AMERICAN CERAMIC SOCIETY

bulletin

emerging ceramics & glass technology

OCTOBER/NOVEMBER 2023

Germany: Building a climate for innovation

ACerS announced 2023–24 leaders | Lead-free piezoceramics | 3D printing for construction

Turning to the future.

What are your firing needs, and are you getting the custom kiln design you require?

For more than a century Harrop has worked hard to design, build, and service custom kilns that fit your specific requirements.

We don't stop there. If you aren't sure what you need, we can help. Our laboratory can run tests to help identify your process boundaries. Through our toll firing facility, we can help to further define the equipment/processing combination that works best for your material. And if you are not ready for a new kiln, we can toll fire your material to meet your production needs.

How can we help you?

HARROP

www.harropusa.com

1.614.231.3621

contents

October/November 2023 • Vol. 102 No.8

feature articles

Germany: Building a climate for innovation

Germany is confronting environmental and human capital challenges as it invests in R&D to support sustainable development goals.

by Randy B. Hecht

Increasing demand for lead-free piezoceramic systems and textured ceramics

Health concerns and production constraints surrounding conventional piezoceramic materials are driving interest and growth in the nascent market for lead-free and textured piezoceramics.

by A. Murat Avcı, Servet Kızılırmak, and Ender Suvacı

departments

News & Trends 3
Spotlight 8
Ceramics in Biomedicine 19
Ceramics in the Environment . . . 20
Ceramics in Manufacturing 23
Research Briefs 24

columns

Business and Market View 7
3D printing for construction: Global markets
by BCC Publishing Staff

Deciphering the Discipline 48
Different scientific philosophies: A visitor's perspective on thinking like an American in Germany
by Jesse Hinricher

meetings

Upcoming dates: 43
ICACC 2024, EMA 2024, PACC-FMAs 2024, GOMD 2024, and 10th International Congress on Ceramics

resources

Calendar 44
Classified Advertising 45
Display Ad Index 47

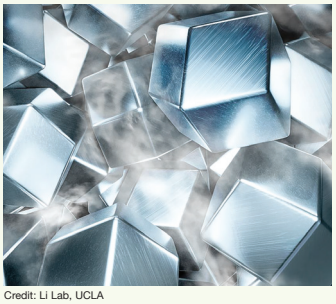
AMERICAN CERAMIC SOCIETY
bulletin

online
www.ceramics.org

October/November 2023 • Vol. 102 No.8

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

As seen on *Ceramic Tech Today*...



Credit: Li Lab, UCLA

Ultrafast deposition reveals true shape of lithium

The complex feedback loop between solid electrolyte interphase formation and lithium deposition means researchers have struggled to develop a general framework for understanding and predicting lithium morphology. Researchers at the University of California, Los Angeles, modified the electrodeposition process to decouple lithium deposition from interface growth and thus reveal the intrinsic deposition morphology of lithium.

Read more at www.ceramics.org/lithium-shape

Also see our ACerS journals...

ACT special issue: Honoring Prof. Ralf Riedel (Vol. 20, No. 1)

The *ACT* January/February 2023 issue honors professor Riedel's (TU Darmstadt, Germany) development of revolutionary ceramic materials.

Explore the issue: https://ceramics.onlinelibrary.wiley.com/toc/17447402/2023/20/1

ACT special issue: Walter Krenkel—CMC-pioneer and dedicated expert on ceramics (Vol. 19, No. 1)

The *ACT* January/February 2022 issue honors professor Krenkel's (University of Bayreuth, Germany) career achievements.

Explore the issue: https://ceramics.onlinelibrary.wiley.com/toc/17447402/2022/19/1

UNITECR 2022 Proceedings

The Unified International Technical Conference on Refractories is a biennial international conference that contributes to the progress and exchange of industrial knowledge and technologies concerning refractories.

Explore the issue: https://bulletin-archive.ceramics.org/unitecr-2022-proceedings

Journal of the American Ceramic Society | International Journal of Applied Ceramic TECHNOLOGY | International Journal of Applied Glass SCIENCE | International Journal of Ceramic Engineering & Science

Read more at www.ceramics.org/journals

American Ceramic Society Bulletin covers news and activities of the Society and its members, includes items of interest to the ceramics community, and provides the most current information concerning all aspects of ceramic technology, including R&D, manufacturing, engineering, and marketing. The American Ceramic Society is not responsible for the accuracy of information in the editorial, articles, and advertising sections of this publication. Readers should independently evaluate the accuracy of any statement in the editorial, articles, and advertising sections of this publication. *American Ceramic Society Bulletin* (ISSN No. 0002-7812). ©2023. Printed in the United States of America. *ACerS Bulletin* is published monthly, except for February, July, and November, as a "dual-media" magazine in print and electronic formats (www.ceramics.org). Editorial and Subscription Offices: 550 Polaris Parkway, Suite 510, Westerville, OH 43082-7045. Subscription included with The American Ceramic Society membership. Nonmember print subscription rates, including online access: United States and Canada, 1 year $135; international, 1 year $150.* Rates include shipping charges. International Remail Service is standard outside of the United States and Canada. *International nonmembers also may elect to receive an electronic-only, email delivery subscription for $100. Single issues, January–December: member $6 per issue; nonmember $15 per issue. Postage/handling for single issues: United States and Canada, $3 per item; United States and Canada Expedited (UPS 2nd day air), $8 per item; International Standard, $6 per item.

POSTMASTER: Please send address changes to American Ceramic Society Bulletin, 550 Polaris Parkway, Suite 510, Westerville, OH 43082-7045. Periodical postage paid at Westerville, Ohio, and additional mailing offices. Allow six weeks for address changes.

ACSBA7, Vol. 102, No. 8, pp. 1–48. All feature articles are covered in Current Contents.

Gaining a second wind—recycled automotive glass hits the road again in new windshields

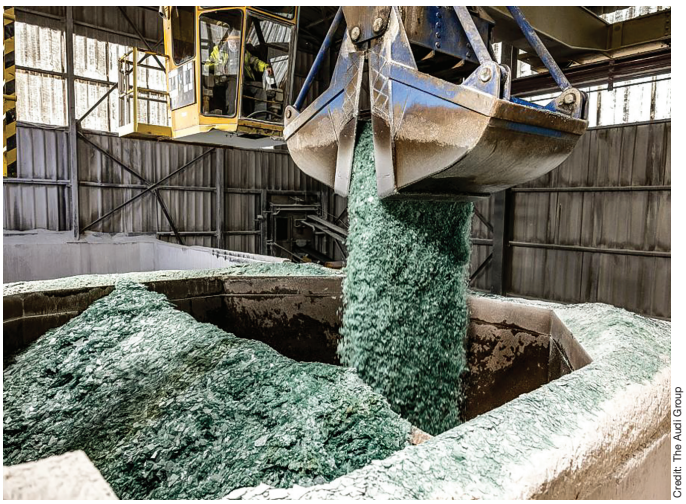
The Greentech Festival in Europe offers a prime platform for companies to publicize their advances in sustainability efforts. This year's event, held in June 2023, was no exception—the Audi Group used the festival to announce the success of its "GlassLoop" pilot project, which explored the potential of recycling defective automobile glass back into new windshields.

There are stringent quality requirements for glass used in automotive applications to ensure safety. As such, companies traditionally prefer to make these products from raw materials rather than risk using recycled materials that may be of lower quality.

Because of this preference for raw materials, car windows that are damaged beyond repair—mainly windshields and panoramic roofs—have to date been reused for less demanding purposes, such as bottles or insulation.

The GlassLoop project aimed to determine if this assumption about raw versus recycled materials was unnecessarily closing off a viable reuse route for defective automobile glass. For the one-year project, which began in January 2022, the Audi Group partnered with Reiling Glas Recycling (Harsewinkel, Germany), Saint-Gobain Glass (Herzogenrath, Germany), and Saint-Gobain Sekurit. An April 2022 Audi press release stated that the companies aimed to process about 40 tons of recycled car glass using the following steps.

1. At selected dealerships in the Volkswagen Group's retail network, customers' damaged windshields are evaluated to determine if they can be repaired.
2. If repair is not possible, the windshields are delivered to Volkswagen's Original Teile Logistik GmbH & Co. KG, which organizes the disposal of unneeded parts. Service partners then remove the windshields for recycling.
3. After removal, the damaged windshields are delivered to Reiling Glas Recycling, where they are first bro-



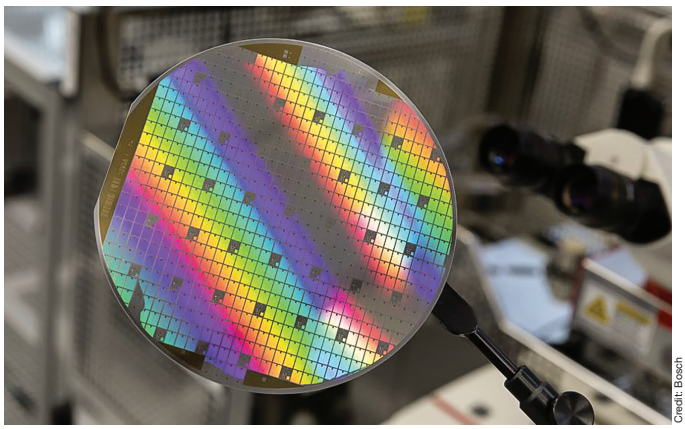
Credit: The Audi Group

Delivery of glass recyclate during the GlassLoop pilot project, which explored the potential of recycling defective car glass back into new windshields.

ken into small pieces. Non-glass materials such as plastic (polyvinyl butyral), window edgings, metals, and wires (heating filament and antenna cables) are then removed using magnets, non-ferrous metal separators, extraction units, and electro-optical sorting units.

4. After these materials are removed, Saint-Gobain Glass separates the glass granulates based on source and color, which are then stored in bins. The granulate is then mixed with quartz sand, sodium carbonate, and chalk, with the recycled glass content ranging between 30–50%.
5. The plate glass is processed into rectangles of about 3 x 6 meters (10 x 20 feet) each. It is then sent to a Saint-Gobain Sekurit plant, which adds glazing to the product.

In the project update announced at the Greentech Festival, the Audi Group confirmed that comparable quality could be achieved in glass containing up to 30% recycled content. The Audi Group and its partner companies now plan to shift this recycled glass into standard production as of September 2023, with production of windshields for the all-electric SUV Audi Q4 e-tron. ■



Credit: Bosch

A silicon carbide power semiconductor from German company Bosch. To prepare for an expected surge in demand for SiC electronics, several semiconductor manufacturers have announced plans to construct new or expand existing fabrication facilities.

SiC chips make inroads in the automotive industry

Silicon is the traditional material used as the wafer in semiconductor chip fabrication. However, despite their ubiquity, silicon-based chips have some disadvantages. For example, silicon's performance degrades badly at high temperatures. And as manufacturers have worked to place more transistors on each chip, considerable heat is generated.

This increased heat generation is especially troublesome for automakers. Chips placed in and around a car's engine already experience high external temperatures. With the trend toward electric vehicle adoption, cars now have more semiconductor chips than ever before—meaning the need for cooling will be far greater.

For this reason, automakers are starting to embrace silicon carbide (SiC)-based chips for automotive applications. Compared to silicon, SiC has excellent thermal conductivity, which enables high-temperature operation with straightforward cooling control. SiC also has a much higher critical electric field strength, which allows it to withstand the higher voltages needed to enable fast battery charging times.

Toyota was an early adopter of SiC, developing and testing SiC power semiconductors for its hybrid vehicles back in 2014. However, Tesla was the first electric vehicle manufacturer to include SiC in its vehicles, with the adoption of a SiC main inverter for the Model 3 in 2017. Now, almost all automakers have expressed an interest in SiC, with companies such as BYD, Hyundai, and Kia choosing SiC modules for their new car models.

To prepare for an expected surge in demand for SiC electronics, several semiconductor manufacturers have announced plans to construct new or expand existing fabrication facilities. For example,

- **February 2022:** German multinational engineering and technology company Robert Bosch GmbH announced plans to further expand its wafer fabrication facility in Reutlingen, Germany. The expansion will primarily

serve the growing demand for microelectromechanical systems and SiC power semiconductors.

- **September 2022**: U.S. semiconductor manufacturer Wolfspeed announced it will build a new, state-of-the-art, multibillion-dollar materials manufacturing facility in Chatham County, N.C. The investment is targeted to generate a more than 10-fold increase from Wolfspeed's current SiC production capacity on its Durham campus.
- **February 2023**: Wolfspeed and German global technology company ZF Friedrichshafen AG announced a partnership to create a joint R&D center in Germany to accelerate SiC innovation. The partnership also includes a significant investment by ZF to support Wolfspeed's planned construction of a SiC device fabrication facility in Ensdorf, Germany.
- **April 2023**: Bosch announced plans to acquire U.S. chipmaker TSI Semiconductors. It plans to upgrade TSI's existing manufacturing facilities in Roseville, Calif., so SiC chips can be produced there.
- **August 2023**: German semiconductor manufacturer Infineon Technologies AG announced it is expanding its factory in Kulim, Malaysia, to increase production of SiC powder modules.

There are challenges to scaling up SiC production, however. An interview with Wolfspeed senior vice president and general manager Cengiz Balkas, available at https://www.youtube.com/watch?v=CoynlzmBFEg, summarizes some of these challenges and outlines several solutions. ■

Collecting data in granular environments—turtle-inspired robot can swim untethered under the sand

The increasing demand for sand, similar to the demand for other critical material resources, is raising concerns about a global shortage. And though numerous studies have called for the development of a global sand governance strategy to address this imminent threat, little headway has been made.

This holdup is due in part to a lack of reliable methods to gauge, monitor, and compare the scale of sand extraction and consumption activities. Unlike water or air, robots cannot be easily deployed to gather data in a sandy environment. That is because movement through granular media, such as sand, presents numerous challenges. For example,

- Large resistive forces due to frictional resistance between sand grains,

Credit: UC San Diego

Shivam Chopra holds the robot he helped to develop as a Ph.D. student in the research group of Nicholas Gravish at the University of California, San Diego. This robot, inspired by turtle hatchlings, can move untethered through sand.

- Nonzero yield stresses that cause unpredictable solid fluid transitions, and
- Extremely limited opportunities for sensing obstacles.

Research in the last 15 years on moving across or within granular environments has mostly focused on two basic approaches: 1) robots that use peristaltic body expansion and elongation, like earthworms; and 2) undulatory robots that use body bending to effectively "swim" in sand, like the sandfish lizard.

Robots based on the first approach face challenges to obtaining autonomous, untethered operation. Robots based on the second approach have successfully navigated shallow, low-density plastic beads, but the resistive forces are comparatively small compared to movement in sand; current actuators may not be able to generate motion in that case.

Appendage-driven robots would have several advantages over these other approaches, including the ability to detect obstacles and generate large propulsive forces through a wide stroke. But they face a fundamental problem: due to the frictional resistance of sand (i.e., nonzero yield stress), an elastic appendage can get stuck in a deformed configuration if the elastic restoring stress is below the yield stress.

Fortunately, nature can serve as prime inspiration for many challenges that researchers face, and this situation is no exception. In a recent open-access paper, researchers from the University of California, San Diego, described how they developed an easily deployable, untethered, appendage-driven robot by observing the motion of sea turtle hatchlings.

After conducting extensive simulations and testing, the UC San Diego team selected a tapered body design and shovel-shaped nose. They also added two foil-like surfaces on the sides of the nose to keep the robot at level depth in the sand.

The robot, which was tested in both a lab tank and La Jolla Shores Beach, traveled at a speed of 1.2 millimeters per second—roughly 4 meters, or 13 feet, per hour. It was able to detect obstacles above its body by monitoring changes in the torque generated by the movement of its flippers, though not obstacles below or directly in front of it.

Next steps include exploring ways to increase the robot's speed, such as by increasing the gait cycle frequency or making the appendages longer. The researchers also plan to modify the design so that the robot can burrow into and out of the sand, rather than being buried at its maximum depth of five inches.

The open-access paper, published in *Advanced Intelligent Systems*, is "Toward robotic sensing and swimming in granular environments using underactuated appendages" (DOI: 10.1002/aisy.202200404). ■

Training the next generation of builders—first large-scale construction 3D printer in the Buckeye State arrives at Ohio State

With housing shortages rampant in countries around the world—and with the houses that are available being unaffordable for many—the construction industry is considering alternative building materials and methods to make housing more affordable.

3D printing is one approach gaining steam in the construction industry. Compared to conventional construction methods, 3D-printing technologies allow companies to develop complex shapes while using less material. It also aids in less material wastage because failed prints can be reused as raw material in later printing stages.

Several companies have started making names for themselves in the 3D printing for construction space. To further expand the use of 3D printing in construction, however, will require training the next generation of builders on these techniques.

In January 2023, 3D-printing construction company Pantheon Innovative Builders delivered a construction-grade 3D printer to The Ohio State University's Center for Design and Manufacturing Excellence (CDME) as part of a new partnership to train the next generation. The printer, which is the modular BOD2 printer from Denmark-based manufacturer COBOD International, is the first large-scale concrete construction printer in Ohio and one of fewer than 10 at universities worldwide.

The research partnership will include testing; print demonstrations; experimental learning for students; and the creation of a workforce development training curriculum, which can count as credit toward post-secondary or trade education. COBOD will provide on-site support with machine startup, training, and material development.

In a press release, Pantheon CEO Ryan Kelly says the company is "extremely excited" for this opportunity to work with CDME and COBOD.

"This partnership will help us create a model to reimagine, retrain and recruit the future construction workforce," he says. ■

3D printing for construction: Global markets

By BCC Publishing Staff

The global market for 3D printing in the construction industry had a value of $8.0 million in 2022 and is anticipated to grow at a whopping compound annual growth rate (CAGR) of 177.7% to reach nearly $4.6 billion by 2028.

