," Schwarz says.

Combining science with fun, GaMES held contests like seeing who could draw out the longest, string-like candy fiber from a beaker of melted hard candy with a wooden stick. This activity demonstrates what a glass fiber looks like.

A testament to the camp's success, Schwarz notes that many younger siblings—dubbed "The Littles"—tagged along. GaMES helped children garner more interest in science.

"More of them saw themselves as being someone who could do science," she says. "I had a ton of parents contact me and said that they wanted to do it again."

Due to COVID-19, GaMES has not taken place since 2019, but Schwarz plans to revive it in the future. Still, Schwarz perseveres with other means of outreach. With the help of her graduate assistant Quentin Altemose and the CGIF, Schwarz is currently developing a glass-only science kit.

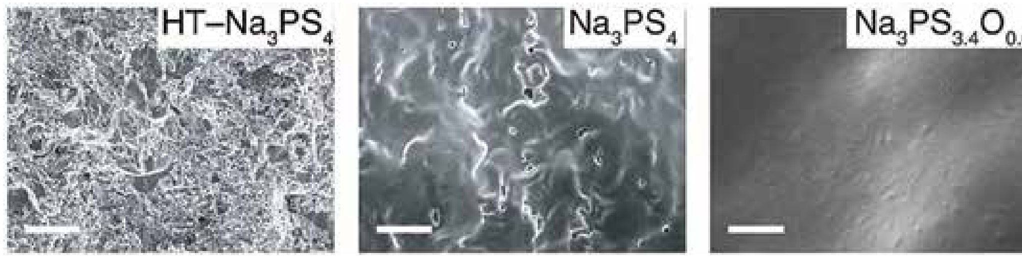
Ursinus College assistant professor Casey Schwartz, right, demonstrates a concept at the 2019 Glass and Materials Science (GaMES) summer camp.

Having a positive impact is also something Schwarz embodies with her outreach efforts.

"You don't know how influential you can be, just like the feeling of showing somebody (anything) for the first time ... there are all these little firsts that could spark something, some kind of imagination," Schwarz says.

Schwarz views science the same way many young students do: "It's all playing. I mean, that's all it is," she says. "We're not testing them or anything. So it's just, like, play around with some material, really have fun with it. That's what science is about." ■

Oxysulfide glass electrolytes show promise for making all-solid-state sodium batteries a reality



Cross-sectional morphology of heat-treated glass-ceramic Na_3PS_4 (left) and glass $Na_3PS_{4-x}O_x$ solid electrolytes (center and right). Scale bar 10 µm.

Researchers led by University of Houston and Iowa State University propose a new homogeneous oxysulfide glass electrolyte could make ambient-temperature all-solid-state sodium batteries a reality.

All-solid-state sodium batteries use nonflammable solid-state electrolytes and earth-abundant sodium metal anodes, giving them an edge in both safety and cost compared to lithium-ion batteries.

Currently, the only successfully commercialized battery featuring a sodium metal anode is the high-temperature sodium–sulfur battery. However, with a required working temperature above 300°C, both the sodium anode and sulfur cathode are liquids, which significantly increases the operational cost and decreases safety due to potential catastrophic failure of the thin ceramic solid-state electrolyte.

A sodium battery that operates at ambient temperatures (under 100°C) with a solid sodium metal anode would allow for safer usage in a broader range of applications. However, when the sodium metal anode is in a solid state, the solid electrolyte must now be not only resistant to direct chemical and electrochemical reaction with sodium but also resistant to solid metallic sodium dendrite penetration.

Researchers have investigated different materials as solid electrolytes for ambient-temperature all-solid-state sodium batteries, including ceramics and glass-ceramics. However, these inorganic electrolytes come with pros and cons.

The new study on the homogeneous oxysulfide glass electrolyte traces its origins to an earlier paper published in 2020 by the Iowa State co-authors, ACerS Fellow Steve Martin and ACerS member Steven Kmiec. In that paper, they explain that Na_3PS_4 is a promising solid-state electrolyte due to its high ionic conductivity, but it is known to be unstable against sodium metal. However, through experimentation, they discovered that adding oxygen to Na_3PS_4 to create Na_3PS_3O will significantly slow the reaction with sodium metal.

In the new paper, they along with the University of Houston researchers and collaborators at Rice University, Purdue University, and University of California, Irvine explore further the potential of this oxysulfide glass system.

They prepared the glass electrolytes via high-energy planetary ball milling of simple precursors. The resulting electrolytes were fully dense and homogeneous with robust mechanical properties. Adding oxygen boosted the mechanical strength.

For $Na_3PS_{3.4}O_{0.6}$ electrolytes, the Young's modulus and hardness were approximately 21 GPa and 1.0 GPa, respectively. These values are the highest among the $Na_3PS_{4-x}O_x$ series and are even higher than those reported for hot-pressed sulfide-based lithium-ion and sodium-ion electrolytes.

In addition to these impressive properties, the researchers state the critical current density—up to 2.3 mA cm^{-2}—is equivalent to the state-of-the-art critical current density value of lithium-based sulfide solid electrolytes.

The $Na_3PS_{4-x}O_x$ composition also enabled reversible sodium plating and stripping, which is difficult to achieve using a pure sulfide electrolyte. The researchers attribute this ability to a self-passivating interphase at the interface between the sodium metal anode and electrolyte.

When the researchers designed and tested batteries featuring tri-layer electrolytes composed of these oxysulfide glasses ($Na_3PS_{3.85}O_{0.15}$ as the inside layer and $Na_3PS_{3.4}O_{0.6}$ as the outside layers), they were able to cycle the batteries for up to 500 hours without short circuiting. Plus, the coulombic efficiency and capacity retention were much higher than those for sodium–sulfur batteries using oxide or polymer solid-state electrolytes.

"These new oxysulfide [solid-state electrolytes], as well as the tri-layer composite [solid-state electrolytes] that they enable, could pave the way for the development of new glass electrolytes for high-energy, safe, low-cost, and long-cycle-life solid-state batteries in general, and all-solid-state [sodium–sulfur] batteries for energy storage devices in particular," they conclude.

The open-access paper, published in *Nature Communications*, is "An electrochemically stable homogeneous glassy electrolyte formed at room temperature for all-solid-state sodium batteries" (DOI: 10.1038/s41467-022-30517-y). ■

Accelerated aging test suggests decades-long performance is possible for new perovskite solar cell

Princeton University and Linköping University (Sweden) researchers recently proposed a new method for performing accelerated aging tests on perovskites.

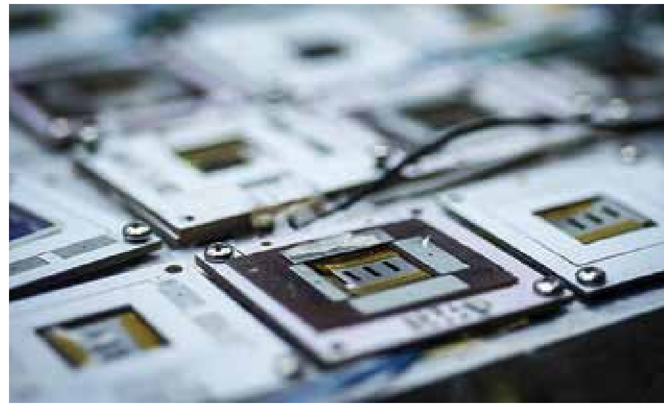
Perovskites are compounds with the same type of crystal structure as calcium titanium oxide, the mineral traditionally referred to as perovskite. When arranged in tandem with silicon, perovskites can greatly increase the power conversion efficiency of solar cells. In addition, perovskite solar cells can

- Be made at room temperature, thus lowering fabrication costs;
- Be used to design flexible and transparent solar cells, thus expanding applications; and
- Have tailorable properties for specific applications and for combining with different platforms.

The lifetime of perovskite solar cells is the main factor hindering their commercialization. Perovskite solar cells tend to deteriorate in sunlight much faster than their silicon counterparts, lasting on average just a few hundred or thousand hours rather than years.

However, compared to the early perovskites a decade ago that lasted only minutes, the lifetime is improving thanks to new compounds and structural designs. But as lifetime improves, researchers run into another hurdle—verifying the stability of these materials on the timescale of months and years.

Fortunately, accelerated aging tests can overcome the need for real-time testing. Accelerated aging tests for organic- and silicon-based photovoltaics involve quantifying the lifetime acceleration factor, which relates the lifetime under a defined standard operating condition to the lifetime under elevated stress conditions. Developing such factors for perovskites is challenging, though, because they are quite sensitive to tem-



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

An array of perovskite solar cells sits under bright light at high temperatures during an accelerated aging test developed by Princeton and Linköping researchers.

perature, light, and electrical stimuli.

The new accelerated aging test proposed by Princeton and Linköping researchers combines constant illumination (simulating full-spectrum sunlight) with elevated temperatures (up to 110°C) at the maximum power point of the solar cells. Measurements are conducted at four different aging temperatures (35°C, 59°C, 85°C, 110°C), and this data is used to forecast the device's performance at room temperature over tens of thousands of hours of continuous illumination.

They used the new accelerated aging test to evaluate a $CsPbI_3$ perovskite solar cell featuring an ultrathin capping layer to optimize light absorption while improving durability. The ultrathin capping layer (only a few atoms thick) of $Cs_2PbI_2Cl_2$ was synthesized between the perovskite active layer and the hole transport layer by treating the $CsPbI_3$ surface with a cesium chloride solution, followed by thermal annealing.

The researchers successfully described degradation rates for the $CsPbI_3$ perovskite cells using a single Arrhenius function across the entire temperature range. This result suggests the same mechanism is responsible for degradation regardless of temperature, which is an important criterion for conducting a reliable accelerated aging test.

Further proof that degradation was caused by the same mechanism came from multiplying the aging time by the acceleration factor, which resulted in an equivalent operating time (at a reference temperature of 35°C) for devices aged at elevated temperatures. All the data could be plotted on one curve for both capped and uncapped solar cells.

Testing showed the $CsPbI_3$ perovskite solar cells with an ultrathin capping layer demonstrated improved power conversion efficiency (17.4%) compared to cells without a capping layer (14.9%). The researchers claim this efficiency is the highest among fully inorganic perovskite solar cells in which all the functional materials in the stack are inorganic.

$CsPbI_3$ cells with the capping layer did not degrade at 35°C and required more than 2,100 hours at 110°C under constant illumination to degrade by 20% of their initial efficiency. Degradation acceleration factors predicted an intrinsic lifetime of more than 5 years, which equals 30 years of outdoor operation in a climate like Princeton, New Jersey. The current threshold for state-of-the art silicon solar cell lifetime is rated at 20 years.

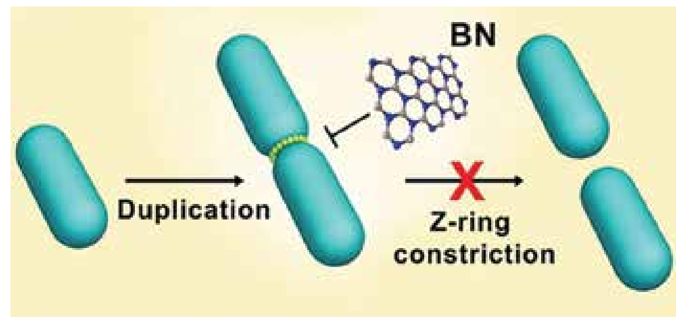
In a Princeton press release, Yueh-Lin (Lynn) Loo, senior author and the Theodora D. '78 and William H. Walton III '74 Professor in Engineering at Princeton, says while the record-setting solar cell highlights the durable potential of perovskite solar cells, the new accelerated aging test is the study's deeper significance.

"We might have the record today, but someone else is going to come along with a better record tomorrow. The really exciting thing is that we now have a way to test these devices and know how they will perform in the long term," she says.

The paper, published in *Science*, is "Accelerated aging of all-inorganic, interface-stabilized perovskite solar cells" (DOI: 10.1126/science.abn5679). ■

ceramics in biomedicine

Boron nitride nanosheets show promise as anti-bacterial drugs



Boron nitride nanosheets exhibited antibiotic-like activity to antimicrobial-resistant bacteria in a recent study. Reprinted with permission from Pan et al., *ACS Nano*. Copyright 2022 American Chemical Society.

Researchers led by Soochow University in China found boron nitride nanosheets exhibit antibiotic-like activity to antimicrobial-resistant bacteria.

Antimicrobial-resistant bacteria are a growing cause of concern around the world. Though secondary treatments are available to treat infections caused by such bacteria, these treatments can cause serious side effects, such as organ failure. Care and recovery can take much longer as well, sometimes up to months.

Scientists are investigating a variety of materials for their potential as antimicrobial agents, including

- Inorganic nanoparticles (e.g., gold, silver, copper, silica, iron oxide, zinc oxide, titanium dioxide, magnesium oxide),
- Carbon-based nanomaterials,
- Two-dimensional materials like graphene,
- Layered double hydroxides, and
- Graphitic carbon nitride.

Some of these materials, such as graphene oxide, face the limitation that they cannot tell the difference between bacteria and mammalian cells, which could lead to damage of healthy organs. Fortunately, boron nitride nanosheets do not face this limitation, as the Soochow University researchers discovered.

Boron nitride features unique lamellar, reticular, and tubular morphologies and physicochemical properties that make it attractive in numerous and varied fields, including adsorption, catalysis, hydrogen storage, thermal conduction, insulation, and radiation protection, among others.

Regarding biocompatibility, a 2017 study by Australian researchers found it depends on boron nitride's size, shape, structure, and surface chemical properties.

In the new study, the researchers explored the antibiotic-like activity of boron nitride nanosheets. Not only did the nanosheets show excellent biocompatibility in mammals, they also demonstrated potent antibacterial efficiency in five multidrug resistant bacteria strains—and they did not trigger the evolution of antimicrobial resistance during long-term use.

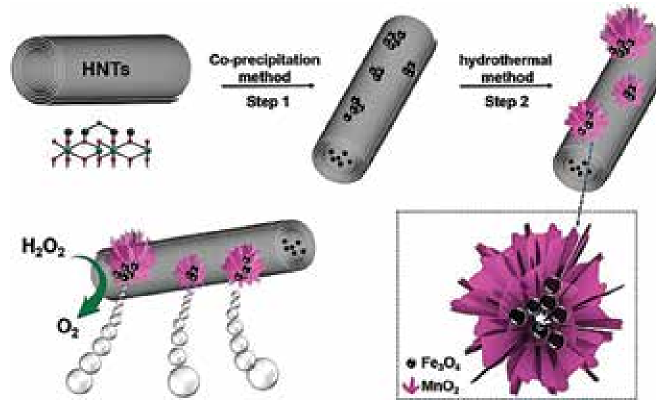
The researchers attribute the nanosheets' success to their interactions with surface proteins that are key to cell division, resulting in inhibition of bacteria growth.

"Overall, our study provided a promising type of nano-antibiotics to overcome infectious diseases induced by resistant bacteria," they conclude.

The paper, published in *ACS Nano*, is "Antibiotic-like activity of atomic layer boron nitride for combating resistant bacteria" (DOI: 10.1021/acsnano.1c11353). ■

ceramics in the environment

Clay locomotion and clean water



Schematic diagram of MnO_2–Fe_3O_4/HNTs nanomotors synthesis for bubble-propelled motion.

In two recent articles, researchers led by Jilin University in China describe the performance of clay-based materials used as self-propelled catalysts for breakdown of organic contaminants in water.

In the first article, published in 2021, the researchers doped natural tubular halloysite clay tubes with oxides of manganese and iron. The resulting material catalyzed the release of free radicals and oxygen from hydrogen peroxide. The free radicals disrupted the bonds of rhodamine B, an organic compound frequently used to model organic contaminants in natural bodies of water.

The shape of the manganese and iron oxide decorations on the surface resulted in directional release of oxygen bubbles during the reaction. This directional release propelled the nanotubes within the water, albeit in various path shapes. The randomness of the travel created a natural stirring action that provided mixing far greater than that achieved by simple Brownian motion of the reactants and catalyst. The result was rhodamine breakdown rates far exceeding those for nonmobile catalysts.

Another interesting aspect of the study was the potential to remove the catalytic nanomotors via magnetic fields. While the clay-based catalyst is relatively inert with low chemical toxicity, nanomaterials can have negative environmental effects and so should be removed after use. With the magnetic susceptibility of the iron oxides, the researchers could alter the paths of the nanomotors to follow external magnetic fields and thus collect them much more readily than with filtration alone.

In addition to low toxicity, the catalytic nanomotors were relatively low cost. The raw materials did not cost much, plus doping the halloysite with manganese and iron used facile and inexpensive precipitation and hydrothermal methods.

In a follow-up article published in 2022, the researchers reported similar results from untreated pelagic clays extracted from the floor of the Indian Ocean. They found this clay has high iron and manganese content and performed similarly to the treated clays.

