AMERICAN CERAMIC SOCIETY

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emerging ceramics & glass technology

AUGUST 2020

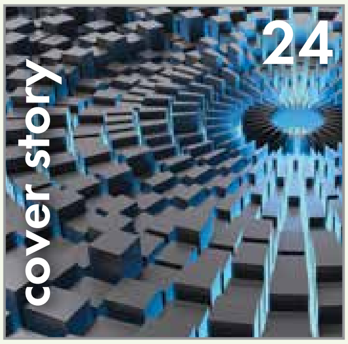
Data-driven approaches to materials and process challenges: A new tool for the materials science field

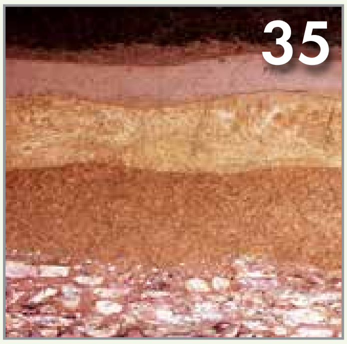
Glass coatings for solar panels | USGS annual mineral review | Virtual Glass Summit

contents

August 2020 • Vol. 99 No.6

feature articles





department

columns

meetings

resources

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August 2020 • Vol. 99 No.6

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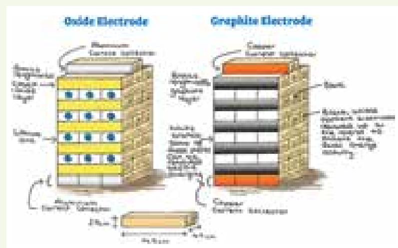

Credit: Driscoll et al., *Journal of Chemical Education* (CC BY 4.0)

Jenga teaches students how lithium-ion batteries work

Lithium-ion batteries are abundant in many everyday devices, but the resources available to teach children how these batteries work and why they are important are limited. A team of researchers from the University of Birmingham's School of Chemistry developed a unique and fun approach to explaining Li-ion battery operation using tower block games like Jenga.

Read more at www.ceramics.org/lithiumlearning

Also see our ACerS journals...

Development of precursor ceramics using organic silicon polymer
By T. Ishikawa and R. Usukawa
International Journal of Applied Ceramic Technology

Boron mining and enrichment waste: A promising raw material for porcelain tile production
By E. Karadagli and B. Cicek
International Journal of Applied Ceramic Technology

Exploratory research in alternative raw material sources and reformulation for industrial soda-lime-silica glass batches
By W. Deng, C. Spathi, T. Coulbeck, et al.
International Journal of Applied Glass Science

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

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ACSBA7, Vol. 99, No. 6, pp 1– 48. All feature articles are covered in Current Contents.

letter to the editor

Dear ACerS Community,

The Black Lives Matter movement, fueled by the recent murders of Ahmaud Arbery, Breonna Taylor, George Floyd, and countless others, has encouraged people all over the world to confront the anti-Blackness and systemic racism that permeate our society. Many people are looking for ways to educate themselves and take action to fight the racial and ethnic inequalities that Black, Indigenous, Latinx, and other ethnic and racially marginalized communities face each day.

With this newfound awareness, I am making the effort to learn about experiences of people in communities outside my own. Through this process, I have been made aware of and have started recognizing my own privileges, such as having access to high-quality education and being offered leadership opportunities within ACerS.

To this end, I want to acknowledge experiences that graduate students may be facing due to COVID–19 that I did not address in my recent *Bulletin* article, which published in the June–July 2020 issue. I focused on my own experiences, which led me to generalize my advice to students who may be experiencing quarantine in a very different way than I am, including

- Students who are mourning the loss of a loved one;
- Students with caretaking duties;
- Students without access to technology like laptops, webcams, or software packages;
- Students who have toxic relationships with their advisors or peers and would not feel further supported if meeting with them remotely during this time;
- Students who do not have access to mental health care or strong support networks; and
- Students who are facing financial challenges due to lack of institutional support, loss of job, or who need to support loved ones who have lost their income.

This list is not exhaustive—there are likely many other experiences of which I still am not aware.

When I said educators have to maintain "high academic standards" in my article, there was an underlying assumption that these standards should stay the same for all students in a global pandemic. Now that I have adjusted more to quarantine over the past few months, I am realizing that all "normal" standards go out the window during this stressful time, and people must be sensitive to what others might be going through. I gave examples and ideas of how I chose to tackle quarantine, but I recognize that my suggestions by no means work for everyone.

I hope others are taking the time to become aware of these differences so we can work together on making our scientific community compassionate and inclusive to all.

Sincerely,

Victoria Christensen, 2019–2020 PCSA chair

message from acers executive committee

To our members on embracing racial diversity and opportunity

The American Ceramic Society represents all people involved in the ceramic and glass industry. We admire the commitment of our young members, such as Victoria Christensen, chair of the President's Council of Student Advisors, to create a just world for all, especially within their chosen profession as ceramic and glass engineers and scientists.

As leaders of the Society, we share that passion and vision and agree that the Society has a role in breaking down racial barriers that persist in society and our profession. Our common enthusiasm for solving grand challenges with ceramic and glass materials binds us and leaves no room for artificial boundaries. Therefore, we must continually challenge ourselves to create an interpersonal culture of diversity in the Society and do our best to export it throughout our sphere of influence.

ACerS recognizes and welcomes its responsibility—and opportunity—to lead positive change in our field.

We are committed to cultivating an industry that offers Black people and other minorities open pathways to successful and satisfying careers working on some of the most promising materials to solve pressing global problems. The Society is committed to establishing and maintaining a culture of racial diversity and seeks to create it intentionally with meaningful actions that have long-lasting impact.

In 2017, ACerS established the Diversity & Inclusion Subcommittee (under the Member Services Committee) to foster a culture of inclusion across all ACerS activities. We have made progress diversifying the racial make-up of committees and the Board of Directors (see www.ceramics.org/about/acers-governance). However, we must do more to improve opportunities for Black colleagues in our profession and global society. As Martin Luther King, Jr., in his "Letter from a Birmingham Jail," wrote, "Whatever affects one directly, affects all indirectly."

The Society's Member Services Committee and Diversity & Inclusion Subcommittee are crafting a practical plan to present to the Board of Directors in July 2020 with actions for immediate implementation. In addition, during its 2021 Strategic Planning Process, the Society will focus on developing long-term strategies to recruit Black people and minorities to the ceramic and glass industry. The plan will include, for example, actions for introducing young people of color to the exciting careers and impacts they can have as ceramic and glass engineers and scientists, working with educators and industry to create multiple pathways to careers, and raising profiles of our Black members with leadership positions in the Society. We welcome your suggestions.

While we work on developing and implementing short-term and long-term actions to remove racism, we reiterate our message of inclusivity sent to the members on June 5, available on the ACerS homepage at www.ceramics.org.

We welcome all suggestions for advancing the Society's goals of effecting meaningful, long lasting change. Most importantly, we invite you to volunteer to work to advance these goals. For both, please contact president@ceramics.org.

Sincerely,

Tatsuki Ohji

Dana Goski

Sylvia Johnson

Elizabeth Dickey

Mark Mecklenborg

Steve Houseman

Executive Committee of The ACerS Board of Directors

news & trends

Sand—a critical material resource with a complicated story and no simple solution

In 2017, a *Science* perspectives paper was published that called for development of a global sand governance strategy to address the imminent threat of sand scarcity.

"Current development trends suggest that sand demand will increase further in the coming years," the authors wrote in the paper. "The resulting acceleration of sand extraction, trade, and consumption will have escalating effects on environmental and human systems. There is a pressing need for an effective global sand governance system."

The authors were spot on—sand demand has continued to increase, and there are certainly escalating effects on environmental and human systems.

However, to understand the demand and the resulting effects, we first need to recognize an important fact—not all sands are created equal.

Desert sand versus ocean sand—what's the difference?

The sand found in deserts is different from the sand found in river beds, for example, because the sand grains form from different materials and via diverse processes.

Most desert sand particles are rounded because they formed from erosion and have been subjected to the brutal forces of wind. These rounded edges mean desert sands are not suitable for construction uses. In contrast, the more angular edges and frequent pores of sands found in places like river beds work better in construction applications, where they can better bind together materials such as concrete.

In terms of the materials that form sands, most sands are classified as either siliciclastic, meaning they contain silicate materials, or carbonate sands, which are rich in carbonate materials. Carbonate sands are typically found on seafloors because the sand forms from broken-down remains of marine creatures or from nonorganic processes, such as precipitation from carbonate-rich waters. Other kinds of sands instead form from erosion of rock, which is how siliciclastic sands are born.

Sand demand: The scale of the problem

Sand grain differences aside, humans are still extracting a lot of sand across the planet for anthropogenic activities—and China may be leading the efforts.

"Around 60 percent of sand use worldwide is in China, which is estimated to consume more sand in three years than the U.S. consumed in the entire 20th century," according to a 2019 *Yale Environment 360* article.

But it is surprisingly difficult to find accurate data to gauge the full extent of sand extraction and consumption activities worldwide.

Some estimates suggest that humans currently use some 50 billion tonnes of sand and gravel per year. And the sheer volume of those activities are bound to have serious consequences.

Humans' voracious sand consumption for infrastructure activities threatens global supply of this critical natural resource. But do we even know how much sand we are consuming worldwide?

"We cannot extract 50 billion tonnes per year of any material without leading to massive impacts on the planet and thus on people's lives," Pascal Peduzzi, a researcher with the United Nations Environment Programme, says in a *BBC Future* article.

However, estimates such as 50 billion tonnes are often based on activity in the cement industry, which, while it consumes a large share of sand, only accounts for a portion of humans' use of the resource.

Notably, such sand use statistics do not account for marine activities—see the "land reclamation" section below—because data on marine extraction of sand simply isn't centrally collected, managed, or monitored.

So it is difficult to quantify just how much sand countries are moving around the earth, stripped from some places and piled up in others. But it is safe to say these activities add up to a lot of sand—much more than 50 billion tonnes per year.

Land reclamation: Redistributing the world's sand

Land reclamation, also known as land fill, is the process of creating new land from oceans, seas, riverbeds, or lake beds. It is frequently used to rebuild land damaged by extreme weather events like hurricanes, to control continual erosion, or to provide some land safeguards against rising seas in the face of climate change.

However, land reclamation efforts also are frequently used to create land where there was none before—and such reclamation efforts by China in the past couple decades exemplify the environmental and geopolitical effects these activities can have.

To perform land reclamation, China has a substantial fleet of huge dredging ships that scrape the bottom of the ocean and suck up sand, water, and anything else along the way with giant centrifugal pumps. That sucked-up sand and more is collected in the ship's hull, transported elsewhere, and spewed back out, reassigned to a new geography.

China has used dredging to create nearly 3,000 acres of new land around the Spratly Islands in the South China Sea within the past decade. But this fresh land isn't meant to protect against rising seas or re-establish habitats—after creating the new land, the country promptly claimed its creation by topping the fresh sand piles with military bases.

"This expansion of Chinese power into the Pacific has alarmed the US as well as China's neighbors," according to an *MIT Technology Review* article. "To show it does not recognize the new islands as Chinese territory, the United States has made a point of flying B-52 bombers over them and sending warships to pass close by. For its part, China has landed long-range bombers on its new runways, as a show of force."

In addition to raising tensions, these land reclamation activities also wreak environmental havoc, destroying habitats, wiping out living creatures, and completely altering natural landscapes.

"All that island building has also caused 'devastating and long-lasting damage to the marine environment,' according to the Hague-based Permanent Court of Arbitration, which rejected China's claim to sovereignty over much of the South China Sea in 2016," the *MIT* article continues. "Most plant and animal life on the seven Spratly reefs was destroyed by the mountains of sand dumped atop the coral. John McManus, a University of Miami marine biologist, called it 'the most rapid rate of permanent loss of coral reef area in human history.'"

Of course, China is not the only country invested in such activities—many other countries around the globe have and do use dredging as a means of land reclamation as well, whether that land previously existed or not. For instance, "Singapore has created an extra 50 square miles of land, growing its size by 20 percent, thanks to more than half-a-billion tons of imported sand," according to the *Yale Environment 360* article.

Regulating sand: Quantification is such an aggravation

Before any sort of sand use or governance strategy can be developed, we need data to quantify just how much sand we are talking about—regulations would be of little use if there was no reliable way to gauge, monitor, and compare the scale of sand extraction and consumption activities.

This situation is not just a problem of not having anyone centrally accountable for collecting and monitoring sand consumption data, however—new research suggests we do not even know how to accurately estimate the amounts and dynamics of sand itself.

Sediment dynamics, or how sand particles behave, may sound like a mundane field of study. But sediment dynamic models are really quite imperative as they help us to estimate the surface area of sand and thus sand volumes.

However, currently used sediment dynamic models often treat all sand particles the same, even though we know they are not. In particular, current models are based on data from round siliciclastic sand particles. But the same models are similarly applied to more angular carbonate sands, despite the known differences in shape, density, and porosity of the particles.

In a new open-access paper published in *Scientific Reports*, researchers from Turkey and Australia catalogued carbonate sand particles from a beach in Australia's Great Barrier Reef and found that, although shape varies from particle to particle, an elliptical shape more accurately models the angular and irregular shapes of carbonate sands rather than round siliciclastic sands.

The researchers' calculations showed that current models assuming a round particle shape incorrectly estimate the surface area of carbonate sand particles, and these differences are not trivial—the researchers say that existing models assuming a round shape can underestimate the surface area of carbonate sand by 35%.

The researchers also used their new and improved models to show that the differences add up to considerable inaccuracies in the way that we estimate the dynamics of these sediments, accounting for up to 20% discrepancies in previous models.

"Keeping track of carbonate sand will become increasingly important," study co-author Tristan Salles says in a *Cosmos* article. "If islands and atolls are at risk from erosion caused by sea-level rise, it will be vital to understand how the sands protecting them will respond to the ocean currents, waves and high-energy sea swells battering them."

And similar logic can certainly be applied to the incredible amount of sand being shifted by human activities, like dredging sea floors and building new islands.

The paper, published in *Scientific Reports*, is "Improved drag coefficient and settling velocity for carbonate sands" (DOI: 10.1038/s41598-020-65741-3).

So what's the solution?

Although we now have better models to more accurately estimate sand and predict its dynamics, the problem still remains—humans are extracting and consuming incredible amounts of sand around the globe, with little to no oversight and no end in sight. There is still no global sand governance strategy, and getting countries around the world to agree to a solution seems like a nearly impossible task.

In the meantime, we can take steps to reduce sand consumption. The *Yale Environment 360* article offers some ideas.

> "What should be done? Technically, some options exist. An untapped source of sand is the material that accumulates on the bottom of reservoirs. It could be dredged or flushed out. There is a win/win here. Dam operators would get the benefit of extra capacity for water storage, though arguably the sand should really be put back into the rivers it came from, rather than diverted for construction.
>
> In developed countries, where new construction often replaces demolished buildings, there is untapped potential to recycle building rubble instead of using new concrete. A third of construction material for housing in the UK is already recycled. Glass recycling reduces that industry's need for new sand. And there are substitutes for sand in concrete manufacture, including ash from power station incinerators, and dust from stone quarries. The problem is that at less than $10 a ton, sand remains very cheap."
>
> –*The Hidden Environmental Toll of Mining the World's Sand*

Of course, these strategies can only go so far, especially in the face of dredging ship fleets moving mountains of sand from one place to another and ever-increasing infrastructure projects. Nearly impossible task or not, the authors of the 2017 *Science* article are still—and perhaps now more than ever—right: "There is a pressing need for an effective global sand governance system. ■

Large and advanced battery technology and markets

By Andrew McWilliams

Large and advanced batteries represented a $61.5 billion global market in 2018. The overall market is projected to grow at a compound annual growth rate (CAGR) of 11.4% between 2019 and 2024 to reach $109.9 billion, making it one of the largest and fastest-growing, technology-driven electrical/electronic sectors.

"Large and advanced battery" is an arbitrary designation developed by BCC Research to describe a market-driven battery classification. As defined in this report, large and advanced batteries must have three attributes: they must be secondary (rechargeable) electrochemical energy storage devices (batteries), "large" in terms of size and energy capacity, as well as technologically advanced. This definition excludes all primary (non-rechargeable) batteries and all lead-acid automotive batteries, as well as all A, C, and D cylindrical batteries and button cells.

Lithium-ion batteries accounted for more than half of the total market in 2019, a share that BCC Research expected to increase to more than 60% by 2023. These gains will come at the expense of other first- and second-generation batteries such as lead-acid, nickel-cadmium, and nickel-metal hybrid batteries. Other emerging battery types, such as sodium-sulfur and vanadium redox batteries, should capture an increasing share of the market.

Much of the value and growth of the large and advanced battery market over the next five years is based on various types of passenger vehicles, portable devices, stationary applications, and other forms of transport.

- **Passenger vehicles:** The market for advanced batteries in various types of passenger vehicles, including pure electric, hybrid, and plug-in hybrid, is predicted to grow at a CAGR of 11.6% to reach $60.9 billion in 2024.
- **Portable devices:** The market for advanced batteries in portable devices, such as personal electronics, portable tools, and military equipment, is predicted to grow at a CAGR of 12.0% to reach nearly $20.3 billion in 2024.
- **Stationary applications:** The market for advanced batteries in stationary applications, such as uninterruptible power supplies, emergency lighting, and electricity storage systems, is predicted to grow at a CAGR of 12.1% to reach $15.3 billion in 2024.
- **Other ground, marine, and air transport:** The market for advanced batteries in other forms of transport is predicted to grow at a CAGR of 9.0% to reach $13.2 billion in 2024.

