AMERICAN CERAMIC SOCIETY

bulletin

emerging ceramics & glass technology

AUGUST 2024

The environmental impacts of deep-sea mining

Data-driven materials research | USGS Mineral Commodity Summaries 2024

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As seen on *Ceramic Tech Today*...

Credit: HarmvdB, Pixabay

Solid-state electrocaloric materials heat up cooling performance

Electrocaloric materials have potential to replace liquid refrigerant in cooling systems, thus avoiding the emission of harmful greenhouse gases. But currently, electrocaloric devices can only operate within a small temperature span. A recent study reported a new electrocaloric prototype with greatly improved temperature span and cooling power.

Read more at www.ceramics.org/electrocaloric

Also see our ACerS journals...

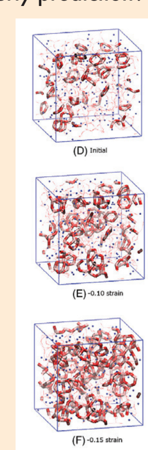
More articles on computational materials science for ceramics and glass will be published in an upcoming special issue of *JACerS*.

Can domain knowledge benefit machine learning for concrete property prediction?
By Z. Li, T. Pei, W. Ying, et al.
Journal of the American Ceramic Society

Applications of machine-learning interatomic potentials for modeling ceramics, glass, and electrolytes: A review
By S. Urata, M. Bertani, and A. Pedone
Journal of the American Ceramic Society

Discovering superhard high-entropy diboride ceramics via a hybrid data-driven and knowledge-enabled model
By J. Lu, F. Zhang, W. Y. Wang, et al.
Journal of the American Ceramic Society

Machine learning-based accelerated design of fluorphlogopite glass ceramic chemistries with targeted hardness
By P. Garg, S. Broderick, and B. Mazumder
Journal of the American Ceramic Society



Credit: S. Urata et al., *JACerS*

Read more at www.ceramics.org/journals

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

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ACSBA7, Vol. 103, No. 6, pp. 1–48. All feature articles are covered in Current Contents.

news & trends

Potential of Atlantic Ocean current collapse and its impacts on global climate

Even before Russia's invasion of Ukraine in February 2022, energy prices were making headlines across Europe. Since the war started, however, discussions on the energy ecosystem in Europe intensified.

In October 2022, the Council of the European Union agreed to an emergency regulation to address high gas prices through new measures on joint gas purchasing, price limiting mechanisms, and transparent infrastructure use. Those measures, which were in effect through March 2023, reduced gas consumption by around 15% and decreased reliance on Russian supplies of pipeline gas from 40% down to 9%.

Even as gas and electricity markets stabilized, the European Commission and European Union members continued work to reduce Europe's dependence on fossil fuels and accelerate the transition to green energy. The REPowerEU Plan, which supports projects in renewable energy, net-zero technologies, and workforce development, launched in May 2022 and received additional financing in July 2023.

Yet Europe's efforts to establish a self-sustainable energy sector may face complications from another threat that might occur sooner than previously theorized—collapse of the Atlantic meridional overturning circulation (AMOC).

The AMOC is a system of surface-level and deep currents in the Atlantic Ocean. This system helps regulate global and regional climate by carrying warm, salty surface waters up north and colder, deep waters back down south.

Changes in temperature and salinity affect the flow of AMOC currents, and multiple studies have found that the AMOC's flow has slowed considerably in recent decades. While this weakening is driven partly by natural variations in the Earth's climate system, human-caused climate change is also a significant factor. Specifically, the melting Greenland ice sheet is introducing an influx of cold, fresh water into the sea that destabilizes the well-defined temperature–density gradients essential to the AMOC's flow.

Over large timescales, the AMOC naturally switches between a strong, fast circulation and a much weaker, slower circulation. However, scientists are concerned that because of the additional temperature and salinity changes resulting from human-caused climate change, the AMOC may cease functioning altogether rather than just slowing down.

A 2019 report by the United Nations Intergovernmental Panel on Climate Change (IPCC) concluded a full collapse of the AMOC would be unlikely this century and generally downplayed disaster scenarios. But debate around the AMOC's potential collapse was reinvigorated last summer when Peter and Susanne Ditlevsen, professors in physics and statistics, respectively, at the University of Copenhagen in Denmark, published an open-access paper in July 2023 suggesting a high likelihood of AMOC collapse between 2025–2095, with a central estimate of 2057.

The Ditlevsens reached this conclusion using a new model that most experts agree is mathematically rigorous and internally consistent. However, many in the scientific community questioned the model's 95% confidence interval.

The model relies on observations of sea surface temperatures from one region in the North Atlantic to extrapolate the future of the entire ocean system. The assumption that these observations can represent the whole system "needs to be further tested," says Levke Caesar, an AMOC expert at the University of Bremen in Germany, in a *Scientific American* article.

Despite these critiques, other studies published in 2021 and 2022 confirm that the AMOC may be approaching a tipping point sooner than the IPCC's prediction. And if collapse does occur, it would have widespread global consequences, as described in the *Scientific American* article.

For example, parts of Europe could experience significant cooling by as much as 5 or 10 degrees Celsius. Meanwhile, tropical rain belts might shift their positions, causing drought in some regions but flooding in others.

Additionally, if the AMOC can no longer ferry large volumes of water around the world, the ocean may absorb less carbon dioxide from the atmosphere. Plus, parts of the deep ocean may receive less oxygen.

Knowing these potential ramifications, "I think this risk should be taken very seriously," writes Stefan Rahmstorf, an ocean expert at the Potsdam Institute for Climate Impact Research in Germany, in a *RealClimate* blog post. ■

Finnish startup scales sand battery technology to the next level

Two years ago, in August 2022, the *Bulletin* reported on the development of a novel sand-based heat storage system by Finnish startup Polar Night Energy. Now, two years later, the company has taken several steps toward widespread commercialization of this technology.

In Polar Night Energy's "sand battery" system, electricity generated from solar and wind power is passed through an array of electric resistive heating elements, heating the air around it. This hot air is circulated through a network of pipes inside an insulated sand-filled steel tank, which warms the sand up to about 500°C (932°F). The air then flows back out of the tank into a heat exchanger, where it heats water that is then circulated through building heating systems.

In July 2022, the first commercial installation of Polar Night Energy's sand battery system took place in the town of Kankaanpää, Finland. Now, in March 2024, Polar Night Energy entered into an agreement with

Corporate Partner news

Allied Mineral Products expands Alabama facility

Allied Mineral Products is investing $23.5 million to expand its production facility in Pell City, Ala., to increase production of heat containment refractory products used in industrial applications. https://alliedmineral.com/news

CoorsTek recognized as a US best managed company

CoorsTek was recognized as a U.S. best managed company as part of a global Deloitte Private program. Honorees are evaluated based on strategy, ability to execute, culture, governance, and financial performance.
https://www.coorstek.com/en/news-events/news

Du-Co Ceramics celebrates 75th anniversary

In February 2024, Du-Co Ceramics Company celebrated 75 years in business. In its more than seven-decade history, Du-Co Ceramics grew from humble beginnings in a repurposed slaughterhouse to a world leader of custom manufactured technical ceramic components and insulators.
https://du-co.com/neve-blog

GCA partners with ecording for sustainable future

GCA partnered with environmental organization ecording to develop sustainable, innovative, and technological solutions against the global climate crisis. Their cooperation will be carried out under the theme "To get nature-friendly packaging glassified."
https://gca.com/en/media/press-release

RHI Magnesita collaborates with startup MCi Carbon on carbon capture and utilization

RHI Magnesita is working with Australian startup MCi Carbon to test and scale-up MCi's carbon capture and utilization technology. RHI Magnesita plans to deploy the technology at its Hochfilzen, Austria, site in 2028.
https://www.rhimagnesita.com/category/press-release ■

Finnish district heating company Loviisan Lämpö to build an industrial-scale system in Pornainen for Loviisan Lämpö's district heating network.

The new system will be about 10 times larger than the one in operation in Kankaanpää, with a thermal energy storage capacity of 100 MWh. This capacity equates to almost one month's heat demand in summer and a one-week demand in winter.

Unlike the system in Kankaanpää, the sand battery in Pornainen will use crushed soapstone as the thermal storage medium. This material is a byproduct from the manufacture of heat-retaining fireplaces by Tulikivi, Finland's largest stone processor and the world's largest manufacturer of heat-retaining masonry heaters.

In a press release, Tulikivi CEO Heikki Vauhkonen says, "This collaboration supports Tulikivi's goals of maximizing the utilization of raw materials."

Construction and testing of the system, which will measure 13 meters high by 15 meters wide, is estimated to take around 13 months. As such, it should be ready to keep residents warm by 2025. ■

By Briana Tom
Guest columnist

Enabling next-generation energy storage: Furnace technologies to produce silicon anode materials

With the growing demands for electric vehicles, developing next-generation batteries that allow for higher power density, faster charge times, and a smaller carbon footprint is becoming more imperative.

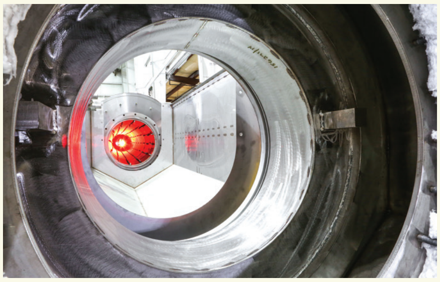
Enter silicon anode materials, which may replace traditional graphite anodes due to their higher specific capacity. Once silicon anode development reaches market readiness levels, commercial-scale plants will need to produce an estimated 20,000–40,000 metric tons per year to fulfill demand from the electric vehicle market.

Scale-up of silicon anode production faces some challenges, though. As the thermal reaction is scaled to larger sizes, the ability to heat or cool the material and the ability to introduce or remove gases from the system become more difficult, impacting both the throughput and total energy consumption of the process.

Harper International Corporation (Buffalo, N.Y.) offers several types of furnaces that can address these challenges. The sections below provide an overview of the factors to consider when selecting a furnace to match a manufacturer's unique thermal chemical processing needs.

Rotary furnaces

Rotary furnaces produce a more homogenous product while reducing processing time and increasing production rates. Systems can be designed to process to a maximum of 2,400°C in specialty atmospheres. These solutions are ideal for powders and bulk materials with good flowability and low residence times.



Scale-up considerations:

- **Temperature range**: Scaling up to production volumes is most easily done at temperatures below 1,200°C because alloy tubes can be used. Higher temperatures require use of ceramic, quartz, or graphite tubes, which have diameter limitations and so require more furnaces to achieve the same production rates.
- **Internal features**: Several types of internal features are used to ensure the powder is continuously exposed to fresh process gas. For example, lifters turn the bed over while riffle flight systems create a continuous stirred tank reactor.
- **Atmosphere flow and seal type**: Atmosphere flow and direction allow for volatiles that are evolved during a reaction to be properly exhausted. End seals help prevent oxygen ingress.

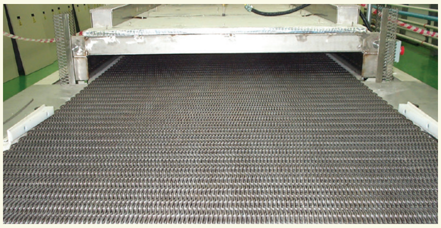
Vertical furnaces

In vertical furnaces, reactions occur more uniformly and quickly over the material's surface layer while minimizing gas-phase entrainment. These systems have fewer moving parts and offer a smaller carbon footprint compared to other furnace technologies. Plus, they can handle process temperatures up to 3,000°C for powders and pellets with good flowability.

Scale-up considerations:

- **Particle size, density, and shape**: These parameters guide selection of vertical screw, dense bed, or dilute bed vertical furnace design for optimal processing.
- **Material conductivity**: Thermal and electrical conductivity affect product temperature through the cross section and so determine if a circular or rectangular tube is a good fit. Unlike a rotary furnace, multiple tubes can be used in a single furnace box.

Horizontal conveyor furnaces



Horizontal conveyor furnaces are ideal for materials with poor flowability. They can provide a high production rate for processes that require exacting control of temperature and atmosphere, with longer residence times requiring multiple specific temperature hold points up to 2,000°C.

Scale-up considerations:

- **Bed depth and belt length**: These two values must be optimized to achieve uniform product.
- **Heating elements**: The type and location of heating elements depends on the atmosphere and temperature range. Their positioning can affect temperature uniformity of the heating chamber, maintenance access, and efficiency.
- **Process belt design**: The choice of belt design, such as mesh, strip, or chain, depends on the processing materials and atmosphere required. The design can impact the belt's longevity and the system's efficiency.

The furnace systems described above offer several ways to address the challenges that come with scaling silicon anode production and illustrate Harper's commitment to fulfilling the individual needs of its valued customers.

About the author

Briana Tom is sales engineer at Harper International Corp. (Buffalo, N.Y.). For more information, contact Jocelyn DiCarlo, sales and marketing administrator, at jdicarlo@harperintl.com.

Lithium mining: Global markets

By BCC Publishing Staff

The global lithium mining market was valued at $5.2 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 10.0% to reach $9.1 billion by 2028.

This market grew significantly in the last decade due largely to demand for lithium-ion batteries in electronic vehicles, consumer electronics, and medical devices. This demand, coupled with declining costs and improved performance, will contribute to lithium production almost doubling by the end of 2028.

Besides batteries, which account for almost 70% of the total lithium produced globally, other uses of lithium include as additives in glass, ceramics, lubricants, and grease to improve temperature resistance as well as catalysts in aluminum production.

Lithium is primarily found in large concentrations in two material types: silicate minerals, such as spodumene and petalite, and mineral-rich salt brines. Salt brines were the major source of lithium in 2021 (approximately 60%), while about 24% of lithium was extracted from silicate minerals. The remaining 16% was sourced from clay deposits and other sources.

Pricing for the different source types of lithium varies a good deal from one reserve to another because the cost of lithium extraction is highly dependent on the quality and depth of the reserves. It also varies by country due to differing tax reforms, supply–demand balances, and geological differences.

To improve operational performance, increase production, and reduce the cost of lithium, mining companies are looking to implement new and emerging extraction technologies, such as direct lithium extraction. This technique uses selective adsorbents, membranes, or solvent extraction processes to reject impurities, such as calcium and magnesium, when extracting lithium from underground brine. Compared to conventional lithium extraction technologies, direct lithium extraction reduces carbon emissions by almost 50% and consumes less water.

Table 1. Global lithium reserves, by country, 2021 and 2022 (metric tons)

* Others include Austria, Congo (Kinshasa), Czechia, Finland, Germany, Mali, and Mexico

Country	2021	2022
Chile	9,200,000	9,300,000
Australia	5,700,000	6,200,000
Argentina	2,200,000	2,700,000
China	1,500,000	2,000,000
U.S.	750,000	1,000,000
Canada	681,000	930,000
Zimbabwe	220,000	310,000
Brazil	95,000	250,000
Portugal	60,000	60,000
Others*	2,700,000	3,300,000
Total	23,106,000	26,050,000

Until the 1990s, the lithium market was dominated by the Americas in terms of production from mineral deposits. In the 21st century, however, most of the world's lithium began being produced by Australia, Chile, and China, with these three countries accounting for 91% of lithium production, according to the U.S. Geological Survey. Almost 70% of the world's lithium reserves are in these three countries (Table 1).

Two major constraints on growth of the lithium mining industry include harmful environmental impacts and the concentration of lithium in politically unstable regions (Figure 1).

With lithium production increasing, lithium-rich countries must follow a balance-out approach for lithium mining without causing environmental or community problems.

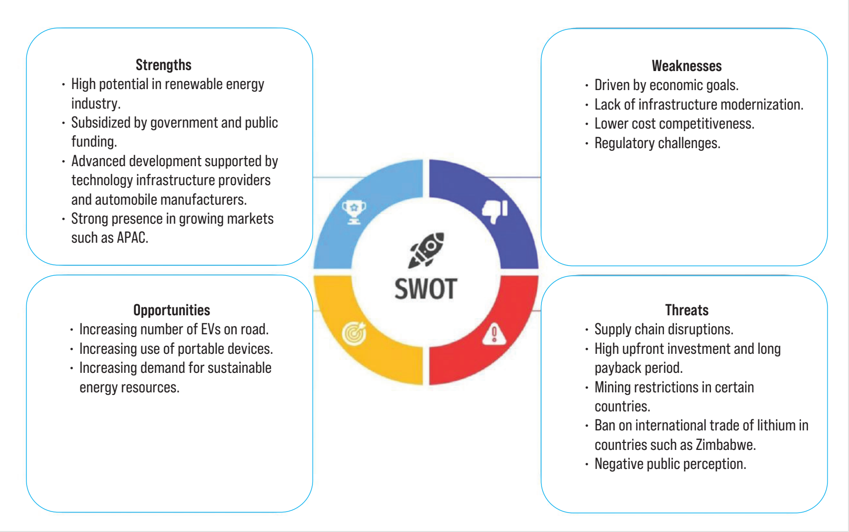


Figure 1. SWOT analysis of the lithium mining industry.