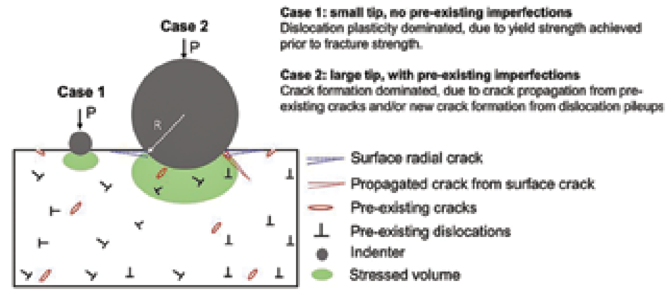
They performed further experiments exploring the effects of pH and reusability of the clay. The best performance was found at low pH values, though degradation of the clay decreased the automotive function and thus it was not reusable. Nonetheless, the potential for even lower cost catalysts was demonstrated.

The 2021 paper, published in *Journal of the American Ceramic Society*, is "Self-propelling nanomotor made from halloysite and catalysis in Fenton-like reaction" (DOI: 10.1111/jace.17821).

The 2022 paper, published in *Journal of the American Ceramic Society*, is "Deep-sea clays using as active Fenton catalysts for self-propelled motors" (DOI: 10.1111/jace.18348). ■

research briefs

Researchers improve procedures for mechanically generating dislocations in ceramics at room temperature



Credit: Fang et al., *Journal of the American Ceramic Society* (CC BY 4.0)

Schematic illustration of the indentation size effect related to dislocation activation and/or crack formation in brittle ceramic oxides. The competing effect between dislocation plasticity and crack formation is closely dependent on the indenter tip radius and pre-existing defects.

In the past year, ACerS member Xufei Fang and his group at the Technical University of Darmstadt in Germany published several open-access papers on the topic of mechanically generated dislocations in ceramics.

Dislocations, or line defects, are areas where atoms are arranged anomalously compared to the rest of the perfect crystal structure. When stress is applied, movement of these dislocations allows atoms to slide over each other, leading to plastic deformation of the material rather than brittle fracture.

In contrast to metals, which contain many dislocations that move easily, ceramics have far fewer and less mobile dislocations. There are both innate and process-related reasons for this difference.

For one, ceramic materials contain mostly covalent and ionic bonds, which are stronger than the metallic bonds found in metals. These strong bonds restrict movement of dislocations in ceramics, especially at room temperature.

The conventional sintering process for ceramics further limits possible ductility because the ceramic experiences grain coarsening, which lowers the number of dislocations in the structure.

Though there have been studies over the years looking at ceramic dislocations and their impact on functional properties, discovery of flash sintering in 2010 accelerated interest in this

Research News

In DNA, scientists find solution to engineering transformative electronics

Researchers led by University of Virginia School of Medicine used DNA to guide a chemical reaction and perform astonishingly precise structural engineering. The result was a lattice of carbon nanotubes assembled as needed for a room-temperature superconductor. The lattice has not been tested yet for superconductivity, but the researchers say it offers a proof of principle. For more information, visit https://newsroom.uvahealth.com. ■

field. Through application of an electric field, this relatively low-temperature sintering process can fully densify a ceramic within a few seconds, which limits grain coarsening and allows retention of dislocations—and thus improves a ceramic's ability to deform plastically without fracture on the microscale.

While many recent studies focus on preserving dislocations through alternative processing routes (e.g., flash sintering, thin film deposition, bicrystal bonding), groups like Fang's are exploring the use of mechanical deformation to generate dislocations as well.

Compared to flash sintering, which can result in poorly controlled dislocation structures, mechanical deformation offers the ability to align dislocations in the sample along their slip planes. However, though scientists have used nanoindentation to achieve dislocation-mediated plastic deformation in many oxides at small scale, bulk deformation is challenging due to the likelihood of crack formation during deformation.

To avoid crack formation, researchers must better understand how dislocations occur in oxides. Fang and his group approached this question by using pop-in behavior as a basis for exploration.

"Pop-in" refers to the sudden jump in displacement at a specific threshold load, appearing as a plateau in the loading curve, during nanoindentation. This jump signifies the elastic–plastic transition and indicates dislocation activation in metallic materials.

In ceramics, both dislocations and cracks typically are observed after indentation, making it difficult to clearly relate dislocation-governed plasticity with pop-in behavior.

Previous studies on ceramics indicate that using indenter tips with a smaller radius promotes dislocation generation while suppressing crack formation. However, a critical tip radius below which the pop-in event correlates only to dislocations without crack formation is not yet identified.

In a March 2021 paper published in *Journal of the American Ceramic Society* (*JACerS*), Fang and colleagues from TU Darmstadt and the Max Planck Institute for Iron Research looked to clarify the competing mechanisms of dislocation-based plasticity and crack formation during indentation tests, which could help inform the critical tip radius.

They chose strontium titanate ($SrTiO_3$), a prototype perovskite and well-known "ductile" oxide, as the model system for this study. They used three other advanced technology-relevant oxides—Al_2O_3, $BaTiO_3$, and TiO_2—to validate the generality derived from $SrTiO_3$.

Through nanoindentation testing with different tip radii, the researchers successfully achieved pop-in behavior that could be solely attributed to dislocation-mediated plasticity. Notably, for extremely small tips, a critical load P_c (larger than the pop-in load P_0) exists at which cracks start to initiate from the dislocation pileup.

"For instance, for a sharp Berkovich indenter (with an effective tip radius of R ≈ 100 nm), the pop-in load is about

$P_0 \approx 0.1$ mN, while the load for inducing cracks can be as high as $P_c \approx 3$ mN. For spherical tip (with an effective tip radius of R = 2 μm), the pop-in load is about $P_0 \approx 6{\sim}7$ mN, while the load for inducing cracks is $P_c \approx 11$ mN," they write.

In April 2022, the researchers published a follow-up open-access paper in *Scripta Materialia*. They used this knowledge concerning critical tip radius to generate dislocations without crack formation in TiO_2, leading to local enhancement of electrical conductivity by 50% compared to dislocation-free regions.

In an open-access *JACerS* rapid communication article published in December 2021, Fang and colleagues from TU Darmstadt further expanded protocols for generating dislocations using nanoindentation.

With $SrTiO_3$ as the model system, the researchers optimized parameters for a cyclic indentation procedure with a large Brinell indenter (diameter of 2.5 mm). After about 10 cycles of repetitive indentation on the same location, they achieved saturation of dislocation density of more than 10^{13} m^{-2} inside the crack-free plastic zone, with a diameter larger than 200 μm.

"The simplicity of this experimental approach merits its application for other room-temperature 'ductile' ceramics, as well as for various structural ceramics if this method is driven to high temperature," they conclude.

The March 2021 open-access paper, published in *Journal of the American Ceramic Society*, is "Nanoindentation pop-in in oxides at room temperature: Dislocation activation or crack formation?" (DOI: 10.1111/jace.17806).

The April 2022 open-access paper, published in *Scripta Materialia*, is "Dislocation-enhanced electrical conductivity in rutile TiO_2 accessed by room-temperature nanoindentation" (DOI: 10.1016/j.scriptamat.2022.114543).

The December 2021 open-access rapid communication, published in *Journal of the American Ceramic Society*, is "Mechanical tailoring of dislocation densities in $SrTiO_3$ at room temperature" (DOI: 10.1111/jace.18277). ■

Clarifying the definition and role of nucleating agents within glass-ceramic systems

In a recent paper, researchers in the United States and Brazil aimed to help advance glass-ceramics research by clarifying some terms and effects for the glass-ceramics community.

The authors of the paper are led by two ACerS Fellows: John C. Mauro, Dorothy Pate Enright Professor at The Pennsylvania State University and recently announced editor-in-chief of *Journal of the American Ceramic Society*, and Edgar D. Zanotto, senior professor at the Federal University of São Carlos and director of the Center for Research, Technology, and Education in Vitreous Materials (CeRTEV).

The authors begin by proposing a clear definition for nucleating agent: *a minority component of the glass composition that leads to increased internal nucleation rates or precipitation and control of desired crystal phases, either by lowering the thermodynamic or the kinetic barrier for nucleation, or some combination thereof.*

Vintage CorningWare dish made from the glass-ceramic Pyroceram. Researchers in the United States and Brazil aimed to help advance research in the area of glass-ceramics by clarifying some terms and effects.

Credit: Gerrilynn Nunley, Flickr (CC BY 2.0)

After breaking down in detail each part of the definition, they provide a table that summarizes the known nucleation mechanisms, nonmetallic nucleating agents, and functionalities based on more well-studied to thoroughly examined systems.

Regarding the nucleating agents, the authors note that to the best of their knowledge, no single component is reported to behave as an effective nucleating agent for all systems, except "water" (OH^-). However, "a small group of compounds is commonly used in various systems," including the oxides TiO_2, ZrO_2, P_2O_5, Ta_2O_5, MoO_3, WO_3, Fe_2O_3, Nb_2O_5, and Cr_2O_3.

Following this section, the authors discuss the complementary roles of thermodynamics and kinetics in the nucleation process. As their proposed definition for nucleating agent emphasizes, nucleating agents support crystal growth by lowering the thermodynamic and/or kinetic barrier for nucleation. However, characterizing and parameterizing the thermodynamics and kinetics of a system and separating their influence on nucleation is a major challenge for researchers.

The authors suggest one strategy for inferring whether a nucleating agent influences kinetics, thermodynamics, or both is to analyze their simultaneous effect on crystal nucleation and growth rates. Thermal analysis of the parent glass performed via differential scanning calorimetry can help clarify these influences.

At this point of the paper, with a framework established for defining nucleating agents and their effect on nucleation, the authors select a few common nucleating agents (TiO_2, ZrO_2, MoO_3, P_2O_5, and OH^-) to demonstrate the strength of their framework.

"However, there is still much to be learned, especially because of the breadth of possible combinations of nucleating agents to glass-ceramic system relationships," the authors write. In the future, "It would behoove the glass community to have a better understanding of the structural effects on the thermodynamics and kinetics involved in these processes."

The paper, published in *Journal of Non-Crystalline Solids*, is "Examining the role of nucleating agents within glass-ceramic systems" (DOI: 10.1016/j.jnoncrysol.2022.121714). ■

Honoring the ACerS Awards Class of 2022

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

The most prestigious of ACerS awards is Distinguished Life Member designation, a recognition bestowed upon only two or three members each year. In 2022, three individuals will receive DLM honors: Sylvia M. Johnson, Tatsuki Ohji, and Kent Weisenstein.

The Society will elevate 19 members to Fellow and recognize many more outstanding members with various Society, Division, and Class awards during the ACerS Annual Honor and Awards Banquet Reception on Oct. 10, 2022.

2022 DISTINGUISHED LIFE MEMBERS

Sylvia M. Johnson

Vision and ambition are key qualities to have in a leader, and ones that Sylvia M. Johnson nurtured since an early age.

During her final two years at Willoughby Girls' High School in Sydney, Australia, Johnson was the only student to register for advanced chemistry. The administration told Johnson the class would be canceled unless she found more students to take it—a challenge she accepted and accomplished.

Following graduation, Johnson attended the University of New South Wales, where she became the first woman to enroll full time in ceramic engineering at UNSW. Johnson earned a first-class honors degree, the highest distinction, and then went on to pursue an M.S. and Ph.D. in materials science and engineering at the University of California, Berkeley.

After graduation, Johnson joined SRI International where, in addition to her research, she rose through the ranks to become director of the Ceramic and Chemical Product Development Laboratory. In 2000, she moved to NASA Ames Research Center as chief of the Thermal Protection Materials and Systems Branch of the Space Technology Division and later became chief materials technologist in the Entry Systems and Technology Division.

Johnson's contributions to the development and application of new and improved thermal protection materials for space and planetary missions are widely recognized. She received the James I. Mueller Award (2011) and Edward Orton Jr. Lecture Award (2015), as well as various NASA awards, including being featured on the women of NASA webpage. She is the author of eight U.S. patents, numerous disclosures, about 60 published papers, and is the editor of two proceedings and one book.

Johnson joined ACerS as a graduate student and found the meetings and networking events to be most valuable. "When I first started coming to the Annual Meeting, everybody was very friendly. You met all these people who were leaders in their field, and they were so welcoming. Also, they remembered your name!" she says.

Johnson has served the Society in a variety of roles, including as a member of the Board of Directors, program chair for the Pacific Coast Regional Meeting, former chair and current counselor of the Northern California Section, general chair for PACRIM-5, and several Society committees. In 2018–2019, she served as ACerS president, a role in which she helped organize greater coordination with the European Ceramic Society, resulting in the formation of a joint award, symposia, and planning meetings. Most recently, she was co-chair of the inaugural Pan American Ceramics Congress, held in Panama City, Panama, July 2022.

Johnson retired from NASA Ames Research Center in 2016 but is still very much involved in ceramics through the Society and other organizations. She is an Honorary Professor at the University of Birmingham (U.K.), president-elect of the International Ceramic Federation, and became an Honorary Fellow of the European Ceramic Society in 2022.

Regarding her recent designation as DLM, Johnson says, "I am deeply appreciative of being a recipient of this honor. It has been a pleasure to work with the Society and so many members over the years and to see the rewards of that work in disseminating knowledge about ceramic technology and science as well as helping to make sure that our field is welcoming to all. I look forward to continuing to contribute to the Society and ceramics field as they both evolve even further than they have in my 45 years of being a member."

Tatsuki Ohji

Finding your dream job can take years of searching. Sometimes, however, it finds you right away.

"When I was a graduate student of mechanical engineering, I took a civil service examination of the Japanese government, and I luckily passed it. I was given a list of positions which the government was filling, and one of them was a researcher position on 'mechanical property characterization of advanced ceramics' in the National Institute of Advanced Industrial Science and Technology [AIST]. It looked very interesting to me because advanced ceramics were called 'new dream materials' at that time, so I took it," says Tatsuki Ohji.

During his more than two-decade career at AIST, Ohji's research made great impacts in the areas of high-temperature strength properties of ceramics in uniaxial tension, strengthening and toughening behavior of advanced ceramics and composites, ultrahigh-temperature composites, and freeze-dry processing approach for making porous ceramics, among others. He authored or coauthored more than 360 peer-reviewed papers and 20 book chapters, as well as edited more than 40 books and conference volumes.

Ohji's relationship with ACerS started more than 30 years ago, when he submitted a paper to *Journal of the American Ceramic Society*.

"When I received the review, I was so amazed and moved to see a lot of valuable, informative, and suggestive comments on my work, and I truly appreciated the kind help of an unknown reviewer, who shared their precious time for an unknown young person outside of the United States like me. I strongly hoped that I would become such a person," he says.

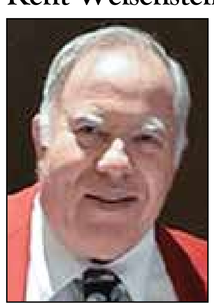
Since then, Ohji served the Society in a variety of roles, including as ACerS president (2019–20), member of the Board of Directors, chair and trustee of the Engineering Ceramics Division, and chair and member of various Society-level committees. He received the W. David Kingery Award (2021), Samuel Geijsbeek PACRIM International Award (2017), John Jeppson Award (2016), and ECD Bridge Building Award (2013).

Ohji is the first Board member and first president who resided on the Asian continent at the time of his ACerS service. During his tenure as president, he focused on fostering and fortifying solidarity and friendship with other ceramic communities worldwide, as well as supporting diversity and inclusion in ACerS leadership.

"Through these many volunteering activities, I was able to make many good friends worldwide. And because we did not anticipate any personal profit for these works, we have created strong heart-to-heart human network, which is now my most important and invaluable treasure," Ohji says.

Regarding his recent designation as DLM, Ohji says, "I felt very humbled and honored when I learned that I was designated a 2022 Distinguished Life Member. With profound gratitude and great humility, I would like to accept this honor. Thank you all very much."

Kent Weisenstein



Kent Weisenstein, an avid baseball and corkball player and lefty pitcher, credits his high school baseball coach, who was also a school counselor, for suggesting ceramic engineering to him. His coach shared some information with him from Missouri School of Mines (now Missouri University of Science and Technology), saying, "You're left-handed. For guys like you that are different, it's better to be a big fish in a little pond than a little fish in a big pond. Have a look at ceramic engineering."

Following his coach's advice, he visited campus, met eminent professors such as Ted Planje and Delbert Day, liked what he saw, enrolled, and graduated in less than four years. He focused on refractories because, he says, "Rolla was known for refractories."

Weisenstein joined the Society in 1960 during his senior year of university. After graduating, he worked as an engineer at H.K. Porter Refractories before cofounding the Missouri Refractories Company in 1973. He served as owner and president of MORCO until it was sold to RHI Magnesita in 2020.

