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emerging ceramics & glass technology

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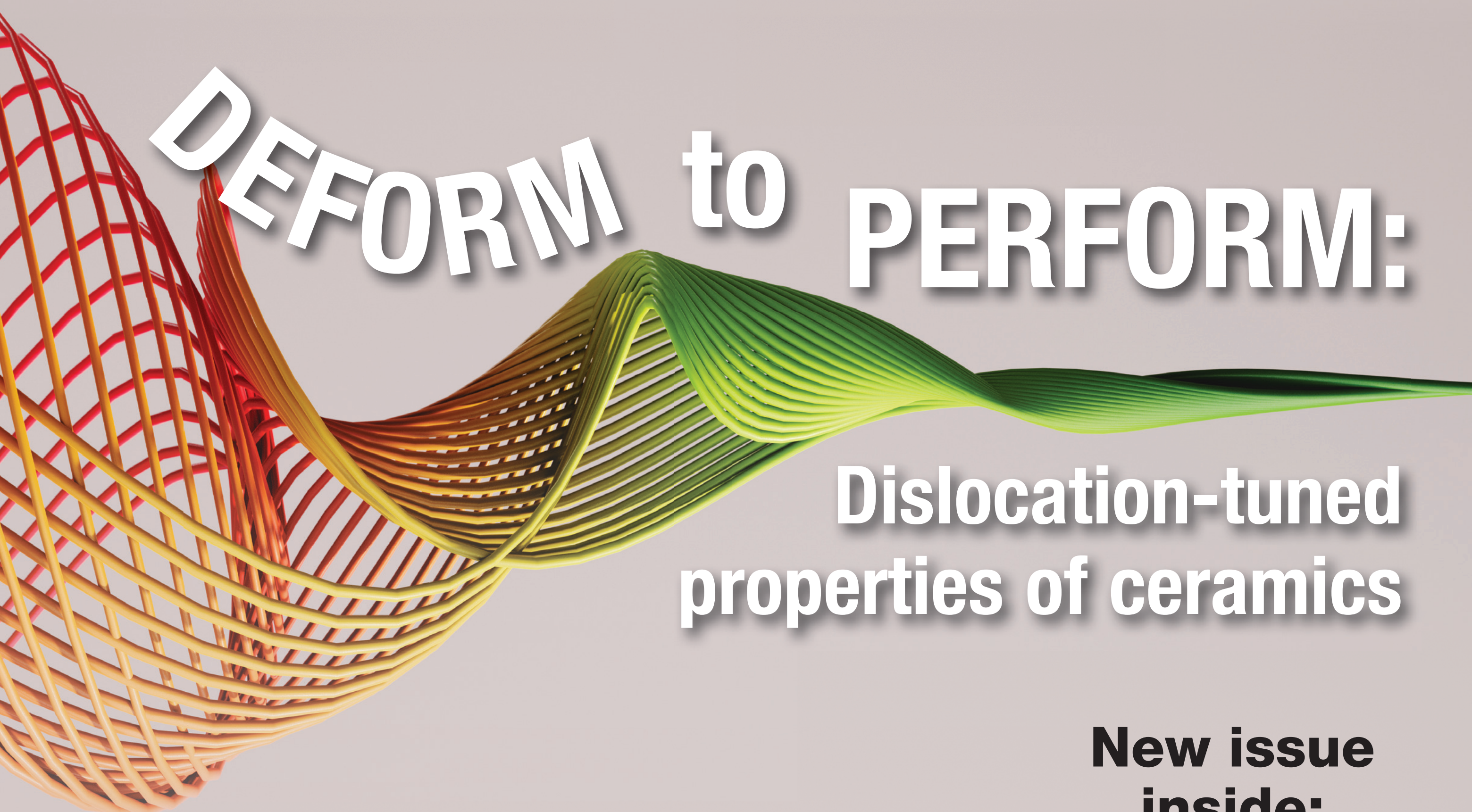

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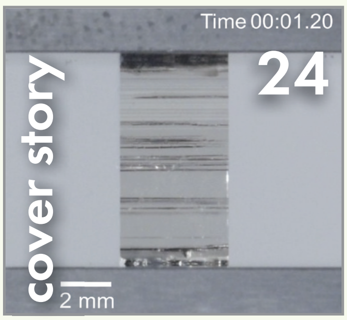

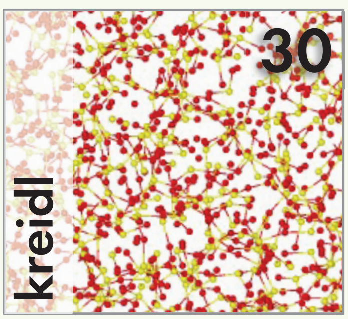

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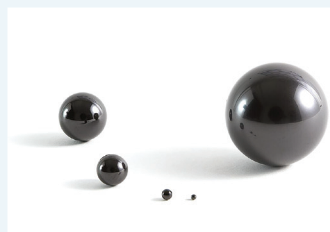

Credit: Lucasbosch, Wikimedia (CC BY-SA 3.0)

Successful plastic deformation in silicon nitride thanks to dual-phase structure

Most explorations of plastic deformation in ceramics have focused on oxide systems. A recent study led by researchers at Tsinghua University in China demonstrated the possibility of plastic deformation in nonoxide ceramics as well, specifically silicon nitride, by harnessing a dual-phase structural configuration.

Read more at www.ceramics.org/beyond-oxides

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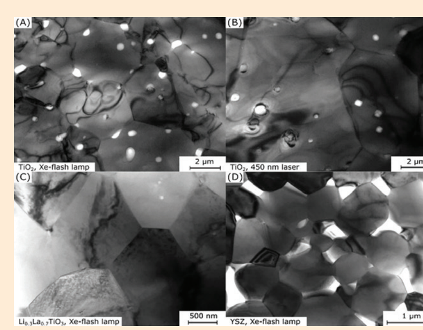

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ACSBA7, Vol. 102, No. 5, pp. 1–64. All feature articles are covered in Current Contents.

news & trends

A new wave in the battle for data—China and the US clash over submarine cable control

Credit: CNBC International, YouTube

Workers position a submarine fiber-optic cable for installation. Concerns that the global submarine cable system may be used to conduct espionage is driving a clash between China and the United States.

Far beneath the waves in some of the most remote areas of the ocean lies a key to modern civilization—the global submarine cable system.

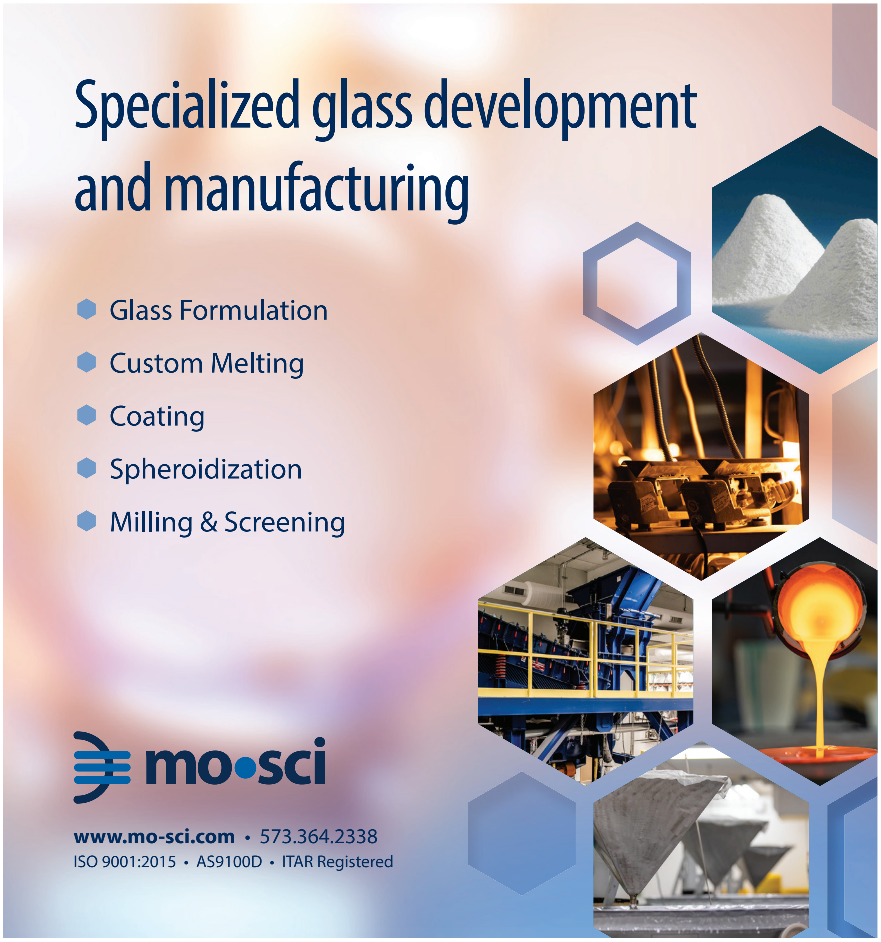
The global submarine cable system consists of fiber-optic cables laid on the ocean floor to carry telecommunication signals between land-based stations. These cables carry about 95% of all global transnational communication data.

As of early 2023, there are 552 active and planned submarine cables connecting all continents except Antarctica. A map of all these cables the Submarine Cable Map, a free and regularly updated resource offered by telecommunications market research company TeleGeography.

Despite the importance of the global submarine cable system to transnational communications, the system is surprisingly fragile. A CTT post in July 2022 (also featured in the August 2022 *Bulletin*) described how natural disasters, human error, and outdated regulations can cause the system to fail.

Accidents are not the only threat to the system's security, however. In recent years, the U.S. government has grown increasingly concerned about the possibility of this network being used to conduct espionage due to the growing prominence of HMN Technologies Co., Ltd. within this industry.

HMN Technologies, previously Huawei Marine Networks Co., Ltd., is a provider of turnkey submarine network solutions. The company was established as a joint venture between China-based Huawei Technologies (51%) and U.K.-based Global Marine Systems Ltd. (49%) in 2008. However, as of 2020, the company is now owned by China-based Hengtong Optic-Electric Co. Ltd. (81%) and New York-based HC2 Holdings, Inc. (19%), the legacy controlling company of Global Marine Group.



news & trends

When HMN Technologies first entered the submarine cable industry, it started by building small cable systems in Papua New Guinea and the Caribbean. But it soon became the fastest-growing manufacturer and layer of submarine cables.

"Altogether, the company has worked on some 90 projects to build or upgrade seabed fiber-optic links," *The Wall Street Journal* reported in March 2019. "The company is now the fourth-biggest player in an industry long dominated by U.S.-based SubCom and Finnish-owned Alcatel Submarine Networks. Japan's NEC Corp is in third place."

While most projects are in the developing world, HMN Technologies has led several significant projects between developed nations, including the 7,500-mile "PEACE Cable" connecting Europe, Asia, and Africa.

The growth of HMN Technologies is concerning to the U.S. government because of its previous owner, Huawei Technologies. Those familiar with U.S.–China relations will recognize Huawei as the company repeatedly targeted by U.S. sanctions to prevent it from building 5G communications networks due to hacking fears.

Even though Huawei Technologies divested its stake in HMN Technologies to Hengtong Optic-Electric Co. Ltd. in 2020, U.S. concerns about the company have not abated.

In March 2023, *Reuters* published a special report revealing the extent to which the U.S. is addressing its concerns. The report details how, over the past four years, the U.S. intervened in at least six public submarine cable deals in the Asia-Pacific region to keep HMN Technologies from winning that business, or forced the rerouting or abandonment of cables that would have directly linked U.S. and Chinese territories.

There is evidence the U.S. campaign is affecting HMN Technologies.

"HMN Tech supplied 18% of the subsea cables to have come online in the last four years, but the Chinese firm is only due to build 7% of cables currently under development worldwide, according to TeleGeography," the *Reuters* report states.

How these political maneuverings will affect the global submarine cable system in the long term remains to be seen. But "When we talk about U.S.–China tech competition, when we talk about espionage and the capture of data, submarine cables are involved in every aspect of those rising geopolitical tensions," says Justin Sherman, a fellow at the Cyber Statecraft Initiative of the Atlantic Council, a Washington-based think tank, in the *Reuters* report.

The *Reuters* report is available at https://www.reuters.com/investigates/special-report/us-china-tech-cables. ■

Swiss startup cracks the 1-kW ceiling for production of solar hydrogen

Credit: Gebert Rüf Stiftung, YouTube

Swiss-based solar hydrogen company SoHHytec's concentrated solar power system produces about half a kilogram of hydrogen in 8 hours, which amounts to a little more than 2 kilowatts of equivalent output power.

The exploration of hydrogen as an alternative industrial fuel source is heating up.

Compared to conventional hydrocarbon fuels, hydrogen only creates water when combusted. That means it can play a significant role in reducing carbon dioxide emissions.

Yet as states vie for federal funding to set up hydrogen infrastructure, and companies start running hydrogen fuel mix tests, there are challenges that must be overcome for hydrogen to become a viable large-scale fuel source.

The development of refractory ceramics that can handle the higher heat release rate of hydrogen firing is one barrier to commercialization. Researchers are making great strides toward overcoming this obstacle.

But production of hydrogen fuel is another challenge that presents a major hurdle. Currently, most hydrogen is produced through steam reforming of natural gas. This "grey" hydrogen process emits about 9–11 kg of CO_2 per kg of hydrogen production.

"Green" hydrogen can be produced through water electrolysis. This process emits no CO_2 if renewable energy sources, such as wind and solar power, provide the electricity.

However, producing hydrogen through water electrolysis is not yet financially viable due to challenges with scaling up the process. As such, in 2021, green hydrogen accounted for less than 0.1% of worldwide hydrogen production, according to a BCC Research report.

Solar hydrogen company SoHHytec is working to overcome the electrolysis scale-up challenge.

SoHHytec is a Swiss-based startup that grew out of the Swiss Federal Institute of Technology Lausanne (EPFL). Their solution, which is based on almost a decade of research and development, uses concentrated solar power to improve the efficiency of green hydrogen production.

In their system, which is illustrated below, a 7-meter-wide parabolic solar dish covered with reflective mirrors concentrates solar radiation onto tandem multijunction III–V semiconductor solar cells. The electricity produced by the solar-cell module drives the water electrolysis process, which takes place through a polymer electrolyte membrane electrolyzer.

In their system, a 7-meter-wide parabolic solar dish covered with reflective mirrors concentrates solar radiation onto tandem multijunction III–V semiconductor solar cells. The electricity produced by the solar-cell module drives the water electrolysis process, which takes place through a polymer electrolyte membrane electrolyzer.

Not all of the concentrated solar energy is converted to electricity. Some of it is converted into waste heat, which is extracted using a heat exchanger. This heat can then be used for space heating or hot water in buildings.

A pilot plant based on this system produced about half a kilogram of hydrogen in 8 hours, which amounts to a little more than 2 kilowatts of equivalent output power. This much energy would allow a car to be driven for about 100 miles (160 kilometers).

This result is significant because it is the first time "We have cracked the 1-kW ceiling for the production of solar hydrogen," says Sophia Haussener, EPFL professor of renewable energy science and engineering, in an *IEEE Spectrum* article.

SoHHytec is now building a system with a larger, 9-meter-wide parabolic solar dish. The first demonstration project for the larger system, which is slated to be operational by the end of 2023, will be for a metalworking company that will use the hydrogen and heat for metal processing. Eventually, the SoHHytec researchers imagine that customers will be able to tie together multiple dishes, which will allow the system to be made as big or small as needed. ■

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Waste heat to power: Global market outlook

By BCC Publishing Staff

The global market for waste heat recovery systems was estimated to be $57.7 billion in 2021 and is projected to grow at a compound annual growth rate (CAGR) of 8.0% to reach $89.0 billion by 2027.

It is estimated that as much as 20–50% of industrial energy consumption is ultimately discharged as waste heat. Waste heat recovery systems can capture and reuse this waste heat to power numerous processes, including preheating combustion air, electricity generation, preheating furnace loads, absorption cooling, and space heating.

The increasing need for energy security is a main driver of the waste heat recovery market. Concerns about energy affordability, greenhouse gas emissions, as well as the predicted rise in global energy demand by 2030 have increased interest in energy efficiency. According to the U.S. Department of Energy, 280,000 MW of waste heat that is released annually in the U.S. could be recycled to meet 20% of the country's electricity demands, reduce greenhouse gas emissions by 20%, and save $70–$150 billion in annual energy expenses.

There are several restraints on the market, though, as described below.

Technical barriers. The heat recovery process itself is the main challenge for waste heat recovery systems. Each heat recovery scenario poses a different set of difficulties, even though power-producing equipment is commercially established and generally standardized. Examples of technological difficulties include

- Waste heat sources at a plant are dispersed, challenging to gather, or come from batch or noncontinuous processes.
- Low volume and seasonal operations minimize waste heat recovery systems' economic advantages.
- Chemical and/or mechanical impurities found in waste heat sources frequently affect the complexity, expense, and effectiveness of the heat recovery process.
- It is challenging or impossible to economically site waste heat recovery systems due to equipment designs and space constraints.

Business barriers. Companies can be hesitant to undertake projects with a reputation for risk, including energy recovery projects that fall outside of their core competencies. For capital-intensive waste heat recovery projects, these worries frequently result in project hurdle rates that are excessively high. Because the expenditures of due diligence, permitting, and siting frequently diminish the returns, small projects (defined as those costing less than $5 million) can be extremely challenging to build.

The waste heat recovery systems market is consolidated, with major players contributing over one-third of the total industry share. Most companies have adopted either a strategy of product differentiation via unique processing technologies or a strategy of focus that is established on a product-type basis. Examples of these strategies can be seen in Table 1, which lists several recent patents related to waste heat recovery systems.

Table 1. Waste heat recovery systems patents, 2020–2022

Inventor/assignee	Publication date	Publication No.	Patent title/abstract
Ford Global Technologies LLC	Jan. 11, 2022	CN108005811B	Waste heat recovery for power generation and engine warm-up.
Enhanced Energy Group LLC	July 5, 2022	CA2890484C	Cycle turbine engine power system.
Sunamp Ltd.	July 5, 2022	US20200217518A1	Energy storage systems.
Cummins Inc.	Aug. 17, 2021	US11092069B2	Rankine cycle waste heat recovery system and method with improved EGR temperature control.
Saudi Arabian Oil Co.	July 27, 2021	US11073050B2	Kalina cycle-based conversion of gas processing plant waste heat into power.
Mitsubishi Power Ltd.	Jan. 20, 2021	EP2103339B1	Exhaust gas treating method and apparatus.
Mitsubishi Heavy Industries Ltd.	Oct. 15, 2020	US20200325799A1	Waste heat recovery system, gas turbine plant provided with same, waste heat recovery method, and installation method for waste heat recovery system.
Mack Trucks Inc.	May 6, 2020	EP2593645B1	Waste heat recovery system with partial recuperation.
Claudio Filippone	May 7, 2020	US20200141353A1	Waste heat recovery and conversion.
Combined Energies LLC	May 5, 2020	US10644338B2	Dynamically responsive high efficiency CCHP system.

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.

Resources

BCC Publishing Staff, "Waste heat to power: Global market outlook" BCC Research Report ENV059A, March 2023. www.bccresearch.com.

acers spotlight

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Remembering ACerS past president John B. "Jack" Wachtman, Jr.

The American Ceramic Society has lost an esteemed member—John B. "Jack" Wachtman died on Dec. 13, 2023, at the age of 94. He is predeceased by his wife, Edith V. Wachtman.

Wachtman grew up in the small town of Conway, S.C., where he attended public schools. During his early school years, Wachtman was influenced by the discovery of geometry, algebra, and physics. He applied for and received a scholarship from Carnegie Institute of Technology (now Carnegie Mellon University) in Pittsburgh, Pa.

Wachtman received B.S. and M.S. degrees in physics from Carnegie Tech and was a research and teaching assistant there from 1949–1951. Wachtman stated in his memoir that "my time at Carnegie was perhaps the highlight of my life. I loved the intellectual life and companionship of the students. The curriculum was designed to give scientists and engineers some degree of liberal arts education to the extent that this was possible."

Wachtman joined the National Bureau of Standards (NBS, now the National Institute of Standards and Technology [NIST]) in 1951 as a physicist in the Engineering Ceramics Division. He received his Ph.D. in physics from the University of Maryland in 1961.

Wachtman left NBS in 1983 and began a second career as the first director of the Center for Ceramic Research at Rutgers, The State University of New Jersey–New Brunswick. During his 12 years at Rutgers, Wachtman taught courses on characterization and mechanical properties of ceramics intended for seniors and incoming graduate students.

After retiring from Rutgers, Wachtman wrote books based on the courses he taught. One of these books, *Mechanical properties of ceramics*, was published in 1996; a revised, second edition that was co-authored with his Rutgers colleagues Roger Cannon and John Matthewson published in 2009. These books were well received, with the first book selling 500 copies in the first six months. According to George Quinn (retired, NIST), these books are by far the best and most balanced textbooks on the topic.

In 1989, Wachtman took on the part-time role as technical editor for ACerS publications, a position he held for 12 years. During this time, his principal focus was on *Journal of the American Ceramic Society*. In his final year as editor, he, along with ACerS staff, succeeded in putting *JACerS* online with a subscription system. According to Mark Mecklenborg, ACerS executive director, "Having Dr. Wachtman involved in this process was essential. His knowledge, expertise, and commitment to the Society positioned the journal for success for many years to come."

One of Wachtman's final contributions to ACerS was editing the book *Ceramic innovations in the 20th century*. This book, published in 1999, coincided with the 100th anniversary of the founding of ACerS.

Wachtman collected a multitude of honors from various organizations, including NBS. In his memoir, Wachtman mentioned that the most meaningful honor to him was the election to the International Academy of Ceramics in 1988, as well as serving as president of The American Ceramic Society (1978) and the Federation of Materials Societies (1975). He was a Distinguished Life Member and an ACerS Fellow.

Wachtman was such an inspiration to so many people that it is fitting he ends his memoir with this closing quotation by polymath Albert Schweitzer: "At times our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lit the flame within us." ■

Editor's notes: ACerS appreciates NIST Library for sharing the "Oral history interview of John B. Wachtman," Feb. 4, 2010, and Wachtman's 24-page "Memories and reflections on a career as a scientist-engineer in research management, teaching, and editing," 2009, revised 2010.

Wachtman also featured in the December 1999 *Ceramic Bulletin* (Vol. 78, No. 12), pp. 36–41, "Profiles in ceramics" by Kathy Woodward.

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Adrian C. Wright, Distinguished Life Member, 1944–2023

Adrian Carl Wright, ACerS Distinguished Life Member and ACerS Fellow, died on March 22, 2023, at the age of 79. Wright, who dedicated his research career to understanding glass structure, was a member of the Glass & Optical Materials Division and also active in the Society for Glass Technology, where he served as the 49th president from 2002–2004.

Wright was professor of amorphous solid-state physics at the University of Reading, U.K. He earned his B.Sc. in chemistry, Ph.D. in physical chemistry, and D.Sc. degrees from the University of Bristol, U.K. After completing his Ph.D. studies, he took a position in 1969 at the University of Reading, where he remained until his retirement as professor emeritus in 2007.

He spent three sabbatical years in the United States working at leading institutions, including Xerox Palo Alto Research Center; Stanford Synchrotron Radiation Laboratory; Argonne National Laboratory; University of California, Los Angeles; University of Florida; and New York State College of Ceramics at Alfred University.

