Solid-state batteries:
Unlocking lithium’s potential with ceramic solid electrolytes
How can you participate in ceramics and glass education outreach?

Education outreach shares the magic of ceramic and glass materials with the next generation—and everyone can find a way to participate.

by David W. Richerson

Announcing ACerS Awards of 2019

The Society will honor members and corporations at the Awards Banquet of the 121st Annual Meeting in October to recognize significant contributions to the engineered ceramic and glass field.

Solid-state batteries: Unlocking lithium’s potential with ceramic solid electrolytes

Recent progress indicates that ceramic materials may soon supplant liquid electrolytes in batteries, offering improved energy capacity and safety.

by Nathan J. Taylor and Jeff Sakamoto

Inspire the next generation through CGIF programs

The Ceramic and Glass Industry Foundation offers a number of outreach programs to inspire the next generation of ceramic and glass scientists and engineers—and there are a number of ways you can get involved!
Fluoride strengthens both teeth and solar cells

Researchers in the Netherlands and China found adding fluoride to perovskite solar cells helps stabilize the material’s structure, much like fluoride in toothpaste protects tooth enamel from decay.

Credit: Proshay

Also see our ACerS journals...

Pressureless all-solid-state sodium-ion battery consisting of sodium iron pyrophosphate glass-ceramic cathode and B' alumina solid electrolyte composite

Journal of the American Ceramic Society

Life cycle assessment of functional materials and devices: opportunities, challenges and current and future trends

By L. Smith, T. Ibn Mohammed, S.C. Koh, and I.M. Reaney
Journal of the American Ceramic Society

Reactive flash sintering of powders of four constituents into a single phase of a complex oxide in a few seconds below 700°C

By V. Avila and R. Raj
Journal of the American Ceramic Society

Charge compensation mechanisms in Li-substituted high-entropy oxides and influence on Li superionic conductivity

By N. Osenciat, D. Bérardan, D. Dragoe, et al.
Journal of the American Ceramic Society

Read more at www.ceramics.org/flouride

Read more at www.ceramics.org/journals
Toward a United Nations Declaration of 2022 as The International Year of Glass

Greetings to all!

Over the past 60 years, the General Assembly of the United Nations has declared “International Years” to recognize global initiatives of important contributions to society. Across the globe, United Nations resolutions have enabled professional societies, museums, journals, and academia to recognize and celebrate their history, their current state, their future and, in their totality, their major contributions to society.

In the 21st century, the United Nations has recognized the International Year of Astronomy (2009), the Year of Chemistry (2011), the Year of Light and Light-Based Technologies (2015), and, in 2019, the Year of the Periodic Table and the International Year of Indigenous Languages. UN declarations of these major fields of international endeavor have given rise to renewed contributions to society world-wide.

International Year of Glass proposed

Against this storied background, an international groundswell has arisen to pursue a United Nations International Year of Glass for 2022. This concept was first introduced at the 2018 Fall Annual Meeting of the International Commission on Glass (ICG) in Yokohama, Japan. In May 2019, ICG, The Corning Museum of Glass, The American Ceramic Society, and The Glass Art Society endorsed the idea in a presentation to the Office of the United States Mission of the United Nations in New York City.

Encouragement received at this meeting gave rise to renewed effort to secure a UN Year of Glass. A subsequent meeting with the UN ambassador from Spain further encouraged the effort to go forth with this historical undertaking.

The work begins

Extensive planning is now underway to inform international art and scientific glass-themed societies and museums of this endeavor to secure the United Nations declaration of the 2022 International Year of Glass. Once a formal resolution is finalized to the UN General Assembly, these groups will be invited to endorse the request to recognize glass as the first material ever to be celebrated in this manner.

I encourage you to consider how your organization might participate in celebration of this seminal moment in the history of our ancient material—glass. Please contact me to learn more and to help us achieve this worthy goal.

Yours in glass,
Dr. Alicia Durán
President, International Commission on Glass
Chair, International Steering Committee for a 2022 Year of Glass
aduran@icv.csic.es
Hydrogen and its applications

The 2019 Ohio Fuel Cell Symposium focused on hydrogen and its applications in energy storage and power generation. What follows is a summary of the advantages, challenges, and opportunities for hydrogen technologies that presenters discussed at the symposium.

The global adaptation of solar and wind power generation has created a significant need for energy storage to ensure availability when the sun does not shine and the winds do not blow. Batteries and pumped storage systems are often used for this application. However, in recent years, the use of hydrogen for energy storage and power generation has been moving forward from technology development to having real-world, business-use value.

Hydrogen advantages

Hydrogen for storage and power generation is not new. Niche applications in communications and warehouse lift trucks have been around for more than 10 years. The key for these applications is the cost of capacity to meet specific up-time needs.

For lift trucks, hydrogen tanks can be changed in minutes while recharging batteries takes hours. For communications, the cost of installing and operating batteries that store enough energy to power a cell phone tower for 48 or 72 hours (e.g., during a hurricane or blackout) is much higher than for hydrogen storage systems. Plug Power (Latham, N.Y.), a leader in these applications of hydrogen power, spoke about how hydrogen and fuel cell production and reliability have been growing steadily through vertical integration.

Another key to hydrogen is long-term storage. Batteries suffer from self-discharge, meaning that while batteries are effective for short-term storage needs (minutes or hours), the internal loss of energy provides challenges for longer term uses. Symposium speakers presented various scenarios for long-term storage, including colocating hydrogen within the nation’s compressed natural gas pipeline system.

Hydrogen challenges

A significant stumbling block to using hydrogen for utility scale energy storage has been the environmental and economic costs of production. Currently the leading method for producing hydrogen is steam methane reforming, which is no cleaner than burning natural gas. Nel Hydrogen (Oslo, Norway), a producer of hydrogen by large-scale electrolysis using grid electricity, made the business case that hydrogen produced with low-cost electricity (i.e., when solar and wind are over-producing) can be used to generate high-cost electricity. The economics support this scenario even when considering efficiencies that are lower than current battery technology.

Raw materials are a challenge for both batteries and hydrogen electrolysis. Using batteries to solve the global electric energy storage needs would require thousands of metric tons of lithium and cobalt. Global reserves of these materials are estimated to be in the hundreds of metric tons. Hydrogen and hydrogen fuel cells use platinum as electrode catalysts. While platinum reclamation is part of the fuel cell and electrolysis companies’ business plans, finding a replacement catalyst is an ongoing opportunity for ceramists and other materials scientists.

Hydrogen markets and opportunities

A huge opportunity for hydrogen and fuel cells is transportation. Driven mainly by environmental concerns, many of the major manufacturers of automobiles and buses have produced fuel cell vehicles. Due to limited availability of hydrogen fueling stations, the early adopters of these vehicles are limited to certain regions of the world such as California, Europe, and cities in China. Many of these vehicles have exceeded performance and longevity goals.