Weisenstein was instrumental in forming the ACerS St. Louis Section in 1964, and in 1965 he led organization of the first annual St. Louis Section Refractories Symposium. His objective for the symposium was to foster interaction between industry and academia, a theme which continues to this day. "We needed to bring industry and universities together—the theory and the practical," he says.

Weisenstein was symposium chair through the 1980s and was celebrated at the symposium's 50th anniversary in 2014 for having attended 50 consecutive symposia. The symposium is now hosted jointly by the St. Louis Section and Refractory Ceramics Division and has become a preeminent international meeting for the refractories community.

"The St. Louis Section having those symposia really tied things together worldwide. Where else can you go in one place and meet 200 people all involved in everything you do?" he says.

In 2000, the St. Louis Section recognized him with its Theodore J. Planje Award, and he has served as counselor for the Section since 1990.

Weisenstein has given back generously to the profession that has given so much to him. He donates generously to the ceramic engineering department at Missouri S&T to support student scholarships, tuition assistance, travel grants, lab fees, and book purchases. He assists many graduate students with funding needed to complete their degrees and organizes plant tours to introduce students to the manufacturing, practical application, and critical importance of ceramics, and refractories in particular.

Being elevated to ACerS Distinguished Life Member is especially meaningful to him. "I was shocked that they picked a left-hander from a small company! I can't thank Rolla and ACerS enough for what they've done for me," he says. ■

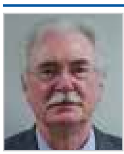
The 2022 Class of Fellows

Kristin Breder is senior principal scientist with Saint-Gobain Research North America. She received an M.S. in physics engineering at the Norwegian Institute of Technology and a Ph.D. in mechanical engineering at University of Massachusetts Amherst. Breder belongs to the Engineering Ceramics and Basic Science Divisions. She currently is on the Board of Directors and previously chaired the Membership Services Committee. She was associate editor of *International Journal of Applied Ceramic Technology* (2004–2006), and she reviews for both *IJACT* and *JACerS*.

Janet Callahan is dean of the College of Engineering and professor of materials science and engineering at Michigan Technological University. She obtained a Ph.D. in materials science from University of Connecticut. Callahan has volunteered extensively for ACerS and ABET, the accreditation board for engineering education.

Shen J. Dillon is professor of materials science and engineering at University of California, Irvine. He received a B.S. and Ph.D. in materials science and engineering from Lehigh University. Dillon belongs to the Basic Science Division. He received the 2015 Robert L. Coble Award for Young Scholars.

Olivier Guillon is director of the Institute of Energy and Climate Research: Materials Synthesis and Processing at Forschungszentrum Jülich, Germany, and professor at RWTH Aachen, Germany. After an engineering degree at the Alès School of Mines in France, Guillon completed his Ph.D. on the nonlinear behavior of ferroelectric ceramics at University of Franche-Comté, France. Guillon belongs to the Engineering Ceramics, Basic Science, and Energy Materials and Systems Divisions. His numerous recognitions include the R.L. Coble Award for Young Scholars.



Joseph Homeny is technical director of the Edward Orton Jr. Ceramic Foundation. He received his Ph.D. in materials science and engineering at The Pennsylvania State University, and a B.S. in ceramic engineering and an M.S. in ceramic science from Rutgers University. Homeny belongs to the Refractory Ceramics Division. He has been on the Ceramic Manufacturing Council and on the leadership team of the Central Ohio Section. Homeny teaches or prepares 15 online courses on glass and refractory technologies in conjunction with ACerS.

Juejun Hu is professor of materials science and engineering at the Massachusetts Institute of Technology. He holds a Ph.D. from MIT and B.S. from Tsinghua University, China, both in materials science and engineering. Hu belongs to the Glass & Optical Materials Division. He served as program chair for the GOMD annual meeting in 2012 and has been an active symposium organizer on multiple ACerS conferences including GOMD, ICC, ICACC, and PACRIM. He has received the Robert L. Coble Award for Young Scholars.

Yuji Iwamoto is professor and vice-president of Nagoya Institute of Technology, Nagoya, Japan. He received a B.S. and M.S. in organic chemistry from Pharmaceutical Sciences of Nagoya City University, Japan, and a Ph.D. in materials science from The University of Tokyo, Japan. Iwamoto belongs to the Engineering Ceramics, Basic Science, and Glass & Optical Materials Divisions. He has received the Richard M. Fulrath Award.

Soshu Kirihara is professor in the Joining and Welding Research Institute at Osaka University, Japan. His work on sustainable geoengineering involves fabricating ceramic and metal components with smart additive manufacturing, design, and evaluation using high-power ultraviolet laser lithography. Kirihara established a start-up company "SK-Fine" through academic-industrial collaboration. He belongs to the Engineering Ceramics and Basic Science Divisions.

Barbara Malič is scientific councilor and head of the Electronic Ceramics Department at Jožef Stefan Institute, Slovenia, as well as head of the doctoral study program "Sensor Technologies" at Jožef Stefan International Postgraduate School. Malič belongs to the Electronics Division.

Lane W. Martin is Chancellor's Professor and chair of the Department of Materials Science and Engineering at University of California, Berkeley and a faculty senior scientist in the Materials Sciences Division at Lawrence Berkeley National Laboratory. He received a B.S. from Carnegie Mellon University and an M.S. and Ph.D. in materials science and engineering from UCB. Martin belongs to the Electronics and Basic Science Divisions. He serves on the Jeppson Award Committee and has received the Robert L. Coble Award for Young Scholars.

The 2022 Class of Fellows (continued)

Blythe McCarthy serves as the Andrew W. Mellon Senior Scientist at the Freer Gallery of Art and Arthur M. Sackler Gallery, which together comprise the National Museum of Asian Art of the Smithsonian Institution in Washington, D.C. McCarthy holds a Ph.D. in materials science and engineering from The Johns Hopkins University and B.S. and M.S. degrees from Massachusetts Institute of Technology. McCarthy belongs to the Art, Archaeology & Conservation Science; Basic Science; and Glass & Optical Materials Divisions. She is past chair of AACSD.

Doris Möncke is associate professor of glass science and engineering at Alfred University. She earned a Ph.D. in glass-chemistry from Friedrich-Schiller-University Jena, Germany. Möncke belongs to the Glass & Optical Materials and Art, Archaeology & Conservation Science Divisions. She was program co-chair of GOMD/PACRIM2021 and for the GOMD Symposium at MS&T 2022. She serves on the Meetings and Kreidl Committees, the Board of Trustees of CGIF, and as GOMD-ICG liaison. She is associate editor of *Journal of the American Ceramic Society* (2020–2022).

Irene Peterson is principal research scientist in the Process Research Directorate at Corning Research & Development Corporation. She received a Ph.D. in materials science and engineering from University of Michigan–Ann Arbor. Peterson belongs to the Glass & Optical Materials and Manufacturing Divisions. She is vice chair of GOMD, and a member of the Manufacturing Division Programming Committee and ACerS Industry Advisory Group.

Joseph V. Ryan is senior materials scientist with the Radiological Materials Group at Pacific Northwest National Laboratory. He received a B.A. in physics from Alfred University and an M.S. and Ph.D. in materials science from The Pennsylvania State University. Ryan belongs to the Glass & Optical Materials; Art, Archaeology & Conservation Science; and Energy Materials and Systems Divisions. He currently serves as vice-chair of GOMD.

Gaurav Sant is professor and Pritzker Endowed Chair in Sustainability in the Samueli School of Engineering at University of California, Los Angeles. He earned a B.S., M.S., and Ph.D. from Purdue University. He belongs to the Cements and Basic Science Divisions.

Alp Sehirlioglu is associate professor of materials science and engineering at Case Western Reserve University. He received a B.S. in materials science and metallurgical engineering from Middle East Technical University, Turkey; M.S. in ceramic engineering from Alfred University; and Ph.D. in materials science and engineering from University of Illinois at Urbana-Champaign. Sehirlioglu belongs to the Electronics Division, where he currently serves as the Nominations Committee chair. He served five years in the officer chain of EDiv (2017–2021). He is associate editor for *Journal of the American Ceramic Society*. He was a founding member and the first co-chair of the Young Professionals Network.

Richard Todd is professor of materials at the University of Oxford, U.K. He studied natural science at Cambridge University, U.K., before spending a few years in the electronics industry; he later returned to school to receive a Ph.D. at Oxford. Todd belongs to the Engineering Ceramics and Basic Science Divisions.

Eric J. Wuchina is senior materials research engineer at the Naval Surface Warfare Center, Carderock Division and is on detail as program officer to the Office of Naval Research, where he manages the Materials for Chemical and Thermal Extremes portfolio. He earned a B.S. in materials engineering and Ph.D. in materials engineering science from Virginia Tech, and an M.S. in engineering materials from University of Maryland. Wuchina belongs to the Engineering Ceramics and Basic Science Divisions.

Yanwen Zhang is Distinguished R&D Staff at Oak Ridge National Laboratory with a joint faculty appointment in the Department of Materials Science and Engineering at University of Tennessee. She received a B.S. and M.S. in solid state physics at Beijing Normal University, China; a Ph.D. in nuclear physics from Lund University, Sweden; and a Ph.D. in science from Beijing Normal University, China. Zhang belongs to the Engineering Ceramics and Basic Science Divisions. She has organized symposia and given numerous invited talks at different ACerS sponsored meetings.

Visit https://ceramics.org/awards/society-fellows to learn more about the 2022 Fellows.

Society Awards

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

Stuart Hampshire, FACerS, is professor emeritus of Materials Science at University of Limerick, Ireland. Following graduation from the University of Sheffield in ceramics technology, he worked in industry on nitride-bonded refractories before undertaking a Ph.D. at the University of Newcastle on sintering of nitride ceramics and post-doctoral research on oxynitride glasses.

Hampshire developed the first degree program in materials science at the University of Limerick and established a research group on ceramic and glass materials. In 1999 as a founding member of the Materials and Surface Science Institute (now the Bernal Institute) Hampshire successfully led a bid for €16 million for state-of-the-art laboratories and analytical facilities. He received the University of Limerick's Award for Excellence in Research in 2007 and was conferred with an Honorary Doctorate from the University of Limoges, France, in 2009.

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

Young-Wook Kim, FACerS, is professor of materials science and engineering at University of Seoul, South Korea. Kim earned a B.S. in ceramic engineering from Yonsei University and M.S. and Ph.D. in materials science and engineering from the Korea Advanced Institute of Science and Technology.

Kim's research interests include the mechanical, electrical, and thermal properties of dense and porous silicon carbide ceramics and the processing of fully ceramic microencapsulated nuclear fuels. He is editor-in-chief of *International Journal of Applied Ceramic Technology* and currently vice chair of ACerS Engineering Ceramics Division.

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

Jiamian Hu is assistant professor in materials science and engineering at University of Wisconsin-Madison. He received a B.S. in materials physics from Sichuan University and a Ph.D. in materials science and engineering from Tsinghua University.

Hu's current research focuses on mesoscale modeling of ferroic (magnetic, ferroelectric, and multiferroic) materials and devices as well as microstructure informatics.

ROSS COFFIN PURDY AWARD recognizes authors who made the most valuable contribution to ceramic technical literature in 2020.

3D printing of high-purity silicon carbide

Published in *Journal of the American Ceramic Society* 2020, 103(3): 1575–1581.

Kurt Terrani, Ultra Safe Nuclear Corporation

Brian Jolly, Ultra Safe Nuclear Corporation

Michael Trammell, Ultra Safe Nuclear Corporation

RICHARD AND PATRICIA SPRIGGS PHASE EQUILIBRIA AWARD honors authors who made the most valuable contribution to phase stability relationships in ceramic-based systems literature in 2021.

Phase equilibria in the La_2O_3–Y_2O_3–Nd_2O_3 *system at 1,500°C.*

Published in *Journal of the European Ceramic Society* 2021, **41**(13): 6606–6616.

O.V. Chudinovych, Frantsevich Institute for Materials Science Problems NASU, Kyiv, Ukraine. National Technical University of Ukraine and Igor Sikorsky Kyiv Polytechnic Institute, Kyiv, Ukraine.

O.R. Andrievskaya, Frantsevich Institute for Materials Science Problems NASU, Kyiv, Ukraine. National Technical University of Ukraine and Igor Sikorsky Kyiv Polytechnic Institute, Kyiv, Ukraine.

J.D. Bogatyryova, Physics and Technology Institute for Metals and Alloys NASU, Kyiv, Ukraine.

V.V. Kovylyaev Frantsevich, Institute for Materials Science Problems NASU, Kyiv, Ukraine.

O. I. Bykov Frantsevich, Institute for Materials Science Problems NASU, Kyiv, Ukraine.

Society Awards (continued)

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

Yifei Zhang is optical engineer at Microsoft Hololens in Redmond, Washington. He completed his Ph.D. in materials science and engineering at Massachusetts Institute of Technology. His dissertation focused on developing new optical phase change materials and exploring their applications in integrated photonics and metasurface devices. Currently at Microsoft Hololens, Zhang specializes in bringing new optical materials and device concepts into the world of mixed reality.

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

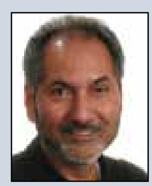
Abhijit Gurav is vice president of ceramic technology at KEMET Electronics Corporation, a YAGEO company, in Simpsonville, South Carolina. He holds a B.S. and M.S. in metallurgical engineering and materials science from the Indian Institute of Technology, India, and a Ph.D. in chemical engineering from the University of New Mexico.

Gurav's current areas of research include electronic properties and behaviors of materials and components, design, processing, reliability testing and modeling of ceramic capacitors for high reliability, dielectric formulations, electrode and end-termination materials, ceramic tape (foil) development, and lamination and sintering of multilayer structures, such as ceramic capacitors.

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

Kathleen Cissel is principal investigator in the Microelectronics and Systems Assurance Lab at the Air Force Research Laboratory in Dayton, Ohio, working for Battelle Memorial Institute. She received a B.S. in physics and classical civilizations from University of Mary Washington, and a M.S. in engineering physics and a Ph.D. in materials science and engineering from the University of Virginia. Cissel is currently president of the Keramos National Board and president of the Microscopy Society of the Ohio River Valley.

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



Santokh Badesha is corporate fellow and manager of open innovation at Xerox. He received B.S. and M.S. degrees with honors in chemistry from Punjab University, India. He received his first Ph.D. from the Punjab Agricultural University and a second Ph.D. from the University of East Anglia, U.K. Badesha currently is record holder for issued U.S patents at Xerox, with 262 issued and an additional 55 at different stages of the patenting process. ■

Corporate Technical Achievement Award

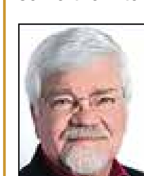
The Corporate Technical Achievement award recognizes a single outstanding technical achievement made by an ACerS Corporate Partner in the field of ceramics.

The award recognizes Mo-Sci Corporation for the commercialization of MIRRAGEN® Advanced Wound Matrix.

MIRRAGEN is based on a first-of-its-kind borate technology that is gradually absorbed by the body. This innovative material can be processed into a fiber or particulate form and can help heal a variety of hard-to-heal wounds, including diabetic ulcers, pressure ulcers, venous ulcers, burns, and surgical incisions prone to scarring.

Mo-Sci is headquartered in Rolla, Mo., where the idea for Mo-Sci originated in 1985 with company founder Delbert Day, Curators Professor Emeritus in Materials Science and Engineering at Missouri University of Science and Technology. Mo-Sci was acquired in 2021 and is now part of the Heraeus Group, a FORTUNE Global 500 listed family-owned portfolio company. ■

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



Gary L. Messing, FACerS, DLM, is Distinguished Professor Emeritus of Ceramic Science and Engineering at The Pennsylvania State University and was founding director of the NSF Industry/University Cooperative Research Center on Particulate Materials at Penn State. Messing's lab studies the improvement of ceramic materials for optical, piezoelectric, and structural applications by regulating microstructure evolution using innovative approaches. ■

Richard M. Fulrath Symposium and Awards

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

Japanese Industrial

Shoichiro Suzuki

Material development for high performance and miniaturization of multilayer ceramic capacitors by using Sn

Suzuki is manager of the Materials and Technology Development Department in the Technology Development Group of the Capacitor Division at Murata Manufacturing Co., Ltd., Japan. He researches dielectric ceramic materials design and processing, and nickel inner electrode for monolithic ceramic capacitors.

Japanese Industrial

Masatake Takahashi

Development of ultrathin piezoelectric type loudspeaker for mobile phones

Takahashi is director of the artificial intelligence and sensing technology development teams at NEC Corp., Japan. He researches the fusion of physical sensing and data analysis to create deeper insights for more efficient city infrastructure operations and maintenance.