Wright pioneered use of neutron scattering and modeling studies to understand the structure and dynamics of a wide range of inorganic glasses and other amorphous solids, including silicate, borate, borosilicate, phosphate, chalcogenide, and fluoroberyllate glasses. He had more than 200 publications in the scientific literature, and he sat on the editorial boards of *Journal of Non-Crystalline Solids* and *Fizika i Khimiya Stekla (Soviet/Russian Journal of Glass Physics and Chemistry)*.

Wright received several prestigious awards, including Fellow in 1995 of both ACerS and the Society of Glass Technology. In 1990, he shared the Worshipful Company of Glass Sellers of London Award, and in 1996, he received the ACerS Glass & Optical Materials Division George W. Morey Award for his establishment of the field of amorphography. He presented the 2006 Samuel R. Scholes Lecture at the New York State College of Ceramics at Alfred University, and he was made an Honorary Fellow of the Society of Glass Technology in 2009.

Most recently, he shared the 2012 Otto Schott Research Award for "his lifelong outstanding scholarly work devoted to the experimental study of glass structure in general." In 2014, he presented the ACerS Edward Orton Jr. Memorial Lecture, titled "*My borate life: An enigmatic journey*," at ACerS Annual Meeting at MS&T in Pittsburgh, Pa. He served on the Steering Committee and Council of the International Commission on Glass. In 2016, he was designated an ACerS Distinguished Life Member.

"He was the consummate scientist and had many original ideas. He was productive until the end of his life," says colleague Steve Feller, B.D. Silliman Professor of Physics at Coe College, Iowa. ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

Meet the 2023–2024 officers and Board members

President-elect

MONICA FERRARIS, FACERS
Full Professor of Science and Technology of Materials
Politecnico di Torino University
Turin, Italy

Since I joined ACerS in 1995, I have learned much from this community. The Society gave me a lot both from professional and personal points of view, and now I feel it is time for me to give back.

I appreciated ACerS' way of working from the very beginning: Good ideas are accepted and supported wherever they come from. If elected, I would like to contribute with passion, energy, and with my personal "can do" attitude.

I am a hard-working, committed, and creative person. With the help of incredibly committed ACerS staff, along with mentoring from former ACerS presidents and senior members, I would like to contribute to making ACerS even more attractive for new members and companies by attracting more young professionals to join ACerS, attend meetings, and participate in activities, including International Chapters; and to increase industry/university international collaborations within ACerS.

I would like to help ACerS fully exploit what we all learned during the pandemic: Networking and personal relationships built at ACerS conferences are extremely important!

I would like to help make ACerS meetings even more attractive and effective by increasing occasions for networking and by helping young and underrepresented professionals build their career within ACerS.

I would focus on attracting, keeping, and rewarding young professionals and companies by connecting them to programs adapted to their specific needs, including those of underrepresented groups.

I would fully support the creation of new International Chapters and GGRN activities, encouraging collaboration with national societies, of course while guaranteeing ACerS financial security.

I would bring an international perspective to the presidency, as other international past presidents have done, but with an additional gender perspective.

Directors

ALEXANDRA NAVROTSKY, DLM, FACERS
Regents Professor, School of Molecular Sciences and School for Engineering of Matter, Transport, and Energy
Director, Navrotsky Eyring Center for Materials of the Universe
Arizona State University
Tempe, Ariz.

I have been a member of The American Ceramic Society since the early 1970s, publishing regularly in the journals and attending many of our meetings. I balance interests in ceramics, solid-state chemistry, materials science, mineralogy, and Earth and planetary science. These interests are tied together by my passion for and research in thermodynamics.

I continue to have a very active research program, having moved from the University of California, Davis, to Arizona State University in 2019. I lead ASU's Center for Materials of the Universe, and I am an active member of FORCE, the Facility for Open Research in a Compressed Environment, which brings unique new high-pressure capabilities to the United States.

The Society has honored me with Fellowship and, more recently, Distinguished Life Membership, as well as the Spriggs and Kingery Awards. More importantly to me, it has continually provided a forum for new interdisciplinary science—its inception, execution, and publication.

If elected to the Board, I will strive to sustain and broaden this forum. ACerS is a relatively small society, especially when compared to organizations like the Materials Research Society or the American Chemical Society. But this smallness makes us a close-knit group of colleagues and friends with a well-defined focus on ceramic materials, ranging from basic to applied and back again.

Though we need to stem attrition, our moderate size makes ACerS a comfortable place for new and younger members and for immigrants (both from different countries and from different fields of knowledge). I contend that a flexible and multidisciplinary approach attracts unconventional people, including those from underrepresented groups. We must augment this natural advantage with specific programs to attract students at all levels, professionals, and life-long-learners. These programs can be at our national meetings, at local Sections and Chapters, in student affiliate organizations, and as individual outreach. We need better communication but also more creativity.

If elected, I will take advantage of my wide reach of contacts and collaborators to bring new ideas to the table.

DILEEP SINGH, FACERS
Argonne Distinguished Fellow
Senior scientist and group leader of thermal and structural materials in the Applied Materials Division
Argonne National Laboratory
Lemont, Ill.

It is an honor and privilege to be nominated to the Board of Directors of The American Ceramic Society.

I joined ACerS as a graduate student in 1986, and I have immensely benefited from the Society in my professional and personal growth over the past several decades. By serving on the Board, I would like to help ACerS continue providing high-quality experiences to the next generation of scientists and engineers and the worldwide ceramics community at large.

Having served on numerous Society-level committees, I have had fruitful interactions with my peers from around the world as well as the dedicated ACerS staff. As part of the Engineering Ceramics Division leadership, I have been fortunate to organize some of the most successful ACerS international conferences (PACRIM, ICACC) on advanced ceramics and initiate new focus areas (such as energy storage) at ICACC, which have blossomed into successful stand-alone symposia. I sincerely believe that my experience will be a positive addition to the ACerS Board and benefit the Society.

If elected, my goal will be to address several current and upcoming challenges the Society faces by working alongside the ACerS leadership in a proactive manner. Some key priorities for me include enhancing membership growth and experience by broadening our membership diversity and mentoring early career members; maintaining high-quality technical content by rapidly addressing emerging areas through our publications and conferences; and ensuring a stable fiscal base for the Society by taking strategic decisions. I plan to work diligently with my Board colleagues to ensure a strong future for ACerS.

TODD STEYER, FACERS
Chief engineer for materials and manufacturing R&D
The Boeing Company
Huntington Beach, Calif.

As a lifelong learner and 35-year member of ACerS, I am excited by the role that ACerS plays in shaping the future of our field as a resource for a growing member base.

I am currently chief engineer for materials and manufacturing R&D at The Boeing Company, Huntington Beach, Calif. I earned a B.S. in metallurgical engineering & materials science from Carnegie Mellon University, Pittsburgh, Pa., and Ph.D. in materials science and engineering from Northwestern University, Evanston, Ill.

An ACerS Fellow, I am a member of the Basic Science Division, Engineering Ceramics Division, Southern California Section, and am a past chair and two-term trustee of ACerS Ceramic and Glass Industry Foundation.

Having joined ACerS as a graduate student, ACerS membership provided me with networking and opportunities to present and publish my research. While getting started in industry, I referenced the *ceramicSOURCE Buyer's Guide* for suppliers/vendors. Organizing the aerospace track for ICC-4 (4th International Ceramics Congress) strengthened my ties to ACerS, so I was happy to join CGIF as a trustee in 2017. Through CGIF, I enjoyed seeing what our pooled resources can do for our field and in the lives of people that the Foundation reaches through the generosity of our donors.

With your support, as a director, I pledge to promote ceramics and glass professions, help build a talent pipeline for our field, and strengthen our Society, Divisions, Sections, and International Chapters by emphasizing our Society's strengths: networking and information. ■

Names in the news

Members—Would you like to be included in the Bulletin's Names in the News? Please send a current head shot along with the link to the article to mmartin@ceramics.org. The deadline is the 15th of each month.

Edgar Dutra Zanotto, FACerS, received the prestigious Brazilian Confederation of Research Support Foundations Award in Science, Technology, and Innovation, as Outstanding Researcher in the Exact Sciences. Zanotto is professor of materials engineering at Federal University of São Carlos, Brazil, and director of CeRTEV. The award recognizes contributions to relevant scientific, technological, or innovative knowledge that converted into benefits for the development and well-being of the Brazilian population. ■

more SOCIETY DIVISION SECTION CHAPTER NEWS

ACerS President-elect

To serve a one-year term from Oct. 4, 2023, to October 2024

Monica Ferraris

ACerS Board of Directors

To serve three-year terms from Oct. 4, 2023, to October 2026

Alexandra Navrotsky
Dileep Singh
Todd Steyer

Division and Class Officers

To serve a one-year term Oct. 4, 2023, to October 2024, unless otherwise noted

2023–2024 ACerS officers

The new slate of ACerS officers has been determined. There were no contested offices and no write-in candidates, automatically making all nominees "elected." ACerS rules eliminate the need to prepare a ballot or hold an election when only one name is put forward for each office. The new term will begin Oct. 4, 2023, at the conclusion of ACerS Annual Meeting at MS&T.

Art, Archaeology & Conservation Science Division

Chair: **Christina Bisulca**
Vice chair: **Fumie Iizuka**
Secretary: **Tami Clare**
Treasurer: **Xiao Ma**
Trustee: **Darryl Butt**
DEI representative: **Christina Bisulca**

Basic Science Division

Chair: **Edwin García**
Chair-elect: **Amanda Krause**
Vice chair: **Ricardo Castro**
Secretary: **Fei Peng**
Secretary-elect: **Ming Tang**
DEI representative: **Victoria Blair**

Bioceramics Division

Chair: **Kalpana Katti**
Chair-elect: **Annabel Braem**
Vice chair: **Hrishikesh Kamat**
Secretary: **Ashutosh K. Dubey**
DEI representative: **TBD**

Cements Division

Chair: **Wil V. Srubar III**
Chair-elect: **Prannoy Suraneni**
Secretary: **Alex Brand**
Trustee: **Matt D'Ambrosia**
DEI representative: **Kendra Erk**

Education and Professional Development Council

Co-chair: **Steven Naleway** (2022–2024)
Co-chair: **Brian P. Gorman** (2023–2025)

Electronics Division

Chair: **Ed Gorzkowski**
Chair-elect: **Matjaz Spreitzer**
Vice chair: **Mina Yoon**
Secretary: **Reeja Jayan**
Secretary-elect: **Aiping Chen**
Trustee: **Geoff Brennecka**
DEI representative: **Brady Gibbons**

Energy Materials and Systems Division

Chair: **Eva Hemmer**
Vice chair: **Yang Bai**
Secretary: **Charmayne Lonergan**
Program chair: **Jianhua Tong**
DEI representative: **Marissa Riegel**

Engineering Ceramics Division

Chair: **Young-Wook Kim**
Chair-elect: **Jie Zhang**
Vice chair/Treasurer: **Amjad Almansour**
Secretary: **Federico Smeacetto**
Trustees: **Valerie Wiesner** and **Palani Balaya**
Parliamentarian: **Manabu Fukushima**
DEI representative: **Federico Smeacetto** (2022–23)

Glass & Optical Materials Division

Chair: **Irene Peterson**
Chair-elect: **Michelle Korwin-Edson**
Vice chair: **Mathieu Bauchy**
Secretary: **TBD**
DEI representative: **Jose Marcial**

Manufacturing Division

Chair: **Joseph Szabo**
Chair-elect: **Sarah Whipkey**
Vice chair: **Bai Cui**
Secretary: **TBD**
Counselor: **William Carty**
DEI representative: **Manoj K Mahapatra**

Refractory Ceramics Division
(term begins March 2023)

Chair: **Robert Hunter**
Vice chair: **Austin Scheer**
Secretary: **John Waters**
Program chair: **Brett Ervin**
Trustee: **Dana Goski**
DEI representative: **Angelo Cristante**

Structural Clay Products Division

Chair: **Jim Krueger**
Chair-elect: **Bryce Switzer**
Vice-chair: **Mike Rixner**
Secretary: **TBD**
Trustee: **Jed Lee** ■

Volunteer spotlight

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

Kelley Wilkerson is assistant teaching professor in the Department of Materials Science at Missouri University of Science and Technology. Her primary focus includes hands-on laboratory experiences at the undergraduate level. She received her bachelor's degree in ceramic engineering (2007) and Ph.D. in materials science (2012) from Missouri S&T. Prior to entering academia, she began her career at Allied Mineral Products working in the refractories industry.

In addition to teaching, Wilkerson has a passion for service and volunteerism. Since starting her teaching career in 2018, she has included service as a critical element of each course with the hope of inspiring students to have a passion for giving back to their community. She also serves the local community by providing STEM outreach events to K–12 students.

A member of The American Ceramic Society since 2007, Wilkerson has held several volunteer positions, including serving on the Strategic Planning and Emerging Opportunities Committee and the *Bulletin* Editorial Advisory Board. She has chaired multiple sessions at MS&T, and most recently served as chair of the Refractory Ceramics Division. Wilkerson has also been a part of the National Keramos Board.

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

IN MEMORIAM

Rodney Bagley

Charles Connors

John "Jack" Wachtman

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

ACerS Carolinas Section 2023 Annual Meeting

Members of the Carolinas Section leadership at the March 30, 2023, Annual Section Meeting. From left: Charles Lakeman, Ed Fuller, Taylor Barrett-Crvich, Jacob Jones, Divine Kumah, Cheryl Brayman, and Fei Peng.

The annual meeting of the ACerS Carolinas Section was held March 30, 2023, at the Advanced Materials Research Lab, Clemson University, S.C.

The student poster winners were

First place co-winners

Mary-Ann Cahoon, Clemson University

Thermal evolution of Yb-doped BaF_2 nanoparticles for silica optical fiber

Ningxuan Wen, Clemson University

Reinforcement learning-based inverse design on thermal metamaterial

Second place co-winners

Xiao Geng, Clemson University

Machine learning-based, inverse microstructure prediction from hardness for laser-sintered alumina

Xin Wang, University of Tennessee, Knoxville

Phase selectivity and stability in compositionally complex nano $(Al_{1/n})Co_2O_4$

Sujithra Chandrasekaran, University of North Carolina, Charlotte

Effect of concentration of NaOH on density and strength of SiC at high compact pressure ■

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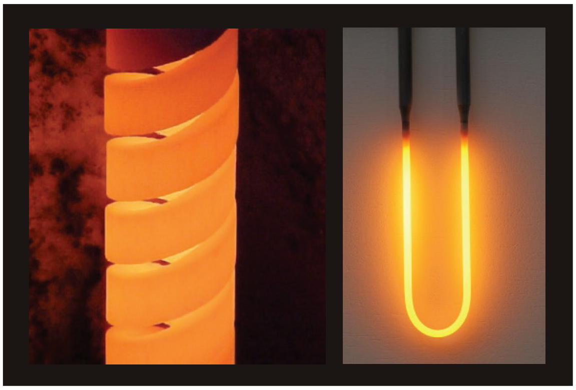

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New Jersey/New York Metro/Philadelphia Section hosts inaugural event, 2023 Malcom G. McLaren Lecture Symposium

Ahmad Safari (left), president of the Ceramic Association of New Jersey, and Lisa Klein (right), chair of the New Jersey/Metro New York/Philadelphia Section, with student winners at the 2023 Malcom G. McLaren Lecture Symposium.

The New Jersey/New York Metro/Philadelphia Section, along with the Rutgers Department of Materials Science and Engineering and the Ceramics Association of New Jersey, hosted the Malcom G. McLaren Lecture Symposium on March 30, 2023.

This annual event recognizes a distinguished member of the ceramics community. This year, the awardee was Benjamin V. Fasano, recently retired from IBM. Fasano gave the McLaren Lecture on the topic of "Advances in microelectronic packaging over the past 40 years." ■

Taiwan Chapter hosts second Taiwan–Japan workshop on powder processing technologies for high-quality products

The second Taiwan–Japan workshop on powder processing technologies was organized by Wei-Hsing Tuan of National Taiwan University and M. Naito of Osaka University. Several members of The American Ceramic Society attended the workshop, which was held March 9, 2023. ■

Attendees at the second Taiwan–Japan workshop on powder processing technologies.

Germany Chapter hosts workshop on lithium storage strategies

The Germany Chapter hosted a workshop on March 21, 2023, featuring Yuki Yamada, Tohru Sekino, and Yu Katayama, who are all affiliated with the Institute of Scientific and Industrial Research at Osaka University, Japan.

The researchers' respective areas of expertise include electrochemistry, solution chemistry, solid/liquid interfaces, nanomaterials science, ceramics, hyper-functionalized materials, materials chemistry, catalysis, and energy storage and conversion. The main focus of the workshop was advances in lithium storage strategies.

Ceramic Tech Chat: Jonathan Volk

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 April 2023 episode of Ceramic Tech Chat, Jonathan Volk, senior manager of in-space manufacturing and advanced materials at commercial space company Sierra Space, talks about how he became involved with the commercial space industry, outlines Sierra Space's vision for commercializing space, and considers the broader impacts of making space a more accessible destination.

Check out a preview from his episode, which features Volk talking about some of the benefits of manufacturing in space.

"There are certain parts of a manufacturing process that benefit from microgravity because it's a stage where if you eliminate those gravitational forces, the defects at that stage of the process could be mitigated. So, for example, the semiconductor manufacturing process. Obviously, you grow a semiconductor crystal initially, and that gets cut into wafers, and then you do your hundreds and hundreds of steps to make your pattern and your etching, and you eventually make a chip. But if you can start out and crystallize a better raw semiconductor material, you're starting off at a much better spot. So, that's something where even if we just did that crystallization stage in microgravity and then do our processing on the ground, we might be able to end up with a much better semiconductor that has fewer defects."

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

AWARDS AND DEADLINES

Nomination deadlines for Division awards: July 1, July 31, and Aug. 4, 2023

Contact: Karen McCurdy | kmccurdy@ceramics.org

Division	Award	Nomination Deadline	Contacts
ECD	**Jubilee Global Diversity**	July 1	Michael C. Halbig michael.c.halbig@nasa.gov
ECD	**Global Young Investigator**	July 1	Jie Zhang jiezhang@imr.ac.cn
ECD	**James I. Mueller**	July 1	Palani Balaya mpepb@nus.edu.sg
ECD	**Bridge Building**	July 1	Young-Wook Kim ywkim@uos.ac.kr
EMSD	**Outstanding Student Researcher**	July 31	Charmayne Lonergan charmayne.lonergan@pnnl.gov
BSD	**GEMS**	August 4	John Blendell Blendell@Purdue.edu

Nomination deadline: Sept. 1, 2023

The Darshana and Arun Varshneya Frontiers of Glass Lectures are presented at the GOMD annual meeting.

Contact: Erica Zimmerman | ezimmerman@ceramics.org | 614.794.5821

Society Awards	Description
Darshana and Arun Varshneya Frontiers of Glass Lectures	Lectures are designed to encourage scientific and technical dialogue in glass topics of significance that define new horizons, highlight new research concepts, or demonstrate the potential to develop products and processes for the benefit of humankind.

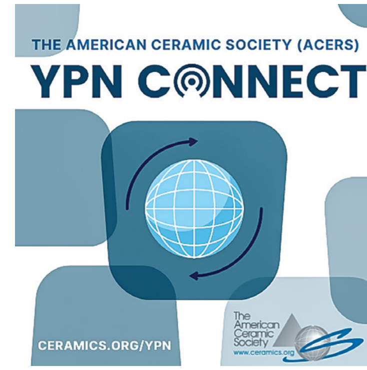
FOR MORE INFORMATION:

ceramics.org/members/awards

Description
Recognizes exceptional early- to mid-career professionals who are women and/or underrepresented minorities (e.g., based on race, ethnicity, nationality, and/or geographic location) in the area of ceramic science and engineering.
Recognizes an outstanding young ceramic engineer or scientist whose achievements have been significant to the profession and to the general welfare of the community around the world. Nominations are open to candidates from industry, academia, or government-funded laboratories across the world.
Recognizes the enormous contributions of James I. Mueller to the Engineering Ceramics Division and the field of engineering ceramics. It is the intent of this award to recognize the accomplishments of individuals who have made similar contributions.
Recognizes individuals outside of the United States who have made outstanding contributions to engineering ceramics.
Recognizes exemplary student research related to the mission of the Energy Materials and Systems Division of ACerS.
Recognizes the outstanding achievements of graduate students in materials science and engineering. The award is open to all graduate students who are making an oral presentation in any symposium or session at the Materials Science & Technology (MS&T) meeting.

STUDENTS AND OUTREACH

ACerS Young Professionals Network offers monthly YPN Connect events



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

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

ACerS GGRN—graduate student membership for ceramics and glass students

Build an international network of peers and contacts within the ceramics and glass community with ACerS Global Graduate Researcher Network.

ACerS GGRN is a membership in ACerS that addresses the professional and career development needs of graduate-level research students who have a primary interest in ceramics and glass.

GGRN members receive all ACerS individual member benefits, plus the opportunity to attend special events at meeting and access to free webinars on targeted topics relevant to the ceramics and glass graduate student community.

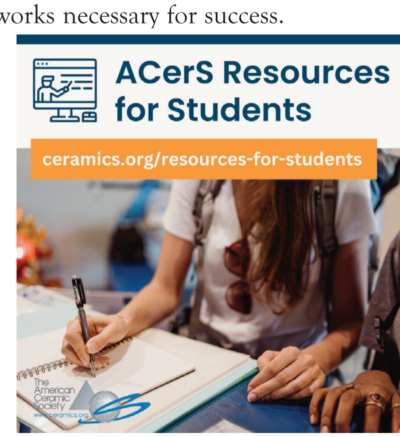
ACerS GGRN is only $30 per year. If you are a current graduate student focusing on ceramics or glass, visit www.ceramics.org/ggrn to learn what GGRN can do for you and to join directly. ■

ACerS resources for students are at your fingertips!

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

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

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



Material Advantage student program

The Material Advantage student program was created for undergraduate and graduate students enrolled in materials science, engineering, and other technical engineering programs at universities around the world. The program offers a single membership fee of $30 and provides access to four distinguished materials science and engineering professional societies: The American Ceramic Society (ACerS), The Association for Iron and Steel Technology (AIST), ASM International, and The Minerals, Metals, and Materials Society (TMS). Join today at www.materialadvantage.org. ■

FOR MORE INFORMATION:

ceramics.org/resources-for-students

From PCSA to industry leaders

PCSA students and CGIF staff introduce the new Glass Science Kit at the Center for Science and Industry in Columbus, Ohio. Front row from left: Brittney Hauke and Nathan McIlwaine. Back row from left: Aubrey Fry, Olivia Brandt, and CGIF staffers Amanda Engen, Helen Widman, and Marcus Fish.

The President's Council of Student Advisors (PCSA), fresh from their autumn annual board meeting, hums with excited energy as a new year begins. With a recently elected chair and visions for change, the PCSA readies itself to help even more students in the ceramics and glass community.

The PCSA primarily serves The American Ceramic Society, but according to PCSA chair Fox Thorpe, a Ph.D. student at the University of California, Davis, it really is a group that helps other students.

"Largely, I think we're a group focused on serving students, and so that's the biggest reason to support the PCSA," Thorpe says.

The PCSA has five committees: Conference Programming and Competitions, Communications, Recruitment and Retention, Education, and Professional Development. The Education and Professional Development Committees are new this year, originating out of a reorganization at the PCSA Annual Business Meeting in October 2022.

Overall, for this year, the PCSA's main goals are to increase international reach and improve support for young professionals in the ceramics and glass community. One way the PCSA aims to achieve these goals is by recognizing the importance of retaining members in ACerS after they are no longer students. As such, the PCSA has plenty of opportunities for alumni to come back and volunteer.