The use of 3D printing for construction started in the 1990s, when multiple organizations started testing 3D printers to create modular elements for full-scale projects. By the 2000s, the frequency of these applications soared, and in 2014, the world witnessed the first ever 3D-printed commercial building. Now, significant technological advancements, including in automation and in data and material preparation, are allowing more construction companies to adopt 3D printing.

3D printing offers construction companies the ability to develop complex shapes while using less material than conventional manufacturing processes. It also aids in less material wastage, as concrete waste and failed prints can be reused as raw material in later stages for printing. Plus, workers skilled in handling 3D printers can perform jobs more easily and reduce the chances of injuries.

While the overall market for 3D printing for construction is still developing, there are several materials that have been successfully used.

Concrete. Traditional concrete is not used in 3D printing for construction as it may clog the printer's nozzle and would not adhere to the successive layers. Instead, the concrete comprises super-plasticizers, fibers, and other ingredients that enable it to settle in an optimal time for layer adhesion. These ingredients also aid in imparting strength to the concrete to reduce the requirement for steel reinforcements.

Polymers. Some common polymers used in 3D printing for construction include polylactic acid, acrylonitrile butadiene styrene, and polyamide. 3D printing construction with recycled plastic, such as polypropylene and Bio-PA, is an area of increasing interest and development as the construction industry seeks more sustainable and eco-friendly solutions.

Local soils. 3D printing for construction makes it possible to use various soils, including clay and sand, as the base material. Using local soils is considered to be environmentally friendly and is time- and cost-effective.

Extrusion and binder jetting are among the most common processes used in 3D printing for construction both commercially and globally. These methods are used in both on-site and off-site construction.

Table 1. Project partnerships around the world

Year	Partners	Description
January 2023	Penquis and the University of Maine	Penquis received $3.3 million in government funding to build economical housing for low-income Mainers in the U.S. The funding will be used to buy nine 3D-printed houses from the Advanced Structures & Composites Center of the University of Maine.
January 2023	University of Johannesburg, Department of Science and Innovation, AfriSam, and KwaZulu-Natal Department of Human Settlements	The University of Johannesburg and the Department of Science and Innovation together launched the first 3D-printed building in South Africa. Other key partners in the project include AfriSam, a cement supplier, and KwaZulu-Natal Department of Human Settlements.
October 2022	Harcourt Technologies and Building for Humanity	Harcourt partnered with Building for Humanity, a British NGO, to 3D print a residential project in the U.K.

3D printing for construction is frequently viewed as a solution to the housing crisis in the United States and elsewhere. According to an estimate by the United Nations Human Settlements Program, by the end of 2030, nearly 30 billion people, which is 40% of the global population, will require access to adequate housing. This estimate also means nearly 96,000 new affordable and accessible houses must be built every day to meet the demand.

Currently, project partnership is the preferred strategy by key market players to establish a strong presence in the rapidly growing 3D printing for construction market. Some examples of these partnerships can be seen in Table 1.

About the author

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

Resource

BCC Publishing Staff, "3D printing for construction: Global markets" BCC Research Report AVM238A, August 2023. www.bccresearch.com. ■

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partners:

Chase Nedrow Industries

QML, Inc.

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

ACerS leaders for 2023–2024

ACerS is pleased to introduce the 2023–2024 Society leadership. New officers and directors were installed at the 125th Annual Business Meeting on Oct. 2, 2023, at ACerS Annual Meeting at MS&T in Columbus, Ohio.

Society officers and directors

Executive Committee

Bordia

President
Rajendra Bordia
George J. Bishop III Chair Professor of ceramic and materials engineering
Clemson University
Clemson, S.C.

Ferraris

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

Mathur

Past president
Sanjay Mathur
Director and chair
Institute of Inorganic Chemistry
University of Cologne
Cologne, Germany

Tipsord

Treasurer
Daniel Tipsord
General manager
Trans-Tech
Adamstown, Md.

Mecklenborg

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

Board of Directors (new)

Navrotsky

Alexandra Navrotsky
Regents Professor of molecular sciences and engineering of matter, transport, and energy
Director of the Navrotsky Eyring Center for Materials of the Universe
Arizona State University
Tempe, Ariz.

FOR MORE INFORMATION:

ceramics.org

Singh

Dileep Singh
Argonne Distinguished Fellow
Senior scientist and group leader for thermal and structural materials
Applied Materials Division,
Argonne National Laboratory
Argonne, Ill.

Steyer

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

Jiang

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

Reigel

Marissa Reigel
Senior R&D manager
Saint-Gobain NorPro
Stow, Ohio

Wong-Ng

Winnie Wong-Ng
Research chemist
National Institute of Standards and Technology
Gaithersburg, Md.

Freiman

Parliamentarian
Stephen Freiman
Freiman Consulting Inc.
Potomac, Md. ■

Board of Directors (returning)

Breder

Kristin Breder
Senior principal scientist
Saint-Gobain Research North America
Northborough, Mass.

Cesarano

Joseph Cesarano
President and founder
Robocasting Enterprises LLC
Albuquerque, N.M.

Graeve

Olivia Graeve
Professor of mechanical and aerospace engineering
Director of the CaliBaja Center for Resilient Materials and Systems
University of California, San Diego
San Diego, Calif.

more SOCIETY DIVISION SECTION CHAPTER NEWS

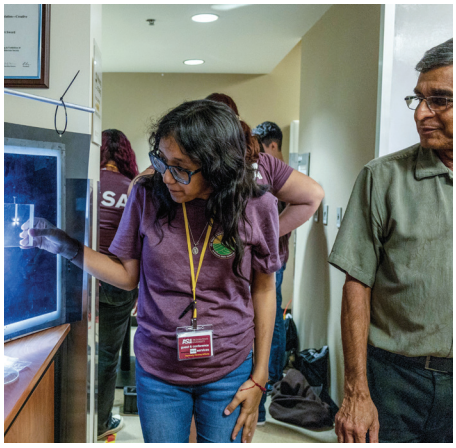
Dayton/Cincinnati/Northern Kentucky Section attends Dayton Dragons game

The ACerS Dayton/Cincinnati/Northern Kentucky Section enjoyed an afternoon of socializing and cheering on the Dayton Dragons vs. the Great Lakes Loons on Sunday, July 9, 2023.

Arizona Section hosts events to promote women in STEM and a summer minicamp for high school students

The Arizona Section hosted the Arizona State University Material Advantage Students and spoke to them regarding women in STEM as part of their diversity, equity, and inclusion efforts. They highlighted the many women in STEM whose contributions may have been forgotten or marginalized. They also stressed why and how gender role models are critical. The Section also held a discussion with roughly 50 local seniors about women in STEM.

Additionally, the Section hosted 55 high school students for a summer minicamp. The students engaged in several hands-on engaging activities, as seen in the accompanying photos. ■



Volunteer spotlight

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

Monica Ferraris is full professor of science and technology of materials at Politecnico di Torino, Italy. She received an M.S. in solid-state chemistry from the University of Torino, Italy. She started her career as junior research scientist with the Italian Telecom Research Laboratory before joining Fiat Research Centre and then Politecnico di Torino. Her research focuses on joining and mechanical testing of ceramics, glass, and composites for energy applications, including fuel cells, nuclear fission, and fusion energy.

Ferraris has been an ACerS member since 1995 and a Fellow since 2018. She is affiliated with the Engineering Ceramics Division. She served as co-editor-in-chief (2015–2020) of *International Journal of Applied Ceramic Technology*, chair of the Italy Chapter (2017–present), chair (2015–2016) of the John Jeppson Award Committee, member of the Meeting Committee (2016–present), and member of the Board of Directors (2019–2022).

Ferraris was awarded the Global Star Award (2011) and designated as a Global Ambassador (2016). She has also received the Engineering Ceramic Division "Bridge Building" Award (2021).

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

Spain Chapter tours Airbus facilities in Madrid

On June 27, 2023, a group from the Spain Chapter, led by Chapter chair Arnaldo Moreno, visited the Airbus facilities in Getafe, Madrid. They took a guided tour, during which they were shown the assembly process of the parts produced in Spain for different Airbus models. The group then visited the Imdea Materials Institute, an Airbus partner. Institute director José Manuel Torralba gave them an explanatory talk about the activities of the Center and the main research and development projects they were conducting for companies in the aerospace, energy, and related sectors. The day closed with a lunch, during which Spain Chapter members had the opportunity to share experiences and impressions of the visits. ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

Ceramic Tech Chat: Steven Jung and Michael Silver

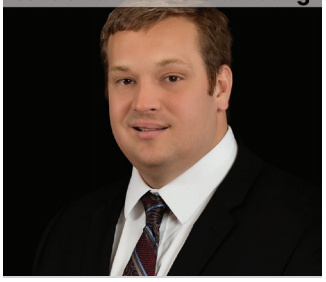
Hosted by ACerS Bulletin editors, Ceramic Tech Chat talks with ACerS members to learn about their unique and personal stories of how they found their way to careers in ceramics. New episodes publish the third Wednesday of each month.

In the July 2023 episode of Ceramic Tech Chat, Steven Jung, chief technology officer at specialty glass manufacturer Mo-Sci, overviews the history of the company, discusses the science behind some of their well-known products, and describes how the company develops specialty glass products for a variety of end-user industries.

Check out a preview from his episode, in which Jung talks about Mo-Sci's first product: a glass microsphere that delivers radiation into a tumor.

"[In the TheraSphere], the glass has an element called yttrium. Yttrium is an element that is able to be put into a nuclear reactor and made radioactive. The yttrium is a beta emitter. It releases energy over a relatively short period, maybe up to a centimeter from the individual microsphere. It releases a high dose of radiation, just kind of around where it's located. And you're able to deliver doses that are significantly higher than what you could do with external beam radiation."

Specialty glasses for healthcare and more: Steven Jung



In the August 2023 episode of Ceramic Tech Chat, Michael Silver, president and CEO of American Elements, explains how he became involved in the materials supply chain, describes what

AWARDS AND DEADLINES

FOR MORE INFORMATION:

ceramics.org/members/awards

Society awards: Nominations due Jan. 15, 2024
Contact: Erica Zimmerman, ezimmerman@ceramics.org

Society awards will be presented at the Annual Awards Banquet during ACerS Annual Meeting at MS&T in October 2024.

Society awards	Description
Distinguished Life Membership	ACerS' highest honor, given in recognition of a member's contributions to the ceramics profession. Nominees must be current members who have attained professional eminence because of their achievements in the ceramic arts or sciences, service to the Society, or productive scholarship.
Fellows	Recognizes individuals who have made outstanding contributions to the ceramic arts or sciences through broad and productive scholarship in ceramic science and technology, by conspicuous achievement in the ceramics industry, or by outstanding service to the Society. Nominees must be 35 years old or older.
W. David Kingery Award	Recognizes distinguished lifelong achievements involving multidisciplinary and global contributions to ceramic technology, science, education, and art.
John Jeppson Award	Recognizes distinguished scientific, technical, or engineering achievements in ceramics.
The European Ceramic Society-American Ceramic Society Joint Award	Recognizes individuals who foster international cooperation between The American Ceramic Society and the European Ceramic Society, in demonstration of both organizations' commitment to work together to better serve the international ceramics community.
The Rishi Raj Medal for Innovation and Commercialization Award	Recognizes one individual whose innovation lies at the cusp of commercialization in a field related, at least in part, to ceramics and glass.
Medal for Leadership in the Advancement of Ceramic Technology	Recognizes individuals who, through leadership and vision in an executive role, have made significant contributions to the success of their organization and in turn have significantly expanded the frontiers of the ceramics industry.

Innovation in materials supply: Michael Silver

comprises innovation at a materials supply company, and discusses how these companies handle some of the most challenging market factors affecting industries right now.

Check out a preview from his episode, in which Silver explains how American Elements works with its customers on sustainability.

"We try to get into the production line with a customer and try to avoid recycling really and try to find reuse methods. I mean, that's really the best way is 100% consumption or coming up with a way where things are really still in a reuse within the same industry. The moment something goes to recycling, you've really lost a massive amount of value. So we try to find ways so that materials are consumed a 100% or are in a reuse state within the same industry."

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

Society awards	Description
Corporate Environmental Achievement Award	Recognizes an outstanding environmental achievement made by an ACerS Corporate Partner in the field of ceramics.
Corporate Technical Achievement Award	Recognizes an outstanding technical achievement made by an ACerS Corporate Partner in the field of ceramics.
Richard M. Fulrath Awards	Promotes technical and personal friendships between Japanese and U.S. ceramic engineers and scientists. Recognizes individuals for excellence in research and development of ceramic sciences and materials. Nominees must be 45 or younger at the time of award presentation.
Karl Schwartzwalder-Professional Achievement in Ceramic Engineering Award	Recognizes an outstanding young ceramic engineer whose achievements have been significant to the profession. A nominee must be younger than 40 years old and must be a member of both EPDC and ACerS.
Robert L. Coble Award for Young Scholars	Recognizes an outstanding scientist who is conducting research in academia, industry, or at a government laboratory. Candidates must be an ACerS member and 35 years old or younger.
Du-Co Ceramics Young Professional Award	Recognizes a young professional member of ACerS who demonstrates exceptional leadership and service to ACerS.
Frontiers of Science and Society - Rustum Roy Lecture	Given each year by a nationally or internationally recognized individual who is conducting research in academia, industry, or at a government laboratory. The committee selects the lecturer, but suggestions from membership are invited.
Edward Orton, Jr. Memorial Lecture	Given each year by a nationally or internationally recognized individual who best represents the past tradition of the Orton Lecturer. Generally, the committee selects the lecturer, but suggestions from membership are invited.
The Navrotsky Award for Experimental Thermodynamics of Solids	Awarded biennially to an author who made the most innovative contribution to experimental thermodynamics of solids technical literature during the two calendar years prior to selection. (Next awarded in 2025)
Ross Coffin Purdy Award	Recognizes the author(s) who made the most valuable contribution to ceramic technical literature during the calendar year two years prior to the year of selection. The 2024 Purdy award is for the best paper published in 2022.
Richard and Patricia Spriggs Phase Equilibria Award	Recognizes the author(s) who made the most valuable contribution to phase stability relationships in ceramic-based systems literature during the previous calendar year (2023).
Morgan Medal and Global Distinguished Doctoral Dissertation Award	Recognizes a distinguished doctoral dissertation in the ceramics and glass discipline. ■

more AWARDS AND DEADLINES

Class and Division awards: Nominations due Jan. 15, 21, or 31, 2024
Contact: Vicki Evans, vevans@ceramics.org

Class	Award	Deadline	Description
EPDC	Greaves-Walker Lifetime Service Award	Jan. 15, 2024	Recognizes an individual who has rendered outstanding service to the ceramic engineering profession and who has exemplified the aims, ideals, and purpose of EPDC.
EPDC	Outstanding Educator Award	Jan. 15, 2024	Recognizes outstanding work and creativity in teaching, directing student research, or in the general educational process (e.g., lectures, publications) of ceramic educators.
EPDC	Arthur L. Friedberg Engineering Tutorial and Lecture	Jan. 15, 2024	Recognizes an individual who has made outstanding contributions to ceramic engineering that relate to the processing or manufacturing of ceramic products. The awardee must be a member of both EPDC and ACerS.

Division	Award	Deadline	Description
AACS	Anna O. Shepard	Jan. 15, 2024	Recognizes an individual(s) who has made outstanding contributions to materials science applied to art, archaeology, architecture, or cultural heritage.
BSD	Early Discovery	Jan. 15, 2024	Recognizes an early career member of ACerS who has demonstrated a contribution to basic science in the field of glass and ceramics.
BSD	Robert B. Sosman Lecture	Jan. 15, 2024	Recognizes an outstanding achievement in basic science that results in a significant impact on the field of ceramics.
BIO	Young Scholar	Jan. 31, 2024	Recognizes excellence in research among current degree-seeking graduate students and postdoctoral research associates.
BIO	Global Young Bioceramicist	Jan. 31, 2024	Recognizes a young ceramic engineer or materials scientist who has made significant contributions to the area of bioceramics, for human healthcare around the globe.
BIO	Larry L. Hench Lifetime Achievement	Jan. 31, 2024	Recognizes an individual's lifetime dedication, vision, and accomplishments in advancing the field of bioceramics, particularly toward innovation in the field and contribution of that innovation to the translation of technology toward clinical use.
BIO	Tadashi Kokubo	Jan. 31, 2024	Recognizes an individual's outstanding achievements in the field of bioceramics research and development.
Cements	Early Career	Jan. 31, 2024	Recognizes an outstanding early career scientist who is conducting research in the field of cement and concrete in academia, industry, or a government-funded laboratory.
GOMD	Norbert J. Kreidl	Jan. 21, 2024	Recognizes a young engineer or materials scientist who has conducted excellent research in glass science. Nominations are open to all degree-seeking graduate students (M.S. or Ph.D.) or those who have graduated within a twelve-month period of the annual GOMD meeting.

Division	Award	Deadline	Description
GOMD	George W. Morey	Jan. 21, 2024	Recognizes new and original work in the field of glass science and technology. The criterion for winning the award is excellence in publication of work, either experimental or theoretical, done by an individual.
GOMD	L. David Pye Lifetime Achievement	Jan. 21, 2024	Recognizes an individual's lifetime of dedication, vision, and accomplishments in advancing the fields of glass science, glass engineering, and glass art.
GOMD	Stookey Lecture	Jan. 21, 2024	Recognizes an individual's lifetime of innovative exploratory work or noteworthy contributions to outstanding research on new materials, phenomena, or processes involving glass that have commercial significance or the potential for commercial impact.
MFG	John E. Marquis Memorial Award	Jan. 15, 2024	Recognizes the author(s) of a paper on research, engineering, or plant practices relating to manufacturing in ceramics and glass, published in the prior calendar year in a publication of the Society, that is judged to be of greatest value to the members and to the industry. ■

STUDENTS AND OUTREACH

ACerS Mentor Programs

Register today for The American Ceramic Society's (ACerS) Mentor Programs. ACerS offers the following programs:

- **Student mentor program**
- **Faculty mentor program**
- **Industry mentor program**

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

The goal of ACerS Mentor Programs is to connect members in an impactful way to help them grow personally and professionally. Many mentor program participants choose to return each program year to take on a new mentee and/or continue with an existing mentee.