American Industrial

Tobias A. Schaedler, FACerS

Additive manufacturing of ceramics using preceramic polymers

Schaedler is manager of the Architected Materials and Structures Department at HRL Laboratories, LLC in Malibu, California. He received a Ph.D. in materials from University of California, Santa Barbara following undergraduate studies in the same field at University of Bayreuth, Germany. Schaedler's service to ACerS includes helping to revive the Southern California Section as chair in 2021; organizing a new symposium on Additive Manufacturing of Glass, Ceramics, and Composites at the 2019 MS&T conference; and coorganizing the Symposium on Additive Manufacturing at the ICACC conference in 2020 and 2021.

American Academic

Jacob Jones, FACerS

Advancing solid state reaction science through in situ X-ray diffraction and processing control

Jones is Kobe Steel Distinguished Professor of Materials Science and Engineering at North Carolina State University, director of the Science and Technologies for Phosphorus Sustainability Center, and director of the Research Triangle Nanotechnology Network. Since 2012, he has been a Senior Visiting Fellow at University of New South Wales, Australia. Jones participates in ACerS Basic Science and Electronics Divisions, and he founded and chairs the Carolinas Section.

Japanese Academic

Takuya Hoshina

Elucidation of dielectric polarization mechanism using THz spectroscopy

Hoshina is associate professor in materials and chemical technology at Tokyo Institute of Technology, Japan. He received a B.S., M.S., and Ph.D. in engineering from Tokyo Tech. Hoshina has studied the structure and properties of dielectric and ferroelectric materials for more than 20 years. ■

Check matscitech.org for latest updates.

Class Awards

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

Jeffrey D. Smith, FACerS, is professor of ceramic engineering in materials science and engineering at Missouri University of Science and Technology. He joined the faculty at Missouri S&T after completing a B.S. in ceramic engineering at Iowa State University and M.S. and Ph.D. degrees in ceramic engineering from the University of Missouri-Rolla. Smith has received more than 30 university teaching awards that are based, in part, upon student input. ■

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

Armin Feldhoff is Extraordinary Professor at Leibniz University Hannover, Germany. He is past chair of the Energy Materials and Systems Division and served as lead organizer for several energy-focused symposia and sessions at various ACerS meetings. His research interests are in physical chemistry of materials with focus on thermo-iono-electric materials for energy conversion and separation technologies. ■

ART, ARCHEOLOGY & CONSERVATION SCIENCE DIVISION ANNA O. SHEPARD AWARD recognizes an individual who has made outstanding contributions to materials science applied to art, archaeology, architecture, or cultural heritage.

Pamela Vandiver, FACerS, is professor of materials science and engineering and adjunct professor in anthropology at University of Arizona. She is also codirector of the Program in Heritage Conservation Science and head of the Laboratory for Cultural Materials. Vandiver's research spans historical ceramics located in countries around the world, including France, China, Korea, Japan, Ukraine, Pakistan, Turkey, Egypt, and more. ■

ACerS Award Lectures

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

Lisa C. Klein, FACerS
Chair, Department of Materials Science and Engineering, Rutgers, The State University of New Jersey
From moon rocks to melting gels
Klein's research focuses on sol-gel science and engineering, particularly sol-gel for electrolytes, electrochromics, membranes, and nanocomposites. More recently, she has focused on sol-gel processing of organic-inorganic hybrids.

EDWARD ORTON JR. MEMORIAL LECTURE

Sanjay Mathur, FACerS
Director of the Institute of Inorganic and Materials Chemistry, University of Cologne, Germany
Visiting professorships at Central South University (China) and National Institute of Science Education and Research (India)
Ceramic particles for precision drug delivery
Mathur's research focuses on application of nanomaterials and advanced ceramics for energy technologies.

ACerS FRONTIERS OF SCIENCE AND SOCIETY RUSTUM ROY LECTURE

Yury Gogotsi, FACerS
Distinguished University Professor and Charles T. and Ruth M. Bach Professor of Materials Science and Engineering
Drexel University, Philadelphia, Penn.
Director of the A.J. Drexel Nanomaterials Institute
Ceramics in flatlands or how to build new materials and devices using nanoscale bricks
Gogotsi's research group works on 2D carbides and nitrides (MXenes), nanostructured carbons, and other nanomaterials for energy, water, and biomedical applications.

BASIC SCIENCE DIVISION ROBERT B. SOSMAN AWARD AND LECTURE

William G. Fahrenholtz, FACerS
Curators' Distinguished Professor of Ceramic Engineering, Department of Materials Science and Engineering, Missouri University of Science and Technology
Ultrahigh-temperature ceramics research at Missouri S&T
Fahrenholtz's research focuses on the processing and characterization of boride and carbide ceramics.

GLASS & OPTICAL MATERIALS DIVISION ALFRED R. COOPER AWARD SESSION

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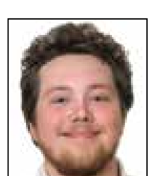

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Additive manufacturing of yttria-stabilized zirconia and lithium silicate electroceramics for energy applications

By John Zaengle, S.K. Sundaram, and Shawn Allan

Additive manufacturing could help accelerate development of yttria-stabilized zirconia and lithium silicate materials for energy generation and storage applications.

Additive manufacturing (AM) has advanced significantly since the late 1990s, with different techniques showing promise for use with advanced materials previously deemed too expensive and difficult to machine.

The energy field is one area in which AM is making inroads. The ability to manufacture precise test pieces quickly with minimal waste can help accelerate the development of advanced material-reliant products, such as solid oxide fuel cells (SOFCs) and batteries.

Lithography-based ceramic manufacturing (LCM) is particularly interesting for 3D printing of energy materials. LCM involves suspending a ceramic powder in a photosensitive resin, with a typical solid loading of 40–50 vol %.[1] Once the part is 3D printed, careful heating burns out the binder as the remaining structure sinters into a monolithic, dense ceramic part. Compared to other AM technologies, LCM is advantageous because of the high resolution prints, which allow for less post-print machining and physical alteration.

This article summarizes work on LCM printing of two materials of interest for energy generation and storage applications: fully stabilized 8 mol % yttria-stabilized zirconia (YSZ) and lithium silicate powders.

Candidate SOFC and battery electrolyte materials

Solid oxide fuel cells (SOFCs) convert chemical energy into electrical energy.[2] A SOFC comprises a porous cathode where oxidation occurs and a porous anode where reduction occurs.[3] In between the anode and cathode is a solid electrolyte, which transports oxygen ions from the cathode to the anode. The electrolyte needs to remain chemically and structurally stable at high temperatures (550–1,000°C) and survive the chemical and structural stresses on each side caused by the electrodes.

YSZ is a proven viable electrolyte material because of its abundance, stability, and cost. It has a cubic fluorite structure, which is important for ion conductivity. The dopant yttria increases intrinsic defects in the structure,[4] which provide vacancies for oxygen ions to move around.[5,6]

The 8 mol % YSZ composition has good thermal and chemical stability.[7] However, inkjet-based printing is the only type of additively manufactured 8 mol % or fully stabilized zirconia parts reported in the literature.[1] A 3 mol % YSZ powder is commercially available for an LCM system, but it is only partially stabilized.

Batteries also require an electrolyte between the cathode and anode. The growing need for high-capacity batteries drives development of a more robust and temperature-resistant battery capable of high cycle rates.

Lithium orthosilicate (Li_4SiO_4) is a lithium-ion conducting electroceramic candidate electrolyte for lithium batteries, CO_2 absorption/capture, and solid tritium breeding applications.[8–10] The high lithium atom density and Li+ interstitials and vacancies in Li_4SiO_4 offer the advantage of elevated operating temperatures (50–100°C) and integration with oxide electrode materials.[8,11]

Battery output power is a function of lithium vacancies in the monoclinic structure: more vacancies leads to more lithium-ion conduction and higher battery power.[9,12] Doping with cations to replace the lithium or silicon in the structure can increase vacancy formation and, thereby, ionic conductivity.[13]

Figure 1. Tosoh TZ-8YS sintered samples, printed from slurry with 42.5% solid loading. Left and center show two common failures (cracking and flaking) and right shows a sample with complex geometry that sintered successfully.

Researchers have used inkjet, direct ink writing, and screen printing to create anode, cathode, and electrolyte parts for battery applications.[14–16] However, LCM printing has yet to be applied to lithium silicate powders.

YSZ and lithium silicate fabrication

Powder and slurries

Five YSZ powders from Inframat Advanced Materials LLC (Manchester, Conn.) and Tosoh Corporation (Tokyo, Japan) were tested to determine if they could form viable slurries for LCM component builds. Based on known standard starting parameters, ideal powders were 0.5–1 µm in size with a low surface area of about 5–7 m^2/g. Two Lithoz binders—MS8 and MS13B—were tested in conjunction with the YSZ powders. The Inframat powders never resulted in a printable slurry. Both Tosoh powders mixed well with the MS8 and MS13B binders. Seven slurry formulations using Tosoh TZ-8YS or TZ-8Y powders and Lithoz MS13B or MS8 binders were mixed, as seen in Table 1.

Lithium silicate (Li_4SiO_4) powder was synthesized using a solid-state reaction method. Once ground, the powder was sieved through a No. 270 mesh or No. 325 mesh sieve, and two slurries were made using the MS13B binder: MD-203 (No. 270 mesh, solid loading 48 vol %) and MD-208 (No. 325 mesh, solid loading 51 vol %). MD-203 was not printed because the lithium silicate partially reacted with MS13B binder during storage, causing the slurry to become too viscous for printing.

Printing

Slurries using the MS13B binder printed well when combined with the TZ-8YS powders; in contrast, MS8 binder combined with TZ-8YS powders did not print as well. Solid loading volumes of 42.5%, 45.5%, 46.5%, and 48.5% were all tested. Solid loadings of 45.5 vol % and 46.5 vol % were the ideal mixtures. Tosoh TZ-8YS test slurry with a 45.5 vol % solid loading was used for two prints. The first went relatively well, with the slurry becoming more viscous toward the end of the print (120 layers). The second print reused the residual slurry in the vat of the printer. The second print made it to layer 63 before the slurry was unusable (i.e., it started to partially cure, resulting in increased viscosity), and the print was aborted.

Table 1. Tosoh powder-based test slurries.

Lithoz batch number	Powder	Binder system	Solid loading (vol %)
MD-193	Tosoh TZ-8YS	MS13B	42.5
MD-196	Tosoh TZ-8YS	MS8	45.5
MD-171	Tosoh TZ-8YS	MS13B	45.5
MD-143 +202	Tosoh TZ-8YS	MS13B	46.5
MD-195	Tosoh TZ-8YS	MS13B	48.5
MD-192 +194	Tosoh TZ-8Y	MS13B	40
MD-204	Tosoh TZ-8Y	MS8	40

The lithium silicate powders used to make slurry MD-208 had larger than standard particles for printable slurry, resulting in a relatively abrasive or rough slurry. Light penetration was quite high, leading to light scattering, which caused some partial curing around the parts' edges, evident as clumps. The larger particles also caused nonuniform flow properties in the slurry. The larger particle size and solid loading of 51% resulted in the printed parts being relatively weak compared to similar YSZ parts.

Sintering

The printed YSZ parts were cleaned of residual slurry, dried, and moved into a drying furnace at 120°C for three days. After the parts were preconditioned, some small cracks appeared on the surface of larger, thicker parts.

Sintering schedules were adjusted slightly from the first profile seen in Table 2, with the second having longer dwell times at lower temperatures. A temperature of 420°C was used for the binder burnout. Longer dwell times resulted in less cracking and flaking in parts, especially for nonideal slurries such as the 42.5 and 48.5 vol % slurries and the TZ-8YS and MS8-based slurry.

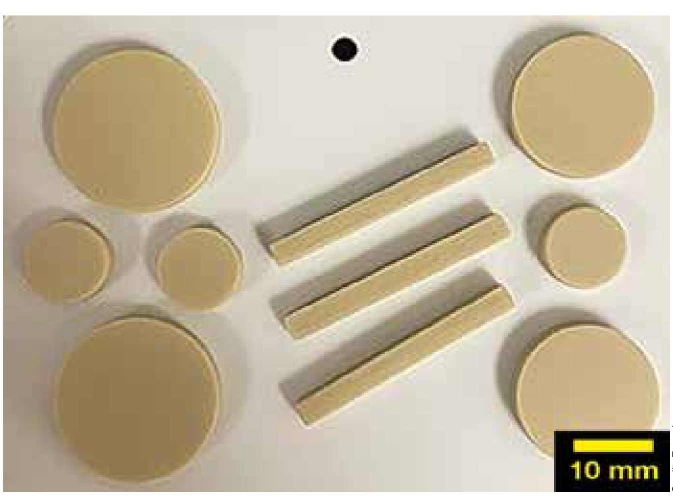
Once fired, the parts with thin walls, such as the turbine found to the right in Figure 1, had no surface damage. The turbine was 18 mm in diameter and 10.5 mm tall. Parts with wide layers, such as the piece to the left in Figure 1, which had printed dimensions 17.5 mm wide and 3 mm tall, resulted in many layers flaking and cracking apart. The Tosoh TZ-8YS samples had cracks between some printed layers, which did not densify during sintering, in constrast to the 42.5 vol %, 45.5 vol %, and 46.5 vol % solid loading slurries. The 48.5% solid loading slurry only resulted in samples that were printed flat to the build plate. Most parts sintered well.

Table 2. YSZ sintering profiles for short and long dwell times.

Short dwell time sintering profiles			Long dwell time sintering profiles		
Temperature (°C)	Ramp (°C/min)	Short dwell (h)	Temperature (°C)	Ramp (°C/min)	Long dwell (h)
140	0.1	4	135	0.1	16
170	0.2	4	170	0.2	4
250	0.2	2	225	0.2	6
420	0.3	0.01	325	0.3	4
500	1.2	0.01	420	1.2	4
600	1.7	0.01	600	1.5	1
1250	1.7	0.01	1050	1.5	1
1450	3.3	2	1450	2.5	2

Table 3. Lithium silicate sintering profiles (* Not included in profile).

Temperature (°C)	Ramp (°C/min)	Dwell (h) Profile 1	Dwell (h) Profile 2	Dwell (h) Profile 3	Dwell (h) Profile 4	Dwell (h) Profile 5
130	0.1	3	3	3	3	3
170	0.1	3	3	3	3	3
220	0.1	4	4	4	4	4
250	0.2	5	5	5	5	5
325	0.2	5	5	5	5	5
430	0.5	2	5	5	5	5
680	1	*	*	*	*	5
700	1	*	*	*	5	*
800	1	*	*	5	*	5
900	1	4	5	*	5	*
120	naturally cooled	naturally cooled	naturally cooled	naturally cooled	naturally cooled	naturally cooled



Credit: Zaengle

Figure 2. MD-208 lithium silicate parts cleaned before preconditioning.

Regarding lithium silicate, these parts had no visible cracking or flaking after printing; however, there were some pinholes on larger samples. During cleaning, the samples had partially cured residue on the edges of the parts. The binder's weak bonding allowed the sharp edges of samples to become rounded during cleaning. Overall, parts stayed intact with no significant flaws and there were no difficulties removing them from the build plate or cleaning. Figure 2 shows examples of cleaned samples before placement in an oven for preconditioning. Parts preconditioned well; no surface cracks were visible once complete.

As shown in Table 3, five sintering profiles were tested, ranging from seven to eight steps. Sintering temperature and dwell times were varied over a narrow range to improve density in the final parts. The fourth and fifth profiles included a step between binder burnout and sintering to heat any unreacted precursors in the material.

Because parts were printed, layers were perpendicular or parallel to the disk face. All the samples had signs of bubbling on the surface after sintering; however, samples printed with the layers perpendicular to the disk's large face had noticeably less bubbling. Additionally, samples with smaller surface area layers had noticeably less bubbling, with only the side facing up during sintering developing surface bubbles. The larger surface area between layers led to more bubbling on the surface, as shown in Figure 3, which was sintered at 900°C.

The samples in Figure 4 were sintered at a lower temperature of 800°C. The samples sintered using profiles 4 and 5 had noticeably more surface bubbles than the first three profiles tested. Profiles 4 and 5 had an additional thermal treatment segment compared to the other profiles.

The samples shown in Figure 4 with the small foot were the two densest parts at about 90% of actual density. The segment held at temperatures in the solid-state reaction range was used to make the base powder. The profiles then ramped to a final sintering temperature. The additional step was to provide more time for the samples at an elevated temperature to react, causing CO_2 off-gassing from the leftover precursors used in solid-state reaction. The CO_2 was believed to cause bubbling, primarily affecting the sample's top-facing surface.

Grain size and density

The two particle sizes of Tosoh powders produced samples with different grain sizes (Table 4). The larger TZ-8YS powders resulted in smaller average grains at 2.7 µm, whereas the TZ-8Y powders displayed more grain growth with an average of 5.3 µm.