ACerS member Kristen Brosnan served as an industrial mentor for the PCSA in 2010. At the time, Brosnan worked at GE Research, and she attributes her connections to ACerS and the PCSA as opening more opportunities for her career.

"I didn't volunteer with the PCSA to get anything back. Personally, that was not the goal," Brosnan says. "I wanted to have fun and give back. And I will say it absolutely benefited my career."

Brosnan is now associate director of research and development at Collins Aerospace. One of her favorite memories about the PCSA is the Annual Business Meeting, when all the student delegates meet in person for networking, collaborating, and bonding.

"It is so energizing, like it literally was the pick-me-up of the year for me because these are the future leaders, and it is just so energizing to see that much energy and passion in the room," Brosnan says. "Who can't get excited about that?"

Kristin Brosnan

For Thorpe, the benefits of the PCSA have extended even further than just professional development.

"I joined the ceramics community with zero network, with zero knowledge, and pretty much like nothing that I knew about materials science," he says. "It's been really good to have people to ask about jobs, internships, postdocs, just having a group of people who are studying the same things and have an interest in similar opportunities."

The continued success and impact of the PCSA would not be possible without the support of donors who see the value in building a network of future ceramics and glass professionals. ■

advances in nanomaterials

New carbon structures open a realm of possibilities

Carbon has played an essential role throughout human history, from heating people's homes and forges (coal) to recording their thoughts (graphite in pencils).

However, the use of carbon in more complex forms started only recently, with discovery of the first fullerene in 1985. This discovery of closed cage "buckyballs" led to the identification of other structures, including carbon nanotubes in 1991 (hollow cylindrical shells of carbon atoms) and graphene in 2004 (a monolayer of carbon atoms).

The exploration for new carbon structures continues. Below are three recent carbon-related discoveries.

Enter the fullertubes

In August 2020, researchers led by Purdue University announced a new carbon structure—the fullertube.

Fullertubes are pill-shaped structures that fall somewhere between spherical fullerenes and cylindrical nanotubes. They essentially consist of two buckyball halves connected by a nanotube midsection.

The first fullertubes consisted of either 90, 96, or 100 carbon atoms. They follow the rule that 12 pentagons and an even number of hexagons can form a closed shell, which allows for an additional number of hexagons.

A two-step chemical separation process allowed scalable quantities of fullertubes to be synthesized with uniform masses, shapes, and properties. This consistency gives fullertubes a leg up on carbon nanotubes, which often are a jumble of random lengths and diameters. As such, fullertubes have great potential as components in electrical circuitry, light-based sensors, or fluorescence imaging of biological cells.

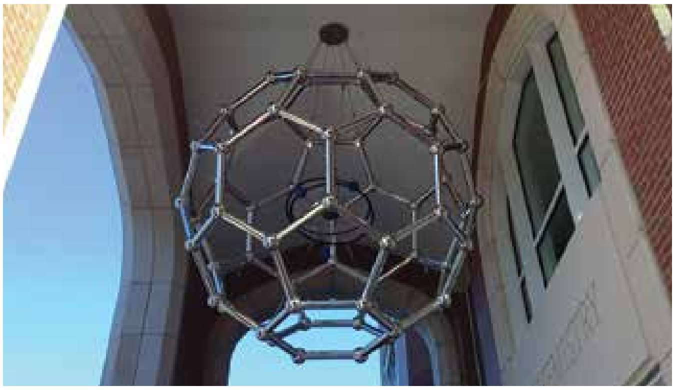
In August 2022, the Purdue-led researchers announced two more fullertube structures, both consisting of 120 carbon atoms. The narrower, longer structure is electrically conductive while the wider, shorter one is a semiconductor, thus expanding applications to transistors and other miniature electronic devices.

The August 2020 paper, published in *Journal of the American Chemical Society*, is "Fullertubes: cylindrical carbon with half-fullerene end-caps and tubular graphene belts, their chemical enrichment, crystallography of pristine C_{90}–D_{5h}(1) and C_{100}–D_{5d}(1) fullertubes, and isolation of C_{108}, C_{120}, C_{132}, and C_{156} cages of unknown structures" (DOI: 10.1021/jacs.0c08529).

The August 2022 paper, published in *Journal of the American Chemical Society*, is "Gigantic C_{120} fullertubes: Prediction and experimental evidence for isomerically purified metallic [5,5] C_{120}–D_{5d}(1) and nonmetallic [10,0] C_{120}–D_{5h}(10766)" (DOI: 10.1021/jacs.2c06951).

Graphullerene: graphene's 'superatomic' cousin

In contrast to fullertubes, which combine fullerenes and nanotubes, a new carbon structure dubbed graphullerene combines fullerenes with graphene.



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

Sculpture of a fullerene, a complex carbon form discovered in 1985.

Researchers at Columbia University and the University of Florida published their paper on graphullerene in January 2023. The material consists of fullerene subunits arranged hexagonally in a covalently interconnected molecular sheet. It is created the same way as graphene, i.e., by peeling ultrathin flakes from a larger three-dimensional crystal (in this case, graphullerite instead of graphite).

The fullerene subunits can be linked together in different ways to produce a variety of magnetic and optical properties, leading to new optical and electronic devices. Graphullerene also displays high thermal conductivity, which means it dissipates heat well and could aid in device miniaturization.

The January 2023 paper, published in *Nature*, is "A few-layer covalent network of fullerenes" (DOI: 10.1038/s41586-022-05401-w).

Broken fullerenes maintain long-range periodicity

The final carbon structure comes from work by researchers at South Korea's Institute for Basic Science and China's University of Science and Technology. Their long-range ordered porous carbon (LOPC) paves the way for the discovery of other crystalline carbons starting from C_{60} fullerenes.

To create LOPC, the researchers mixed C_{60} fullerene powder with alpha lithium nitride (α-Li_3N). When heated, the α-Li_3N acts as a catalyst, breaking some of the fullerene's carbon–carbon bonds. New carbon–carbon bonds are then formed with neighboring C_{60} molecules.

The resulting LOPC consists of a string of broken C_{60} cages bonded to each other. As such, it demonstrates the unusual situation of having long-range periodic order even though not every broken C_{60} cage is identical to its neighbors.

The researchers see several possible applications for LOPC, including in harvesting, transformation, and storage of energy; catalysis to generate chemical products; and separation of molecular ions or gases.

The January 2023 paper, published in *Nature*, is "Long-range ordered porous carbons produced from C_{60}" (DOI: 10.1038/s41586-022-05532-0). ■

Deep learning network detects individual carbon nanotubes in SEM images

University of Missouri (Mizzou) researchers developed a deep learning technique to segment carbon nanotube (CNT) forests in scanning electron microscopy images.

Due to their tiny size, synthesizing individual CNTs is difficult and often impractical for device-level integration. So, CNTs are more frequently grown as "forests," i.e., as collective arrays on a support substrate.

The tradeoff of growing CNTs in bulk is that the CNT forest has vastly diminished properties due to the higher incidence of structural defects.

Researchers looking to improve the physical properties of CNT forests can compare these traits to the forest's growth parameters, which can guide modification of the synthesis process. Unfortunately, testing for physical properties of CNT forests often requires destruction of the forest, which prevents further data collection.

A method to determine physical properties of CNT forests indirectly using images would avoid the data limitation of current destructive testing methods. To develop such a method, the first step is creating a program capable of segmenting the dense forest into individual CNTs.

Classical image processing approaches, such as thresholding and maximum entropy, only partially parsed out individual CNTs. Instead, emerging machine learning processes may enable a better way to segment images for analysis.

In a conference paper from the European Conference on Computer Vision, the Mizzou researchers explain that because of data complexity and ambiguity, there is a shortage of high-quality datasets with associated labels that can enable use of supervised learning-based approaches.

So, "Self-supervising learning has emerged as an approach to learn good representations from unlabeled data and to perform fine-tuning with labeled features at the down-stream tasks," they write.

As explained in a 2020 review paper, self-supervised learning models are trained using pseudo labels that are generated automatically without the requirement for human annotations. This training procedure consists of two steps: a pretext task and a downstream task. Feature representation is learned in the pretext task, while model adaptation and quality evaluation are completed in the downstream task.

The self-supervised segmentation method proposed by the Mizzou researchers consists of a novel deep neural network that uses two complementary sets of self-generated training labels.

- The first label, intensity thresholded raw input image, serves as a weak label that leads the network to perform binary CNT segmentation.
- The second label, CNT orientation histogram calculated directly from the raw input image, constraints the segmentation process by enforcing the network to preserve orientation characteristics of the original image.

These labels are used to conduct a two-component loss function.

- The first component is dice loss, which is computed between the predicted segmentation maps and the weak segmentation labels.
- The second component is mean squared error loss (MSE), which measures the difference between the orientation histogram of the predicted segmentation map and the original raw image.

The weighted sum of these two loss functions is used to train the deep neural network. Specifically,

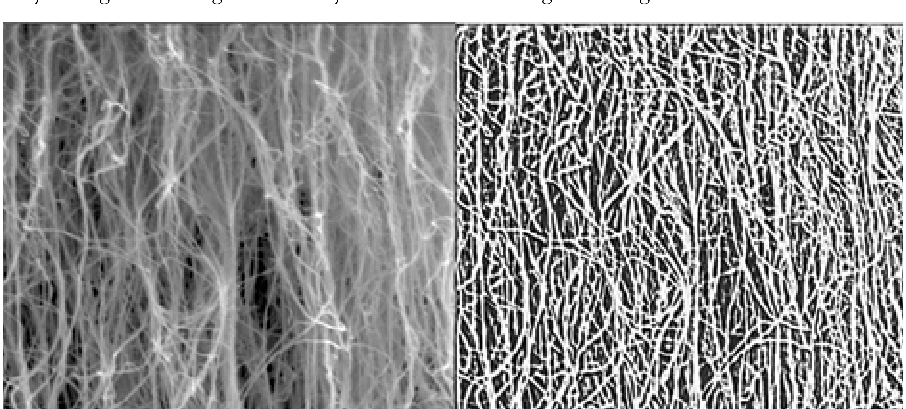
- The dice loss forces the network to perform background–foreground segmentation using local intensity features.
- The MSE loss guides the network with global orientation features and leads to refined segmentation results.

After training the proposed network, the researchers compared its performance to three other segmentation methods: adaptive intensity thresholding, k-means clustering, and a recent unsupervised deep learning-based segmentation method based on differentiable feature clustering.

The researchers found their deep neural network results in more refined segmentation masks with better recall of the individual CNTs compared to the other three methods. Additionally, compared to the k-means clustering and unsupervised deep segmentation methods, the proposed network is more robust to illumination variations.

While this study focused on three CNT parameters—diameter, density, and growth rate—the researchers emphasize that the proposed network can be retrained using new datasets to improve performance or to adapt to new image characteristics. It could also be used to analyze other curvilinear structures, such as biological fibers or synthetic fibers.

The paper, published in *Computer Vision–ECCV 2022 Workshops*, is "Self-supervised orientation-guided deep network for segmentation of carbon nanotubes in SEM imagery" (DOI: 10.1007/978-3-031-25085-9_24). ■



Credit: University of Missouri

Raw scanning electron microscopy image of a carbon nanotube forest and the output from a new deep learning model developed at the University of Missouri.

research briefs

Piezoelectric effect observed in liquids for the first time

In a recent paper, researchers at Michigan State University reported the observation of piezoelectricity in liquids for the first time.

Piezoelectricity refers to the generation of an electric charge in certain materials resulting from applied mechanical stress. Materials that exhibit this "direct" piezoelectricity also exhibit "converse" piezoelectricity, i.e., the generation of mechanical strain by applying an electric field.

Current understanding of the mechanisms behind piezoelectricity requires a material to have substantial structural organization. It is not surprising, then, that all known piezoelectric materials are solids because liquids and gases are generally considered to have no persistent order.

"As a consequence, one would hardly ever think to look for a piezoelectric response from a liquid," says Gary Blanchard, professor of chemistry at Michigan State University.

Yet this basic assumption was turned on its head in the new paper published by Blanchard and Ph.D. candidate Md Iqbal Hossain, which reported the observation of piezoelectricity in room-temperature ionic liquids.

Ionic liquid is the term for a salt in the liquid state. Unlike conventional liquids such as water and gasoline, which are predominantly made of electrically neutral molecules, ionic liquids consist of ions and have a net electrical charge.

Ionic liquids are recognized as highly promising alternative green solvents in chemical processes. They also have been used as additives in advanced (solid-phase) materials, such as perovskite solar cells.

In an *IEEE Spectrum* article, Blanchard says his group was conducting experiments designed to better understand the basic properties of ionic liquids. They were shocked to find two different room-temperature ionic liquids each generated electricity when a piston squeezed them within a cylinder.

Blanchard and his students repeated the experiment multiple times to confirm reproducibility of the results. They also filled the cylinder with two standard liquids, ethylene glycol and 1 M NaCl in ethylene glycol, to confirm neither produced a measurable piezoelectric response when compressed.

With this validation, they then tested if the room-temperature ionic liquids exhibited converse piezoelectricity. They did so by applying an electric charge to ionic liquids stored in a lens-shaped container. Upon application, there was a measurable change in the ionic liquid's focal length—i.e., how much it bent incoming light—which suggests the liquid experienced mechanical strain.

Blanchard says they are still trying to identify the fundamental mechanisms behind the piezoelectric effect in these liquids. What is certain, though, is that "the current theory for solid-state piezoelectric materials will require some modification to account for the experimental observations presented here," he and Hossain write in the paper.

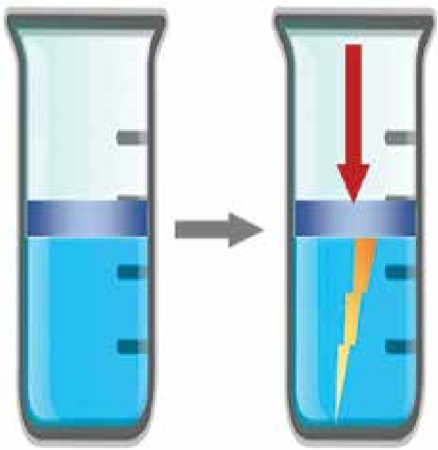


Illustration of an ionic liquid being compressed by a piston in a cylinder, resulting in the generation of an electric charge. Reprinted with permission from Hossain and Blanchard, *The Journal of Physical Chemistry Letters*. Copyright 2023 American Chemical Society.

The magnitude of the piezoelectric effect in these ionic liquids is an order of magnitude smaller than that of quartz, a widely used piezoelectric ceramic. Blanchard says it will be interesting to see if other ionic liquids have a bigger effect.

The paper, published in *The Journal of Physical Chemistry Letters*, is "Ionic liquids exhibit the piezoelectric effect" (DOI: 10.1021/acs.jpclett.3c00329). ■

Research News

Stab-resistant fabric gains strength from carbon nanotubes, polyacrylate

Fabrics that resist knife cuts can help prevent injuries and save lives. But a sharp enough knife or a very forceful jab can get through some of these materials. Now, researchers report that carbon nanotubes and polyacrylate strengthen conventional aramid to produce lightweight, soft fabrics that provide better protection. They say it is because the nanotubes create bridges between the fibers, thereby increasing friction. Additionally, the nanotubes form a thin, protective network that disperses stress away from the point of impact and helps prevent fiber disintegration. For more information, visit https://www.acs.org/pressroom/presspacs/2023.html. ■

Using solar farms to generate fresh desert soil crust

In a proof-of-concept study, Arizona State University researchers adapted a suburban solar farm in the lower Sonoran Desert as an experimental breeding ground for biocrust. Biocrusts, or biological soil crusts, are communities of living organisms that form a thin layer on the surface of soils in arid and semi-arid ecosystems. They play a crucial role in maintaining soil health and ecosystem sustainability, but human activities can lead to the degradation of biocrusts. During the three-year Arizona State study, photovoltaic panels promoted biocrust formation, doubling biocrust biomass and tripling biocrust cover compared with open areas with similar soil characteristics. For more information, visit https://news.asu.edu. ■

Discovery of ferroelectricity in elementary substance expands understanding of this property

In a recent open-access paper, researchers in China and Singapore experimentally confirmed the discovery of ferroelectricity in an elementary substance.

Ferroelectricity is the property of certain materials to exhibit spontaneous electric polarization that can be reversed through application of an external electric field. Ferroelectricity occurs due to the movement of positively and negatively charged ions within a unit cell, which leads to the creation of electric dipole moments.

Researchers traditionally assumed such electron redistribution could only be achieved in compounds. They expected atoms in the unit cells of an elementary substance (i.e., material consisting of a single element) to be identical, and so would not spontaneously form dipole moments.

In the past decade, some theoretical works suggested that ferroelectricity is possible in certain elementary substances. Specifically, the elements situated between metals and insulators in the periodic table, such as silicon and tellurium, show flexible bonding abilities. This ability allows them to have both positively and negatively charged ions in a unit cell—a basic feature for achieving ferroelectricity.

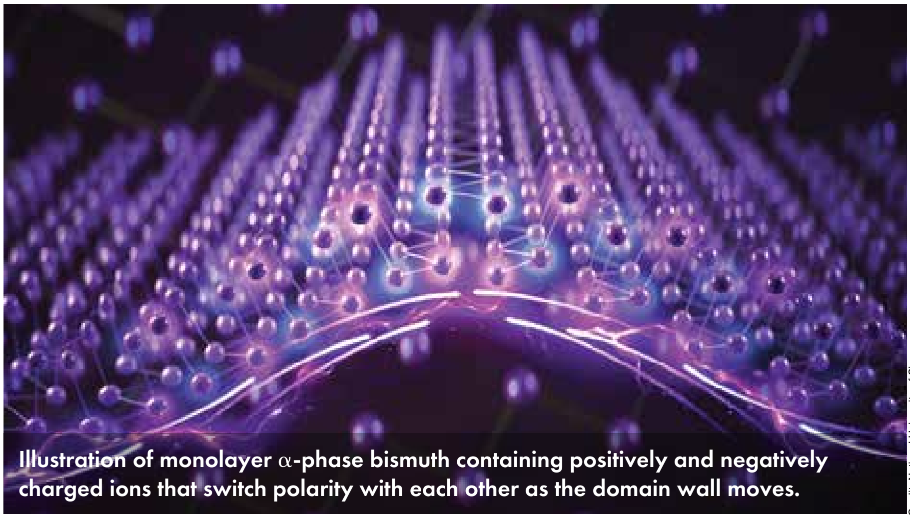


Illustration of monolayer α-phase bismuth containing positively and negatively charged ions that switch polarity with each other as the domain wall moves.

Credit: National University of Singapore

In 2018, the Chinese and Singaporean researchers, along with colleagues in the United States, used first-principles calculations to predict that monolayers of arsenic, antimony, and bismuth in the anisotropic α-phase structure could achieve in-plane ferroelectric polarization. Now, they experimentally confirmed ferroelectricity in monolayer α-phase bismuth.

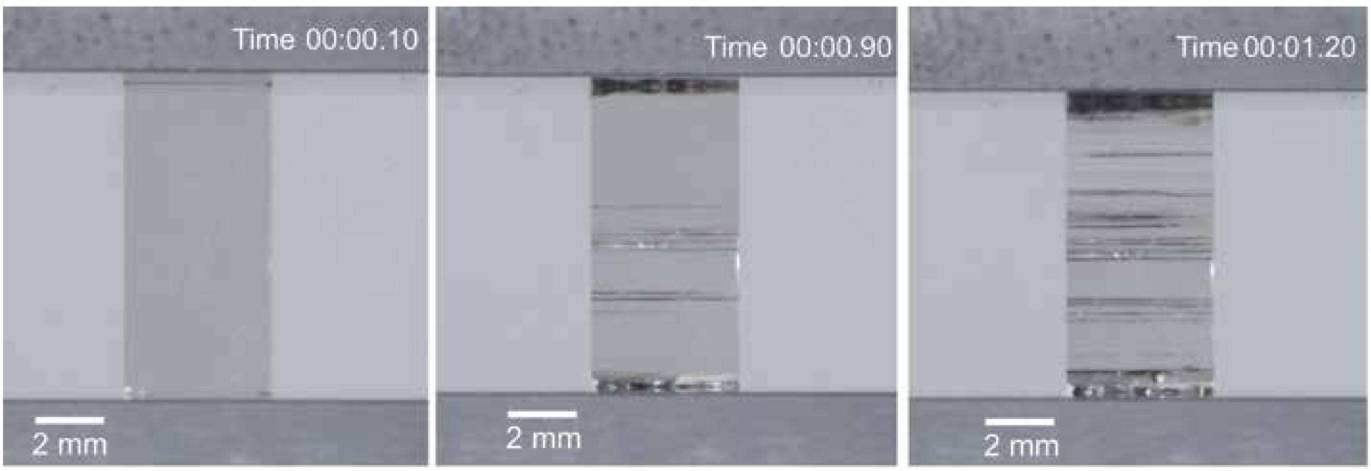
Their experiment involved growing monolayer α-phase bismuth on highly oriented pyrolytic graphite. Noncontact atomic force microscopy measurements confirmed the bismuth's structure, namely that it had two different states in two neighboring domains separated by a domain wall.

Based on this knowledge of the structure, along with measurements from scanning tunnelling spectroscopy and Kelvin probe force microscopy, the researchers concluded that in-plane polarization could be confirmed.

In a National University of Singapore press release, senior author and NUS professor Andrew Wee says that, in addition to overturning the assumption that ferroelectricity only exists in compounds, "we believe that single-element ferroelectricity in [monolayer α-phase bismuth] would introduce a new perspective to the study and design of novel ferroelectric materials, and inspire new physics of elemental materials in the future."

The open-access paper, published in *Nature*, is "Two-dimensional ferroelectricity in a single-element bismuth monolayer" (DOI: 10.1038/s41586-023-05848-5). ■

Deform to perform:
Dislocation-tuned properties of ceramics



Single-crystal strontium titanate deformed at room temperature during bulk compression.

By Xufei Fang, Atsutomo Nakamura, and Jürgen Rödel

Engineering dislocations into ceramics paves the road to harness versatile, unexpected functional and mechanical properties, which may open a new era for dislocation-based ceramic technologies.

Most materials science textbooks teach us that ceramics are infamously brittle due to the strong ionic and/or covalent bonding, and thus display little or almost no plasticity, particularly at room temperature.

Yet there are growing reports of ceramic materials (predominantly in single-crystal form) that can plastically deform at room temperature, with some of these discoveries tagged as "surprising" (for strontium titanate)[1] or "extraordinary" (for zinc sulfide).[2]

How are researchers achieving such counter-intuitive results? While several techniques have brought limited success (described in the next section), methods for engineering dislocations into ceramics have led to the most significant developments. This article will summarize these developments and consider what is next for the field of dislocations in ceramics.

From improved fracture toughness to ductile ceramics

Ceramics have much lower fracture toughness (about several $MPa{\cdot}m^{1/2}$) compared to metals (normally tens and hundreds of $MPa{\cdot}m^{1/2}$). This brittleness significantly limits the technological application of ceramics as structural or load-bearing materials.

Researchers have explored various ways to improve the fracture toughness of ceramics. The 1975 *Nature* paper "Ceramic steel?" successfully ignited (phase) transformation toughening of ceramics.[3] However, to date, this mechanism works mainly for zirconia-based ceramics. To toughen other types of ceramics, researchers have concentrated efforts on the bridging mechanisms and process-zone toughening, in addition to crack deflection.[4]

Rather than simply toughening ceramics, overcoming the inherent brittleness of ceramics so that they can plastically deform is an enduring pursuit that traditionally has met with limited success. One recent novel approach, namely "bond switching" for a dual-phase structure with coherent interface design, achieved room-temperature plastic deformation in silicon nitride with covalent bonding up to a total engineering strain of about 32%.[5] But this approach—which seems to have met the requirement of "changing the bond strength,"[6] which is a prerequisite for dislocation motion in metals[5]—is limited to the submicrometer range, and the general applicability in bulk samples remains elusive.