Many battery systems contain one or more toxic metals, including highly toxic metals such as lead, cadmium, and (until recently) mercury. Other battery constituents are not particularly toxic but can create safety hazards, such as overheating.

Innovations in battery materials should result in higher-performing and safer batteries that could displace existing batteries and allow commercialization of new battery-powered products. Examples of battery material research that are at a relatively advanced stage include graphene-based batteries, which are in the early stages of commercialization as of 2020, and glass electrolytes, which were developed at The University of Texas at Austin by a team of engineers led by John Goodenough.

About the author

Andrew McWilliams is a research analyst for BCC Research. Contact McWilliams at analysts@bccresearch.com.

Resource

A. McWilliams, "Large and advanced battery technology and markets" BCC Research Report FCB024H, May 2020. www.bccresearch.com.

Table 1. Large and advanced battery systems

First-generation large and advanced battery systems
Lead-acid batteries
Nickel-cadmium batteries
Next-generation large and advanced battery systems
Nickel metal hydride batteries
Lithium-ion batteries
Lithium-polymer batteries
Specialty large and advanced battery systems
Silver-zinc secondary batteries
Silver-cadmium secondary batteries
Nickel-hydrogen secondary batteries
Metal-air batteries
Nickel-zinc batteries
Emerging large and advanced battery systems
Sodium-sulfur batteries
High-temperature lithium batteries
Redox and flow batteries
Nickel-iron batteries
Calcium-metal sulfide batteries
Sodium-metal chloride batteries
Lithium-sulfur batteries

ACerS Division membership provides networking, leadership opportunities

One of the benefits of being a member of an ACerS Division is that it is relatively easy to establish new friends and contacts who share common interests, technical knowledge, and industry challenges.

Find out from two ACerS members the benefits that involvement with ACerS Divisions brings.

John Dowdle – Structural Clay Products Division

John Dowdle is director of sales at Old Hickory Clay Company, a company which mines, processes, and blends ball clay and kaolin clay for a number of various industries in North America and internationally.

Dowdle earned his bachelor's degree in ceramic engineering from Clemson University and became involved in Keramos, the national professional ceramic engineering fraternity. He eventually joined ACerS as a student and maintained his membership while working for companies Leviton Manufacturing Company and Prince Minerals.

Dowdle considers membership in the Structural Clay Products Division (SCPD) to be a good resource for him.

"You have the opportunity to network with customers, suppliers, and equipment manufacturers—you get exposed to everybody in multiple industries," he explains. "For me, personally, the networking has been a huge benefit."

Dowdle attends ACerS Annual Meetings as well as the SCPD and Southwest Section meetings. He eventually became more involved in the SCPD, working his way through various officer positions—first as secretary, then vice chair, chair-elect, chair, and is currently serving as trustee. In this positions, he has organized Division meetings and programs, sold sponsorships, set up plant tours, and facilitated technical sessions.

"When you become involved, you put yourself out there," Dowdle says. "Even though people don't know you personally, they know who you are. And it may lead to a new business opportunity down the road."

Being in sales, Dowdle says ACerS meetings are an opportunity to see multiple customers in one location. "It's always important to visit customers face to face, but having multiple customers at one location leads to multiple opportunities."

"I've met a lot of great people and made a lot of good friends over the years," he continued, "and I've always enjoyed seeing them when I go to these meetings. And even those I don't really do business with, I still look forward to seeing them. You never know who your next contact or resource may be."

Left to right: Harold Newman, John Dowdle, John Dowdle Sr.

Credit: John Dowdle

David Lange (left).

Credit: David Lange

David Lange – Cements Division

David Lange, an ACerS Fellow and Della Roy Lecture Award recipient, is professor of civil and environmental engineering at the University of Illinois at Urbana-Champaign. Lange became involved with ACerS and its Cements Division as a Ph.D. student at Northwestern University in the early 1990s.

"One of my two advisors, Hamlin Jennings, who was active in the Cements Division, was very influential on my outlook in the field," Lange recalls.

At that time, the Cements Division was a small Division, which gave Lange a chance to step into leadership positions, such as program organizer, program chair, division officer, poster judge, and more. He eventually became a mentor to the up-and-coming younger generations of students.

Through the '90s, Lange says the Cement Division grew and thrived, and it became recognized as one of the best conferences in the world for highlighting basic science in cement. Lange recalls that sometime around 2010 the Division began organizing its own summer meetings and hosting them on various college campuses.

"The Cements Division meeting became a nice experience for the grad students," he says. "And our division has contributed big ideas to the materials science community at large." He believes these meetings contributed to the increase in membership over the years. (Cements Division membership has increased by 23% over the past five years.)

Lange feels he has greatly benefitted from his Division membership over the years. "I especially enjoyed my early years when the leading senior people of the field were present at meetings—Hal Taylor, Sid Diamond, Fred Glasser, and Eric Sellevold, among others. I got to know them socially and personally," he recalls, "and you learn how they do their research.

What advice would he give to prospective ACerS members?

"If you have a commitment to your technical discipline, you owe it to yourself to become involved in a professional community," he says. "And ACerS is a key society to get involved in for researchers in cement and concrete materials. ■

acers spotlight

SOCIETY, DIVISION, SECTION, AND CHAPTER NEWS

ACerS welcomes new Northern California Section

ACerS is pleased to announce that the Board of Directors recently approved a petition to establish the Northern California Section of The American Ceramic Society. Officers of the new section are:

– Chair: **Scott McCormack**
– Funding Secretary: **Andy Nieto**
– Recruitment Secretary: **Adrian Radocea**
– Events Secretary: **Samuel Zhu**
– Treasurer: **Jenny Beach**

The Northern California Section serves ACerS members who reside or work in these California counties: Alameda, Amador, Calaveras, Contra Costa, El Dorado, Madera, Marin, Mariposa, Merced, Monterey, Napa, Sacramento, San Benito, San Francisco, San Joaquin, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Stanislaus, Sutter, Tuolumne, and Yolo. ■

MS&T20 registration for ACerS Distinguished Life and Senior, Emeritus members

ACerS is again offering complimentary Annual Meeting at MS&T20 registration for Distinguished Life Members and reduced registration for Senior and Emeritus members. These special offers are only available through ACerS and are not offered on the MS&T registration site. Registration forms are available at https://ceramics.org/acers-spotlight/mst20-registrations-distinguished-life-emeritus-and-senior-members and should be submitted by Aug. 28, 2020, to Erica Zimmerman at ezimmerman@ceramics.org. ■

IMPORTANT NOTICE about mail service!

The U.S. Postal Service has received notices that various international postal operators are no longer able to process or deliver mail or services originating from the United States due to disruptions related to the COVID–19 pandemic.

As a result, the U.S. Postal Service is unable to deliver mail to affected countries, effective June 12 and until further notice.

Therefore, ACerS is unable to mail membership cards, membership renewals, and other mailings to numerous countries outside of the U.S., and the list of countries continues to change. For an updated list of affected countries, please visit https://bit.ly/2ChXqCg.

We will mail items to you as soon as possible. In the interim, please watch your email for electronic delivery of items originating from the Society. ■

Do you qualify for Emeritus member status?

If you will be 65 years old or older by Dec. 31, 2020, and will have 35 years of continuous membership in ACerS, you are eligible for Emeritus status. Note that both criteria must be met. Emeritus members enjoy waived membership dues and reduced meeting registration rates. To verify your eligibility, contact Erica Zimmerman at ezimmerman@ceramics.org. ■

Volunteer Spotlight

Du

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

Jincheng Du is professor of materials science and engineering at the University of North Texas in Denton, Texas. He received his Ph.D. in ceramics from Alfred University and completed his postdoctoral training at Pacific Northwest National Laboratory and University of Virginia prior to joining UNT. He has published over 180 papers, three book chapters, and one book.

Du has received numerous distinctions, including the W.E.S. Turner Award of ICG, the Fulbright U.S. Scholar Award, and the Gordon Fulcher Distinguished Scholar Award from Corning Inc. He also is the recipient of the Research Leadership Award and the Early Career Award for Research and Creativity of UNT.

Du is an ACerS Fellow and serves as an editor of *Journal of the American Ceramic Society* and associate editor of the *International Journal of Applied Glass Science*. Du became a member of ACerS when he was a graduate student and has remained involved throughout his career. He currently is chair of the Glass & Optical Materials Division and served as program chair of GOMD 2018.

We extend our deep appreciation to Du for his service to our Society! ■

Names in the news

Dickey

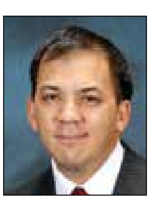
Elizabeth Dickey, Distinguished Professor and associate department head in the Department of Materials Science and Engineering at North Carolina State University, was named head of the Department of Materials Science and Engineering at Carnegie Mellon University effective January 2021.

Trolier-McKinstry

Susan Trolier-McKinstry, Flaschen Professor of Ceramic Science and Engineering and professor of electrical engineering at The Pennsylvania State University, was named an Evan Pugh Professor, an elite and prestigious distinction conferred by the university.

Kirchner

Katelyn A. Kirchner, materials science and engineering major in the College of Earth and Mineral Sciences at The Pennsylvania State University, received first place in the ninth annual Outstanding Undergraduate Thesis Award for her paper, *Beyond the average: A statistical investigation of fluctuations in glass-forming systems*



Hemrick

James Hemrick left Reno Refractories and returned to Oak Ridge National Laboratory in Tennessee.

Laurencin

Cato T. Laurencin was named president of the IMHOTEP Connecticut NMA Society, a community-based affiliated organization of the National Medical Association, on July 1, 2020. The National Medical Association (NMA) represents the interests of Black physicians and the patients that they serve.

Lu

Kathy Lu, professor of materials science and engineering at Virginia Tech, was accepted as a Fellow into the 2020–2021 cohort of the Executive Leadership in Academic Technology, Engineering and Science Program and was awarded the prestigious Fulbright Distinguished Chair award for 2020–2021.

Society, Division, Section, and Chapter news (cont)

Kim

Young-Wook Kim, ACerS Fellow and professor of materials science and engineering at University of Seoul in South Korea, has been appointed editor-in chief of the *International Journal of Applied Ceramic Technology* published by The American Ceramic Society and Wiley beginning January 2021. He succeeds co-editors Hua-Tay Lin (founding editor) and Monica Ferraris, whose terms expire at the end of the year.

Richerson

David W. Richerson received the Albert Nelson Marquis Lifetime Achievement Award and was profiled in Marquis Who's Who Millennium Magazine.

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

In memoriam

William Glen Allen
Edward Saleeby
Adam Holterhoff

Some detailed obituaries can also be found at www.ceramics.org/in-memoriam.

My Fulbright experience in Brazil: A wonderful journey on glass research and cultural exchanges

Attendees at a workshop at LaMaV, Federal University of São Carlos, Jan. 27, 2020. Front: Profs. Edgar D. Zanotto, Hellmut Eckert. Second row center: Profs. Jincheng Du, Jose Pedro Rino, with students surrounding the professors.

Jincheng Du, professor in the Department of Materials Science and Engineering at the University of North Texas in Denton, Texas, used his Fulbright U.S. Scholar Award to work with Edgar Zanotto's group at the Vitreous Materials Lab (LaMaV) at Federal University of São Carlos, Brazil. Learn about his experience as a Fulbright scholar in Brazil by visiting https://bit.ly/Brazil_Fulbright_Experience.

AWARDS AND DEADLINES

Morgan Medal and Global Distinguished Doctoral Dissertation Award

Deadline for Nominations: Jan. 15, 2021

The award recognizes a distinguished doctoral dissertation in the ceramics and glass discipline. The awardee must have been a member of the Global Graduate Researcher Network and have completed a doctoral dissertation as well as all other graduation requirements set by their institution for a doctoral degree 12 months prior to the application deadline.

The award is sponsored by Morgan Advanced Materials and will be presented at the Annual Awards Banquet at ACerS Annual Meeting at MS&T.

For complete nomination instructions, visit https://ceramics.org/awards/global-distinguished-doctoral-dissertation-award.

Submit nomination materials electronically (preferred) or by mail. If submitting electronically, send to Erica Zimmerman at ezimmerman@ceramics.org.

Awards and Deadlines (cont)

Upcoming nomination deadlines

2021 Class of Fellows Nominations: Deadline Aug. 20, 2020

The 2021 Class of Society Fellows recognizes members who have made outstanding contributions to the ceramic arts or sciences through productive scholarship or conspicuous achievement in the industry or by outstanding service to the Society. Nominees shall be persons of good reputation who have reached their 35th birthday and who have been members of the Society at least five years continuously. Visit http://bit.ly/SocietyFellows to download the nomination form.

Nominations for Varshneya Frontiers of Glass Lectures

Submit nominations for the two Darshana and Arun Varshneya Frontiers of Glass lectures that will be presented at the PACRIM14 meeting, May 23–28, 2021, in Vancouver, BC, by **Sept. 1, 2020**.

The Frontiers of Glass Science and the Frontiers of Glass Technology lectures 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.

Please submit nominations for individuals who have helped to define new horizons in glass science and technology to Erica Zimmerman at ezimmerman@ceramics.org. Additional information can be found at www.bit.ly/VarshneyaLectures.

Outstanding Student Researcher Award

The Outstanding Student Researcher Award recognizes exemplary student research related to the mission of the Energy Materials and Systems Division (EMSD). The award is open to U.S. and international graduate and undergraduate students actively engaged in research related to the EMSD. Applicants must have an accepted abstract for MS&T20. It is strongly encouraged that undergraduate submissions present extracurricular projects, i.e., research conducted outside the normal scope of one's coursework. Instructions, templates, and examples can be found at ceramics.org/awards/outstanding-student-researcher-award. Applications will be accepted until **July 31.** ■

Ceramographic Competition and Roland B. Snow Award

Start working now on your entry for the 2020 Ceramographic Exhibit & Competition, organized by the ACerS Basic Science Division! This unique competition, to be held at ACerS Annual Meeting at MS&T20 in October in Pittsburgh, Pa., is an annual poster exhibit that promotes the use of microscopy and microanalysis as tools in the scientific investigation of ceramic materials. The Roland B. Snow award is presented to the Best of Show winner of the competition. Winning entries also are featured on the back covers of the *Journal of the American Ceramic Society*. Read more about the rules of entry for this year's competition at www.ceramics.org/roland_b_snow_award. ■

STUDENTS AND OUTREACH

MS&T20 student contests

Students, be sure to take note of all the student contests at MS&T20 in Pittsburgh, Pa., including:

- Undergraduate Student Poster Contest,
- Undergraduate Student Speaking Contest,
- Graduate Student Poster Contest,
- Ceramic Mug Drop Contest,
- Ceramic Disc Golf Contest,
- Humanitarian Pitch Competition.

For more information on any of the contests or student activities at MS&T20, visit www.matscitech.org/students or contact Yolanda Natividad at ynatividad@ceramics.org. ■

Students and outreach (cont)

PCSA Humanitarian Pitch Competition at MS&T20

The President's Council of Student Advisors is hosting the Humanitarian Pitch Competition for students to pitch their ideas to a panel of judges about how they can address a challenge a community is experiencing. By using their materials engineering background, they should aim to show how improved materials/processes will benefit the community in need.

Students may put together a team of up to four participants to develop a solution to a real-world problem using materials science. Both undergraduate and graduate students are eligible to participate. Visit www.ceramics.org/pitchcomp for further details and submit abstracts by **September 1**.

Graduation gift from ACerS

ACerS offers a one year Associate Membership at no charge for recent graduates who have completed their terminal degree. ACerS is a truly global community and an Associate Membership can connect you to more than 10,000 professionals from more than 70 countries. More than 35% of our members live and work outside North America. They collaborate and inspire one another through participation in divisions, classes, sections, and technical interest groups. Visit www.ceramics.org/associate to learn about this vibrant community and to join as an Associate Member. For more information or questions, please contact Yolanda Natividad at ynatividad@ceramics.org.

CERAMICANDGLASSINDUSTRY FOUNDATION

ACerS creates new Student Travel Fund

Our younger colleagues—current undergraduate and graduate students—will soon deal with budgetary restrictions that their universities established due to the economic realities of the COVID-19 pandemic. That is why ACerS created a new Student Travel Fund—to increase our financial support of student attendance at ACerS meetings.

To help launch this new student travel fund, several generous ACerS members have helped create a $10,000 matching gift challenge. That means that every dollar you donate to the ACerS Student Travel Fund this summer will be doubled!

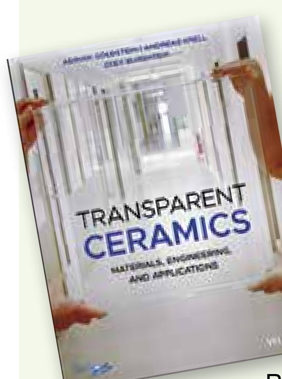
As an experienced member of the ceramic and glass community, you have developed professional relationships, many of which were made possible through ACerS meetings. Our younger members, who are trying to start their professional careers, can benefit the most by participating in ACerS meetings. With your help, we can encourage more students to attend ACerS meetings and become lifelong members of our ceramic and glass materials community.