The sintered TZ-8Y parts had several minor features on the surface compared to the TZ-8YS parts. An example of the feature variation is the presence of small humps on the visible grains' surface. The TZ-8YS grains had prominent features compared to the features seen on the surface of the TZ-8Y samples. The surface variation between the TZ-8YS and TZ-8Y parts shows some correlation between solid loading and particle sizes of the base powder. The TZ-8Y samples had larger grains with a slightly lower density of 93% vs. 97% for the TZ-8YS samples. Figure 5 is an example of the layering from the 3D printing process that remains on the surface of the YSZ parts even after sintering. Figure 5 also includes a close-up of a microcrack in the ceramic structure (left). Figure 6 shows examples of the YSZ surface microstructure. Both have small pores throughout the microstructure.

The sintering profiles of the lithium slurries were adjusted to improve bulk density and average grain size. Table 5 shows how the sintering profiles affected density and grain size. The dwell time for debinding, sintering temperature, and dwell, and later a reaction temperature and dwell were altered to improve density and grain size. Profile 5 yielded the best results for density with an average of 87%, and the highest parts density was 90%. The samples with a lower surface area between layers relative to size resulted in the best density. Samples subjected to higher sintering temperatures of 900°C resulted in larger grain sizes, as seen in profiles 1, 2, and 4, where 3 and 5 sintered at 800°C. Profiles 4 and 5 with an additional step at 680°C or 700°C showed improved density and grain size.

When the first three profiles were tested, the sintering temperature and debinding dwell alterations had minimal effect. Profile 4 and 5 included a step to react any carbonates remaining in the material, which improved density and grain growth. The left of Figure 7 corresponds to the first three profiles and shows pinholes or an open structure. The right of Figure 7 is an example of the microstructure seen in the last two profiles that have improved grain growth and density.

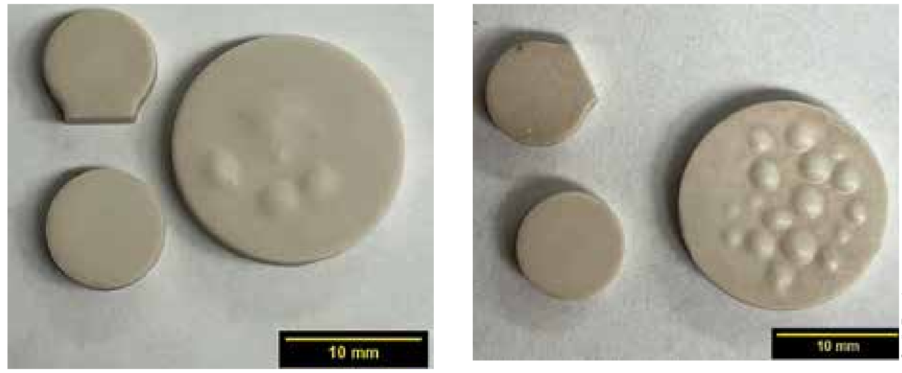


Figure 3. Lithium silicate samples sintered using Profile 4 from Table 3. Left shows the sample top; right shows the sample bottom.

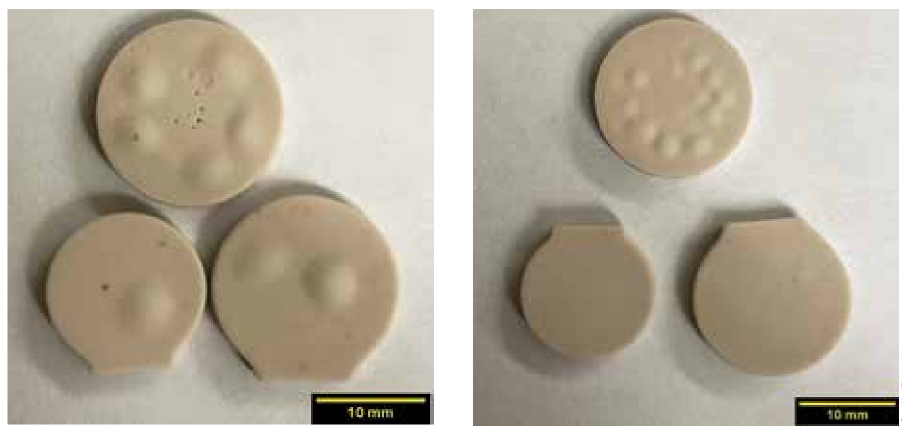


Figure 4. Sintered lithium silicate from sintering profile five top (left) and bottom views (right).

Table 4. Tosoh YSZ sintered grain size.

Slurry solid loading	42.5*	45.5*	45.5 MS8	46.5*	48.5*	40*	40 MS8
Average grain diameter	2.5 µm	3.7 µm	2.6 µm	2.5 µm	2.4 µ m	6.0 µm	4.5 µm
Grain size standard deviation	2.5+/- µm	2.3+/- µm	2.4+/- µm	2.8 +/- µm	2.8+/- µm	5+/- µm	4.5+/- µm
Average bulk density	97.9%	95.3%	96.0%	98.3%	97.2%	92.5%	93.4%

* Made with Lithoz MS13B binder.

Conductivity and activation energy

Impedance spectroscopy was used to determine the activation energy of 3D-printed YSZ and lithium silicate samples. The key features tested were layer orientation to determine if there were any effect on the conductivity and activation energy of the material. AM YSZ samples resulted in a bulk conductivity average of 1.33×10^{-3} Ω-cm at 300°C. AM lithium silicate samples resulted in an average bulk conductivity value of 5.14×10^{-5} S cm^{-1} at 300°C compared to Adnan et al.,[12] who reported a conductivity value of 1.16×10^{-4} S cm^{-1} at 100°C. The conductivity values were less for the AM parts compared to monolithic parts given the reported values were recorded at lower temperatures.

Table 6 compares the bulk experimental averages found in the literature.[11,26] The bulk activation energy for both lithium silicate layer orientations resulted in 0.22 eV. However, the surface orientation had slightly higher bulk resistance values compared to the layered orientation. The same bulk resistance variation was observed in the YSZ samples, with somewhat higher resistance values for surface orientation samples than layer orientation samples. The bulk activation energy for the two YSZ compositions had a 0.1 eV difference, with the TZ-8Y samples having higher activation energy. Both YSZ and lithium silicate materials demonstrated no significant direct effect on electrical properties caused by varying layer orientation during printing and electrode placement.

Lithium silicate experimental activation energy was determined for the temperature range 125–300°C with a printed layer thickness of 100 µm. A 100-µm-layer thickness is relatively high compared to typical LCM layers. The experimental average bulk activation energy for lithium silicate was 0.22 eV. The lowest recorded

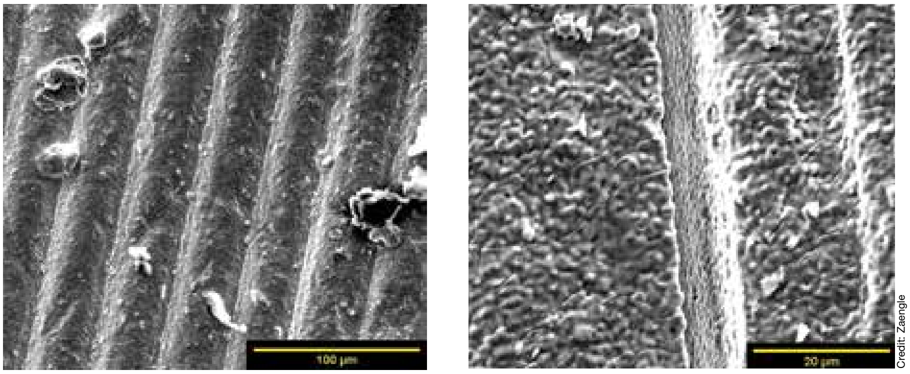


Figure 5. Layered microstructure of sintered YSZ parts.

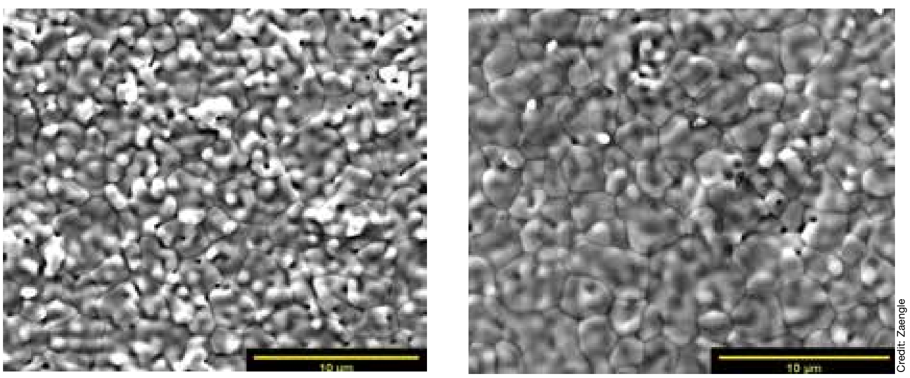


Figure 6. Flat surface microstructure of sintered YSZ parts.

Table 5. Lithium silicate density and grain size.

	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Average density	84%	78%	84%	85%	87%
Average grain size (GS)	35 μm	27 μm	18 μm	42 μm	22 μm
GS standard deviation	15+/- μm	11+/- μm	9+/- μm	20+/- μm	8+/- μm

bulk activation energy found was from Adnan et al.,[11], which was 0.19 eV for samples prepared by sol-gel, pressed into pellets and sintered. The 3D-printed lithium silicate samples had high porosity with an average density of roughly 85% and large outgassing from unreacted precursors, creating large-scale disconnectivity and defects in the materials, thus increasing the activation energy.

YSZ experimental activation energy was determined for a temperature range from 300–500°C with a printed layer thickness of 25 μm. The practical average bulk activation energy was 0.34 eV, with Kwon et al.,[26] reporting bulk activation energies of 1.16 eV. The lower activation energy for the experimental 3D-printed and sintered material may be attributed to electrons potentially finding a path of least resistance not found in traditionally formed parts. The layering may lead to microcracks in the bulk material and uneven sintering, leading to stresses in individual layers, also causing delamination. The thermal profile does not separate debinding from sintering, combining both processes into one. Debinding may be causing tunneling in the microstructure from the escaping binder gases during sintering, leading to a nontraditional microstructure.

Conclusions

Five YSZ powders with two binder systems were tested at varying solids loading percentages. Two powders, the Tosoh TZ-8YS and TZ-8Y and the Lithoz MS13B and MS8 binders, resulted in printable slurries. Seven total variations were successfully printed and sintered. The TZ-8YS powders with a solid loading of 45.5–46.5% matched with MS13B binder were determined to be the ideal slurry for 8 mol % YSZ. The best-sintered densities achieved for the Tosoh slurries was 98.3% for TZ-8YS and 93.4% for TZ-8Y.

Five batches of lithium silicate powder were made, resulting in two lithium silicate slurries. The binder used was Lithoz MS13B. The slurry formulations resulted in high curing depths and solid loading amounts. However, the slurry tended to cure when mixed, so working times were limited to one week. One lithium silicate slurry was successfully printed and sintered. The slurry contained 51% solid loading and MS13B binder. The best-sintered density for the lithium silicate slurries was 87%.

Samples printed with different layer orientations were tested to determine any significant bulk conductivity variations and activation energy variations using impedance spectroscopy. There was no direct evidence of layer orientation having substantial effects on tested samples' bulk conductivity and activation energies. Preliminary characterization was used to determine how effectively parts could be printed. Micro surface cracking, surface bubbling, and activation energies for conduction revealed a significant difference between traditional manufacturing and AM. These results demonstrate that these materials can be successfully 3D printed and sintered to produce dense products.

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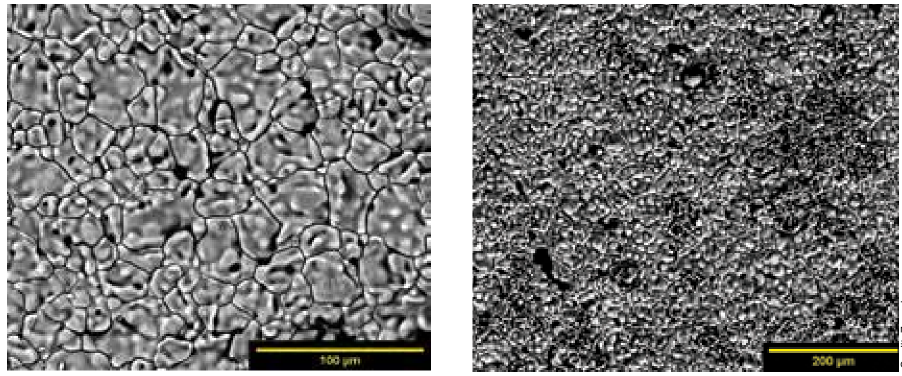

Figure 7. Lithium silicate sintered part using profile three (left) and profile four (right).

Table 6. Bulk activation energy—Experimental vs. literature values.[11,26]

	Experimental average	Experimental range between samples	Literature average	Literature range
Lithium silicate	0.22 eV	0.01	0.19 eV	0.02
YSZ (TZ-8Y)	0.39 eV	0.01	1.16 eV	0.18
YSZ (TZ-8YS)	0.29 eV	0.01	1.16 eV	0.18

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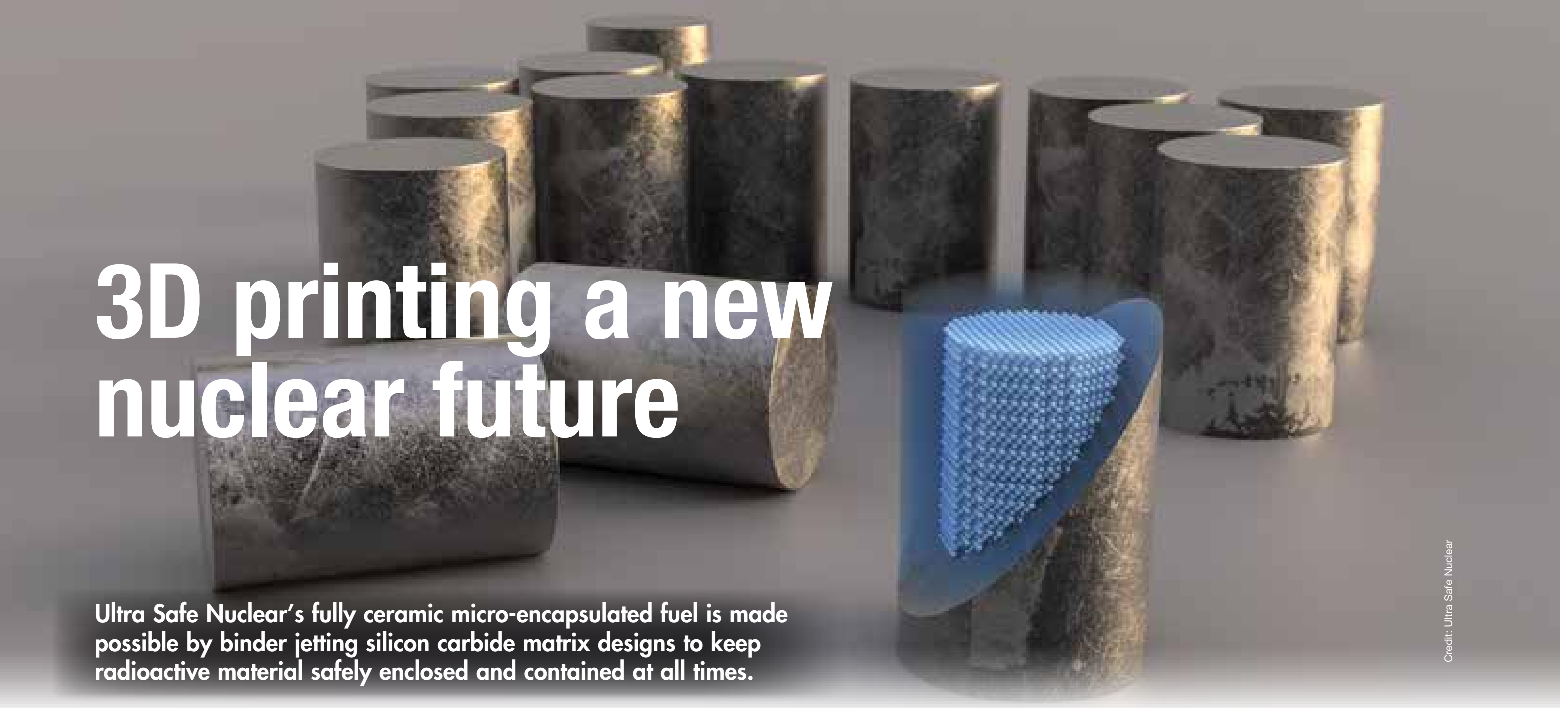

3D printing a new nuclear future

Ultra Safe Nuclear's fully ceramic micro-encapsulated fuel is made possible by binder jetting silicon carbide matrix designs to keep radioactive material safely enclosed and contained at all times.