We encourage all who are interested to sign up for one or more of the mentor programs being offered. Space is limited! Sign up to be a mentor and/or mentee at https://ceramics.org/mentorship. ■

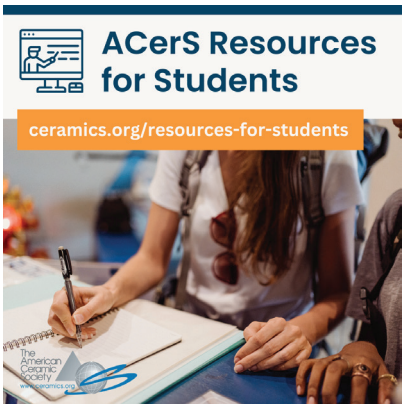
Grad students: Choose GGRN to advance your career

Build an international network of peers within the ceramic and glass community by joining the Global Graduate Researcher Network (GGRN). GGRN is ACerS membership option that addresses the professional and career development needs of graduate-level research students who have a primary interest in ceramics and glass.

Membership in GGRN is only US$30 per year. Visit www.ceramics.org/ggrn to learn how GGRN membership can help you in your future career. You may also contact Yolanda Natividad, ACerS senior membership manager, at ynatividad@ceramics.org if you have any questions. ■

ACerS resources for students are at your fingertips

ACerS offers an abundance of opportunities for students. For those who are focusing on ceramics and glass, ACerS can help them earn recognition, gain access to the latest technical information, and build their networks necessary for success.



Visit ceramics.org/resources-for-students to learn more about the following resources for students.

- Awards and scholarships
- Financial support
- Student Mentor Program
- Learning Center
- Job Search Resource Center
- ...and more! ■

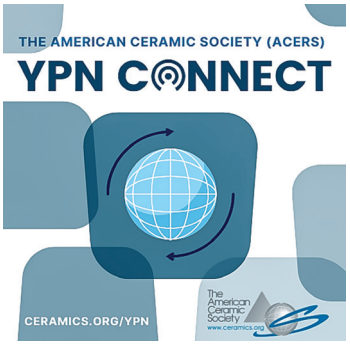
FOR MORE INFORMATION:

ceramics.org/resources-for-students

ACerS Young Professionals Network offers monthly YPN Connect events

Join fellow young professionals at YPN Connect! These monthly virtual networking events are open to both ACerS YPN members and nonmembers, so be sure to invite your colleagues and friends.

Register by visiting www.ceramics.org/ypn so that we may send you the connection details. We look forward to seeing you! ■



2023 PCSA Creativity Competition awardees

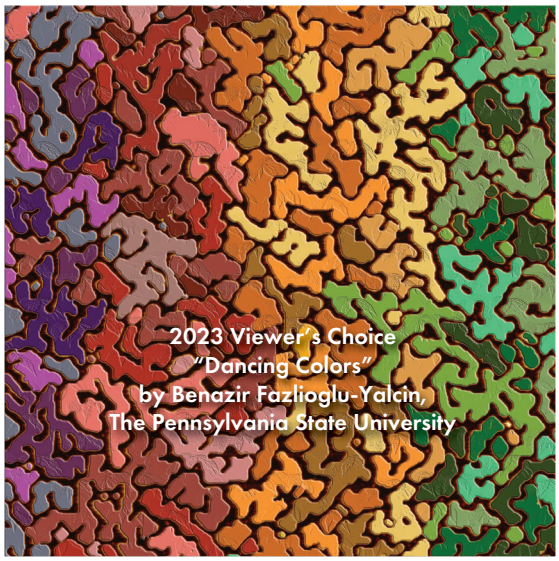
Combining both science and art into any one individual's skill set is important because it can help nurture creativity in research and cultivate innovation in the workplace. For this reason, ACerS President's Council of Student Advisors (PCSA) organizes an innovative artistic initiative in the form of the annual PCSA Creativity Competition for students.

This competition serves to encourage the harmonious co-existence of art and science in the ceramics and glass community. Students who dabble in ceramic and glass-related arts either for their research or just for fun are encouraged to share their talent.

Participants may enter any of the following creations: glass-blowing, stained glass, pottery, 3D printing (ceramic or glass), artistic painting of a ceramic-related image, digital 3D rendering of a ceramic-related process, or other ceramic or glass-related forms of art.

This year's PCSA Creativity Competition garnered 24 entries from individuals at 16 different universities around the world. Out of these submissions, three awardees were chosen. Each awardee will receive $100, a glass plaque sponsored by Corning Inc., and will be recognized at the MS&T23 Student Awards Ceremony.

Thanks again to all the participants in this year's PCSA Creativity Competition! Watch for the 2024 competition opening by visiting www.ceramics.org/pcsacreative. ■



CERAMIC AND GLASS INDUSTRY FOUNDATION

CGIF launches new Ceramic and Glass Industry Tour program at Allied Mineral Products

The Ceramic and Glass Industry Foundation (CGIF) launched its newest program, Ceramic and Glass Industry Tours, with a kick-off tour for science teachers at Allied Mineral Products, a global leader in refractory ceramics. The tour, along with an industry luncheon, took place at the Allied Mineral Products headquarters in Columbus, Ohio, on July 27, 2023. Fifteen science teachers attended this inaugural tour.

After a brief introduction, teachers were divided into groups led by different Allied professionals. Each group met with another Allied professional who walked them through their role at the company and how their role plays a part in the process of creating and testing different refractory materials.

"I loved the whole tour," says Todd Bolenbaugh, who teaches at Tolles Career and Technical Center in Plain City, Ohio. "We had five different things that we got to look at, and each one of them had its own unique perspective: creating the batching of materials, how you test materials, how you look at the chemistry of those things, how you operate, how you do quality control. It was so interesting just to see the big picture and all the different components."

Throughout the tour, each Allied professional also gave the teachers insight into their educational background so that teachers could learn more about potential post-graduation pathways for their high school students. At the industry luncheon, teachers and Allied professionals engaged in lively discussions about their respective classroom and industry experiences.

"I was inspired to attend this tour today because I like seeing how the things that I teach in my class are applied in practical ways in industry, because I'm trying to give my students as many career exploration opportunities as possible," says Brittnee Lydy, who teaches at Dayton Regional STEM School.

Credit: CGIF

An Allied Mineral employee, left, discusses refractory materials and their uses with a local teacher during the July 2023 Industry Tour.

The CGIF is grateful that Allied Mineral Products generously hosted teachers and gave them a professional development experience that will not only help them be better informed teachers, but that will also better inform their students about career opportunities that they do not usually learn about in school.

"I just wanted to thank everybody for hosting us. I think it's really important to look to the future generations in order to educate folks to see what these new career paths are," Lydy says. "We're supposed to be preparing our students to be next century learners, but if we don't know what's out there, we can't prepare them very well. So inviting us here and showing us what you do helps us better understand how to prepare our students."

Help us create more unique experiences such as industry tours for educators by giving now at ceramics.org/donate. ■

Credit: CGIF

An Allied Mineral employee explains different types of minerals and their uses to teachers during the July 2023 Industry Tour.

Credit: CGIF

A teacher, left, and Allied Mineral employee engage in conversation about career pathways before the industry luncheon.

Copper-glazed ceramic tiles combat bacteria through hydrophobicity and ion dissolution

In a recent study, three researchers from the Icheon Branch of the Korea Institute of Ceramic Engineering and Technology investigated the potential of copper glazes to create a superhydrophobic ceramic tile.

Superhydrophobicity describes a substance that has an extreme aversion to water and thus is extremely difficult to get wet. It is hoped that superhydrophobic ceramic coatings could inhibit bacterial adhesion and prevent formation of thick biofilms on the underlying surface—thus achieving sterilization through blocking the pathogen rather than destroying it, which may inadvertently contribute to increasing bacterial resistance.

Copper glazes, which contain either black/red copper oxide, copper carbonate, or copper sulfate, are traditional porcelain glazes. Fortuitously, copper and copper alloys are solid antimicrobial materials that are widely used in the development of antibacterial products.

The Korean researchers previously showed that oxidation and reduction heat treatment conditions can affect the antibacterial properties and hydrophobicity of copper glazes. However, so far, the durability of copper glazes when applied to ceramic tiles has not been confirmed.

In this study, the researchers systematically investigated the antibacterial properties of copper-glazed ceramic tiles by installing them in a public restroom, where they were evaluated every six months for two years.

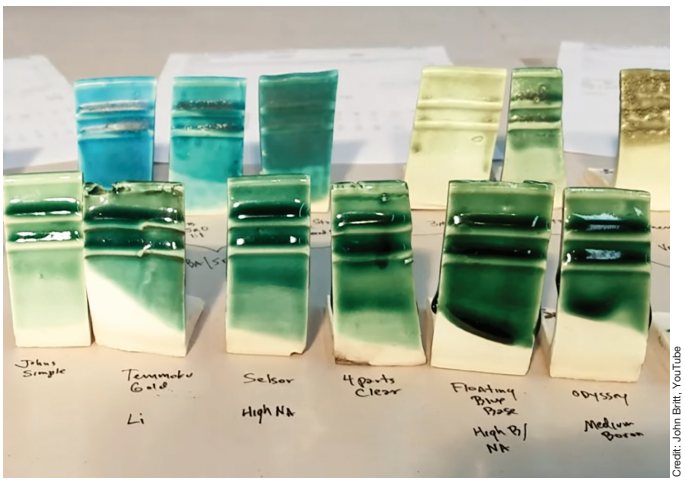
Compared to ceramic tiles coated in a standard glaze without copper, which showed no antibacterial activity against the common bacteria *Staphylococcus aureus* and *Escherichia coli*, the copper-glazed tiles exhibited some antibacterial activity against both types of bacteria, dependent on the glaze thickness.

The best results were achieved for a copper glaze with a thickness of 150–200 µm, which maintained antibacterial efficiency at 99.9% against both bacteria for all two years.

These results were achieved despite the surface being only mildly hydrophobic (water contact angle of 109.6 ± 0.4°, in contrast to a superhydrophobic contact angle of 150°). The additional factor of copper ion dissolution, which killed bacteria adsorbed on the surface, contributed to the success.

It may be tempting to attribute most of the success to the copper ion dissolution. However, the researchers showed the mild hydrophobicity played an equally important role because thinner/thicker glazes with smaller contact angles did not maintain the same antibacterial efficiency. For example, copper glazes with a thickness of 200–250 µm (contact angle of 66.3° ± 1.2°) had antibacterial efficiencies of only 89.4% and 82.1% against *S. aureus* and *E. coli*, respectively.

Ultimately, then, the combination of hydrophobicity and ion dissolution "together inhibit the formation of colonies of *S. aureus* and *E. coli* bacteria on the glaze surface," the researchers write.



Example of various copper glazes. Researchers in the Republic of Korea recently demonstrated the potential of copper-glazed ceramic tiles to maintain long-lasting antibacterial efficiency.

The paper, published in *Journal of the Korean Ceramic Society*, is "Antibacterial persistence of hydrophobically glazed ceramic tiles" (DOI: 10.1007/s43207-022-00216-x). ■

Modified starch aids in selective separation of feldspar and quartz from tailings

Researchers from Central South University and Southwest University of Science and Technology in China investigated using depressants to help separate feldspar and quartz from mine waste (tailings).

Currently, feldspar and quartz are sourced largely from open-pit mines that focus specifically on extracting these minerals. However, a lot of feldspar and quartz goes to waste in other mining operations that focus on extracting other materials.

For example, feldspar and quartz are major components of the granite-based ores from which nonferrous metals are extracted. But after the metals are extracted, these silicates are simply thrown away as tailings.

Researchers suspect these tailings may become the primary source of feldspar and quartz in the future. In addition to being more cost effective than open-pit mining, processing tailings provides a way to dispose of the waste without depositing it in the environment.

Extracting feldspar and quartz from the tailings is complicated, however, by the minerals' physicochemical similarities. This similarity prevents the use of physical separation methods, such as filtration and distillation, because the minerals cannot be selectively separated out.

Recent studies have demonstrated the potential of flotation to selectively separate out feldspar and quartz. Unfortunately, the most effective flotation methods to date rely on strongly acidic conditions, which comes with the risks of environmental pollution and equipment corrosion.

Depressants may provide a way to separate out feldspar and quartz under more favorable conditions. These substances increase the efficiency of the flotation process by selectively inhibiting the interaction of certain minerals with the collector, i.e., the reagent used to form a thin hydrophobic layer on the mineral surface. By preventing the collector from attaching to the undesired minerals, the desired minerals can be separated out more easily.

Credit: James St. John, Flickr (CC BY 2.0)

Picture of a tailings pond, which contains the waste left over from mining. In the future, rather than being left in the environment, tailings may be processed further to extract valuable minerals like feldspar and quartz.

Few studies have explored the use of depressants to aid in flotation separation of quartz and feldspar. The recent study helped fill this gap in the literature by investigating the potential of hydroxypropyl starch (HPS) as a depressant.

HPS is a modified starch that had its hydroxide groups replaced with propylene epoxide via a nucleophilic substitution reaction in a sodium hydroxide solution. It is widely used as a binder, suspending agent, and thickening agent in paper, textile, oil drilling, and daily chemical industries due to its nontoxicity and stable chemical properties.

For this study, the researchers used HPS in combination with magnesium chloride as the activator and sodium oleate as the collector. They conducted micro-flotation tests on pure quartz and feldspar samples as well as bench-scale flotation tests on granite tailings.

The micro-flotation tests showed that without depressants, quartz and feldspar could be only partially separated at a pH of 10.50. The addition of HPS increased the selectivity index from 4.57 to 7.52. The bench-scale flotation tests confirmed the effectiveness of HPS as a depressant.

Raman and X-ray photoelectron spectroscopy analysis revealed the mechanisms behind HPS' effectiveness. The modified starch reacted with aluminum sites on the feldspar surface, thereby reducing the adsorption of the sodium oleate collector. By preventing the attachment of the collector, HPS inhibited the flotation of feldspar but not the flotation of quartz.

"The research findings are expected to provide a new strategy for efficient flotation separation of quartz from feldspar and the comprehensive utilization of tailings," the researchers conclude.

The paper, published in *Minerals Engineering*, is "Selective flotation of quartz from feldspar using hydroxypropyl starch as depressant" (DOI: 10.1016/j.mineng.2023.108022). ■

Remediating mine waste—ceramics aid in treatment of acid mine drainage

With the rapid growth of the global mining sector, miners need to adopt improved regulations and lower-impact methods to reduce the sector's environmental footprint. Two recent studies support this goal by investigating the use of ceramics to treat acid mine drainage.

Acid mine drainage is the formation and movement of highly acidic water rich in heavy metals. It forms through the chemical reaction of surface water (e.g., rainwater, snowmelt, pond water) and shallow subsurface water with rocks that contain sulfur-bearing minerals, resulting in sulfuric acid. Heavy metals can be leached from rocks that encounter the acid, a process that may be substantially enhanced by bacterial action.

Many streams impacted by acid mine drainage have a pH of 4 or lower—similar to battery acid. Plus, compared to other types of water pollution, acid mine

drainage is especially harmful because it can occur indefinitely, even after mining has ended. As such, remediation of acid mine drainage must be a purposeful and active process.

Long-term treatment of acid mine drainage by alkali diffusion ceramic reactor

In July 2022, researchers from several organizations and universities in the Republic of Korea described a novel alkali diffusion reactor that they designed for the long-term remediation of acid mine drainage.

Traditionally, acid mine drainage is remediated by using neutralizing chemicals to increase pH and promote metal precipitation. But current systems struggle to provide long-term treatment because of the gradual depletion of the treatment agent and operating energy.

"Therefore, more research is needed to develop a continuous and cost-effective treatment technology which can sustain persistent and long-term AMD [acid mine drainage] loads," the researchers write.

Their alkali diffusion reactor consists of porous ceramic columns that release neutralizing chemicals without any electrical devices, such as pumps or pH adjusters. The column's irregular pore morphology and smaller pore size allows for longer-term release and consumption of the neutralizing chemicals.

Testing revealed that the system—featuring sodium bicarbonate as the neutralizing material and activated carbon as the filling material—could remediate acidity and metals in acid mine drainage for up to a year without electricity or additional neutralizing chemicals. The system could also be reused at least five times with no appreciable loss in activity.

Thus, the system "can be applied to mining areas where the passive system is insufficient because of low efficiency, and the active system is not affordable because of budget limitations and geological sites," the researchers conclude.

The paper, published in *Chemosphere*, is "Long-term treatment of acid mine drainage by alkali diffusion ceramic reactor: Simultaneous metal removal mechanisms" (DOI: 10.1016/j.chemosphere.2022.134186).

Porous titania beads for remediation of arsenic contamination

In April 2023, researchers from several organizations and universities in Australia developed porous titanium dioxide bead adsorbents to remove arsenic from acid mine drainage.

As noted earlier, acid mine drainage is a mixture of highly acidic water with various heavy metals. Due to this variability in chemical composition and pH, acid mine drainage prevention and treatment are complex and site-specific.

Some contaminants, such as arsenic, cannot be adequately removed through the conventional neutralization methods. Instead, adsorption—or the adhesion of atoms or molecules to the surface of a solid substance—provides a way to remove these contaminations.