Please support the next generation of ceramic and glass professionals by giving online at www.ceramics.org/donate. Your gift to the ACerS Student Travel Fund will give these same great opportunities to many more students and young professionals.

ACERS BOOKSHELF

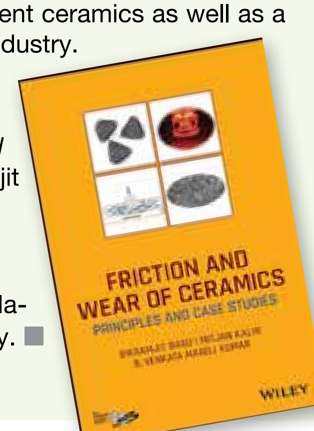
Check out two new titles from ACerS/Wiley

Looking for a new book to read this year? Two new titles by Wiley-ACerS are available on www.wiley.com/ceramics.



Transparent Ceramics by Adrian Goldstein, Andreas Krell, and Zeev Burshtein

The authors provide a history of transparent ceramics and a detailed account of various applications and uses of transparent ceramics as well as a look at the future of the industry.



Friction and Wear of Ceramics: Principles and Case Studies by Bikramjit Basu, Mitjan Kalin, and B. V. Manoj Kumar

This book covers the area of tribology broadly, providing important introductory chapters to fundamentals, processing, and applications of tribology.

Graphene quantum dots may help treat ulcerative colitis

Researchers from Seoul National University in Korea investigated the ability of graphene quantum dots to help treat certain kinds of autoimmune diseases.

To date, the exact cause of many autoimmune diseases is unknown. Instead, treatment focuses on controlling the immune system response. As such, much research on autoimmune diseases focuses on identifying and developing materials that provide control over the immune response.

Previous studies have shown the interaction of graphene quantum dots with immune cells, including macrophages and T cells. These results prompted the researchers of the new study to investigate how well graphene quantum dots may aid in treating inflammatory bowel diseases, such as Crohn's disease and ulcerative colitis.

They note in an open-access paper that immunosuppressive drugs are commonly used already to treat such diseases. However, "the treatments for [inflammatory bowel diseases] are often accompanied by complications such as infections and malignancies," they write.

"Thus, alternative drug with less side effects is still needed," they add.

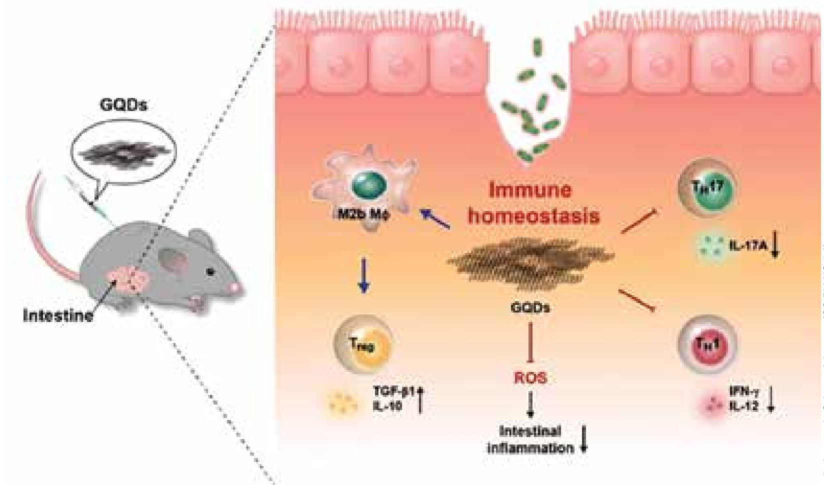
In their study, the researchers used the dextran sulfate sodium colitis animal model to investigate the inhibitory effects of graphene quantum dots on acute and chronic colitis. In this model, which is widely used in inflammatory bowel disease research, dextran sodium sulfate is used to cause epithelial damage in mice, which induces a human ulcerative colitis-like response.

The researchers found that mice treated with graphene quantum dots experienced increased survival rates and reduced weight loss compared with untreated mice, and they scored lower on a disease activity index based on weight loss, activity, stool consistency, bleeding, and hair condition. In addition, the mice had lower levels of myeloperoxidase (a biomarker of ulcerative colitis) and reduced shortening of the colon—a characteristic feature of the disease.

In the paper, the researchers note several important factors that helped prevent tissue degeneration and intestinal inflammation in the graphene quantum dot-treated mice, including suppressed excessive T cell activity, enhanced intestinal infiltration of regulatory T cells, and conversion of classically activated M1-like features of macrophages to anti-inflammatory M2 macrophages.

In a *Physics World* article, the researchers say they are now working to develop an oral version of the therapy and moving toward clinical trials.

"After studying the pre-clinical research this year, we are targeting stage 1 clinical trials in 2022," Byung Hee Hong, professor and head of the Graphene Research Laboratory at Seoul National University, says in the article.



Schematic diagram showing how graphene quantum dots (GQDs) affect a mouse colitis model, including preventing tissue degeneration and ameliorating intestinal inflammation.

The open-access paper, published in *Science Advances*, is "Graphene quantum dots as anti-inflammatory therapy for colitis" (DOI: 10.1126/sciadv.aaz2630). ■

Breathalyzers detect COVID–19

Credit: Perena Gouma

The portable, battery-operated breathalyzer prototype to detect COVID–19.

Researchers at The Ohio State University are developing a breathalyzer to detect COVID–19.

The research is being led by FACerS Pelagia-Iren (Perena) Gouma, Edward Orton, Jr., Chair in Ceramic Engineering and director of the Advanced Ceramics Research Laboratory.

Gouma began exploring use of breathalyzers for medical diagnostics in 2003, following her invention of a selective ammonia gas sensor that can discriminate and measure ammonia gas in a complex environment.

Her diagnostic breathalyzer concept is similar to an alcohol breathalyzer—inexpensive and easy to use—but it uses selective gas sensing elements to detect certain biomarkers in breath that signal disease.

Compared to swab-based testing methods, Gouma says her method is advantageous as results are available immediately.

"My breathalyzer technology detects the chemical compounds in breath so it is non-invasive, non-intrusive, and will tell you the result within 15 seconds of exhaling into the device," she says in an email. "Other tests, whether they are called 'breathalyzers for breath condensates' or 'swab-based saliva tests,' look for biological components in the breath, which require separate testing. Therefore, they cannot compete with my technology."

With funding from the National Science Foundation, Gouma pursued her breathalyzer concept and soon received a patent on a selective nitric oxide sensor that uses a radical single exhale detection design.

"At that time, the only acceptable breath testing relied on the Sievers NO analyzer that required 30 liters of breath sample, and single exhale sensing was out of the question," Gouma says. However, single exhale is very important because it gives very reproducible results; in contrast, "multiple exhales change the balance of metabolites in breath, thus giving unreliable results," she explains.

Since then, Gouma has received tens of other patents on sensors for breath analysis. Overall, she says the field of breath analysis is growing quickly and the medical field is investing in establishing breath biomarkers for various diseases.

Gouma started investigating the development of breathalyzers aimed specifically at detecting infectious diseases a few years ago. In 2017, she published an article on a breathalyzer that detected the flu virus, and that research was the basis for the new COVID–19 technology.

The infectious disease breathalyzers use ceramic sensors to target biomarkers, such as nitric oxide and isoprene, that signal infections. The COVID–19 breathalyzer targets biomarkers that give a response specific to that infection and includes advances on nanomaterials for detecting specific breath gases at concentrations that can make a diagnosis.

Gouma says her team initially tested the new breathalyzer by using gas canisters that were mixed to simulate the breath gas mixture as a result of COVID–19 infection. However, they are now conducting human and animal testing and expect to receive emergency use authorization soon to start deploying the device as needed. ■

Coordination polymer glass may provide solid support for PEM fuel cells

Researchers from several universities, institutions, and corporations in Japan developed a coordination polymer glass with high intrinsic proton conductivity for use in hydrogen-fueled polymer electrolyte membrane (PEM) fuel cells.

Compared to other fuel cells, PEM fuel cells deliver high-power density with low weight and volume. However, for the solid polymer membrane in the fuel cell to properly conduct ions, it must be surrounded by liquid water.

This water requirement places limitations on the fuel cell efficiency, so a big goal for researchers is to develop proton conductive materials that do not require water to work well.

Several studies in the past decade have focused on proton conductivity of coordination polymers and metal–organic frameworks because of their tailorable pores and ability to accommodate guest molecules. However, these materials are intrinsically nonmoldable because of their crystalline nature, and the grain boundary causes gas leaking and additional resistance in the electrolyte layers.

More recently, coordination polymers and metal–organic frameworks in liquid and glassy states have received attention as moldable materials. Despite their potential, "there are still a limited number of reports on proton-conductive CP/MOFs glass, and there are no reports of CP/MOFs to satisfy the criteria for sufficient proton conductivity (above 10 mS $cm^{-}1$) under anhydrous conditions," the researchers explain in their recent paper.

In their study, the researchers aimed to develop a coordination polymer glass with high intrinsic proton conductivity by focusing on protic ionic liquids.

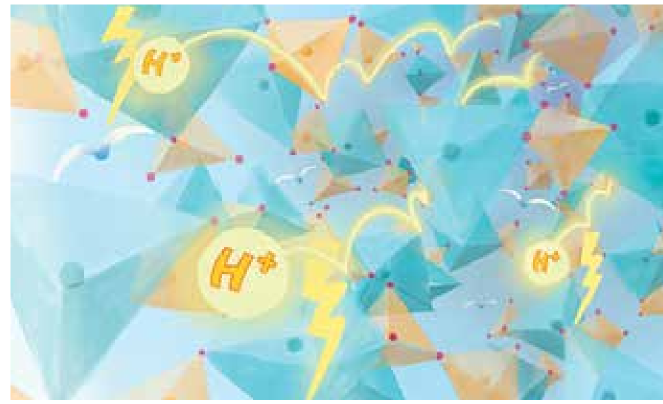
Protic ionic liquids are a subset of ionic liquids and made by mixing an acid and a base. Some protic ionic liquid compositions have achieved high proton conductivity and high chemical and thermal stabilities, but they typically exhibit low viscosity, limiting use in membranes. Further, high mobility of both cations and anions in coordination polymer glass results in a low transport number of protons, which "leads to a decrease in the open-circuit voltage (OCV) in fuel cells," the researchers write.

To overcome some of these problems, the researchers proposed using metal ions in addition to the protic ionic liquid when synthesizing coordination polymer glass.

"Appropriately selected metal ions can interact with the anions to form a [coordination polymer] with the desirable characteristics of moldability, proton conductivity, as well as a high transport number," they write.

Using zinc ions (Zn^{2+}) and the protic ionic liquid diethylmethylammonium dihydrogen phosphate (dema)($H_2PO_4^-$), the researchers synthesized a coordination polymer glass that produced a high open-circuit voltage of 0.96 volts, well within the range of current water-based electrolytes.

In a Kyoto University press release on the study, the researchers say they plan to continue their work with the aim of achieving fuel cell membranes with higher performance and long-term stability.



Credit: Izumi Mindy Takamiya, Kyoto University (CC BY 4.0)

The molecular structure of a new coordination polymer glass facilitates movement of protons across it under dry conditions at 120°C.

The open-access paper, published in *Chemical Science*, is "Coordination polymer glass from a protic ionic liquid: proton conductivity and mechanical properties as an electrolyte" (DOI: 10.1039/D0SC01737J). ■

Butter-like ceramic interlayer may solve interface instability of solid-state batteries

Scientists at Chalmers University of Technology in Sweden and Xi'an Jiaotong University in China developed a new high-performance ceramic interlayer that could aid in the commercialization of solid-state batteries.

Several challenges to commercializing solid-state batteries remain, including creating a stable interface between the solid electrolyte and electrodes. So devising strategies to stabilize that interface is key to unlocking the potential of solid-state batteries.

The interlayer created by the Swedish and Chinese scientists helps stabilize that interface. The interlayer is a paste-like mixture of glass-ceramic nanoparticles [$Li_{1.5}Al_{0.5}Ge_{1.5}(PO_4)_3$, otherwise known as LAGP] within an ionic liquid. Despite its butter-like consistency, the material provides a battery interlayer with adequately high ionic conductivity, high thermal stability, and low interfacial resistance.

In the lab, the team showed that adding the interlayer to solid-state coin cell test batteries composed of a ceramic LAGP electrolyte and lithium metal anode enhanced the batteries' performance and durability by acting as a sufficient barrier between electrode and electrolyte.

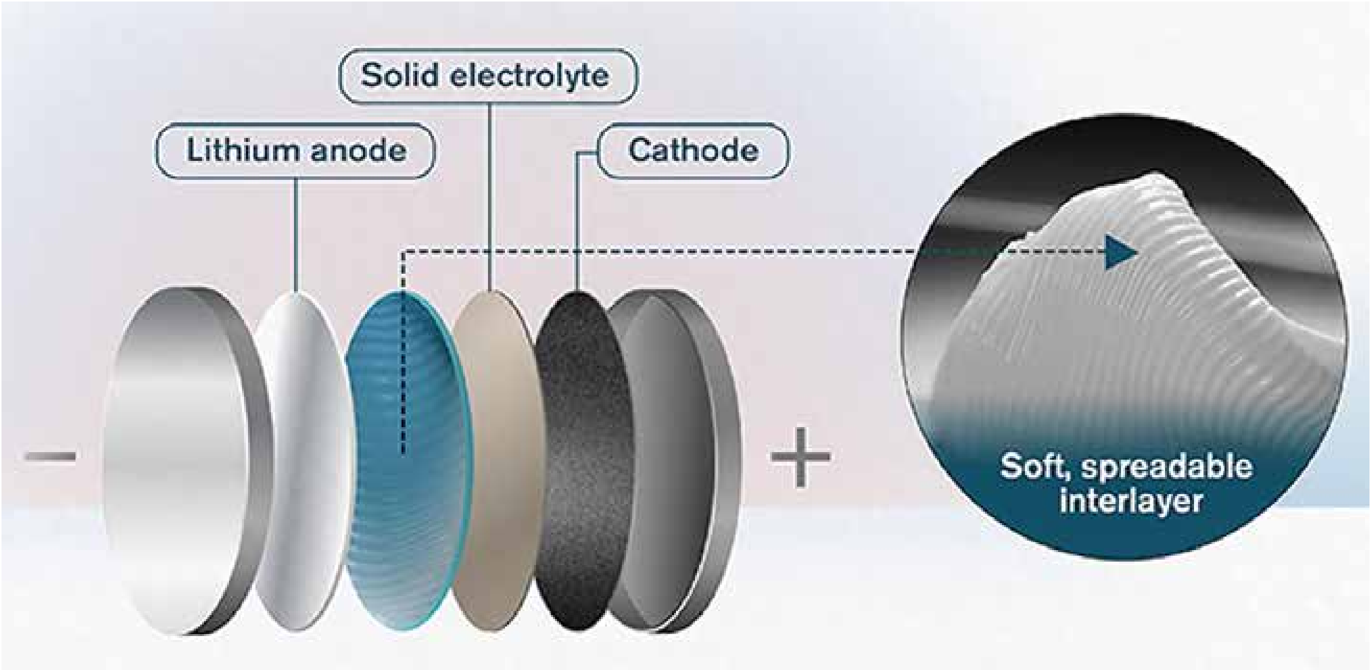
When tested under heating, the interlayer protected batteries even after intense heating for 40 minutes. In contrast, similar batteries sans the protective interlayer caught fire and burned to a pile of ash during the heating tests.

In the open-access paper describing their work, the researchers indicate that reaction between the interlayer ingredients contributes to the layer's thermal stability, as the ionic liquid breaks down to deposit an "in-situ coating of amorphous carbon on the LAGP nanoparticles."

In addition to offering thermal stability, they also showed that the interlayer suppressed formation of dendrites.

In an email, Chalmers professor of physics and senior author Aleksandar Matic says the paste-like consistency of the interlayer means it can be easily incorporated with coating processes once large-scale processes for manufacturing solid-state batteries are developed. Also, he says they plan to explore how thin they can make the interlayer—perhaps less than 10 micrometers—yet maintain good performance and reproducibility.

The open-access paper, published in *Advanced Functional Materials*, is "Design of a multifunctional interlayer for NASCION-based solid-state Li metal batteries" (DOI: 10.1002/adfm.202001444). ■



Credit: Yen Strandqvist; Chalmers University of Technology

A new butter-like ceramic interlayer makes solid-state battery cells much more stable and thus able to withstand much higher current density.

Pursuing carbon capture at the industrial scale

Credit: akersolutions, YouTube

A cement plant in Norway could become the first full-scale carbon capture and storage facility for cement production.

A cement plant in Norway could become the first full-scale carbon capture and storage (CCS) facility for cement production.

According to an article on the United Nation's Climate Technology Centre & Network website, "CCS is a combination of technologies designed to prevent the release of CO_2 generated through conventional power generation and industrial production processes by injecting the CO_2 in suitable underground storage reservoirs."

CCS is not yet proven in cement production at the industrial scale. However, many studies are underway to investigate the technology's feasibility, such as the study in Norway.

The Norwegian study is being led by Norcem, a Norwegian manufacturer of cement and subsidiary of HeidelbergCement, one of the largest building materials companies in the world. According to Norcem's website, the company is the sole producer of cement in Norway, with plants in Brevik (south) and Kjøpsvik (north).

n July 2016, a feasibility study by the Norwegian government showed CO_2 capture was technically possible at three industrial emission sites in Norway, including Norcem's Brevik site. The Norwegian Parliament approved the revised national budget for the second half of 2018 to include funding for Norcem to begin advanced planning studies.