Symposium speakers discussed markets for solid oxide fuel cells (SOFCs). For example, small-scale SOFCs (2–10 kW) have better prospects in Europe and Japan where electricity is relatively expensive, and houses are heated with hot-water boilers (which takes advantage of the thermal energy given off by SOFCs).

Buildingsized combined heat and power units are being tested in the United States, though representatives of the most active companies in this space did not attend the symposium. Presenters did suggest that appliance-sized SOFC and solid oxide electrolysis units have benefits over turbine technology in grid balancing and off-grid applications.
Business news

PLANTS, CENTERS, AND FACILITIES

Pilkington invests €30 million on Gladbeck float glass line renovation
NSP Pilkington spent €30 million and created 530 jobs by renovating its Gladbeck float glass line. Pilkington hopes the complete renewal of the glass melting furnace’s technique can improve the energy efficiency of the plant, reduce gas consumption, and reduce carbon dioxide emissions by 20%.

https://www.glass-international.com

Centorr Vacuum Industries invests in its Applied Technology Center
Centorr Vacuum Industries added new furnace capability to its Applied Technology Center for customer use for process proofing, toll work, and process development runs. The new furnace is based on Centorr’s successful Super VII platform and will join two smaller System VII furnaces and induction melting furnace, and a continuous belt furnace already in use.

https://vacuum-furnaces.com

ACQUISITIONS AND COLLABORATIONS

Korea, Germany to jointly develop laser glass-welding technology
The Korea Institute of Machinery Materials will jointly develop laser-enabled glass-welding and underwater processing technologies with the Laser Zentrum Hannover in Germany, a globally renowned research institution in the field of cutting-edge laser technology.

http://www.donga.com/en

BYD and Toyota join forces to develop electric cars and batteries
Asian carmakers BYD and Toyota are teaming up to develop electric cars and batteries with a view to bringing the jointly developed vehicles to market by 2020. The deal will see electric sedans and “low-floor” SUVs developed by the two companies, which will then be launched in China under the Toyota badge early next year.

https://thedriven.io

MARKET TRENDS

Optical ceramics market to reach US$552.3 million by 2026
According to a recent Reports and Data report, the global optical ceramics market was valued at US$148 million in 2018 and is expected to reach US$552.3 million by year 2026, at a CAGR of 15.3%. Currently, aluminum oxynitride holds the largest share of the market.

https://www.reportsanddata.com

Medical ceramics booming at a CAGR of 6.1% by 2025
The Global Medical Ceramics Market report expects the global medical ceramics market to reach US$23.10 billion by 2025, from US$13.64 billion, growing at a CAGR of 6.1% during the forecast period 2018 to 2025.

https://risemedia.net
Residential energy storage, blockchain, and energy sharing systems

By Christopher Maara

The global residential energy storage systems (RESS) market grew from nearly $2.5 billion in 2017 to $3.0 billion in 2018. Over the forecast period 2018–2023, overall revenues from global RESS shipments are forecast to grow at a compound annual growth rate (CAGR) of 30.0% to reach a value of $11.2 billion.

The market is spurred by a number of factors, including feed-in tariff (FIT) and net metering revisions in historic residential photovoltaic (PV) hotspots, subsidies and tax incentives, rapid price reductions in lithium-ion battery prices, and rising electricity tariffs.

The largest RESS market is PV rooftop plus storage, which is valued at $1.6 billion in 2018, accounting for 52.8% of the application market. Backup power accounts for 27.9% of the market ($842 million), electric vehicle applications account for 14.8% ($447 million), and energy cost management accounts for 4.5% ($137 million). Energy storage deployed behind-the-meter in residential applications has the potential to eclipse the utility storage segment (Figure 1).

The largest technology submarket is lithium-ion storage, on account of its low cost (Table 1). The market for these systems is forecast to grow at a CAGR of 33.2% to reach $890 million by 2023. This market will be driven by emerging end-user markets such as electric vehicle and e-bike charging and consumer needs, leading to a wider variety of solutions/applications.

Peer-to-peer (P2P) energy-trading platforms are currently the most common blockchain-based applications in the energy market. Implications for this business model on the electricity market include

• Lower electricity costs by skipping intermediaries and automating processes,
• Reduced burden on transmission grids by localizing energy markets, and
• Higher sense of community by allowing consumers to independently negotiate the prices on the P2P platform and set their own price preferences.

Unlike traditional power plants, storage systems are capable of both absorbing electricity from and providing electricity to the grid. The falling price of electric storage systems and the increasing integration of renewables in the electricity production mix mean that a greater number of households will find renewable and electric storage systems more affordable.

About the author
Christopher Maara is a research analyst for BCC Research. Contact Maara at analysts@bccresearch.com.

Resource
Attend your Division business meeting at MS&T19

Six ACerS divisions will hold executive and general business meetings at MS&T19 in Portland, Ore. General business meetings will be held Monday and Tuesday in the Oregon Convention Center. Plan to attend to get the latest updates and to share your ideas with Division officers.

Most Division Executive Committee meetings will be held Sunday afternoon (September 29) in the Portland Marriott Downtown. For times and locations, check with the Division chair or Erica Zimmerman at ezimmerman@ceramics.org.

Monday, September 30
• Basic Science Division: Noon–1:00 p.m.
• Electronics Division: 12:30–1:30 p.m.
• Engineering Ceramics Division: 12:30–1:30 p.m.
• Nuclear & Environmental Technology Division: 6:00–7:00 p.m.

Tuesday, October 1:
• Glass & Optical Materials Division: 4:45–5:45 p.m.
• Bioceramics Division: 1:00–2:00 p.m.

One and done – pay your dues once with an ACerS Lifetime Membership

ACerS Lifetime Membership allows members to avoid future dues increases, maintain awards eligibility, and eliminates the need to renew each year. The cost to become a Lifetime Member is a one-time payment of $2,000. Join the growing list of Lifetime Members while securing ACerS member benefits for your entire lifetime.

To learn more about Lifetime Membership, contact Kevin Thompson at (614) 794-5894 or kthompson@ceramics.org.

Volunteer Spotlight

ACerS is pleased to announce that Valerie Wiesner has been selected for Volunteer Spotlight. Wiesner has been a very active and committed member of ACerS since joining in 2010 as a graduate student. Her notable contributions to date include advancing and enhancing the involvement of students and young professionals, as well as underrepresented populations in the Society.

In addition to serving as an officer of the Engineering Ceramics Division, Wiesner is chairing the 44th ICACC to take place in February 2020. Wiesner is also a member of the Strategic Planning and Emerging Opportunities Committee (2019–present), Member Services Committee (2018–present), and Education and Professional Development Council (2014–present), and serves as an ACerS representative to the Materials Advantage Committee. She previously was an officer of the Northern Ohio Section.