Dislocation research in ceramics

Apart from the above endeavors, since the late 1950s, a rather continuous line of research on ductile ceramics has focused on dislocations.

Dislocations are one-dimensional line defects that are the main carriers of plastic deformation in crystalline solids. Nowadays, dislocation-mediated plastic deformation is best known in metallic materials. It is, however, worth mentioning that the very first systematic studies on dislocation multiplication and motion were conducted on nonmetallic lithium fluoride by Gilman and Johnston using the chemical etching method,[7,8] which coincides with the rising prominence of transmission electron microscopy in the mid-1950s.

With the difficulty of inducing plasticity in most ceramics at room temperature, investigations of dislocations in ceramics initially focused on alkali halides and magnesium oxide. The development of high-temperature mechanical testing techniques in the 1950s gradually opened the window for probing dislocations in more ceramics, with many more studies in this field taking place in the 1970s–1980s.[9]

Since about 2003, various promising proofs-of-concept for a wide range of functional properties tuned by dislocations in ceramics were identified and investigated,[10] revealing a new research wave that likely will open a new chapter for dislocation engineering in ceramics.

New perspective for dislocations in ceramics

Charged feature of dislocation cores in ceramics

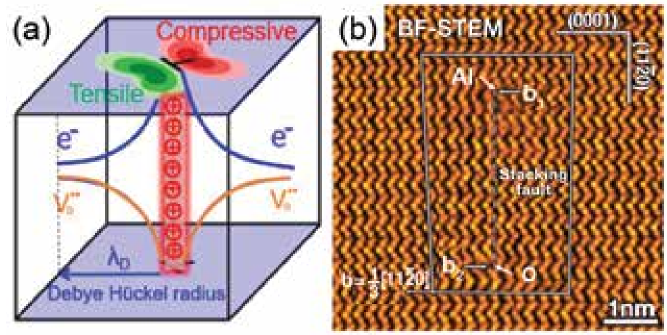
Unlike metals, dislocations in ceramics with ionic and/or covalent bonding may carry charges at their cores,[12,13] with a surrounding space charge layer for charge compensation (Figure 1a). For instance, the bright-field scanning transmission electron microscopy image in Figure 1b demonstrates a nonstoichiometric dislocation core in aluminum oxide (α-Al_2O_3). The lateral charge extension can be described by the Debye-Hückel radius (Figure 1a). Its value is prone to change if the charge of the core can be altered. For instance, reducing oxide samples with dislocations at high temperatures has been found to change the charge carrier concentrations around dislocations.[14]

Dislocation-tuned functional properties

The charges of the dislocation core, together with the high local strain field surrounding dislocations, bring vast opportunities to tune the mechanical and physical properties in ceramics. For instance, dislocations in ceramics can: 1) tune the potential barrier for thermal or electrical scattering; 2) act as pinning centers for domain walls in ferroelectrics; 3) provide sites for enhanced transport and reaction rate owing to the local atomic distortion; and 4) serve as self-doping elements to local charge states and local bandgaps of the material.

Moreover, in contrast to point defects that suffer from a drastic decrease in stability due to thermal activation at elevated temperatures, dislocations provide much better structural stability at high temperatures. For instance, high-temperature stability was reported up to 1,200°C in polycrystalline strontium titanate.[15] This thermal stability enables potential new applications by shifting the boundary for current applications to much higher temperatures. The impact of employing dislocation networks to tailor functional oxides is promising, such as "hard" piezoelectrics for electronic applications, electronic or ionic conductors, thermoelectrics, and photoconductivity (Figure 2).

Most recently, Höfling et al. mechanically imprinted dislocation networks into bulk single-crystal barium titanate by uniaxial creep experiments at 1,150°C, which led to a 19-fold increase in the large-signal piezoelectric coefficient (d_{33}*).[16] Such a giant increase is attributed to the ferroelectric domain structures being skewed by dislocations, which strongly modify the electromechanical forces for dislocation-domain interaction.



Credit: a) Fang, Nakamura, and Rödel; b) Shibata et al., *Science*

Figure 1. (a) Schematic of a positively charged edge dislocation core with a compensating space charge surrounding it. The Debye-Hückel radius of the space charge is indicated by λ_D. The elastic stress fields are indicated on top of the sketch. (b) Atomic-resolution bright-field scanning transmission electron microscopy (BF-STEM) image of a basal edge dislocation core in aluminum oxide (α-Al_2O_3), illustrating a typical core structure of a basal dislocation observed from the $\langle 1\bar{1}00\rangle$ direction. The dislocation core is dissociated into two partials ($^1/_3\langle 10\bar{1}0\rangle$ and $^1/_3\langle 01\bar{1}0\rangle$) connected by a $\{11\bar{2}0\}$ stacking fault, with the upper partial core terminated by an aluminum column, whereas the lower partial core is terminated by an oxygen column. Both core terminations lie in between the aluminum and oxygen atomic planes. Each partial core is nonstoichiometric due to the excess of aluminum or oxygen, suggesting possible charged cores. Figure (b) reprinted/adapted with permission from Ref. 11. Copyright 2007, American Association for the Advancement of Science.

As for room-temperature deformation, Hameed et al. reported dislocation-tuned superconductivity well above the superconducting transition temperature in single-crystal strontium titanate that was plastically deformed at room temperature.[17] The superconducting transition temperature increases as high as 30–50°C in the deformed sample, which is suggested to be influenced by the local strain surrounding the dislocations.

Further explorations of dislocation-based electrical properties in strontium titanate as well as titanium dioxide have been reviewed by Szot et al.[18]

Dislocation-tuned mechanical properties

As dislocations are one of the main carriers for plastic deformation, it is expected that engineering dislocations into ceramics can significantly impact the mechanical properties, such as yield strength, hardness, and creep. Most significantly, dislocations can improve fracture toughness and damage tolerance to combat the brittleness of ceramics.

For instance, Li et al. reported about 12% plastic strain at room temperature with micropillar compression of flash-sintered titanium dioxide.[19] The large plasticity (six times higher than conventionally sintered titanium dioxide) is proposed to be caused by the enrichment of preexisting dislocations and stacking faults generated during the highly nonequilibrium sintering process. Besides tailoring plasticity, Porz et al. demonstrated a two-fold increase of the crack-tip toughness by engineering surface dislocations into single-crystal strontium titanate.[20]

Deform to perform: Dislocation-tuned properties of ceramics

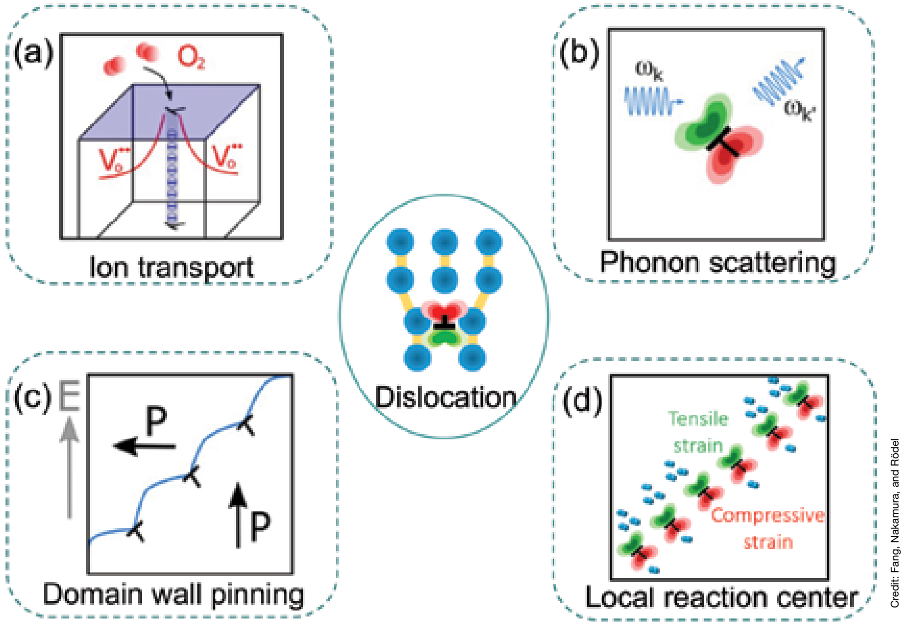


Figure 2. Perspectives for versatile functional applications: (a) dislocations act as a fast diffusion path for oxygen, holding potential for solid oxide fuel cells; (b) dislocations scatter phonons to reduce thermal conductivity, benefiting the thermoelectric figure of merit; (c) dislocations act as pinning centers for domain walls, leading to enhanced electromechanical properties in ferroelectrics; and (d) dislocations act as local active centers, boosting reaction rates.

Dislocations with charged cores exhibit both elastic and electrostatic characteristics, which are subject to modifications in physical fields (e.g., light irradiation, electric field). This charged feature marks another fundamental difference between dislocations in ceramics and metals (which only have elastic characteristics), offering new opportunities to tune the dislocation-mediated plastic deformation and fracture toughness.

Recently, Oshima et al. provided a striking example of photoplasticity in bulk single-crystal zinc sulfide: An ultimate plastic strain of about 45% was observed in complete darkness, contrasting the almost immediate fracture (~2% strain) under ultraviolet light (365 nm).[2] Such an effect was coined as photoplasticity, with the impact of light most significant near the absorption edge of the bandgap. The decreased plasticity of zinc sulfide in ultraviolet light was attributed to the suppressed dislocation mobility caused by the reconstruction of charged dislocation cores due to electron–hole pairs excited by light.

Besides light illumination, electric field and electron beam injection can also significantly impact the plastic behavior of ceramics (even at room temperature), possibly by altering the local electronic state of dislocations. A combination of these external fields with mechanical loading may hold a key to unlocking room-temperature plasticity in many more ceramic materials.

Ceramic dislocation toolboxes

Toolbox: Engineering dislocations into ceramics

To tune the functional and mechanical properties of ceramics, the prerequisite is to engineer dislocations with controllable densities and a scalable plastic zone size. Ideally, the spatial arrangement of dislocations and their mesostructure would be controllable as well.

Due to the brittleness of most ceramics, engineering dislocations into ceramics without crack formation remains one of the most pressing bottlenecks. In brief, dislocation engineering in ceramics can be achieved mainly by a) interface design; b) processing; and c) mechanical deformation.

a) Interface design. Well-aligned dislocations can be produced by bicrystal interface bonding,[21] while the interface lattice mismatch may produce high-density threading dislocations during thin film growth. Both methods require strict fabrication parameters (e.g., temperature, pressure, impurity of the crystals) to achieve samples of high quality, and they are not suitable for mass production. Moreover, this method currently provides only a well-structured interface and not a bulk material.

b) Processing. High densities of dislocations up to about $10^{14}/m^2$ were reported using new sintering techniques (e.g., flash sintering of titanium dioxide).[19] These processing techniques yield polycrystalline samples that are very often rich in pores and microcracks, and grain boundaries also add to the structural complexity.

c) Mechanical deformation. Dislocations can be induced by bulk compression at both room temperature and high temperature,[1] or via micromechanical testing, such as nanoindentation.[22] Additionally, simple surface grinding was found to achieve an extremely high dislocation density (up to ~$10^{15}/m^2$) in strontium titanate,[23] although it is limited only to the near-surface region (~2 μm in depth, Figure 3).

Among these approaches, mechanical deformation offers the opportunity to align dislocations in the sample on their slip planes for functional anisotropy. However, due to the high Peierls stress in most ceramics, plastic deformation in these ceramics strongly relies on thermal activation and dislocation dissociation. Dislocations are thus introduced mainly via high-temperature bulk compression above 1,000°C.

Plastic deformation is featured by discrete surface slip bands after deformation, with dislocation-rich regions extracted for functionality evaluation. In fact, quite a few ceramic materials exhibit large plasticity at temperatures below 800°C, which holds much potential for engineering.

Here, we focus on dislocation engineering via mechanical deformation. To this end, we present a specific example of room-temperature deformation of single-crystal strontium titanate, a prototypical perovskite with cubic structure at room temperature.

In 2001, Brunner et al. found that single-crystal strontium titanate can yield plastic deformation up to about 7% in uniaxial bulk compression even at room temperature.[1] The discovery was termed "surprising" in the original publication title. After this work, there were quite a few studies on the plastic deformation of

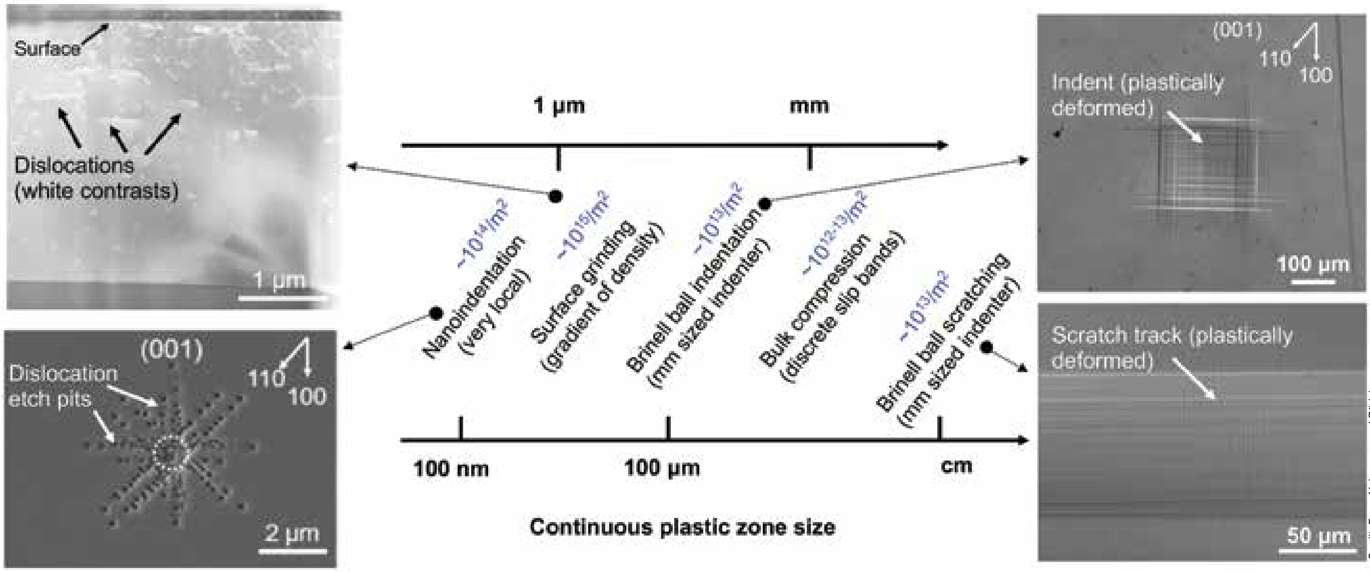


Figure 3. Overview of mechanical engineering approaches to tune dislocation density and plastic zone size in single-crystal strontium titanate at room temperature. The dislocations are visualized either directly by transmission electron microscopy and chemical etching, or indirectly by slip traces after plastic deformation. Note that the dislocation density in undeformed reference samples is about $10^9/m^2$.

strontium titanate ranging from −196°C (liquid nitrogen) up to about 1,500°C,[24] from bulk deformation to nanoscale testing.[22] Single-crystal strontium titanate therefore became a model material to study, particularly in regard to room-temperature dislocation plasticity.

Figure 3 summarizes the methods to mechanically engineer dislocations into single-crystal strontium titanate at room temperature (note the uniaxial bulk compression test is not displayed in Figure 3 due to its wide application). Dislocation densities from about $10^9/m^2$ (in undeformed reference samples) up to about $10^{15}/m^2$ were achieved, with a continuous plastic zone size from hundreds of nanometers up to mm- or cm-sized regions without crack formation. The authors of this article achieved these results by addressing the dislocation mechanics in strontium titanate (dislocation nucleation, multiplication, motion, and their competition), which will be discussed in the following section.

Toolbox: Dislocation mechanics in ceramics

In addition to the above experimental toolbox, this section focuses on the overarching engineering principles for dislocations in ceramics from the mechanics perspective.

The primary goal of dislocation engineering in ceramics is to avoid crack formation while promoting dislocation-mediated plastic deformation. Different to most metallic materials, ceramics at room temperature have limited slip systems that can be activated. (In most cases, there are only two independent slip systems, although physically there are six interdependent slip systems that can be activated, e.g., in sodium chloride and strontium titanate). The limited number of slip systems at room temperature does not fulfill the von Mises criterion, which is required for general plastic deformation in polycrystalline materials.

To circumvent this limitation, most studies of plastic deformation in ceramics were limited to single crystals. Focusing on single crystals, we suggest examining the dislocation-based plasticity from the following aspects: dislocation nucleation, dislocation multiplication, dislocation mobility, and the potential competition among these aspects.

Specifically, for room-temperature plastic deformation, one needs to select target materials that display appreciable dislocation mobility, which is the case for most alkali halides, strontium titanate, magnesium oxide, and zinc sulfide in bulk deformation, as mentioned above. It would not be feasible to aim for room-temperature bulk plastic deformation in aluminum oxide, for example, due to the extremely high lattice friction stress (several GPa at room temperature), except for nanoindentation or micro- or nanopillar compression.

Furthermore, it is worth noting that the potential competition among the above three fundamental factors (dislocation nucleation, multiplication, and mobility) can lead to interaction and reaction of dislocations, which may result in crack initiation. On the other hand, by applying external physical stimuli (e.g., electric field, light illumination, and magnetic field), the dislocation mechanics can be altered to significantly enhance or suppress the plastic deformation, as coined by electroplasticity, photoplasticity, and magnetoplasticity. The impact of external fields on dislocation mechanics, particularly how the fields are interacting with the (charged) dislocation cores, requires more extensive studies.

Because most ceramics have low fracture toughness (resistance to crack propagation), once cracks are nucleated or present, it becomes challenging to keep the cracks from propagating under external loading. Hence, we would like to point out that, in addition to the ongoing endeavors of using dislocations to increase the fracture toughness of ceramics,[20] a more appealing path is to focus on increasing the threshold for crack initiation based on dislocations, namely, improving the damage tolerance. If the crack initiation can be effectively suppressed (most relevant for single crystals or highly dense polycrystalline samples), the threshold for the onset of material failure would be correspondingly improved.

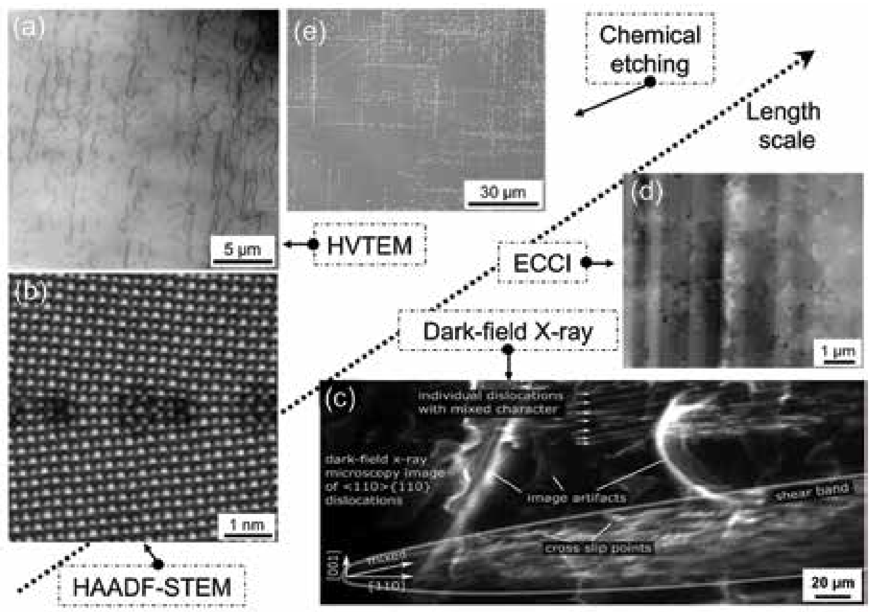


Figure 4. Representative characterization methods for dislocations in ceramics based on strontium titanate: (a) High-voltage transmission electron microscopy (HVTEM) featuring dislocations (dark lines) over a large view; (b) Dislocations at a low angle grain boundary imaged by scanning transmission electron microscopy (STEM) with a Cs-corrector for atomic resolution); (c) Dark-field X-ray microscopy features the dislocations (white contrast) in the shear bands; (d) Electron channeling contrast imaging (ECCI) image revealing the dislocations as bright spots in the near surface area; and (e) Dislocation etch pits (white spots) after chemical etching. Figure (c) reprinted/adapted with permission from Ref. 20. Copyright 2021, American Chemical Society.

Credit: a,b,d,e) Fang, Nakamura, and Rödel; c) Porz et al., *Materials Horizons*

Toolbox: Characterization of dislocations

A comprehensive understanding of dislocation mechanics for better control of dislocation engineering, as well as for better design of dislocation-tuned functional and mechanical properties, depends closely on the characterization of dislocations (sub)structure and their spatial arrangement. Thanks to the development of various techniques for revealing and imaging dislocations, a rich variety of tools is available.

As depicted in Figure 4, various techniques are available to probe dislocations at different length scales, with a focus on different structural characterizations spanning from atomic scale up to macroscale.

For instance, the scanning transmission electron microscopy method with a Cs-corrector is recognized as the best method for observing the atomic arrangement with atomic resolution. Thus, it has been an indispensable tool to probe the dislocation core, which is believed to hold the key to opening the design of next-generation functional materials using dislocations.

Chemical etching, the most classical approach, has been employed since the 1950s. This method allows for the study of the dislocation surface distribution in areas ranging from microscale (micrometer) up to macroscale (millimeter). The elegant works by Gilman and Johnston on lithium fluoride were briefly mentioned before.[7,8]

In addition to these techniques, it is worth mentioning that high-voltage transmission electron microscopy (HVTEM, with an acceleration voltage up to 1 MV, which became commercially available at the end of the 1960s, first in Japan) has been historically employed to study dislocation mechanics, allowing a much larger view of sample size (up to tens of micrometers) with higher sample thickness. For instance, Messerschmidt et al. systematically investigated the dislocation behavior in single-crystal magnesium oxide back in the 1970s and 1980s.[25] Their results brought abundant insights into dislocation motion and dislocation-crack tip interactions, yet the value of such work was underrated due to historical reasons, probably also because of the limited material system being investigated (magnesium oxide).

For other techniques such as electron channeling contrast imaging, dark-field X-ray microscopy, and dislocation decoration, readers are referred to the literature for more details.

Some open questions

Exciting and promising progress has been made in the past few years, extending the boundary of our understanding of dislocations in ceramics. Nevertheless, quite a few open questions remain to be answered. For instance,

1. What are the fundamental mechanisms for controlling dislocation plasticity in ceramics? Why are some ceramics (e.g., single-crystal strontium titanate, potassium niobate, magnesium oxide, zinc sulfide, calcium fluoride) plastically deformable at room temperature while most others (even with the same crystal structure, e.g., barium titanate) are not? How can we identify or predict more room-temperature deformable ceramics?

2. External stimuli, such as light irradiation, electric field, and magnetic field, may dramatically affect the plasticity of some ceramics, even at room temperature, by changing the dislocation multiplication and mobility. How can we use such physical fields to efficiently and effectively assist the plastic deformation of ceramics?

3. Point defects, such as oxygen vacancies, in ceramic oxides can carry charges. How would the charged point defects interact with the charged dislocation cores, and thus potentially impact the mechanical and functional stability over a long-time span? In particular, how would the external stimuli affect such interactions?