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

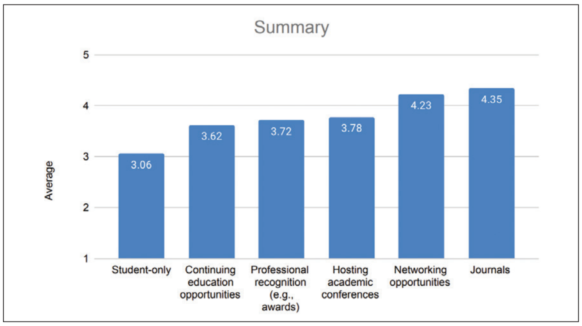
BCC Publishing Staff, "Lithium mining: Global markets," BCC Research Report EGY184B, February 2024. https://bit.ly/BCC-February-2024-lithium ■

SOCIETY DIVISION SECTION CHAPTER NEWS

FOR MORE INFORMATION:

ceramics.org

ACerS member survey: Benefits and opportunities for growth



Credit: Amanda Engen

Figure 1. Graph showing how ACerS members rank the level of importance of various ACerS offerings.

The American Ceramic Society's Strategic Planning for Emerging Opportunities (SPEO) Committee met in April 2024 to discuss the results of the ACerS Member Survey, which was distributed from January to March 2024 to Society members. Overall, 365 members participated in the survey, which is an increase from 178 participants the last time this survey was conducted in 2022.

Survey participants ranged from 21 to 70 years old, with 76.1% male, 20.9% female, and 2.2% who preferred not to report their gender identity. More than half of participants reported being in the ceramic and glass materials field for at least 10 years.

More than 45% of participants work in academia, while 30% work in industry, with the remaining participants being retired, working in government, or not presently working. Just more than 70% of participants reported that ACerS is their primary association.

In addition to basic demographics, the survey explored the importance of certain ACerS offerings to members using a Likert scale, with one representing not important and five representing extremely important. The averages for each ACerS offering, ranked from most important, include

- Access to journals and scholarly publications: 4.35
- Networking opportunities: 4.23
- Hosting academic conferences: 3.78
- Professional recognition (e.g. awards): 3.72
- Continuing education opportunities: 3.62
- Student-only opportunities: 3.06

The order of these results remained consistent across participants' career levels, which ranged from undergraduate students to retired. However, the relative importance of these offerings decreased as participants became more advanced in their careers. Only networking opportunities and access to journals and scholarly publications maintained higher averages across all career levels.

Regarding places of work, the results show that those who work in academia tend to be more interested in professional recognition and conferences, while industry participants tend to be less interested in those categories. Members who consider ACerS their primary professional society rated all offerings higher across all categories.

The survey also asked participants to describe ACerS in one phrase. Overall, the descriptive phrases were positive, with members describing ACerS as a "tight-knit community" that provides new knowledge and friendships while also "fostering ceramic scientists in global development."

Members expressed a need for education on artificial intelligence, machine learning, and other computer-based topics. There was strong interest in courses on energy materials, environmental issues, and additive manufacturing.

In summary, the results indicate that ACerS provides excellent services and resources for its members and does a great job fostering discussion of important topics within the ceramic and glass materials community. Some areas that ACerS can improve on include relating to the general public, creating more opportunities for international members to participate, and providing more networking opportunities.

Regarding next steps, SPEO chair Monica Ferraris asked each committee chair to review the survey data and determine actions and recommendations of relevance to each committee. SPEO will work to implement these recommendations in the coming year. ■

New ACerS Conference Mentor Program: Supporting professional growth at meetings

Some of the ACerS Conference Mentor Program participants posed with an Elvis impersonator during GOMD 2024 in Las Vegas, Nev.

Mentorship is a cornerstone of professional growth, fostering innovation and community within the ceramics and glass field. The American Ceramic Society understands this importance, and the Society has for several years offered mentoring opportunities through its Student, Faculty, and Industry Mentor Programs: https://ceramics.org/mentorship.

This year, ACerS expanded its mentoring opportunities with the new **ACerS Conference Mentor Program**.

Designed for conference attendees, this program pairs experienced conference attendees with newcomers to offer guidance and support, enriching the conference experience for first-time attendees. Program benefits include

- **Navigating conferences:** For newcomers, attending a conference can be overwhelming. Mentors offer practical advice on navigating conference logistics, maximizing networking opportunities, and making the most of conference sessions.
- **Building confidence:** Having a mentor by their side boosts mentees' confidence, encouraging them to actively engage with peers, present their work, and participate in discussions, ultimately enhancing their conference experience.
- **Long-lasting connections:** The mentorship bond formed during the conference may extend beyond the event, leading to lasting professional relationships, collaboration opportunities, and ongoing support within the ceramics and glass community.

The ACerS Conference Mentor Program has so far taken place at GOMD24, Cements24, and ICC'10. The conference mentor programs will continue into 2025 and are being planned for the following conferences: ICACC, EMA, Greater Missouri/Refractories Symposium, PACRIM with GOMD, and Cements.

Join us in fostering talent, promoting knowledge exchange, and shaping the future of ceramics and glass. Together, we can unlock the full potential of our community!

Learn more about the ACerS Conference Mentor Program at ceramics.org/acers-conference-mentor-program. ■

Mark your calendars: 2025 ACerS Mentor Programs registration opens this fall

ACerS Mentor Programs facilitate knowledge transfer, skill development, and career guidance by pairing seasoned professionals with emerging talents. These year-long programs are offered for students, faculty, and industry.

Registration to participate as a mentor or mentee in the 2025 ACerS Mentor Programs will open in **fall 2024**. Visit https://ceramics.org/mentorship to learn more. ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

Eastern Tennessee Section hosts virtual seminar

The ACerS Eastern Tennessee Section invited Claudia Rawn, professor in materials science and engineering and director of education, diversity, outreach, and recruitment for the Center for Advanced Materials and Manufacturing at the University of Tennessee, Knoxville, to present a virtual seminar on May 23, 2024, titled “Synthesis and characterization of $Ca_{12}Al_{14}O_{33}$ and isostructural compounds.” ■

Pittsburgh Section: Registration open for 2024 Golf Outing

Registration is open for the Pittsburgh Section 2024 Golf Outing. This year the event will take place at Birdsfoot Golf Club on Monday, Aug. 26, 2024. Register and prepay for the event by **August 12**. To register, complete the registration form at https://bit.ly/PittsburghGolf2024 and return to Bill Harasty at bill1psu@gmail.com. ■

Attend your Division business meeting at MS&T24

Six ACerS Divisions will hold executive and general business meetings at ACerS Annual Meeting at MS&T24 in Pittsburgh, Pa. General business meetings will be held Monday or Tuesday in the David L. Lawrence Convention Center. Plan to attend to get the latest updates and to share your ideas with Division officers.

Monday, Oct. 7
Electronics Division: Noon–1 p.m.
Engineering Ceramics Division: Noon–1 p.m.
Bioceramics Division: 2–2:30 p.m.
Energy Materials and Systems Division: 4:30–5:30 p.m.

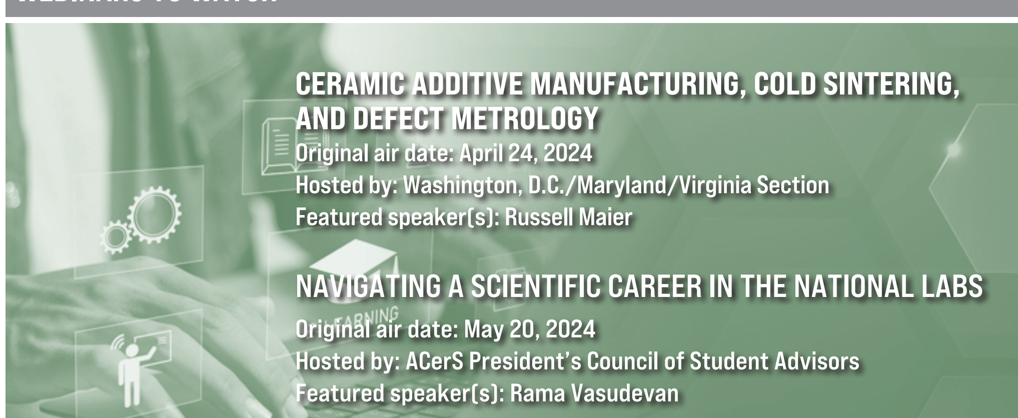
Tuesday, Oct. 8
Glass & Optical Materials Division: 11 a.m.–Noon
Basic Science Division: Noon–1 p.m. ■

Member notice: Do you qualify for Emeritus membership?

If you will be 65 years old (or older) by **Dec. 31, 2024**, and will have 35 years of continuous membership in ACerS, you are eligible for Emeritus status. Note that both criteria must be met. Emeritus members enjoy waived membership dues and reduced meeting registration rates. To verify your eligibility, contact Vicki Evans at vevans@ceramics.org. ■

WEBINARS TO WATCH

Check out these recent additions to the ACerS Webinar Archives:



CERAMIC ADDITIVE MANUFACTURING, COLD SINTERING, AND DEFECT METROLOGY
Original air date: April 24, 2024
Hosted by: Washington, D.C./Maryland/Virginia Section
Featured speaker(s): Russell Maier

NAVIGATING A SCIENTIFIC CAREER IN THE NATIONAL LABS
Original air date: May 20, 2024
Hosted by: ACerS President's Council of Student Advisors
Featured speaker(s): Rama Vasudevan

ACerS members can view these webinars and other past recordings by visiting the ACerS Webinar Archives at www.ceramics.org/webinararchives.

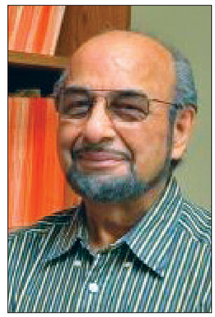
FOR MORE INFORMATION:

ceramics.org/members

MEMBER HIGHLIGHTS

Volunteer Spotlight: Amar Bhalla and Steven Tidrow

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



Amar Bhalla is Distinguished Research Professor of electrical and computer engineering at the University of Texas at San Antonio (UTSA). He has a B.S. and M.S. in physics from the University of Rajasthan in India and a Ph.D. in solid-state science from The Pennsylvania State University. Prior to joining UTSA, Bhalla worked in various roles at NASA Marshall Space Flight Center and The Pennsylvania State University.

Bhalla's current research focuses on understanding the nanostructure–property relationships of ferroic materials so they can be used in sensors for structural health and human health monitoring.

Bhalla has served ACerS in various roles, including as an active member of several committees, organizer of more than 60 symposia, and chair (1992–1993) and trustee (1998–2002) of the Electronics Division. He is a recipient of the Electronic Division's Edward C. Henry Award (1993), which recognizes "the best paper of the last 10 years," and was named an ACerS Global Ambassador Award in 2016. He is an ACerS Fellow and Distinguished Life Member, as well as an Academician of the World Academy of Ceramics.

Steven Tidrow is an Inamori Professor of materials science and engineering within the New York State College of Ceramics at Alfred University. He earned a B.S. in engineering physics and an M.S. in applied physics from Texas Tech University and a Ph.D. in engineering physics from the University of Oklahoma.

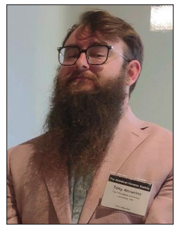
After graduation, Tidrow served as a National Research Council Associate within the Electronics Technology and Devices Laboratory, a predecessor of the U.S. Army Research Laboratory (ARL). He later joined ARL as a principal investigator in 1994 and became a team leader in 1998. During this time, he conducted and led research on energy conversion; energy storage; and radio-wave, microwave, and millimeter-wave devices. He transitioned to academia in 2005 as chair of the Department of Physics and Geology at the University of Texas–Pan American.

Tidrow is an ACerS Fellow (2017) and Global Ambassador (2019). He previously served as chair (2014) and trustee (2016–2022) of the ACerS Electronics Division. He has also organized/co-organized numerous symposia and conferences.

We extend our deep appreciation to Bhalla and Tidrow for their service to our Society! ■

more MEMBER HIGHLIGHTS

ACerStudent Engagement: Tony Annerino



Tony Annerino is a Ph.D. student in materials science and engineering at The Ohio State University and serves as a member of the ACerS President's Council of Student Advisors (PCSA). He also volunteers at outreach events with the Ceramic and Glass Industry Foundation on behalf of the PCSA.

"My experience attending ACerS functions as a graduate student has been incredibly helpful building my network of connections with other academic researchers and industrial contacts. I have greatly enjoyed participating in the education outreach opportunities that other ACerS members have introduced me to."

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

Ceramic Tech Chat: Alessandro De Zanet

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 May 2024 episode of Ceramic Tech Chat, **Alessandro De Zanet**, Materials Research Fellow at Leonardo Labs, explains how networking led to his involvement in the ceramics field, describes some of the communities he is involved with in ACerS, and highlights the reimagined annual student section of the June/July 2024 *ACerS Bulletin*.

Check out a preview from his episode on how he approaches the practice of networking.

"Networking is not something that you do to get something. But it's a very genuine experience in which you just share your experience. And then maybe some collaborations will start, but it's not the real aim. It's more about the exchange of your experience, your stories. And that's right."

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

Names in the News

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

Clive Randall, FACerS, Distinguished Professor of materials science and engineering and director of the Materials Research Institute at The Pennsylvania State University, was named an Evan Pugh University Professor. The Evan Pugh University Professorship is the highest distinction bestowed upon faculty by Penn State. ■

Material Advantage members participate in 2024 Congressional Visits Day

Group shot of student participants in Congressional Visits Day 2024.

Twenty-two students from seven universities participated in the 2024 Material Advantage Student Program's Congressional Visits Day (CVD), which was held April 9–10 in Washington, D.C.

CVD is an annual two-day event that provides students with an opportunity to visit the U.S. capital to educate congressional decision makers about the importance of funding for basic science, engineering, and technology.

The CVD experience began with an opening reception on April 9 at The Credit Union House. Students partook in hors d'oeuvres and networking, and they also had the opportunity to prepare "elevator speeches" for their meetings the following day. The event's speakers, listed below, shared insightful advice and experiences with the participants.

- **Sean Gallagher**, senior government relations officer, American Association for the Advancement of Science (AAAS)
- **Sophia Chan**, APS/AAAS Congressional Fellow
- **Marie Fiori**, MRS/Optica AAAS Congressional Fellow

The following day, Material Advantage members descended upon the U.S. Capitol offices to attend meetings with their respective congressional leaders, sharing with them the importance of continued funding being allocated to science, engineering, and technology.

Continued thanks to David Bahr, head and professor of materials engineering at Purdue University; Iver Anderson, senior metallurgist at Ames Laboratory and adjunct professor in the Department of Materials Science and Engineering at Iowa State University; and Megan Malara, director of medical modeling, materials, and manufacturing at the Center for Design and Manufacturing Excellence at The Ohio State University for conducting training and for their assistance in helping to coordinate the CVD event. ■

AWARDS AND DEADLINES

Nomination deadlines for Division awards: Aug. 4, Sept. 1, or Sept. 25, 2024

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

Division	Award	Deadline	Contacts	Description
BSD	Graduate Excellence in Materials Science (GEMS)	August 4	Amanda Krause krause@cmu.edu	Recognizes the outstanding achievements of graduate students in materials science and engineering. The award is open to all graduate students who are giving an oral presentation in any symposium or session at the 2024 Materials Science & Technology meeting.
EMSD	Student Stipend for ACerS Annual Meeting at MS&T	September 1	Charmayne Lonergan clonergan@mst.edu	Supports the attendance of students with current or future interests in the nuclear and/or environmental fields of ceramic and materials engineering at the 2024 Materials Science & Technology meeting.
BSD	Ceramographic Competition and Roland B. Snow Award	September 25	Klaus van Benthem benthem@ucdavis.edu	Presented to the Best of Show winner of the Ceramographic Exhibit & Competition, an annual poster exhibit to promote the use of microscopy and microanalysis in ceramics research.

FOR MORE INFORMATION:

ceramics.org/members/awards

CERAMICANDGLASSINDUSTRY FOUNDATION

CGIF holds outreach event at COSI's Big Science Celebration

In May 2024, the Ceramic and Glass Industry Foundation (CGIF) participated in the sixth annual COSI Big Science Celebration in downtown Columbus, Ohio.

The COSI Big Science Celebration, organized by the Center of Science and Industry, is renowned as the largest STEM event in the state. It provides a platform for science enthusiasts of all ages to engage in cutting-edge scientific demonstrations and interactive exhibits.

CGIF staff and members of the President's Council of Student Advisors (PCSA) Education Committee presented an engaging and educational exhibit at the event. The heart of their booth was the captivating Candy Fiber Pull lesson from the CGIF's Materials Science Classroom Kit, which shows the transformation of melted hard candy into thin fibers, mirroring the formation of glass fiber. This hands-on activity fascinated participants, offering a tangible demonstration of materials science in action.

Also helping in the booth were Eric Muskovin and Tim Powers (retired) of glass fiber producer Owens Corning. They explained the intricate science behind fiberglass and provided samples of fiberglass insulation. These real-world examples helped attendees, from curious children to enthusiastic adults, understand the practical applications of fiberglass in everyday life.

Overall, CGIF's involvement in the COSI Big Science Celebration reinforced the foundation's commitment to promoting STEM education and fostering meaningful community connections. This dynamic event showcased the exciting possibilities within materials science and highlighted the vital role of outreach in inspiring the next generation of ceramic and glass professionals.

Credit: CGIF intern Charlee Gutridge

PCSA students, CGIF staff, and Owens Corning volunteers at the COSI Big Science Celebration in downtown Columbus, Ohio. From left, top row: Tony Annerino, Eric Muskovin, Helen Widman, Brittney Hauke, Tim Powers, Emilee Fortier, Marcus Fish. Bottom row: Lori Houghton, Nathan McIlwaine, and Sevag Momjian.