Wiesner is a research materials engineer at NASA Glenn Research Center. She received a Ph.D. in materials science and engineering from Purdue University.

We extend our deep appreciation to Wiesner for her service to our Society.

Corporate Partner news

We are pleased to welcome the following Corporate Partner:
• Cancarb Limited
For more details contact Kevin Thompson at 614-794-5894 or kthompson@ceramics.org.

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Names in the news

ACerS members Farshad Rajabipour (professor) and Mina Mohebbi (a recent doctoral graduate) at The Pennsylvania State University received the 2019 Outstanding Article Award by the American Society for Testing and Materials (ASTM) journal, Advances in Civil Engineering Materials, for their article published in said journal.

The Nuclear & Environmental Technology Division will present the D.T. Rankin Award to Connie Herman, who has demonstrated exemplary service to the Division. Herman is associate laboratory director, environmental stewardship at Savannah River National Laboratory (SRNL) and an ACerS Fellow.

AWARDS AND DEADLINES

ACerS/BSD Ceramographic Exhibit & Competition

The Roland B. Snow Award is presented to the Best of Show winner of the 2019 Ceramographic Exhibit & Competition organized by the ACerS Basic Science Division. This unique competition, held at MS&T19 in Portland, Ore., is an annual poster exhibit that promotes the use of microscopy and microanalysis in the scientific investigation of ceramic materials. Winning entries are featured on the back covers of the Journal of the American Ceramic Society. Learn more at http://bit.ly/RolandBSnowAward.

STUDENTS AND OUTREACH

Compete in student contests at MS&T19

Join fellow Material Advantage student members from around the world at MS&T19 in Portland, Ore., and compete in the following student contests:

Undergraduate Student Speaking and Poster Contests

Submit entries for the MA Undergraduate Student Speaking Contest and the Undergraduate Student Poster Contest by Sept. 9, 2019. Rules for each contest as well as where to send entries can be found at matscitech.org/students.

Design contests for students

Start working on your pieces for the Ceramic Mug Drop and Ceramic Disc Golf Contests. These popular contests will be held during MS&T19 on Tuesday, October 1 in the exhibit hall. Contact Geoff Brennecka at geoff.brennecka@mines.edu with your intent to participate.

For more information on the contests and student activities at MS&T19, visit matscitech.org/students, or contact Yolanda Natividad at ynatividad@ceramics.org.

ACerS student tour to Pacific Northwest National Laboratory (PNNL)

Students will have an opportunity to attend a tour at the Pacific Northwest National Laboratory (PNNL) in Richland, Wash. on Wednesday, Oct. 2, 2019 during MS&T19. The ACerS student tour to PNNL will be an all-day event and is open to all MS&T19 student registrants. The tour offers students the chance to see the national laboratory’s cutting-edge scientific research, instrumentation, and unique facilities for advancing batteries, solid oxide fuel cells, glass and ceramic wasteforms, and more.

Space is limited and registration is on a first come, first served basis. To register visit www.matscitech.org/students. U.S. Citizens: Registration forms must be submitted by September 9. Please note that the registration deadline for Non-U.S. Citizens has now passed. If you have any questions, please contact Yolanda Natividad at ynatividad@ceramics.org.
NEW - PCSA Humanitarian Pitch Competition at MS&T19

The President’s Council of Student Advisors (PCSA) is hosting the Humanitarian Pitch Competition for students to pitch ideas to a panel of judges about how improved materials and processes can address a challenge that a community is experiencing.

A team may consist of up to four participants. They will 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 be sure to submit abstracts by September 1.

4th Annual ACerS PCSA Creativity and Microstory Contest

Ever tried to combine science with art? Give it a try and compete in ACerS PCSA’s 4th Annual Creativity and Microstory Competition! Deadline for submissions has been extended to Aug. 30, 2019. There are multiple prize categories, so there are many ways to win. The winning entries will be displayed in the ACerS booth at MS&T19 in Portland, Ore. Check out all the details at www.ceramics.org/pcsacreative.

Student travel grants and tour offered at the 80th GPC

The Glass Manufacturing Industry Council offers $500 travel grants to graduate and undergraduate students who will be attending the 80th Conference on Glass Problems, Oct. 28–31, 2019, in Columbus, Ohio. Student travel grants are available on a first-come, first-served basis. Students are also invited to attend the Owens Corning plant tour in Newark, Ohio, on October 28, from noon to 4 p.m. Students must register in advance to participate. To apply for a grant or register for the tour, visit the Student tab at http://glassproblemsconference.org and submit your application(s) by Sept. 23, 2019. Contact Donna Banks at dbanks@gmic.org with any questions.

Give GGRN a “like” on Facebook

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

If you are not a current GGRN member but are a graduate student or working towards your Ph.D. and your work includes ceramics or glass, be sure to stop by www.ceramics.org/ggrn to join GGRN today.
Glass Camp and chemistry of raku pottery—Creative introductions to chemistry and glass materials

- Ursinus College, a CGIF grant recipient, offered its unique Glass and Materials Science Camp to students in June. Ursinus’ first GaMES (Glass and Materials Science to Engage Students) camp is designed to be both fun and educational and to provide real opportunities for students ages 10-16, especially girls and those from underserved student populations, to engage in scientific learning, collaborative research, problem solving, and discussion. Led by Casey Schwarz, an assistant professor of physics, as well as two Ursinus summer fellows, Kateryna Swan ’20 and Max Liggett ’20, the camp was funded by a grant from The Ceramic and Glass Industry Foundation.

- In June, the CGIF made a generous donation to the Donors Choose organization to benefit the science department at Louisville High School in Louisville, Ohio. Pete Carpico, a chemistry teacher and Science Club advisor at Louisville High, made a project request to Donors Choose, an organization that connects the public with public high schools to make it easy for anyone to help a classroom in need. Carpico requested funding for an enameling kiln and related materials to combine art and chemistry to enable his students to see the ways that chemistry applies. “Combining raku pottery making and glass projects into chemistry class may seem like a stretch, but materials science provides the needed connection,” explains Carpico. “I love to challenge my students to see the application of chemistry into everything around them.

- ACerS members Andrew Hoffman, Olivia Rodell, Les Harmon, Andy Gerbing, and Kaylea Pogue recently volunteered their time and expertise at the National Science Teachers Association National Conference in St. Louis, Mo., on April 11-13, 2019. They assisted CGIF staff by explaining scientific concepts and demonstrating lab activities from the CGIF’s Materials Science Classroom Kit at the conference.

The CGIF was pleased to offer 13 students, both domestic and international, travel grants of $1,000 each to attend the European Ceramic Society’s (ECerS) Summer School on high and ultra-high temperature ceramics in Turin, Italy, June 14–15, 2019. From left to right top to bottom: Summer School Attendees Becher Watson, Becca Walton, Robin De Meyere, Andrew Gibson, Alex Leide, Meteo Groet, Nick Goossens, Mike Brova, Niquana Smith, Jamesa Stokes, Lavina Backman.