Credit: EARTHWORKS, Flickr (CC BY 2.0)

Acid mine drainage from the Mike Horse Mine complex in Montana. Acid drainage is often marked by "yellow boy," a yellowish-orange substance that occurs when the pH of acidic mine drainage rises above pH 3, so that the previously dissolved iron precipitates out.

Many adsorbents demonstrate poor adsorption or chemical instability in acidic conditions below pH 3. Titania, on the other hand, demonstrates high chemical stability over a wide pH range, as well as photocatalytic activity, low cost, and nontoxicity.

The researchers found that their titania beads could successfully and selectively remove arsenic from simulated and real acid mine drainage solutions with pH as low as 2.6. This preferential removal was retained even when the concentration of iron(II + III)—which is typically found in large amounts in acid mine drainage—was two orders of magnitude higher than that of the arsenic.

In this case, titania beads that were not functionalized demonstrated superior adsorption capabilities than ones that were functionalized with a primary amine.

"However, functionalization with an amine or other functional group may produce an adsorbent better suited to remediation of other sites affected by AMD [acid mine drainage]," the researchers write.

The paper, published in *Journal of Environmental Management*, is "Porous titania beads for remediation of arsenic contamination from acid mine drainage" (DOI: 10.1016/j.jenvman.2023.117384). ■

Adsorption of complex pollutants: Designing hydrogarnets to remove humic substances from water

Researchers from Nagoya Institute of Technology in Japan published a paper exploring the use of hydrogarnet as an adsorbent for humic substances.

Humic substances are natural organic polyelectrolytes that are formed by the breakdown of animal and vegetable matter in aqueous environments. They have positive effects on plant physiology by improving soil structure and fertility and by influencing nutrient uptake and root architecture. However, in waterways, humic substances can aggravate pollution by interacting with disinfectants, such as chlorine, to produce toxic byproducts.

Removing humic substances from water is not a simple endeavor. Humic substances have a complex, heterogeneous structure, which complicates the removal of these molecules from aqueous environments through adsorbents. To succeed, an adsorbent would need to increase the number of interactions between the humic substance and the material surface.

Hydrogarnet has shown excellent potential as an adsorbent for humic substances. Hydrogarnet refers to garnets in which hydroxide groups have partially replaced the silica units $[Ca_3Al_2(SiO_4)_{3-x}(OH)_{4x}]$. They can be categorized as grossular ($x = 0$), hibschite ($0.2 < x < 1.5$), or katoite ($1.5 < x < 3$) depending on the degree of substitution.

Controlling the chemical composition of hydrogarnet is difficult, but some studies have reported that adjusting the preparation conditions can offer control over the resulting structure. So, the researchers of the recent paper investigated the effects of heat treatments to control hydrogarnet composition and adsorption properties.

For this study, heat treatments of the hydrogarnets took place at 320°C, 350°C, and 440°C. To confirm crystallinity of the hydrogarnet before and after heat treatment, the researchers performed selected area electron diffraction.

Analysis confirmed that treatment temperature did affect the chemical composition. Specifically, increasing the temperature tended to decrease the hydroxy group content of the hydrogarnet. Hydrogarnet content in the sample treated at 440°C was only two-thirds of that in the sample without heat treatment.

Along with a decreased hydroxy group content, heat-treated samples exhibited a partial collapse of the garnet structure, leading to the formation of a silica-rich amorphous phase around the surface.

Regarding adsorption properties, the researchers found that the heat-treated samples exhibited a much higher maximum adsorbed amount and adsorption rate for humic substances compared to the untreated sample. Specifically, the sample treated at 440°C exhibited approximately seven times the adsorption properties for humic acid.

The researchers attribute these improved adsorption properties to an increase in pH and increased exposure of the hydrogarnet surface due to dissolution of the silicon phase when samples were soaked in a solution containing the humic substance.

The paper, published in *Ceramics International*, is "Controlling the chemical composition of garnet with hydroxy groups for humic acid removal" (DOI: 10.1016/j.ceramint.2022.11.307). ■

ceramics in manufacturing

Effects of expanded graphite content on the performance of magnesia carbon bricks

In June 2023, researchers from Changwon National University in the Republic of Korea published a paper describing how they systematically investigated the effects of expanded graphite content (0–4 wt.%) on magnesia carbon (MgO–C) bricks.

MgO–C bricks can be fabricated using various carbon sources, such as expanded graphite, carbon black, carbon nanotubes, carbon nanofibers, and graphene and its oxides. Among these, expanded graphite is particularly promising because it has a layered structure that fills the gaps between magnesia particles and promotes the formation of beneficial high-temperature phases with different antioxidants, such as aluminum or silicon.

However, expanded graphite is more prone to oxidation than flaky graphite. This tendency may lead to iron contamination when present in large amounts or the release of carbon emissions, among other issues. As such, studies must be done to determine the optimum amount of expanded graphite for MgO–C brick production.

In the recent study, the researchers created MgO–C bricks by combining magnesia particles, flaky and expanded graphite, aluminum and silicon (antioxidants), a phenolic resin (novolac; binder), and hexamethylenetetramine (curing agent).

They determined that expanded graphite efficiently absorbed and relieved thermal stress and suppressed thermal deformation. But when the quantity of expanded graphite reached 4 wt.%, the number of apparent pores increased, leading to a decrease in fracture strength and also thermal shock resistance.

Ultimately, an expanded graphite content of 2 wt.% provided optimal performance, which the researchers attributed to the fine and uniformly distributed pores in that sample.

The paper, published in *International Journal of Applied Ceramic Technology*, is "Effects of expanded graphite content on the performance of MgO–C refractories" (DOI: 10.1111/ijac.14464). ■

Credit: Jucos Refractory, YouTube

A worker handles a magnesia carbon brick at a Zibo Jucos Co., Ltd. plant in China. MgO–C bricks can be fabricated using various carbon sources, and significant effort has gone into determining which source can best improve the brick's thermal shock resistance.

Geochemistry provides insight into ceramic production and exchange of ancient Wari civilization

In a recent study, researchers from The Field Museum in Chicago, the University of Illinois-Chicago, and the University of North Carolina-Greensboro used ceramic geochemical analysis to learn more about the ancient Wari civilization.

The expansive Wari civilization (also spelled Huari) was the first political structure to unify the south-central and north-central Andes. It was located in the Ayacucho valley of Peru during the Middle Horizon period (600–1000 CE).

This period saw many cultural changes, for example, in burial practices and ceramic styles. The Wari also developed their own iconography. But the artistic style of the Wari is the civilization's most lasting legacy, significantly influencing the later Inca civilization (1200–1533 CE).

The researchers aimed to understand the role that ceramic production and exchange played among the differing communities with whom Wari established relationships. Although the Wari empire is considered the first "unifying" political structure in the region, the population was too diverse to completely integrate it both politically and culturally.

Ceramic samples in this study were analyzed over a 15-year period using multiple instruments housed at The Field Museum's Elemental Analysis Facility. In particular, laser ablation inductively coupled plasma mass spectrometry was used for geochemistry analysis. These results were combined with statistics, including the Mahalanobis distance, which helps determine which regional group a sample likely belongs to.

The 189 samples analyzed in this study came from three regions:

- **The Ancash region**, including the Callejón de Huaylas valley, was an important thoroughfare between northern and southern governments. As such, this region contains many imported objects and the production of Wari-type wares. Samples consisted of pottery from villages across the valley, as well as decorated Wari-related ceramics and press-molded blackwares.
- **The Arequipa region**, located between the Wari center in Ayacucho and the southernmost parts of the Moquegua Valley, may have been part of the Wari empire, with foreign settlers bringing Wari customs and crafting practices. Samples were recovered from four sites in the mid-Majes Valley and its upper Chuquibamba Tributary, including from elite temples and ceremonial centers, as well as local dwellings.
- **The Moquegua region** in southern Peru extends from the coast to the highlands. This region was inhabited by two different civilizations: the Wari and Tiwanaku, who both established colonies in the area. Local ceramic production was practiced in both cultures, although the Wari potters created new ceramics (Wari fineware) made from a previously unused clay source. The samples from this region include decorated and undecorated utilitarian ware (nearly half of the samples), including those from the Cerro Baúl Palace.

Credit: The Metropolitan Museum of Art

An example of a Wari bottle, which seamlessly merges the body of an anthropomorphized feline with that of a flask-like vessel. The artistic style of the Wari is the civilization's most lasting legacy.

Analysis of the Ancash samples revealed that the decorated ceramics did not appear to represent a single production center or geological locale. But they had more geochemical similarities than the Callejón de Huaylas styles produced using highland Ancash raw materials. Meanwhile, the blackwares appeared to have been made using clays from Castillo de Huarmey on the Ancash coast.

For the Arequipa samples, three primary compositional groups were detected, but the samples featured a wide variety of ceramic styles. The researchers hypothesize that Arequipa communities had "unequal access to Wari exchange networks," but

Research News

Scientists trap light inside a magnet

Researchers at City College of New York showed that trapping light inside magnetic materials may dramatically enhance their intrinsic properties. The properties of a layered magnet that hosts strongly bound excitons, i.e., quasiparticles with particularly strong optical interactions, means it is capable of trapping light all by itself. As the recent experiments show, the optical responses of this material to magnetic phenomena are orders of magnitude stronger than those in typical magnets. That is because the light bounces back and forth inside the magnet, enhancing the interactions. For more information, visit https://www.ccny.cuny.edu/news. ■

Coffee offers performance boost for concrete

RMIT University researchers developed a technique to make concrete 30% stronger by replacing a portion of the sand with waste coffee grounds that were turned into biochar using a low-energy process without oxygen at 350°C. The inspiration for their work was to find an innovative way of using the large amounts of coffee waste that Australia generates each year, about 75 million kilograms. The researchers plan to develop practical implementation strategies and work toward field trials. For more information, visit https://www.rmit.edu.au/news.

"potters in Arequipa's highlands and coastal valleys replicated Wari wares and iconography using local clay recipes."

The geochemistry of Cerro Baúl Palace samples from the Moquegua region matched with previously identified compositional groups, including from the Cerro Mejia Mountain. This finding indicates that potters in the Moquegua region used clays near the Otora Valley, which is a unique source distinct from Moquegua Valley clays.

Overall, the results of this study showed that

- A standardized paste recipe or highly controlled clay source was not the norm across the Wari empire. Additionally, local groups used clays with similar geochemistries to produce both finewares and plainwares.
- In Ancash and Arequipa, the production of Wari-type pottery was based on established local knowledge of clay sources.
- Elites were more directly involved in controlling and producing Wari pottery in the Moquegua region.
- The influx of Wari finewares from other regions occurred, but their consumption was not necessarily restricted to elite centers.
- Potters with expertise in Wari ceramics invented new forms and designs, as well as new manufacturing methods, innovating ceramic production in all three regions.
- Local communities played an important role in brokering political economic relations, particularly with regard to the production and exchange of all types of pottery.

The researchers conclude, "Wari ceramic production and exchange was simultaneously local and global, incorporating the desires, motives, and everyday actions of small communities, local elites, and Wari colonists."

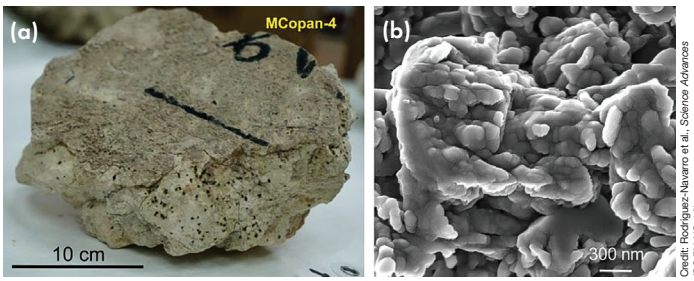
The paper, published in *Journal of Archaeological Science: Reports*, is "Crafting cosmopolitanism: Ceramic production and exchange during Wari imperialism (600–1000 CE)" (DOI: 10.1016/j.jasrep.2023.103878). ■

Maya plasters owe their strength to plant-induced biomimetic structure

Lime plasters and mortars from the ancient Maya civilization are long-lasting materials that researchers are working to understand. In April 2023, researchers from the University of Granada in Spain published an open-access paper that provides more answers to this question—and potentially helps to explain the performance of lime plasters and mortars made by other ancient civilizations as well.

The Maya civilization is considered one of the most dominant Indigenous societies to have developed in the Americas prior to the arrival of the Europeans. While the origins of Maya culture remain murky, it is believed to have first emerged between 7000–2000 BCE and reached its peak in 200–900 CE.

Like other pre-Columbian civilizations, the Maya independently figured out how to turn limestone into plasters and mortars. However, Maya plasters are known for being particularly durable, with most generally lacking typical damage features (such as fracturing or scaling) despite having stood for centuries in a hot and humid tropical environment.



(a) A Maya plaster sample corresponding to a fine two-layer plaster floor from the mid-Classic period (500–700 CE). (b) A field emission scanning electron microscope image of the sample showing its nanogranular structure.

Many research groups have tried to identify the secret behind Maya plaster durability. It is believed that natural additives have something to do with it, as certain organics, such as carbohydrates, have been found in Maya plasters and mortars that match those present in common trees in the area.

In the recent open-access paper, the Spanish researchers collected samples from mid- to terminal-classic (540–850 CE) Maya structures at the Copán archaeological site in Honduras.

The sampled structures at this World Heritage Site included a temple called Rosalila, which was the principal religious sanctuary at Copán in the late 6th century CE. Rosalila is known for its excellent state of preservation and elaborate stucco decorations.

Rather than just bulk chemical analysis, the researchers performed various microscopy, spectroscopy, and diffraction analyses on the samples so they could gain a deep understanding of the samples' crystalline structures.

The analyses showed that most samples contained organic molecules, specifically polysaccharides, that matched the bark extracts from local trees. Additionally, these samples had a crystalline structure that looked very similar to the tough calcium carbonate structures found in sea urchin spines and mollusk shells.

Were the organic molecules directly responsible for the formation of this biomimetic structure? To test this hypothesis, the researchers worked with modern local Maya masons to obtain polysaccharide-rich bark extracts from the local trees, which they then used to make their own lime plasters.

Careful observation of the plasters throughout the fabrication process showed that the organic additives did trigger a similar formation pathway seen with calcium carbonate biominerals. Plus, once set, the resulting lime plaster had a similar crystalline structure to the Copán samples.

"Apparently, by serendipity, or more likely by trial and error, the Maya masons formulated biomimetic lime plasters with superior properties and durability," the researchers conclude.

For the samples that did not contain organic additives, the researchers hypothesized that it may be due to the plaster's end-use application.

"...where a more elaborate plaster or finishing surface was required, organics were added by ancient Maya masons (e.g., in substrates for mural painting, stucco masks, or floors), whereas in coarser plaster elements (i.e., MCopan-1 and MCopan-2), no organics were added (likely to make the process less complex and/or labor intensive)," they write.

Ultimately, these results can help today's construction industry develop new lime-based plasters and mortars "for their use in architectural heritage conservation and in modern, sustainable construction," the researchers write.

The open-access paper, published in *Science Advances*, is "Unveiling the secret of ancient Maya masons: Biomimetic lime plasters with plant extracts" (DOI: 10.1126/sciadv.adf6138). ■

The American Ceramic Society is pleased to offer our

ACerS LEARNING CENTER

CERTIFICATE PROGRAM

This program is designed for those who wish to take multiple courses for career advancement.

CUSTOMIZABLE PROGRAMS

Ceramic Manufacturing Certificate

Glass Manufacturing Certificate

Advanced Ceramics Certificate

SCAN ME

The American Ceramic Society
ceramics.org

Germany: Building a climate for innovation

In June 2023, the Fraunhofer Institute for Ceramic Technologies and Systems announced that its researchers had developed RECOSiC, an environmentally friendly recycling process that converts silicon carbide byproducts and waste back into high-quality silicon carbide.

Credit: Fraunhofer IKTS

By Randy B. Hecht

Germany is confronting environmental and human capital challenges as it invests in R&D to support sustainable development goals.

As high temperature records were set and broken throughout the world during summer 2023, the climate crisis became the literal hot topic of the year.

But if Germany was stunned by the new normal in summer heat, the government was prepared to adjust its climate targets and programs.

The German Sustainable Development Strategy was introduced in 2002 and has been updated every four years since 2004. Built on "72 indicators and targets across 39 fields of action," it provides a framework for monitoring improvements as well as "off-track indicators...for goals which will probably not be reached."[1]

To underscore the connection between sustainable practice and economic development, the Federal Research Ministry's "Research for Sustainability" program focuses on creating knowledge but "also aims to apply knowledge and become faster at translating research findings into practical application" in such fields as "green hydrogen, the circular economy, climate change mitigation and bioeconomy." Its goal is to lead "the transformation of energy systems, resource efficiency, and climate protection."[2]

Those objectives are creating opportunities for smaller players in the market.

From academic to entrepreneurial

"Germany has a very strong culture of supporting and mentoring small- and medium-sized enterprises," says ACerS president Sanjay Mathur, director and chair of the Institute of Inorganic Chemistry at the University of Cologne (Figure 1). "The country has very well-structured pathways to take R&D that is being done in academia or certain specialized institutions to the market."

In most countries, Mathur notes, high technology ventures are analyzed initially in terms of barriers to entry. But the German approach is to start by considering whether those ventures can be drivers for collaboration between business and academia. The resulting research relationships "are formally structured in a way that you have enough degrees of freedom to operate," he says, and afford Ph.D. students the opportunity to be funded by industry. His experience includes "regular and lively interaction" to ensure "absolute trust and

transparency so that we can do something together."

"Entrepreneurship is promoted in all possible ways," Mathur says. There are stakeholder meetings. Technology scouts visit the labs and propose joint venture partners for promising projects. When university researchers attain a "great fundamental insight" but have no product, there are opportunities for knowledge transfer. "You can become a kind of consultant and be part of a big consortium," Mathur says.