Concluding remarks

As the numerous studies referenced throughout this paper show, the conventional belief that "ceramics are brittle" can be misleading and should be addressed more carefully, for example, by specifying the temperature and scale at which fracture occurs.

For an advanced understanding of dislocation-mediated plastic deformation of ceramic materials, it is necessary to clarify the boundary conditions for mechanical deformation. For example, having or not having preexisting dislocations in the volume can make a significant difference on the plastic deformation of ceramics, as in the case of dislocation-rich, flash-sintered titanium dioxide samples that display appreciable plastic strain.

The same holds true for the deformation volume containing preexisting cracks or not. Regarding boundary conditions, the loading scenario (bulk compression or micro- or nanopillar compression), the temperature (high temperature or room temperature), the texture (single, bi- or polycrystalline), and even the strain rate during deformation can be detrimental for the outcome of plasticity or cracking.

Further progress will hinge on an extension of the deformation toolboxes based on, for example, prototypical strontium titanate toward other functional ceramics. An ultimate question most relevant for engineering application is, how far is it still to really achieve the "dislocation technology"[10] in functional ceramics? This achievement not only requires expertise and knowledge of mechanics, but it also requires in-depth characterization and understanding of the electronic structure induced by dislocations, which is closely related to the electrical conductivity, superconductivity, photoconductivity, and thermal conductivity, to name a few.

Overall, we expect to see a rise of dislocation studies in ceramics in the coming years, and a joint effort will undoubtedly be beneficial for advancing this exciting field.

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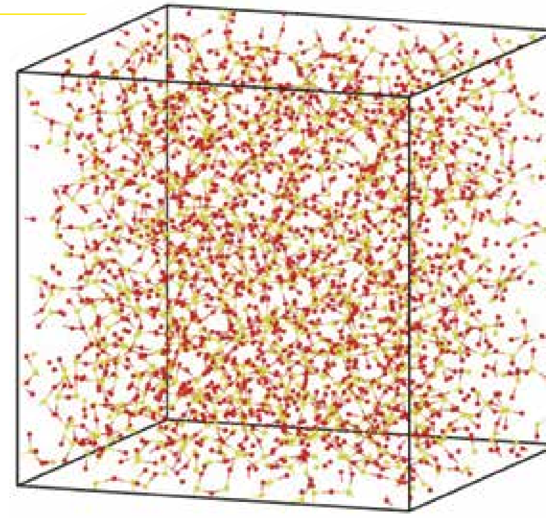
Decoding the structural genome of silicate glasses

By Qi Zhou, Mathieu Bauchy, and Ying Shi



Credit: Zhou

A 3D rendering of the structure of silica glass.

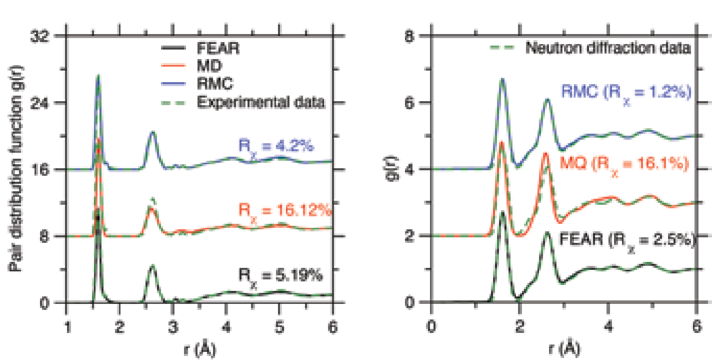
Silicate glasses can exhibit a wide range of properties.

To understand, tune, and enhance the properties of silicate glasses, one needs to decode the "glass genome," that is, to uncover how basic structural features control a glass's macroscopic properties.[1,2] Such decoding requires accurate knowledge of the atomic structure of silicate glasses. However, despite silicate glasses' ubiquity and technological importance, their atomic structure—especially at the medium-range order—remains only partially understood.[3]

Here, we present force-enhanced atomic refinement (FEAR) as a powerful modeling technique to unveil the three-dimensional structure of glasses.

Limitations of present experimental techniques

To date, no experimental technique can directly probe the three-dimensional atomic structure of silicate glasses. Conventional experiments solely offer some "fingerprints" of the glass structure—for instance, diffraction experiments and nuclear magnetic resonance can provide the structure factors and coordination numbers. Although this information offers some useful constraints on the nature of the glass structure, it does not directly reveal the three-dimensional structure itself.



Credit: (left) Zhou et al., *J. Non-Cryst. Solids* 2021 (CC BY 4.0); (right) Zhou, Shi, and Bauchy

Fig. 2. Neutron pair distribution functions (PDFs) of (left) silica and (right) sodium silicate glasses obtained by force-enhanced atomic refinement (FEAR), molecular dynamics (MD) using the melt-quench (MQ) method (1 K/ps), and reverse Monte Carlo (RMC). All the PDFs are compared with available experimental neutron diffraction data. The silica graph is republished from Ref. 9, while the sodium silicate graph is created from data reported in Ref. 7.

Challenges with modeling approaches

As an alternative route to experiments, atomistic simulations offer direct and full access to the atomic structure of glasses. However, atomistic simulations come with their own challenges and limitations.[4,5]

For example, molecular dynamics (MD) simulations solely rely on knowledge of the interatomic forcefield. Following the melt-quench method, melts are equilibrated at high temperature and subsequently quenched to the glassy state with a high cooling rate. Although this melt-quenching approach roughly mimics the experimental synthesis protocol of glasses, MD simulations are limited to very large cooling rates (typically 10^{-2} to 10^{2} K/ps) due to their computational cost.[5] This limitation is serious because the structure and properties of glasses depend on their thermal history.

An additional example is conventional reverse Monte Carlo (RMC) simulations, which solely rely on knowledge of experimental constraints.[6] As a key advantage, RMC simulations can yield glass structures that are compatible with such constraints while bypassing the melt-quenching route, thereby avoiding the issue of the cooling rate. However, an RMC simulation remains an ill-defined approach because, for instance, numerous atomic structures can exhibit the same pair distribution function. As such, glass structures that are generated by RMC typically exhibit an excellent agreement with the experimental data but may nevertheless be fairly unrealistic (e.g., showing extremely high potential energy).[7]

Force-enhanced atomic refinement (FEAR)

To overcome the limitations of MD and RMC, we adopted force-enhanced atomic refinement, or FEAR. This recent method leverages all available information, namely, (i) the interatomic forcefield, which is typically used by MD simulations; and (ii) experimental constraints, which are typically used by RMC simulations.[8]

In detail, FEAR relies on an iterative combination of sequential energy minimizations and RMC refinements wherein a pair distribution function (PDF) obtained by diffraction is used as the target. Technical details can be found in Refs. 7 and 9.

Quantitative agreement with experimental data

Figure 2 shows the neutron PDFs of silica and sodium silicate glasses. The level of agreement between FEAR and diffraction data is comparable to what is achieved by RMC, which is not surprising because RMC solely aims to minimize the difference between the simulated and experimental PDFs.

On the other hand, the level of accuracy offered by FEAR largely exceeds that of MD. Although MD yields a reasonable description of a glass's short-range order, the level of agreement between MD and diffraction data is lower at the medium-range order. In contrast, for both glasses, the PDFs of the glass structures generated by FEAR show an excellent agreement with experimental neutron data for both the short- and medium-range length scales.[7,9]

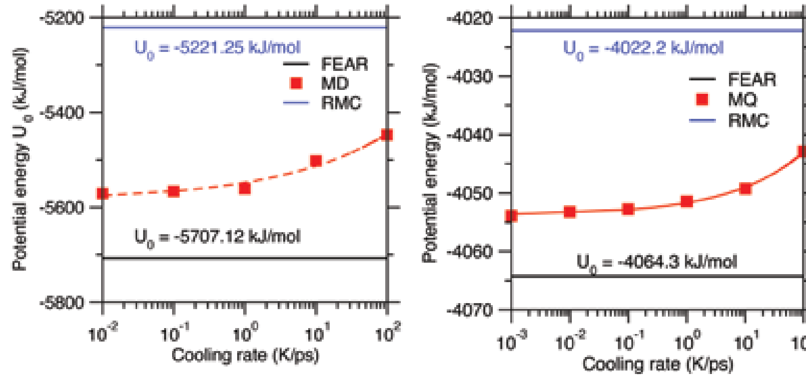
Unmatched thermodynamic stability

In addition to demonstrating excellent agreement with experimental data, the glass structures generated by FEAR exhibit an unmatched level of thermodynamic stability.

Figure 3 shows the molar potential energy of silica and sodium silicate glass structures generated by FEAR. It can be seen that FEAR yields some potential energies that are significantly lower than those offered by RMC—meaning the FEAR glasses are more thermodynamically stable. The high energy of the RMC structures exemplifies the fact that, although the PDFs calculated from these glass structures offer an excellent match with diffraction data, the configurations yielded by RMC are thermodynamically unstable.

The potential energy of the structures generated by FEAR is also notably lower than those obtained by MD, including for very slow cooling rates. This result demonstrates that, although FEAR and MD rely on the same interatomic forcefield, FEAR allows the simulated glass to reach more stable energy states.

All these results demonstrate that FEAR offers an improved description of the atomic structure of glassy silica as compared to traditional MD simulations based on the melt-quench method or RMC simulations.



Credit: (left) Zhou et al., J. Non-Cryst. Solids 2021 (CC BY 4.0); (right) Zhou, Shi, and Bauchy

Figure 3. Molar potential energy of melt-quenched (MQ) glasses generated by molecular dynamics (MD) simulations as a function of the cooling rate for (left) silica and (right) sodium silicate glasses. Values obtained for the glasses generated by force-enhanced atomic refinement (FEAR) and reverse Monte Carlo (RMC) are shown as horizontal lines for comparison. The silica graph is republished from Ref. 9, while the sodium silicate graph is created from data reported in Ref. 7.

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About the authors

Qi Zhou completed her Ph.D. in winter 2022 under the advisement of Mathieu Bauchy at the University of California, Los Angeles, and Ying Shi at Corning Inc. Contact Zhou at qi1197@ucla.edu.

Editor's note

Zhou will present the 2023 Kreidl Award Lecture at the Glass & Optical Materials Division Annual Meeting on June 6, 2023. Learn more about the conference at https://ceramics.org/gomd2023.

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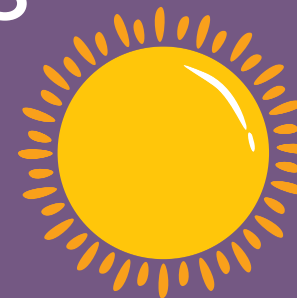

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Chair's update on PCSA activities and welcome to the student *ACerS Bulletin* issue

By Fox Thorpe, PCSA chair

The impermanent nature of life as a student imparts the necessity of an effective community.

From collaborative research and peer review to mentorship and camaraderie, community is central to our career and personal experiences. While we all strive to learn continuously, no one remains a student forever, and while our studies are our own, no one is a student alone. The ensemble of our mentors, colleagues, collaborators, and friends provides a network that enriches our personal growth and professional development.

When beginning their studies, students often find themselves in a new place, learning new things, surrounded by new people, and looking for a new home. Within ceramics, many students find their new home within ACerS. This year's issue of the *Bulletin* will feature student perspectives on the impact of the ceramics community.

The ACerS President's Council of Student Advisors (PCSA) began its year with a self evaluation and restructuring to better serve the ACerS community and represent students. In October 2022, the PCSA and its 46 student representatives, from 28 universities and eight countries, created its vision for the year.

Credit: ACerS

2022–2023 PCSA delegates at the PCSA annual meeting in October 2022. PCSA chair Fox Thorpe (center with blue jacket) stands with then-ACerS president Beth Dickey (right of Thorpe).

- **The Conference Programming Committee** is organizing conference activities focused on engaging students and enriching the conference experience. They recently organized and hosted career panels at EMA and ICACC and the shot glass drop competition at ICACC.
- **The Professional Development Committee** is a new committee focused on helping students grow their professional network and navigate the professional landscape. This committee is currently organizing webinars and a professional development event at ACerS Annual Meeting at MS&T 2023.
- **The Education Committee** is creating lesson plans and online tools, which complement the Materials Science Classroom Kits, to enable and empower anyone to perform K–12 outreach activities for ceramics and glass science. They are also working to establish local programs with robust and sustained outreach collaborations.
- **The Communications Committee** is generating engaging content to educate others about ceramics and ACerS events.
- **The Recruitment and Retention Committee** is looking for the next group of motivated and committed PCSA delegates. They are also focusing on helping and encouraging students to remain within ACerS after they graduate.

Additionally, the PCSA has instituted a diversity, equity, and inclusion taskforce to ensure its practices and activities are best suited for any students who wish to participate.

I am personally grateful to the ACerS community, where I have grown my professional network, learned invaluable lessons, and made lifelong friends. It is my hope that you enjoy this year's student issue of the *ACerS Bulletin*.

Fox Thorpe is a Ph.D. candidate at the University of California, Davis, studying in the McCormack Lab. As the 2022–2023 PCSA chair, he seeks to make the PCSA a more efficient and effective organization to better realize its goals in serving and representing the student community. ■

Congressional Visits Day 2023 recap

Credit: ACerS (all photos)

By Yolanda Natividad
ACerS liaison to the Material Advantage Student Program

The Material Advantage Student Program's Congressional Visits Day 2023 (CVD) was back to in person for the first time since 2019. This year's event took place on April 18–19, 2023.

The annual Material Advantage CVD event gives students an opportunity to visit Washington, D.C. to educate congressional decision makers about the importance of funding for basic science, engineering, and technology.

Students and faculty from the following universities participated in this year's event. Some university teams managed to schedule eight different appointments with their various members of Congress!

Alfred University
Case Western Reserve University
Colorado School of Mines
Iowa State University
Northwestern University
The Pennsylvania State University
The University of Alabama
University of Connecticut
University of Florida
University of North Texas
University of Tennessee Knoxville
University of Utah
University of Virginia
Washington State University

Each year, the CVD experience begins with an opening reception. The 2023 reception on April 18 featured talks by Alessandra Zimmermann, writer and analyst for the R&D Budget and Policy Program at the American Association for the Advancement of Science, and Jakob Lindaas, legislative assistant in the office of U.S. Sen. Martin Heinrich.

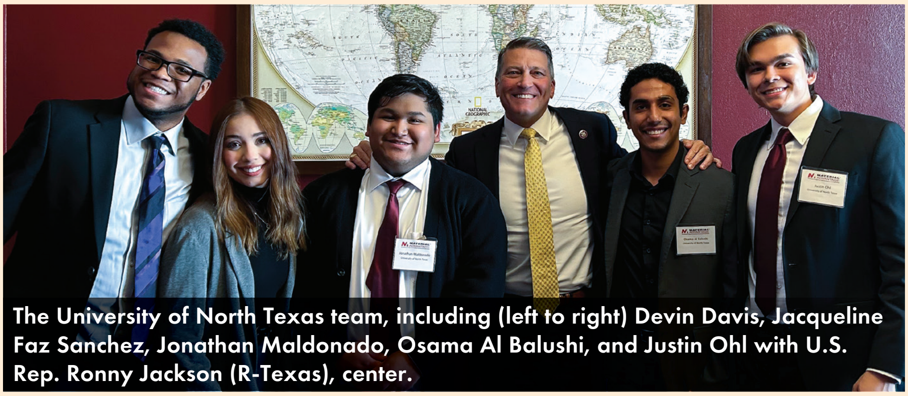
Attendees at the 2023 Material Advantage CVD opening reception.

After talks concluded, students were shown the dos and don'ts of a congressional visit, in addition to a chance to do some role-play interactions in advance of their appointments on the following day.

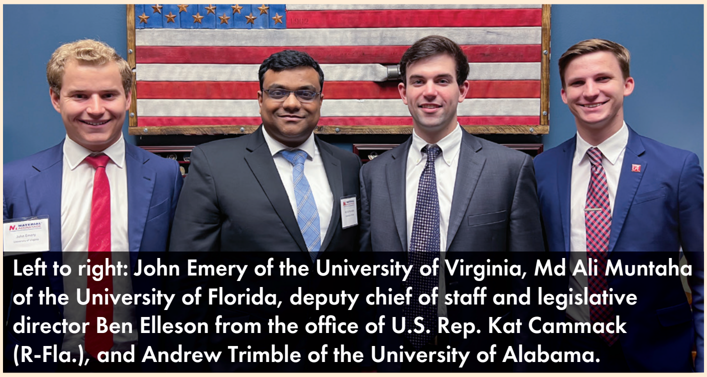
Thank you to David Bahr, head and professor of materials engineering at Purdue University; Iver Anderson, senior metallurgist at Ames Laboratory and adjunct professor in the materials science and engineering department at Iowa State University; and Megan Malara, director of medical modeling, materials, 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.

We look forward to being back in D.C. again next year. If you are a student and did not get a chance to participate this year, make sure that you register EARLY for the 2024 CVD event. Or if you are a professor/faculty advisor, make sure to plan on gathering a group together from your university.

Visit the Material Advantage website for future updates at www.materialadvantage.org. It is an opportunity that you will not want to miss! ■



The University of North Texas team, including (left to right) Devin Davis, Jacqueline Faz Sanchez, Jonathan Maldonado, Osama Al Balushi, and Justin Ohl with U.S. Rep. Ronny Jackson (R-Texas), center.



Left to right: John Emery of the University of Virginia, Md Ali Muntaha of the University of Florida, deputy chief of staff and legislative director Ben Elleson from the office of U.S. Rep. Kat Cammack (R-Fla.), and Andrew Trimble of the University of Alabama.

The Washington State University team, including (left to right) Raine Antonio, John Bussey, Brooke Downing, and Harvey Walker.

Appreciating the breadth and depth of the materials science community

By Benazir Fazlioglu-Yalcin

As a student who was always enthusiastic about studying and controlling change in life, I decided to pick a major where I could touch, smell, and see change. Unsurprisingly, chemistry soon became the top runner of my choices.

I loved the way teaching was done in the chemistry department at my undergrad university, Boğaziçi University in Turkey. The curriculum consisted of theory classes followed by student labs, which gave us the opportunity to apply what we learned in classes. I still get excited remembering the first time I saw an iodine solution changing its color from deep purple to a completely transparent solution during a redox reaction—and it was happening in my test tube!

As I progressed through my undergraduate degree, I started moving toward the materials science side of things as I became aware of the importance of studying and controlling change on a bigger scale. This realization led me to pursue my Ph.D. journey in the Department of Materials Science and Engineering at The Pennsylvania State University, with a focus on experiment rather than theory.

The Penn State materials science and engineering department is diverse with people coming from numerous different disciplinary backgrounds, including physics, chemistry, and various engineering fields. Despite these differences, students in the department share a love of materials. This love is what bonds the greater materials science community, regardless of whether you specialize in polymers, metals, or ceramics.

Because of this diverse pipeline of students entering materials science, the community benefits from a wide array of skills that can lead to immediate and fruitful collaborations on both small and large scales.

For example, the first time I truly appreciated this meshing of disciplines was during a study group session where my friends and I were struggling with a homework question. The question was somewhat related to chemistry, and my friends asked me to go to the whiteboard and explain that specific concept to them. That moment really made me feel like a part of the community.

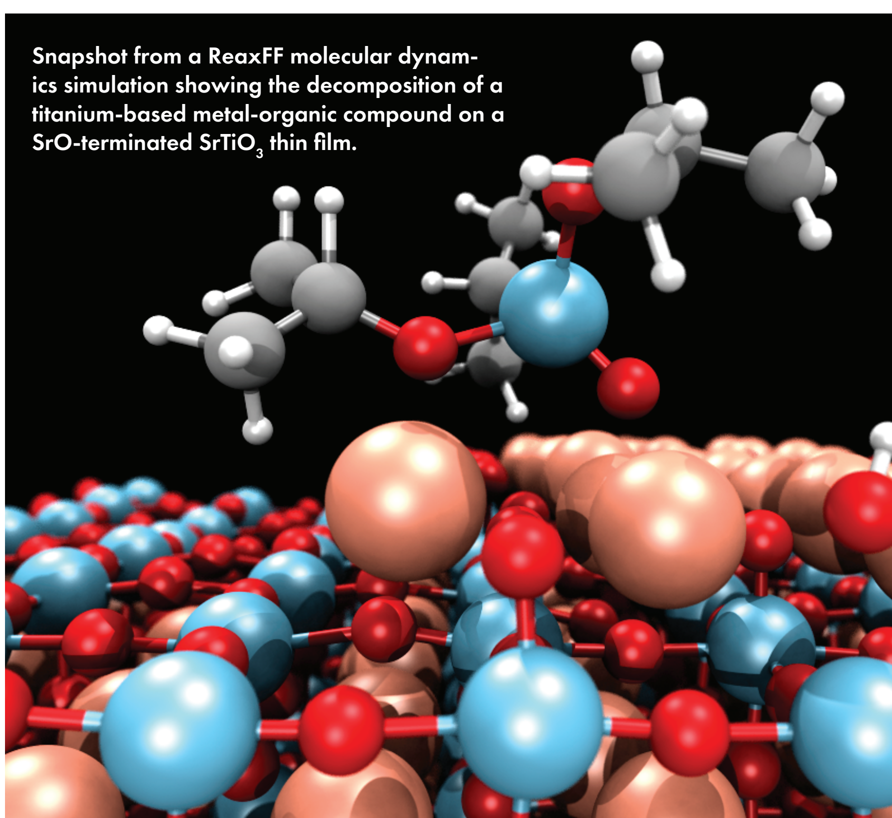
Later on in my Ph.D. journey, I was the one benefitting from the materials science community's vast knowledge base. One of my advisors suggested that I learn how to use computational tools and simulations to back up my experiments. As someone who prefers to physically interact with change, simulations did not appeal to me. However, during the COVID-19 pandemic, we were not allowed to go to our labs. So, learning how to integrate computational tools into my research was the only thing I could do.

With guidance from my advisors and others in my two research groups, I learned how to use various computational tools and gained an appreciation for such research. Now, I see myself as a half-experimental, half-computational materials scientist.

My current research involves growing thin films of ceramic oxides using an advanced technique called molecular beam epitaxy. I also run ReaxFF molecular dynamics simulations, which allow me to "observe and control" change that we cannot see with our bare eyes. The combination of these two approaches constitutes a powerful tool for the questions we have as scientists.

New research ideas come to my mind every day, and these ideas excite me despite knowing that, to realize them, I must come out of my comfort zone even more than I already have. At this point, though, I am confident there will always be someone with the expertise and willingness to help me, thanks to the breadth and depth of the materials science community.

Benazir Fazlioglu-Yalcin is a fourth-year Ph.D. candidate in materials science and engineering at The Pennsylvania State University. Her research focuses on $BaTiO_3$ thin films and atomic-scale ReaxFF simulations of them. She enjoys reading and listening to novels, woodburning, pencil drawing, hiking, and spending time with her cat, Siva. ■



Snapshot from a ReaxFF molecular dynamics simulation showing the decomposition of a titanium-based metal-organic compound on a SrO-terminated $SrTiO_3$ thin film.

Credit: Benazir Fazlioglu-Yalcin

Using materials science to benefit marginalized communities

By Luz Gomez

Throughout my undergraduate education, I struggled to feel a sense of belonging. As a first-generation Latina student from a low-income community in Los Angeles, Calif., my first few years in university were challenging to navigate.

I started my educational journey at the University of California, Irvine, as a political science major. The desire to benefit marginalized communities, such as my own, influenced my decision to join a program that helped me better understand the systems of government. During my first year, however, my interest in engineering grew because of enjoyable chemistry and physics classes. By the end of my first year, I changed my major to materials science and engineering.