ACERS BOOKSHELF

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

Glass-Ceramic Technology, 3rd Edition explores glass-ceramics new materials and properties and reviews the expanding regions for applying these materials.

Non-Destructive Evaluation of Corrosion and Corrosion-assisted Cracking is an important resource that covers the critical interdisciplinary topic of nondestructive evaluation of degradation of materials due to environment.

Bioceramics and Biocomposites: From Research to Clinical Practice covers the basic science and engineering of bioceramics and biocomposites for applications in dentistry and orthopedics, as well as the state-of-the-art aspects of biofabrication techniques, tissue engineering, remodeling, and regeneration of bone tissue.
Breaking the limit of oxide glass microductility

Researchers from Aalborg University in Denmark, Technical University of Denmark, and University of California, Los Angeles, created a microductile oxide glass with crack resistance more than ten times higher than previous glasses.

Oxide glasses, though ubiquitous in modern day technologies, are known for being brittle. To reduce brittleness, scientists have attempted several post-processing methods, including thermal tempering, chemical strengthening, and crack-sealing particle inclusion. While these methods do overcome some limitations of brittleness, post-processing steps can increase production costs significantly.

Instead of post-processing, another more economical way that scientists are investigating to reduce brittleness is to create intrinsically ductile glasses. At this point, creating truly ductile glasses is still out of reach. However, creating microductile glasses, or glasses that deform under sharp contact without cracking, is achievable.

Scientists create microductile glasses by tuning a glass’s network structure to promote densification, a type of plastic deformation. Caesium aluminoborate, the oxide glass created in the recent study, has shown fairly decent crack resistance in previous work. What pushed the glass to strikingly high crack resistance levels in this study was a counterintuitive trick—the researchers aged the glass in a humid atmosphere.

“Vickers indents at loads as high as 490 N (50 kgf) can be generated by subjecting the caesium aluminoborate glass, whereas only around 30 N loading was possible in freshly polished samples of the same composition reported elsewhere,” the researchers report in the paper.

In an email, ACerS member and Aalborg University professor of chemistry Morten Smedskjaer explains they came up with the idea to age the glass during a previous study. “We nor-
mally quantify the densification contribution to indentation by annealing indents below $T_g$ and look at the indent volume changes after annealing,” he says. “However, we were having problems to do this for the caesium aluminoborate glass, because its indent volume was changing over time under ambient conditions, i.e., not only due to annealing.”

“We had not seen this effect previously, which was caused by the aging in ambient air, so this is how we got interested in the effect of aging on indentation deformation and cracking,” he adds.

In the study, the researchers explain that aging the caesium aluminoborate glass in ambient air causes the glass to become hydrated. The reason why hydration so significantly increases the glass’s crack resistance, though, is not certain.

“We have some discussion about possible reasons in the new paper,” Smedskjaer says, including

1. Compressive stresses arising due to volume expansion created by hydration,
2. Water promoting stress relaxation (as has been found in other studies), and
3. OH-groups in the surface making the glass network very flexible.

There are other possibilities as well, and the researchers plan to conduct more studies to work out the details and to see if hydration has a similar effect on other glass compositions.

The open-access paper, published in Advanced Science, is “Breaking the limit of micro-ductility in oxide glasses” (DOI: 10.1002/advs.201901281).

### Unified thermal transport formula for crystals and glass

In the case of ordered and disordered materials such as crystals and glass, these materials exhibit fundamentally different heat conduction mechanisms. However, researchers from Switzerland and Italy show the two thermal transport theories used to model heat conduction in these materials may be more similar than previously believed.

Michele Simoncelli (Ph.D. student) and Nicola Marzari (professor; director of NCCR MARVEL) at Swiss Federal Institute of Technology Lausanne–EPFL, and professor Francesco Mauri at the University of Rome Sapienza derived a general formula of thermal transport that describes equally well both ordered and disordered materials, as well as everything in between.

Depending on what limits they place on the formula, it reduces to either the Boltzmann transport equation (BTE) for simple crystals or the Allen-Feldman formulation for harmonic glasses.

The key to developing their general formula was accounting for a fundamental component of heat propagation—quantum tunneling. “[Phonon wave packets] are not only allowed to propagate particle-like in space but also to tunnel, wave-like,” Simoncelli says.

### Research News

#### Oddball edge wins nanotube faceoff

Rice University theoretical researchers discovered that nanotubes with segregated sections of “zigzag” and “armchair” facets growing from a solid catalyst are far more energetically stable than a circular arrangement would be. The theory is a continuation of the team’s discovery last year that Janus interfaces are likely to form on a catalyst of tungsten and cobalt, leading to a single chirality that other labs reported growing in 2014. The Rice team now shows such structures are not unique to a specific catalyst, but are a general characteristic of a number of rigid catalysts. For more information, visit https://news.rice.edu.

#### Innovative AI system could help make Army fuel cells more efficient

The Army Research Office funded a research team to develop an AI system that identifies promising materials for creating more efficient fuel cells. The system, called CRYSTAL for crystal phase mapping, involves multiple bots each taking on a different part of the problem, from predicting the phase structures of various combinations to making sure those predictions obey the rules of thermodynamics. The system identified a unique catalyst composed of three elements crystallized into a certain structure, which is effective for methanol oxidation and could be incorporated into methanol-based fuel cells. For more information, visit https://www.army.mil.
Ordered and disordered materials transport heat quite differently based on their contrasting atomic structures. A new theory can describe thermal transport in both.

from one branch to another,” the researchers explain in their paper. While such tunneling contributions are negligible in perfect crystals, the tunnels become more relevant as system disorder increases. In a glass, these tunnels result in the Allen-Feldman formalism.

To account for quantum tunneling, the researchers derived their general transport equation from the Wigner phase space formulation of quantum mechanics. They then showed how this general equation can be reduced to both the BTE and Allen-Feldman formulations.

More than uniting the BTE and Allen-Feldman formulations, the largest benefit of the general theory is the ability to calculate heat transport for intermediate materials that are both crystal-like and glass-like, such as thermoelectrics.

The paper, published in Nature Physics, is “Unified theory of thermal transport in crystals and glasses” (DOI: 10.1038/s41567-019-0520-x).
Oxide ceramic films could replace polymeric separators

Researchers from Donghua University in Shanghai showed a separator made from an oxide ceramic film could prove a better option than polymeric separators in batteries.

The main reason Li-ion batteries short circuit is due to failure of the separator, the permeable membrane between a battery’s anode and cathode that keeps the two from touching. Many separators fail because they are made of polymeric materials that have low melting temperature, poor mechanical strength, and poor chemical inertness.