In 2017, Norcem contracted with Aker Solutions to pursue the advanced planning studies. Aker Solutions is an engineering company based in Oslo, Norway, and the company previously carried out extensive testing with a pilot capture plant at Norcem's Brevik site. The results were so promising that Norcem selected Aker Solutions' carbon capture technology for the advanced planning studies.

Aker Solutions now has tested its technology at Norcem's Brevik site for 18 months, and "the promising results from the pilot testing give us confidence that realization of the full-scale capture plant will be successful," Per Brevik, director of sustainability and alternative fuels at HeidelbergCement Northern Europe, says in an Aker Solutions press release. What's more, the Aker CCS process was certified by DNV GL, a quality assurance company and technical advisor to the oil and gas industry.

This summer, the CCS setup at Brevik will undergo a review by Gassnova, the Norwegian state enterprise for carbon capture and storage. If the technology wins government approval and funding, construction on the full-scale facility could start in January 2021.

If the Brevik plant goes ahead, "half of the CO_2 emissions trapped by the Aker equipment will be shipped to the Norwegian coast, where it will be pumped in a pipeline to a storage well being developed 2,500 m below the North Sea bed at the Troll gas field, some 65 km off Bergen," an Engineering News-Record article explains. It is expected that up to 400,000 tonnes of CO_2 could be captured and stored each year.

Norcem is not the only subsidiary of HeidelbergCement pursuing CCS. Lehigh Cement Company, a leading producer of bulk and bagged cement in North America, also launched a feasibility study on a full-scale CCS project at its plant in Edmonton, Alberta, Canada. The $3-million study, which is partly funded by the Canadian government, is set for completion late this year. ■

Graphene may smooth out carbon fiber's high price

A team of researchers from The Pennsylvania State University, the University of Virginia, and Oak Ridge National Laboratory, in collaboration with industry partners Solvay (Neder-Over-Heembeek, Brussels, Belgium) and Oshkosh Corp. (Oshkosh, Wisconsin), showed that adding just a small amount graphene to carbon fiber precursor materials could make carbon fiber more affordable.

Carbon fiber is an attractive option in the automotive world due to the material's high strength and stiffness yet low weight. However, carbon fiber costs 10-times the price of steel, making it difficult to rationalize the price difference for automobiles except in racing vehicles or high-end models.

The reason carbon fiber costs so much is because of polyacrylonitrile (PAN). This polymer is used to create 90% of carbon fibers found in the market today, but its production requires an enormous amount of energy.

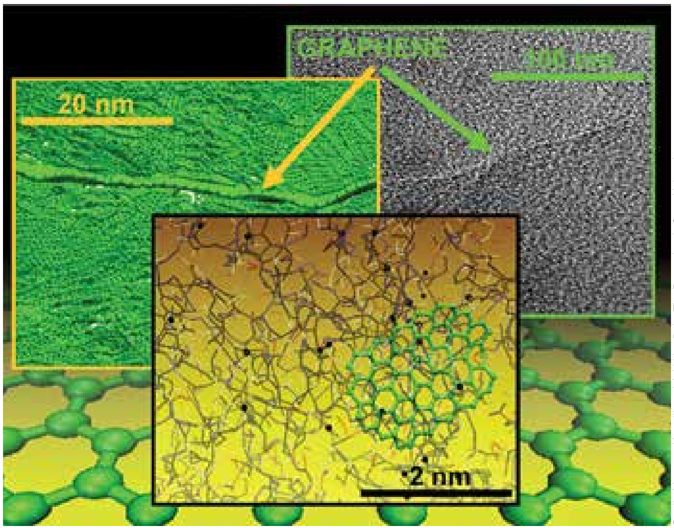
Less expensive carbon alternatives have been explored, but they have not yet been able to generate the high-quality carbon fibers that PAN produces. However, the researchers of the new study found doping PAN fibers with a small amount of graphene, just 0.075 wt %, produces carbon fibers with a tensile strength of 1,916 MPa and Young's modulus of 233 GPa—225% higher strength and 184% higher Young's modulus compared to similar fibers without added graphene.

The researchers show in their open-access paper that this enhanced mechanical strength traces back to graphene's ability to reduce the size of pores in fibers spun from PAN, which they speculate is because flat graphene nanosheets help guide PAN molecules as they solidify into fibers, reducing large voids that structurally weaken the fibers. When processed, these better-aligned PAN molecules result in stronger, reinforced carbon fibers.

Atomistic and molecular dynamics simulations attributed this reinforcement to several factors. "The simulation results show that the addition of graphene introduces favorable edge chemistry, promotes carbon content, enhances polymer chain alignment, and increases crystallinity," the researchers write in the paper.

Ultimately, the findings could translate into strategies that require less processing to generate sufficiently strong carbon fibers, which would reduce cost. Another possibility is that less expensive precursor materials could be used as carbon sources that still can generate adequately strong carbon fibers with graphene's assistance.

The open-access paper, published in *Science Advances*, is "Graphene reinforced carbon fibers" (DOI: 10.1126/sciadv.aaz4191). ■



Credit: Margaret Kowalik and Adri Van Duin, The Pennsylvania State University

Computer simulations show that adding graphene to the carbon fiber production process greatly strengthens the material.

research briefs

Ultrafast heating system using photon energy

In a recent research brief, three researchers in Japan describe an ultrafast heating system using photon energy.

In recent years, scientists have become interested in harnessing thermal radiation to generate heat in a controlled fashion—in other words, to create heating systems based on photon energy.

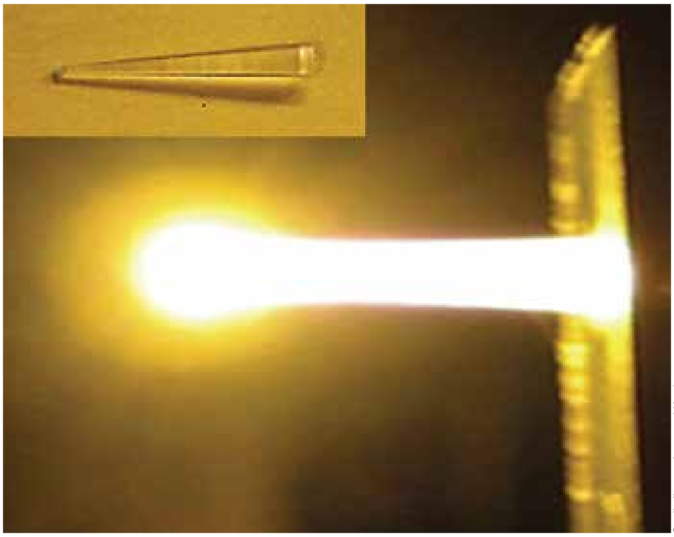
Traditionally, such an idea was viewed as impracticable due to Planck's law, which forms our basic understanding of thermal radiation. This law sets an upper limit for radiative heat transfer between bodies at different temperatures, meaning it limits how much heat a photon-based heating system could produce.

However, Planck's law was derived under the assumption that all dimensions involved in a thermal problem are much longer than the thermal wavelength. But in recent years, advances in nanomaterials and engineered nanostructures means the Planckian limit can be greatly overcome—making the idea of a photonic heating system feasible.

The three researchers were led by Akio Ikesue, ACerS Fellow and founder of World Lab. Co., a company that develops special ceramics. Ikesue is renowned in the field of transparent laser ceramics because his yttria alumina garnet (YAG)-based lasers were the first to achieve laser performances close to single crystals.

Ikesue explains in an email that he established the photonic heating technology described in his recent research brief around 25–30 years ago, but he did not share it at a conference nor submit a technical paper. However, because the concept of flash heating has become "hot news" lately, he started looking into photonic heating with renewed interest.

In the research brief, Ikesue and his colleagues Yan Lin Aung (World Lab. Co.) and T. Kamimura (Osaka Institute of Technology) describe their YAG-based photonic heating system, which uses photons to heat a specially designed ceramic tip at very fast rates—the time required to reach 1,000°C is about 100 milliseconds, and the heating rate reaches 10,000°C per second.



Credit: Ikesue, Aung, and Kamimura

Example of the transparent yttria alumina garnet ceramic cone used in a new ultrafast photonic heating system, which can reach temperatures of up to about 1,900°C in approximately 200 milliseconds.

Ikesue says there still is much unknown about the full potential of the photonic heating system, such as lifetime durability. However, they continue to investigate different system components, including wired versus wireless setups, other transparent ceramics besides YAG, and the wavelength of light used.

For more information on the YAG-based photonic heating system, visit https://ceramics.org/YAG-photon-heating. For questions on the research or inquiries concerning collaborations on future studies, contact Ikesue at poly-ikesue@s5.dion.ne.jp or Yan Lin Aung at poly-yan@r2.dion.ne.jp. ■

Research News

Strainoptronics: A new way to control photons

George Washington University researchers demonstrated for the first time that a 2D material wrapped around a nanoscale silicon photonic waveguide creates a novel photodetector that can operate with high efficiency at the technology-critical wavelength of 1,550 nanometers. To create the device, they stretched an ultrathin layer of molybdenum telluride on top of a silicon photonic waveguide and then used their newly created strainoptronics "control knob" to alter its physical properties to shrink the electronic bandgap. They note these novel 2D material-based photodetectors are 1,000 times more sensitive compared to other photodetectors using graphene. For more information, visit https://mediarelations.gwu.edu/news-releases. ■

Plug-and-play lens simplifies adaptive optics for microscopy

Researchers from Delft University of Technology, CNR-Institute for Photonics and Nanotechnology, and University Medical Center Rotterdam developed a new plug-and-play device that can add adaptive optics correction to commercial optical microscopes. Typically, adaptive optics requires building a custom microscope that incorporates a deformable mirror. The researchers instead created a shapeable smart lens made of a glass disk-shaped container filled with a transparent liquid. The lens functions like the deformable mirror, but instead of reflecting light, it transmits light. As light travels through the liquid, it gets distorted differently depending on the shape of the lens. For more information, visit https://www.osa.org/en-us/about_osa/newsroom. ■

Fluorescing boron nitride nanotubes provide look at material's motion in solution

In a recent study, Rice University researchers investigated how boron nitride nanotubes (BNNTs) move in solution.

Compared to carbon-based nanomaterials, boron-based nanomaterials still are not well understood. However, what is known shows that boron-based nanomaterials may have superior and complementary properties to carbon-based nanomaterials. For example, borophene is stronger and more flexible than graphene, and BNNTs are electrically insulating rather than conducting (the opposite of carbon nanotubes). So learning more about the structure and fundamental properties of boron-based nanomaterials is advantageous.

Credit: Jeff Fitlow, Rice University

Rice University graduate student Ashleigh Smith McWilliams holds a vial of fluorescing boron nitride nanotubes. She and colleagues captured video of the nanotubes in motion to prove their potential for materials and medical applications.

The Rice University researchers wanted to look at how BNNTs move in solution because "Understanding how BNNTs diffuse in solution is paramount to producing aligned films and fibers, as it provides a time scale for relaxation and reorientation," they write in the paper. "Additionally, knowing how BNNT diffusion compares to that of other materials, such as polymers, can allow us to design composites that maximize BNNTs' desired properties."

Unfortunately, investigating the real-time dynamics of BNNT dispersion can be surprisingly difficult because BNNTs are highly polydisperse, meaning the distribution of chain lengths and molecular weights in the BNNT structure is non-uniform. Common ensemble techniques used to investigate dispersion, such as dynamic light scattering, require uniformity to work best and thus do not help in this case.

Fortunately, there is a technique that allows for real-time dynamics studies at the level of an individual particle or molecule—fluorescence microscopy, which uses an optical microscope that detects fluorescent light to study the properties of organic or inorganic substances.

"This technique has been previously utilized to measure diffusion and bending dynamics information for single-walled carbon nanotubes and germanium nanowires, as well as to perform groundbreaking dynamics studies on many biomolecules," the researchers write.

The researchers previously showed BNNTs can be individualized in solution (made to not clump) when dispersed in a mixture containing surfactants, i.e., a substance that reduces the surface tension of a liquid and thus increases its spreading properties. In this study, the researchers used surfactants hosting a fluorescent molecule (rhodamine B) so fluorescence microscopy could be used for analysis.

They took videos of the dispersion, which they used to calculate translational and rotational diffusion coeffcients. These values then were compared to predicted values for a rigid rod experiencing Brownian motion, i.e., the random motion of particles caused by collisions with other molecules in a suspending fluid.

The calculated and predicted values aligned, indicating BNNTs do act like rigid rods, just like carbon nanotubes. And this knowledge will have "important repercussions" on future developments, the researchers say.

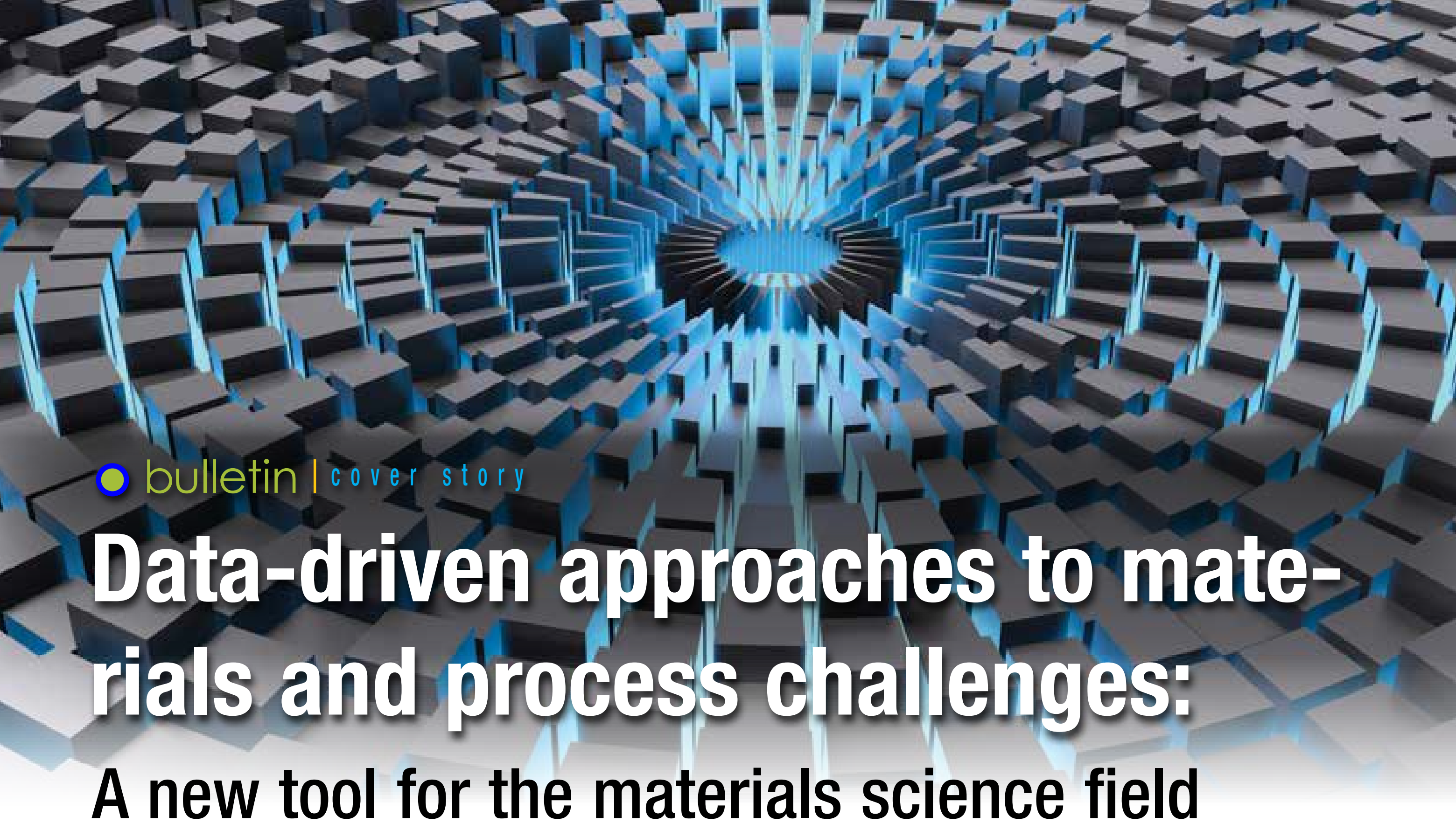
"... knowing that BNNTs diffuse similarly to many rigid polymers and other nanomaterials can aid our design and manufacturing of composites that can translate to the macroscale the BNNTs' nanoscale properties," they write.

"Moreover, since the experimental results for BNNTs fit the theoretical model so well, we can use established theories for crowded rods to predict how the BNNTs' environment, e.g., confinement size, affects their diffusion," they add. "This will be particularly useful for biomedical studies, where confinement in the cytoskeleton can dramatically change the dynamics of rods."

In a Rice University press release, professor and chair of the Department of Chemistry Matteo Pasquali says these results should help the community move much faster toward applications.

"For example, we could make fibers and coatings that are thermally conductive but electrically insulating, which is very unusual as electrical insulators have poor thermal conductivity," he says.