Unfortunately, as I transitioned into my new program, the COVID-19 pandemic started. The mandatory transition to online for all social and academic activities hindered my ability to connect with my materials science peers.

Fortunately, through luck and personal effort, I began making inroads into the materials science community. I was delighted to discover that my initial desire to benefit marginalized communities could still be achieved through the materials sciences, as demonstrated in the examples below.

Inspiring the next generation through Girls in STEM

In the summer of 2020, I stumbled upon a club at UCI called Girls in STEM.[1] Girls in STEM aims to promote science, technology, engineering, and mathematics to high school girls in disadvantaged communities and provide resources that would make the transition to higher education easier.

I joined Girls in STEM, and through this club I mentored a handful of girls in high school, plus facilitated workshops on different engineering disciplines and my own experiences in the field.

Helping disadvantaged communities through green engineering

In my fourth year at UCI, school proceeded back to in person. I decided to take advantage of this last year and reached out to professors for hands-on research experience.

I was intrigued by materials science professor Julie Schoenung's research on sustainability and green engineering. Low-income communities of color, such as my own, face greater risks from environmental hazards because they are more likely to live near sources of industrial pollution, such as oil drilling and refineries.[2] Working toward green technology and clean energy would benefit these communities the most. So, I joined Schoenung's research group as an undergraduate research assistant in winter quarter 2022.

I worked independently alongside a graduate student to investigate the mechanical properties of high-entropy oxides, a novel ceramic material with potential applications in energy storage, lithium-ion batteries, and catalysts.[3] In the laboratory, I fabricated samples, investigated their mechanical properties through hardness testing, helped build equipment, and observed several advanced synthesis and characterization methods.

In addition to gaining valuable technical skills, these experiences were the first time I had worked with people who, like me, wanted to use materials science to benefit society. Such interactions gave me more confidence in myself and my skills, and talking with graduate students opened my eyes to graduate school as a way to achieve my goal of helping others.

Pursuing diversity and inclusion through engineering education

My decision for what to pursue in graduate school was influenced by a class in fall 2021 that I took with assistant professor of teaching Natascha Buswell. She mentioned her background in engineering education during the class, and

Luz Gomez, right, and graduate student mentor Salma El-Azab at the University of California, Irvine's Undergraduate Research Symposium.

Credit: Luz Gomez

I reached out to her over the summer to learn more about the discipline and her research. In fall 2022, I joined Buswell's research group, where I learned about diverse engineering education research methodologies and ongoing developments in inclusion and diversity in engineering education.

Through my work with Buswell, I learned that this field would support my goal to establish a sense of belonging for marginalized groups and create an educational environment in which they can thrive. I decided to pursue graduate studies in engineering education, and I will begin my studies at The Ohio State University in fall 2023.

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Luz Gomez recently graduated with a B.S. in materials science and engineering from the University of California, Irvine. Her research focused on mechanical properties of high-entropy ceramic oxides. In fall 2023, she will begin her graduate studies at The Ohio State University in engineering education. She is passionate about her community and spends her free time volunteering in organizations promoting diversity in engineering.

‘Life’ experience, ‘liberty’ to experiment, and the ‘pursuit’ of science

By Randi Swanson

New experiences are often intimidating, but as my advisor likes to tell me, “It’s good to be nervous; that means you care.” While I was not necessarily intimidated to spend an entire summer alone in Dayton, Ohio, at the Air Force Research Laboratory (AFRL), I was definitely apprehensive in the sense that I did not know what to expect.

I had already moved across the country once for graduate school at the University of California, Davis, so I was not a stranger to readjusting and making friends in a new environment. As anyone who has relocated for the short or long term knows, the difficulty of adapting can be significantly alleviated by the people surrounding you. At UC Davis, I was surrounded by like-minded students my age who were going through the same journey as myself. However, at AFRL, this would not be the case.

The opportunity to spend a summer at AFRL came about because, at UC Davis, I am graciously being funded by the United States Air Force. My research focuses on characterizing the microstructure of ultrahigh-temperature ceramics (UHTCs) using 3D characterization techniques to track flaws throughout processing. The choice of processing parameters affects the “critical flaw size” distribution in the microstructure; however, the specifics of this relationship are difficult to model and thus must be characterized in further detail. This research requires access to experimental techniques that are not widely available, such as X-ray micro-computed tomography (X-μCT). I do not have access to this technique at UC Davis, but I do have access to it at AFRL.

We all have preconceived notions about new experiences based on our previous experiences. I would be lying if I said I did not expect the environment at the AFRL to be a bit intense—militaristic, if you will. However, my preconceived notions could not have been farther from the truth.

While there was of course the expectation to perform to the best of your ability, as in any job, I was happily surprised by the welcoming, diverse, and supportive colleagues that I had the honor of working with all summer. The scientists who work at AFRL, from new hires to project managers, treated me with the upmost respect, which made me feel confident in my research and presentation experiences.

The pleasant atmosphere was not the only aspect of the AFRL that made the overall experience experimentally fruitful. As previously mentioned, my research requires access to instruments that are not ubiquitous, such as X-μCT. The X-μCT laboratory at AFRL allowed me to gather significant amounts of data on UHTC microstructure characterization, and these scans account for most of my Ph.D. research data thus far.

The X-μCT laboratory manager, Thao Gibson, not only helped with data acquisition, but she also took the time to discuss the particularities of computed tomography to ensure I had a firm understanding. This anecdote is just one example of the benevolent nature of the laboratory personnel that has no doubt aids in AFRL’s scientific success.

Randi Swanson, far right, takes a selfie with AFRL research materials engineer Katie Detwiler and materials research intern Tyriek Craigs during a monthly Wingman event, in this case canoeing. Each research team at AFRL sponsors Wingman events to provide team-building opportunities for group members.

The culture at AFRL is a great example of how a positive environment generates more collaboration and scientific breakthroughs. With a budget of more than $2 billion, AFRL is constantly developing science and technology through in-house and contractual programs.[1] The success of AFRL is not just due to the brilliant scientists that are employed there, but also to the environment of respect and curiosity that is culminated every day.

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Randi Swanson is a second-year Ph.D. student in chemical engineering at the University of California, Davis, studying microstructure evolution of ultrahigh-temperature ceramics for aerospace applications. In her free time, she enjoys playing the piano and laughing with friends. ■

Toward a green community: Tuning electrochemical parameters to improve morphology of Sb_2Se_3 solar absorber layers

By Cassondra Brayfield

Due to fossil fuel use in the hundred years between 1900 and 2000, the amount of CO_2 rose by 132.5 parts per million per volume (ppmv), which corresponds to 2.51 W/m^2 of radiative force on the environment.[1,2] This rise in greenhouse gas emissions has led to noticeable changes in sea level and global temperature.[3]

To have any chance of slowing or reversing this process, academic, industrial, and government communities must work together to make the switch to renewable, carbon-neutral energy sources.

Solar is one green energy sector that has witnessed much cross-community collaboration, particularly in the design of photovoltaic panels. Photovoltaic panels are multilayered modules that convert solar energy into electricity. Researchers in academia, industry, and government have explored many different compositions for these layers in pursuit of an earth-abundant, nontoxic, and efficient design.

The absorber layer has the greatest potential for improvement. It is the layer that functionally absorbs the sunlight and, via an *n*-type or *p*-type region, converts the sun's energy into usable, storable energy.

Some materials studied for the absorber layer include CdTe, $Cu(In,Ga)Se_2$, $Cu_2(Zn,Sn)S_4$, and recently Sb_2Se_3. The downside to the former three options is that indium and tellurium are scarce, and cadmium is toxic to humans.[4] In contrast, antimony and selenium are relatively plentiful and nontoxic.

Thin films of Sb_2Se_3 have been produced through various methods, including reactive pulse laser deposition, spin-coating, spray pyrolysis, thermal evaporation, and physical and chemical vapor deposition. But many of these methods are considered nonuniform and/or expensive.

Electrochemical deposition is an alternative thin film manufacturing technique that has minimal waste, easy setup, and low cost. Plus, because one chemical bath can be used repeatedly, it has large potential for industrial scalability.[5]

Many parameters of the electrochemical deposition process are tunable, providing great control over the final thin film's properties. In the Osterloh research group at the University of California, Davis, we are exploring these parameters to achieve ideal Sb_2Se_3 film deposition.

For example, we discovered that an increase in the deposition temperature allows for more nucleation sites to deposit at the start of the process. These close-knit sites lead to denser particle growth, which results in more conformal films. (Increasing the temperature any higher than 70°C, however, will cause the solution to boil, leading to holes in the film.)

We also found that adding $KMnO_4$ to the chemical treatment the film undergoes before deposition leads to a film with stronger atomic bonding. Plus, compared to untreated films, the uniformity and conformity of particles in the $KMnO_4$-treated films are much greater (Figure 1).

Finally, we showed that annealing the film after deposition in an argon atmosphere infused with additional selenium powder improved the film's density, coverage, and homogeneity, as well as its selenium content (Figure 2).

Future work must be done to observe how these Sb_2Se_3 absorber layers perform when integrated with a full device. It would also be interesting to perform the annealing treatment prior to the electrochemical deposition to determine if it leads to even better nucleation due to a possible seed coating.

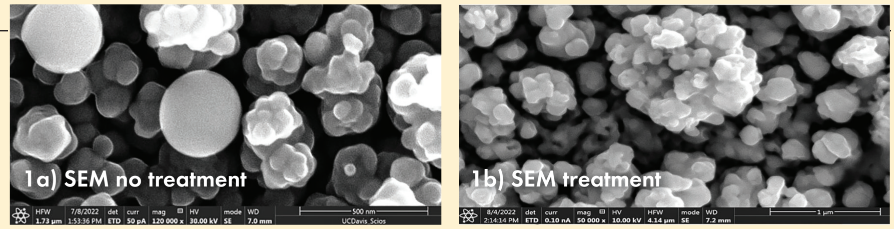

Figure 1. The left sample (a) did not receive $KMnO_4$ treatment, while the right sample (b) did receive treatment, resulting in a homogeneous field of separate globular nanoparticles.

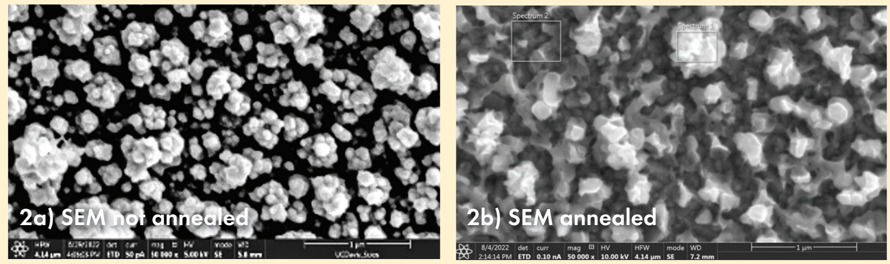

Figure 2. The left image (a) is the original deposited film, while the right image (b) shows the same film after annealing, leading to a merging of the globular nanoparticles.

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Cassondra Brayfield is a Ph.D. candidate in materials science and engineering at the University of California, Davis. She is currently working on a variety of energy science projects, including synthesizing catalysts to produce alternative fuels and deposition of the absorber layer for photovoltaic cells. When not researching or teaching, she is also interested in ballet, wine, swimming, reading, throwing parties, and all things outdoors.

Graduate Interconnect program: Guiding a successful transition for incoming international students to graduate student life

By Arturo Meza

The pursuit of an academic degree can take you to many places around the world. The United States, however, is a common landing place for students.

According to the Open Doors 2022 Report on International Education Exchange,[1] as of the 2021/22 academic year, there are 948,519 international students in the U.S. Though these students come from many different cultural backgrounds, they do share one thing in common: a home far away from their university.

While transitioning to a different culture may be easy for some, it is challenging for many others. To help with this transition, the University of California, Irvine (UCI) developed a peer mentor program that provides a supportive community for international students in their new home away from home.

The Graduate Interconnect program (GIC) is run by the division of graduate education at UCI.[2] The division extensively trains domestic and international graduate students who wish to play the role of mentors within the program. These peer mentors then conduct outreach with international students, even before the incoming students arrive on campus.

GIC peer mentors guide incoming international students on what to expect upon arriving in their new community. They provide information on where to buy essential items, such as furniture and groceries, and even offer advice on how to make new friends. GIC peer mentors also provide international students with details about the variety of campus resources available to them, including how and when to access them.

Most fun of all are the social events put on through the GIC program to help incoming international students engage with their new community, make friends, and share experiences that ultimately help them build a network. For example, the GIC fall quarter mixer is a social event where all the mentees gather on campus—either the UCI graduate housing community or a designated campus venue—with food and beverages provided by the GIC program.

Throughout my time at UCI, I was very lucky to be part of the GIC program as a mentee and as a mentor. I came to UCI from my hometown of Hermosillo, Mexico, where I also got a B.S. and M.S. in materials science and engineering. When I started graduate school, my peer mentor came from the same department and coincidentally was a member of the research group that I later joined. This arrangement helped me engage socially and professionally in my department and community.

The GIC program also informed me of other campus resources, such the UCI Fresh Hub that provides basic needs for UCI students. Plus, relevant information included in the Graduate Interconnect blog written by current graduate students helped me manage my time and focus on my studies and research.[3]

The impact the GIC program had on me when I arrived at UCI motivated me to serve as peer mentor in my later years, as I was eager to transfer my experiences to incoming international students and help them become a part of the community as effectively as I did.

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Arturo Meza is a fifth-year Ph.D. student at the University of California, Irvine, in the materials science and engineering department. He studies the electrical behavior of novel ceramic materials for industry applications. Outside of research, he enjoys camping in nature, stargazing, and is passionate about astrophotography.

Credit: Graduate Interconnect program

Group photo of the 2022/23 Graduate Interconnect program peer mentors.

Navigating a Ph.D. with the help of our Graduate Student Association

By Salma El-Azab

When I moved across the country to begin graduate school in the fall of 2019, I was bright-eyed, hopeful, but nervous about what to expect. Would I be able to balance my coursework with graduate research? Would I even like the research topic once I became more deeply involved with the field?

UCI materials science and engineering Graduate Student Association Halloween party, October 2021.

During my first semester at the University of California, Irvine, everything went smoothly, which assured me that I had made the perfect choice. I did well in my courses, got the lay of the lab, and made amazing new friends in my department.

I also got involved in my department's graduate student association (GSA) during my first term of graduate school. GSAs provide a central base for graduate students to socialize, participate in outreach, and seek out professional development opportunities. But the importance of GSAs in building a strong student community was thrown into sharp relief in March 2020.

In mid-March of 2020, I volunteered with GSA to help put on our department's annual recruitment event for prospective graduate students. By the next week, though, the whole world was under lockdown due to the COVID-19 pandemic.

It would be more than half a year before I returned to the lab. But I was still able to maintain some semblance of normalcy in other aspects of my graduate school life through GSA. For example, GSA successfully engaged students through virtual mixers and research-based contests, plus organized virtual outreach events for children in the local school district.

By the time I began my second year of graduate school, I successfully ran to be vice president of GSA. I wanted to help my peers and incoming students maintain a sense of community that had been tarnished by the onset of the pandemic.

To do so, I helped coordinate more virtual events, such as the ones mentioned above. Most notably, in spring 2021, we ran an entirely virtual recruitment event that provided prospective students with robust resources to get a good perspective on our program and our campus. This included videos that we recorded, edited, and narrated about our shared research facilities, housing options, and things to do in Southern California.

I was elected president of GSA by the start of my third year. At this point, things had transitioned back to being in-person, which presented a challenge for GSA. How would we engage graduate students who were burnt out on online functions, plus an additional two cohorts who had no exposure to what our department was like before the pandemic?

To address this challenge, we would need to successfully engage students both socially and professionally. While social engagement was easy enough—we had plenty of experience planning mixer events—the professional engagement required a bit more effort.

Since the pandemic, students missed out on a lot of professional development opportunities, such as conferences, internships, and networking. As GSA president, I spearheaded several professional development opportunities. For example, we brought in guest speakers from different career paths to show students what they could do with a degree in materials engineering. A patent lawyer, a policymaker, and an entrepreneur are just a few of the people who came to network with students and answer their questions.

I also started back up the tradition of connecting undergraduate students to graduate students through mixers. Such mixers provide undergraduate students a way to learn about graduate school and laboratory research from those with first-hand and immediate knowledge on the topic. I met undergraduate Luz Gomez through a GSA-sponsored connection mixer, and working with her has been an excellent opportunity for me to bolster my mentorship skills as well as learn about project management and technical communication.

The world may have changed in ways we could have never anticipated, but at least for graduate students in the materials science and engineering department at UCI, things have only gotten better. GSA provided a community through which to restore the strong sense of camaraderie that blurred during the pandemic. Leading this work gave me the confidence and sense of belonging that I needed to push my own research forward.

Salma El-Azab is a fourth-year Ph.D. candidate in the Department of Materials Science and Engineering at the University of California, Irvine. She is a member of professor Julie Schoenung's group, where she does research on the mechanical behavior of high-entropy oxides. Outside of the lab, she enjoys hiking, kayaking, crocheting, and cooking. ■

Refractories Symposium resumes in St. Louis with sustainability theme

Credit all images: ACerS

On March 28–30, 2023, the refractory ceramics community celebrated the in-person return of the ACerS St. Louis Section and Refractory Ceramics Division Annual Symposium on Refractories in St. Louis, Mo.

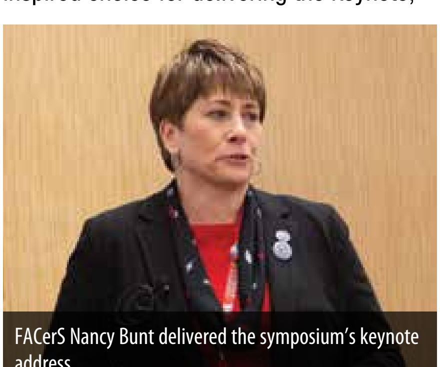
"It was a pleasure to have approximately 220 members of the refractory ceramics community back in St. Louis after four long years of being apart," says Kelley Wilkerson, chair of the Refractory Ceramics Division.

Attendees came from 11 countries spanning the globe: Europe, Canada, South America, Australia, China, India, and Korea. Close to half were first-time attendees!

The theme of this year's symposium was sustainability. Symposium organizers Alex Stansbery (Resco Products), John Waters, and Behzad Majidi (Pyrotek Inc.) recruited talks that covered the range from sustainable approaches to raw materials, to improving thermal processes with refractories, to optimizing refractory formulations, to converting foundry waste to saleable products. There was much discussion of life cycle assessments (LCA) and how corporations are using LCAs and various certification tools to develop robust sustainability programs to hold themselves accountable.

The symposium opened with a keynote address by FACerS Nancy Bunt. Bunt was an inspired choice for delivering the keynote,

David Tucker (center) received the 2023 Theodore J. Planje Award. Planje Awardees in attendance from left: Jeffrey Smith, J.P. Willi, Ruth Engel, Andreas Buhr, Tucker, Dilip Jain, Thomas Vert, Nancy Bunt, and Christopher Parr.



FACerS Nancy Bunt delivered the symposium's keynote address.

as she has nearly 40 years of experience in the industry and is now global sustainability director of the Imerys Refractory, Abrasives, and Construction Business Area.

The United Nations' 17 Sustainability Goals are well known, but perhaps less well known is the United Nations Global Compact–Accenture CEO Study. The most recent study defines resilience as "a company's ability to withstand, adapt, and prosper through uncertainty and volatility—to emerge stronger and strengthen competitive advantage."

Bunt tied resilience to sustainability, noting that sustainability is at the core of resilience, and she described how the Imerys Sustain-Agility program supports both sustainability and resilience at the point where most manufacturing begins—raw materials.

The symposium closed with a talk by Paul Ormond of Evergreen Alumina, a start-up company tackling the challenge of aluminum foundry waste. Ormond introduced an "industrial waste-to-value" technology based on a closed-system proprietary process that generates neither waste nor effluent. The patent-pending process was developed by refractory industry veteran Riley Robbins.

Two awards were presented at the meeting. The St. Louis Section awarded its Theodore J. Planje Award to David Tucker of Imerys-Mulcoa, and the RCD

Incoming Refractory Ceramics Division chair Bob Hunter (right) recognizes outgoing chair, Kelley Wilkerson.

Allen Award went to professor Stefan Schaffoener of the University of Bayreuth, Germany. Schaffoener reported on his latest research on functional porosity in composite ceramic refractories.

An evening reception and expo gave attendees time to reconnect, talk about business, and meet all the new attendees. Dinner, lunch, a Top Golf kick-off event, and plenty of coffee breaks set the stage for networking and great conversations about refractories.

View photos from the Refractories Symposium on ACerS Flickr page at https://bit.ly/Refractories2023. Next year's symposium theme will relate to failure analysis. The details are yet to be worked out, but the symposium will take place in St. Louis in March 2024. ■

UPCOMING DATES

HOTEL MONTELEONE, NEW ORLEANS, LA.

ACerS Glass & Optical Materials Division will hold its annual meeting and conference in New Orleans, La., from June 4–8, 2023.

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Glass Week 2023 is organized by the Glass Manufacturing Industry Council and Alfred University. It is endorsed by The American Ceramic Society. *Glass Worldwide* is the official journal.

Calendar of events

June 2023

4–8 ACerS Glass & Optical Materials Division Annual Meeting (GOMD 2023) – Hotel Monteleone, New Orleans, La.; https://ceramics.org/gomd2023

5–8 ACerS 2023 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Omni Austin Hotel Downtown, Austin, Texas; https://ceramics.org/clay2023

14–16 13th Advances in Cement-Based Materials – Columbia University, New York, N.Y.; https://ceramics.org/cements2023

21–22 16th International Seminar on Furnace Design: Operation & Process Simulation – Hotel Horal, Velke Karlovice, Czechia; https://www.gsl.cz/news/events/16th-int-seminar-on-furnace-design-operation-process-simulation

July 2023

2–6 ➨ XVIIIth Conference of the European Ceramic Society (ECerS) – Lyon, France; https://www.ecers2023.org

18–23 ➨ 10th International Conference on Borate Glasses, Crystals, and Melts and the 3rd International Conference on Phosphate Materials – Corning, N.Y.; https://boratephosphate2020.org

August 2023

21–24 Materials Challenges in Alternative & Renewable Energy 2023 (MCARE 2023) combined with the 6th Annual Energy Harvesting Society Meeting (EHS 2023) – Hyatt Regency Bellevue, Bellevue, Wash.; https://ceramics.org/mcare-ehs-2023

27–31 ➨ 11th International Conference on High Temperature Ceramic Matrix Composites – Ramada Plaza Jeju Hotel, Jeju, Korea; https://www.ht-cmc11.org

27–31 ➨ The International Conference on Sintering 2023 (Sintering 2023) – Nagaragawa Convention Center, Gifu, Japan; https://www.sintering2021.org

30–31 EMC Ceramists Additive Manufacturing Forum (yCAM) 2023 – Leoben, Austria; https://euroceram.org/2023-ycam-forum-in-leoben

September 2023

12–15 China Refractory Minerals Forum 2023 – InterContinental, Dalian, China; http://imformed.com/get-imformed/forums/china-refractory-minerals-forum-2023

25–28 ➨ 12th International Conference on Microwave Materials and Applications, Mainz, Germany; https://converia.uni-mainz.de/frontend/index.php?folder_id=786&page_id=

26–29 ➨ Unified International Technical Conference on Refractories (UNITECR) with 18th Biennial Worldwide Congress on Refractories – Kap Europa, Frankfurt am Main, Germany; https://unitecr2023.org

October 2023

1–4 ACerS 125th Annual Meeting with Materials Science & Technology 2023 – Columbus Convention Center, Columbus, Ohio; https://matscitech.org/MST23

November 2023

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

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

January 2024

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

February 2024

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

July 2024

14–19 International Congress on Ceramics – Hotel Bonaventure, Montreal, Canada; www.ceramics.org

August 2024

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

Dates in RED denote new event in this issue.