To enhance the stability of separators, efforts have been focused on several methods, including

• Fabricating ultrastrong separators with special polymers that can withstand high temperatures of 120°C–350°C
• Blending different polymers together to construct multicomponent separators, and
• Forming composite separators by filling or coating polymeric separators with chemically and thermally stable ceramic particles.

Though these methods do improve polymer separator stability, there are still some challenges. For example, thermal runaway can cause temperatures to reach over 500°C, at which point the separators degrade immediately. Also, ceramic particles may block pores and impede Li-ion transfer.

Though polymer is the precedent material for Li-ion battery separators, it is not the only option.

“Oxide ceramics have been widely used in engineering and technology fields and enjoyed rapid development because of their superior properties such as robust mechanical strength, exceptional thermal and chemical stability, and physical integrity,” the Donghua researchers explain in an open-access paper on their research.

Specifically, the researchers note that recently scientists have successfully fabricated binary oxide ceramic films such as ZrO$_2$, TiO$_2$, and Al$_2$O$_3$ with shape memory performance. The mechanical responses of these “soft” oxide ceramics offer appealing prospects to a variety of fields, with one application being Li-ion battery separators.

In their study, the Donghua researchers developed a scalable ceramic nanofiber fabrication technique based on electrospinning and calcination. They used this method to create a variety of ceramic films, including binary oxide of SiO$_2$, ternary oxide of BaTiO$_3$ (BTO), and quaternary oxides of Li$_7$La$_3$Zr$_2$O$_{12}$ (LLZO) and Li$_{0.33}$La$_{0.56}$TiO$_3$ (LLTO).

The researchers found that when applied to Li-ion batteries, all their synthesized ceramic nanofiber separators exhibited low internal ionic penetration resistivity, high chemical stability, and robust mechanical strength. Additionally, the ceramic separators rendered batteries with high thermal stability over the operating temperature range without thermal runaway.

The researchers gave two words of caution in their conclusion. One, despite attempting to minimize the separators’ pore sizes by increasing film thickness and by adding a small amount of polyvinilidene fluoride (PVDF) polymers in the electrolytes, the films still had a larger average pore size than commercial separators. Two, they did not characterize the separators’ ability to resist lithium dendrite growth, which is another safety factor that should be considered.

Despite these limitations, the researchers conclude, “This work provides a promising strategy to produce oxide ceramic films that possess both soft and rigid properties with a low-cost and scalable synthesis method.”


Rust: Another way to generate electricity

From the viewpoint of DOD, rust is a problem to suppress. Rust costs the Pentagon up to $21 billion per year. Corrosion of metals is such a large problem that the DOD established the Office of Corrosion Policy and Oversight in 2002 to help branches determine how much money to spend on rust prevention and to ensure oxidation does not take big-dollar weapons systems offline.

However, in other situations, rust may be beneficial. In a paper published in the *Proceedings of the National Academy of Sciences*, researchers at the California Institute of Technology and Northwestern University show that rust could offer a new means of sustainable power production. They demonstrated rust can generate electricity when saltwater runs over it.

Electricity is often generated via interactions between metal compounds and saltwater (think of batteries). However, electricity generated this way is usually the result of a chemical reaction in which one or more compounds are converted to new compounds.
In the case of rust, electricity is generated from kinetic energy of the flowing saltwater, a phenomenon known as the electrokinetic effect. Studies testing this effect on carbon nanotubes, graphene, and dielectric-semiconductor architectures have demonstrated promising conversion efficiencies of 30%. In comparison, some of the best solar panels are around 20%.

Fabricating carbon nanostructured films of usable size, though, is difficult. But rust does not face that limitation.

“It’s basically just rust on iron, so it’s pretty easy to make in large areas,” Thomas Miller, Caltech professor of chemistry, says in a Caltech press release. “This is a more robust implementation of the thing seen in graphene.”

The researchers used physical vapor deposition (PVD) to deposit nanolayers of iron, nickel, vanadium, aluminum, and chromium in 5, 10, 20, and 50 nm thick layers on glass slides. When the slides were removed from the PVD machine, the metals spontaneously oxidized in air.

The researchers flowed saltwater solutions of varying concentrations over the oxidized slides and found slides with iron, vanadium, and nickel nanolayers produced open-circuit potentials of several tens of millivolts and current densities of several microamps per cm².

In the paper, the researchers explain why these oxidized metals demonstrated better results than aluminum and chromium. “Structures whose oxide nanooverlayers contain only a single oxidation state, such as those formed from [aluminum] or [chromium] metal, should still produce currents due to contact electrification, but the lack of introxide electron transfer would diminish their current output,” they say.

In the press release, Miller says the electrokinetic effect could be useful in scenarios involving moving saline solutions.

“For example, tidal energy, or things bobbing in the ocean, like buoys, could be used for passive electrical energy conversion,” he says. “You have saltwater flowing in your veins in periodic pulses. That could be used to generate electricity for powering implants.”

The paper, published in *Proceedings of the National Academy of Sciences*, is “Energy conversion via metal nanolayers” (DOI: 10.1073/pnas.1906601116).
In a recent paper published in Matter, researchers from Texas A&M propose a new technique that could extend the shelf life of 2D material MXene by years.

MXenes rapidly degrade when kept in the open, and current strategies for mitigating MXene oxidation have mostly involved restricting oxygen exposure or freeze-drying MXenes under vacuum. However, Texas A&M professor of materials science and engineering Miladin Radovic explains these techniques are not ideal.

“Restricting oxygen exposure is not an option for most of the potential applications of MXenes,” he says in an email.

In their study, the researchers led by Radovic and associate professors of chemical engineering Micah Green and Jodie Lutkenhaus looked for new techniques to increase oxidation stability of MXene nanosheets. Radovic says the researchers decided to expose MXenes to antioxidants because “[t]hese antioxidants have proven effective in other applications.”

The researchers focused on Ti$_3$C$_2$T$_x$, the most common MXene. They diluted colloidal Ti$_3$C$_2$T$_x$ nanosheet dispersions with a premixed aqueous solution of sodium L-ascorbate (NaAsc) and then stored the NaAsc-stabilized dispersions for 21 days in closed bottles at ambient temperature.

X-ray diffraction patterns of NaAsc-stabilized dispersions and control dispersions made with deionized water showed marked differences. “[T]he colloidal Ti$_3$C$_2$T$_x$ nanosheets retained their pronounced (002) peak at a 2θ angle of around 6.5°,” the researchers write in the paper. “However, the (002) peak disappeared completely from the XRD spectrum for Ti$_3$C$_2$T$_x$ stored in deionized water, indicating the total oxidation of crystalline MXene to an amorphous structure.”

“Collectively, these XRD results suggest that the crystalline structure of Ti$_3$C$_2$T$_x$ nanosheets can be effectively retained by introducing an antioxidant,” they state.