Given these market opportunities, Mathur prioritizes "inculcating an entrepreneurial mindset" in his students and faculty members. There are bench-to-business courses. There is the academic equivalent of cross-sectoral or interdepartmental collaboration, as when students of management and natural sciences draw on their combined expertise—a process that Mathur notes has produced start-up enterprises. His department has also engaged big corporations to teach dedicated courses on topics such as innovation management or technology transfer that are beyond the faculty members' knowledge.

The platform for business development and technology commercialization is designed to support students' ability to plan a venture, manage a start-up, and attract investors. This approach positions the university to serve as an incubator for fledgling businesses. Three of Mathur's students pioneered a hybrid material for greener processing of photovoltaics and started a company that has done well and has received ongoing government support. An exchange student from India, after observing an electrospinning technique used to draw fibers from ceramics, started a company to market equipment that he engineered.

Universities have established intellectual property and patent policies to govern ownership of products and solutions that emerge from collaborative R&D. In some cases, the university retains ownership of intellectual property that results from its R&D activity. Other agreements structure shared ownership by the university and its industry partner or outline terms for a lump-sum payment to the university in return for ownership of intellectual property and patents.

Sustainability and circularity

"Sustainable growth is part of the national strategy and also of institutional strength," Mathur says. "How do we address the challenges of the energy sector, climate change, the circular economy, and futuristic mobility? It's clear to the university leadership that these things must be part of the research portfolio."

He sees decarbonization of ceramic processing and increased energy efficiency —for example, via low temperatures in ceramic sintering—as major drivers of the industry's contributions to sustainable practice in industry.

"The National Sustainable Development Strategy is very, very ambitious, and it will require major transformation, not only in the research and development landscape, but in the way industry functions, the way the business is done. At the same time, we also need to involve the civilian society," Mathur says. He sees the university's role as producing "students

Credit: Sanjay Mathur

Figure 1. Sanjay Mathur in his lab at the University of Cologne. He says that Germany has "very well-structured pathways" to transition R&D conducted in academia or certain specialized institutions to the market.

ACerS International Germany Chapter

Credit: Sanjay Mathur

Besides providing opportunities to exchange science and engineering ideas, ACerS Germany Chapter organizes social outings to encourage networking and camaraderie among those working in the ceramic and glass industry. Here the Chapter enjoys a 2022 winery tour with ACerS executive director Mark Mecklenborg (blue shirt, center). Chapter chair and ACerS president Sanjay Mathur is pictured in the center (white shirt).

The Germany Chapter of The American Ceramic Society serves ACerS members in or near the cities of Cologne, Bonn, Aachen, Dusseldorf, and Dortmund for the purpose of promoting the arts and sciences connected with ceramics and glass science and engineering. Events such as workshops, industrial showcases, and seminars are planned to enhance and facilitate the interaction, technical discussions, and potential collaborations between ACerS members in Germany.

The Chapter is headquartered in Cologne, North-Rhine Westphalia. Interested ACerS members may contact any of the officers to learn more about getting involved with the Chapter.

Chair: **Ziyaad Aytuna**, z.aytuna@uni-koeln.de

Vice chair: **Anna Kathrin Schmidt-Verma**, averma7@uni-koeln.de

Secretary: **Sumiya Iqbal**, sumiqbal35@gmail.com

Treasurer: **Ruth Adam**, radam2@smail.uni-koeln.de

DEI representative: **Kruti Halankar**, kruti.halankar@uni-koeln.de


Credit: SCHOTT AG

Figure 2. Matthias Müller, executive vice president of R&D and new ventures at SCHOTT AG, says the company tracks market trends that align with opportunities to innovate in diverse sectors.

who are global citizens" and joining in a national conversation about "how we make sustainability livable."

Mathur notes that Germany shut down all its nuclear reactors, and renewables generate close to 45% of its energy today. Plus, the government is subsidizing the production of electric vehicles and photovoltaics.

There is a "huge market on small houses becoming energy self-sufficient by installments," he says, and the country introduced a 49-euro train ticket that is good for travel nationwide, which has reduced the use of cars. The country is also exploring opportunities for applying the business model used in innovation-based engineering to other sectors, such as agriculture.

Mathur sees ceramics as contributing to the national sustainability priorities by playing a role in renewable energy technologies by advancing innovations in solid oxide fuel cells, solar cell panels, and batteries.

"If they are deployed heavily, they will reduce fossil fuels, support decarbonization, and support Germany's goal to transition toward a carbon neutral society," he says.

Mathur also monitors progress toward processing concrete that can be reused and integrating biopolymer fibers to create lightweight concrete. Plus, he is looking to additive manufacturing as a means of reducing materials usage.

"Ceramics will never go out of fashion," he says. "R&D in the European and German ceramic industry is contributing significantly to sustainability. This is definitely something which we are part of, and also proud to be part of."

Environment and enterprise

Businesses are finding parallels between the call to serve the common good and the need to operate profitably. SCHOTT AG is tracking market trends that align with opportunities to innovate in areas as diverse as energy, space, and medical technology.

Matthias Müller, executive vice president of R&D and new ventures, notes that advances in the development of electronic mobility and climate-neutral mobility depend on high-performing battery technology (Figure 2).

"We are intensively working on providing ion-conducting materials for the next generation of batteries, the all-solid-state batteries. Oxidic materials, of course, but also hybrid materials. There, glass can become an enabler," he says (Figure 3).

Given the long timelines for all-solid-state battery development, demand for mature materials even at early stages presents a challenge to SCHOTT as a supplier. So, one imperative Müller sees is alignment across the value chain to adapt to the pace and scale of development.

The company's work on specialty glasses and high-tech materials that can withstand extreme environments in space proved to have new utility with the onset of COVID-19 vaccines that had to be transported frozen. SCHOTT launched the first product on the global market "capable of keeping closure integrity over the whole temperature range, which is required for mRNA," Müller says.

In the field of medical technology, SCHOTT's R&D extends, for example, to body implants and interfaces.

"Hermetic sealing of glass really exhibits quite a significant potential to have—even on a millimeter to micrometers scale—safe implants or interfaces, being inactive in the body later on," Müller says. "This is a very interesting new field."

Medical applications for specialty glasses range from vision correction to the use of light or radiation therapies.

Pursuing diversity and climate neutrality

There are also internal sustainability targets to pursue.

"We as an energy intensive industry, with gas melting and gas processing, have a particular responsibility," Müller says.

He notes that the company's objectives include being climate neutral by 2030, which he terms an intentionally ambitious goal, but also one that has been well received by customers and has increased employee motivation (Figure 4).

Circularity is one area of sustainable focus. It presents layers of challenges in the case of specialty glass integration into customers' products and systems.

"Glass in general, but also the specialty glasses, are a material class that in most cases is highly environmentally friendly, because it does not easily dissolve and everything which is bonded into the glass is tightly bonded," Müller says. "Compared to container glass or window glass, in the specialty glass area, recycling is a rather challenging topic, but we already started together with customers to work on that. And, of course, we have closed loops in our own operations."

To meet its environmental, operating, and profitability targets, the company must strategize to ensure access to adequate human capital and has established a network within academia for access to Ph.D. and master's candidates in Germany, throughout Europe, and globally.

"The area of glass manufacturing, and particularly glass science, is a rather small community," Müller says. "But very often we also take advantage of general natural scientists—for example, from chemistry or physics—entering into our field."

SCOTT also has a diversity and inclusion program that the R&D team strongly supports "because creativity, of course, takes a bit of great benefit from diversity. We want to gain the broadest possible perspectives we can include into our efforts in R&D," Müller says.

A ceramic innovation institute

With an 80-million-euro annual budget,the Fraunhofer Institute for Ceramic Technologies and Systems is one of the world's largest research institutions in ceramics. The scope of its work encompasses the entire ceramics universe under the activities of two major divisions: Structural Ceramics (automotive, medical, and machine engi-


Credit: SCHOTT AG

Figure 3. SCHOTT is researching solid electrolytes and ion-conducting materials for use as cathodes in all-solid-state batteries.


Credit: SCHOTT AG

Figure 4. In July 2023, SCHOTT announced it had succeeded in producing a glass test melt with 100% hydrogen in the laboratory. The results confirmed that a change in melting technology away from using fossil fuels is possible.

neering applications) and Functional Ceramics (electronic and electrochemical applications).

"Our biggest business segment right now is energy and environmental technology, including water treatment" says Institute director Alexander Michaelis. "This segment drives our research right now. Our mission is technology transfer, and we have one key performance indicator, which is how many projects and much revenue we get from industry."

Among its biggest current revenue drivers are green hydrogen and battery technology, and one of its major areas of activity is in the field of lithium-ion batteries for mobility.

"But I think the bigger market is stationary applications, which are needed for successful energy transition," Michaelis says. "You have to have electrochemical storage for short time peak shifts in applications, and here lithium-ion batteries are not a good solution due to safety issues and materials availability."

Michaelis says they are looking into alternatives, with the most important alternative being high-temperature sodium chloride batteries. Fraunhofer IKTS has partnered on this project with companies in Australia and Germany, such as Altech, with the goal of producing at gigawatt scale for stationary applications.

"These kinds of systems are urgently needed for energy transition," Michaelis says.

Another big need is storage for longer timeframes.

"Then you need other kinds of technologies, such as green hydrogen," Michaelis says. "We also do a lot of development of high-temperature electrolysis systems, so-called solid oxide electrolysis, that are based on ceramic materials and have a 30% higher power to hydrogen conversion because waste heat can be used in the process."

Among the advances they are developing is co-electrolysis capability, which enables conversion not only of water into hydrogen but also of carbon dioxide into carbon monoxide for generation of syngas. This syngas can be used for petrochemical production of all kinds of e-fuels.

Attracting talent to work on 'mega topics'

The scope of Michaelis's team's work at the Fraunhofer Institute has created not only diversified business lines for generating profit but also organizational growth: there were 100 employees when Michaelis assumed his role as Institute director in 2004, and today he oversees a staff of 800.

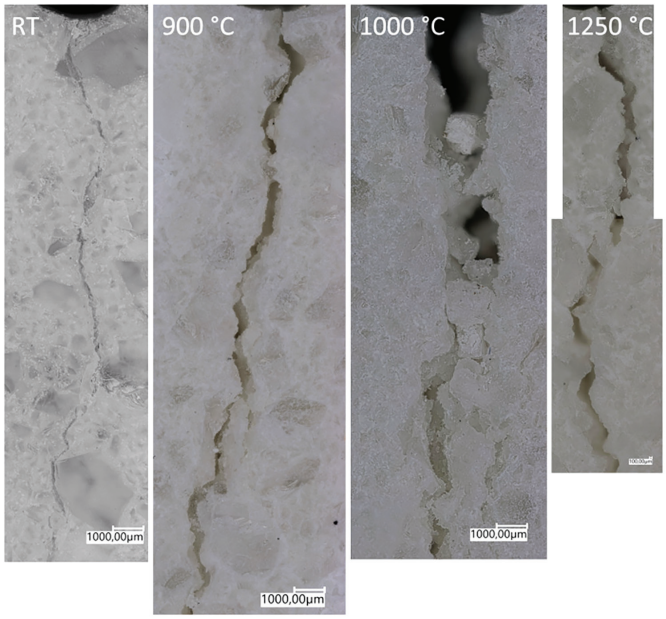
"We were always able to get excellent people resources, and we still do. I think it's very important that you work on the right subjects," he says.

Instead of pitching the work as materials science, which he fears "sounds a little bit old-fashioned," he tells candidates about the applications and solutions they will be helping to pioneer for energy-transition, closed cycle technologies, and water treatment—"all these mega topics." He sees offering the opportunity to make a real contribution as the best way to attract young talent. Fraunhofer IKTS, which conducts business in English, also recruits international personnel, and he believes "there's no limit to cross-border collaboration."

The Institute's initiatives are likewise designed for impact beyond Germany's borders. The Institute is one of 25 partners in a European Union-funded project launched in summer 2023 in response to the regulatory requirement for European air traffic to be climate neutral by 2050. The project partners are collaborating on hydrogen and battery electric engines as well as wing optimization. The designs are projected to reduce fuel consumption by up to 15%.[3]

In July 2023, Fraunhofer IKTS announced that its researchers "have developed an extremely heat-resistant ceramic-based ink. For the first time, this enables metal components processed in the automotive industry at temperatures over 1,000°C to be marked with a code...The advantages of the technology are not simply the ability to detect production glitches and defective components at an early stage. It also opens up wide-ranging possibilities for designing process chains in the industry more efficiently and reducing their carbon footprint significantly."[4]

And in June 2023, the Institute announced that its researchers had developed RECOSiC, "an especially environmentally friendly recycling process" that converts silicon carbide byproducts and waste "back into high-quality silicon



Credit: Brochen et al., *International Journal of Ceramic Engineering & Science* (CC BY 4.0)

Figure 5. Example of research conducted at Forschungsgemeinschaft Feuerfest e. V. This image, which shows the crack path at different temperatures for fused silica bricks, is from a study on the fracture behavior of refractory materials up to service temperatures.

carbide. This new process improves yields and also reduces the dependency on suppliers of raw materials."[5]

Looking to the future, Michaelis sees continued demand for solutions that advance the world's energy transition, especially those that achieve energy cost reductions—and in that respect, he sees ceramics as a field with an essential role to play in sustainable development.

An emerging climate for refractories

About midway between Bonn and Frankfurt lies Kannenbäckerland, where Europe's largest clay deposits were discovered in the late 16th century. Many refractories continue to process those raw deposits in production facilities to this day. In 2022, German refractories generated 1.4 billion euros in sales and employed 6,500 people, most working in medium-sized companies.

Germany's refractory sector "is one of the most important in the world and a leader in product solutions and manufacturing technologies," says Thomas Kaczmarek, managing director of Deutsche Feuerfest Industrie e.V. (DFFI), the German Refractory Association. "The companies not only manufacture ceramic components and materials—they also organize a sustainable raw material economy, create jobs, and ensure all relevant training paths."

DFFI, which will celebrate its 75th anniversary in 2024, is headquartered in an office that is also home to three other refractory organizations. Together, they form the European Refractory Center and collaborate with nearby institutes, training facilities, and universities that focus on ceramics. The Association advocates for its members' shared economic and technical interests.

"It aims to be involved in important political decisions and in the development of legal frameworks," Kaczmarek says, "and it participates in education and training, and science and research in the interests of the member companies at German and European level."

Prominent enterprises within this refractory ecosystem include the Deutsches Institut für Feuerfest und Keramik, which Kaczmarek describes as "one of the world's leading materials testing laboratories for refractory raw materials, products, and system solutions." Equally notable is the Forschungsgemeinschaft Feuerfest e. V., which "carries out research and development projects, from basic research to publicly funded joint research between producers and users to individual cooperation in product or process technology" (Figure 5).

Sharing knowledge, nurturing young talent

Knowledge-sharing is a priority among the member organizations, and the European Center for Refractories (ECREF) regularly hosts informational, networking, and educational or training events designed to strengthen the refractory sector in Germany.

For example, ECREF organizes the annual International Colloquium on Refractories, Europe's largest refractory event. The event, held in Aachen, combines a scientific conference; trade fair for refractory companies and suppliers of raw materials, machinery, and services; and networking and social events. The 66th colloquium takes place September 2024.

Additionally, ECREF's range of seminars includes a recurring three-day event entitled "Refractories: Key technology and its applications," which is conducted in both German and English. The "Steel meets refractory" event provides a twice-yearly forum for technology experts from both sectors to discuss R&D and product development challenges.

The German Refractory Association hosted the International Technical Conference on Refractories (UNITECR) Sept. 26–29, 2023, in Frankfurt, where the theme, "The carbon challenge," was designed to promote discussion of the transition from carbon to green hydrogen-based steel manufacture.

"The replacement of fossil fuels in high-temperature processes will have an impact on refractory materials," Kaczmarek notes. "New technologies will require new lining concepts. Modified and new refractory lining concepts will also help to save energy and lower the carbon emissions for existing technologies and processes."

In addition to the scientific conference program at UNITECR, which included 219 lectures, student contributions were recognized with the Gustav Eirich Award and a poster SLAM. A Women@Refractories networking event provided a forum for women in the industry to connect, and a similar reception for young professionals gave those entering the industry an opportunity to meet new friends and colleagues.

Post-graduate education and professional development are the focus of the organizations' Integrated Refractory Education System, which provides vocational training and qualification at all levels from apprenticeship to doctorate. Kaczmarek explains: "The offer is even broader with the qualification as a state-certified ceramics technician or the academic education for a Bachelor of Engineering in the field of materials technology glass/ceramics at the Koblenz University of Applied Sciences. It is rounded off with a Master of Ceramic Science and Engineering degree."

As it is across all sectors, sustainability is a priority in the German refractory industry.

"Refractories are made from natural materials. Their production is energy intensive and generates emissions," Kaczmarek says. "At all levels of production, our industry is working together to reduce these emissions."

He adds, "We are committed to continue down the decarbonization road, guided by the ambitions of the European Green Deal."

The circular economy is another important aspect for the refractory industry as it aims to preserve limited resources and to reduce its own ecological footprint in addition to the footprint of its customer segments.

"Secondary raw materials from our industry are increasingly being reused. This reuse protects raw materials and limits the emissions associated with mining," Kaczmarek says.

He adds, "We see ourselves as a system partner for our customers. The German companies don't just deliver bricks; we see ourselves as system partners for our customers. Together we want to develop products and processes so that we can significantly reduce energy requirements overall in the future."