The paper, published in *The Journal of Physical Chemistry B*, is "Real-time visualization and dynamics of boron nitride nanotubes undergoing Brownian motion" (DOI: 10.1021/acs.jpcb.0c03663). ■



bulletin | cover story

Data-driven approaches to materials and process challenges:

A new tool for the materials science field

By Richard Padbury

To keep pace with new demands in the materials science industry, scientists and engineers will need to speed up materials discovery and commercialization. Data-driven methods can augment existing experimental methods to accelerate the process.

The materials science industry is expected to grow significantly over the coming years. This growth, in itself, is not surprising because materials are at the center of every major challenge, from providing solutions to climate change and environmental issues to enabling developments in agriculture, healthcare, energy production, and transportation—even the way we live and interact as a society is, and will be, affected by materials.[1]

In the same way that scientists discovered thermodynamics, electricity, the laser, and transistor (discoveries that fueled the first three industrial revolutions), today's scientists will need to speed up the development and discovery of innovative materials designed to deliver new functionalities to meet future demands.[2] For example, to build a clean energy future, we will need to both develop novel materials to create more efficient solar panels, wind turbines, and energy storage devices and develop materials that can scrub the air of existing pollutants. We also need to replace materials that are subject to supply disruptions due to finite resources of rare-earth minerals and feedstock derived from fossil fuels. Furthermore, to support a sustainable future, the toxicity and recyclability of new materials must also be taken into consideration.

There is a risk the current pace of development will not keep up with these new demands. For the most pressing challenges facing society, we cannot afford to wait 20 years or more to develop

Capsule summary

GROWING DEMAND

The engineered materials industry is expected to grow significantly over the coming years. But there is a risk the current pace of materials development will not keep up with these new demands.

ACCELERATED DISCOVERY

Researchers use data-driven methods for materials discovery and testing to augment existing experimental methods to greatly accelerate the commercialization process.

INDUSTRY OPPORTUNITIES

Companies are now beginning to use the data-science knowledge generated by mainstream academic and government research to tackle everyday challenges across their enterprises.

the necessary solutions (the average time it currently takes for novel materials to reach commercial maturity).[3] The task is now upon us to develop the next materials breakthroughs to support a more secure and prosperous future.

The evolution of materials

Known materials available today were developed over many thousands of years as humans advanced from the early stages of alchemy through the evolutionary periods of the stone, bronze, and iron ages. At each period, curiosity fueled the effort to develop new materials with the aim of filling gaps in material property spaces to advance new applications and processes.

The science involved in these discoveries include

- development of materials with new compositions, such as the development of binary and ternary ceramics;
- manipulation of microstructure and thermomechanical processing to control the distribution of strengthening phases and defects;
- discovery of nanomaterials, which expanded our historical view of materials to previously unattainable property spaces; and
- creation of novel material architectures, such as hybrids and composites, often inspired by nature, to achieve multifunctional properties.

The classifications of materials obtained from these developments—from metals and ceramics to polymers and composites—form discrete clusters in property space due to their distinctive atomic structures and bond types that underpin their unique properties (Figure 1).[4] If we take a moment to look around ourselves, it is clear these essential materials surround us in our everyday lives.

However, the common denominator under all developments is the significant time it has taken to discover, develop, and commercialize them. Just why does it take so long to develop novel materials? As we will explore next, the answer is concealed in the complex, multiple length scale structure of materials.

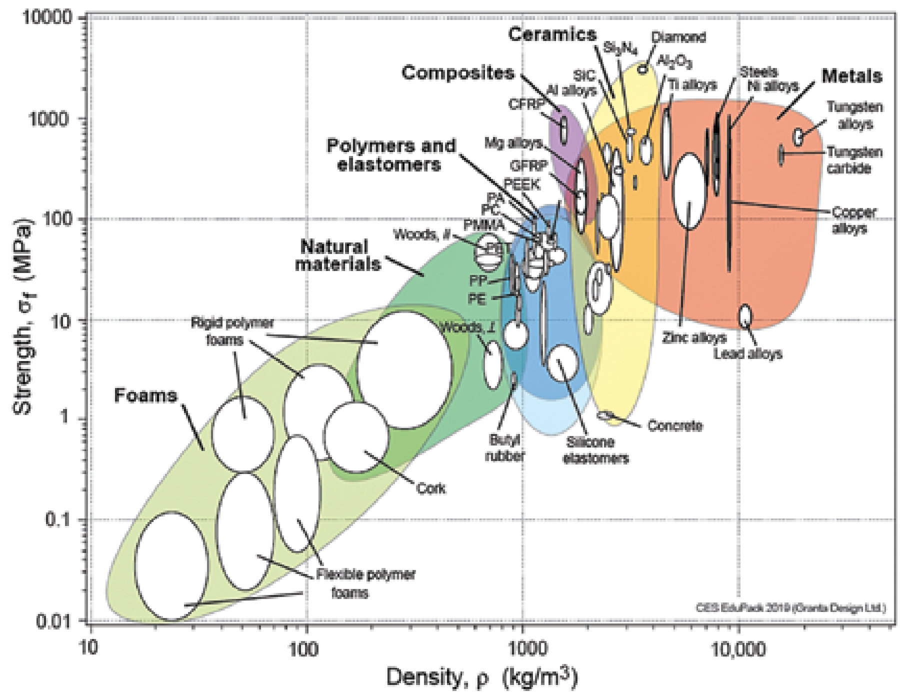


Figure 1. Ashby plot of strength vs. density highlighting the many categories of materials that form the materials universe.

The multiple length scale challenge

The materials science framework deals with the understanding of process-structure-property (PSP) linkages, from which multiple, intertwined relationships exist (Figure 2).[5] Materials scientists and engineers leverage their intuition and expert knowledge to investigate these multifaceted relationships and develop new material chemistries and properties.

A key challenge for materials scientists and engineers is formulating an understanding of the hierarchical nature of materials because the underlying structures form over multiple time and length scales.[6] At the atomic scale, interactions between pairs of elements inform the short-range order of multiple elements and molecules into lattice structures or repeat units. When these repeat units come together, they produce unique microstructures over increasing length scales that correspond to a material's macroscopic properties and morphology, at scales we can sense and use their characteristics.

Going back to the atomic scale, there is a seemingly infinite number of ways to arrange and rearrange atoms and molecules into new lattice or repeat unit structures, resulting in a diverse universe of materials with unique mechanical, optical, dielectric, and conductive properties.[7] Subsequently, countless materials remain undiscovered as it would require astronomical timescales and significant resources to test a composition and repeat before discovering a successful result.[8] Furthermore, when scientists do isolate a promising composition, there are many steps along the road to commercialization, each acting like a series of resistances in an electrical circuit, that must be overcome to progress a new technology forward—again, these steps

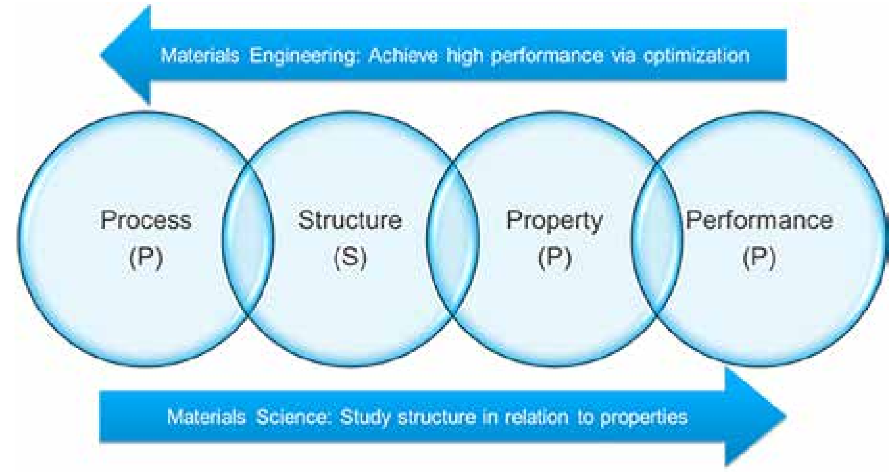


Figure 2. Processing-structure-property relationships that govern applied materials science and engineering. Adapted from A. Agrawal et al.[5]

introduce time and cost to the development pathway.

To overcome this challenge, scientists and engineers leverage tools that can improve the economics of designing experiments to develop new materials. For example, statistical methods can tune in to key variables that control a process or the evolution of material microstructure to achieve desirable properties. However, statistical methods, such as those developed by George Box, Donald Behnken, and Genichi Taguchi, are ideally constrained to a small subset of process-structure or structure-property linkages. Therefore, it is not possible to survey all relationships, across multiple length scales and PSP linkages, that may have varying degrees of influence on material performance.[6] This limitation can lead to an undershoot in target properties, if key variables or relationships are unintentionally missed by experimental designs, or greatly limit the scope of an investigation. Therefore, in the same way there are many more new materials to discover, it is also likely hidden properties exist in known materials that have simply not been tested before. One example of a hidden property is the development of lithium iron phosphate for lithium-ion battery cathodes. The material was first synthesized in the 1930s but was not identified as a suitable cathode material until 66 years later in 1996.[8]

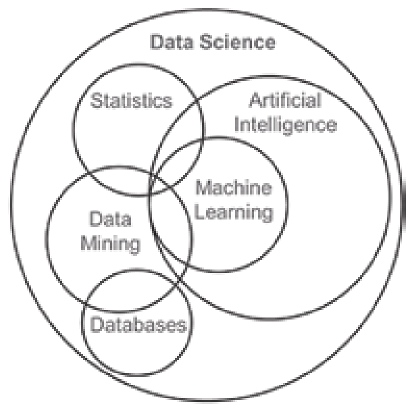
Several factors beyond the technical challenges contribute to the long period between materials discovery and commercialization. These factors range from misaligned market needs with the value proposition of a new material to the way we store, share, and report experimental data (often it is not easily accessible).[3] For example, identical experiments may be conducted in different parts of an organization, with scientists in the organization unable to check which experiments have been run. In tandem, the rigorous approval processes in highly regulated industries—implemented for good reason—increase the time and cost to validate new materials and processes for specific applications. Consequently, once a material is successfully commercialized, it becomes deeply rooted within industry,[9] such as the widespread use of silicon and aluminum oxide for semiconductor applications or the use of hydroxyapatite and Bioglass for medical devices. However, as legacy materials approach their limits and pressure on finite resources increases, new techniques are urgently needed that can speed up development and further expand our horizons into untapped regions of materials property space.

A new paradigm

The materials science field is entering a paradigm shift; the currently accepted methods of discovering materials are not irrelevant nor are they being replaced, but they are being augmented

What is data science?

Adapted from Rangaswamy et al.,[11] Elsevier, 2018



Data science envelops many overlapping subfields, from the well-known disciplines of knowledge discovery in databases (KDD), data mining, and statistics to the emerging fields of machine learning (ML) and artificial intelligence (AI).

The challenge with this picture is that it can be difficult to precisely explain the differences between these overlapping disciplines, which is key to understanding how to use each appropriately. After closer inspection, many subfields borrow the same methods, for instance, linear regression is as applicable in statistics as it is in ML. Therefore, explanations differentiating each discipline may be captured in cultural differences depending on individual schools of thought.

Without speculation, what has definitively occurred over the last few decades is an increase in computing power; an improvement in the ability to store and transfer data due to technological advances, such as the internet; and significantly increased data volumes, even in materials science. These improvements have prompted the use of more advanced methods of analyzing data, beyond simple linear models, and have led to cutting-edge forms of prediction and automation.

These advanced methods still require significant input from their human counterparts and still need to be systematically programmed so they can be deployed. Notably, no method can currently create, innovate, reason, apply logic, ethics, and morals or provide curiosity in the same way that humans can to make informed decisions. Therefore, it is reasoned that true forms of AI are still far away from being realized.

Nonetheless, what is possible through a common goal of learning from data is the extraction of powerful insights to develop actionable solutions. So the data science toolbox should be considered an assistant that augments our human ability to solve problems. ■

by techniques acquired from the cross-fertilization of materials science with other scientific disciplines.[5] This new way of thinking builds on the existing materials data and knowledge generated over many centuries and also includes methods of overcoming limited access to the data.

The emerging developments begin with the advent of the computer in the early 1950s, when more complex challenges could be solved by methods derived from quantum mechanics, such as density functional theory (DFT). As automation and computing power improved, increased calculation speeds led to the rise of high throughput (HT) simulation techniques.[9,10] Today, methods such as HT-DFT are capable of calculating the thermodynamic and electronic properties of tens to hundreds of thousands of known or hypothetical material structures. These methods resulted in a data explosion, and as the volume and variety of data accelerated, analyses became too big and complex for direct involvement by researchers.[9] Subsequently, data-driven methods from the computer and data science fields (Sidebar: "What is data science?)[11] were employed to help analyze the streams of data coming out of computational experiments. While state-of-the-art HT-DFT can greatly improve the efficiency of developing new materials, certain restrictions exist, from limitations in computing resources to the size of the material system that can be calculated and the types of properties that can be accurately modeled.[12] Furthermore, there are still many material structures left to explore, and it remains impractical, even for computational techniques, to explore them all.

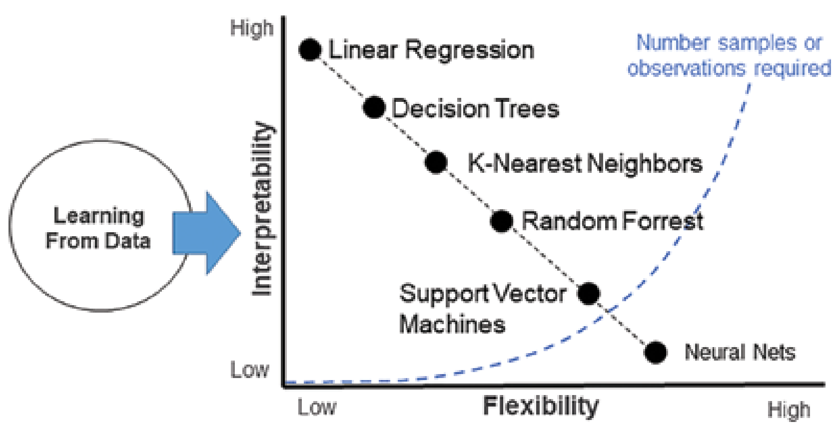
Over the last 20 years, the use of data-driven methods expanded to help tackle the challenge of discovering and developing new materials, leading to the creation of a new field aptly known as Materials Informatics (MI).

MI underpins the acquisition and storage of materials data, the development of surrogate models to make rapid property predictions or gain new physical insights from materials data, and experimental confirmations of new materials with the core objective of accelerating materials discovery and development.

The MI framework leverages a wider range of data-driven algorithms (Sidebar: "Introduction to algorithms"),[13] using their ability to digest large volumes of complex data and resulting prediction accuracy, which enables researchers to explore many more PSP linkages and multiscale relationships than previously possible. Interestingly, these data-driven techniques are not new, as many have existed since the first computers were developed.[10] Furthermore, certain approaches have been around for many centuries, such as Bayesian and Gaussian

Introduction to algorithms

Adapted from James et al.,[13] Springer, 2014



An algorithm is a step-by-step procedure that takes inputs and produces an output based on a set of instructions. The coefficients, or weighting of each input, are estimated by "learning" from data generated by observations or an experiment. Once the coefficients are estimated, the algorithm is known as a model and can be used to predict new outputs on data the model has not yet "seen."

Model accuracy is assessed by measuring the quality of fit or cross-validating with data from the training dataset that is left out of the model training step. An optimal model will generalize well to new data, resulting in accurate predictions. However, the model requires a trade-off between bias (how well the model matches the training data) and variance (how well the model predicts output of new data). A model that underfits tends to have high bias–low variance as the model is less flexible to capturing trends in the training data. Conversely, overfitting leads to models that have low bias–high variance as the model is too flexible and fits the training data too closely by including noise or insignificant variables.

This trade-off leads to an important concept known as the curse of dimensionality. As the number of variables (or dimensions) increases, each having a range of possible values, the number of combinations of values exponentially increases. Therefore, an algorithm needs to be trained on samples with enough combinations of values to learn sufficient relationships and patterns in the data to avoid overfitting. In materials science, this requirement means collecting more samples, which can be costly and thus has important implications on when to use one technique over another.

There are many different types of algorithm, but many generally follow an inverse relationship between interpretability and flexibility, providing researchers with a wealth of techniques to analyze a wide variety of different datasets. Typically, if the goal is to understand the precise relationship between variables and a corresponding output, interpretable and rigid models, such as linear regression, are most suited to this type of problem. These models are particularly useful if the goal is to prove a hypothesis. If prediction accuracy is the goal or data has high-dimensionality, more flexible algorithms can be leveraged to include more variables and observations in the dataset or reduce dimensional complexity with minimal loss of information.