Help expand the CGIF's presence at outreach events like this one by visiting ceramics.org/donate. ■

Ferroelectric tungsten trioxide allows for single-layer color-changing display

Researchers at The Ohio State University led by ACerS Fellow Pelagia-Irene Gouma described an advancement in simplifying one increasingly relevant optical device: electrochromic smart windows.

Smart windows improve the energy efficiency of buildings by regulating the amount of light entering the building. They work via a phenomenon called electrochromism, which is when a material displays changes in color or opacity in response to an electrical stimulus.

Tungsten trioxide (WO_3) is the most common electrochromic material used in smart windows to regulate light transmission. Specifically, its gamma (γ) phase and hexagonal crystal structures are well known to exhibit traditional electrochromic behavior.

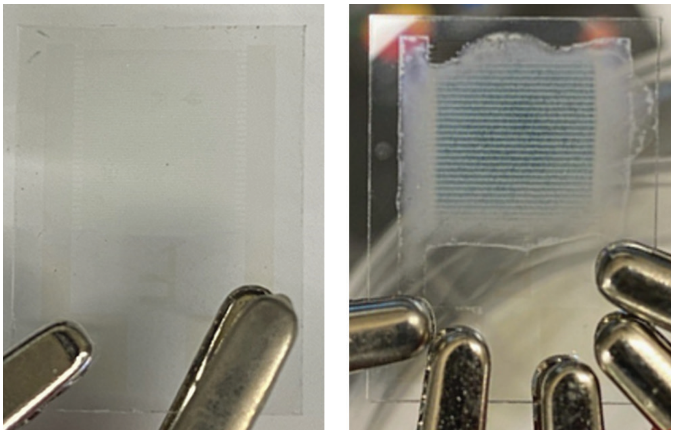
To trigger the color change in WO_3, ions must be inserted into the WO_3 structure. Smart windows typically achieve this feat via a five-layer assembly consisting of a transparent electrode, a layer of WO_3, an electrolyte, an ion storage layer, and another transparent electrode.

Researchers have attempted to develop simpler electrochromic devices with fewer layers using complex gel mixes, but these devices face challenges with lifetime, stability, and ease of manufacturing. In the new study led by Gouma, these challenges are overcome by adopting the lesser-known epsilon (ε) phase of WO_3.

ε-WO_3 is an acentric, monoclinic polymorph of WO_3 that conventionally is only stable at −45°C. Based on its structure, researchers believed ε-WO_3 may be ferroelectric, meaning it exhibits a spontaneous electric polarization. However, experimental confirmation of this hypothesis was lacking, in part because no one had successfully stabilized the polymorph at room temperature for testing.

Gouma and her team recently fabricated a nanostructured powder sample of ε-WO_3 that proved stable at room temperature. They then began testing its potential use in selective gas sensing, which is a focus of Gouma's. During this testing, the material's unique electrochromic behavior was revealed.

"We applied a voltage one day and noticed a color change that was reversible upon the switching of the voltage," Gouma explains in an email. "This [color change] was obviously an effect that had to do with dipole alignment, and we confirmed in this paper that it is a new form of chromism (ferrochromism)."



A sample of epsilon-phase tungsten trioxide before (left) and after (right) an electric current is passed through it.

Essentially, ferrochromism means ε-WO_3 can experience color-change without assistance from an ion storage layer or electrolyte. This feat is accomplished because ε-WO_3 is ferroelectric in nature, which previously was just hypothesized.

Gouma and her team developed and tested a single-layer smart window based on ε-WO_3 that successfully changed color in response to electrical stimulus, which indirectly confirmed the material's ferroelectric nature. They then experimentally confirmed the ferroelectricity through tests at the Air Force Research Laboratory, as reported in the recent paper.

While further investigations are needed to understand the performance limits of ε-WO_3, these early results show that "developing the next generation of ECDs [electrochromic devices] is possible using this ferroelectric polymorph of WO_3," they write.

The paper, published in *ACS Applied Optical Materials*, is "Chromism in ferroelectric ε-WO_3: Single-layer solid-state color-changing devices and displays" (DOI: 10.1021/acsaom.4c00021). ■

Research News

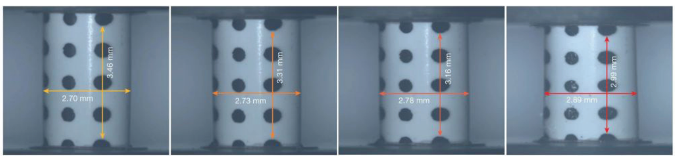
New catalyst unveils the hidden power of water for green hydrogen generation

An international, multidisciplinary team developed a new catalyst that, for the first time, achieves stability in proton-exchange-membrane water electrolysis at industrial conditions without the use of iridium. To obtain the catalyst, the team looked into cobalt tungsten oxide ($CoWO_4$). Based on this starting material, they designed a delamination process using basic water solutions whereby tungsten oxides would be removed from the lattice and exchanged by water and hydroxyl groups in a basic environment. This process could be tuned to incorporate different amounts of water and hydroxyl groups into the catalyst, which would then be incorporated onto the anode electrodes. For more information, visit https://www.icfo.eu/newsroom.

Researchers leverage shadows to model 3D scenes, including objects blocked from view

Researchers from Massachusetts Institute of Technology and Meta introduced a method that creates physically accurate 3D models of an entire scene, including areas blocked from view, using images from a single camera position. Their technique combines LiDAR (light detection and ranging) technology with machine learning and uses shadows to determine what lies in obstructed portions of the scene. In addition to improving the safety of autonomous vehicles, the method could make augmented/virtual reality headsets more efficient by enabling a user to model the geometry of a room without the need to walk around taking measurements. For more information, visit https://news.mit.edu.

Twisted-layer structure allows bulk boron nitride ceramics to plastically deform



Snapshots from a uniaxial compression test of a millimeter-long twisted-layer bulk boron nitride ceramic.

Researchers from Yanshan University in China achieved plastic deformation in a bulk boron nitride ceramic by modifying its layered van der Waals structure.

Van der Waals materials have layered crystal structures with strong in-plane covalent bonding but weak interlayer interactions. Researchers have taken advantage of this structure to create van der Waals materials with slightly misaligned layers that break the inherent symmetry of the crystal structure and often cause unique changes in the material's electrical properties.

The Yanshan University researchers hypothesized that twisted layers may affect a van der Waals material's mechanical as well as electrical properties. They synthesized a twisted-layer bulk ceramic from onion-like boron nitride nanoparticles using conventional spark plasma sintering. The ceramic consisted of 3D interlocked boron nitride nanoplates whose layers formed a laminated structure with various twisting angles.

Room-temperature uniaxial compression tests found the twisted-layer bulk ceramic exhibited a high engineering strain up to 14% before fracture, which is almost one order of magnitude greater than other typical engineering ceramics (~1%). Plus, its compressive strength reached 626 MPa, which is five to 10 times that of other commercial hexagonal boron nitride ceramics.

The researchers reproduced the twisted-layer bulk ceramics using hot pressing sintering, a synthesis route that will allow the materials to be more easily scaled up for practical applications.

The open-access paper, published in *Nature*, is "Twisted-layer boron nitride ceramic with high deformability and strength" (DOI: 10.1038/s41586-024-07036-5). ■

Toward wider 5G network coverage: Novel wirelessly powered relay transceiver

Tokyo Institute of Technology researchers designed a novel wirelessly powered relay transceiver for 28 GHz millimeter-wave 5G communication. The proposed transceiver consists of 256 rectifier arrays with 24 GHz wireless power transfer. These arrays consist of discrete integrated circuits, including gallium arsenide diodes, and baluns, which interface between balanced and unbalanced signal lines, DPDT switches, and digital integrated circuits. Notably, the transceiver is capable of simultaneous data and power transmission, converting 24 GHz WPT signal to direct current and facilitating 28 GHz bi-directional transmission and reception at the same time. For more information, visit https://www.titech.ac.jp/english/news. ■

Elastic strain 'map' guides the fine-tuning of material properties

Researchers led by Nanyang Technological University and Massachusetts Institute of Technology created a "map" showing how to tune crystalline materials to produce specific thermal and electronic properties.

The map, which combines first principles calculations and machine learning, plots the stability regions of a crystal in six-dimensional strain space and so reveals the conditions under which a material can exist in a particular phase.

Using the map, the researchers determined it should be possible to either increase or reduce the lattice thermal conductivity of diamond by more than 100% or by more than 95%, respectively, purely by reversible elastic strain.

Achieving these results in industry would require modified manufacturing processes and device designs to accommodate the increased strain. But "I think it's definitely a great start," says first author and postdoc Zhe Shi in an MIT press release.

The open-access paper, published in *Proceedings of the National Academy of Sciences*, is "Phonon stability boundary and deep elastic strain engineering of lattice thermal conductivity" (DOI: 10.1073/pnas.2313840121). ■

Fiber-optic probe offers inside look at the brain's vasculature

In a novel study published in May 2024, researchers in the U.S. and Canada reported on the development and testing of a modified optical coherence tomography (OCT) approach that can be used inside the brain.

OCT is a newer intravascular imaging technique that uses near-infrared light to create images from inside blood vessels. A large-scale clinical trial in 2023 found OCT may be safer and lead to better outcomes for patients during stent insertion than the common angiography-guided procedure, which uses a special dye and X-rays to image blood vessels.

Despite these benefits, researchers struggle to adapt OCT for use inside the brain's vasculature for several reasons. First, the fiber-optic probes used in OCT are typically quite stiff, making them too rigid to twist and bend through the brain's convoluted passageways. Additionally, the torque cables, which rotate the OCT lens to image surrounding vessels and devices, are too large to fit inside the catheters that are telescopically advanced into the brain.

The new OCT method is the brainchild of Giovanni Ughi, assistant professor of radiology at the University of Massachusetts Chan Medical School in Worcester. He and his colleagues spent the past decade adapting OCT for use in the brain, which they did by altering the properties of the fiber-optic glass and devising a new system of rotational control that does away with torque cables.

After initial testing in rabbits, dogs, pigs, and human cadavers, Ughi's team sent the device to two clinical groups at St. Michael's Hospital (Toronto, Canada) and Sagrada Familia Clinic (Buenos Aires, Argentina). Across the two groups, neurosurgeons treated 32 participants with various conditions arising from aberrant blood vessels by snaking the imaging probe through the patients' groins or wrists and into their brains. The new OCT procedure proved to be safe and well-tolerated across different anatomies, underlying disease conditions, and the complexity of prior interventions. In many cases, it provided information that led to actionable insights, such as achieving proper placement of stents that were not flush against the arterial wall.

Credit: Bango Renders, StockSnap.io

A modified optical coherence tomography technique may improve medical treatment of patients with various conditions arising from aberrant blood vessels inside the brain.

"[This study] was a huge confirmation that the technology is ready to move forward," says Ughi in an *IEEE Spectrum* article.

To advance this technology, Ughi is serving as senior director of advanced development and software engineering at startup Spryte Medical. The company is in discussions with regulatory authorities in Europe, Japan, and the United States to determine the steps necessary to bring the imaging probe to market.

The paper, published in *Science Translational Medicine*, is "Volumetric microscopy of cerebral arteries with a miniaturized optical coherence tomography imaging probe" (DOI: 10.1126/scitranslmed.adl4497). ■

Rooting for efficiency—vibrating rotary file speeds up root canal treatments

Researchers at Fraunhofer Institute for Ceramic Technologies and Systems IKTS in Germany created a rotary file that features both rotational and vibrational motion to overcome the jamming problem during root canal treatments.

Root canal treatments remove inflamed or infected pulp (soft tissue) from the inside of a tooth using small, rotating files. The rotary file must be periodically removed and cleaned because the pulp will eventually build up on the tool and jam its rotation.

To create the new file, the Fraunhofer researchers developed a piezoceramic stack actuator that integrates with a conventional nickel-titanium alloy rotary file. The actuator overlays the rotating motion of the file with axial vibration, which in theory should prevent the file from getting clogged with tissue as quickly.

A Fraunhofer press release reports that dentists at the Rostock University Medical Center successfully trialed the technology on artificial teeth. They completed the root canal procedures more quickly due to fewer required cleaning stops.

In addition to operational benefits, the piezoceramic stack actuator was constructed from lead-free materials, which "fulfills future requirements of the European RoHs [Restriction of Hazardous Substances] Directive," the press release says.

Learn more about this invention by visiting https://www.fraunhofer.de/en/press-newsroom.html. ■

Nanoparticles and pregnancy: Placental impairment disrupts blood vessel formation

Researchers at Empa, the Swiss Federal Laboratories for Materials Science and Technology, aimed to shed more light on the developmental toxicity mechanisms of titania and silica nanoparticles during pregnancy.

There is ample evidence that nanoparticles can affect the healthy growth of a fetus, but the mechanisms involved are largely unknown. Most studies focus on the direct effects of translocated particles on fetal tissues. But several groups have investigated how nanoparticles could cause indirect harm by accumulating in the placenta and interfering with essential tissue functions and the release of signaling factors.

In the new study, the Empa researchers looked more closely at how the food-relevant nanoparticles, as well as diesel exhaust nanoparticles, affect the human placental secretome, i.e., the set of steroid- and proteo-hormones, metabolic proteins, growth factors, and cytokines that the placenta secretes to adapt maternal physiology to pregnancy.

However, to obtain meaningful results on the transport and effect of nanoparticles, the use of human placental tissue was a must because "The structure, metabolism, and interaction of maternal and fetal tissue are unique and species-specific," says Tina Bürki-Thurnherr, deputy head of Empa's Laboratory for Particles–Biology Interactions, in an Empa press release.

To acquire this tissue, they sourced fully functional human placentas from planned caesarean sections at the Cantonal Hospital of St. Gallen, Switzerland.

Testing on these samples revealed that nanoparticles disrupt the production of many messenger substances, with impaired blood vessel formation being the main result. On the other hand, development of the nervous system did not appear to be affected, though future analyses are needed to identify what other disorders the nanoparticles may trigger indirectly.

"As the effects can have an impact on the health of the pregnant woman and the development of her child, these findings should be taken into account in the risk assessment of nanomaterials," Bürki-Thurnherr says.

The open-access paper, published in *Advanced Science*, is "Nanoparticles dysregulate the human placental secretome with consequences on angiogenesis and vascularization" (DOI: 10.1002/advs.202401060). ■

Space travel health hazards: Effects of high-energy radiation on synthetic bone materials

Researchers at the University of Maryland, Baltimore County (UMBC) worked with colleagues at NASA to investigate the effects of high-energy radiation on hydroxyapatite, a material used in bone regeneration treatment.

For synthetic hydroxyapatite to adhere well with natural bone, its electrical properties are an important factor. But electrical properties of materials can change upon exposure to radiation, which is prevalent in space.

They exposed silicon-substituted hydroxyapatite to gamma radiation using Cs-137 as the radiation source. Even though Cs-137 only has a radiation dose of 5 μm curie, the sample's dielectric constant and resistivity changed significantly.

A material's dielectric constant and resistivity depend on the amount of oxidation and grain boundaries in the sample. So, modifying the processing parameters during material synthesis may help counteract the changes during high-energy irradiation.

The open-access paper, published in *International Journal of Ceramic Engineering & Science*, is "Effect of high-energy radiation on electrical properties of synthetic bone materials" (DOI: 10.1002/ces2.10202). ■

Green steel: Reducing carbon emissions in the production of industrial metals

In addition to cement and concrete, steel production is another emissions-intensive industry. However, "The emissions reduction potential of conventional process routes and scrap is limited," according to the International Energy Agency website, "and so innovation this decade will be crucial to commercialize new near zero-emission steel production processes."

On May 22, 2024, three groups announced different approaches to reduce carbon emissions in this heavy industry.

Hydrogen in steel production: Effects on refractories

In a monthly newsletter, Austria-based international refractories manufacturer RATH announced the results of its study on how hydrogen firing affects the refractory materials used in steel plants.

The use of hydrogen as a replacement for fossil fuels is a hot topic in many industries, including steel and glass, because it generates little or no carbon dioxide depending on its production method. However, using hydrogen to fire a furnace changes its atmosphere and temperature characteristics. So, manufacturers may need to adopt novel refractory materials and configurations to maintain current furnace lifetimes and maintenance schedules.

In the study conducted by RATH personnel, comprehensive comparative corrosion tests were carried out on the company's portfolio of aluminosilicate and high-alumina refractory materials. Samples in the form of lightweight bricks, dense bricks, monolithic products, high-temperature wool mats, and vacuum-formed parts were all evaluated. Main findings from the study were

- High-corundum materials showed very good corrosion resistance in all products;
- Under certain conditions, mullite was a suitable material in an atmosphere containing hydrogen;
- Glass phases and SiO_2 phases were significantly reduced in high-hydrogen atmospheres;
- Foreign oxides and impurities in the refractory material significantly affected system stability;
- Porosity of refractory materials had only a minor influence on corrosion;
- Corrosion rate significantly increased in the temperature range 1,250–1,400°C; and
- Phosphate-bonded fired bricks were only slightly more resistant to corrosion than phosphate-free products.