Entries in BLUE denote ACerS events.

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

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INDUSTRY NEWS

KYOCERA PLANS 'SMART' FACTORY FOR SEMICONDUCTOR APPLICATIONS

Kyocera Corp. reached an agreement to acquire 37 acres of land for a "smart" factory at the Minami Isahaya Industrial Park in Isahaya City, Nagasaki Prefecture, Japan. The agreement includes a developed site of about 14 acres, where construction will begin in October 2023, and another 23-acre, pre-developed site that Kyocera plans to acquire in 2024. The factory will produce fine ceramic components used in semiconductor-related applications, as well as semiconductor packages, with production expected to begin in 2026.

A rendering of the new plant.

IFGL has manufacturing facilities in India, China, Germany, U.K., and U.S.

IFGL REFRACTORIES ACQUIRES U.K. REFRACTORIES BUSINESS

Kolkata, India-based IFGL Refractories Ltd. said its subsidiary in the U.K., Monocon International Refractories, completed the acquisition of Sheffield Refractories, a manufacturer and installer of monolithic refractory products, shotcreting materials, and other specialty monolithic products for the iron and steel, cement, incineration, and waste-to-energy industries. Sheffield's revenue from operations during the 12 months ending Sept. 30, 2022, was more than GBP 17.5 million.

PILKINGTON REBUILDS LINES, EXPANDS IN N.C.

Glass manufacturer Pilkington North America, Inc. plans to invest $86.8 million in its operations in North Carolina. The project includes the rebuild of one of its two float glass lines, expansion of existing coating capabilities, and other building and equipment improvements at the company's float glass facility in Laurinburg, N.C. The project will create 20 jobs. PNA is part of Tokyo-based NSG Group, a supplier of glass and glazing systems for the automotive, architectural, solar, and creative technology sectors. The Laurinburg plant produces float glass for the architectural market.

Pilkington in the U.K. invented the float manufacturing process for glass in 1952.

U.S. Rep. Matt Cartwright (D-Pa.) is shown a launch tube window.

DEFENSE CONTRACT FOR INFRARED GLASS AWARDED TO SCHOTT

Schott was awarded a multimillion-dollar contract from a defense contractor for infrared glass. The order supplies glass for launch tube windows, a component of air defense systems provided to the U.S. Army. Schott is already producing launch tube window parts for an existing order, and will now be able to extend production and further support employment of more than 150 people at its site in Duryea, Pa.

The transactions are part of Saint-Gobain's "Grow & Impact" strategic plan.

SAINT-GOBAIN SELLS TWO BUSINESS UNITS

Saint-Gobain signed an agreement to sell its glass processing business Glassolutions in Switzerland to the privately-owned German group Aequita. The business generated sales of around 25 million euro in 2022, and employs approximately 70 people at its production site in Kreuzlingen. This transaction is part of Saint-Gobain's business profile optimization strategy. Saint-Gobain also completed the sale of its scintillation and photonic crystals business to SK Capital Partners and Edgewater Capital Partners, two U.S.-based private investment firms.

DOE SUPPORTS STUDIES ON RARE EARTHS FROM MINE WASTES

The U.S. Department of Energy announced $16 million from the Bipartisan Infrastructure Law to support projects in West Virginia and North Dakota that are developing rare earth element and critical minerals extraction and separation refineries. The University of North Dakota will complete a study to recover and refine minerals from North Dakota lignite mine wastes. West Virginia University will complete a study of producing minerals using acid mine drainage and mineral tailings feedstocks. Both projects were awarded $8 million.

The studies will identify risks and costs of producing rare earth elements from mining wastes.

The agreement will continue for two years and may be extended for an additional year.

HAYDALE INKS AGREEMENT ON BORON NITRIDE WITH SAINT-GOBAIN

Haydale signed an agreement with Saint-Gobain to further develop Saint-Gobain's boron nitride powder solutions. Saint-Gobain Boron Nitride, a business unit within Saint-Gobain Ceramics, develops advanced hexagonal boron nitride, an advanced synthetic ceramic used in electronics, automotive, and metal forming industries, among others. Haydale is a technology and advanced materials group based in the United Kingdom.

RAK CERAMICS UPGRADES KILN TECHNOLOGY

RAK Ceramics announced a $14 million investment in its sanitary ware production line in the United Arab Emirates to upgrade the facility with new kiln technology. The investment will allow an upgrade of the heat exchanger system with the capability for future conversion to hydrogen fuel and waste heat recycling. RAK, based in Ras Al Khaimah, UAE, specializes in ceramic porcelain wall and floor tiles, tableware, sanitary ware, and faucets.

RAK aims to go online with the new machinery in the first half of 2024.

WEATHERING THE STORM: HOW MANUFACTURERS ARE COPING WITH VOLATILE ENERGY COSTS

By David Holthaus

As a cost of doing business, energy has been relatively cheap for many years. That changed in 2022, when a variety of factors—notably a war started by one of the world's leading natural gas suppliers—caused energy prices to spike.

In Europe, wholesale gas prices hit an all-time high in August 2022. Shortages and blackouts were feared as Russia cut its gas exports to the continent when the European Union initiated sanctions over the war in Ukraine.

In the U.S. in 2022, the natural gas spot price hit its highest annual average since 2008, according to the Energy Information Administration. A decline in U.S. production, combined with increased demand from Europe and weather-driven demand in the States, all contributed to the price surge.

Fortunately, 2023 has been a different story. In Europe, natural gas prices normalized back to pre-war lows, according to SEB Research, a division of the Swedish investment bank. Reduced industrial consumption, increased exports from the U.S. and other alternative suppliers, and a relatively mild winter combined to bring prices back in line, the firm says.

In the U.S., reduced consumption (thanks to a mild winter) and increased natural gas production resulted in natural gas prices dropping 40% from December 2022 to January 2023. The Energy Information Administration forecast that prices would, on average, drop 50% in 2023 from last year's spikes.


The energy-intensive glass and ceramic industries are especially vulnerable to energy costs. *Credit: Schott*

RISING ENERGY COSTS STILL A THREAT, EXECS SAY

Despite the reprieve from price increases, energy costs remain a top concern for business leaders. That can be seen in a study of 2,300 executives around the world commissioned by ABB Electrification, a division of Zurich-based conglomerate ABB Ltd. Published in March 2023, the findings show that energy costs and stability challenges are impacting businesses across the board, with 74% of survey respondents saying rising costs are a "major" or "moderate" threat to their companies' competitiveness.

Over the last year, higher energy costs caused businesses to reduce spending in other areas (34% cited this impact) and reduced profit margins (also 34% of respondents). Executives say dealing with energy challenges may outweigh spending normally considered necessary to remain competitive, including employee recruitment; retaining or developing talent, salaries, overtime, and bonuses; and investing in new technology for greater productivity.

Apart from reductions in investment in the workforce, businesses also reduced spending in other key areas as a result of energy challenges, including technology (38%), infrastructure (33%), marketing (31%), manufacturing (27%), and research and development (18%).

Looking out over the longer term (3–5 years), if energy costs and uncertainty persist, businesses anticipate further spending and investment reductions in similar areas to the last year, with the main impacts being employee-related, including staff recruitment (42%), compensation (38%), and training and development (37%). Respondents say other affected areas would include spending on technology (37%), infrastructure (34%), and marketing (33%).

Much of the concern can be attributed to the inherently volatile nature of energy costs and the knowledge that the factors that contributed to the spikes in 2022 are still with us. The war in Ukraine is still raging, and an unpredictable climate means a harsh winter could push consumption to the point that prices surge again.

On top of that is global economic uncertainty, particularly concern-

Hydrogen fuel projects will test a developing technology

By David Holthaus

In the energy-intensive glass and ceramic manufacturing industries, decarbonizing the heating and firing processes is a major challenge. Hydrogen is one technology that holds promise for replacing natural gas. However, the technology is still under development and is years away from being commercially available on a broad basis, says Erik Muijsenberg, vice president of Glass Service, Inc. a Vsetin, Czechia-based consulting firm that works with glass and ceramic makers to optimize their furnace technologies.

"I see a very big future for hydrogen, but not in the next 10 or 15 years," Muijsenberg says.

The hydrogen fuel technologies available now are more expensive than natural gas, and they are not necessarily very efficient or green, as much of the hydrogen produced now is based on fossil fuels, Muijsenberg explains. But there are many projects under way that will provide data and help the technology to be developed for wider use.

Ardagh Glass Packaging in Limmared, Sweden, a subsidiary of Ardagh Group, signed an agreement with Absolut Vodka to use a partly hydrogen-fired glass furnace for large-scale production of the vodka maker's glass bottles. Ardagh's Limmared facility currently uses a combination of natural gas and electricity to power its furnaces. In the second half of 2023, Ardagh will launch a pilot replacing 20% of its natural gas with green hydrogen to manufacture all of Absolut's bottles. The hydrogen will be produced onsite at Ardagh by using renewably sourced electricity.

"There are challenges with such innovation, but we are committed to being an early mover in future-proofing our glass manufacturing operations worldwide," says Bo Nilsson, managing director of Ardagh Glass Limmared AB.

In December 2022, glass manufacturer Encirc and spirits giant Diageo announced a partnership to build a new furnace at Encirc's Elton plant in Cheshire, U.K., which will reduce carbon emissions by 90%, with an energy mix of green electricity and low carbon hydrogen. The process will produce up to 200 million Smirnoff, Captain Morgan, Gordon's, and Tanqueray bottles annually by 2030, the companies say.

The U.K. has been a leader in developing the infrastructure for hydrogen technology. Its HyNet project aims to produce, store, and distribute hydrogen, as well as capture and store carbon, throughout the northwest of England and North Wales.

Saint-Gobain in March 2023 carried out a test production of flat glass using more than 30% hydrogen at its Herzogenrath site in Germany. With the test, the company says it "has proven the technical feasibility of manufacturing flat glass with a significant proportion of hydrogen."

Ceramics manufacturer NGK says it has been conducting hydrogen flame evaluation tests in a test furnace installed near its headquarters in Nagoya, Japan, since January 2022. The company says it will install a new firing furnace at a hydrogen combustion test field in Tokai, Japan.

These and many other projects could provide the investment and information needed to scale up the use of low-carbon hydrogen as an alternative fuel for industries.

Ardagh Glass will manufacture Absolut Vodka bottles in a hydrogen fuel pilot project. *Credit: Absolut Vodka*

ing China. The country ended its strict zero-COVID policy in December 2022, reopening its borders and moving away from the testing and quarantine orders that slowed its economy over the last three years. China's economic growth of 3% in 2022 was its slowest in decades. The International Monetary Fund now predicts growth of 5.2% in that country, the world's second-largest economy, this year. Stronger growth in China could mean steeper global demand for gas, possibly exerting upward pressure on prices.

"Energy cost inflation, volatility, and supply insecurity are a problematic combination that need monitoring closely," says Morten Wierod, president of ABB Electrification.

COPING WITH COST VOLATILITY

With the memory of last year's energy spikes still fresh, manufacturing leaders can take steps to improve their energy resiliency. Among the cheapest steps are basic efficiency measures, says Michael Lyda, a technical supervisor with Advanced Energy, a North Carolina-based nonprofit energy consulting firm.

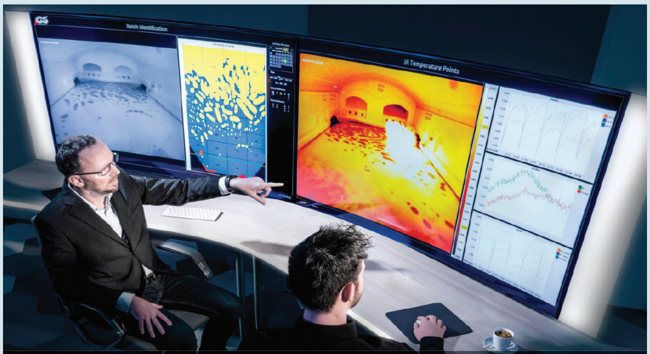
"Energy efficiency is the low-hanging fruit," he says.

Old lighting technology can be replaced to create near-immediate savings, Lyda says. Simply turning the lights off at times and in places where they are not needed will add up, and dropping the use of old, inefficient technologies will yield savings.

"Only use energy when it needs to be used," he says.

Business leaders are becoming conscious of their companies' energy usage, and more to the point, of the energy waste in their companies' processes, the ABB survey found. Thirty-four percent say they have increased investment focused on improving energy efficiency, while 22% say they are switching off lights and equipment when not in use. Twenty-two percent report using less heating or air conditioning in their operations.

For example, Saint-Gobain, the Paris-based materials manufacturing giant, recently received an award from the U.S. Department of Energy for implementing a smart energy management system at its gypsum plant in Buchanan, N.Y.



Glass Service Inc. experts use artificial intelligence software to measure batch and temperatures in a furnace analysis. *Credit: Glass Service Inc.*

The system was designed in-house and consists of more than 180 energy meters that allow employees to track and contextualize energy data, forecast future energy use, and tackle actual losses once they are identified. Within the first three months of installation, the system helped identify several opportunities to reduce energy use and enabled the plant's team to identify process changes and projects to address them, the company says. The company plans to deploy similar technology at some of its 145 manufacturing sites throughout the U.S.

Lyda says his company can work to help industries meet the ISO 500001 energy standard. The standard provides a framework of requirements for organizations to develop an energy management system by creating policies for more efficient use of energy, fixing targets and objectives, using data to better understand and make decisions about energy use, and measuring the results for continuous improvement. It is a standard that is more often practiced in Europe than in the U.S. due to European Union directives, Lyda says.

Energy efficiency becomes especially critical in the glass and ceramic manufacturing industries, as the processes are so energy intensive, with furnaces reaching temperatures of more than 1,500°C for the melting and refinement of raw materials.

Glass Service Inc., a company based in Vsetin, Czechia, has been in business for 33 years and has developed technologies to help optimize furnace efficiency. The company offers experience in furnace engineering, data analysis and auditing, and furnace monitoring, and it can provide mathematical simulation studies to model the combustion and discover methods to improve efficiency, says Erik Muijsenberg, vice president.

The CoorsTek facility in Rayong, Thailand, where a rooftop and carport solar photovoltaic system will be installed. *Credit: CoorsTek*

Glass Service has conducted simulation studies of more than 800 furnaces around the world, Muijsenberg says.

"Energy has become more expensive and decarbonization is important," he says. "We want to find a solution using less or no fossil fuels."

The company is working to develop technologies that are greener and more efficient, including developing a hydrogen burner, as well as melters that are all electric or use hybrid sources of energy.

"There's more need than ever before to make these changes available," Muijsenberg says.

MOVING FORWARD WITH ALTERNATIVE ENERGY SOURCES

But high energy costs may, paradoxically, result in diverting or delaying investments meant to help achieve decarbonization commitments, the ABB survey found. More than half (58%) of the respondents say the cost of energy could delay achieving their sustainability and carbon reduction targets by anywhere from one to five years.

At the same time, 40% say they were "very concerned" about the security and reliability of their businesses' energy supply, and many are moving forward with plans to take action over the next 12 months, including installing onsite, renewable energy sources (40%), such as solar or wind, or procuring renewable power under long-term power purchase agreements (36%).

CoorsTek, the Golden, Colo.-based manufacturer of technical ceramics, is one company proceeding with plans to reduce its carbon footprint. In March 2023, the company signed a long-term agreement with TotalEnergies ENEOS for a 1.5 megawatt-peak rooftop and carport solar photovoltaic system at its 110,000-square-foot manufacturing facility in Rayong, Thailand. The system is expected to generate about 2,000 megawatt-hours of renewable electricity annually, realize significant cost savings, and reduce the company's carbon footprint by about 840 metric tons of CO_2 emissions per year.

"It's our first foray into onsite renewables," says Dara Ward, CoorsTek's corporate sustainability manager. "It's something that our leadership is very committed to seeing played out globally."

CoorsTek broke ground on its Rayong facility in January 2021 and began operations in January 2022. The facility is a production hub for Southeast Asia.

"It's a really perfect opportunity for us to evaluate solar because we would have a brand new roof and a lot of space," Ward says.

Under the agreement, TotalEnergies ENEOS will finance, install, and operate the system. The company is a 50/50 joint venture between TotalEnergies and ENEOS to develop onsite, business-to-business solar

Advanced nuclear reactors hold promise for clean, efficient energy

By David Holthaus

Nuclear energy has acquired a poor image over the years. As a result, the development of a promising technology that could help further the decarbonization of the planet has been slowed.

Major nuclear reactor incidents at Three Mile Island in the United States, Chernobyl in Ukraine, and, most recently, Fukushima in Japan have demonstrated how serious problems can be at such sites. Some older nuclear plants were decommissioned and closed, and nuclear now accounts for only 10% of the world's energy production, according to the World Nuclear Association.

But nuclear technology has advanced to the point where small, modular nuclear reactors—and even microreactors—may soon be providing low-carbon, efficient energy for manufacturers and power suppliers. Several companies are developing advanced reactors using different technologies that promise to be safer and easier to deploy than conventional nuclear technology.

"All of them have the potential to compete globally once deployed, and they will offer consumers more access to a reliable, clean power source that can be depended on in the near future to flexibly generate electricity and drive industrial processes," says the U.S. Department of Energy.

The DOE's Advanced Reactor Demonstration Program (ARDP) is supporting several projects.

TerraPower is a Bellevue-Wash.-based company founded by Bill Gates that is working on a demonstration project for a sodium fast reactor in Kemmerer, Wyo., in collaboration with PacifiCorp, a utility that is retiring a coal-fired plant in that community. In fall 2022, the two companies announced they would study the feasibility of deploying up to five additional small modular reactors and integrated energy storage systems in the PacifiCorp service territory by 2035.

X-Energy Reactor Company, based in Rockville, Md., is developing the first grid-scale advanced nuclear reactor for an industrial site in North America. The company is working with materials science company Dow and intends to install a high-temperature, gas-cooled reactor plant at one of Dow's U.S. Gulf Coast sites. The companies say the site will be selected sometime this year.

"From the beginning to the end of the supply chain, our technology can supply both power and heat to businesses in most sectors of the economy to help limit their carbon footprint," says J. Clay Sell, X-energy CEO. X-energy was selected by DOE in 2020 to receive up to $1.2 billion under the ARDP in federal cost-shared funding to develop, license, build, and demonstrate an operational advanced reactor and fuel fabrication facility by the end of the decade.

A rendering of a Westinghouse eVinci microreactor plant. *Credit: Westinghouse*

Westinghouse, based in Pittsburgh, Pa., is in the process of licensing its eVinci microreactor that is designed to provide five megawatts of electricity for more than eight years without refueling. The eVinci is factory built and assembled before it is shipped in a container to its location. Westinghouse says it can be used for electricity and heating for remote communities, universities, mining operations, industrial centers, data centers, and defense facilities. Westinghouse says the passive safety features of its design allow the reactor to operate and achieve safe shutdown without the need for additional controls, external power sources, or operator intervention, enabling highly autonomous operation.

BWX Technologies, Inc., based in Lynchburg, Va., is building an advanced, transportable, nuclear microreactor under a contract awarded by the U.S. Department of Defense. The company says the transportable microreactor will "deliver clean, zero-carbon energy where and when it is needed in a variety of austere conditions for not only the DoD but also potential commercial applications for disaster response and recovery, power generation at remote locations, and deep decarbonization initiatives." The company expects it to be completed and delivered to the Idaho National Laboratory in 2024 for testing.

The DOE is using its National Reactor Innovation Center at the Idaho National Laboratory to test these innovations. It has awarded grants to help support their development and demonstration over the next several years, it says.

"These aggressive timelines are needed to ensure the United States takes advantage of the advanced reactor market that's expected to be worth billions of dollars," the agency says. "That's why we plan to invest more than $600 million in these projects over the next seven years, pending the availability of future appropriations by Congress."

distributed generation across Asia. It is headquartered in Singapore and plans to develop 2 GW of decentralized solar capacity over the next five years. CoorsTek will purchase the solar electricity generated for the duration of the contract. CoorsTek plans to take the learnings from the project and apply them at other plants, Ward says.

CoorsTek also works with utilities at some of its sites to implement strategic energy management programs to identify opportunities for efficiencies and savings, Ward says.

On the natural gas side of things, "We see a lot of volatility," Ward says. "So we're always looking at ways to hedge and reduce our consumption because that's the best way to become more resilient against these rising prices."

Specialty glass maker Schott is another company moving forward in the face of global economic challenges. Schott is based in Mainz, Germany, and operates in more than 30 countries. The company is switching to 100% green electricity and has made a 60% reduction

CAN DECENTRALIZED ENERGY GET GOOD ENOUGH, FAST ENOUGH?

This article was originally published on EY.com and is authored by Arnaud de Giovanni, EY global renewables leader, and Ben Warren, EY global power and utilities corporate finance leader, using research from the EY Renewable Energy Country Attractiveness Index. Republished with permission.

The need for energy resilience has never been more urgent. Ramping up renewable generation, accelerating energy diversification, and increasing energy storage are global priorities amid heightened geopolitical tensions, supply chain shortages, an increase in extreme weather events, and soaring natural gas prices.

These issues were some of the topics on the agenda for thousands of government and business delegates from around the world at the 2022 United Nations Climate Change Conference (COP27) as they sought to collaborate in solving the myriad challenges presented by the climate emergency.

Decentralization has been talked about for decades, but, as markets seek to rapidly integrate more renewables and improve grid flexibility, it is encouraging that now, with stronger regulatory support, we are beginning to see real progress.

For countries to reach net zero, the integration of renewables must improve significantly. Distributed energy resources (DERs) have a vital role to play in allowing a range of green energy sources to be integrated into the grid, but delivering new and more efficient approaches to permitting, connecting, and managing energy flows is particularly urgent.

Responding to waves of demand or localized power challenges has long been a weakness of centralized grids. However, smart grids are now moving into focus, offering bidirectional flows of electricity and data using two-way communication and control capabilities to optimize the flow of energy along a network and enable real-time responses to change in demand.

With a more energy-resilient future on the horizon, now is the time to seize the power of a more flexible energy system.

The global transition from centralized grid networks to decentralized distributed energy systems is accelerating. From microgrids, small-scale renewables, and combined heat and power facilities, to distributed energy storage and controllable loads, a plethora of options is emerging.

The primary drivers of this transition are increasing pressure on markets to reach their decarbonization goals and a desire to strengthen energy security, particularly in the wake of the war in Ukraine. A favorable climate for DERs has also emerged, with the cost of technologies falling and regulatory support increasing, notably the tax benefits in the U.S. Inflation Reduction Act and the European Commission's REPowerEU plan.

DERs offer the potential for increased grid flexibility and have a key role to play in boosting energy resilience, allowing markets to adapt to changing conditions and to recover rapidly from disruptions. Excess electricity generated by self-sustaining distributed systems can be stored and used when centralized grids are hit by outages. This ability means DERs will be vital in helping counter the high number of grid failures caused by extreme weather in recent years.

Markets around the world are adopting a variety of measures to integrate more DERs, such as metering policies to support distributed solar power and favorable legislation for installing rooftop photovoltaics.

There are challenges to be overcome, however. For example, weatherproofing energy infrastructure to protect it against extreme hot and cold weather, and ensuring there is enough capacity to accommodate the accelerating rollout of electric vehicles.