MARKET SNAPSHOT

Economic powerhouse, recharging

Germany looks to rebound from global economic pressures, supply chain disruptions, and war to return to GDP growth

By Randy B. Hecht

The 27 member countries in the European Union account collectively for one-sixth of global trade and make up the world's third-largest economy, behind the United States and China. But the EU's economic clout derives disproportionately from one powerhouse member: Germany generates 25% of the EU's annual GDP of 16 trillion euros (equivalent to US$17.569 trillion).

The CIA World Factbook sums up Germany's economic strengths and challenges:[a] on one hand, a service-based and export-driven economy, highly skilled and educated labor force, and conservative fiscal policies; on the other hand, disruptions caused by lost access to Russian gas, increased defense spending, and rising debts.

The Department of Commerce International Trade Administration flags additional concerns, including "demographic changes and resulting labor shortages, supply chain bottlenecks, burdensome debt, especially on the municipal level," and high inflation, including energy price hikes that resulted from the war in Ukraine.

These factors contributed to Germany's falling into a recession last winter, when the Federal Statistics Office reported drops in economic output of 0.4% and 0.1% during the fourth quarter 2022 and the first quarter 2023, respectively. Although the country exited recession in the second quarter of 2023, economic output was stagnant for the period.

On July 17, 2023, the International Monetary Fund forecast "slightly negative" annual GDP growth for Germany in 2023 but added "Growth is expected to regain momentum gradually in 2024–25…Inflation is expected to continue falling amid softening energy prices and tightening fiscal policy…Over the medium term, average GDP growth is expected to fall back below 1% due to accelerating headwinds from population aging, absent significant increases in productivity and/or labor supply growth."[b]

Reichstag Building. Credit: hoch3media, Unsplash

Germany's estimated 2023 population of 84,220,184 represents a negative growth rate of 0.12%. The active labor force accounted for 44,515,312 people, or 52.85% of the total population in 2022. Real GDP for 2021 is estimated at $53,200 per capita.

Historically, Germany has recorded a trade surplus, with 2021 exports estimated at $2.004 trillion versus import volume of $1.775 trillion. Leading export commodities include cars and vehicle parts, packaged medicines, medical cultures and vaccines, aircraft, industrial machinery, and medical instruments. The country's largest export trading partners are the United States, China, France, Netherlands, and Italy.

Leading import commodities are cars and vehicle parts, medical cultures/vaccines, packaged medicines, crude petroleum, natural gas, and computers. Germany's largest import trading partners are China, the Netherlands, Poland, Italy, and France.

Leading industries in Germany include automotive, mechanical engineering, chemicals, electrical and batteries, manufacturing, metals, finance and banking, telecommunications, healthcare, and retail. Coal, lignite, natural gas, iron ore, copper, nickel, uranium, potash, salt, construction materials, timber, and arable land are among the country's natural resources.

The Commerce Department's International Trade Administration's Germany Country Commercial Guide covers various topics,[c] such as doing business in Germany, leading sectors for exports and investments, and customs regulations and standards (including tariff and non-tariff barriers, export controls, import requirements and documentation, product standards, and trade agreements).

Germany is the sixth-largest market for U.S. exports. Additional information and foreign commerce support are available via the websites of American Chamber of Commerce in Germany[d] and German American Business Council.[e]

References

[a]"Germany—country summary," CIA World Factbook. https://www.cia.gov/the-world-factbook/countries/germany/summaries/#economy

[b]"IMF Executive Board concludes 2023 Article IV consultation with Germany," International Monetary Fund. Published 17 July 2023. https://www.imf.org/en/News/Articles/2023/07/14/pr23264-germany-imf-executive-board-concludes-2023-article-iv-consultation-with-germany

[c]"Germany country commercial guide," International Trade Administration. https://www.trade.gov/germany-country-commercial-guide

[d]American Chamber of Commerce in Germany. https://www.amcham.de

[e]German American Business Council. https://www.gabc-washington.com

References

[1]"What is sustainable development?" Federal Ministry for the Environment, Nature Conservation, Nuclear Safety, and Consumer Protection. Accessed 15 Aug. 2023. https://www.bmuv.de/en/topics/sustainability-digitalisation/sustainability/what-is-sustainable-development#c12444

[2]"Research for sustainability." Federal Ministry of Education and Research. Accessed 15 Aug. 2023. https://www.bmbf.de/bmbf/en/research/environment-and-climate/research-for-sustainability/research-for-sustainability_node.html

[3]"On the way to clean aviation," Fraunhofer Institute for Ceramic Technologies and Systems IKTS. Published 5 July 2023. Accessed 15 Aug. 2023. https://www.ikts.fraunhofer.de/en/press_media/press_releases/2023_7_5_n_on_the_way_to_clean_aviation.html

[4]"Heat-resistant ceramic ink for data codes on metal components," Fraunhofer Institute for Ceramic Technologies and Systems IKTS. Published 3 July 2023. Accessed 15 Aug. 2023. https://www.ikts.fraunhofer.de/en/press_media/press_releases/2023_7_3_p_heat-resistant_ceramic_ink_for_data_codes_on_metal_components.html

[5]"Energy-efficient and low in emissions—silicon carbide recycling with RECOSiC©," Fraunhofer Institute for Ceramic Technologies and Systems IKTS. Published 1 June 2023. Accessed 15 Aug. 2023. https://www.ikts.fraunhofer.de/en/press_media/press_releases/2023_6_1_p_energy-efficient_and_low_in_emissions_silicon_carbide_recycling_with_recosic.html ■

Max Planck Gesellschaft: The research behemoth investigating everything

Visit the Max Planck Institute's website, and the first thing you will learn is "There is no such thing as 'the' Max Planck Institute." The name is shorthand for 85 institutes and research facilities (including five institutes and one research facility located outside Germany) whose workforce includes almost 20,900 employees, more than 2,500 guest scientists, and 519 scholarship holders.

Institutes focused on materials science research include

Max Planck Institute for the Structure and Dynamics of Matter (Hamburg)
"New methods are enabling physicists and biologists at the Max Planck Institute for the Structure and Dynamics of Matter to break new scientific ground. With the help of new radiation sources, especially the X-ray free-electron laser being built at the DESY in Hamburg, the researchers can show the properties and behavior of matter at a spatial resolution of a few nanometers and at time intervals of a few billionths of a billionth of a second. This provides them with completely new insights into the structure and function of biological materials and into the properties of solids and their electronic and structural dynamics. The coherent light of lasers enables the physicists to inspect the collective properties, for example, superconductivity, of complex solids, including many types of ceramics."

Website: https://www.mpg.de/7067564/structure-and-dynamics-of-matter

Max Planck Institute for Polymer Research (Mainz)
"Scientists at the Max Planck Institute for Polymer Research…investigate polymers in all their different facets — their production, their physical properties, and their applications…Moreover, the researchers in Mainz are developing new procedures to spectrographically investigate polymers and to simulate their behavior on the computer. They also work with soft matter, which, like wine gums, combines the properties of solid bodies and liquids."

Website: https://www.mpg.de/154064/polymer-research

Max Planck Institute for Solid State Research (Stuttgart)
"Lithium batteries that provide electric cars with power, superconductors that conduct electricity over long distances without loss, solar cells that harvest solar power…These are some of the phenomena which scientists investigate at the Max Planck Institute for Solid State Research. Solid state materials include metals, ceramics and even crystals of organic molecules. Just how the structures of these materials affect their electrical, mechanical and magnetic properties, is what solid-state researchers seek to understand. To this end, researchers particularly focus on solids at the nanoscale."

Website: https://www.mpg.de/153319/solid-state-research

Max Planck Institute of Colloids and Interfaces (Pottsdam-Golm)
"Tiny apatite crystals in bones, vesicles formed out of membranes, pores in membranes for fuel cells and microcapsules as vehicles for medical drugs—all these are structures that are larger than an atom, yet too small to be seen with the naked eye. These are the kinds of nanostructures and microstructures that scientists at the Max Planck Institute of Colloids and Interfaces examine and create."

Website: https://www.mpg.de/152349/colloids-and-interfaces

Max-Planck-Institut für Eisenforschung GmbH (Düsseldorf)
"Novel alloys for automotive lightweight design, materials for sustainable energy conversion and storage, and machine learning methods for material design—just a few examples of the research areas investigated at the Max-Planck-Institut für Eisenforschung. The researchers study complex materials down to the atomic scale while considering real environmental conditions."

Website: https://www.mpg.de/152964/eisenforschung

Max Planck Institute for Intelligent Systems (Tübingen, Stuttgart)
"Research expertise in the areas of computer science, material science and biology is brought together in one Institute, at two different sites. Machine learning, image recognition, robotics and biological systems will be investigated in Tübingen, while so-called learning material systems, micro- and nanorobotics, as well as self-organization will be explored in Stuttgart. Although the focus is on basic research, the Institute has a high potential for practical applications in, among other areas, robotics, medical technology, and innovative technologies based on new materials."

Website: https://www.mpg.de/1342929/intelligent-systems-tuebingen

Max Planck Institute of Microstructure Physics (Halle)
"The scientists at the Max Planck Institute for Microstructure Physics in Halle…investigate how the microstructure and nanostructure of metallic compounds affect their physical properties, for example how they behave as fiber optics or their magnetic characteristics. Their research concentrates on materials in low dimensions, for instance in a two-dimensional thin layer, a virtually one-dimensional nanowire or a minute heap of atoms, which physicists call a quantum dot and which, in some respects, resembles a single atom."

Website: https://www.mpg.de/153709/microstructure-physics

Max Planck Institute for Chemical Physics of Solids (Dresden)
"The key research focus of the Institute is compounds of different metals. Chemists and physicists as well as experimental and theoretical scientists use state-of-the-art instruments and methods to investigate how the chemical composition, configuration of atoms and external forces affect the behavior of electrons. It is these that are responsible for the magnetic, electronic, and chemical properties of the compounds, and thus for their potential use as materials."

Website: https://www.mpg.de/149744/chemical-physics-of-solids ■

Directory

ASSOCIATIONS

German Ceramic Society
The Deutsche Keramische Gesellschaft (German Ceramic Society, DKG), based in Cologne, is a professional networking and knowledge exchange organization dedicated to promoting the "development and application of new ceramic materials and products at home and abroad." In addition to sponsoring educational activities, symposiums, and congresses, it is a funding agency for ceramics R&D.

Its research projects "are generally developed in the DKG committees, but also bilaterally between members and research institutes," the website notes. "For the DKG, privately financed or funded joint industrial research is an essential part of its research activities."

The DKG's cooperation partners include

- Association of the German Refractory Industry eV https://www.dffi.de
- Federal Association of the Ceramic Industry eV http://www.keramverbaende.de
- German Glass Technology Society http://www.hvg-dgg.de/home.html
- Institute for Brick Research Essen eV https://www.izf.de/index.php/en
- Metallurgical Association of the German Glass Industry eV www.hvg-dgg.de/home.html
- Research Association of the Brick Industry eV https://www.ziegel.de/forschung
- Research Association Refractory eV https://www.fg-feuerfest.de/basis

Website: https://www.dkg.de

Media library: https://www.dkg.de/themen/mediathek_und_referate_und_publikationen/mediathek

CORPORATIONS AND RESEARCH INSTITUTES

CeramTec GmbH
Plochingen
https://www.ceramtec-group.com/en

Ceratec GmbH
Kreuztal
https://ceratec.de/en

Christian Guttmann nanoquartz
Ruhla
https://en.nanoquartz.de

DLR Zentrum Koeln
German Aerospace Center
Cologne
https://www.dlr.de/en

DoCeram
Dortmund
https://www.moeschter-group.com/en/doceram/overview

Duravit AG
Hornberg
https://www.duravit.de

FCT Fine Ceramic Technologies
Frankenblick
https://www.fct-systeme.de/en

Forschungszentrum Juelich
Jülich
https://www.fz-juelich.de/en

Fraunhofer IKTS
Dresden
https://www.ikts.fraunhofer.de/en.html

Fritz-Haber-Institut der Max Planck Gesellschaft
Berlin
https://www.fhi.mpg.de

Glassomer GmbH
Freiburg im Breisgau
https://www.glassomer.com

Grow Platform GmbH - Bosch Advanced Ceramics
Ludwigsburg
https://www.growplatform.com/stories/bosch-advanced-ceramics

GTT Technologies
Herzogenrath
https://gtt-technologies.de

Helmholtz Institute
Ulm
https://hiu-batteries.de/en

Heraeus
Hanau
https://www.heraeus.com/en/group/home/home.html

INMATEC Technologies GmbH
Rheinbach
https://inmatec-gmbh.com/?lang=en

KRAHN Ceramics GmbH
Dinslaken
https://www.krahn-ceramics.com/en

Leibniz Institute for Solid State & Materials Research
Dresden
https://www.ifw-dresden.de

Max Planck Gesselschaft
Multiple locations
https://www.mpg.de/institutes

MTU Aero Engines
Munich
https://www.mtu.de

Brandenburg Gate. Credit: Modes Rodriguez, Flickr (CC BY-NC-ND 2.0)

Directory

CORPORATIONS AND RESEARCH INSTITUTES (cont.)

Nabaltec AG
Schwandorf
https://nabaltec.de

Nano-Care Deutschland AG
Rehlingen-Siersburg
https://nano-care.com

Onyx Coating GmbH
Berlin
https://onyxcoating.com

PI Ceramic GmbH
Lederhose
https://www.piceramic.com/en

QSIL Ingenieurkeramik
Ilmenau
https://qsil.com/en

Rauschert Industries Inc.
Pressig
https://rauschert.com/en

SCHOTT AG
Mainz
https://www.schott.com/en-us

Sembach GmbH & Co. KG - Technische Keramik
Sembach Technical Ceramics
Lauf an der Pegnitz
https://sembach.de

uniglassAC GmbH
Aachen
https://uniglassac.de

Zell Quartzglas and Technical Ceramics Technology GmbH
Geesthacht
https://zell-quarzglas-keramik.de

UNIVERSITIES

Eberhard Karls Universität Tübingen
Tübingen
https://uni-tuebingen.de/en

Friedrich Schiller University Jena
Jena
https://www.uni-jena.de/en

Goethe University Frankfurt
Frankfurt am Main
https://www.uni-frankfurt.de/de

Humboldt-Universität zu Berlin
Berlin
https://www.hu-berlin.de/en

Justus-Liebig-University Giessen
Giessen
https://www.uni-giessen.de/jlyou

Karlsruhe Institute of Technology
Karlsruhe
https://www.kit.edu/english/index.php

Leibniz University Hannover
Hanover
https://www.uni-hannover.de/de

RWTH Aachen University
Aachen
https://www.rwth-aachen.de/cms/~a/root/lidx/1

Technische Universitaet Darmstadt
Darmstadt
https://www.tu-darmstadt.de/index.en.jsp

TU Bergakademie Freiberg
Freiberg
https://tu-freiberg.de/en

University of Erlangen-Nuremberg Institute of Biomaterials
Erlangen
https://www.biomat.tf.fau.eu

Universität Duisburg-Essen
Duisburg-Essen
https://www.uni-due.de

Universität Erlangen-Nuremberg
Erlangen-Nuremberg
https://www.fau.eu

Universität Bayreuth
Bayreuth
https://www.uni-bayreuth.de/en

Universität Bremen
Bremen
https://www.uni-bremen.de/en

Universität zu Köln
Cologne
https://portal.uni-koeln.de/en/uoc-home

Universität Freiburg
Freiburg im Breisgau
https://uni-freiburg.de

Universität Koblenz
Koblenz
https://www.uni-koblenz.de/de

Universität Stuttgart
Stuttgart
https://www.uni-stuttgart.de/en ■

Oktoberfest celebrations. Credit: Patrick Langwallner, Unsplash

REGISTER NOW

48TH

INTERNATIONAL CONFERENCE
AND EXPOSITION ON

ADVANCED CERAMICS AND COMPOSITES

JAN. 28–FEB. 2, 2024

HILTON DAYTONA BEACH RESORT AND OCEAN CENTER

DAYTONA BEACH, FLA., USA

ceramics.org/icacc2024

The American Ceramic Society
ceramics.org

Engineering Ceramics Division
The American Ceramic Society

Organized by the Engineering Ceramics Division of The American Ceramic Society

Credit: Dougsim, Wikimedia (CC BY-SA 4.0)

Figure 1. Image of a piezoelectric compensator based on Pierre Curie's design. It could produce very small electric currents by exerting changing tensile forces on a piezoelectric crystal located near the top of the device.

Increasing demand for lead-free piezoceramic systems and textured ceramics

By A. Murat Avcı, Servet Kızılırmak, and Ender Suvacı

Piezoelectric ceramics are indispensable to our way of life. Their ability to transform electrical energy into mechanical energy (and vice versa) makes these materials useful in many sectors and industrial applications.

These materials track their origin to the year 1880,[1] when the phenomenon of piezoelectricity was first discovered by two French brothers, Jacques and Pierre Curie, in crystals of Rochelle salt and quartz (Figure 1). Later, the Curies discovered that electrical fields can result in dimensional changes in piezoelectric materials, an interaction termed the "inverse piezoelectric effect."

After World War II, as the number of applications for piezoelectricity started to grow, researchers started to investigate polycrystalline formulations. It was then during the 1950s that the well-known lead zirconate titanate (PZT) was first synthesized.

PZT-based piezoelectric materials offered far superior piezoelectric characteristics than other alternatives proposed to that date. This superior performance led PZT to become the most common piezoelectric ceramic in use today, with applications in numerous fields ranging from energy harvesting equipment to consumer electronics.

The piezoceramic market today

Improved manufacturing techniques and an increasing demand for piezoelectric properties in many fields have allowed piezo device usage to expand in the automotive, avionics, energy harvesting, consumer electronics, and defense industries (Figure 2).