Making steel with electricity: Commercialization of molten oxide electrolysis

In a news story, the Massachusetts Institute of Technology News Office reported on the work of university spinout Boston Metal, which is commercializing an electrochemical process called molten oxide electrolysis (MOE) to decarbonize steelmaking.

Credit: Cambridge University, YouTube

University of Cambridge researchers partnered with Materials Processing Institute to test their simultaneous steel and cement recycling process at scale in an electric arc furnace.

In general, electrolysis is a technique that uses direct electric current to drive an otherwise nonspontaneous chemical reaction. In Boston Metal's process, iron ore rock is fed into a modular cell that contains an anode and cathode immersed in a liquid electrolyte. When electricity runs between the anode and cathode and the cell reaches about 1,600°C, the iron oxide bonds in the ore are split, producing pure liquid metal that can be collected from the bottom of the cell.

The only byproduct of the MOE reaction is oxygen, and the process does not require water, hazardous chemicals, or precious-metal catalysts.

Since the company was founded in 2012, the MOE process went from being a coffee cup-sized experiment producing a few grams to an industrial-scale method producing hundreds of kilograms. Boston Metal's leadership expects the process will be scaled to produce tons of metal by 2026, but they are already using the process to recover high-value metals from mining waste at the company's Brazilian subsidiary, Boston Metal do Brasil.

Simultaneous steel and cement recycling significantly reduces emissions from both industries

In a press release, researchers at the University of Cambridge in the U.K. announced how the simultaneous recycling of steel and cement can significantly reduce carbon emissions in both of these industries.

Traditionally, lime–dolomite flux is used in steel recycling to protect the steel from air, provide the required basicity for the process, protect the lining and graphite electrodes, and increase energy efficiency.

However, the Cambridge researchers found that recovered cement paste can be substituted for the lime–dolomite flux with only slight adjustments to account for the silica content in the paste.

This substitution has two benefits:

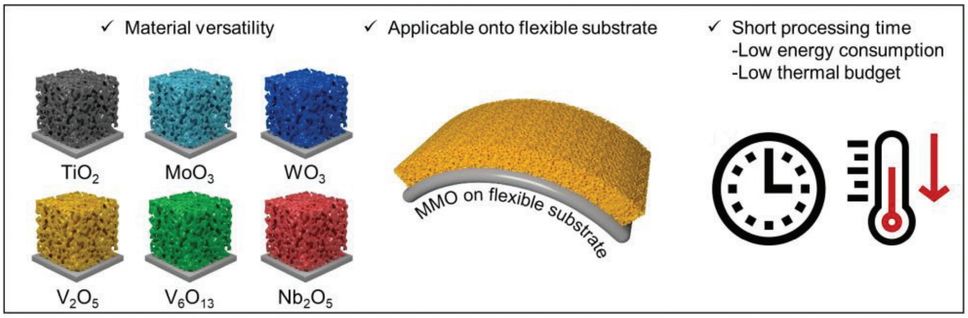
- In the traditional process, the lime–dolomite flux ends up as a waste product (slag). Using cement paste, however, results in recycled cement that can be used to make new concrete (despite its higher levels of iron oxide).
- If the process is powered by emissions-free electricity, it can lead to zero-emissions cement while also reducing the emissions of steel recycling by reducing lime–dolomite flux requirements.

In partnership with Materials Processing Institute, the Cambridge researchers showed the process can be performed at scale in an electric arc furnace. In the press release, they say the process could possibly produce one billion metric tons of cement per year by 2050, which represents roughly a quarter of current annual cement production.

The researchers have filed a patent on the Cambridge Electric Cement process to support its commercialization. ■

Low-temperature synthesis of mesoporous metal oxides unlocks flexible electronic integration

Researchers from various universities in the Republic of Korea recently developed a low-temperature process (150–200°C) to remove the block copolymer (BCP) template during mesoporous metal oxides (MMOs) synthesis.



Schematic showing the benefits of a new low-temperature synthesis process for mesoporous metal oxides developed by researchers in the Republic of Korea.

MMOs play an important role in the emerging nano industry. These materials have well-defined structures consisting of interconnected pores ranging in size between 2 and 50 nm. Because of their large surface area and pore volume, MMOs find application as supports for nanoparticles in electrocatalysis, sensing, adsorption, and energy storage devices.

The synthesis of MMOs can be achieved through various methods, including hydrothermal, electrochemical, and microwave-assisted synthesis. Of all these methods, BCP template-assisted sol-gel synthesis is considered the most effective in synthesizing MMOs due to the highly tunable chemical composition of BCPs and metal oxide precursors.

However, the high temperatures used in this method to condense the precursors and remove the BCP template can have some undesirable effects. For one, rapid crystallization can occur in certain MMO compositions at high temperatures. Additionally, the high temperatures are incompatible with most flexible substrates, preventing the integration of MMOs onto flexible electronics.

In the new method, the researchers used a BCP called PS-b-PEO as the template and vanadyl isopropoxide as the metal oxideprecursor; these materials were dissolved in a mixture of toluene and 1-butanol. After casting the solution onto a fluorine-doped tin oxide glass, evaporation-induced self-assembly occurred, resulting in a mesostructured composite consisting of core polystyrene blocks surrounded by polyethylene oxide shells containing hydrolyzed precursor. Heat and oxygen plasma were then simultaneously applied to the composite.

The researchers successfully synthesized mesoporous V_2O_5 at temperatures higher than 100°C and pressures below 100 mTorr. Complete removal of the template occurred at 200°C throughout the entire film, which was attributed to oxygen radicals diffusing into the V_2O_5 framework. Further analysis showed that the low-temperature process suppressed preferential crystal growth in the MMO, resulting in the formation of small V_2O_5 nanocrystals within an amorphous matrix.

Using different types of inorganic precursors (metal alkoxide and chloride), the researchers synthesized a wide range of MMOs with this method, including those based on titanium, niobium, tungsten, and molybdenum. MoO_3 is normally difficult to synthesize using conventional thermal methods at high temperatures because of its fast crystallization.

The researchers also successfully fabricated a flexible micro-supercapacitor by directly synthesizing a mesoporous V_2O_5 electrode onto an indium tin oxide-coated colorless polyimide film. The energy storage performance of this device was well maintained under severe bending conditions.

The paper, published in *Advanced Materials*, is "Low-temperature, universal synthetic route for mesoporous metal oxides by exploiting synergistic effect of thermal activation and plasma" (DOI: 10.1002/adma.202311809). ■

The environmental impacts of deep-sea mining

Sea cucumber *Amperima sp* on the seabed in the eastern Clarion-Clipperton Fracture Zone. The lives and habitats of animals such as this one are at risk if deep-sea mining activities proceed without sufficient and reliable scientific knowledge.

By Thomas Frölicher and Samuel Jaccard

To ensure the perennial protection of the fragile marine environment, a precautionary approach should be adopted when considering the pursuit of deep-sea mining activities.

To limit global warming to 1.5°C relative to preindustrial times and achieve net-zero emissions by 2050 as outlined in the Paris Agreement, transitioning to renewable energy sources such as solar and wind power is essential.[1] Yet, these technologies often rely on rare earth minerals. Mass production of personal technologies, such as mobile phones and laptops, further increases the demand for these finite, nonrenewable resources.

The accelerated need for minerals to support the green transition[2] has raised concerns about potential bottlenecks as the most readily available and high-grade ores on land may become exhausted and potentially increasingly vulnerable to geopolitical instabilities. This concern led to the possibility of opening up new mining frontiers to supply these minerals. One of the most contentious proposals involves exploiting mineral resources in the deep sea.

What is deep-sea mining?

Deep-sea mining relates to the process of extracting valuable mineral resources from the deep seabed. The occurrence of deep-ocean mineral deposits has been known for more than a century.[3] However, investigations dedicated to better documenting their genesis, geographical distribution, and resource potential have recently gained considerable traction.

Economic interest has traditionally focused on nickel, copper, and manganese for nodules; cobalt, nickel, and manganese for crusts; and copper, zinc, gold, and silver for seafloor massive sulfides. Research undertaken in the last decades has revealed that additional metals, including rare earth elements (REEs) such as lanthanum, cerium, praseodymium, neodymium, europium, gadolinium, and yttrium, are potential byproducts of mining the more traditional target metals. The metals enriched in these marine deposits are essential for a variety of high-tech, green-tech applications and may play a crucial role in the energy transition.

A brief description of the general characteristics of the three types of deposits—including their genesis, geographical distribution, and main metal resources—is outlined in the following sections. For details, see Reference 3.

Polymetallic (or manganese) nodules on the abyssal seafloor

Typical chemical composition: Mn (22–30%), Fe (5–9%), Ni (1.2–1.4%), Cu (0.0–1.4%), Co (0.15–0.25%), Li, Zr, Mo, Te, Pt, and REEs.

Polymetallic nodules occur throughout the global ocean, generally on, or below, the surface of sediment-covered abyssal plains (blue areas in Figure 1).[4,5] They cover about 38 million km^2 at water depths ranging between 3,500–6,500 m, notably in the

*This article consists of sections from the report "The state of knowledge on the environmental impacts of deep-sea mining" (University of Bern, 2023). Republished with permission. Access the full report at https://boris.unibe.ch/183008.

Clarion-Clipperton Fracture Zone (CCZ; a 5,000 km stretch of seafloor between Hawaii and California), Penrhyn Basin (south central Pacific), Peru Basin, and the center of the north Indian Ocean.[5] Fields have also been reported in the Argentine Basin (SW Atlantic Ocean) and the Arctic Ocean, yet these areas have only been poorly explored.

The CCZ is the area of greatest economic interest due to high concentrations of nickel and copper as well as high nodule abundance. Nodule abundance in the CCZ ranges between 0–30 kg/m^3 and the total amount of polymetallic nodules within the region is estimated to be about 21 billion tons, amounting to about 6 billion tons of manganese.

Polymetallic nodules often occur as potato-shaped concretions that vary in size from tiny particles to pellets larger than 20 cm and are abundant in abyssal plains characterized by oxygenated bottom waters and low sedimentation rates (i.e., < 10 mm/kyr). Metal-rich nodules occur in areas of moderate surface ocean biological productivity. Nodules grow optimally near or below the carbonate compensation depth (CCD), which characterizes the depth at which biogenic carbonate particles raining from the surface ocean are completely dissolved. Indeed, above that depth, located at approximately 4,000–4,500 m depth in the Pacific Ocean, biogenic calcite increases sedimentation rates and dilutes sedimentary organic matter contents necessary for diagenetic reactions that release nickel and copper. The favorable combination of water depth and surface biological productivity in the CCZ leads to its seafloor being located just at or below the CCD. Areas further to the south are characterized by higher biological production in the sunlit surface ocean, leading to higher sediment accumulation. Under these conditions, widespread nodule formation is hampered.

Altogether, polymetallic nodules grow with average rates of 10–20 mm/Myr and usually have an age of several Myr. Nodule growth is one of the slowest of all known geological processes and thus Fe–Mn nodules are not considered a renewable resource.

Cobalt-rich crusts or ferromanganese crusts on seamounts

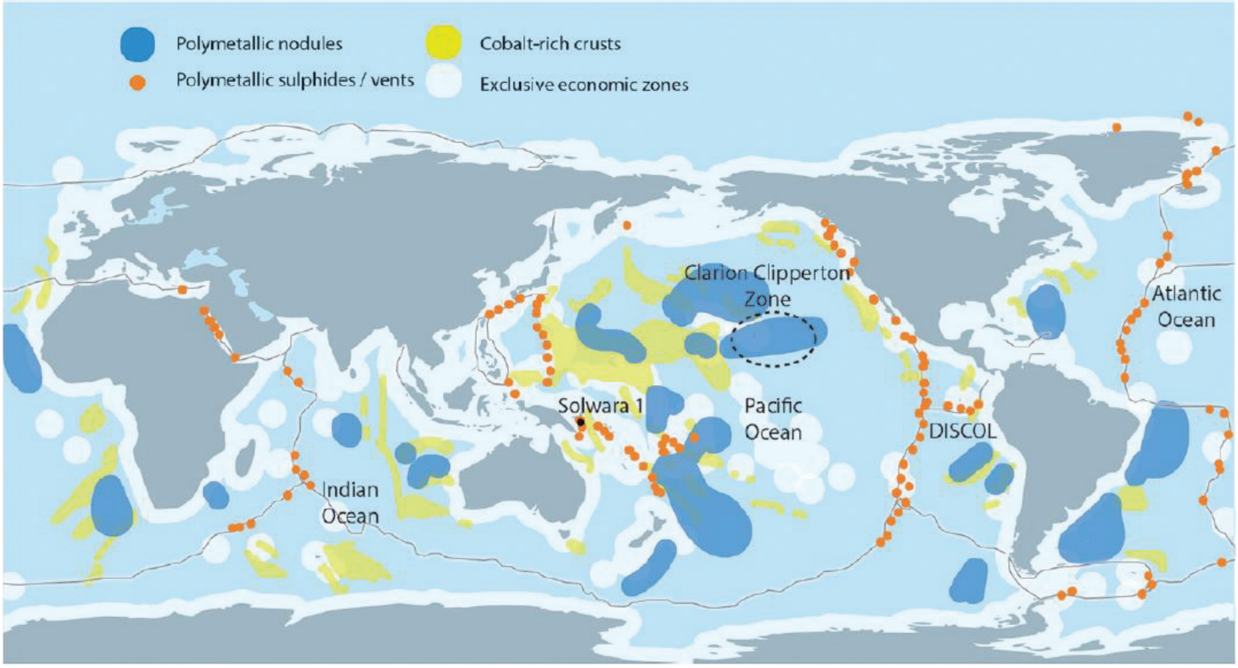
Typical chemical composition: Mn (13–27 %), Fe (6–18 %), Co (0.3–1.2 %), Ni (0.17–0.73 %), Te, Zr, Nb, Mo, W, Pt and REEs.

Cobalt-rich crusts (CRCs) are typically found at water depths ranging between 400–7,000 m, with the thickest and most metal-rich crusts occurring at depths of about 800–3,000 m.[6] Cobalt and nickel concentrations significantly decrease with increasing water depth. Cobalt-rich crust deposits are found throughout the global ocean (yellow areas in Figure 1). They occupy 1.7 million km^2 and 54% of the known crusts are in Exclusive Economic Zones.[5] The richest crust deposits are typically found in the western Pacific Ocean, where seamounts are abundant. The main settings include seamounts and submerged volcanic mountain ranges where strong abyssal currents have maintained the seafloor barren of sediments for millions of years. Fe–Mn crusts vary in thickness from less than 1–250 mm and are generally thicker on older seamounts.

In contrast to nodules, ferromanganese crusts are generally attached to a hard substrate, making them more challenging to mine. Indeed, successful crust recovery requires the Fe–Mn crusts to be detached from the substrate with minimum dilution and contamination by substrate rock material.

Seafloor massive (polymetallic) sulfides at active or inactive hydrothermal vents

Typical chemical composition: Cu (6–10%), Zn (15–22%), Co, Au, Zn, Pb, Ba, Si, and REEs.



Credit: Frölicher and Jaccard, University of Bern

Figure 1. Map outlining the location of the three main marine mineral deposits, including polymetallic nodules (blue), cobalt-rich ferromanganese crusts (yellow), and seafloor massive sulfides (orange). Modified from References 4 and 5.

Seafloor massive sulfides (SMS) represent the third and last discovered type of deep-sea mineral deposits. SMS deposits are areas of hard substratum with high base metal and sulfide content that form through hydrothermal circulation and are commonly found at hydrothermal vent sites (orange areas in Figure 1). Deep-sea vents are primarily concentrated along Earth's mid-ocean ridges and, to a lesser degree, island arc systems. Areas of potential polymetallic sulfide deposits are estimated to cover about 3.2 million km^2 globally,[7] and about 42% of the known sulfide deposits are in Exclusive Economic Zones.[5]

The composition of hydrothermal sulfide deposits varies widely depending on the geologic context and the nature of the substrate affected by hydrothermal circulation. The major minerals forming seafloor massive sulfide deposits are rich in iron, copper, and zinc as well as in gold and silver. The rare earth elements bismuth, cadmium, gallium, germanium, antimony, tellurium, thallium, and indium, which are essential for the high-tech industry, can significantly enrich some deposits.

Mining technology

All proposed seabed mining operations are based on a broadly similar concept of using a seabed collector, a vertical riser system, and support vessels involved in the processing and transporting of ore. Most proposed seabed collection systems envisage the use of remotely operated vehicles, which would extract deposits from the seabed directly using mechanical and/or pressurized water drills. The material is then transferred to a surface support vessel, where the material will undergo processing directly onboard the ship. Wastewater and sediment are returned to the ocean and the ore will eventually be transported to shore where it will be further processed.

Compared to land mining operations, there is less overburden to remove (that is, the materials that need to be eliminated to gain access to the ore of interest), and no permanent mining infrastructures are required. Indeed, marine-based mine sites do not require roads, buildings, water/power transport systems, or waste dumps that typically characterize terrestrial mines.

Further important drivers of deep-sea mining include the fact that many of the mineral deposits present at a single marine mining site contain multiple metals of interest. Thus, compared to terrestrial mining, less ore may be required to provide a given amount of metal.

In addition, acid mine drainage and stream/soil contamination will be avoided by deep-sea mining as will many other issues typically faced by terrestrial mining, such as displacement and exploitation of local populations, deforestation, and large-scale depletion of (ground) water resources.