By Rick Lucas

Binder jetting enables manufacturing of a silicon carbide nuclear innovation by Ultra Safe Nuclear—critical to delivering a safe, efficient, and carbon-free energy future.

Nuclear energy is increasingly seen as a vital part of supplying carbon-free energy to a world with ever-increasing demands for electricity.

While renewable sources such as solar and wind continue to grow, in some energy circles, it is believed that nuclear alone stands as a reliable baseload energy source that can operate continuously to meet the minimum level of power demand 24/7 without negative environmental consequences. With this growing movement, next-generation nuclear energy concepts are redefining the safety paradigm of nuclear power, aided by advanced manufacturing techniques that process materials in ways not previously possible.

Seattle-based Ultra Safe Nuclear is forging the way to bring innovative concepts to market, and technologies such as 3D printing are necessary to produce its all-new designs that deliver optimal performance in technical ceramic materials.

Ultra Safe Nuclear's journey started in 2011, the same year a devastating earthquake hit Japan. The Fukushima Daiichi nuclear power facility shut down operations as designed. However, 50 minutes after the quake, the facility was hit with a tsunami, flooding and destroying all but one of the power generators used to keep cooling water circulating, leading to a meltdown and the subsequent explosion of three reactors.

The tragic accident also hit the nuclear industry at an already tough time. The high cost of traditional reactors and their extensive infrastructure needs, in addition to the memory of high-profile accidents such as Chernobyl, were slowing plant development and escalating decommissioning in many countries.

At the same time, many governments were beginning to come to the incongruent conclusion that nuclear is one of the most reliable, portable, and green baseload energy sources.[1] The United States, European Union, Canada, Japan, and many other states and countries now view nuclear power, which generates no carbon dioxide, as vital to energy infrastructure as world electricity consumption continues to rise.

Leading nuclear experts have known for some time there was a better way to execute safe nuclear energy. The technologies used in facilities such as Three Mile Island and Fukushima dated back to the 1950s and 1960s, when advanced and safe materials and their methods of manufacture were not available. Those reactors relied on the outdated philosophy of active safety systems and features. So, while calls to phase-out nuclear power were growing louder, the founders of Ultra Safe Nuclear knew that walking away completely would pose dire consequences in the fight against climate change and the resilience of global electricity systems.

Instead, they chose to focus on inherently safe Generation IV Nuclear Energy. Exploiting a 3D printing technology could allow them to more effectively use silicon carbide to control nuclear fission and prevent accidents altogether.

Innovating with silicon carbide to shift the nuclear paradigm

Ultra Safe Nuclear aims to combine a highly advanced and safe reactor system design with a highly advanced and safe fuel system. This holistic approach leverages 3D printing breakthroughs to yield an approach to nuclear fuel that can take a six-decade-old technology and transform it to deliver a safer, more efficient reactor in the 21st century.

Internationally recognized nuclear fuel expert Kurt A. Terrani, former national technical director at Oak Ridge National Laboratory, joined the team at Ultra Safe Nuclear in February 2021 to advance the company's mission of producing safe, controlled, and reliable nuclear energy on demand, anywhere in the world (Figure 1). He says small and advanced reactors, which run on different fuels and coolants while operating in different ways than the gargantuan nuclear facilities of the past, will deliver a paradigm shift in nuclear energy.

The key to Ultra Safe Nuclear's innovation is fully ceramic microencapsulated (FCM®) fuel. The manufacturing of FCM fuel is enabled by Desktop Metal (Burlington, Mass.) innovative binder jet additive manufacturing systems, which can 3D print silicon carbide heat-resistant ceramic powder into unique geometries that safely surround a standard type of nuclear fuel particle.

Ultra Safe Nuclear produces coated fuel particles, or microencapsulated spheres, known in the industry as TRISO, a tristructural isotropic particle fuel.

"TRISO is a mature technology shown to provide extreme resistance to radionuclide release under a whole host of conditions," Terrani says.

Traditionally, these fuel microspheres would be put into a soft graphitic matrix. However, these matrices were not structurally strong and served as a poor barrier to radionuclide release. Ultra Safe Nuclear's answer was to replace this graphitic matrix with a refractory ceramic: silicon carbide (SiC).

One of the hardest substances known to man and featuring extreme environmental stability, SiC is one of the most versatile industrial ceramics and is often used in aerospace, armor, plasma shield, and high-temperature applications.

"It's an exceptional material for very harsh environments—those that are highly oxidizing, highly corrosive, or for applications that operate at extreme temperatures. It's a bit of a panacea as a material," Terrani says. In fact, in 1926, the U.S. Patent Office named silicon carbide (also known as carborundum) as one of the 22 patents most responsible for the industrial age.

The conditions within a nuclear reactor are some of the harshest in all of industry, yet SiC does not shrink or excessively swell like the traditional graphitic matrix. SiC also has a very high resistance to oxidation and corrosion, offering unique stability under all the demanding conditions of the nuclear reactor core. It is irradiation induced, irradiation resistant—meaning it can be irradiated to affect the microstructure in a way that makes the material resistant to future irradiation.

"Through exploiting fundamental laws of nature, we have created a design for a passively safe reactor, so you do not need a concrete dome, exclusion zone, or big water reservoir because it is inherently safe," Terrani says, explaining the idea behind the Ultra Safe Nuclear approach. "We're leveraging a high-temperature resistant fuel with multiple inherent barriers to radionuclide release at the center of our reactor system. That is the essence of the Ultra Safe approach."

Ultra Safe Nuclear is using this novel approach to fuel its extremely reliable and safe micro modular reactor (MMR™) energy systems. Modular reactors produce smaller amounts of energy than the classic large plants and eliminate the high investment cost of the concrete and steel construction of traditional nuclear reactors. These MMRs produce 5 megawatts of power; for perspective, a single megawatt powers about 800 average U.S. homes for a year. But the MMRs also are highly transportable and ideal for use in remote locations. Such reactors are also likely to power future bases on the moon and Mars.

Credit: Ultra Safe Nuclear

Figure 1. Kurt A. Terran, executive vice president of Ultra Safe Nuclear's Core Division, works with advanced techniques like binder jet 3D printing to manufacture nuclear reactor components.

3D-printed silicon carbide breakthrough

This ultrasafe approach starts with the feedstock silicon carbide. Given the demanding nature of the harsh nuclear environment, purity of the silicon carbide material is of the utmost importance to Ultra Safe Nuclear production. The team developed its own material specification with a focus on properties such as stoichiometry, where the composition features exactly one silicon atom for one carbon atom, and a fully crystalline structure without impurities.

"It is essential that the end product is 100%, not just mostly, silicon carbide. Some processes may introduce other phases that, for example, limit the service temperature up to 1,000°C, but it is essential that our material is pure so we have no surprises," Terrani emphasizes.

Ingots of high-purity SiC, however, are difficult to make, and it is an incredibly cumbersome material to manufacture or form into complex parts with traditional methods. Despite its high hardness value, SiC is a relatively brittle material and can only be machined using diamond computer numerical control techniques that could account for up to 90% of the cost of the part designed for subtractive manufacturing.

Thus, for decades, despite the industry's desire to work with silicon carbide, there was no viable or affordable manufacturing process to transform highly pure, crystalline, nuclear-grade SiC into the shapes and forms needed for nuclear applications. The material was often relegated to use as a coating through chemical vapor deposition that created a thin layer tens of microns thick.

Binder jet 3D printing, in contrast, allows Ultra Safe Nuclear to use pure SiC powder for the efficient production of a variety of shapes. With a process highly similar to printing on paper, binder jet 3D printing is widely regarded as the fastest method of 3D printing for high-volume output. The technology inkjets a binder into a bed of powder particles such as

Figure 2. Desktop Metal 160PRO system used by Ultra Safe Nuclear.

metal, sand, or ceramic to create a solid part, one thin layer at a time. Importantly for binder jet 3D printing SiC, the whole process is carried out at low temperatures.

"There was a whole host of additive manufacturing methods out there, but a large portion of those rely on a high-temperature process during deposition," Terrani explains. "With metals, they are melting the particles to connect them together, but you cannot do that with the high melting point of silicon carbide. Binder jet technology is unique because it really relies on the physical characteristics of the powder, and it is essentially highly agnostic to the chemical and phase structure of the material. So, we can select highly pure, highly crystalline carbide feedstock powder, nuclear grade powder, and then form these really complex geometries, and that just was not previously possible."

The binder jet 3D printing process can process a range of the powdered feedstocks as long as the particles will spread in the machine (Figure 2). Standard processes run powder between 9–12 μm d50 and some applications run material with 50 μm d50. The material cost of SiC is a relatively small fraction of the cost for Ultra Safe Nuclear to produce parts, especially when the value-add of the complex geometries 3D printing can produce is considered.

"Our specification happens be on the coarser side of the size regime, which actually makes it quite available and economic," Terrani says. "This specification also affords us the leeway to use virgin powder throughout our production to keep our process consistent."

Ultra Safe Nuclear uses a domestic supplier to provide large batches of silicon carbide powder in a consistent fashion, an essential factor for reliable production. To mitigate negative effects on the powder flowability during manufacturing, the binder jetting process is performed in tightly controlled environmental conditions (e.g., humidity) and the powder supply is audited as well to consistently meet product specification requirements.

Once 3D printed, the SiC acts as a shell for the nuclear fuel particles, but it needs to be fully densified before use. SiC will often be infiltrated with silicon or other matrices for densification. For example, sintering aids help form a liquid phase at the sintering temperature to allow the grains of silicon carbide to bond together. However, adding such aids is not an option in a nuclear environment with a focus on material purity.

"Radiation will affect one material one way and another differently, so material uniformity and homogeneity are key," Terrani says.

With a chemical vapor reactor onsite (Figure 3), Ultra Safe Nuclear developed an infiltration process to densify its 3D prints without any shrinkage. During chemical vapor infiltration, introduced chemicals react with the 3D-printed preform fibers to fill the air pockets to make a solid SiC component. By marrying binder jetting with chemical vapor infiltration to fill the porous SiC structure with more high-purity crystalline silicon carbide, Ultra Safe Nuclear can realize highly complex, near-net shapes within 200 micrometers of the original CAD design without the need to sinter the SiC, apply any pressure, or introduce secondary phases.

3D printing ready for prime time

The team at Ultra Safe Nuclear already had many decades of experience processing ceramics, which gave the company a unique perspective in doing a full lifecycle analysis of their production, including costs, schedule, and yields.

"Binder jet technology really shines. It is a low-cost and high-yield process for us as a part of our complex serial manufacturing," Terrani says of Desktop Metal's SiC printing.

Compared to the traditional way of processing technical ceramics, including mixers to create slurries, injection molders, and furnaces, Terrani says binder jet 3D printing is simple and elegant. Most importantly to his team, he says, it is also a "cost-effective and reliable process."

Beyond production efficiencies, Ultra Safe Nuclear's 21st century manufacturing strategy with binder jetting allows the company to optimize the performance of its reactors by tapping the design freedom that comes with 3D printing. Previously, the team was limited to one design mass produced

Credit: Nathan Taylor

Figure 3. A SiC chemical vapor reactor at Ultra Safe Nuclear.

from hard tooling. Because this tooling was expensive and hard to change with long lead times, designers made a single design as generic yet efficient as possible.

Binder jet 3D printing directly from digital design files without the need for tooling allows the Ultra Safe Nuclear team to iterate their designs quickly and create unique shapes not otherwise manufacturable. This design freedom allows shapes, wall thicknesses, and cooling channels to be tailored to each Ultra Safe Nuclear reactor for operational efficiency and optimal safety.

"With binder jetting we have the design freedom to have unique parts—we do not need to make the same thing," Terrani says. "And because we are getting clean materials, it is also possible to fabricate pure silicon carbide nuts, bolts, and screws. We can fasten and connect things together as needed. It is kind of unprecedented."

Beyond performance, the ability for mass customization with 3D printing allows Ultra Safe Nuclear to add an additional layer of quality assurance to its mission of safe, responsible nuclear energy (Figure 4).

"We print an ID on these parts, so from the moment of birth we track the reactors' manufacturing DNA throughout production, operational lifetime, and upon their discharge," Terrani says. "Binder jetting silicon carbide allows us to create a new paradigm of safe, reliable, carbon-free nuclear energy for use by industry and remote communities."

Their approach is gaining momentum, with testing of Ultra Safe Nuclear's FCM fuel underway by the Nuclear Research & Consultancy Group in the Netherlands. Separately, Ultra Safe Nuclear, through its joint venture Global First Power, is also working to deploy its first-of-a-kind MMR at Chalk River Laboratories, a site owned by Atomic Energy of Canada Limited and managed by Canadian Nuclear Laboratories.

"Ultra Safe Nuclear is on the bleeding edge of nuclear fuel and reactor design, pioneering new advances in safety and performance," Terrani concludes. "Powering up a new generation of micro reactors represents a watershed moment in zero-carbon energy production in the U.S. and worldwide."

Credit: Ultra Safe Nuclear

Figure 4. 3D-printed SiC part at Ultra Safe Nuclear with unique tracking ID.

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About the author

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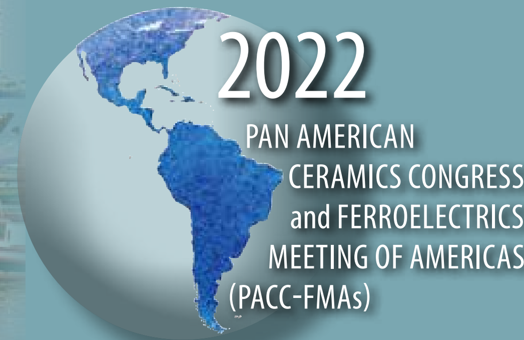
ACerS meeting highlights

INAUGURAL PACC-FMAS MEETING CONVENES IN PANAMA CITY



Nearly 100 participants from 26 countries met July 24–28, 2022, in Panama City, Panama, for the inaugural Pan American Ceramics Congress (PACC) combined with the Ferroelectrics Meeting of Americas (FMAs). Originally scheduled for July 2020, PACC-FMAs was rescheduled to this year due to the COVID-19 pandemic.

PACC was led by program chairs Tatsuki Ohji (AIST, Japan) and Sylvia Johnson (retired, NASA) while FMAs was chaired by Amar Bhalla (University of Texas San Antonio).

The technical program for PACC-FMAs included invited and contributed talks along with a poster session on Monday evening. In addition to live presentations, the technical program featured 110 video presentations for those who could not travel due to travel restrictions.

Johnson and Bhalla welcomed attendees during the plenary session on Monday morning and thanked the country chairs, symposium organizers, presenters, and conference sponsors Wiley and Deltech, Inc. Attendees heard from three excellent plenary speakers.

- Edgar Zanotto, professor of materials science and engineering at Federal University of São Carlos, Brazil, lead the session with his talk titled "R&D on vitreous materials in the Americas: Current efforts and a look to the future."
- Peter Littlewood, professor and chair of the physics department at James Franck Institute of the University of Chicago, delivered the next talk on "Materials for energy and sustainability."
- Darryl Butt, dean of the College of Mines & Earth Sciences at University of Utah, delivered the final talk on the topic "The science of art: Metaphors on the value of diversity."

Attendees explore the Miraflores Lock during an optional canal tour on Wednesday afternoon.

Credit: ACerS president-elect Sanjay Mathur

During the conference banquet on Tuesday night, ACerS past-president Dana Goski thanked all the organizers and participants and presented certificates of appreciation to Johnson, Ohji, and Bhalla. Goski also acknowledged and thanked ACerS past-president Mrityunjay Singh for his initiation and vision for the conference back in 2018.

Wednesday afternoon provided free time for attendees to take in Panama City's local attractions, including the optional canal tour. During this tour, attendees watched the functioning of the Panama Canal from the Miraflores Locks.

The tour continued with a drive around the Amador Causeway and, finally, attendees had the chance to walk around the Colonial Panama or Old Quarters, where they took in the "Paseo Esteban Huertas," Metropolitan Cathedral, National Theater, Simon Bolivar Plaza, and many other attractions of the colonial period.

Attendees tour the historic district of Panama City during an optional tour on Wednesday afternoon.

Credit: ACerS

"The PACC-FMAs conference has provided an exciting forum for interdisciplinary interaction among scientists from different countries with broad background in materials science in a naturally beautiful setting. At the same time, the emerging new ideas are also setting a platform for the contents of the next PACC-FMAs conference" says Bhalla.

Johnson also thinks of this meeting as a beginning. "We have nucleation, and now we need growth, which will come with the aid of our members and colleagues throughout the Americas and the world. This meeting has shown that small has the benefit of facilitating discussion and networking," she says.

Young materials scientists also found great value in the conference. "PACC-FMAs provided an excellent opportunity to develop new professional skills and to personally interact with high level officials of The American Ceramic Society and the Ferroelectrics Meeting of Americas. The participants were very friendly and helpful to us," says Ximena Audrey Velásquez Moya, student at the National University of Colombia in Bogotá.