Some prevalent commercial lead-based piezoelectric ceramics are Pb, $ZrTiO_3$ (PZT), $(1–x)Pb(Mg_{1/3}Nb_{2/3})O_3–xPbTiO_3$ (PMN-PT), $(1–x)Pb(Zn_{1/3}Nb_{2/3})O_3–xPbTiO_3$ (PZN-PT), and $(1–x–y)Pb(In_{1/2}Nb_{1/2})O_3–yPb(Mg_{1/3}Nb_{2/3})O_3–xPbTiO_3$ (PIN-PMN-PT). These ceramics, which are modified with dopants to endow them with certain properties, can be classified as either "hard" or "soft" piezoelectrics.

Hard piezoelectrics typically exhibit a coercive field of more than 10 kV/cm. This property is achieved through acceptor doping (Fe^{3+}, Al^{3+} for PZT), which hardens the domain wall movement and gives the ceramics high power applicability. In contrast, soft piezoelectrics rely on donor doping (Ta^{5+}, Nb^{5+} for PZT), which makes the domain walls more mobile and thus suitable for low power applications. The coercive field in this case is less than 1 kV/cm.

Piezoceramics can also be categorized based on their applications, either resonance or nonresonance (Rödel et al., 2015).[2] In resonance mode systems, piezo stacks stretch and pull back at a frequency close to the natural resonance frequency of the system. Large displacements can be obtained in these systems (Huo et al., 2018).[3] Nonresonance systems are frequently used in acceleration, shock, and knocking sensors, as well as energy harvesting systems. Both resonance and nonresonance systems are used in different temperature regimes, and the materials must be designed with Curie temperatures and temperature stabilities proper to these application areas.

Another important property of piezoceramics from the application standpoint is the piezoelectric coefficient, which indicates the electrical–mechanical energy conversion efficiency. In the past decade, single crystals that have near morphotropic phase boundaries were reevaluated with extremely high piezoelectric coefficients and ultrahigh electromechanical coupling factors (Sun et al., 2015).[4]

Although lead-based piezoceramics are the main drivers of the piezoelectric industry today, their high lead content (~60 wt.%) raises concerns about potential negative effects on human and environmental health both before and after their use. Another disadvantage of lead-containing piezoceramic systems is the challenging production environment. High vapor pressure of PbO complicates both polycrystalline and single crystal production of PMN-PT and PZN-PT.

In addition to these challenges, the incongruent melting behavior of the solid solution enhances the tendency of chemical segregation. These heterogeneities of crystals may induce undesirable electrical and mechanical performances during poling and high field device applications (Park et al., 2002).[5] Though these problems in the single crystal systems can be partially overcome via solid-state crystal conversion growth methods, slow crystal growth kinetics limit the expansion of this approach for mass production.

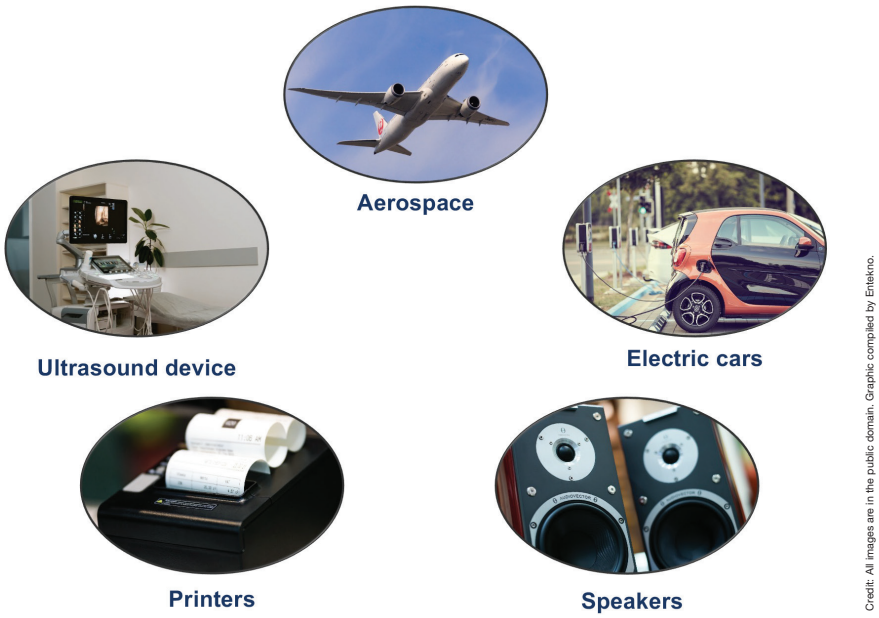


Figure 2. Examples of piezoceramic devices used in daily life.

These health concerns and production constraints have prompted demand for lead-free piezoceramic compositions. This demand has been accelerated by changes in legislation that aim to limit and ultimately eliminate the use of hazardous chemicals. For instance, the Restriction of Hazardous Substances (RoHS), which was adopted by the European Union in February 2003, decreases and restricts the use of specific harmful ingredients found in electrical and electronic equipment.[6] The EU recently released an update for RoHS that mandates all homogenous parts containing lead levels of more than 0.1 wt.% be subject to restrictions. Although piezoceramics have been exempted from this update for the moment, the ultimate goal is to eliminate lead in all materials. As such, in the future, it is expected that this mandate will significantly impede inclusion of major piezoelectric materials, which have lead levels up to 60 wt.%, in common applications.

History of lead-free piezoceramics and the market today

The first studies on lead-free piezoelectric systems took place more than 50 years ago, with the work of Jaeger and Egerton in 1962.[7] In 2004, the work of Saito et al. fueled interest in lead-free piezoceramics by showing that the synergistic effect of combining compositional and microstructural design can lead to piezoelectric properties on par with those seen in PZT-based piezoceramics.[8] In that study, they doped $(Na_{0.5}K_{0.5})NbO_3$ with hexagonal pseudo-ilmenite type $LiTaO_3$ to form a morphotropic phase boundary. With this compositional study, improvement in piezoelectricity was supported by hybridization covalency onto ionic bonding by using Cohen's calculation.[9]

Investigations into lead-free piezoceramics have concentrated mainly on alkaline niobate ($K_{0.5}Na_{0.5}NbO_3$), barium titanate ($BaTiO_3$), sodium bismuth titanate ($Na_{0.5}Bi_{0.5}TiO_3$), bismuth ferrite ($BiFeO_3$), and their derivates. These piezoceramics are used in the manufacturing, automotive, consumer electronics, and medical sectors, among others. They are used as actuators, sensors, positioning devices, and capacitors, in addition to other applications.

According to a BCC Research report,[10] the global market for lead-free piezoelectric ceramics stands at about $184.1 million as of 2021. The market is expected grow to $402.1 million by 2026 at a compound

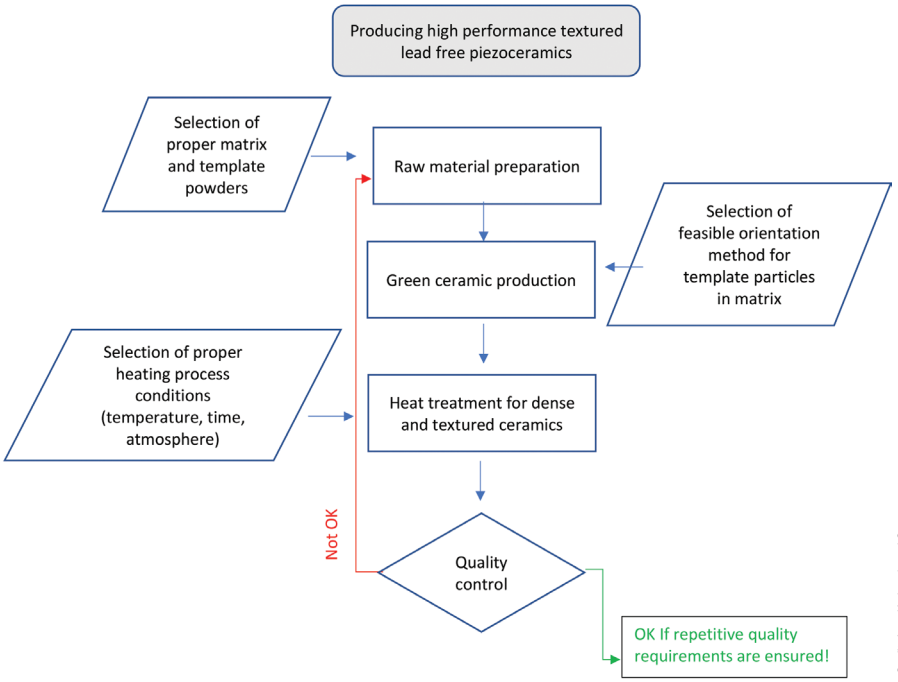


Figure 3. Critical steps of the templated grain growth process.

annual growth rate (CAGR) of 16.9%. This projected CAGR for lead-free piezoceramics is greater than the CAGR for the whole piezoelectric market (5.9%).

The increased market penetration of lead-free piezoelectric systems can be directly attributed to stricter environmental regulations worldwide, growing concerns about public health, and expanding demand for piezoelectric devices.

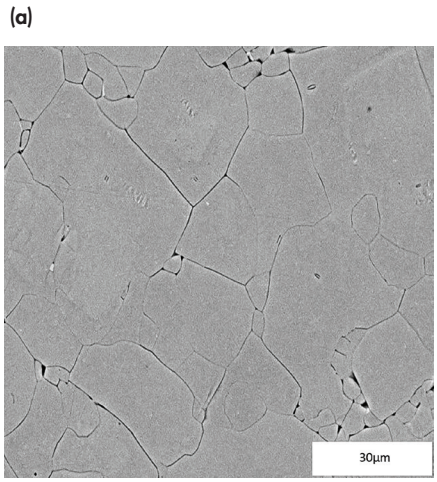
Textured piezoceramics

Recently, textured piezoelectric ceramics have attracted attention. These materials exhibit improved properties with respect to conventional piezoceramics, which have randomly oriented grains.

Textured ceramics can be manufactured via a templated grain growth (TGG) process (Figure 3).[11] In this process, template particles (anisometric large seeds) are distributed among the fine equiaxed matrix grains. These particles are aligned during the shaping process, and during heat treatment, the templates grow at the cost of fine matrix particles via Ostwald ripening process. Because the particles maintain their initial alignment, the final microstructure is composed of crystallographically oriented grains that exhibit a textured character (Figure 4).

Two important components of the TGG method are the matrix powder and template particles. Matrix powder characteristics should be tailored so that the templates have sufficient thermodynamic driving force to grow at the cost of the fine matrix grains. Additionally, the templates are key components to induce texture development. Template characteristics such as morphology, aspect ratio, thermodynamic stability, and lattice parameter matching with respect to the matrix grains must be carefully considered. Consequently, it is important to form an understanding of the relationship between template characteristics and texture development.

It is important to develop innovative forming techniques suitable for matrix and template particles used in texturing processes. To evaluate the efficacy of these innovative techniques, the microstructure and physical properties of the textured ceramics parts can be assessed after sintering. The results play a vital role to examine and modify the processing conditions to obtain the best results.



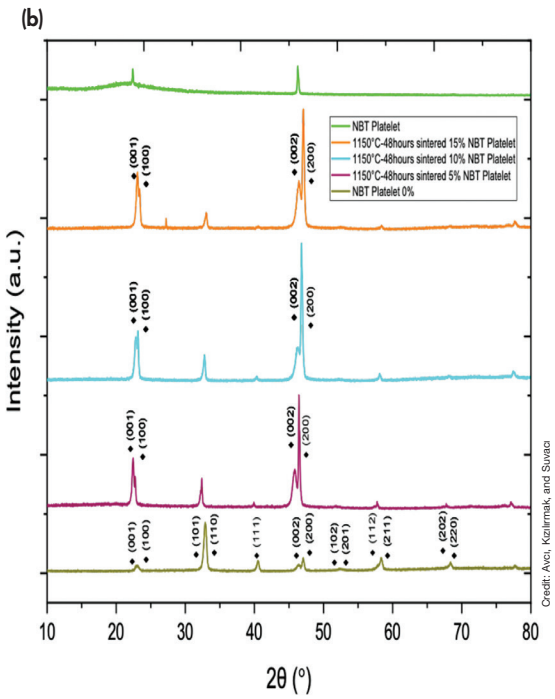


Figure 4. The SEM micrograph (a) and XRD patterns (b) of $Na_{0.5}Bi_{0.5}TiO_3$ platelets and crystallographically textured $(Na,K)_{0.5}$ $Bi_{0.5}Ti_{O3}$–$BaTi_{O3}$ system studied by Entekno Materials Co.

Acknowledgements

The authors thank Gamze Welsh for her editorial support during the preparation of this article.

About the authors

A. Murat Avcı, Servet Kızılırmak, and Ender Suvacı are production manager, electroceramic products leader, and chief technology and innovation officer, respectively, at Entekno Materials Co. in Eskişehir, Türkiye. Contact Entekno at info@enteknomaterials.com and visit the website at www.enteknomaterials.com.

References

[1]"A history of the piezoelectric effect," OnScale. Accessed 15 Aug. 2023. https://onscale.com/piezoelectricity/history-of-piezoelectricity

[2]Rödel, J., Webber, K.G., Dittmer, R., Jo, W., Kimura,M., Damjanovic, D., "Transferring lead free piezoelectric ceramics into application," *J.Eur.Ceram.Soc.* 2015, 35.

[3]Huo, D., Chen, W., Sun, Y., "Chapter 4: Vibration assisted milling," *Hybrid Machining* 2018, 77–109.

[4]Sun, E., Cao, W., "Relaxor based ferroelectric single crystals: growth, domain engineering, characterization and applications," *Prog. Mater. Sci.* 2015.

[5]Park, S.E.E., Hackenberger, W., "High performance single crystal piezoelectrics: application and issues," *Current Opinion in Solid State and Materials Science* 2002, 6.

[6]"RoHS compliance FAQ," RoHS Guide. Last updated 15 Aug. 2023. Accessed 15 Aug. 2023. https://www.rohsguide.com/rohs-faq.htm

[7]Jaeger, R.E., Egerton, L., "Hot pressing of potassium–sodium niobates," *J. Am. Ceram. Soc.* 1962, 45(5).

[8]Saito, Y., Takao, H., Tani, T., Nonoyama, T., Takatori, K., Homma, T., "Lead free piezoceramics," *Nature* 2004, 432.

[9]Cohen, R. E. "Origin of ferroelectricity in perovskite oxides," *Nature* 1992, 358: 136–138.

[10]"Lead-free piezoelectric ceramics: Technologies and global opportunities," BCC Research, April 2022, Report Number NAN063B.

[11]Messing, G.,L., Trolier-McKinstry, S., Sabolsky, E.M., Duran, C., Kwon, S., Brahmaroutu, B., Park, P., Yılmaz, H., Rehrig, P.W., Eitel, K.B., Suvacı, E., Seabaugh, M., Oh, K.S., "Templated grain growth of textured piezoelectric ceramics," *Critical Reviews in Solid State and Materials Sciences* 2004, 29(2): 45–96.

[12]Wu, J., Xiao, D., Zhu, J., "Potassium sodium niobate lead-free piezoelectric materials: Past, present, and future of phase boundaries," *Chem Rev.* 2015, 115.

[13]Wu, J., "Advances in lead-free piezoelectric materials," Springer, 2018 ■

The 'very important role' of ceramics in energy on full display at MCARE/EHS 2023

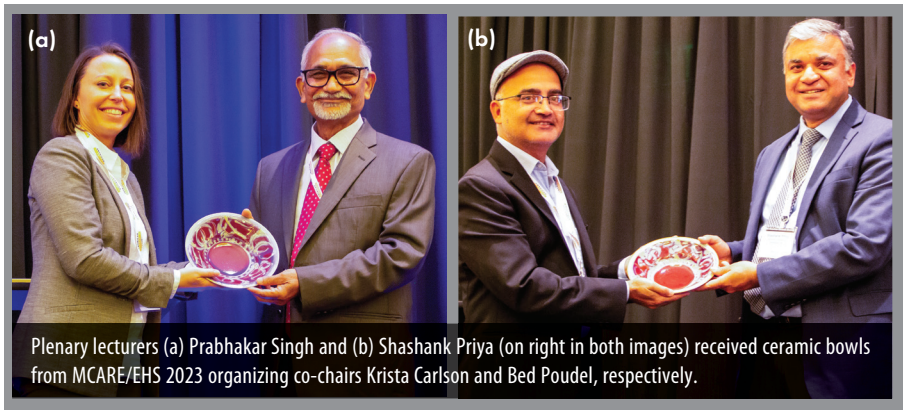
Credit: ACerS (all photos)

The combined Materials Challenges in Alternative & Renewable Energy and Energy Harvesting Society meeting took place Aug. 21–24, 2023, in Bellevue, Wash. Almost 170 attendees, including 25 students, from 16 countries gathered for the conference.

During the opening plenary session on Monday morning, MCARE/EHS organizing co-chair Krista Carlson from the University of Nevada, Reno, reflected on the history of MCARE. ACerS past president and Distinguished Life Member George Wicks and ASM International past president Jack Simon led the initial charge to launch the meeting in Florida in 2008. But as of 2013, ACerS has worked with the Korean Institute of Chemical Engineers to host MCARE in alternating years between the United States and Republic of Korea.

For this reason, "MCARE manifests the vision of being a global voice for ceramics and glass," ACerS president Sanjay Mathur said during the opening plenary session.

Following Carlson and Mathur's introductory greetings, Prabhakar Singh from the University of Connecticut gave the first plenary lecture on materials for electrochemical energy systems. He emphasized how this field of research has a long history spanning 200 years, but it is only recently that the potential of these systems started being realized. His talk highlighted the many opportunities to expand on this potential.