It is important to note that a single algorithm will not work for all possible datasets, which further signifies the importance of using a wider toolset when designing experiments and analyzing materials data. ■

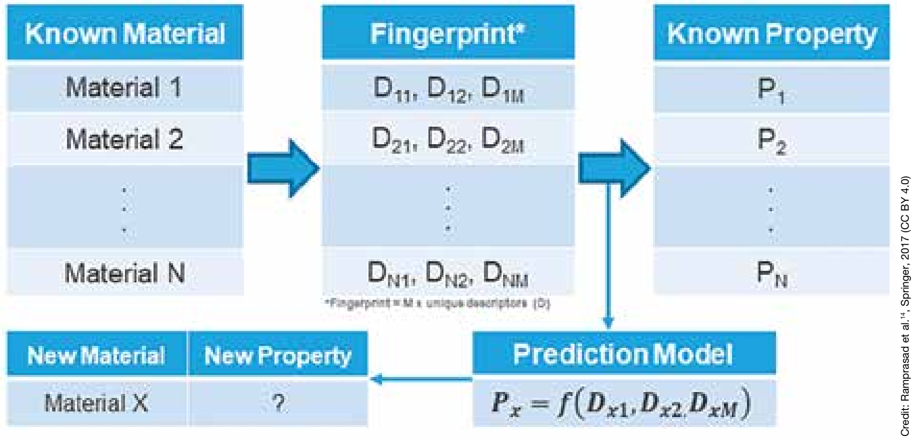


Figure 3. Predictive modeling framework that leverages existing materials data to train models to predict properties of new materials. Adapted from Ramprasad et al.[14]

processes based on the 100-year-old mathematical formulations of Thomas Bayes and Carl Friedrich Gauss, respectively.

Numerous industries have leveraged advanced analytics for decades to support decision-making, including market, social media, financial, manufacturing, and distribution data.[10] Moreover, the closely related pharmaceutical industry pioneered the use of data-driven techniques for drug discovery and development as early as the 1970s, creating the parallel field of bioinformatics. Until recently, the materials science industry trailed behind these businesses, but we are now beginning to witness the disruptive potential of predictive modelling and discovery-based data mining techniques, in combination with computational and physical experiments, to decrease the materials development timeframe.

Predictive modeling

With a critical volume of historical materials data, the underlying characteristics that best describe material behavior can be "learned" by algorithms and used to train surrogate models that can make accurate forecasts on new data. Such learning methods establish a mapping between a suitable representation of a material, called the material's fingerprint, and any of its properties from existing data (Figure 3).[14]

The fingerprint is composed of an optimal number of descriptors (or variables) that the model can use to learn what a material is and accurately predict its properties. In essence, the material fingerprint is the DNA code and descriptors are the individual "genes" that connect the empirical or fundamental characteristics of a material (e.g., elemental composition) to its macroscopic properties.[15] Once a suitable number of descriptors and quantities are obtained (to avoid overfitting and high variance, see Sidebar: "Introduction to algorithms") for a range of materials from a database, they can be mapped to their corresponding output property data by finding the best fit to the observations resulting in a predictive model.

Once a model is validated, the model predictions are instantaneous, which makes it possible to forecast the properties of existing, new, or hypothetical material compositions, purely based on past data, prior to performing expensive computations or physical experiments. Predictive models are highly suited for interpolation, i.e., searching within an existing database. Extrapolation, i.e., leaping from one composition space to another or expanding the original database, is also possible but can lead to larger errors and uncertainties. However, methods that promote easy assessment of model uncertainties can be used to overcome this issue by supporting the decision as to which set of experiments should be performed next.[16] Subsequently, once new data is collected and confirmed by computational or physical experiment, it can be fed back into the model to improve accuracy and iteratively narrow in on new candidates for a specific application. This explanation of predictive modeling demonstrates that MI is not intended to replace experiments (or the scientist) but rather help arrive at a desired result in a much shorter timeframe.

While predictive models are attractive for identifying and developing new materials, there are other useful tools available in the advanced analytics toolbox that can identify structure, patterns, and relationships in complex input data that do not necessarily require the associated outputs. These tools become highly beneficial when a systematic search for each significant variable of a process or microstructure evolution mechanism is computationally or experimentally expensive because they involve many variables.[6]

For example, dimensionality reduction techniques can transform vast arrays of input data into a reduced, easily visualized space—typically two or three dimensions—and identify relationships or patterns with minimal loss of information.[6] With this technique, what may have once required a large collection of graphs can now be summarized in a single chart representing the entire process.

While dimensionality reduction and clustering techniques are not predictive tools, they can support predictive modeling with complex data in which the number of observational data is too low or the number of variables needs to be reduced to improve the efficiency of an analysis.

Practical applications of MI

One of the most compelling opportunities offered by MI is the potential to accelerate the discovery of new materials. As constituent elements of a material increase, the number of possible combinations begin to explode. For example, a ternary compound of the form $A_xB_yC_z$ (where *x*, *y*, and *z* are stoichiometric quantities) corresponds to billions of possible inorganic materials that increases as more constituents are included.[7] However, not all of these materials will be stable and finding those that are stable would take an unfathomable amount of time.

To calculate material properties, computational methods require crystal structure information, which is not readily available nor easy to calculate for all possible candidates across the vast compositional space.

To overcome this challenge, researchers trained a surrogate model on a small subset of existing DFT data from the Inorganic Crystal Structure Database (ICSD) to predict the formation energy of new materials solely based on their stoichiometric composition. The model was subsequently used to instantly scan 1.6 million ternary compounds of which 4,500 previously unknown materials were expected to be stable based on their predicted formation energies.[12]

While the output is astonishing, the approach is certainly not trivial and demonstrates the potential to leverage data-driven techniques to discover new materials that could have important implications on replacing critical materials that are approaching their limitations or subject to supply disruptions.

Data-driven approaches also are used to explore the likelihood of achieving a set of target properties given a series of opposing constraints, such as materials that are difficult to secure due to pressure from finite resources. For example, a study of more than 2,800 compounds identified as being either abundant or scarce was used to compare the charge/discharge voltages and specific energies (key performance properties for batteries) against their relative abundances. Approximately 500 materials with known voltages and specific energies were used to train a data-driven model (using material chemical formula as model input) to predict the properties of the 2,800 candidates. Subsequently, Figure 4 visualizes the model predictions and indicates the density of candidates that may be found at a particular region of property space.

It is clear the highest density of candidates are clustered around a specific energy of 500 Wh/kg and average voltage of 2.5–3V. However, the study reveals scarce materials offer a greater likelihood of finding candidates with higher specific energy while abundant materials offer the widest range of possible voltages. The approach demonstrates how data-driven algorithms can be used to assess simultaneously the trade-off between performance and multiple constraints, such as resource considerations over a vast composition space at groundbreaking speeds.[17]

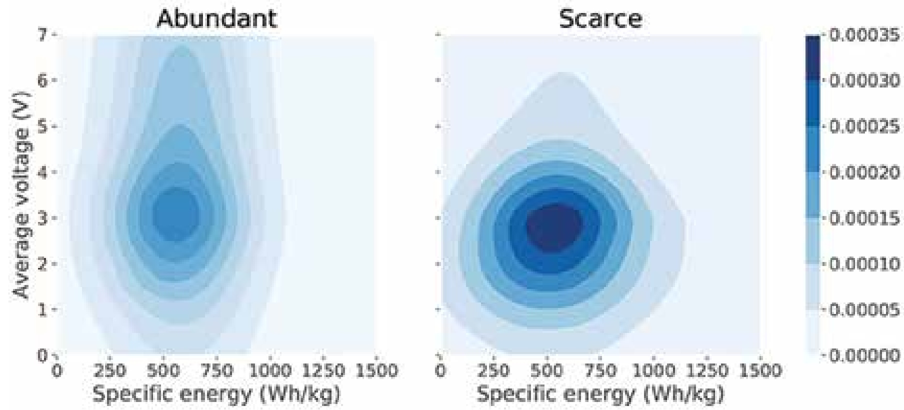


Figure 4. Design space visualization plots for abundant and scarce cathode materials based on the summed probability density, which indicates how easy it is to find candidates in a particular property space region.

Getting started—Important considerations

Data-driven methods for materials holds a great deal of promise, but it is important to note they can lead to the development of "fools-gold" as they are only as good as the data they consume.[18] For example, equivalent materials properties may be measured differently depending on the data source, and these contextual differences, among other hidden variables, can introduce errors into analyses, thus limiting their accuracy. Furthermore, materials data is diverse (e.g., numerical, text, image, graphical, spectra) and still sparsely populated relative to other industries.

These challenges have spearheaded a global effort at academic and government levels to develop techniques and methodologies that continue to generate large quantities of high-fidelity materials property data and develop structurally diverse materials databases that can be interrogated by advanced algorithms.[8] This effort is achieved by means of both HT computational techniques as well as the emerging use of HT experimental techniques based on combinatorial materials synthesis and rapid screening via automated instrumentation.[9] These techniques are similar to the combinatorial chemistry techniques used for drug discovery in the pharmaceutical industry.

Researchers are also developing ways of unifying global materials databases to explore patterns across separate databases that cover different aspects of materials science (i.e., databases of crystal structures and physical properties).[5,10,19] Such a change of scale requires new data management methodologies to certify the validity of materials data and to ensure it can be found, accessed, and shared in a commonly accepted format.

At the enterprise level, most companies (big or small) have historical data from a wide variety of sources, including supplier and customer data. However, accessing sufficient datasets remains a challenge within each organization, independent of size, as data sources may not be easily accessed or may be stored in various formats, from tracking data in spread sheets and, in some cases, by hand in notebooks.

For many organizations, simply applying advanced analytics to data via open-source or even commercial software will not work as model development must be based on the goals of the analysis, the solutions being sought, and the available data. So they require access to data workflows that can inspect, clean, and store data in a structured format; scalable and flexible analytics capabilities that include the correct hardware, software, security protocols, and other relevant data infrastructures; upfront investment in equipment, including materials characterization or high-performance computing capabilities; and skilled workers, especially materials scientists, data scientists, and data engineers, which can be expensive.

Organizations that attempt to build these new capabilities from the ground up may face steep learning curves resulting in failure or a much longer-term return on investment due to the inherent challenges of acquiring, structuring, and analyzing data.

Opportunity for industry

Mainstream developments in MI have primarily been led by the academic and government communities. However, sufficient progress was achieved over the last few years to attract the attention of industry. Companies are now beginning to practice the principles of MI and apply the new knowledge generated by mainstream academic and government research to everyday challenges across their enterprises.[20] Subsequently, a number of emerging industry–university–government ecosystems are evolving around the world that are composed of major government research institutes, multinational companies, and early- to late-stage start-ups. Together, these organizations are pioneering the use of MI across the materials development lifecycle that not only involves discovery and design but also includes downstream process optimization and after deployment in the field, with a growing number of commercial successes.

While these developments are exciting examples of transformation in the materials science industry, the most exciting prospect is that materials scientists and engineers can now leverage a much wider range of data-driven tools within the familiar experimental framework to solve a variety of challenges, from materials development to process optimization, that may have been unsolvable or too complex to address until now. While the analytics tools have been available for many decades, the right technological advances (from increased computing power to accelerating data volumes) and materials industry needs have converged at the right point in time to take advantage of these powerful methods today and support the developments of the future.

As technologies continue to improve, new methods will constantly evolve at an ever-increasing pace, which will positively impact materials challenges further down the line. An imperative is now upon us to stay on top of these emerging developments and to find our unique place amongst the growing materials informatics ecosystem.

About the author

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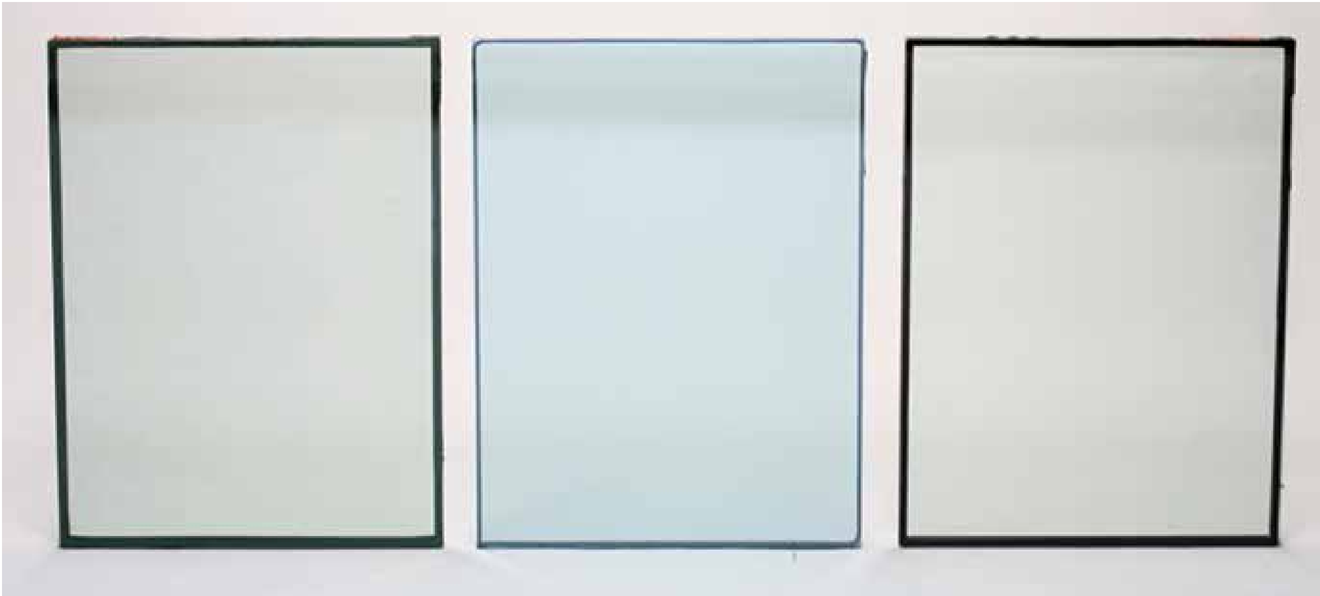


Credit: Vitro Architectural Glass

Some examples of Vitro's low-E coatings.

Coated glass for solar energy

By Lisa McDonald

Since Bell Labs announced the invention of the first practical silicon solar cell in 1954,[1] solar photovoltaic systems have improved dramatically and are now one of the leading technologies in the shift to renewable energy.[2]

Much research on photovoltaic systems focuses on increasing the conversion efficiency of individual photovoltaic cells by improving or developing new materials from which the cells are made. But there is another important aspect to photovoltaic systems that also has garnered much attention—glass coatings.

Manufacturers of architectural glass already engineer coatings on glass to improve energy efficiency of buildings. For example, Pennsylvania-based Vitro Architectural Glass sells its Solarban® and Sungate® brands of coated glass products to the architectural glass industry. And, in recent years, the company has worked to expand the use of similar and some new coatings in solar applications.

Ashtosh Ganjoo is senior group leader at Vitro Architectural Glass, and he has played an important role in developing the company's product portfolio for the solar market. We asked Ganjoo to tell us more about the importance of glass coatings in solar applications and where the market is headed in the near future.

Q. *Why are coatings for glass necessary and important in solar applications?*

A. It is all about improving the performance of the final product. For example, although reducing the iron content in the glass significantly increases the light transmitted to the photovoltaic cells (for crystalline silicon modules), there still is approximately 4% loss due to reflection from the front surface. By adding a durable antireflecting (AR) coating, we can reduce this loss by half or more. While this reduction may seem small, utility-scale solar fields are huge and, over the lifetime of the unit, this reduction results in significant energy capture.

When we talk about "solar" applications, people often only think about solar panels that produce electricity. But another area to focus on is in management of heat radiation into buildings. And again, it is about how to improve the performance of those systems. By reducing the heat load inside a building, we need less energy to run the HVAC systems—meaning we need less energy produced, either by power plants that produce greenhouse gases or more environmentally friendly solar panels.

Vitro Architectural Glass enables reduced heat load by coating the glass with a low-E solar-control coating that allows the glass to act as a solar filter and only permits the visible part of the spectrum to enter the building. The infrared part of the solar spectrum (or the heat) is reflected, thus reducing the heat load in the building. Similarly, coating glass with certain materials like transparent conductive oxides (TCO) adds another functionality used in, for example, thin film solar modules, OLEDs, and dynamic glazings, where the coating is used as a conductor of electricity or charge and the glass substrate provides transparent mechanical support. An antisoiling or hydrophobic coating on a solar panel helps in keeping the solar panels clean and thus helps in maintaining the efficiency and power output from the solar cell.

Q. *What are the different types of glass coatings?*

A. There are various types of glass coatings for solar and architectural purposes.

For solar applications, we have antireflectance (AR) coatings that help in getting more light to the photovoltaic cells, antisoiling and hydrophobic coatings that help in keeping the solar panels clean and do not allow water to be stick to the surface, and transparent conductive oxides coatings that act as a conductor that transfers the power out of the solar cell.

For architectural applications, we have low-emissivity (low-E) solar control coatings, which help keep the heat out of a building and thus reduce the energy usage in summer. These coatings also keep the heat inside the building during winter and thus reduce the amount of energy to heat a building. There also are coatings that enable a flying bird to see glass and thus avoid collision and damage or death to the bird.

Q. *What techniques are used to apply coatings to glass?*

A. There are various ways to make coatings on glass, including chemical vapor deposition (CVD), sputtering, plasma depositions, evaporation, and sol-gel, among others. Some of these techniques are more laboratory or small-scale depositions, but others, such as CVD and sputtering, are used in manufacturing to make large pieces of glass (for example, 130 in. × 204 in.).

Q. *What challenges do you face or what factors must you consider when improving/developing glass coatings?*

A. In manufacturing, the biggest challenges are cost, speed, and finding materials that are easily available and are not exotic, toxic, or pose any other issues. Additionally, materials should be easy to deposit and have high deposition rates so the throughput is high.