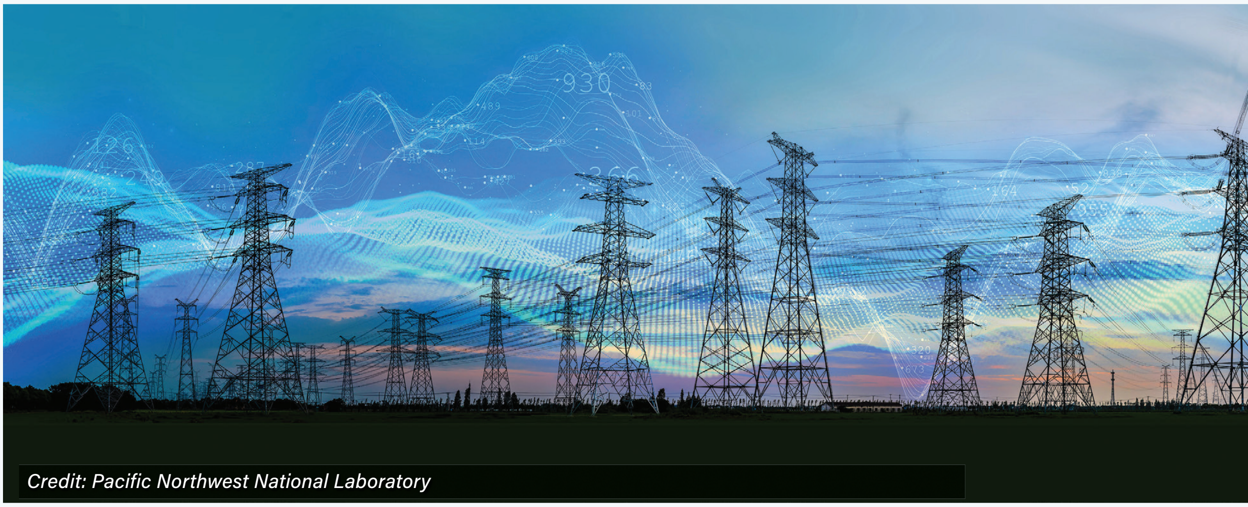
The intermittent nature of renewables will need to be balanced by more sophisticated energy storage or conventional power-generation capacity, and smart grids are likely to be at the heart of this changing energy landscape. Equipped with robust data flows, they offer improved reliability, efficiency, and flexibility—from smart meters that

in its carbon emissions. Schott uses natural gas to fire its furnaces, but electricity is its next largest energy source. Schott is relying on renewable, independently verified, green sources of electricity. Since last year, the company also relies on power purchase agreements, or contracts with operators of renewable energy plants such as wind farms.

"Globally, we are experiencing a lot of economic uncertainties," says Jens Schulte, a board member and head of Schott's zero carbon program. "However, we don't want these to negatively impact our progress in the fight against climate change."

NGK Group, the Nagoya, Japan-based maker of high-performance ceramics, set an incremental goal of cutting emissions by 25% by 2025 compared to 2013 levels. As one of its strategies for meeting its target, the company is installing solar at its manufacturing plants in Poland and Thailand. In Poland, it is installing a large-scale photovoltaic system with a total capacity of 15.1 MW on the roofs of two factories and on neighboring land at one of them. In Thailand, it is installing a system with a total capacity of 4.25 MW on the rooftops of its buildings there.

These and many other projects are promising developments, but large-scale, industrywide conversion away from natural gas to renewable sources is a long-term and expensive prospect. For green energy sources to be made available on an industrial scale,



Credit: Pacific Northwest National Laboratory

allow consumers to monitor their electricity usage, to automation that can isolate local faults so they do not shut down an entire network.

Indeed, smart grid technology is creating a new energy distribution model in markets without established national grids, whereby the overall grid is composed of microgrids that can switch to operating independently. This technology provides greater resilience for isolated rural areas, as well as for highly concentrated urban areas where brownouts or blackouts can result from surges in demand.

While their benefits are many, smart grids present several challenges, particularly in making them intelligent enough to manage the integration of DERs, bringing together a wide range of power sources, and controlling the flow of electricity so that it meets demand.

In addition, cybersecurity will be an issue, given the interconnectedness of DER ecosystems, with the increased potential attack surface area making such systems more vulnerable to cyber attacks.

Storage and supply management can also be problematic. As electric vehicles scale up, for example, they will be both a strain on the grid and a support, able to absorb excess generation from renewable energy resources, as well as acting as real-time, demand–response assets. But work still needs to be done on optimizing them as DERs.

Accelerating the use of renewable resources will require annual electric network investments to nearly triple by the late 2020s, to almost $800 billion, according to the International Energy Agency. This investment will need to be matched by an eightfold increase in investment in digital assets.

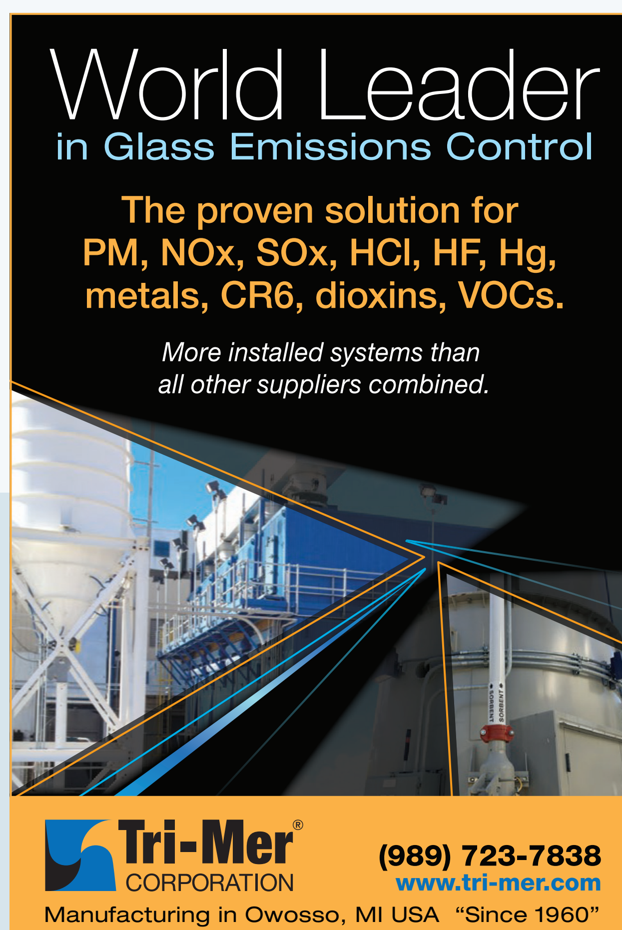
Continued regulatory support for DERs will be required, therefore, if markets are to realize the potential of such technology to bolster energy resilience through increased grid flexibility and help achieve the world's decarbonization goals.

it will require infrastructure investments by energy suppliers and grid operators.

"The electricity network, the electric infrastructure, needs to be increased," Muijsenberg says. "That will be a challenge for industry."

He sees the energy supply transition taking 10 to 15 years, as furnaces cannot be replaced at any time because they have defined lifetimes and are planned in investment cycles.

Until then, forward-thinking manufacturers will continue to invest in efficiency measures and renewable energy sources so they can weather the volatility of energy markets.



A NANOCERAMIC APPROACH TO THE CLIMATE CRISIS AND CARBON REDUCTION

By Jan Thoren

Over the past decade, mounting evidence indicates that natural disasters, including wildfires, floods, earthquakes, and hurricanes, are becoming increasingly more common and more intense throughout the world.[1] As the rate at which never-before-seen events take place continues to rise, the need to adopt greater resilience against such events is universally recognized as requiring a global response.

Nations around the world are setting climate-related goals to slow the rising intensity of catastrophic events. For example, the United Nations established a Net Zero Coalition to meet the Paris Accord target of 45% emissions reduction by 2030, followed by net zero by 2050.[2] The two most important issues are to "Build Back Better,"[3] as per the UN, and to lower carbon emissions as soon as possible.

Reducing emissions and developing materials with greater resistance to extreme events were the goals of the late architectural physicist John Orava. In 2001, following 9/11, Orava was tasked by two United States entities (the Federal Emergency Management Agency and Department of Housing and Urban Development) to develop high-performance, low-carbon solutions. Over the next decade, Orava developed and patented several solutions involving closed loop building systems and advanced nanomaterials based on unfired ceramics.

After Orava's death in 2010, his trustee, innovation partner, and companion Jan Thoren worked to established a new company to commercialize the patents as per his wishes. Thoren and architect Ron Suverkrop founded NanoArchitech in San Francisco, Calif., in 2015. In 2018, Jeff Selph became chief technology officer of NanoArchitech, bringing his own patents and expertise to the company.

The mission of NanoArchitech is to encourage the shift to mainstream sustainability and prepare communities to survive increasing climate-related threats. To do so, inventors at NanoArchitech have pioneered, researched, tested, and built new technologies for various types of infrastructure, including for water storage, bridge and building renovation, and prefabricated housing. However, the company's main approach to "Build Back Better" involves cementitious nanoceramic composites.

Figure 1. Zaha Hadid, a London-based architect, is known for innovative designs with creative curves. The Beijing Daxing International Airport terminal in China (left) and the One Thousand Museum high-rise residential condominium in Miami, Fla. (right) are examples of her iconic style. *Credit: (left) QuantFoto, Flickr (CC BY-NC-ND 2.0); (right) ucumari photography, Flickr (CC BY-NC-ND 2.0)*

NanoArchitech's work on nanocomposites was inspired by affordable precast and 3D-printing methods that aim to move modern (square) design toward resilient curvature. NanoArchitech engineers have developed several proprietary nanoceramic formulations that are price competitive due to their unfired manufacturing process, which offers huge cost and carbon savings.

Today's focus is on affordable and resilient building envelopes, which are described in more detail below. But NanoArchitech plans to someday use its nanocomposites for elaborate structures, such as the marvelous designs of Zaha Hadid (Figure 1).

CEMENTITIOUS NANOSCALE BUILDING MATERIALS

A nanocomposite is a multiphase solid material where either a) one of the phases has one, two, or three dimensions of less than 100 nanometers or b) the atomic structure features nanoscale repeating distances between the different phases that comprise the material. In the broadest sense, this definition can include porous media, colloids, gels, and copolymers, but it is usually taken to mean the solid combination of a bulk matrix with a reinforcing second phase.

Nanocomposites offer the ability to design and create new materials with unprecedented flexibility and improvement in their physical properties. At NanoArchitech, cementitious nanoceramic coatings and composites are formulated and manufactured to be lighter, stronger, and faster setting than the standard Portland cement, plus they are highly resistant to fire, water, mold, and toxins.

Sold under the brand name Neuskyns™, the NanoArchitech composites are made from commonly available minerals and recycled materials, bringing the carbon footprint to nearly zero depending on the chemical engineering. Specifically, the Neuskyns proprietary, patented formulations feature a variety of powder components consisting of oxides and acidic materials that are phosphate bonded in conjunction with other raw and recycled materials.

Neuskyns is sold as a powder in 50-pound buckets or one-ton super sacks. When water is added to the powders, the components react exothermically within minutes at room

NanoArchitech: Steering the legacy of climate tech for a resilient planet

NanoArchitech evolved from 18 years of research and development led by architectural physicist John Orava. The company was formally established in 2015 by architects Jan Thoren and Ron Suverkrop to further develop his technology.

Based on this strong foundational history and years of testing and building, Thoren, CEO, expects that Nanoarchitech's multifunctional and long-lived products will help propel the green economy, the Environmental Protection Agency's "Healthy Buildings, Healthy People" initiative, and support net-zero goals.

NanoArchitech has won several awards and acknowledgements in Europe and the United States for its products since 2013, when the company placed as a semifinalist in the Cleantech Open national competition in San Jose, Calif. Since then, other awards include the "Best new materials for a building envelope" in Architectural Record in 2019, the "Most Innovative Architectural technology in 2020" in Builtworlds magazine, and the "Top Ten Material Solution Providers" in Manufacturing Technology Insights in 2021. A full list of awards can be viewed at https://nanoarchitech.com/honors.

NanoArchitech is currently involved in the Impel Accelerator program at Lawrence Berkeley Labs in Berkeley, Calif. The interdisciplinary NanoArchitech team is excited to hear of other innovations in nanoceramic materials, and they look forward to continuing the incorporation of ceramics, glass, and photovoltaics in global green building projects.

TABLE 1. COMPARISON OF ENGINEERING PROPERTIES OF NEUSKYNS WITH COMMON BUILDING MATERIALS.

Material attribute	Neuskyns	Portland cement	Stucco	Asphalt
Typical strength (psi)	2,200–12,000	2,000–4,000	1,200–1,500	2,000–5,000
Fire-proof	Yes	No burns <1,000°F	No	No
Heat resistance	Tolerates >2,700°F	Low	Low	Low
Water-proof	Yes	No	No	No
Conductivity of hydrocarbons	Negligible	High	N/A	N/A
pH 3–11 tolerance	Yes	No	No	No
Hardening time	5–40 mins	2–4 hrs	<1 hr	>5 hrs
Functional cure time	15–60 minutes	1–3 days	1 day	1–3 days
Can apply below 32°F	Yes	No	No	No
Expansion or contraction	Minimal	Yes	Yes	Yes
Temperature related cracking	No	Yes	Yes	Yes
Self-leveling	Yes	No	No	No
Bonds to itself	Yes	No	No	No
"Green" material	Yes	No	No	No
Tolerant of salt water	Yes	No	No	No
Underwater setting	Yes	No	No	No
Combustible due to fire	No	Yes	N/A	N/A
Flame spread index	No flame and no smoke for Neuskyns			
Smoke test				

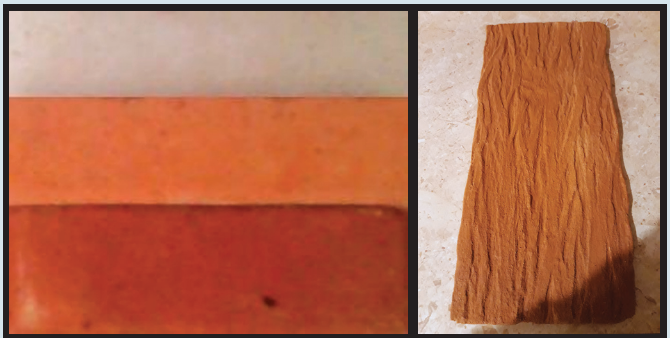


Figure 2. (left) Pigmented Neuskyns. (right) Neuskyns slab embossed with redwood bark pattern. *Credit: NanoArchitech.*

Figure 4. Bridge walls cured in less than two hours in subzero temperatures in Ontario, Canada. *Credit: NanoArchitech.*

temperature and create a high density, strong covalent bond with the surface on which it is being applied. (It does not bond with rubber or plastic, however, which makes them useful for molding Neuskyns.)

The exothermic chemical reaction can cause the temperature of the mixture to reach up to 170°F. When the exothermic reaction commences, the mixture is pasty and can self-level on a substrate or in a container. The overall performance attributes are the result of the reaction and the use of precise specifications of raw materials and mixture methodologies. Table 1 compares engineering properties of the Neuskyns nanoceramic formulation to other common building materials, namely, Portland cement, stucco, and asphalt.

DIVERSE FORM FACTORS AND USE CASES

The Neuskyns nanoceramics can be colored to blend in with surrounding materials, and decorative patterns can be applied, as shown in Figure 2. Figures 3 and 4 (described below) show two successful use cases for the material in the Caribbean and Canada, demonstrating the breadth of its usefulness.

Between 2014–2017, more than 200 prefabricated ceramic structural insulated panel (C-SIP) homes were built in the Caribbean (Figure 3). The homes were simple two- or three-bedroom houses with a $\frac{3}{8}$-in. finish of nanoceramic over a Styrofoam core attached to a steel frame. The homes were prefabricated in Florida and moved by truck and ferry to the island sites. Selph designed the C-SIPs in accordance with Miami-Dade high hurricane resistant building codes. The successful installations have now withstood two category 5 hurricanes without damage, and they set a precedent for higher standards of building in the Caribbean hurricane corridor.

Figure 3. The first Neuskyns nanoceramic housing designed for hurricane resilience in the Caribbean. *Credit: NanoArchitech.*

At the other weather extreme, Neuskyns nanoceramics were used to repair a set of bridge walls in a frigid Canadian environment (Figure 4).

CONCLUSION

The United Nations' plea to "Build Back Better" needs immediate answers and a robust response with new materials. Current legacy materials do not hold up to the extreme weather patterns that the world is now experiencing.

The NanoArchitech team is confident that nanoceramic composites hold the key to withstanding the challenges that are threatening the built environment. And after more than 10 years of investigations and trials, NanoArchitech's products have proven their worth in extreme temperatures and hurricane corridors.

NanoArchitech's unique "green chemistry" process has led to the continued development of new nanocomposites with low- to zero-carbon footprints. Plus, by eliminating the traditional heat-intensive manufacturing process for ceramics, production cost could be reduced by at least 50% as these products become mainstream.

Of course, there are ceramic materials that will continue to require kiln processing. Exploration is underway to neutralize the footprint, while recognizing that for buildings, price must be affordable.

We invite you to partner with us in this worldwide race to net zero.

ABOUT THE AUTHOR

Jan Thoren is cofounder and CEO of NanoArchitech following a 25-year career as an architect. Contact Thoren at jan@nanoarchitech.com.

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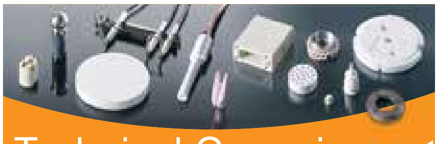

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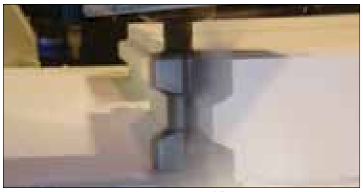

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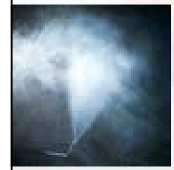

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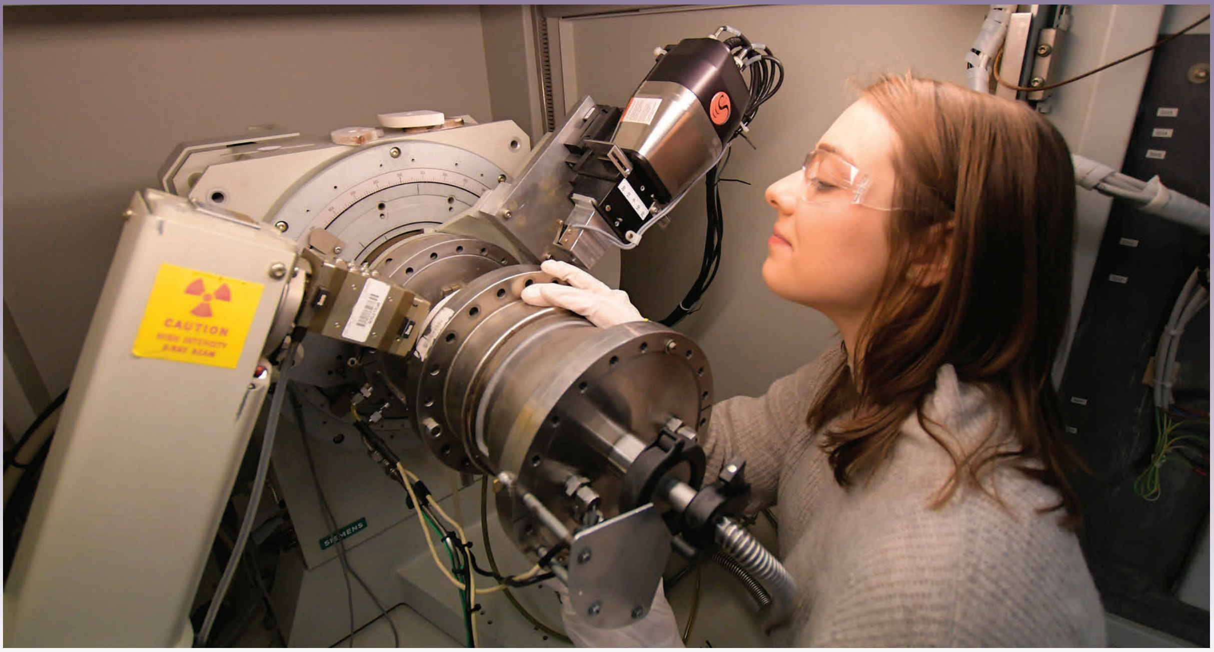

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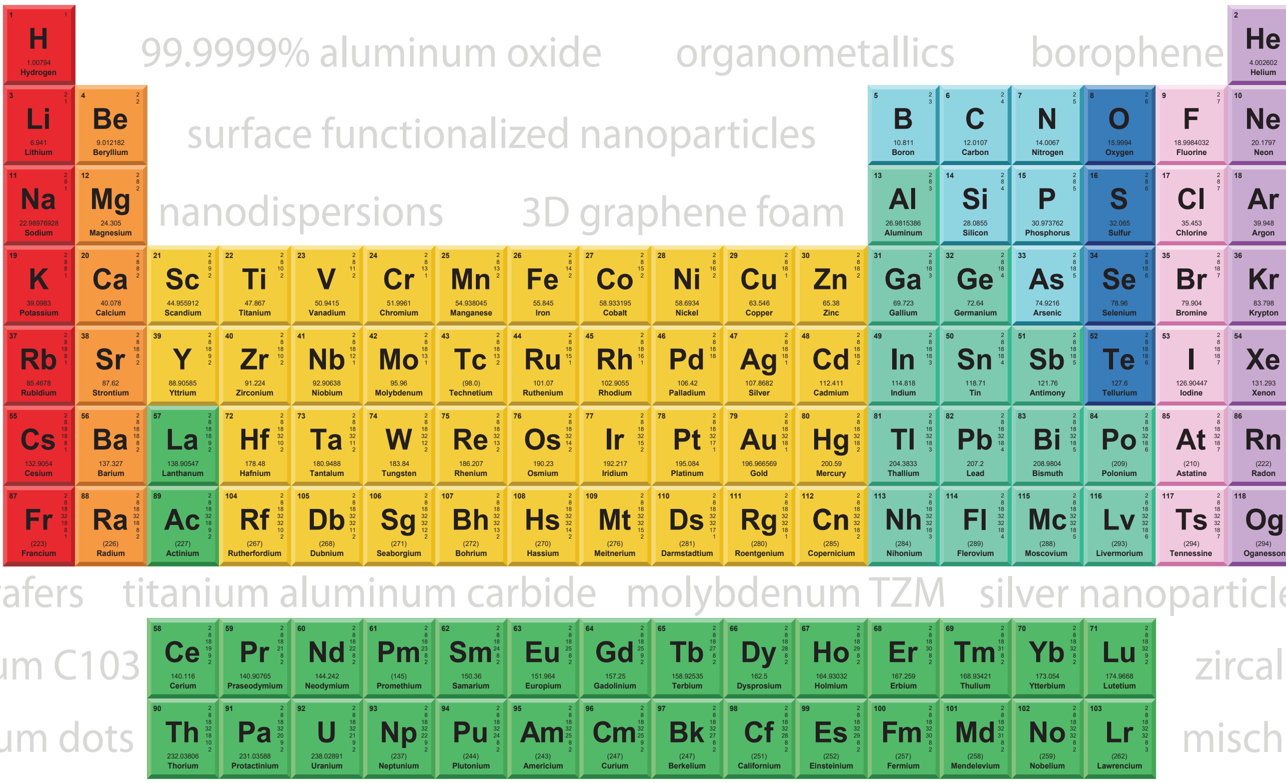

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