The researchers conducted several other tests, such as measuring changes in electrical conductivity and chemical composition, to complement their X-ray diffraction findings. Taken together, the tests supported the conclusion that antioxidants restrict oxidation in MXenes.

Why do antioxidants so effectively restrict oxidation? According to the researchers, “The origin of this stability against oxidation is attributed to the association of L-ascorbate anions to the edges of Ti$_3$C$_2$T$_x$ nanosheets, which prevent otherwise detrimental oxidation reactions.”

NaAsc is not the only antioxidant that associates with reactive sites on the MXene nanosheets. The researchers tested several related compounds, including vitamin C, and found these antioxidants offer the same protection.

In a Texas A&M press release on the research, Green notes the researchers made the discovery about a year ago, and the treated MXenes are still stable.

Radovic says they are currently testing the effectiveness of this method for other MXenes and also testing some other antioxidants. “[F]irst results are quite promising,” he says.

The paper, published in Matter, is “Antioxidants unlock shelf-stable Ti$_3$C$_2$T$_x$ (MXene) nanosheet dispersions” (DOI: 10.1016/j.matt.2019.05.020).
At many points in Dawn Bonnell’s career, she has found herself in uncharted territory at the low end of a learning curve. “It can be stressful, but ultimately if you can wade through it, then you can accomplish something,” she says.

Bonnell is quite familiar with accomplishments. She is currently vice provost for research as well as Henry Robinson Towne Professor of Materials Science and Engineering at the University of Pennsylvania, with a long list of awards, accolades, and other accomplishments that attest to her success.

But as an undergraduate at the University of Michigan, Bonnell knew little about ceramic materials. That all changed when she had the opportunity to work in the lab of T.Y. Tien studying structural technical ceramics. “After I learned some of the techniques and measurement tools, particularly microscopy, I just fell in love.”

Bonnell continued climbing the learning curve through graduate work, studying ceramics at the University of Michigan. But just as she reached the top of that curve, Ph.D. in hand, Bonnell slid to the bottom of a new learning curve when she took a temporary diversion to work in industry before beginning her academic career.

At the time, IBM had recently invented and won a Nobel Prize for the scanning tunneling microscope. When Bonnell got an opportunity to work at IBM using this new imaging tool to examine the surface of materials, she jumped at the chance. “It changed my trajectory entirely,” she notes.

Scanning tunneling microscopy had mostly been used in the semiconductor industry to study silicon. But Bonnell recognized the potential of the technique and an opportunity that was completely wide open. It was a risk, Bonnell says, yet one that paid off—her work was some of the first to apply scanning tunneling microscopy to ceramic materials.

“It’s extremely intellectually rewarding to find something new that other people haven’t seen before, to actually be able to discover things and move the field in a new direction,” she says.

Yet beyond this personal success, Bonnell also strives to create supportive research environments through her mentoring, leadership, and even administrative duties.

“The more gratifying aspect of my career to date has been working with students and postdocs, with all the things they’ve accomplished,” Bonnell explains. “They are incredibly talented and creative, able to take ideas that I started with into new directions.”

Of course, Bonnell herself does not shy away from venturing in new directions. As professor at the University of Pennsylvania, Bonnell founded and directed the Nano/Bio Interface Center, a National Science Foundation-funded center that studies nanobiotechnology by merging arts, science, engineering, and medicine.

Through both her work with the Nano/Bio Interface Center and her current role as vice provost of research, Bonnell deeply values her ability to support new ideas. “To be able to provide resources for people who are doing really great things and help support them to find new directions is extremely satisfying,” she says. “They can make a lot bigger impact than I can make individually myself. And to be a small part of that feels very good.”

Such a collaborative approach is also what Bonnell appreciates about the ceramics community. When she was a young scientist, Bonnell says she did not appreciate how uniquely supportive the ceramics community was to professional growth and development. “I didn’t think of that as unique, because that was the only environment I had at the time,” she reflects.

But now having experienced other disciplines and other fields that are not nearly as supportive, Bonnell recognizes how special the ceramics community is and how large of a role ACerS plays in fostering that spirit. “It really is a unique aspect of the ceramics community—and I think the Society really embodies that.”

Minoru Tomozawa

Minoru Tomozawa earned his B.S. from Yokohama National University in Japan and, without any thought of graduate school, took a position as a research engineer with Nippon Electric Company.

It was 1961—the dusk before the dawn of the semiconductor era. This timing was...
fortunate for Tomozawa because working on vacuum tube technology put him on the path that became his life’s work.

“At the time, semiconductors just started. I wanted to work on semiconductors, but as a materials engineer I was assigned to work on glasses. I had no idea what it is, but gradually I found out it was an important part of electronics,” he recalls.

As vacuum tube technology became obsolete, new and exciting applications for glass emerged with the development of laser glasses and color television.

Tomozawa says, “There was some need for glass research and engineering. I spent four and a half years learning the basics of glass processing and research. Then I felt I needed more basic study of materials science, and that’s when I thought maybe I should go back to graduate school.”

Thinking he would get a master’s degree and then return to Japan, he accepted a fellowship at the University of Pennsylvania in the United States.

“I found out you don’t have to get a master’s degree. If you try hard enough you can get a Ph.D. in three years.” He studied spinodal phase separation, the theory developed by John Cahn, which was a hot topic at the time.

Graduation led to a postdoctoral position at Rensselaer Polytechnic Institute in Troy, N.Y., and before long opportunity found the young researcher during a faculty search. “I was a post doc, and the subject was glass, so I was very much interested. . . . Then the advisor said, why don’t you apply for the position?”

The rest was history—a very long history.

Initially, proposal writing to acquire funding challenged Tomozawa.

“Then I began to think, maybe writing proposals is a good way to think hard, he says. Proposal writing really makes you think hard. In retrospect, I thought proposal writing was good training to plan research carefully.”

After six years on the faculty, Tomozawa took one-year sabbatical to work in glass manufacturing industry in Japan. He says, “That helped me to connect science and practical applications. So even though I do science, when I want to sell an idea and say why this is important in society, that was a good connection.”

Tomozawa says his life’s work will be his research on the effect of water content on mechanical properties of glasses. “I knew a small amount of water had a great impact on properties. I thought if you put in lots of water, you magnify the phenomenon so you can clearly see how the small amount of water is affecting the glass,” he explains.

Having been to nearly all Glass and Optical Materials Division meetings and most MS&T conferences, Tomozawa credits ACerS with helping him find information and colleagues.

Tomozawa notes that the ancient Roman motto, “Happy is the man who finds the cause of things,” applies to basic science research. “I feel very fortunate having a job with its main objective being my pursuit of happiness.”

Winnie Wong-Ng

When Winnie Wong-Ng was accepted into the chemistry rather than mathematics program at the Chinese University of Hong Kong, she was unsure at first about pursuing a degree in that field. Now a senior researcher at the National Institute of Standards and Technology, Wong-Ng is glad she gave chemistry a chance. “I enjoy my work here every day very much,” she says.