In the glass industry, coatings added by sputtering are deposited while the glass is moving. For a cost-effective and faster throughput process, the deposition temperature is preferred to be room temperature. Thus, the deposited coatings should have the needed properties in the as-deposited state and should not require any heat processing to activate the properties.

We need to consider that the manufacturing cost needs to be low, which includes the material cost and the manufacturing cost (e.g., processing and post-processing). The uniformity of the process, including thickness of the coating, aesthetics, and other properties, is important as we need to use the whole piece of glass that is coated. If there are nonuniformities, the yield goes down, which pushes the cost up. In some cases, we have layers that are very thin and having any nonuniformity can impact the properties.

Q. *What new types/techniques of glass coatings are being developed currently and/or planned for commercialization in the near future?*

A. For the coatings on glass, there are new deposition processes for manufacturing being developed, such as atomic layer deposition (ALD) and plasma-enhanced chemical vapor deposition (PECVD), among others. These processes have advantages, including higher deposition rates, cleaner processes, and better coating properties, in addition to the possibility of depositing new materials to achieve better performance. However, we need to consider the scalability of the technologies and the process costs.

Q. *What does the current market look like for glass coatings? How is the market expected to change in the next 5–10 years?*

A. The current market for coated glass, like many markets worldwide, has been impacted by the COVID-19 pandemic. With few exceptions, construction has slowed dramatically. Having said that, Vitro Architectural Glass remains committed to supporting our customers while maintaining a safe working environment for our employees. Over the longer term, the key drivers of improved energy efficiency, green energy production, and green life-cycle products remain in place and will result in growth of the market for coated glass products.

The low-E coatings are gaining more acceptance due to concerns with energy usage. These coatings enable building owners to save money on energy to cool the building and to save on heating due to reduction in heat loss. The coatings for solar, both for crystalline materials and for thin films, are gaining ground as solar interests are growing. New applications, including dynamic glazings, are enabling new functionalities and thus growing interest. In the next 5–10 years, we expect the coating market to grow as more and more new and energy-efficient applications emerge and as we add functionalities to the glass.

For more information on Vitro Architectural Glass's work on solar control and coatings for glass in solar and other energy applications, visit www.vitroglasshub.com.

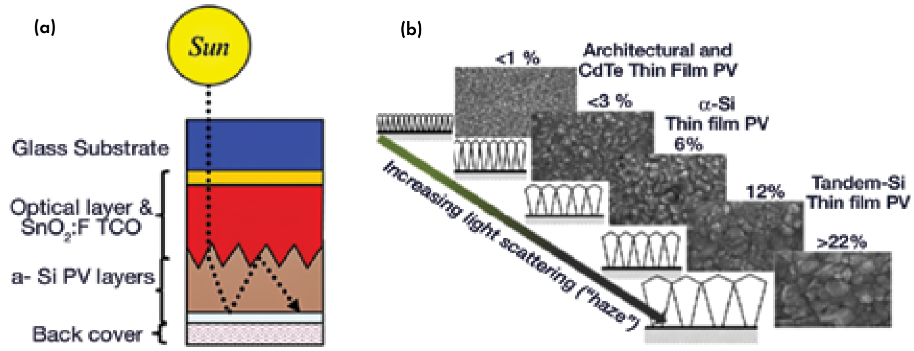


Figure 1. (a) Schematic diagram of a thin films amorphous silicon-based photovoltaic solar cell. (b) SEM images of SnO_2:F with different haze level. The numbers (%) above the SEM images indicates the haze levels corresponding to each image.

References

[1]"April 25, 1954: Bell Labs Demonstrates the First Practical Silicon Solar Cell," *APS News* 18(4): 2. Available from https://www.aps.org/publications/apsnews/200904/physicshistory.cfm.

[2]"Renewables 2019," International Energy Agency. Available from https://www.iea.org/reports/renewables-2019. ■

Annual commodity summary sees continued production value increases despite trade war

By Lisa McDonald

Continued tariffs, new trade agreements, increased production values—this year brought different successes and challenges for the nonfuel mineral industry, all of which are captured in the annual United States Geological Survey *Mineral Commodity Summaries* report.[1]

The *Mineral Commodity Summaries* spotlights the events, trends, and issues that took place the previous year in the nonfuel mineral industry. And because raw materials are what make our high-tech world possible, every August the *ACerS Bulletin* provides a look at some of the key facts covered in the report, including statistics on production, supply, and overall market for more than 90 minerals and raw materials.

The estimated value of total nonfuel mineral production in 2019 increased by 3% from 2018 to $86.3 billion. The total value of industrial minerals production increased by 3% as well, to $58.2 billion. Of this total, $27.7 billion came from construction aggregates production. Crushed stone accounted for the largest share of total U.S. nonfuel mineral production value in 2019 with 22%.

Trade wars started in 2018 continued in 2019, with various import duties being either newly levied, continued, or removed. In May, the U.S., Canada, and Mexico reached an agreement on trade terms, resulting in the removal of the ad valorem duties for aluminum and steel imports on Canada and Mexico. Also in May, the U.S. and China failed to reach an agreement, which resulted in the U.S. increasing tariffs for List 3 items to 25% and China imposing additional import duties for certain items. In December, a phase one trade agreement was reached between the U.S. and China, which reduced some tariff rates and resulted in additional tariffs not being implemented.

Since Executive Order 13817 was issued in December 2017, the federal government has made several steps toward ensuring secure and reliable supplies of critical minerals in the U.S. In May 2018, a final list of critical minerals was published in the Federal Register, which included 35 minerals or mineral material groups. In June 2019, the U.S. Department of Commerce issued a report[2] containing six calls to action, 24 goals, and 61 recommendations that describe specific steps the U.S. government will take to achieve objectives outlined in the executive order.

The U.S. continues to rely on foreign sources for raw and processed mineral materials. In 2019, imports made up more than one-half of the U.S. apparent consumption for 46 nonfuel mineral commodities, and the U.S. was 100% net import reliant for 17 of those. In terms of critical minerals, these minerals comprised 14 of the 17 mineral commodities with 100% net import reliance and comprised 17 of the 29 remaining mineral commodities with imports greater than 50% of annual consumption. In line with previous years, China and Canada supplied the largest and second largest number of nonfuel mineral commodities, respectively.

On the next two pages, an infographic summarizes some of the salient statistics and trends for a handful of mineral commodities that are of particular interest in the ceramic and glass industries. Readers are encouraged to access the complete USGS report at https://doi.org/10.3133/mcs2020.

References

[1]*Mineral Commodity Summaries 2020*, U.S. Geological Survey, Reston, Va., 2020.

[2]*A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*, U.S. Department of Commerce. Published June 4, 2019. Available at https://www.commerce.gov/news/reports/2019/06/federal-strategy-ensure-secure-and-reliable-supplies-critical-minerals. ■

USGS MINERAL COMMODITY SUMMARIES

BAUXITE AND ALUMINA

Leading producer

Bauxite 

Alumina 

End use industries
Abrasives, cement, chemicals, proppants, refractories, slag adjuster in steel mills

Trend in global production
0.8% decrease for alumina
13.1% increase for bauxite

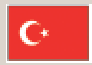
U.S. production
1.6 million tons of alumina

U.S. import/export
>75% net import reliance for bauxite;
54% net import reliance for alumina

World reserves
55 to 75 billion tons

BORON

Leading producer



End use industries
Glass, ceramics, abrasives, cleaning products, insecticides, insulation, semiconductors

Trend in global production
Cannot be calculated

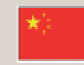
U.S. production
N/A

U.S. import/export
Net exporter

World reserves
Adequate

CEMENT

Leading producer



End use industries
Construction

Trend in global production
1.2% increase

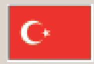
U.S. production
88.5 million tons of cement;
78.0 million tons of clinker

U.S. import/export
15% net import reliance

World reserves
Raw materials are abundant

FELDSPAR

Leading producer



End use industries
Glass, tile, pottery

Trend in global production
1.6% increase

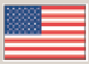
U.S. production
470,000 tons (marketable production)

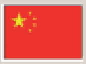
U.S. import/export
13% net import reliance

World reserves
More than adequate

CLAYS

Leading producer

Kaolin 

Bentonite 

End use industries
Tile, sanitaryware, absorbents, drilling mud, construction, refractories, paper, proppants

Trend in global production
No change for bentonite;
2.5% increase for Fuller's earth;
0.5% decrease for kaolin

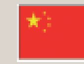
U.S. production
26.0 million tons (46.2% common clay;
21.2% kaolin; 18.1% bentonite; 14.5% other)

U.S. import/export
Net exporter

World reserves
Extremely large

GALLIUM

Leading producer



End use industries
Integrated circuits, optoelectronic devices

Trend in global production
22.5% decrease

U.S. production
none (primary)

U.S. import/export
100% net import reliance

World reserves
Estimate unavailable

INDIUM

Leading producer

End use industries
Flat-panel displays, alloys, solders, semiconductors

Trend in global production
2.6% increase

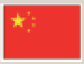
U.S. production
none

U.S. import/export
100% net import reliance

World reserves
Estimate unavailable

GRAPHITE (NATURAL)

Leading producer



End use industries
Brake linings, lubricants, powdered metals, refractory applications, steelmaking

Trend in global production
1.8% decrease

U.S. production
none

U.S. import/export
100% net import reliance

World reserves
>800 million tons

*Based on 2019 data. See Mineral Commodity Summaries 2020

IRON AND STEEL
Leading producer

End use industries
Construction, transportation (auto), machinery, equipment; energy

Trend in global production
4.0% increase for pig iron; 5.0% increase for raw steel

U.S. production
23 million tons of pig iron; 87 million tons of steel

U.S. import/export
21% net import reliance

World reserves
N/A

KYANITE
Leading producer

End use industries
Refractories, abrasives, ceramic products, foundry products

Trend in global production
Cannot be calculated

U.S. production
90,000 tons

U.S. import/export
Net exporter

World reserves
Significant

LITHIUM
Leading producer

End use industries
Batteries, ceramics, glass, grease

Trend in global production
18.9% decrease

U.S. production
Withheld

U.S. import/export
>25% net import reliance

World reserves
Significant

NIOBIUM
Leading producer

End use industries
Steel industry, aerospace alloys

Trend in global production
8.5% increase

U.S. production
none

U.S. import/export
100% net import reliance

World reserves
More than adequate

RARE EARTHS
Leading producer

End use industries
Catalysts, ceramics, glass, metallurgical alloys, polishing

Trend in global production
10.5% increase

U.S. production
26,000 tons (bastnaesite concentrates)

U.S. import/export
100% net import reliance for compounds and metals; Net exporter of mineral concentrates

World reserves
Relatively abundant in earth's crust, but minable concentrations less common

SODA ASH
Leading producer

End use industries
Glass, chemicals, distributors, soap, detergents

Trend in global production
1.8% increase

U.S. production
12.0 million tons

U.S. import/export
Net exporter

World reserves
Practically inexhaustible

TITANIUM DIOXIDE (PIGMENT)
Leading producer

End use industries
Paints, plastic, paper, catalysts, ceramics, coated textiles, floor coverings, inks, roofing granules

Trend in global production
N/A

U.S. production
1.1 million tons

U.S. import/export
Net exporter

World reserves
Data not available

YTTRIUM
Leading producer

End use industries
Abrasives, bearings and seals, high-temperature refractories, jet engine coatings, metallurgy, phosphors

Trend in global production
N/A

U.S. production
N/A

U.S. import/export
100% net import reliance

World reserves
Reserves are adequate, but worldwide issues may affect production

ZEOLITES (NATURAL)
Leading producer

End use industries
Animal feed, odor control, water purification, absorbent, fertilizer, pesticide

Trend in global production
9.1% increase

U.S. production
98,000 tons

U.S. import/export
Net exporter

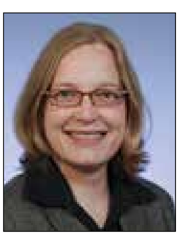
World reserves
No estimate available

VIRTUAL GLASS SUMMIT

The American Ceramic Society
www.ceramics.org

VIRTUAL GLASS SUMMIT PROGRAM CHAIRS

Jessica Rimsza
Sandia National Laboratories
Albuquerque, N.M.



Delia Brauer
Otto Schott Institute of Materials Research
Friedrich Schiller University
Jena, Germany

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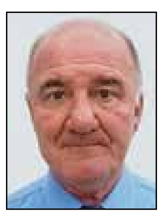
We invite you to attend the **Virtual Glass Summit**, Aug. 3–5, 2020. This online-only event is coordinated with the ACerS Glass & Optical Materials Division and will include three full days worth of presentations from its annual meeting, canceled due to the COVID-19 pandemic.

Special lectures from the winners of the Stookey Lecture of Discovery, the Norbert J. Kreidl Award for Young Scholars, Varshneya Science Technology lecture, and L. David Pye Lifetime Achievenent Award will be presented.

STOOKEY LECTURE OF DISCOVERY



Antoni Tomsia, Lawrence Berkeley National Laboratory, California

Title: *Glass scaffolds for bone tissue engineering*

NORBERT J. KREIDL AWARD FOR YOUNG SCHOLARS

Yifei Zhang, Massachusetts Institute of Technology

Title: *Reconfigurable materials and optics: A phase change for the better*

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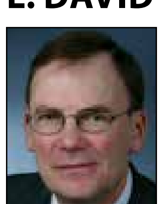
VARSHNEYA SCIENCE TECHNOLOGY LECTURE

Younes Messaddeq, University of Laval, Canada

Title: *Idea to innovation of optical fibers*

L. DAVID PYE LIFETIME ACHIEVEMENT AWARD



Reinhard Conradt, professor emeritus, RWTH Aachen University, Germany

Title: *Thermodynamics and kinetics of batch melting*

AUG. 3-5, 2020

ceramics.org/VGS

SCHEDULE OF EVENTS

Monday, August 3, 2020

9:45 – 10 a.m.	Opening Remarks: Jincheng Du, Jessica Rimsza, Delia Brauer
10 – 10:50 a.m.	Stookey Lecture (Antoni Tomsia)
10:50 – 11 a.m.	Break
11 a.m. – 12:30 p.m.	Concurrent morning Technical sessions
12:30 – 1:30 p.m.	Lunch break
1:30 – 4:10 p.m.	Concurrent afternoon Technical sessions

Tuesday, August 4, 2020

10 – 10:50 a.m.	Kreidl Lecture (Yifei Zhang)
10:50 – 11a.m.	Break
11 a.m. – 12:30 p.m.	Concurrent morning Technical sessions
12:30 – 1:30 p.m.	Lunch break
1:30 – 3 p.m.	Concurrent aftrenoon Technical sessions
4 – 5 p.m.	Student Career Roundtable sponsored by IJCES

Wednesday, August 5, 2020

10 – 10:50 a.m.	Varshneya Glass Technology Award lecture (Younes Messaddeq)
10 – 10:50 a.m.	L. David Pye Lifetime Achieve-ment Award lecture (Reinhard Conradt)
10:50 – 11a.m.	Break
11 a.m. – 12:30 p.m.	Concurrent morning Technical sessions
12:30 – 1:30 p.m.	Lunch break
1:30 – 4:30 p.m.	Concurrent aftrenoon Technical sessions

TECHNICAL PROGRAM

Symposium 1:	**Fundamentals of the Glassy State**
Symposium 2:	**Glass and Water: Degradation of Amorphous Materials**
Symposium 3:	**Optical and Electronic Materials and Devices – Fundamentals and Applications**
Symposium 4:	**Glass Technology and Cross-Cutting Topics**

WHY ATTEND THE VIRTUAL GLASS SUMMIT?

Here are five reasons why you should attend ACerS Virtual Glass Summit:

• **It is safe.** We cannot meet in person right now, but technology has made it possible to learn about the latest glass research in a safe environment.

• **It is affordable.** You will not have to spend money on airfare, hotel, tips, or meals. And the registration rate is a fraction of the cost of an in-person meeting at $149 USD for ACerS members ($25 USD for students).

• **Networking opportunities.** You can still network with those in your field or industry online.

• **Watch ALL of the sessions you are interested in.** The frustration of having to choose between concurrent sessions is over. All sessions will be recorded so you can go back and watch the ones you missed on your own time (up to one year).

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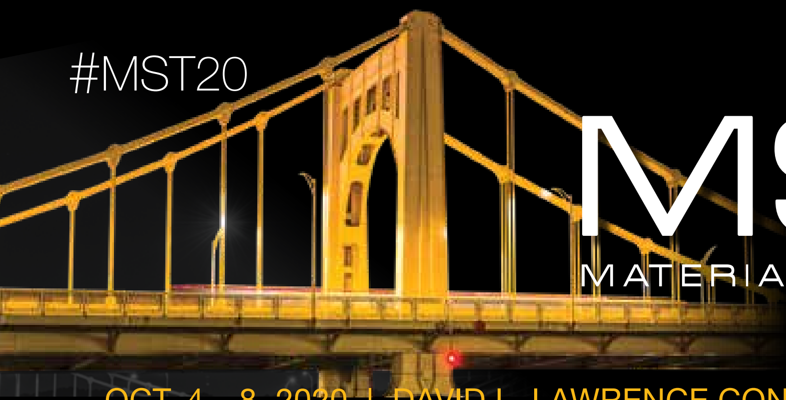

#MST20

Technical Meeting and Exhibition

MS&T20

MATERIALS SCIENCE & TECHNOLOGY

OCT. 4 – 8, 2020 | DAVID L. LAWRENCE CONVENTION CENTER | PITTSBURGH, PA, USA

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PLENARY SPEAKER

Tuesday, Oct. 6, 2020 8 – 10:40 a.m.