Environmental impacts of deep-sea mining

The seabed covers 70% of Earth's surface and is home to some of the most pristine and diverse ecosystems on our planet. The ocean floor, at an average depth of 4,000 m, is characterized by high pressure, temperatures close to freezing, and no sunlight available to sustain photosynthetic productivity.

For humans, this environment is inhabitable, barely accessible, and extreme. Yet the relatively stable environmental conditions have allowed a vast diversity of taxa that are not found in shallower waters to thrive. The deep-sea ecosystems provide a broad range of critical ecosystem services, such as fish and shellfish for food, products that can be used for pharmaceuticals, climate regulation, and cultural/social value for humankind.[9]

However, these ecosystems remain poorly understood.[8] It is anticipated that mining activities on the seafloor will generate harmful, potentially irreparable environmental impacts.[5,9–14] These impacts can be divided into five categories (Table 1):[15] (1) direct removal of the resources and destruction of seafloor habitat and organisms, (2) generation of sediment plumes, (3) chemical release, (4) increase in noise, temperature, and light emissions, and (5) cumulative impacts including possible conflicts.

The recovery of deep-sea ecosystems from mining disturbances is expected to be slow, as revealed by a small-scale in-situ experiment called the "DISturbance and reCOLonization" (DISCOL) experiment.[16,17] DISCOL, which aimed to investigate the decadal-scale environmental impacts generated by deep-sea mining, began in 1989 in the Peru Basin nodule field. After 26 years, the impacts of mining are still evident in the mega benthos of the Peru Basin, with significantly reduced suspension-feeder occurrence and diversity in disturbed areas, and markedly distinct faunal assemblages. Local microbial activity was also reduced up to fourfold in the affected areas, and microbial cell numbers were reduced by about 30–50%.[17] However, it is yet unclear whether the results of the DISCOL experiment can be extrapolated.

Nevertheless, deep-sea mining disturbances are expected to be virtually irreversible because the targeted polymetallic deposits were formed over millennia and associated ecosystem dynamics may have evolved over similar timescales.[7] Moreover, deep-sea mining will compound with further anthropogenic stressors including climate change, bottom trawling, and pollution, further reducing the likelihood of recovery.

As mined deep-sea habitats are unlikely to recover naturally, habitat restoration may provide an alternative. However, the costs of habitat restoration could be exorbitant and possibly still be inadequate to prevent large-scale species extinctions. Additionally, the recolonization of abyssal communities is very slow, making it difficult to monitor the effectiveness of restoration approaches.

Understanding the long-term impact of mining on deep-sea biological communities is challenging due to the lack of continuous long-term baseline timeseries.[18] Data collection in the deep sea is often lacunar, making it impossible to know what happened between sampling campaigns. To address this lack of data, there is a need for intensified, high-resolution observation systems of deep-sea ecosystems and appropriately resolved timeseries.

Key knowledge gaps

The scientific knowledge gaps that need to be closed to inform decision-making related to seabed mining can be subdivided into two main categories: (1) a paucity of environmental baseline data and insufficient detail of the min-

Pressure	Potential impact	Affected ecosystem services	Habitat
Extraction of sea floor substrate	–Loss of benthic fauna by direct removal –Changes in sediment composition –Habitat loss or degradation –Stress induced on fauna	**Supporting** –Nutrient cycling –Circulation –Chemosynthetic production –Secondary production –Biodiversity	–Benthopelagic –Benthic
Extraction plume	–Loss of or damage to benthic species by smothering of organisms (from macrofauna to microorganisms) –Behavioral changes in animals –Changes in sediment composition –Changes in seabed morphology	**Regulating** –Carbon sequestration –Biological regulation –Nutrient regeneration –Biological habitat formation –Bioremediation and detoxification	–Benthopelagic –Benthic
Dewatering plume	–Clogging of feeding, sensorial, or breathing structure –Mechanical damage to tissues –Stress	**Provisioning** –CO_2 storage –Fisheries –Natural products	–Pelagic –Benthopelagic –Benthic
Release of substances from sediments (extraction and dewatering plume)	–Toxicity –Nutrient release –Turbidity		–Pelagic –Benthopelagic –Benthic
Underwater noise	–Disturbance of animals		–Pelagic –Benthopelagic –Benthic
Underwater light	–Disturbance of animals		–Pelagic –Benthopelagic –Benthic

Credit: Frölicher and Jaccard, University of Bern

Table 1. Seabed mining pressures, potential impacts on different habitats and ecosystem services that might be affected. Modified from Chapter 18 of the World Ocean Assessment Report II.[15]

ing operation; and (2) a general lack of comprehensive knowledge related to the cumulative (in)direct environmental impacts caused by deep-sea mining and insufficient risk assessment.

Evaluating the effects likely to arise from mining operations by means of environmental impact assessments (EIAs) is essential in ensuring that environmental considerations are considered in decision-making. The purpose of EIAs is to consider the environmental impact prior to deciding on whether to proceed with a proposed development.

Even though EIAs are a widely used and accepted approach, the processes underpinning EIAs for deep-sea mining are not yet fully developed. Therefore, there is considerable debate pertaining to the effectiveness of EAIs in the context of deep-sea mining.[19]

Further information on baseline data from potential mining sites, and improved understanding of deep-sea ecosystem structures and functions, as well as the recovery of deep-sea biomes following environmental degradation is essential for developing robust EIAs. Closing these scientific gaps related to deep-sea mining is critical to fulfilling the overarching obligation to prevent serious harm and ensure effective protection.

Given that deep-sea scientific research is challenging as well as time and resource-intensive, closing these gaps is likely to require substantial time and a capacity-intensive, coordinated scientific effort.

Recommendation

The importance of the deep sea as a habitat cannot be overstated, as it supports a substantial portion of Earth's biodiversity, much of which remains to be unraveled. The deep sea plays a critical role in Earth's climate regulation, fisheries production, and is an integral part of the common heritage of mankind. Yet, deep-sea ecosystems are under increasing stress from climate change, bottom trawling, and pollution. Deep-sea mining activities will only exacerbate these anthropogenic stressors, leading to potentially irreversible environmental consequences, including loss of biodiversity and ecosystem functioning/connectivity and habitat degradation. Furthermore, deep-sea mining activities may engender potentially deleterious consequences on carbon sequestration dynamics and deep-sea carbon sequestration.

Insufficient scientific knowledge pertaining to deep-sea ecosystems as well as the services they provide combined with a paucity of standardized, effective environmental impact assessments make it difficult to fully appreciate the risks deep-sea mining poses to biodiversity and human well-being. Nevertheless, the anticipated long-lasting environmental impacts of deep-sea mining are incompatible with (inter)national policy agendas, which aim to minimize biodiversity loss.

Given the critical importance of the ocean to our planet and its inhabitants and the potential for irreversible loss of biodiversity and ecosystem functions, a precautionary approach must be adopted to minimize the deleterious environmental consequences of deep-sea mining. Despite an increase in deep-sea research, the publicly available scientific knowledge is insufficient to enable evidence-based decision-making to effectively manage deep-sea mining activities. The absence of a robust regulatory framework and yet undefined enforcement procedures is a serious concern and calls for a precautionary approach.[8]

In the current context, we recommend that commercial deep-sea mining exploitation of mineral resources be precautionarily paused until sufficient and reliable scientific knowledge is obtained to ascertain that the environmental impacts of mining activities on marine and benthic ecosystems are minimized and strict, enforceable regulations are put into place.

Acknowledgments

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US takes next steps in domestic mining expansion with feasibility surveys and projects

By Helen Widman

The U.S. government has progressed to the next stage of its plans to strengthen domestic supply chains, as described in the annual United States Geological Survey *Mineral Commodity Summaries*.[1]

The USGS *Mineral Commodity Summaries* report spotlights events, trends, and issues from the past year in the nonfuel mineral industry. Every August, the *ACerS Bulletin* shares some of the key facts covered in the report, including statistics on production, supply, and overall market for more than 90 minerals and raw materials.

In 2023, the total value of nonfuel mineral production in the United States was estimated to be $105 billion, an increase of 4% from $101 billion in 2022. The total value of industrial minerals production was $69.9 billion, an increase of 7% from 2022. Of this total, $35.2 billion came from construction aggregates production. Crushed stone accounted for the largest share of total U.S. nonfuel mineral production value in 2023 with 23%.

Operational issues, reduced ore grades, and weather-related issues caused a decrease in production for the metals sector. On the flip side, increased demand for aggregates caused an increase in production value for the industrial minerals sector.

Following two years of focused efforts to update the U.S. Geological Survey's critical minerals list and establish funding avenues to support an expansion of the domestic mining sector, the U.S. government has now started investing in numerous mineral exploration and feasibility surveys and nascent mining projects.

For example, in February 2023, the USGS Earth Mapping Resources Initiative launched the "National Map of Focus Areas for Potential Critical Mineral Resources in the United States," which outlines focus areas of mineral systems and their deposits around the country. Throughout 2023, the U.S. government invested $22.3 million across Alabama, Alaska, Arizona, Montana, New Mexico, New York, and Utah to map resources of critical minerals in those states.

Meanwhile, regarding mining projects, in July 2023, the U.S. Department of Energy announced $32 million in funding to support the construction of facilities that produce rare earth minerals and other critical metals to help alleviate reliance on international sources.[2]

Notably, in November 2023, production was restarted at a high-purity granular polysilicon facility in Washington state, which had not been active in four years. The material produced here will then go to a facility in Georgia that produces silicon ingots, wafers, and cells for solar module production. Solar-grade wafers have not been produced in the U.S. since 2016, so this effort should also help alleviate reliance on foreign sources.

It will take several years to reap the benefits from the projects described above, so for now, the U.S. remains reliant on foreign sources for raw and processed mineral materials. In 2023, the U.S. was 100% net import reliant for 12 of the 50 individually listed critical materials and was more than 50% net import reliant for an additional 29 mineral commodities.

As in 2022, recycling provided the only source of domestic supply for antimony, bismuth, chromium, germanium, tin, tungsten, and vanadium. In 2023, the consumption of many mineral commodities decreased compared to the previous year.

With these programs and initiatives in place to help bolster domestic production, the U.S. government is now taking a more direct stance in its trade war against China. In May 2024, the U.S. announced new Section 301 import tariffs, including one on rare earth magnets.[3] This tariff is the first time that a Section 301 import tariff has been imposed on rare earth materials since the U.S.–China trade and technology war began in 2018.

These tariffs may be a boon for Wyoming, which hosts a plentiful supply of rare earth minerals. Several rare earth minerals companies are already operating in the state, and these tariffs provide them the opportunity to penetrate the rare earths market and regain equal footing with suppliers in China.[4]

On the next two pages, a table summarizes some of the salient statistics and trends for a handful of mineral commodities that are of particular interest in the ceramic and glass industries.

Access the complete USGS report at https://doi.org/10.3133/mcs2024.

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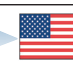
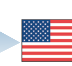
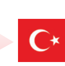
USGS MINERAL COMMODITY SUMMARIES

Leading producer highlights

	END-USE INDUSTRIES	TREND GLOBAL PRODUCTION	US PRODUCTION	US IMPORT/ EXPORT	WORLD RESERVES	LEADING PRODUCER
ABRASIVES (fused aluminum oxide and silicon carbide)	Bonded and coated abrasive products	0.76% decrease for fused aluminum oxide; no change for silicon carbide	20,000 metric tons fused aluminum oxide; 40,000 metric tons silicon carbide	>95% net import reliance for fused aluminum oxide; 73% net import reliance for silicon carbide	Fused aluminum oxide: adequate; Silicon carbide: more than adequate	Fused aluminum oxide Silicon carbide
BAUXITE AND ALUMINA	Bauxite: refined for alumina or aluminum hydroxide, abrasives, cement, chemicals, proppants, refractories, slag adjuster in steel mills Alumina: used in production of aluminum, abrasives, ceramics, chemicals, refractories	No change for bauxite or alumina	Bauxite production information withheld 780,000 metric tons alumina	>75% net import reliance for bauxite; 59% net import reliance for alumina	Between 55 billion and 75 billion metric tons bauxite	Bauxite Alumina
CEMENT	Construction	No change for cement production or clinker capacity	91,000 metric tons cement; 77,000 metric tons clinker	22% net import reliance	Reserves of lime and stone (crushed) are very large and plentiful, respectively	
CLAYS	Tile, sanitaryware, absorbents, fillers and extenders, drilling mud, construction, paper, refractories	2.0% decrease for bentonite; 4.8% increase for Fuller's earth; 1.7% decrease for kaolin	26,000 metric tons (50.0% common clay, 17.0% kaolin, 18.1% bentonite, 8.9% Fuller's earth, 6.4% other)	Net exporter	Extremely large	Bentonite Fuller's earth Kaolin
FELDSPAR	Glass, tile, pottery	1.5% increase	590,000 metric tons (marketable production)	12% net import reliance	More than adequate	

	END-USE INDUSTRIES	TREND GLOBAL PRODUCTION	US PRODUCTION	US IMPORT/ EXPORT	WORLD RESERVES	LEADING PRODUCER
GALLIUM	Integrated circuits, optoelectronic devices	No change	None (primary)	100% net import reliance	Gallium contained in world resources of bauxite is estimated to exceed 1 million tons, and a considerable quantity could be contained in world zinc resources. However, less than 10% of the gallium in bauxite and zinc resources is potentially recoverable.	
GRAPHITE (natural)	Batteries, brake linings, lubricants, powdered metals, refractory applications, steelmaking	4.9% decrease	None	100% net import reliance	>800 million metric tons	
INDIUM	Flat panel displays, alloys, solders, compounds, electrical components, semiconductors	0.9% decrease	None	100% net import reliance	Estimate unavailable	
IRON and STEEL	Construction, automotive, machinery and equipment, appliances	No change for pig iron; 1.1% increase for raw steel	21 million metric tons pig iron; 80 million metric tons raw steel	13% net import reliance	N/A	Iron and steel 
KYANITE	Refractories, abrasives, ceramic products, foundry products	Cannot be calculated	85,000 metric tons	Net exporter	Significant	Kyanite  Andalusite 
LITHIUM	Batteries, ceramics and glass, lubricating greases, air treatment, mold flux powders, medical uses	21% increase	Withheld	>25% net import reliance	Identified lithium resources total ~105 million metric tons worldwide	
MICA (scrap and flake)	Joint compound, oil- well-drilling additives, paint, roofing, rubber products	3.7% increase for scrap and flake	38,000 metric tons sold and used; 65,000 metric tons ground	28% net import reliance	More than adequate	
RARE EARTHS	Catalysts, ceramics, glass, metallurgical applications, alloys, polishing	15.4% increase	43,000 metric tons mineral concentrates	>95% net import reliance for compounds and metals; net exporter of mineral concentrates	Relatively abundant in earth's crust, but minable concentrations less common	
SODA ASH	Glass, chemicals, distributors, flue gas desulfurization, soap and detergents, pulp and paper, water treatments	No change	11,000 metric tons	Net exporter	About 47 billion metric tons of identified natural soda ash resources; synthetic soda ash is practically inexhaustible but costlier to produce	 
TITANIUM DIOXIDE (pigment)	Paints, plastic, paper, catalysts, ceramics, coated textiles, floor coverings, inks, roofing granules	N/A	920,000 metric tons	Net exporter	Data not available	
YTTRIUM	Catalysts, ceramics, electronics, lasers, metallurgy, phosphors	Between 10,000 and 15,000 metric tons	N/A	100% net import reliance	Reserves may be adequate, but worldwide issues could affect production	 
ZEOLITES (natural)	Animal feed, odor control, water purification, wastewater treatment, absorbent, fertilizer, aquaculture, pesticide	20% increase	84,000 metric tons	Net exporter	Estimate not available, but likely large	

Leveraging artificial intelligence for advanced glass science and discovery

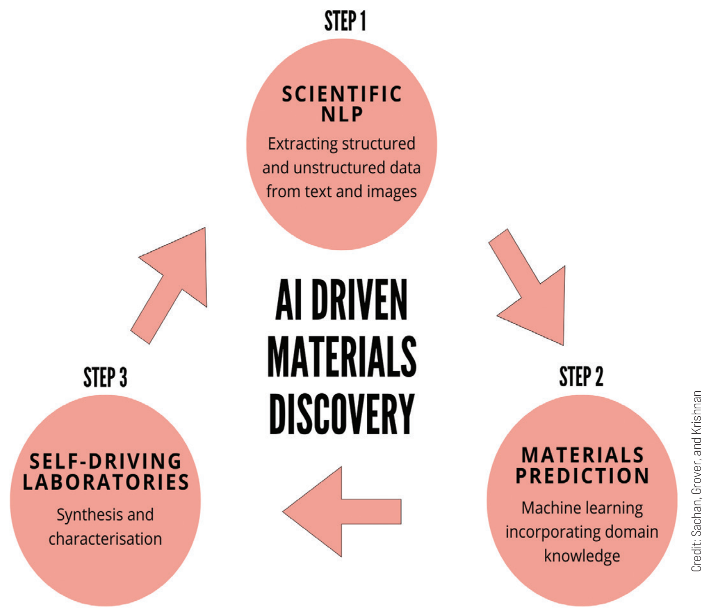


Figure 1. Three-step cyclic process of AI-based materials discovery.

By Anurag Sachan, Hargun Singh Grover, and N. M. Anoop Krishnan

In modern times, the demand for materials with highly engineered functionalities has spurred the need for rapid innovation. This demand is accentuated by advancements in the fields of digital manufacturing, 3D printing, and internet of things platforms, where technological disruption is happening at a rapid pace.