Building upon the success of this year's meeting, PACC-FMAs will continue as a biannual meeting with the next event scheduled for 2024.

View more pictures from PACC-FMAs at https://bit.ly/PACCFMAs-2022-photos. ■

UPCOMING DATES

OCT. 9–12, 2022
Register now!

ACerS 124TH ANNUAL MEETING with MS&T22

MATERIALS SCIENCE & TECHNOLOGY

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https://www.matscitech.org/MST22

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NEW this year—The Materials Science and Technology Partnership has engaged the commercial exhibition firm Event Partners to sell and manage the full exhibition at MS&T22. In addition, Event Partners will co-locate two commercial exhibitions run by the company within MS&T22: The Advanced Materials Show and the first-ever Nanotechnology Show.

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

JAN. 17–20, 2023
Register soon!

ELECTRONIC MATERIALS AND APPLICATIONS 2023 (EMA 2023)

ceramics.org/ema2023

DOUBLETREE BY HILTON ORLANDO, ORLANDO, FLA.

EMA 2023 is an international conference focused on electroceramic materials and their applications in electronic, electrochemical, electromechanical, magnetic, dielectric, and optical components, devices, and systems. Jointly programmed by the Electronics Division and Basic Science Division of The American Ceramic Society.

JAN. 22–27, 2023
Register soon!

47TH INTERNATIONAL CONFERENCE AND EXPO ON ADVANCED CERAMICS AND COMPOSITES (ICACC 2023)

ceramics.org/icacc2023

HILTON DAYTONA BEACH RESORT AND OCEAN CENTER, DAYTONA BEACH, FLA.

The 47th ICACC returns as an in-person conference. The conference will provide a platform for state-of-the-art presentations and information exchange on cutting-edge ceramic and composite technologies.

JUNE 4–9, 2023
Save the date!

2023 GLASS & OPTICAL MATERIALS DIVISION ANNUAL MEETING (GOMD 2023)

ceramics.org/gomd2023

HOTEL MONTELEONE, NEW ORLEANS, LA.

ACerS Glass & Optical Materials Division will hold its annual meeting in New Orleans, La., from June 4–9, 2023.

Calendar of events

September 2022

7–9 5th Energy Harvesting Society Meeting – Hyatt Regency Baltimore, Baltimore, Md.; https://ceramics.org/event/5th-energy-harvesting-society-meeting

October 2022

9–12 ACerS 124th Annual Meeting with Materials Science & Technology 2022 – David L. Lawrence Convention Center, Pittsburgh, Pa.; https://ceramics.org/MS&T22

12–13 AM Ceramics 2022 – Fraunhofer IKTS, Winterbergstraße, Dresden, Germany; http://www.am-ceramics.dkg.de

30–Nov 3 7th International Conference on Electrophoretic Deposition – LaFonda on the Plaza, Santa Fe, N.M.; http://engconf.us/conferences/materials-science-including-nanotechnology/electrophoretic-deposition-vii-fundamentals-and-applications

November 2022

6–8 Total Solutions Plus (TPS) – Hyatt Regency, Indian Wells, Calif.; https://www.ctdahome.org/tsp/2022/index.shtml

30–Dec 2 ASEAN Ceramics – IMPACT Forum Hall 4, Bangkok, Thailand; https://aseanceramics.com/thailand/#thai-about

December 2022

7–9 ➡ 7th Highly-functional Ceramic Expo Tokyo – Makuhari Messe, Chiba, Japan; https://www.ceramics-japan.jp/en-gb.html

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 International Year of Glass event

ACerS meeting highlights

Breakout sessions, award presentations, and a 3D-printed anteater highlight Cements 2022

Attendees of Cements 2022.

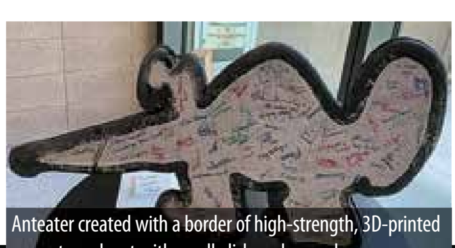
Credit: ACerS

After a two-year hiatus from in-person meetings due to the COVID-19 pandemic, The American Ceramic Society's Cements Division hosted the 12th Advances in Cement-Based Materials meeting from July 10–13, 2022, at the University of California, Irvine.

Both days opened with plenary keynote talks followed by breakout sessions on topics including materials characterization techniques, additive manufacturing using cementitious materials, and supplementary and alternative cementitious materials.

Denise Silva, the Division's immediate past chair, announced the 2022 Brunauer Best Paper Award, "Shifting factor—A new paradigm for studying the rheology of cementitious suspensions," by Sara Mantellato and Robert J. Flatt of ETH Zürich and published in *JACerS*. The Division's inaugural Early Career Award was presented to Shiho Kawashima of Columbia University by Division trustee Jeffrey Thomas.

Following the business meeting, Barbara Lothenbach of Empa presented the Della Roy lecture, "Uptake of ions by C-S-H." Lothenbach's lecture was followed by the Della Roy Reception, sponsored by Elsevier and Lehigh Hanson. The evening ended with an outdoor poster session.



Anteater created with a border of high-strength, 3D-printed concrete and cast with an alkali-based geopolymer.

Credit: ACerS

Providing some levity to the meeting, University of California, Irvine Ph.D. students Wei Geng, Amadeu Malats Domènech, and Kathryn Jones constructed the university's anteater mascot out of high-strength, 3D-printed concrete cast with an alkali-based geopolymer.

View more photos from Cements 2022 at https://bit.ly/Cements2022. ■

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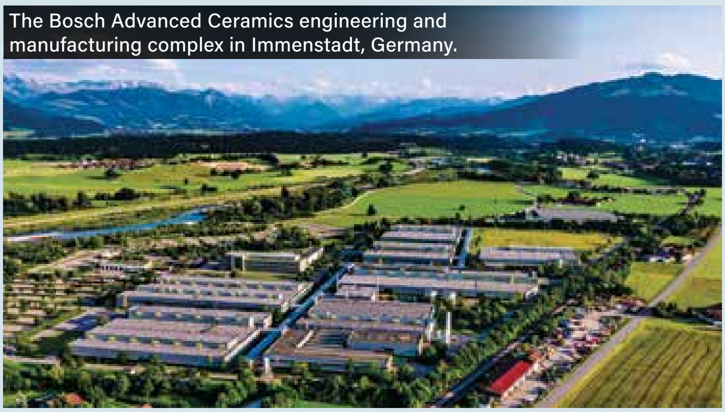
CORRECTION:
In the June/July 2022 issue of *Ceramic & Glass Manufacturing*, the given founding place of HarbisonWalker International was incorrect. This error has been corrected in the archival version of the issue.

INDUSTRY NEWS


The Bosch Advanced Ceramics engineering and manufacturing complex in Immenstadt, Germany.

BOSCH COLLABORATES ON ADDITIVELY MANUFACTURED MICROREACTOR

Bosch Advanced Ceramics collaborated with the Karlsruhe Institute of Technology and the chemical company BASF to develop a complex microreactor made of technical ceramics for high-temperature reactions. It was produced using additive manufacturing. Microreactors are used to research the fundamentals of chemical–technical processes, among other things, which requires them to withstand extreme temperatures. Bosch says the use of additive manufacturing enabled the design and construction of very small internal flow channels for the chemical reactions inside the reactor.

SINTX ACQUIRES ADVANCED CERAMICS COMPANY

SINTX Technologies, Inc. acquired Technology Assessment and Transfer, Inc. SINTX says the acquisition will significantly increase its capabilities in the aerospace, defense, and biomedical markets. TA&T, based in Maryland, is a nearly 40-year-old advanced ceramics business that specializes in developing and commercializing materials for defense, biomedical, and industrial applications. The company's technologies and products include 3D printing of ceramic medical devices and heat exchangers, chemical vapor infiltration, and deposition of complex fiber-reinforced ceramic matrix composites.


Salt Lake City-based SINTX develops advanced ceramics for medical and nonmedical applications.


In the U.S., about one million people receive an artificial knee joint every year.

FDA MOVES FORWARD ON CERAMTEC KNEE REPLACEMENT

CeramTec says that the U.S. Food & Drug Administration confirmed that its ceramic total knee replacement device and proposed plan for use meet the criteria of a "breakthrough device." The goal of the FDA's Breakthrough Devices Program is to provide patients and health-care providers with access to new medical devices by speeding their development, assessment, and review. Hadi Saleh, CEO of CeramTec, says, "The ceramic knee is one of the lighthouse projects in our innovation pipeline." He says the company is working to introduce it to the U.S. market in a few years.

NANO DIMENSION ACQUIRES NETHERLANDS-BASED COMPANY

Nano Dimension Ltd., a supplier of ceramic additive manufacturing 3D printers, acquired Formatec Holding B.V., which includes its two subsidiaries, Admatec Europe B.V. and Formatec Technical Ceramics B.V. Based in the Netherlands, Admatec/Formatec comprises two complementary businesses operating together to develop and manufacture 3D printing systems for ceramic and metal end-user parts. Nano Dimension says it paid $12.9 million for Admatec/Formatec. The business posted $5.3 million in revenue, with a gross margin of 56%, in 2021.


Admatec's Admaflex 130 3D printers.

AGREEMENT SIGNED TO EXPAND SEMICONDUCTOR MANUFACTURING

STMicroelectronics and GlobalFoundries Inc. signed a memorandum of understanding to create a jointly operated 300-mm semiconductor manufacturing facility adjacent to ST's existing 300-mm facility in Crolles, France. The facility is targeted to operate at full capacity by 2026, with up to 620,000 300-mm wafer per year production. ST and GF say they will receive significant financial support from France for the new facility, which will contribute to the objectives of the European Chips Act, including the goal of Europe reaching 20% of worldwide semiconductor production by 2030.

STMicroelectronics' semiconductor manufacturing plant.

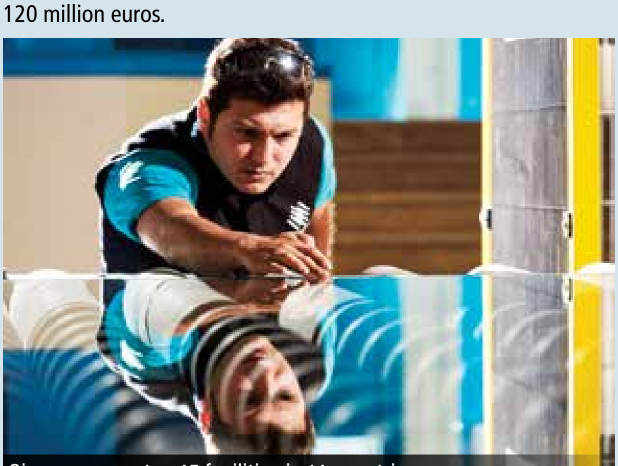
Dalmia Bharat Refractories provides refractory materials and services in more than 40 countries.

REFRACTORIES SUPPLIERS REACH LICENSE AGREEMENT

Shinagawa Refractories entered into a know-how license agreement with Dalmia Bharat Refractories of India. Shinagawa aims to expand its footprint in India, and it says the agreement serves as the first step toward future development. Shinagawa, headquartered in Tokyo, is one of the largest refractory suppliers in the world. Dalmia Bharat provides refractory materials and services to clients in more than 40 countries, and operates seven manufacturing sites: five in India, one in China, and one in Germany.

ŞIŞECAM INVESTS IN FURNACE FOR ENERGY GLASS

Şişecam plans to invest in a patterned glass furnace with a capacity of 600 tons per day and energy glass processing lines with a capacity of 20 million square meters per year at its facility in Mersin, Turkey. Şişecam currently operates eight flat-glass lines and one patterned-glass line at four locations in Turkey. With the latest investment, Şişecam says it aims to be one of the main suppliers in the renewable energy sector globally. Once it reaches full capacity, the new furnace is expected to generate annual sales revenue of 120 million euros.



Şişecam operates 45 facilities in 14 countries.

STOELZLE INVESTS IN FURNACE EXPANSION

Stoelzle Częstochowa rebuilt and expanded its flint furnace so it can now reach a production capacity of 480 tons per day thanks to three more efficient and faster production lines. The total investment amounts to 45 million euros and increases the efficiency of the melting output by 45%. With the investment at the Polish site, the company says it reached a milestone in its long-term growth strategy. It opened a logistics center in 2021 and installed a high-speed spraying line in March 2022.

The Stoelzle team and guests inside the new furnace.

HOW IT'S DONE: CREATING A CULTURE OF QUALITY

By David Holthaus

Quality is more than a buzzword; in the manufacturing world, it is an essential practice.

As long ago as 1930, a vice president of a milk manufacturer described the practice of quality in a now oft-quoted speech: "Quality is never an accident. It is always the result of high intention, sincere effort, intelligent direction, and skillful execution."

Quality improves productivity, enhances worker safety, saves money, and creates loyal customers. Attaining high quality consistently is a never-ending process of continuous analysis and improvement.

To get at the recipe for a culture of quality, we interviewed executives at two refractory manufacturers, Saint-Gobain and Allied Mineral Products. Their products must withstand extreme temperatures and corrosive environments—meaning quality is of utmost importance.

The Saint-Gobain Group is a $44 billion company with 166,000 employees. *Credit: Saint-Gobain*

SAINT-GOBAIN

Saint-Gobain is a 350-year-old Paris-based multinational corporation that attained an international reputation for quality. Its SEFPro division provides refractory solutions to the glass industry, which it has done for the past 85 years.

Andrea Kazmierczak has worked for Saint-Gobain for more than 18 years and is currently R&D process leader with the SEFPro unit at its Northborough, Mass., location. She spoke to us about the company's quality processes.

Q: ***What is your role in improving and protecting quality?***

A: It's twofold. At Saint-Gobain, one of the major functions of R&D is to have strong relationships with our customers. We learn about ways to help provide value to them, by improving the quality or guaranteeing the quality of materials. We support the customer at every step of their project through the various services we provide. We help our customers identify defects in their glass, so they can rely on us to quickly and efficiently analyze the problem and provide them with the information to correct it. We work very closely with our global fleet of manufacturing plants in pursuing new technologies and implementing processes to ensure that our facilities are providing the best quality of materials to our customers.

Q: ***Can you drill down on some specifics and best practices that your company follows?***


Andrea Kazmierczak

A: Something that stuck with me early on as a process engineer and then a quality manager is just the cost of quality, investing in quality testing. You have employees, technicians, and engineers involved to analyze the data. That cost is not negligible. But it has been instilled in me how much that can affect the quality of the products going forward. Catching a problem early on will save a tremendous amount of money. Looking at things like qualifying and ensuring good quality raw materials is a good example of that. If you cannot certify that your raw materials are stable, that they are within a set specification, you could have a ticking time bomb and you will not know it until you have a load of scrap materials. Investing that time early on is critical.

Q: ***How do you work to catch problems early?***

A: Quality is everyone's job. It is important to instill that in everybody. Operators and technicians are empowered to speak up if they see something different, or an incoming shipment comes in a different color bag, or if you have something that just does not look the same. Everybody's empowered to speak up and bring attention to these things.

Q: ***How do you create that culture, that attitude among employees?***

A: That is everybody's bottom line. We are all trying to reach the same goal, to support our customers in every aspect of their project. We want to understand our customer's needs and deliver what they want, on time, all the time. It is instilled in process engineers the first day you come in. We place a big emphasis on traceability, so we can relate the materials and process to quality. During a customer furnace tear-down, we can often go back to the drawing or a parts list and trace the history of each part manufactured from the raw material to when it left out dock.

Q: ***Is there a continuous improvement process that you follow?***

A: Yes, that's involved with the ISO 9000 system, and there is a strong emphasis on continuous improvement and getting to the root cause of a problem. If there is an issue, we log it, and either talk in a small group or a large group to hash out the corrective action, continuous improvements and the preventive maintenance or preventive actions that make sure we do not have a repeat occurrence or similar one in another area. It is really for the customer to have complete confidence about the quality of the materials they purchase.

Q: ***Is their employee training along those lines?***

A: Everyone coming in learns about quality. There is information about the cost of quality, and process engineers go through a SMART program where they get a handle on every aspect of the plant. They are put into an operator's shoes in different departments.

Q: ***When you visit a plant, what do you look for?***

A: A lot of my projects are in the later stages of getting out to a customer, so I'm helping to make sure that the properties we attained in a lab are maintained throughout the scaleup of the process. Sometimes when you are in the fire at the manufacturing plants, it is hard to see the long-term or systemic problems that can happen.

Q: ***How do you work with your suppliers to ensure quality?***

A: We have lists of critical suppliers and we do audits on them. There are different categories, different tiers of suppliers. Critical or sole source suppliers, for instance, would be more closely scrutinized. We make sure we have secondary sources for raw materials. If we do make a change, it is not done lightly. We go through extensive quality control checks whenever we make a change to the batch or process, no matter how minor it is. We make sure everything's still as expected. There is a follow-up required for each of those changes.