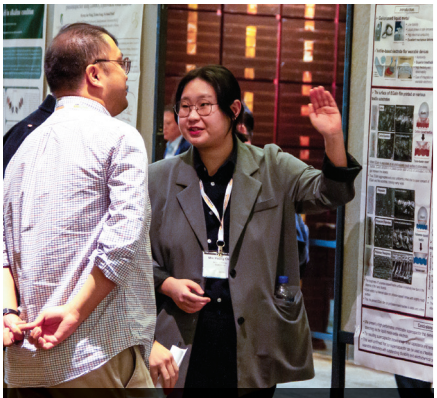


Plenary lecturers (a) Prabhakar Singh and (b) Shashank Priya (on right in both images) received ceramic bowls from MCARE/EHS 2023 organizing co-chairs Krista Carlson and Bed Poudel, respectively.

On Wednesday morning, Shashank Priya from the University of Minnesota gave the second plenary lecture on energy harvesting materials and systems. As with Singh's lecture on electrochemical energy systems, Priya stressed that researchers are just beginning to realize the potential of energy harvesting technologies. As an example of this potential, he described several experiments conducted at The Pennsylvania State University and Virginia Tech on different energy harvesting technologies.

Many other alternative and renewable energy technology areas were covered during the meeting's 11 symposia, including deep dives on hydrogen fuel production, nascent perovskite-based devices, and challenges with sustainable nuclear energy. Yet one thing was clear from all the talks—that "ceramics are going to play a very important role [in energy]," as Mathur stated during the opening plenary session.

View more photos from MCARE/EHS 2023 on ACerS Flickr page at bit.ly/MCARE2023. Next year, the Korean Institute of Chemical Engineers will host MCARE 2024 at the Jeju Lotte Hotel on Jeju Island, Republic of Korea, from Aug. 19–23, 2024. ■


Students presented their research during a poster session on Wednesday, Aug. 23.


On Sunday, Aug. 20, ACerS held a dinner to thank all the meeting and symposium organizers, plenary speakers, and supporters of the MCARE/EHS 2023 meeting.

UPCOMING DATES

JAN. 28–FEB. 2, 2024
Register soon!

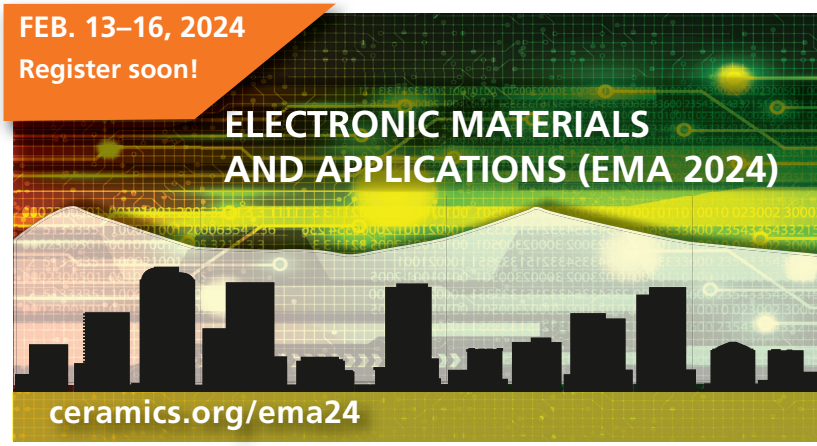
48TH INTERNATIONAL CONFERENCE AND EXPO ON ADVANCED CERAMICS AND COMPOSITES (ICACC2024)

ceramics.org/icacc2024

HILTON DAYTONA BEACH RESORT/OCEAN WALK VILLAGE, DAYTONA BEACH, FLA.

This conference has a strong history of being one of the best international meetings on advanced structural and functional ceramics, composites, and other emerging ceramic materials and technologies.

FEB. 13–16, 2024
Register soon!



HILTON CITY CENTER, DENVER, COLO.

Jointly programmed by the Electronics Division and Basic Science Division, this conference is designed for those interested in electroceramic materials and their applications.

APRIL 7–11, 2024
Call for papers!

HILTON PANAMA, PANAMA CITY, PANAMA

In 2022, the first PACC conference was held jointly with the Ferroelectric Meeting of Americas (FMAs) to facilitate interactions in and among the countries of the Americas and to provide an insight into the work being done in these countries for others around the world. The 2024 PACC will also be jointly held with the FMAs.

MAY 19–23, 2024
Call for papers!

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

The American Ceramic Society values diverse and inclusive participation within the field of ceramic science and engineering. ACerS strives to promote involvement and access to leadership opportunity regardless of race, ethnicity, gender, religion, age, sexual orientation, nationality, disability, appearance, geographic location, career path or academic level.

Calendar of events

November 2023

5–10 ➨ 15th Pacific Rim Conference on Ceramic and Glass Technology – Shenzhen World Exhibition & Convention Center, Shenzhen, China; https://ceramics.org/event/15th-pacific-rim-conference-on-ceramic-and-glass-technology

6–9 ➨ Glass Week 2023 (Conference on Glass Problems and GMIC Symposium) – Columbus Convention Center, Columbus, Ohio; glassproblemsconference.org

27–Dec. 1 SIPS 2023 (Sustainability through Science and Technology) – Hyatt Dreams Playa Bonita, Panama; https://www.flogen.org/sips2023/?p=186#toop

28–Dec. 1 ➨ International Conference on Ceramics and Geomaterials in Central Africa – University of Yaoundé, Yaoundé, Cameroon; https://www.cacers.org/?lang=en

January 2024

28–Feb 2 48th International Conference and Expo on Advanced Ceramics and Composites (ICACC 2024) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla; https://ceramics.org/icacc2024

February 2024

13–16 Electronic Materials and Applications (EMA 2024): Basic Science and Electronic Materials Meeting – Hilton City Center, Denver, Colo.; https://ceramics.org/ema2024

March 2024

26–28 59th Annual St. Louis Section/Refractory Ceramics Division Symposium on Refractories – Hilton St. Louis Airport Hotel, St. Louis, Mo.; https://ceramics.org/event/59th-annual-st-louis-section-refractory-ceramics-division-symposium-on-refractories

April 2024

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

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

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

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

May 2024

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

June 2024

17–19 ACerS 2024 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Sheraton Oklahoma City Downtown Hotel, Oklahoma City, Okla.; https://ceramics.org/SCPD2024

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

July 2024

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

August 2024

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

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.

classified advertising

Business Services

custom finishing/machining

custom/toll processing services

firing/melting/drying

laboratory/testing services

maintenance/repair services

DISPLAY ADVERTISER

AdValue Technology‡	www.advaluetech.com	15
Alfred University‡	www.alfred.edu/CACT	Inside back cover
American Elements‡	www.americanelements.com	Outside back cover
Centorr Vacuum Industries, Inc.‡	www.centorr.com	21
Deltech, Inc.‡	www.deltechfurnaces.com	3
Deltech Kiln and Furnace Design‡	www.dkfdllc.com	23
Free Form Fibers	www.fffibers.com	23
Gasbarre Products‡	www.gasbarre.com	17
Harrop Industries Inc.‡	www.harropusa.com	Inside front cover
I Squared R Element‡	www.isquaredrelement.com	13
Linde Company	www.lindeus.com/glass	5
Mo-Sci‡	www.mo-sci.com	9
Paul O. Abbe‡	www.pauloabbe.com	19
Special Shapes Refractory Co.	www.ssrco.com	25
TevTech‡	www.tevtechllc.com	11
The American Ceramic Society‡	www.ceramics.org	26, 27, 37, 41, 46
Thermcraft‡	www.thermcraftinc.com	21

CLASSIFIED & BUSINESS SERVICES ADVERTISER

Advanced Ceramic Technology	www.advancedceramictech.com	45
Bomas‡	www.bomas.com	45
Centorr Vacuum Industries Inc.‡	www.centorr.com	45, 46
Edward Orton Jr. Ceramic Fdn.	www.ortonceramic.com/testing	46
Harrop Industries Inc.‡	www.harropusa.com	45, 46
PPT - Powder Processing & Technology LLC	www.pptechnology.com	45
PremaTech Advanced Ceramic	www.prematechac.com	45
Rauschert Technical Ceramics Inc.‡	www.rauschert.com	45
Spectrochemical Laboratories	www.spectrochemicalme.com	46
Zircar Ceramics Inc.	www.zircarceramics.com	45
Zircar Zirconia Inc.	www.zircarzirconia.com	45

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

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

Jesse Hinricher
Guest columnist

Different scientific philosophies: A visitor's perspective on thinking like an American in Germany

"If I'm an advocate for anything, it's to move. As far as you can, as much as you can. Across the ocean, or simply across the river. Walk in someone else's shoes–or at least eat their food."[1]

American celebrity chef Anthony Bourdain said this quote in reference to a culture's food, yet it applies equally well for exploring their scientific method. I moved to Germany to follow my Ph.D. adviser and ended up having the most significant research exposure of my life.

My Ph.D. is on the manufacture of solid-state oxide electrolytes for advanced batteries. I began this work in the Department of Materials Science and Engineering at Massachusetts Institute of Technology in professor Jennifer Rupp's research group. In my second year, Rupp accepted a new position at the Technical University of Munich in Germany, and I decided to follow her there (Figure 1).

I was trepidatious about restarting a lab on the other side of the world and about engaging with a new culture in a new language. Also, given some of the stereotypes that depict Germans as rigid or even harsh, I expected the research environment to be more unyielding or intense. However, I need not have worried. What I found when I landed was a welcoming, friendly, and curious culture that had distinct similarities with and differences from U.S. research groups.

First, I was surprised at how the German academic system operates. Each group, called a "chair" in the German academic vernacular, is defined by the individual professor. Group size can be massive—some groups have more than 30 Ph.D. students, as well as master's students, postdocs, and group leaders. Due to this large size, it is common for Ph.D. students to meet with their professor only once or twice per semester, whereas in the U.S., we typically meet more often.

Also, there is very little central equipment within a department, so each group is responsible for purchasing, operating, and maintaining their own scientific instruments. In our chair, we have our own Raman spectrometer, pulsed-laser deposition system, SEM, and DSC/TGA. A neighboring group has their own XRD; still another group has their own ICP-MS. This siloing of equipment into the research group makes it more difficult to access new equipment, and often if a certain measurement is required, Ph.D. students must ask each other for a favor.

Credit: Jesse Hinricher

Figure 1. Professor Jennifer Rupp's research group at the Technical University of Munich, Germany, 2023. Rupp is on the far right. Jesse Hinricher (author) is second from right.

Second, German work habits are the largest difference between this country and the U.S. Germans are generally very disciplined with their working time and have a sharper distinction between their work and their hobbies. By 5 pm, my German colleagues will typically leave their computer at the office and pursue other interests. This hard stop to the workday gives them time to read more, follow global politics, participate in athletics, and generally become more well-rounded individuals. Conversely, my U.S. colleagues are rarely without their computers, frequently check email outside of work, and are almost solely focused on their research topic. This prioritization of work leads to a U.S. research culture that is faster paced and a German one that is more refreshed and structured.

My time in Germany has been a first-rate experience with a scientifically renowned culture and disciplined approach to tackling research problems. U.S. researchers could benefit from taking more time away from work to gain a greater perspective in our labs and industries. Likewise, German researchers could benefit from greater collaboration and access to shared equipment.

I am excited to continue experiencing German culture and building relationships in Germany and Europe. My hope is that more U.S. and German researchers will work together to solve the most pressing problems our world faces; there is a lot to benefit from on both sides, both culturally and scientifically.

References

[1]Anthony Bourdain: No Reservations, Season 9, Episode 10: "Brooklyn," 2012.

Jesse Hinricher is a Ph.D. student in professor Jennifer Rupp's research group at Massachusetts Institute of Technology and a guest doctoral candidate at the Technical University of Munich, Germany. His research focuses on manufacturing solid-state oxide electrolytes for advanced batteries. In his spare time, he enjoys studying German and riding trains. ■

Alfred University
Outside of Ordinary

CACT Center for Advanced Ceramic Technology

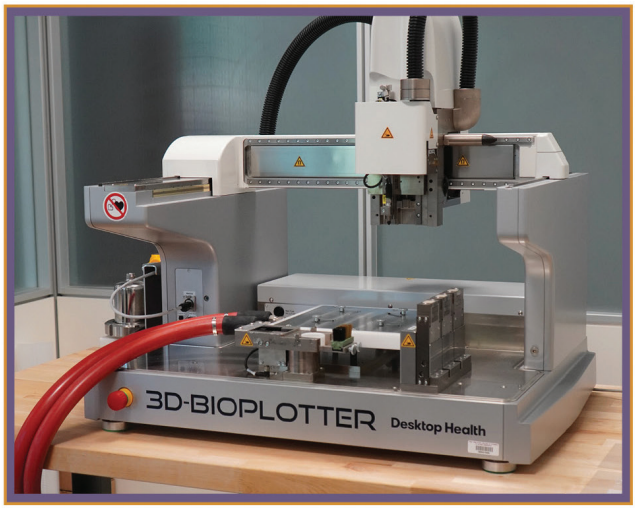
NEW CAPABILITIES AT ALFRED UNIVERSITY

THE BRUKER SKYSCAN 2214CT SCANNER

- 3-D printed materials, which may have internal pores or flaws
- Sintered bodies which likewise may have internal pores or flaws.
- Density variations in materials made using advacned synthesis process such as freeze casting, tape casting, injection molding, etc.
- Interfaces in laminated tape-cast parts and in other dissimialr materials joints
- Materials flaws and flaw growth under compressive loading

ENVISIONTEC MULTI-MATERIAL 3D BIOPLOTTER

- Utilizes a simple process through which a liquid, melt, paste, or gel is dispensed from a material cartridge through a needle tip from a 3-axis system, for a maximum build volume of 150 x 150 x 140 mm.
- Allows printing temperatures ranging from 2-250°C, with individual temperature control of up to three printing heads, and the ability to polymerize via UV curing at 365 nm.
- Can print parts for a wide range of biomedical applications, including hard and soft tissue regeneration, scaffold supports, hydrogels, and non-degradable device components.



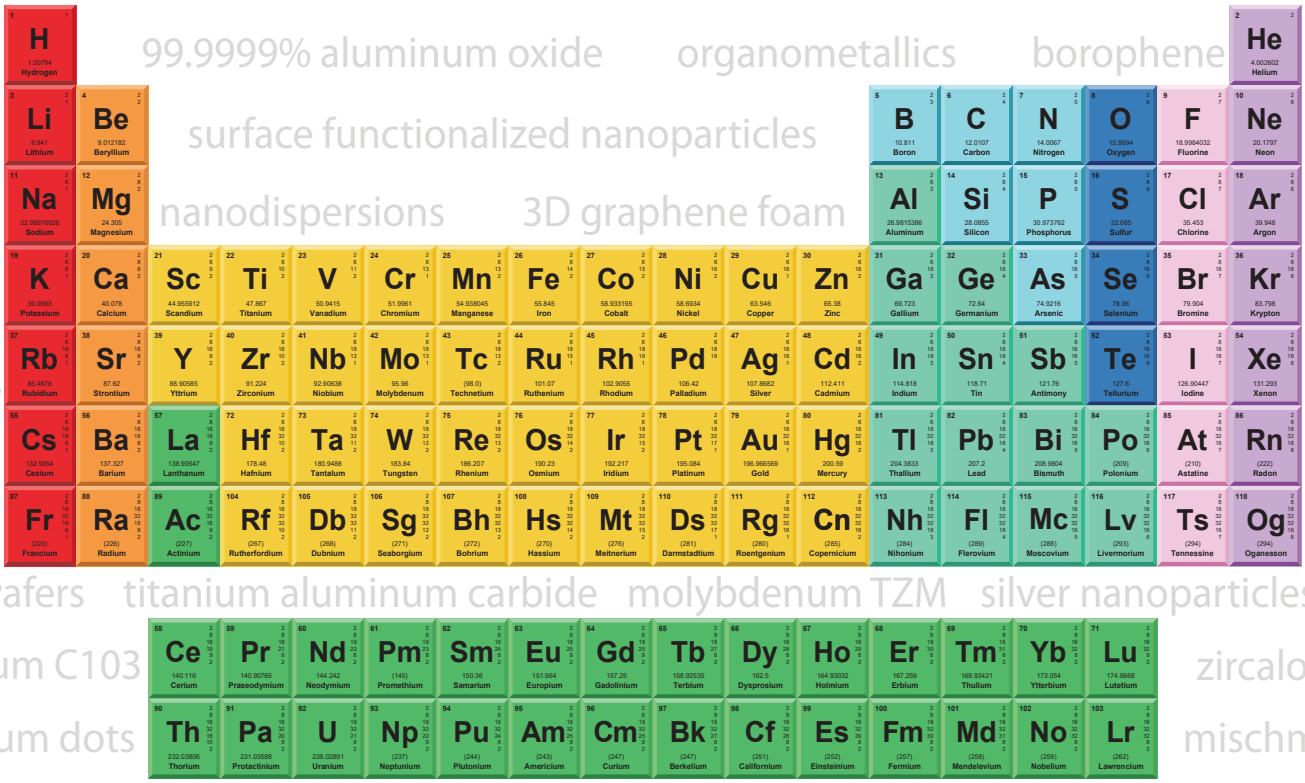
For more information:

John Simmins
Director of the Center for Advanced Ceramic Technologies
607-871-3143; simmins@alfred.edu

David Gottfried
Deputy Director, Business Development/Government Relations, CACT
607-871-2486, gottfried@alfred.edu

AMERICAN ELEMENTS

THE ADVANCED MATERIALS MANUFACTURER®



Now Invent.™

The Next Generation of Material Science Catalogs

Over 35,000 certified high purity laboratory chemicals, metals, & advanced materials and a state-of-the-art Research Center. Printable GHS-compliant Safety Data Sheets. Thousands of new products. And much more. All on a secure multi-language "Mobile Responsive" platform.

American Elements Opens a World of Possibilities..... Now Invent!

www.americanelements.com