AIST ADOLF MARTENS MEMORIAL STEEL LECTURE

Nina Fonstein
scientific advisor, ArcelorMittal, USA

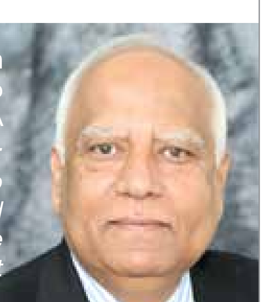
Effects of Retained Austenite Stability and Microstructure Refinement on Properties of Advanced High Strength Sheet Steels

TMS/ASM JOINT DISTINGUISHED TMS/ASM JOINT DISTINGUISHED LECTURESHIP IN MATERIALS AND SOCIETY

Charles H. Ward
chief, Manufacturing and Industrial Technologies Division, Air Force Research Laboratory, USA

Integrating Materials and Manufacturing

ACERS EDWARD ORTON JR. MEMORIAL LECTURE



Mrityunjay Singh
chief scientist, Ohio Aerospace Institute, USA

Additive Manufacturing: Disruptive Threat to Global Supply Chains and Enabler for Sustainable Development

HOTEL

Reserve your hotel room directly on the website at matscitech.org/mst20. Deadline is **Sept. 9, 2020**.

WESTIN PITTSBURGH
ACerS Headquarters Hotel
$229 plus tax/night single or double

COVID-19 UPDATE

Your safety and well-being are our top priority! At this time, we are moving forward with MS&T20 as scheduled. The MS&T organizing societies are monitoring news and information related to COVID-19 on an ongoing basis and will follow guidance from the U.S. Centers for Disease Control and Prevention, the World Health Organization, and federal, state, and local governments. If plans should change, we will provide updates through the MS&T20 website and by e-mail to registrants, exhibitors, presenters, and other confirmed participants.

#MST20

REGISTER BEFORE SEPT. 3, 2020 TO SAVE!

MATSCITECH.ORG/MST20

The American Ceramic Society www.ceramics.org Annual Meeting | AIST Association for Iron & Steel Technology STEEL PROPERTIES & APPLICATIONS | TMS FALL MEETING

ACerS LECTURES AND AWARDS

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

Monday, Oct. 5 **9 – 10 a.m.**

John R. Hellmann, Pennsylvania State University, USA

ACerS RICHARD M. FULRATH AWARD SESSION

Monday, Oct. 5 **2 – 4:40 p.m.**

Shashank Priya, Pennsylvania State University, USA

Tomoaki Yamada, Nagoya University, Japan

Takeshi Kobayashi, National Institute of Advanced Industrial Science and Technology, Japan

Hiroshi Sato, TDK Electronics GmbH & Co OG, Japan

Edward P. Gorzkowski III, U.S. Navy Research Lab, USA

ACerS FRONTIERS OF SCIENCE AND SOCIETY—RUSTUM ROY LECTURE

Tuesday, Oct. 6 **1 – 2 p.m.**

James Adair, Pennsylvania State University, USA

ACerS GOMD ALFRED R. COOPER AWARD SESSION

COOPER DISTINGUISHED LECTURE

Tuesday, Oct. 6 **2 – 4:30 p.m.**

John Kieffer, University of Michigan, USA

ACerS GOMD ALFRED R. COOPER YOUNG SCHOLAR AWARD PRESENTATION

Winners will be announced after selection by the Cooper Award Committee

ACerS BASIC SCIENCE DIVISION ROBERT B. SOSMAN LECTURE

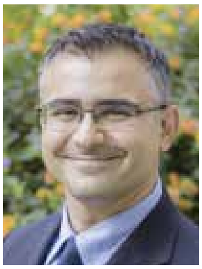
Wednesday, Oct. 7 **1– 2 p.m.**

Wayne Kaplan, Technion - Israel Institute of Technology, Israel

SHORT COURSES

View the MS&T Short Course web page for dates, times.

SINTERING OF CERAMICS



Saturday, Oct. 3 9 a.m. – 4:30 p.m.

Sunday, Oct. 4 9 a..m – 2:30 p.m.

Instructor: **Ricardo Castro**, University California, Davis

SPECIAL EVENTS

- **MS&T WOMEN IN MATERIALS SCIENCE RECEPTION**
  Sunday, Oct. 4 5 – 6 p.m.
- **ACerS BASIC SCIENCE DIVISION CERAMOGRAPHIC EXHIBIT & COMPETITION**
  Monday, Oct. 5 8:30 a.m. – 6 p.m
- **ACerS 122ND ANNUAL MEMBERSHIP MEETING**
  Monday, Oct. 5 1 – 2 p.m.
- **MS&T PARTNERS' WELCOME RECEPTION**
  Monday, Oct. 5 5 – 6 p.m.
- **ACerS ANNUAL HONOR AND AWARDS BANQUET**
  Monday, Oct. 5 7:30 – 10 p.m.
- **ACerS BASIC SCIENCE DIVISION CERAMOGRAPHIC EXHIBIT & COMPETITION**
  Tuesday, Oct. 6 7 a.m. – 6 p.m.
- **GENERAL POSTER SESSION WITH PRESENTERS #1**
  Tuesday, Oct. 6 11 a.m. – Noon
- **GENERAL POSTER SESSION WITH PRESENTERS #2**
  Tuesday, Oct. 6 Noon – 1 p.m.
- **GENERAL POSTER SESSION WITH PRESENTERS #3**
  Tuesday, Oct. 6 4:45 – 5:45 p.m.
- **ACERS BASIC SCIENCE DIVISION CERAMOGRAPHIC EXHIBIT & COMPETITION**
  Wednesday, Oct. 7 7 a.m. – 5 p.m.
  Thursday, Oct. 8 7 a.m. – Noon

Calendar of events

August 2020

3–5 ACerS Virtual Glass Summit Online event; https://ceramics.org/event/acers-virtual-glass-summit-2020

24–27 Electroceramics XVII – Online conference organized by the European Ceramic Society and Technische Universität Darmstadt (Germany); www.electroceramicsxvii.org

September 2020

8–10 56th Annual St. Louis Section/Refractory Ceramics Division Symposium on Refractories – Hilton St. Louis Airport Hotel, St. Louis, Mo. www.ceramics.org/stlouisrcd2020

NEW DATE **29** Ceramic Manufacturing Solutions Conference – VIRTUAL ONLY EVENT; www.ceramics.org/CMSC

October 2020

4–8 ACerS 122nd Annual Meeting with Materials Science & Technology 2020 – David L. Lawrence Convention Center, Pittsburgh, Pa.; www.matscitech.org

12–13 Fluorine Forum 2020 Grand Hotel Huis ter Duin (Noordwijk), Amsterdam; http://imformed.com/get-imformed/forums/fluorine-forum-2020-revised

20–23 ➨ International Research Conference on Structure and thermo-dynamics of Oxides/carbides/nitrides/borides at High Temperature (STOHT)-Arizona State University, Ariz.; https://mccormacklab.engineering.ucdavis.edu/events/structure-and-thermodynamics-oxidescarbidesnitridesborides-high-temperatures-stoht2020

26–29 ➨ 81st Conference on Glass Problems (GPC2020) – Greater Columbus Convention Center, Columbus Ohio; https://glassproblemsconference.org

November 2020

8–13 7th Int. Conference on Electrophoretic Deposition (EPD 2020) – Santa Fe, New Mexico; http://www.engconf.org/conferences/materials-science-including-nanotechnology/electrophoretic-deposition-vii-fundamental-and-applications

15–19 Pan American Ceramics Congress and Ferroelectrics Meeting of the Americas (PACC-FMAs 2020) – Hilton Panama, Balboa Avenida Aquilino de la Guardia, Panama City, Panama; www.ceramics.org/PACCFMAs

29–Dec 3 2020 MRS Fall Meeting & Exhibit – Boston, Mass.; www.mrs.org/fall2020

January 2021

20–22 Electronic Materials and Applications (EMA2021) – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla.; www.ceramics.org/ema2021

24–29 45th International Conference and Expo on Advanced Ceramics and Composites (ICACC2021) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; www.ceramics.org/icacc2021

March 2021

15–17 China Refractory Minerals Forum 2021 – InterContinental Dalian, Liaoning, China; http://imformed.com/get-imformed/forums/china-refractory-minerals-forum-2020

NEW DATE **24–29** ➨ 2nd Global Forum on Smart Additive Manufacturing, Design and Evaluation (SmartMADE) – Osaka University, Nakanoshima Center, Japan; http://jwri.osaka-u.ac.jp/~conf/Smart-MADE2020

27–31 ➨ The Int'l Conference on Sintering 2022 – Nagaragwa Convention Center, Gifu, Japan; https://www.sintering2021.org

April 2021

25–30 ➨ International Congress on Ceramics (ICC8) – Bexco, Busan, Korea; www.iccs.org

May 2021

NEW DATE **3–5** 6th Ceramics Expo – I-X Center, Cleveland, Ohio.; https://ceramics.org/event/6th-ceramics-expo

16–19 ➨ Ultra-high Temperature Ceramics: Materials for Extreme Environment Applications V – The Lodge at Snowbird, Snowbird, Utah; http://bit.ly/5thUHTC

NEW DATE **17–20** China Ceramitec 2021-Messe München, Germany; https://www.ceramitec.com/en

23–28 14th Pacific Rim Conference on Ceramic and Glass Technology (PACRIM 14) – Hyatt Regency Vancouver, Vancouver, British Columbia, Canada; www.ceramics.org/PACRIM14

June 2021

28–30 MagForum 2021: Magnesium Minerals and Markets Conference – Grand Hotel Huis ter Duin, Noordwijk, Amsterdam; http://imformed.com/get-imformed/forums/magforum-2020

September 2021

14–17 20th Biennial Worldwide Congress Unified International Technical Conference on Refractories – Hilton Chicago, Chicago, Ill.; www.ceramics.org

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Entries in BLUE denote ACerS events.

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ADINDEX

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DISPLAY ADVERTISER

AdValue Technology‡	www.advaluetech.com	11
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Harrop Industries Inc‡	www.harropusa.com	Inside front cover
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L&L Special Furnace Co	www.llfurnace.com	15
Mo-Sci Corporation‡	www.mo-sci.com	5
TevTech‡	www.tevtechllc.com	7
The American Ceramic Society‡	www.ceramics.org	19, 31, 34, 38–39, 47, Inside back cover

CLASSIFIED & BUSINESS SERVICES ADVERTISER

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Bomas‡	www.bomas.com	45
Centorr/Vacuum Industries Inc.‡	www.centorr.com	46
Detroit Process Machinery	www.detroitprocessmachinery.com	46
Edward Orton Jr. Ceramic Fdn.	www.ortonceramic.com/testing	46
Harrop Industries Inc.‡	www.harropusa.com	45, 46
Mohr Corp.‡	www.mohrcorp.com	46
PPT - Powder Processing & Technology LLC	www.pptechnology.com	46
PremaTech Advanced Ceramic	www.prematechac.com	45
Quality Executive Search Inc.‡	www.qualityexec.com	45
Rauschert Technical Ceramics Inc.‡	www.rauschert.com	45
Specialty Glass Inc.	www.sgiglass.com	45
Spectrochemical Laboratories	www.spectrochemicalme.com	46
Zircar Ceramics Inc.	www.zircarceramics.com	45
Zircar Zirconia Inc.	www.zircarzirconia.com	45

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A regular column offering the student perspective of the next generation of ceramic and glass scientists, organized by the ACerS Presidents Council of Student Advisors.

Xi Shi
Guest columnist

Critical materials for a greener future—lead-free piezoelectric devices

Piezoelectric devices have found a plethora of applications in automotive and manufacturing industries, medical diagnostics, as well as everyday commodities, such as cigarette lighters. Lead zirconate titanate ($Pb(Zr_{1-x}Ti_x)O_3$, PZT) piezoceramics in particular have dominated the global market share for decades. However, the hazard of lead and lead oxide during the use and disposal of PZT poses a threat to human health and the environment. Thus, along with the RoHS directive released by the European Parliament in 2006,[1] there have been increasing global endeavors toward lead-free piezoceramics as "greener materials."

The recent decades have witnessed stupendous progress on developing lead-free ceramics with high piezoelectric coefficients and large normalized strains comparable to those of lead-containing components. Examples include barium calcium zirconium titanate ($Ba_{1-x}Ca_xZr_{1-y}Ti_yO_3$, BCZT), sodium bismuth titanate–barium titanate–potassium sodium niobate ($Na_{1/2}Bi_{1/2}TiO_3$–$BaTiO_3$–$K_{1/2}Na_{1/2}NbO_3$, NBT–BT–KNN), and bismuth potassium titanate–sodium bismuth titanate ($Bi_{1/2}K_{1/2}TiO_3$–$Na_{1/2}Bi_{1/2}TiO_3$, BKT–NBT), to name a few.

Interestingly, most of these piezoelectrics are known as "relaxors," a class of ferroelectrics with nanosized domains, disordered microstructure, and peculiar ferroelectric properties, such as high dielectric permittivity and frequency dispersion on the permittivity–temperature plots. The distinct behaviour of relaxors originates from the chemical disorder, with more than one type of cation occupying the A or B sublattice position of ABO_3 perovskites.

NBT–BT–KNN relaxor ceramics especially have received extensive attention due to the superior ferroelectric properties. The most studied composition, 0.94NBT–0.06BT, sits at the morphotropic phase boundary of the NBT–BT phase diagram and has a high piezoelectric constant of 125 pC/N and can generate a usable electromechanical strain of 0.4% below 100°C.[2]

For 0.94NBT–0.06BT, nanosized domains nucleate with cooling below 520°C, remaining ergodic, i.e., loosely correlated to each other. As an ergodic relaxor, it has a reversible phase transition to ferroelectric; the field and the repetitive phase transitions under alternative loading are known to be the origin of its giant strain output. With further cooling, nano regions become closely correlated with each other until their ergodicity is broken below 120°C. As a nonergodic relaxor, its field-induced transition is irreversible.

Fatigue has been a crucial and concerning issue for piezoceramics under long-term high voltage cycling. For PZT, the domain wall "pinning," i.e., stabilization by point defects, is the key fatigue mechanism, which results in deteriorated ferroelectric polarization and cracks at the near electrode region and in the bulk. In contrast, ergodic relaxors could exhibit "fatigue-free" behavior due to the absence of domains at the pinning sites for defects during loading.

Our recent study found that at 40°C, 0.91NBT–0.06BT–0.03KNN showed premium fatigue performance, with its maximum polarization degrading by only 6% after 10^3 cycles of loading at high field (Fig. 1). Also, we found the point defects play a critical role in NBT-BT-KNN. The reduced oxygen vacancy level in the 0.94NBT–0.06BT sample could relieve the electrical fatigue remarkably.

To date, only a few lead-free piezoelectric devices are commercially-viable, such as the NBT-based transducer, KNN-based ultrasonic motor, and alkali niobate/tantalate-based knock sensor.[3] Though it might take a while before lead-free piezo devices completely replace lead-based ones, the prospect is undeniably positive with the concerted efforts from global materials scientists.

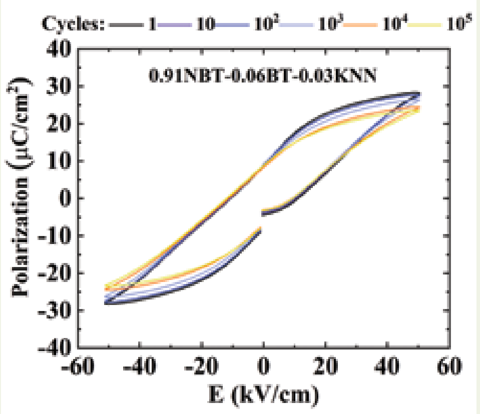

Fig. 1 The evolution of hysteresis polarization loops of 0.91NBT-0.06BT-0.03KNN with cycles when fatiguing at 40°C under triangular waveform with a maximum field of 50 kV/cm at 10 Hz. Replotted from Shi et al.[4]

References

[1]Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 (2003) "Restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)," *Official Journal of the European Union* 37: 19–23.

[2]H. Simons, J.E. Daniels, J. Glaum, A.J. Studer, J.L. Jones, M. Hoffman (2013) "Origin of large recoverable strain in 0.94 ($Bi_{0.5}Na_{0.5}$) TiO_3-0.06$BaTiO_3$ near the ferroelectric-relaxor transition," *Applied Physics Letters* 102(6): 062902.

[3]C.-H. Hong, H.-P. Kim, B.-Y. Choi, H.-S. Han, J.S. Son, C.W. Ahn, W. Jo (2016) "Lead-free piezoceramics–Where to move on?" *Journal of Materiomics* 2(1): 1–24.

[4]X. Shi, N. Kumar, M. Hoffman (2020) "Electrical fatigue behavior of NBT-BT-x KNN ferroelectrics: effect of ferroelectric phase transformations and oxygen vacancies," *Journal of Materials Chemistry* C 8(11): 3887–3896.

Xi Shi is a Ph.D. candidate in the School of Materials Science & Engineering at the University of New South Wales in Sydney, Australia. She is currently president of the Postgraduate Council and the postgraduate representative of Equity, Diversity, and Inclusion. She enjoys sketching, baking, and running.