Allied Mineral Products: Where quality begins at the top

Founded in 1961, Allied Mineral Products has grown into a global company and leading producer of monolithic refractory products for a wide range of industries. Based in Columbus, Ohio, the company operates 12 manufacturing facilities in eight countries, and sells its products in 100 countries.

At Allied, quality begins at the top, says Doug Doza. Doza is an executive vice president who has worked at Allied for more than 37 years. "It's the corporate culture," he says. "It's driven by leadership."

Allied has built a reputation for quality through a sustained focus on its customers, who range from steelmakers to aluminum producers to heat treating operations.

"Our quality system is really about customer focus," Doza says. "How do you characterize and measure our products and our raw materials throughout our process so that the products we produce are fit for use in the eyes of the customer."

Sounds almost simple, but maintaining reproducibility and consistency with products that must withstand extreme temperatures, molten metal, and other thermal shock conditions is an ongoing process that involves continuous improvement and measurement, as well as communication with customers.

That necessarily involves engaging the company's employees in quality assurance and making its practice a part of everyone's role on a daily basis, Doza says.

"Employees need to be actively involved and understand the product and the products' features so that they can develop appropriate inspection plans," he says.

Allied employs teams of engineers who work with customers to help determine what their needs are. They work to understand the customers' processes and goals and what the products' performance requirements will be. They then engineer solutions by selecting products from Allied's extensive list or creating advanced ceramic customized solutions that make the best use of an existing product or creating a new one.

Some of the employee owners of Allied. *Credit: Allied Mineral Products*

Doug Doza

"If you do not understand the customer's needs, you cannot design or manufacture a product that is optimized for their process," Doza says.

Training and communication within the organization, as well as outside the organization, by the Allied team and with its customers is ongoing.

Befitting a company in the business of precision manufacturing, Allied measures employee engagement on a regular basis. The company annually asks employees to complete a Gallup-style survey that ascertains how they feel about their jobs and other workplace issues. "There are metrics that go with employee engagement," Doza says. "You need to have measurements and rate yourself to those measurements."

At Allied, employees tend to be inherently interested in the company's performance because they are owners of the company through an employee stock ownership plan. "Employee engagement is part of our calling," Doza says.

Part of the company's ongoing training and employee communication plan is promoting awareness of shared goals so employees can optimize their work to benefit the company and themselves.

Allied also holds employee round tables regularly where employees can hear about new projects and have opportunities to meet with senior leadership. It is a practice Allied has been doing for about 25 years, Doza says.

"Twice a year we sit down and they ask us questions until they're out of questions," he says. "The executive team wants to know—how can we get better and how can Allied get better? What's happening that we're not aware of?"

Allied's efforts ultimately come down to this continuous improvement practice, Doza says. "What decisions do we make today to make us better tomorrow?"

The Jon K. Tabor Global Business Center at Allied Mineral Products. Tabor, former chairman and CEO of Allied, who recently passed away, was an inspiration behind Allied's quality culture. *Credit: Allied Mineral Products*

Q: ***St. Gobain is such a large company, with so many different sectors and so many manufacturing plants. Are there practices you could spotlight that help the company ensure it has a culture of quality across all divisions?***

A: We look at what the core values are for the customer, and the quality really comes from the commitment to the customer. We are committed to providing them with a product that meets their needs. We get an understanding of what the customer wants, and once you meet with a customer, you start to become invested in their success.


SEFPro is dedicated to offering refractory solutions to the glass industries. Employees work to ensure that properties attained in a lab are maintained throughout the scaleup of the process. *Credit: Saint-Gobain*

Q: ***Are there any new trends or new practices that you have implemented or you are seeing in the industry?***

A: There is a lot of potential for using sensors and nondestructive testing techniques to help our customers monitor their furnaces better. We have a complete suite of services where we can help monitor gas emissions to help them get a longer life out of their furnace or maybe diagnose issues or improve efficiencies and detect if there are any temperature leaks. The current trends are leading us to help customers get more and more lifetime out of their furnaces, and help them adapt to environmental regulations.


Northborough, Mass., is Saint-Gobain's largest research center. *Credit: Saint-Gobain*

DEFLECTION ELBOWS PREVENT BLOWOUTS, PRESERVE PURITY OF CERAMICS AT COORSTEK

By Charles Williston

CoorsTek is a world leader in technical ceramics, or materials that are highly resistant to mechanical, chemical, electrical, and thermal degradation. Applications span numerous industries, including aerospace and defense, chemicals, electronics, energy, and medical.

In 2019, CoorsTek opened its Center for Advanced Materials (CCAM) in Golden, Colo. It combines a research and development hub, an analytical laboratory, and a materials manufacturing facility. CCAM's mission is to accelerate production of commercial ceramics using the latest technologies.

Its manufacturing side is dedicated to handling alumina (Al_2O_3), which rates 9 on the Mohs hardness scale, just below diamond.

"It's extremely abrasive," says Andrew Harm, CoorsTek process engineer, who led the commissioning of CCAM's eight pneumatic conveying systems.

These dilute-phase lines were built to transport the alumina between operations, from railcar unloading to mixing, milling, spray drying, and storage. The conveying systems' elbows were unfortunately no match for the abrasive alumina.

"I don't think it was communicated clearly how abrasive our materials are," Harm says. "They very quickly started poking holes in the elbows."

CoorsTek installed Smart Elbow deflection elbows after experiencing failures of ceramic-lined sweep elbows along its eight pneumatic lines conveying highly abrasive alumina. *Credit: HammerTek*

In some cases, the elbows failed after handling only 20,000 to 30,000 lbs (9,100 to 13,600 kg) of alumina. "Our batch size is 100,000 lbs (45,400 kg), so it was a substantial issue for us," Harm says.

In addition to downtime, premature wear caused product contamination with as much as 150 ppm of magnetic iron emanating from pipeline and elbow wear. "We care about iron in our material, especially our materials that go to the semiconductor industry and for defense," Harm says. "The chemistry and purity are extremely important."

PREVENTING ABRASIVE ALUMINA FROM IMPACTING THE ELBOW WALL

The ceramic linings of the original elbows had a Mohs hardness of just 5 to 6. As those wore through, Harm and his staff experimented with other types of elbows. The most effective proved to be Smart Elbow deflection elbows from HammerTek Corp.

These specialty bends have a spherical vortex chamber protruding from the inlet leg. As material enters the bend, a portion of the flow is diverted automatically into the vortex chamber, where it forms a loosely packed mass that slowly rotates in the direction of flow. This mass gently deflects incoming particles around the bend. Because some material continuously filters out of the chamber as new material enters, the rotating ball of material is continuously replenished. In addition, the material exits evenly across the outflow of the elbow without skidding along the outside radius as occurs with sweep elbows.

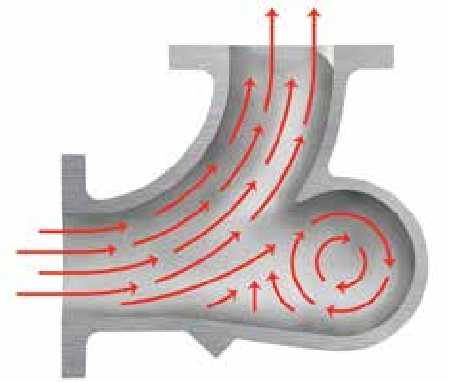
Although the deflection elbows are more expensive initially than other styles Harm tried, such as blind tees, they reduced costs and improved quality. "We get very little wear from the deflection elbows, so we're not wearing off that metal into our product. That by itself is enough for us to justify the cost," he says.

Eliminating the blowouts, the mess, and unscheduled downtime was a bonus. "We can make the case from a purely manufacturing standpoint, too," Harm adds.

REPLACING SWEEP ELBOWS PROACTIVELY

CoorsTek initially installed the deflection elbows in phases after it commissioned each conveying system and the original sweeps wore out.

"We did that with a couple of systems, but by the time we started running the fifth or sixth system, we went whole hog," Harm says.



A spherical vortex chamber protruding from the deflection elbow causes a loose ball of ceramic material to rotate in the same direction as the airstream that powers it, deflecting particles around the bend without impacting or wearing the elbow wall. *Credit: HammerTek*

CoorsTek replaced most of its double-wall sweep elbows (foreground) with Smart Elbow deflection elbows (rear). *Credit: HammerTek*

"Waiting [for a blowout] was causing too much unplanned downtime. If you already have the part on hand and plan for it, changeout time is minimal, maybe half an hour."

Replacing difficult-to-access elbows, however, takes more time and planning. The most difficult were the elbows atop CCAM's 90-foot-tall (27.4 m) outdoor silos. It took two days and required hiring a crane and building special scaffolding, but there was no alternative, Harm says. "We can't be blowing our material out to the open," he affirms.

The silo elbows were the last of the 65 Smart Elbow bends that CoorsTek installed. Some of the bends are cast iron, but most are made from HammerTek's HammerLoy, a more abrasion-resistant material.

REDUCING PRESSURE DROP BY ONE-HALF TO ONE-THIRD

In addition to preventing contamination and blowouts, the deflection elbows reduced pressure drop. "With the blind tee elbows, we get 0.2 to 0.3 psi (1.38 to 2.1 kPa) pressure drop across the elbow itself. With the HammerTek elbows, we get about 0.1 psi (0.69 kPa) drop," Harm says. "That's a pretty significant difference. If we used four or five of those other elbows, it could mean a 20 percent pressure drop just across the elbows. It could drop the rate enough that we couldn't send material through."

Throughputs among the eight systems range from 4,000 to 20,000 lbs (1,800 to 9,000 kg) per hour. Conveying line runs are 80 to 300 ft (24.4 to 91.4 m) and pipeline diameters are 4, 5, or 6 in. (100, 125, or 150 mm). At the discharge end, material velocities can exceed 100 mph (161 km/h).

The oldest of the HammerTek elbows, installed two years ago, continues to perform. In noncritical areas, CoorsTek still has some blind tees and sweeps with double-wall construction.

"If we can get away without replacing them, great," Harm says. "But the first time one of those fails, we'll go ahead and swap those out as well."

ABOUT THE AUTHOR

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Additive manufacturing of ceramics: Toward a single-step process without the need for post-pyrolysis and sintering

Additive manufacturing (AM) of ceramics is an active field of research that aims to develop and optimize processes to produce customized, complex ceramic parts useful in various sectors. In fact, AM is entering the era where industrial applications are becoming economically profitable and AM ceramic parts can be produced with mechanical properties close to conventionally produced ceramics.[1]

Currently, AM is achieved most commonly through multistep "indirect" processes. Indirect processes require two or more supplementary steps, such as pyrolysis (debinding) and sintering, to transform the green body into a final product with desired geometry and properties.[2,3]

In contrast, single-step "direct" processes for ceramics AM do not require supplementary steps. These processes use high-power lasers to melt and/or sinter ceramic powders point by point to produce a dense part layer by layer with final properties. Currently, only powder bed fusion and direct energy deposition allow single-step fabrication of ceramic parts.

Recently, inspired by photopolymerization, pressureless sintering, and photonic sintering technologies, researchers at the Georgia Institute of Technology received funding from the U.S. Office of Naval Research to develop a new single-step ceramic AM process that does not require post-process pyrolysis or high-power lasers.

To tackle this challenge, three different groups at Georgia Tech are conducting experiments involving (1) development of new ceramic/preceramic chemistries and (2) better understanding of nonthermal processes (e.g., illumination, activated species, sonic energy) for fusing and ceramizing ceramic/preceramic materials.

The first group, led by professor Rampi Ramprasad, is establishing computational protocols based on density functional theory coupled with thermodynamics and excited state dynamics. These protocols will allow the determination of transformation pathways to ceramic materials starting from a variety of ceramic/preceramic materials.

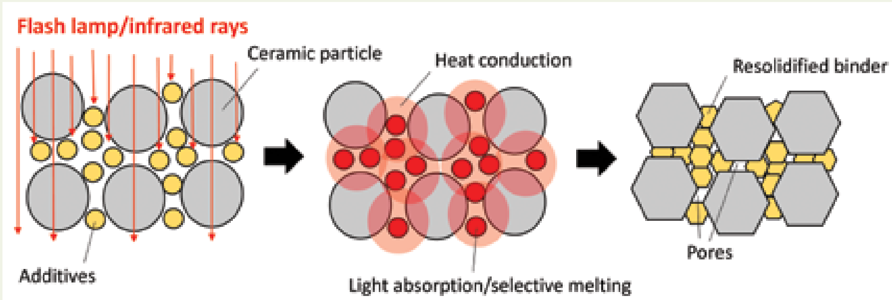

Figure 1. Strategy to induce low-temperature sintering of thin ceramic layers. Inspired by Yan and Okada (2016).

The second group, led by professor Jerry Qi, specializes in the 3D printing of soft active materials to enable 4D printing methods.

The third group, of which we are a part, is led by professor Mark Losego. We are developing new ceramic/preceramic chemistries and ceramization methods that will allow us to bind ceramic particles via surface coatings or the use of additives to promote liquid phase sintering at low temperatures (below or around 1,000°C).

We are particularly interested in photonic sintering methods, which have been widely studied in the field of semiconductors and electronics. These processes offer the ability to rapidly process films at either low or high temperatures, thus greatly reducing processing time compared to conventional thermal processing.

Regarding these methods in terms of ceramics research, Gilshtein et al. (2021) proposed a flash lamp annealing method to sinter thin layers (up to 3 μm) of alumina suspensions at lower temperature (around 1,000°C) than the usual sintering temperature of alumina (> 1,500°C).[4] Meanwhile, Yan and Okada (2016) used infrared light to mildly sinter a mixture of silicon powders, copper nanoparticles, and carbon nanotubes.[5]

We are studying the combination of AM technologies, such as aerosol printing, ink-jet printing, and direct ink writing, with these demonstrated flash lamp/infrared irradiation techniques to sinter ceramic parts layer by layer without the need for a post-firing step. Ideally, this project will help identify completely new paradigms and ceramic/preceramic chemistries that expand the existing toolbox for direct AM of ceramic components. Moreover, the use of light technologies could help to save energy and time in the manufacturing process of ceramics.

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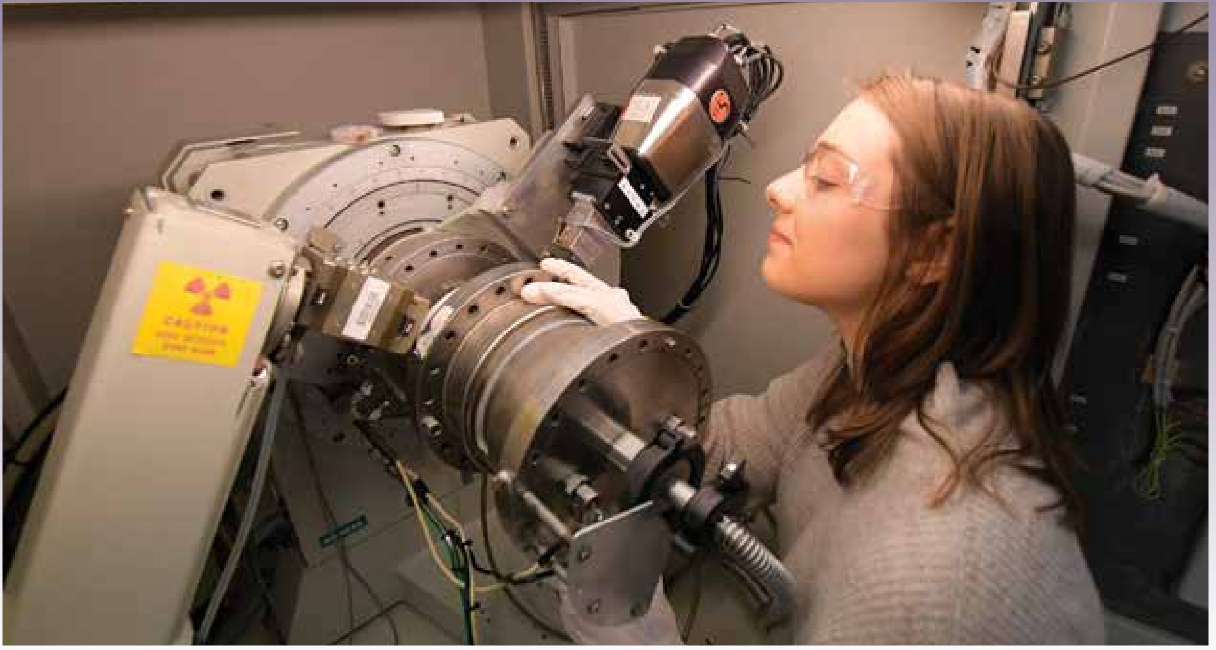

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