Traditional trial-and-error methods of materials discovery struggle to meet this demand. So, researchers are adopting artificial intelligence (AI) and machine learning (ML) techniques to speed up the development process.[1,2]

AI and ML systems leverage vast datasets and advanced algorithms to identify novel compositions and structures in a much shorter timeframe and with greater accuracy than traditional methods. In addition, these technologies can quickly analyze vast amounts of data on structure–property relationships, which enables the development of engineered materials with properties optimized for various applications.

Glass, a disordered material obtained by the fast quenching of liquids, presents an ideal candidate for data-driven modeling due to several key factors.[3] First, their formation is highly versatile, as almost all elements or combinations thereof can create a glass when cooled at the required rate. Second, unlike crystalline materials, glass properties are dictated primarily by composition and processing conditions owing to their disordered structure. This feature allows for continuous tuning of the compositions, facilitating tailored design. Finally, there exists extensive experimental data on glass properties, which is ideal for modeling.

Consequently, the glass community has increasingly embraced AI and ML approaches to address various challenges in glass development, including property prediction, tailored design, understanding underlying physics, and expediting modeling processes. This paper highlights one such system, Python for Glass Genomics (PyGGi),[4] and describes how it aims to help predict and optimize the composition–property relationships in glasses.

AI and ML for materials discovery

In the realm of materials science, understanding and predicting the complex relationships between composition, structure, and properties is pivotal for developing innovative materials. AI and ML systems accomplish this understanding through a three-step cyclic process (Figure 1).

The first step involves curating the information that has been created thus far by researchers and published in the scientific literature. Natural language processing algorithms can play a major role in this regard by extracting data from scholarly journals and books and organizing the information within large-scale databases.[5,6] This process allows for data extraction and dissemination at an unprecedented scale and pace compared to manual data curation.

The second step involves exploiting this information to predict new materials. Specifically, understanding the intricate patterns in the data and decode these patterns to discover tailored materials. Here, again, ML models combined with optimization can play a crucial role in accelerated materials discovery.[7,8]

The final step involves the actualization of the material, i.e., fabricating the computer-designed material in a laboratory. This step often involves high-throughput experiments, which can be automated using robotics, planning, and AI.[9] Such approaches are now possible, more than ever, due to the advent of large language models.[10]

While work remains to support the adoption of these methods in industry, the scientific studies referenced above and others provide strong evidence to conclude that AI and ML systems hold huge promise to disrupt and accelerate materials modeling, design, discovery, and manufacturing.

Obtaining data for computer-driven discovery

In the domain of glass science, engineering, and technology, two significant challenges obstruct the adoption of AI and ML systems: (1) the need for high-fidelity experimental datasets and (2) the automation of data extraction from literature.

The first challenge hinges on the requirement for consistent and reliable datasets, encompassing properties such as density, elastic moduli, hardness, glass transition temperature, and liquidus temperature, among others. Current databases, such as Interglad[11] and SciGlass,[12] suffer from inconsistencies and outliers, while proprietary data from companies such as Corning Inc. (Corning, N.Y.) remain inaccessible to the broader research community.

Addressing this challenge calls for an international collaborative effort to establish a universally accepted experimental glass property database allowing for the development of high-quality data-driven models. Initiatives such as PyGGi, described in the next section, offer platforms for sharing data that align with the FAIR data principle (findability, accessibility, interoperability, and reusability) and thus foster collaboration within the glass community.

The second challenge revolves around automating the extraction of data from literature, a task currently reliant on manual curation, which is inefficient for the vast amount of potentially relevant information available. Recent advancements in AI present opportunities to streamline this process, as seen in other fields such as materials science with the ChemDataExtractor toolkit.[13] However, the complex representations of glass compositions pose a unique challenge, necessitating the development of a glass-specific information extraction system to accurately parse and extract data from literature.

While natural language processing algorithms have shown promise in other domains,[5] a tailored approach for glass science literature currently is lacking, representing a crucial hurdle to overcome for the automated extraction of datasets from the literature. Addressing this challenge would significantly enhance the accessibility and utilization of valuable information within the glass research community, ultimately accelerating progress in glass science, engineering, and technology.

There have been recent efforts to combine and exploit existing databases such as SciGlass and Interglad to develop AI algorithms that can extract information from the literature. DiSCoMaT, which uses Interglad data along with data from other papers to create tables of compositions in an automated fashion, is one such model.[6] However, evaluating the performance of these models at scale for creating large databases is still an open problem.

Further, there have been several works that employ ML to predict properties of glasses.[14] However, most of these models are limited to a small range of compositions or properties. In addition, these models are either closed source and not accessible to a larger crowd or require high-level knowledge of computation and programming to use.

Thus, a SciGlass- or Interglad-like package that people can use on their own desktop for applications ranging from undergraduate education to development of commercial glass composition is a need of the hour. One such package that is developed with the aim to democratize glass discovery and make knowledge accessible to a wide range of audiences is Python for Glass Genomics (PyGGi).

Python for Glass Genomics

PyGGi is a pioneering software package developed by Substantial Artificial Intelligence (New Delhi, India), a startup aimed at accelerating and democratizing materials discovery. The software, which leverages machine learning algorithms to predict and optimize the composition–property relationships in glasses, comprises three main packages:

- **PyGGi Bank** facilitates exploration of a vast composition–property database, aiding users in retrieving glass compositions based on selected compounds and properties.
- **PyGGi Seer** employs data-driven techniques to predict up to 25 different properties for various glass compositions, crucial for material development.
- **PyGGi Zen** focuses on composition optimization, assisting users in discovering new glass compositions meeting specific property requirements.

The data-driven models developed for PyGGi are trained on extensive datasets of more than 300,000 glass compositions, encompassing more than 180 compounds and 25 different properties. By doing so, PyGGi can handle the nonlinear behavior exhibited by glasses as a function of their composition, making it a robust tool for material innovation.

Properties in the PyGGi database include optical, mechanical, electrical, and physical characteristics, among others. Compositions include oxides (e.g., SiO_2, B_2O_3, Al_2O_3), halides (e.g., LiF, NaF, MgF_2), and other compounds.

PyGGi is meant to be useful in both academic and industrial settings. From a teaching perspective, PyGGi is an excellent tool to explore different glass compositions and their properties. The glass selection chart allows a student to choose glass compositions with targeted properties. Further, the ternary diagram gives insights into the nonlinear and complex behavior of glasses. This feature is equally useful for an industry professional working on glasses for a variety of applications to either finetune their glass compositions or to discover new glass compositions with targeted properties, as demonstrated in the next section.

Case study

To demonstrate the capabilities of PyGGi, the authors used it to develop an alumina-based phosphate glass with high refractive index and Abbe number for low dispersion applications.

Reason for study

Due to its excellent optical properties, glass has been used extensively as a component in communication technologies, including as touch screens for smartphones and other displays, core and cladding materials for fiber optic cables, and substrates for liquid crystal displays. There are several factors to consider when designing glasses for these purposes.

Glass can have high dispersion, resulting in colors corresponding to different wavelengths with different focal points.

Smartphone screens and other display glasses are manufactured using traditional melt cooling processes followed by expensive finishing operations, such as grinding and polishing. Therefore, a high temperature is required to form the glass, requiring additional post-treatment at a lower temperature to make it usable.

To address these challenges, glasses with excellent optical properties and a low glass transition temperature are desirable. To this extent, phosphate glasses are an attractive candidate due to their unique structure and optical and thermodynamic properties.

Step-by-step process

Step 1: Search the PyGGi Bank glass database to find similar glasses available in literature. PyGGi Bank can be searched iteratively to look at the Abbe number and refractive index of different kinds of phosphate glasses.

Step 2: Based on the required characteristics of the glass and the glass compositions searched in the first step, the next step is to choose the components. The following components were chosen: B_2O_3, Al_2O_3, MgO, CaO, BaO, Li_2O, ZnO, La_2O_3, Gd_2O_3 and P_2O_5.

Step 3: Run an optimization in PyGGi Zen with the following parameters (Figure 2):

1. Methodology: Genetic algorithm
2. Target property: Abbe number (maximized)
3. Components: Use the ones selected in Step 2
4. Constraints on components: $60\% \le P_2O_5 \le 100\%$
5. Constraints on other properties: Refractive index ≥ 1.55

Step 4: Analyze the results obtained in Step 3. To optimize the results, run the algorithm iteratively in PyGGi Zen while adding constraints to the various glass components. Table 1 shows compositions obtained after running the optimization.

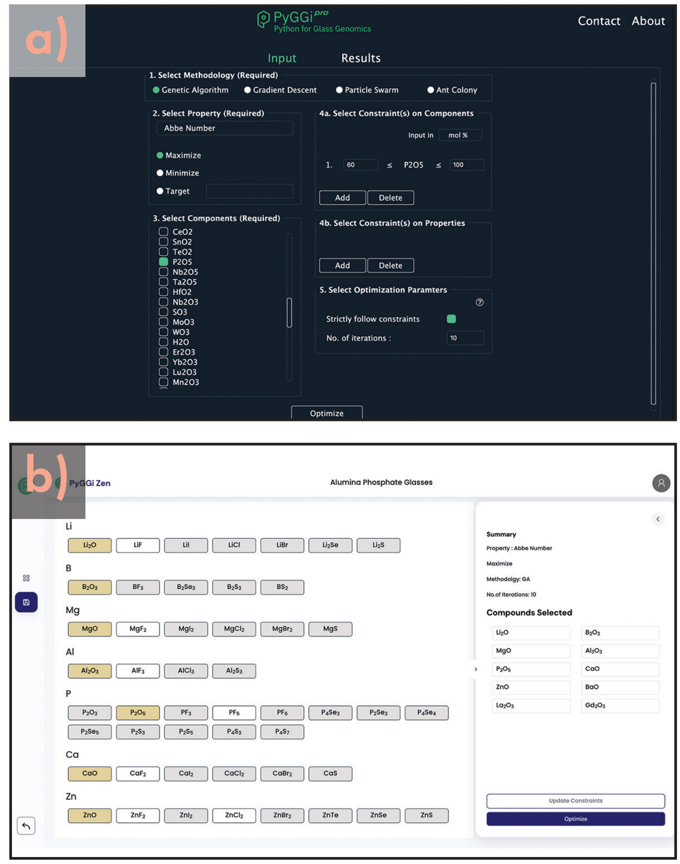
Step 5: After satisfactory results are obtained, optimized glass compositions from Step 4 are downloaded. These compositions are then input to PyGGi Zen and other properties of interest such as hardness, refractive index, glass transition temperature, and liquidus temperature are predicted (Table 2).

Step 6: The results obtained in Steps 4 and 5 can be graphically analyzed using the tools available in PyGGi Zen and PyGGi Seer.

Outlook

It goes without saying that AI and ML systems are revolutionizing different phases of human life. While the impact in areas such as computer science, computational modeling, automation, and coding are more visible, it is impacting other sectors such as materials, construction and manufacturing, and medicine as well, albeit at a slower pace.

In the realm of glasses, modeling advancements in the last two to three decades have accelerated innovation in this field at an incredible rate compared to the material's development over the last 5,000 years. In addition, packages such as PyGGi have allowed researchers and companies with limited



Credit: Sachan, Grover, and Krishnan

Figure 2. Screenshots showing how the parameters and glass components decided in Step 2 are input into a) the desktop and b) web versions of PyGGi Zen.

R&D resources to contribute innovations by reducing reliance on the expensive and tedious trial-and-error discovery process. Furthermore, such approaches cut the environmental footprint of glass development during the discovery, manufacturing, and deployment period by supporting the identification of glass compositions with low carbon footprints and process optimization.

Overall, embracing a collaborative human–AI approach to advanced glass science and discovery enables a future where novel materials and technologies are adopted quickly and efficiently through inclusive, sustainable, and scalable development.

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Table 1. Optimized glass compositions (wt.%).

Sample #	B_2O_3	Al_2O_3	MgO	CaO	BaO	Li_2O	ZnO	La_2O_3	Gd_2O_3	P_2O_5
1	15.54	3.39	0.92	2.72	15.78	3.38	0.32	0.57	1.38	56
2	15.54	3.39	1	3.05	11.75	3.38	0.32	0.57	0.97	60.03
3	16.82	3.01	0.8	3.72	14.61	2.35	0	0.47	1.15	57.07
4	17.14	3.31	1.13	3.72	13.75	0	0	0.47	1.15	59.33
5	20.86	3.31	0.8	0.53	13.75	0	0	0.47	1.15	59.13
6	18.54	0.39	1.33	2.72	11.75	3.38	0.32	0.57	0.97	60.03
7	17.32	2.01	0.8	3.72	14.61	2.35	0	0.47	1.15	57.57
8	17.32	2.51	0.8	3.72	14.11	2.35	0	0.47	1.15	57.57
9	17.32	2.51	0	3.72	14.11	2.35	0	0.47	1.15	58.37
10	21.54	2.39	1.4	2.72	9.9	0.38	0.32	0.57	0	60.78

Table 2. Properties of optimized glass compositions.

Sample #	Refractive index	Abbe number	Glass transition temperature (K)	Hardness (GPa)	Liquidus temperature (K)
1	1.559625	66.39965	728.69	5.17	1131.3
2	1.551692	67.01077	723.75	5.18	1137.73
3	1.557878	66.55641	731.31	5.13	130.61
4	1.554092	66.74953	760.63	5.18	1139.35
5	1.548762	67.06789	749.45	4.96	1129.12
6	1.552433	66.36196	715.77	5.13	1129.78
7	1.557966	66.3882	726.69	5.12	1128.95
8	1.557154	66.50497	728.85	5.11	1130.28
9	1.556245	66.63231	724.2	5.09	1128.41
10	1.54524	67.4689	740.76	5.07	1135.72

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Automated nanoindention and its role in data-driven materials research

By Krisztián Bali, Tamás Tarjányi, Kun Wang, and Xingwu Wang

Machine learning has the potential to revolutionize the discovery and development process of novel materials.[1] However, to properly train these models, researchers must have access to massive amounts of experimental data.

Automated systems provide a way to collect and process high-quality data at record speeds by reducing the need for manual operation and oversight. Recently, researchers at Alfred University in New York had the opportunity to explore the benefits of automated experimentation when Semilab (Budapest, Hungary) loaned the university its new IND-1500 nanoindentation system (Figure 1) in October 2023.

This system is the next generation of Semilab's basic IND-1000 tabletop nanoindentation system. Like its predecessor, the IND-1500 nanoindenter can collect and process data without constant oversight by a human operator. But it has several new user-friendly features, including a simplified user input interface, consolidated electrical feeds, and, notably, a vibration isolation air cushion.

These features reduce the impact of environmental factors on the data collection process, such as mechanical vibrations from nearby roadways, and thus improve the noise-to-signal ratio in the collected data. As a result, data on a material's mechanical properties can be automatically collected and processed with 99% accuracy.

Prior to the loan of the IND-1500 system, Alfred researchers relied on a manual nanoindentation system that did not feature any automation. With the new system, they simply input an estimated Poisson ratio and the machine then generated large datasets for a wide variety of materials, including ceramics, metals, and layered semiconductors, in just a few hours.[2,3]

As an example of the system's capabilities, the researchers nanoindented a transition metal diboride sample (Figure 2), which has intended uses in various extreme environmental conditions, such as mechanical abrasion, ultrahigh temperatures, high pressures, and severe chemical attacks. Based on a 5 mm x 5 mm x 1 mm sample, the IND-1500 nanoindentation system generated 200 data points in five minutes. In comparison, when similar experiments were performed on the original manual nanoindentation system, it took 10 times as long to collect this amount of data.

Ultimately, this experience with the IND-1500 nanoindentation system demonstrates the importance of automated systems in realizing the benefits and potential of data-driven materials research in both academic and industrial settings.

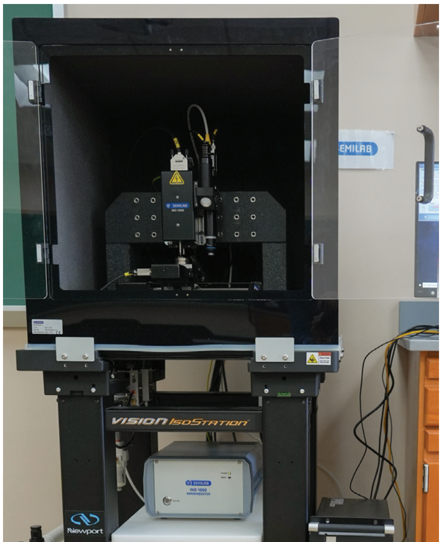
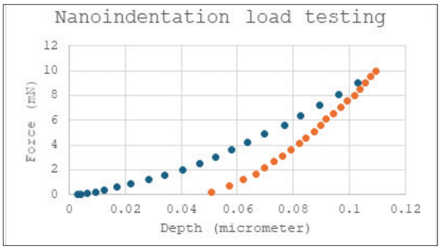


Figure 1. The Semilab IND-1500 nanoindentation system at Alfred University. The nanoindenter is placed within an enclosed chamber on top of a vibration isolation air cushion to prevent environmental factors from affecting the experiment.

Credit: Tony Augustine, Alfred University



Credit: Bryan Zaremba and Kun Wang

Figure 2. Graph of the load displacement curve for a nanoindented transition metal diboride.[2] Blue dots: elastic–plastic loading curve. Orange dots: elastic unloading curve.