Growing up in Hong Kong, university was not a given for Wong-Ng. Yet Wong-Ng was an ambitious child, and she says her father, whom she lost at an early age, inspired her to work hard and pursue higher education.

After receiving her bachelor of science in chemistry, a “number of miracles,” including sponsorship from a stranger, enabled Wong-Ng to move to the United States and earn her Ph.D. in inorganic chemistry at Louisiana State University. She then moved to Canada for a postdoctoral and research/associate lecturer position in the chemistry department at the University of Toronto, but she found securing a permanent job difficult. That is when she heard about a position as a crystallographer with the Joint Committee on Powder Diffraction Standards (now the International Centre for Diffraction Data, ICDD) and she returned to the U.S.

“That job changed my life,” Wong-Ng says. At ICDD, Wong-Ng worked on a collaboration with the National Bureau of Standards and realized just how much she enjoyed lab work. When the collaboration came to an end, she applied for and began a full-time job as a research chemist at the Bureau, now called the National Institute of Standards and Technology (NIST).

Over her 30 years as a NIST researcher, Wong-Ng took part in and led diverse projects that greatly benefitted the ceramics community, including developing more than 800 reference X-ray powder diffraction patterns, about 50 phase diagrams for ceramic systems, and publishing more than 350 scientific papers. She also created two standard reference materials for the alignment of single crystal diffractometers (SRM 1990) and for the calibration of Seebeck coefficient measurements (SRM 3451).

Wong-Ng joined ACerS right after she went to work at NIST. “We in the ceramics division were all encouraged to go to the ACerS Annual Meeting,” she recalls. Since that first meeting in 1986, Wong-Ng says she has attended every Annual Meeting.

Wong-Ng served as chair (2005–2006) and trustee (2013–2016) of the Electronics Division (ED) and during her time as trustee, she oversaw significant membership growth as a result of the hard work of the division leaders. Prior to 2013, ED membership had been steadily declining, but during Wong-Ng’s time as trustee, membership increased over 40% by 2016. In addition to her roles in the ED, Wong-Ng serves as associate editor of the Journal of the American Ceramic Society, and has been involved with a number of ACerS committees including the Nominating Committee and the Publications Committee.

For Wong-Ng, holding these leadership roles in ACerS is an honor. “To be able to serve ACerS and its membership is the most meaningful part to me,” she says of her time as a member. “And I’m having fun doing all these activities!”
The 2019 Class of Fellows

Palani Balaya is associate professor at the National University of Singapore. He received his Ph.D. and M.Phil. in physics from the University of Hyderabad in India. Balaya belongs to ACerS Engineering Ceramics, Basic Science, and Manufacturing Divisions and is a member of the Education and Professional Development Council.

Bikramjit Basu is professor at the Materials Research Center with joint appointment at Center for Biosystems Science and Engineering and Interdisciplinary Center for Energy Research at Indian Institute of Science, Bangalore. He earned his Ph.D. in engineering ceramics at Katholieke Universiteit Leuven, Belgium. He is an active member of ACerS Engineering Ceramics Division.

Kristen H. Brosnan joined GE Research in 2007 and is technology manager leading the Metals & Ceramics team in the Structural Materials Division. Brosnan was recognized with the GE Women in Technology award. She serves as vice-chair of the Basic Science Division, chair of the ACerS Jeppson Award Committee, and on the Nominating Committee and Diversity & Inclusion Subcommittee.

Ricardo H.R. Castro is professor in the Department of Materials Sciences and Engineering at University of California, Davis. Castro has a Ph.D. in metallurgical and materials engineering from the University of São Paulo, Brazil. He is founding editor-in-chief of the ACerS International Journal of Ceramic Engineering & Science, a new online, gold open-access journal. Castro is a regular instructor for ACerS Sintering of Ceramics short course and is a member of ACerS Basic Science and Engineering Ceramics Divisions.

J.Gary Childress recently retired from the Edward Orton Jr. Ceramic Foundation in Westerville, Ohio, after serving 17 years as Orton’s general manager. Childress graduated from Clemson University with a B.S. in ceramic engineering. Prior to joining Orton, Childress served as vice president of Hecla Mining Company and president of Kentucky-Tennessee Clay Company. Childress served on the ACerS political action committee and as past chair of the Southwest Section and the former Whitewares Division.

Pelagia-Irene (Perena) Gouma is the Edward Orton Jr., chair in Ceramic Engineering at The Ohio State University. Her previous appointment was with the Institute of Predictive Performance Methodologies and with the MSE Dept. at the University of Texas-Arlington. Gouma is a member of the National Academy of Inventors, was a Fulbright Scholar to UNICAMP in Brazil, and has received the prestigious ACerS Richard M. Fulrath award.

Yoon-Bong Hahn is Fellow of Korea Academy of Science and Technology, director of BK21 Center for Future Energy Materials and Devices, and head of the School of Semiconductor and Chemical Engineering, Chonbuk National University. He received his Ph.D. in metallurgical engineering from University of Utah. Hahn, now acting as a Global Ambassador for ACerS, has served as a lead and cochair of Materials Challenges in Alternative and Renewable Energy (MCARE) and has coorganized over 18 symposia and conferences on ceramic and related materials.

Sossina M. Haile received her Ph.D. in materials science and engineering from Massachusetts Institute of Technology. She assumed her current position at Northwestern University after serving 18 years on the faculty of California Institute of Technology. Haile has held continuous membership in ACerS since 2012. She currently serves on the Diversity and Inclusion Subcommittee.

William Lloyd Headrick, Jr. is director of research and technology at Missouri Refractories in Pevely, Mo. He had been assistant research professor at Missouri University of Science and Technology, where he received a Ph.D. in ceramic engineering. He serves in ACerS, ASTM International, The Refractories Institute, and the Association for Iron & Steel Technology with the goal of improving youth outreach from the refractories industry. He has held many officer positions and served on many committees for Refractory Ceramics Division and ACerS St. Louis Section. He is currently secretary of ACerS Manufacturing Division. He has received an ACerS Global Ambassador award for his student outreach work and is an incoming member of ACerS Board of Directors.

Nobuhito Imanaka is full professor, Department of Applied Chemistry, Faculty of Engineering, Osaka University, Japan. Imanaka received a Ph.D. in applied chemistry from Osaka University. He is a member of ACerS Engineering Ceramics Division as well as president of the Rare Earth Society of Japan, an executive member of Japan Association of Chemical Sensors, and an executive member of the Japan Society of Colour Material.
The 2019 Class of Fellows (continued)

Charles Lewinsohn is associate technical fellow in CoorsTek’s corporate R&D in Golden, Colo. He earned a Ph.D. in ceramic science and engineering from The Pennsylvania State University. He belongs to ACerS Engineering Ceramics Division and Colorado Section and is an associate editor for the International Journal of Applied Ceramic Technology. He has served on the Meetings, Corporate Achievement Award, and Coble Award Committees. He received the Fulrath Award in 2010.