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Isaak Il’ich Kitaigorodskii ...and the evolution of glass-ceramics

Isaak Il’ich Kitaigorodskii’s developments in glass coloring processes allowed development of the ruby stars of the Moscow Kremlin.

By Maziar Montazerian

Russian scientist Isaak Il’ich Kitaigorodskii played a central role in shaping the field of glass and glass-ceramic development, significantly expanding potential applications of these novel materials.

Our well-known glass-ceramics textbooks by McMillan,[1] Hlaváč,[2] and Höland & Beall[3] highlight the history of a key discovery: In 1739, French chemist René-Antoine Ferchault de Réaumur became the first known person to produce partially crystallized glass (the so-called Réaumur porcelain).

Réaumur achieved this feat by heat treating soda-lime-silica glass bottles in a bed of gypsum and sand for several days. While successful in converting the glass into a polycrystalline porcelain-like material, his method resulted in a product prone to sagging, deformation, and low strength due to uncontrolled surface crystallization.

More than two centuries later, Voldán used differential thermal analysis to study crystallization in fused basalt (1955 and 1957) while Lungu and Popescu investigated the crystallization of fluoride-nucleated glasses with good mechanical properties (1955).[2] However, the research credited as being the main impulse for developing glass-ceramics came in 1953, when Stanley D. Stookey of Corning Glass Works (now Corning Incorporated) accidentally crystallized Fotoform®, a photosensitive glass containing dispersed silver nanoparticles.[4] The resulting glass-ceramic, which Stookey and his colleagues at Corning developed into the first patented glass-ceramic Fotoceram®, contained lithium disilicate ($Li_2Si_2O_5$) and quartz (SiO_2) as its main crystalline phases.

In the 70 years since that discovery, the field of glass-ceramics experienced considerable growth, as evidenced by the increasing use of that term and related words in published documents (Figure 1). Their appealing properties, which combine glass (optical transparency and translucency) and ceramic (strength and toughness) phase characteristics,[5] led to the

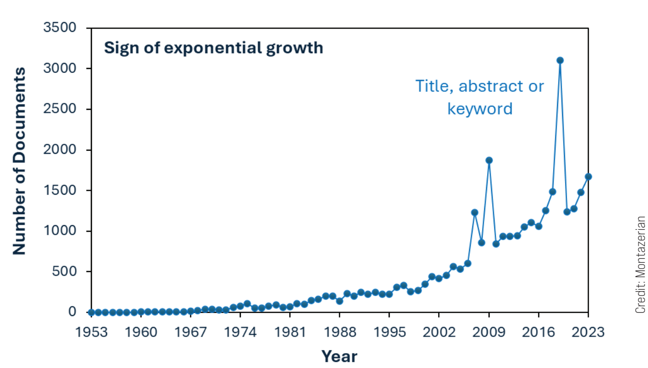

Figure 1. Number of published documents per year extracted from the Scopus database that contain the words “glass-ceramic” OR “glass ceramic” OR “vitroceramic” OR “sitall” OR “pyroceram” OR “vitrokeram” OR “devitroceram” in the article’s title, abstract, or keywords.

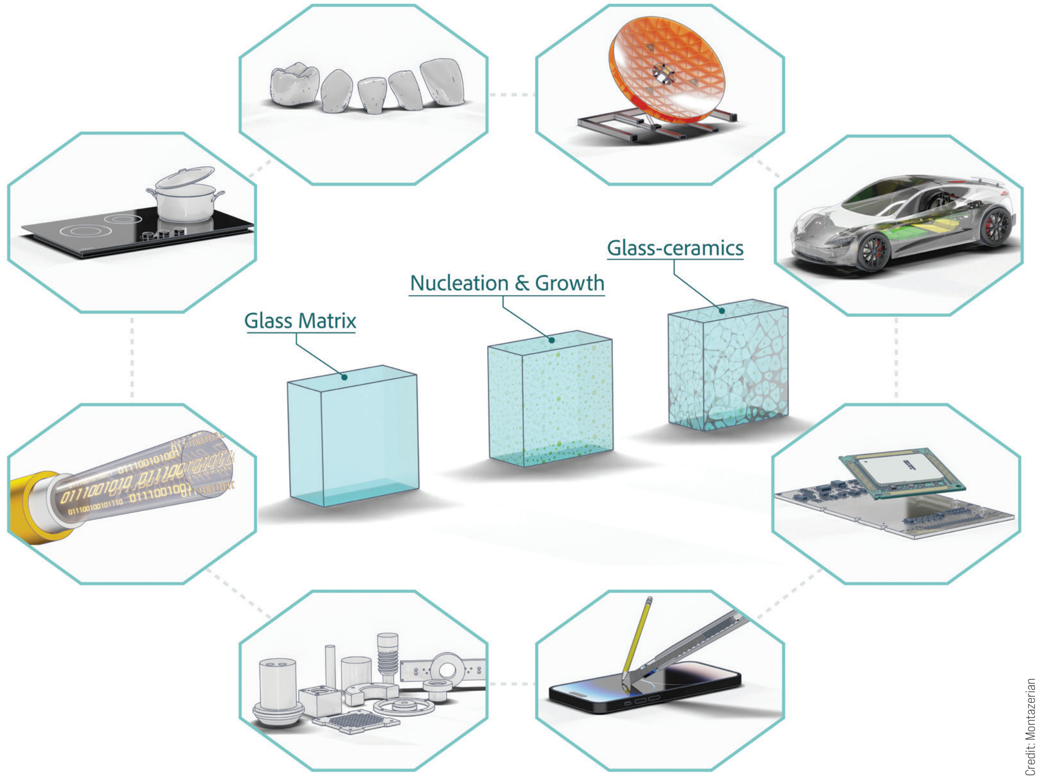

Figure 2. (Center) Illustration of the glass-ceramic development process, which involves the heat-controlled nucleation and growth of crystals within a parent glass matrix. (Surrounding hexagons) Some general applications of glass-ceramics, from clockwise top left: dental prostheses, telescope mirrors, solid-state batteries for electric vehicles, electronic substrates, scratch-resistant and tough displays, machinable mica glass-ceramics for aerospace and other applications, glass-ceramic fibers for fiber amplifiers and lasers, and kitchenware.

commercialization and use of these material across several industries, including healthcare, kitchenware, aerospace, electronics, architecture, energy, and waste management, among others (Figure 2).

As with many great scientific discoveries, there is more to the story of glass-ceramics development than just the narrative presented in the textbooks. Astbury's 1965 *Nature* article "Glass-ceramics: A new technology?" emphasizes that some concurrent glass-ceramics developments were done in the Union of Soviet Socialist Republics.[6] Now, further study of recently translated Russian articles have revealed the significant contributions of Isaak Il'ich Kitaigorodskii (1888–1965),[7] professor at D. Mendeleev Institute of Chemical Technology in Moscow (now D. Mendeleev University of Chemical Technology of Russia).

From 1933 until his death, Kitaigorodskii established and served as a faculty member in the university's glass technology department, which was the first department focused on glass technology in the nation. During his more than 30 years as department head, he devoted his efforts, time, and ability to making the department a prominent scientific and educational center in the field of glass science and technology.[8,9]

Among Kitaigorodskii's scientific pursuits, discussed in more detail below, his contributions to glass-ceramic technology were remarkable. Between 1940 and 1965, he along with colleagues and students at Moscow D. Mendeleev Institute of Chemical Technology pioneered the development of "stone glass," or a glassy matrix mixed and reinforced with secondary crystalline phases, notably corundum or microlite. Recognizing the benefits of crystalline phases within a glassy matrix, Kitaigorodskii expanded his research to pursue the development of "sitalls," or glass-ceramics.[10] These materials, unlike stone glass, result from controlled crystallization of a glass rather than the manual addition of secondary crystalline phases. Kitaigorodskii's research on sitalls in the 1950s and 1960s paralleled similar efforts in the United States on glass-ceramics.

To advance the use of sitalls in application, Kitaigorodskii first focused on developing a fundamental understanding of the material, specifically the theory of crystallization by nucleation agents and glass reinforcement by secondary phase.[9,11] His theoretical advancements, comprehensive empirical evidence, and rigorous administrative efforts resulted in notable achievements. In 1959, the Avtosteklo facility in Konstantinov successfully manufactured key components for supersonic aircraft using sitalls, which had low thermal expansion and excellent dielectric properties. These components were developed under industrial prototype circumstances. The world's first production line for sheet glass-ceramic material, made from steel furnace slag known as slag sitall, was established at the same plant in 1966.

Isaak Il'ich Kitaigorodskii and the evolution of glass-ceramics

In 1963, Kitaigorodskii and his colleague N. M. Pavlushkin, who became the department head of glass technology at D. Mendeleev Institute of Chemical Technology after Kitaigorodskii stepped down, were awarded the Lenin Prize for their work on sitall.[7] The Lenin Prize was one of the most prestigious awards of the Soviet Union for accomplishments relating to science, literature, arts, architecture, and technology.

In addition to his work on stone glass and sitalls, Kitaigorodskii helped advance the glass manufacturing industry in Russia. For instance, the ruby stars of the Moscow Kremlin were created based on his developments in glass coloring processes, and he played a key role in establishing the domestic production of light bulbs.[12] He invented other novel forms of glass as well, notably foam glasses.

Kitaigorodskii's extensive research resulted in more than 300 publications and made him the recipient of multiple accolades. Furthermore, he made significant contributions to education through writing textbooks and supervising students.

Knowing that it typically takes at least five years of research (often longer) to develop a product from idea conception to industrialization (1954–1959), Kitaigorodskii appears to have begun his work on sitalls around the same time as Stookey's discovery of glass-ceramics in 1953. The parallel work of both these researchers indicates a purposeful push for glass-ceramic development. It is only now, though, that Kitaigorodskii's contributions to the research and potential applications of glass-ceramics are being recognized more broadly outside his home country.

Learn more about Kitaigorodskii and his contributions to glass science and technology in Reference 7.

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Jonathon Foreman
ACerS journals managing editor

Routes to raw material sustainability in ceramic and glass production

When considering raw material supplies, sustainability has many components. Among these are

- Substantial natural supply or replenishable source;
- Reducing the resources needed to obtain, process, and transport the materials; and
- Minimizing the environmental damage during extraction, processing, and disposal.

These goals can be achieved through several routes, such as local sourcing, using waste materials in the production of new products, and substituting low-emission materials for ones that are more highly polluting. The challenges to using such raw materials include developing processes that accommodate inconsistent composition (e.g., impurities in a waste stream) and physical properties, such as particle size and crystal structure.

Though finding and utilizing alternate sources of high-value materials, such as rare earths, dominates the headlines, high-volume traditional ceramic applications are benefitting now from the research into identification and adoption of alternate types and sources of raw materials. For example, the open-access article by Kriven et al., "Why geopolymers and alkali-activated materials are key components of a sustainable world: A perspective contribution," provides a look at "the transformative potential" of geopolymers and other materials to provide better properties for construction materials with lower environmental impact.

Furthermore, in the open-access article "Alternative raw material research for decarbonization of U.K. glass manufacture," Deng et al. describe the potential for substantially reducing carbon dioxide emissions in glass production by incorporating ancient raw materials—namely biomass ash—into modern processes. They found the simple steps of sieving and washing the ash substantially reduced impurity content. Additionally, they showed that adding approximately 5% biomass ash to green soda-lime-silica container glass batches has little impact on the color and redox state of the resulting glasses.

Utilizing local resources is particularly important in emerging market countries to take advantage of readily available materials and to minimize transportation resources and costs. In the paper "Sustainable activation of pumice with partially variable substitutions of metakaolin and/or fumed silica," Turkish researchers Bagci and Kafkas collaborated with Samuel and Kriven in the U.S. to prepare geopolymers with alkali-activate local pumice as a raw material. Mixing the activated pumice with metakaolin yielded more geopolymer than mixing with fumed silica and resulted in higher compressive strength.

Also, in Africa, many of the millet growing countries are grappling with serious environmental challenges posed by the accumulation of unmanaged waste in tandem with their population growth and urbanization rate. The authors of the open-access article "Use of waste husk from millet grain cultivation in the production of fired clay bricks" formulated bricks using different ratios of waste millet husk along with locally sourced grey clay and laterite (Figure 1). The authors conclude that the husk could be used as a pore former in processing bricks with good thermal and mechanical properties for load-bearing construction applications.

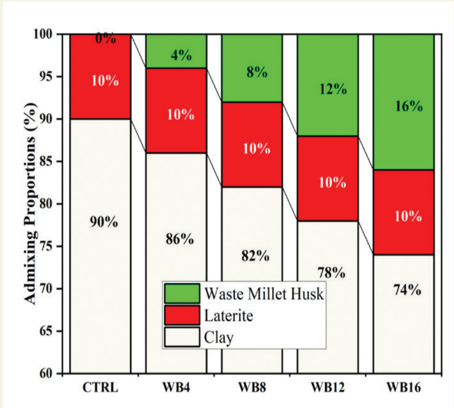

Figure 1. Raw materials admixed ratios of various brick series.

Reclaiming waste from manufacturing provides dual benefits. It can reduce disposal volumes and costs while providing inexpensive raw materials for other processes. The articles by Fang et al. ("Effect of Fe_2O_3 additive on the preparation of Si_3N_4–Si_2N_2O composite ceramics via diamond-wire saw silicon waste") and Jiang et al. ("Preparation of nano SiC by carbothermic reduction of silicon cutting waste with phenolic resin") mention that the process of cutting high-purity silicon ingots into wafers for solar photovoltaic cells is highly wasteful. Cutting silicon results in up to 40% of the ingots, or about 160,000–200,000 metric tons annually, being converted to powder. Because the silicon powder is contaminated with carbon and metal oxides from the cutting tools, it is difficult to reuse in the photovoltaic application and often becomes hazardous waste. However, according to the authors of the two articles, the composition of these powders does not hinder—and may even be beneficial for—conversion to high-temperature silicon nitride carbide and silicon carbide ceramics, respectively.

The Topical Collection "Sustainable ceramic and glass raw materials" can be found on the ACerS Publication Central hub at https://ceramics.onlinelibrary.wiley.com. Click on the "Collections" menu and select "Topical Collections" from the drop down. You will see this collection along with others created over the past few years. You can also directly access this collection at https://ceramics.org/publications-resources/journals/sustainability-collections. ■

SUSTAINABILITY GUIDES DISCUSSION AT CERAMICS EXPO 2024

CERAMICS EXPO

For the second year in a row, Ceramics Expo was held at the Suburban Collection Showplace in Novi, Mich., April 30–May 1, 2024.

Ceramics Expo is the leading annual supply chain exhibition and conference for the advanced ceramic and glass industry. It kicked off with a VIP networking event on Monday night, which featured lively casino-style games. The following two days were filled with an exhibition, conference talks, and moderated sessions. For the third year, the co-located Thermal Management Expo ran alongside Ceramics Expo.

The presentations and panel discussions at Ceramics Expo focused on materials and product development the first day and innovation and manufacturing the next. While key sectors such as automotive, aerospace, and energy were touched on frequently during the talks, one highlight was the in-depth exploration of thermal management solutions, which are critical in enhancing the performance and efficiency of high-power electronics and energy systems.

During the first day of talks, two sessions on sustainable practices within the ceramics industry attracted much attention. Experts from Intel, Henkel, McDanel Advanced Material Technologies, and more discussed how to integrate ecofriendly practices and materials into manufacturing to reduce environmental impacts while maintaining production efficiency and quality.

On the second day of talks, a panel session moderated by Amanda Engen, ACerS director of communications and workforce development, addressed the critical challenges facing the ceramic and glass materials science workforce. Panelists included Fatima Majid, senior manager of talent programs at LIFT; David Gottfried, deputy director for business development at Alfred University; and Marissa Reigel, senior R&D manager at Saint-Gobain NorPro. They discussed the pressing need for skilled professionals and innovative training solutions within the ceramics sector, emphasizing strategic initiatives to enhance skill sets from on-the-job training to the future of formal education.

Outside the conference sessions, exhibitors showcased a variety of new materials and technologies at their respective booths, demonstrating how modern ceramics continue to push the boundaries of what is possible in manufacturing and product development. Exhibitors not only highlighted current trends but also addressed the challenges facing the ceramics sector with potential customers, including supply chain issues and the need for more sustainable manufacturing practices.

See more pictures from Ceramics Expo 2024 on the ACerS Flickr page at https://bit.ly/Ceramics-Expo-2024. Ceramics Expo will again take place at the Suburban Collection Showplace in Novi, Mich., April 28–30, 2025. ■

Top right: Nathan Henderson, senior applications scientist at Bruker Corporation, coauthored one of the feature stories in the March 2024 *ACerS Bulletin*. Pictured is Henderson in the Bruker booth at Ceramics Expo, which included a printout of their article on the table (top left).

Bottom: Doug Thurman, president of Sunrock Ceramics Company, greets attendees stopping by his booth at Ceramics Expo. Thurman is past president (2022–2023) of the Association of American Ceramic Component Manufacturers, and he contributed a column about the association to the April 2024 *ACerS Bulletin*.

(All photos credit: ACerS)

CUTTING-EDGE GLASS ADVANCEMENTS LIGHT UP GOMD 2024 IN LAS VEGAS

The 2024 Glass & Optical Materials Division (GOMD) Annual Meeting was held in the dazzling lights of Las Vegas, Nev., from May 19–23. The event saw a robust turnout with 311 attendees, including 71 students, representing 22 countries.

"This meeting was the first ACerS conference held in Las Vegas, and from the reaction of our attendees, it won't be the last," says Andrea Ross, ACerS director of meetings, marketing, and membership.

Below are highlights from GOMD 2024.

SHORT COURSE ON GLASS CRYSTALLIZATION KICKS OFF MEETING

Before the conference began on Sunday night, a preconference short course on "Nucleation, Growth, and Crystallization in Glasses" provided attendees with a valuable learning opportunity. ACerS Fellow Edgar D. Zanotto, senior professor at the Federal University of São Carlos, led the course.

AWARD LECTURES HIGHLIGHT CUTTING-EDGE ADVANCEMENTS

The first award lecture on Monday morning was the Stookey Lecture of Discovery. Delivered by Jasbinder S. Sanghera, acting superintendent of the Optical Sciences Division at the U.S. Naval Research Laboratory, his lecture titled "Infrared materials and fiber optics" highlighted the development and applications of infrared glasses and fiber optics, showcasing innovations in environmental monitoring, exoplanet discovery, and high-power laser systems.

On Tuesday, ACerS Fellow Stephen H. Garofalini, Distinguished Professor of materials science and engineering at Rutgers University, presented the George W. Morey Award Lecture. His talk, titled "Evolution of molecular dynamics simulations of glass surfaces and interfaces," provided a comprehensive overview of the advancements in simulation techniques that are critical to understanding glass behavior at the molecular level.

Also presented on Tuesday was the Norbert J. Kreidl Award for Young Scholars, which was awarded to Brian Topper of Clemson University. His lecture, titled "Evolving the lever rule for borate glass structure," introduced a new approach to quantifying the short-range structural units of glass-forming melts, providing insights into the structure of binary zinc borate glasses.

On Wednesday, Zanotto, who taught the preconference short course on Sunday, delivered the Darshana and Arun Varshneya Frontiers of Glass Science lecture. His presentation, titled "Unlocking crystal nucleation in supercooled liquids and glasses," explored the early stages of crystallization and the significant progress made in understanding crystal nucleation in various glass formers.

a) Carol Jantzen, one of this year's recipients of the L. David Pye Lifetime Achievement Award, poses with an Elvis impersonator during the Conference Celebration on May 21.

b) GOMD 2024 attendees at a career panel and networking event on May 22.

c) GOMD chair Irene Peterson presents ACerS Fellows Edgar D. Zanotto, left, and Shibin Jiang, right, with this year's Darshana and Arun Varshneya Frontiers of Glass Science and Technology awards, respectively.

(All photos credit: ACerS)

The following morning, on Thursday, ACerS Fellow Shibin Jiang, founder and chair of AdValue Photonics Inc., presented the Darshana and Arun Varshneya Frontiers of Glass Technology lecture. His lecture, titled "Rare-earth-doped glasses, fibers, lasers, and applications," highlighted the development and commercialization of novel glass fibers and their applications in high-power laser systems for defense and materials processing.

In addition to the award lectures, the L. David Pye Lifetime Achievement Award was presented at the conference. This year, the annual award honored ACerS Fellow Manoj Choudhary, professor at The Ohio State University, and ACerS Fellow and Distinguished Life Member Carol Jantzen, affiliate faculty member at the University of South Carolina Aiken, for their outstanding contributions to the field.

NETWORKING EVENTS INSPIRE STUDENTS AND YOUNG PROFESSIONALS

Networking events at GOMD 2024 included a poster session and reception on Monday, the Conference Celebration on Tuesday, and a career panel on Wednesday. The Conference Celebration broke away from the traditional awards dinner, opting instead for food stations, live entertainment, and ample opportunities for attendees to connect in a relaxed atmosphere.

GOMD 2024 also witnessed the launch of the new ACerS Conference Mentor Program, which aims to connect first-time conference attendees with experienced individuals who have frequently attended past ACerS events. There were nine mentor/mentee matches made at GOMD, and participants reported that the program was "wonderfully successful" at engaging international students who often have previously stuck to themselves.

View more photos from GOMD 2024 on ACerS Flickr page at https://bit.ly/GOMD2024. Next year, GOMD will take place alongside the 16th Pacific Rim Conference on Ceramic and Glass Technology in Vancouver, Canada, in May 2025. ■

UPCOMING DATES

DAVID L. LAWRENCE CONVENTION CENTER, PITTSBURGH, PA.

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

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

The 49th International Conference & Exposition on Advanced Ceramics & Composites (ICACC 2025) will provide a platform for state-of-the-art presentations and information exchange on cutting-edge ceramic and composite technologies.

HILTON CITY CENTER, DENVER, CO.

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

HILTON HYATT REGENCY VANCOUVER, VANCOUVER, BRITISH COLUMBIA, CANADA

Join us in Vancouver from May 4–9, 2025, for the 16th Pacific Rim Conference on Ceramic and Glass Technology and the Glass & Optical Materials Division Meeting (GOMD 2025).

calendar

Calendar of events

August 2024

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

13–15 ★ Properties and Testing of Refractories – Hilton Garden Inn and Orton headquarters, Westerville, Ohio; https://ceramics.org/homeny-properties-and-testing-refractories

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

19–23 ➨ Materials Challenges in Alternative Renewable Energy (MCARE) 2024 – The Lotte Hotel Jeju, Jeju Island, Republic of Korea; https://www.mcare2024.org/index.php

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

September 2024

3–5 and 10–12 ★ Sintering of Ceramics – Virtual; https://ceramics.org/castro-sintering-course

October 2024

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

January 2025

26–31 International Conference and Expo on Advanced Ceramics and Composites (ICACC 2025) – Hilton Daytona Beach Oceanfront Resort, Daytona, Fla.; https://ceramics.org/icacc2025

February 2025

25–28 EMA 2025: Basic Science and Electronics Division Meeting – Hilton City Center, Denver, Colo.; https://ceramics.org/event/ema-2025-basic-science-and-electronic-materials-meeting

May 2025

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

July 2025

8–11 ➨ The 8th International Conference on the Characterization and Control of Interfaces for High Quality Advanced Materials (ICCCI 2025) – Highland Resort Hotel & Spa, Fujiyoshida, Japan; https://ceramics.ynu.ac.jp/iccci2025/index.html

September 2025

28–Oct. 1 ACerS 127th Annual Meeting with Materials Science and Technology 2025 – Greater Columbus Convention Center, Columbus, Ohio; https://www.matscitech.org/MST25

January 2026

25–30 International Conference and Expo on Advanced Ceramics and Composites (ICACC 2026) – Hilton Daytona Beach Oceanfront Resort, Daytona, Fla.; https://ceramics.org/icacc2026

May 2026

31–June 5 12th International Conference on High Temperature Ceramic Matrix Composites (HTCMC 12) and Global Forum on Advanced Materials and Technologies for Sustainable Development (GFMAT 2026) – Sheraton San Diego Hotel & Marina, San Diego, Calif.; https://ceramics.org/htcmc12_gfmat2026

August 2026

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

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

Entries in **BLUE** denote ACerS events.

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

★ denotes a short course

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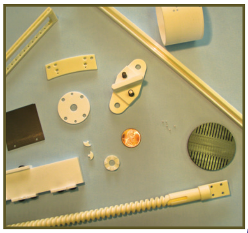

Business Services

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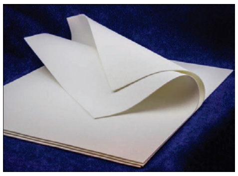
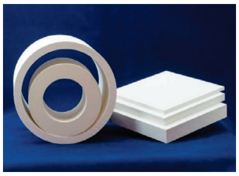
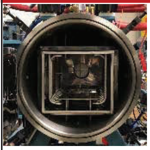
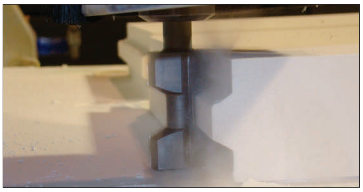




custom/toll processing services





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AUGUST 2024

AMERICAN CERAMIC SOCIETY bulletin

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Carter Glynn
Guest columnist

From slimes to sun power: Looking at tellurium recovery from copper residue

With the rush toward renewable energy, the need for materials to support this transition has exploded. One of these materials is tellurium, an element rarer than gold or platinum in the Earth's crust (0.001 ppm versus 0.004 ppm and 0.005 ppm, respectively).

More than half of the world's tellurium is used in the form of cadmium telluride (CdTe), a direct bandgap material for thin-film solar technology. CdTe solar cells have continued to gain market share in the solar industry due to their greater energy efficiency and lower production costs compared to silicon solar cells.[1]

More than 95% of the world tellurium supply is a byproduct of copper production. Copper production involves casting mined copper concentrates and recycled copper scrap into anodes, which are then electrorefined to increase the purity of the copper (Figure 1).[2] During the electrorefining process, impurities within the anode form fine black solids, or "slimes," that sink to the bottom of an electrorefining cell. The slimes are collected and sent through several processing methods to recover numerous materials, including tellurium (>1 wt.%).

The first step in tellurium recovery is a process called decopperization. The most common decopperization method involves a pressurized sulfuric acid leach with oxygen to remove copper from the slimes by dissolution. During this process, tellurium oxidizes and forms tellurous acid (H_2TeO_3), which enters the leachate along with the copper. Copper and tellurium are then separated from the solution by adding solid copper to the leachate to form solid Cu_2Te.

The amount of tellurium recovered through decopperization is inconsistent. Literature suggests that the recovery of tellurium can vary from 60–80% depending on many factors, including pretreatment of the slimes, starting composition, and processing conditions of the autoclave leach.[3] Additionally, tellurium is known to reprecipitate during extended leaching times.[4] Due to these factors, as well as the hurdles to establishing a consistent recovery process in copper refineries, currently only 29% of the tellurium present in copper anode slimes is recovered.[5]

To increase recovery rates, research groups have worked to characterize the slimes and optimize the autoclave leach process to understand how temperature, partial pressure of oxygen, sulfuric acid concentration, and solid-to-liquid ratios affect metal recovery. However, the impact of slime compositions and leaching time on tellurium extraction during pressure leaching has not been fully investigated.

My research at Missouri University of Science and Technology will focus on the impact of slime composition and leaching time on metal recovery rates. Regarding slime composition, my group plans to process slimes collected from multiple refineries under similar leaching conditions to observe how the recovery of tellurium can change based on the starting composition of the slimes.

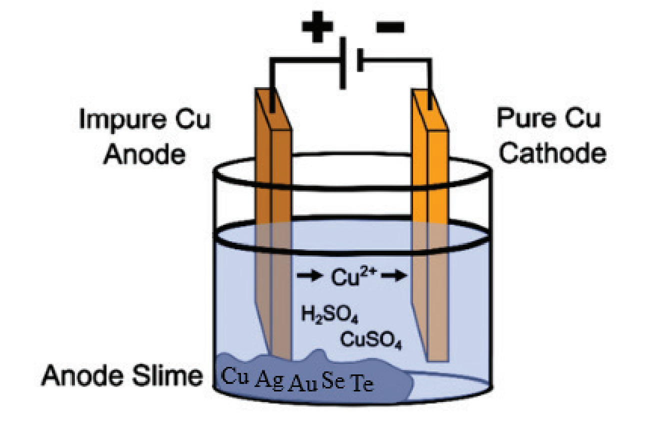


Figure 1. Simplified copper electrorefining cell displaying the formation of high-purity copper from cast copper anodes. An electrochemical reaction dissolves the anode to form copper ions and slimes. The slimes sink to the bottom of the cell while the copper ions deposit onto the cathode to form pure copper.

Additionally, trials of extended leaching times are planned to investigate how tellurium may reprecipitate out of the leachate solution. Reprecipitation of tellurium after oxidation from tellurous acid to telluric acid (H_2TeO_4) is known to occur industrially, but it is not well reported in scientific journals. Better understanding of the precipitation process could help in identifying what tellurium compounds form along with what additions can be made to the slimes or leaching process to prevent this occurrence.

Ultimately, the results from these studies will improve tellurium recovery, thus helping fulfill the need for these valuable materials in the renewable energy transition.

References

[1]Barbato, M., et al., "CdTe solar cells: technology, operation and reliability," *Journal of Physics D: Applied Physics* 2021, **54**(33): 333002.

[2]Ngan, A., et al., "From contaminant to commodity: a critical review of selenium usage, treatment, and recovery," *Reviews in Environmental Science and Bio/Technology* 2024, **23**(1): 223–255.

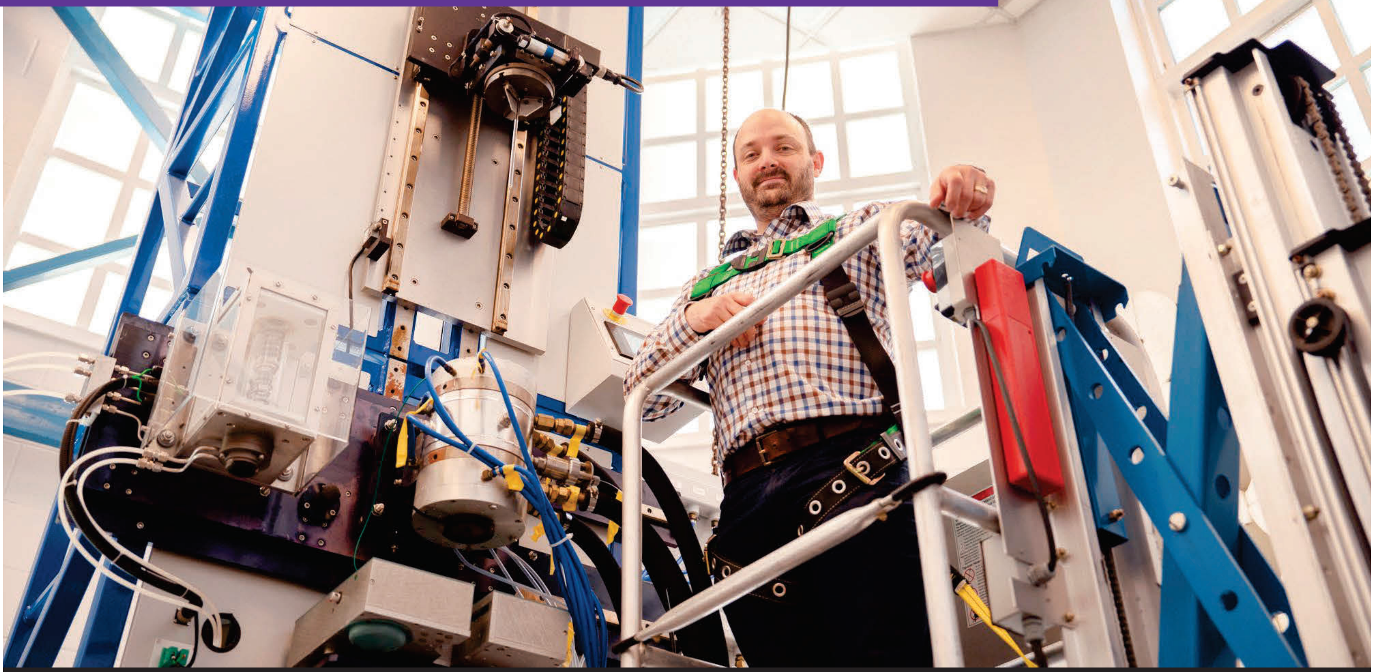
[3]Hoffmann, J.E., "Recovering selenium and tellurium from copper refinery slimes," *JOM* 1989, **41**: 33–38.

[4]Bäckström, J., "Copper, nickel, and tellurium yields during leaching of anode slime," Luleå University of Technology [master's thesis], 2010. Available from https://bit.ly/3VaynqU

[5]Nassar, N. T., et al., "Global tellurium supply potential from electrolytic copper refining," *Resources, Conservation and Recycling* 2022, **184**: 106434.

Carter Glynn is a master's student in the group of professor Michael Moats at Missouri University of Science and Technology. His work focuses on the recovery of tellurium from copper anode slimes. In his spare time, he enjoys rock climbing and mountain biking.

WELCOMING NEW FACULTY



Dr. Benjamin Moulton —

Alfred University would like to introduce you to our latest faculty member Dr. Benjamin Moulton has been hired as Assistant Professor of Glass Science. Ben earned a Ph. D. in Earth Sciences at the University of Toronto, Canada after which he spent time at the Center for Research, Technology, and Education in Vitreous Materials (CeRTEV) at the Federal University of São Carlos (UFSCar) in Brazil and then in Materials Science at Friedrich-Alexander Universität Erlangen-Nürnberg (FAU) in Germany. Dr. Moulton's research focuses on the role of structure in all properties, with an emphasis on the mechanical properties and crystallization behavior. Ben is interested in building broad-based models of glass structure that allow for predictive intuitions based on the chemistry of the glass. This goal intersects with understanding the links between mechanics (e.g., toughness, strength), optics (e.g., transparency, refractive index), processing (e.g., the glass transition, viscosity) and thermodynamics (e.g., heat capacity) and structure as well as pragmatic considerations such as environmental impact of source materials and energy demand. In the years ahead, he hopes to explore more exotic compositions, including producing non-traditional oxide glass that require hyper-quenching and fiber draw approaches.

Alfred University OUTSIDE of ORDINARY

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