Xingbo Liu is the Statler Endowed Chair Professor of Engineering and associate chair of Research, Mechanical & Aerospace Engineering Department, Statler College of Engineering & Mineral Resources, West Virginia University. He received his Ph.D. in materials science from University of Science and Technology, Beijing, and subsequently joined WVU in early 2000 as a postdoctoral student. Liu is with ACerS Basic Science and Engineering Ceramics Divisions and served as chair of the BSD.

Josef Matyas has his Ph.D. in chemistry and technology of inorganic materials from the Institute of Chemical Technology, Czech Republic. He currently researches development of advanced waste forms for safe sequestration of nuclear waste streams to maximize loading of waste and minimize disposal volumes. He is past chair of the Nuclear & Environmental Technology Division and has served as chair-elect, secretary, and program committee chair. He has also served as secretary and treasurer of the former National Institute of Ceramic Engineers. He organized more than a dozen symposia for the Division at MS&T, ICACC, MCARE, and CMCEE meetings.

John L. Provis is professor of cement materials science and engineering, and head of the Engineering Graduate School at the University of Sheffield, Sheffield, U.K. He holds a Ph.D. from the University of Melbourne, Australia, and has held his current position at Sheffield since 2012. He is a member of the Cements Division and the U.K. Chapter of ACerS.

Jianrong Qiu is chair professor at Zhejiang University, China. He received his Ph.D. in materials science from Okayama University, Japan. Qiu is a member of ACerS Glass & Optical Materials Division and received the G. W. Morey Award in 2015.

Tanguy Rouxel is a mechanical engineer (ENSAM, Paris), doctor in ceramic science (ENSCI, Limoges) and professor of glass science and solid mechanics at the University of Rennes 1. Rouxel received the Alfred R. Cooper lecture award from the ACerS Glass & Optical Materials Division.

Rodney Trice is professor at the School of Materials Engineering at Purdue University and has focused on many fundamental and applied research topics over the last 25 years. Trice has encouraged his students to participate in ACerS through the President’s Council of Student Advisors. He is currently ACerS Meetings Committee chair and a member of the Technical Programming Committee.

Takaaki Tsurumi is professor of Nano-Phononics Laboratory in the Department of Metallurgy and Ceramics Science at Tokyo Institute of Technology, Japan, where he received his Ph.D. degree. His awards include the ACerS Fulrath Award, the Tejima Award for Ph.D. thesis of Tokyo Institute of Technology, the Awards Advancements in Ceramics Science and Technology of the Ceramics Society of Japan, and the Award of Academic Achievements in Ceramics Science and Technology of the Ceramics Society of Japan.

Jingyang Wang is distinguished professor of Chinese Academy of Sciences (CAS) and division head of the Advanced Ceramics and Composites Division at the Shenyang National Laboratory for Materials Science, and the Institute of Metal Research (IMR), CAS, China. He received his Ph.D. in materials science from IMR, CAS, China. He started his academic career as assistant professor in IMR and was promoted to full professor. He serves/served as a board of director of ACerS, chair of Engineering Ceramics Divisions, chair of ACerS John Jeppson Award Committee, committee member of Geijsbeek PACRIM International Award, president of WAC Forum Committee, and is a member of the International Advisory Board of the European Ceramic Society.

Shujun Zhang is professor at ISEM, Australian Institute for Innovative Materials, University of Wollongong, New South Wales, Australia. He received his Ph.D. in solid state chemistry from Institute of Crystal Materials, Shandong University. He is associate editor-in-chief of IEEE Transaction on Ultrasonics, Ferroelectric and Frequency Control; associate editor for Journal of the American Ceramic Society, Science Bulletin, and Journal of Electronic Materials; and section editor-in-chief of Crystals. He is a member of ACerS Electronics Division and senior member of IEEE.
Society Awards

Navrotsky Award for Experimental Thermodynamics of Solids
Monday, September 30, 2019 8:10 – 8:55 a.m.

The Navrotsky Award for Experimental Thermodynamics of Solids was established through a gift from Alexandra Navrotsky, Arizona State University professor, who has built a distinguished career studying thermodynamics of materials.

The biennial award will be presented to an author who made the most innovative contribution to experimental thermodynamics of solids technical literature during the two calendar years prior to selection. The recipient will receive a certificate, $5,000 prize, and is expected to give a talk on the cited work during the conference at which the award is made. Navrotsky says “I just celebrated my 75th birthday. In that spirit, I thought that an award in thermodynamics through The American Ceramic Society would give the field more visibility and show that in ceramics, and materials science in general, thermodynamics is alive and well.”

Alexander Beutl


Beutl is currently a junior scientist at Austrian Institute of Technology. He received his Ph.D. from the Department of Inorganic Chemistry at the University of Vienna.

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

Michael J. Cima is professor of materials science and engineering at Massachusetts Institute of Technology and has an appointment at the David H. Koch Institute for Integrative Cancer Research. Cima’s research concerns advanced forming technology such as complex macro- and microdevices, colloid science, MEMS, and other microcomponents for medical devices used for drug delivery and diagnostics, high-throughput development methods for formulations of materials, and pharmaceutical formulations.

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

Sanjay Sampath is Distinguished Professor of Materials Science at Stony Brook University (State University of New York) and director of the Center for Thermal Spray Research, an interdisciplinary industry–university collaborative research center in-field of thermal spray processing and coatings.

He is associate editor of the Journal of the American Ceramic Society. He was also principal investigator on a major DARPA grant aimed at developing new 3D processing tools for maskless direct writing of mesoscale electronics and sensors. Sampath is an elected Fellow of ACerS and ASM.

ROSS COFFIN PURDY AWARD recognizes authors who made the most valuable contribution to ceramic technical literature in 2017.

“Ultra-fast firing: Effect of heating rate on sintering of 3YSZ, without electric field” in Journal of the European Ceramic Society 2017; Volume: 37, Issue 6; 2547-2551

Jessica Krogstad is assistant professor of materials science and engineering at the University of Illinois, Urbana-Champaign. She received her Ph.D. from University of California, Santa Barbara. She researches microstructural evolution of porous ceramics subject to irradiation, microstructural and phase evolution in highly porous ceramic aerogels subject to extreme thermal gradients, and microstructural contributions to twin-mediated, nonlinear deformation of polycrystalline ceramics. Krogstad belongs to ACerS Engineering Ceramics Division and ACerS Young Professionals Network. She is faculty advisor to ACerS President’s Council of Student Advisors, vice-chair of the Material Advantage Committee, and faculty advisor for the UIUC Material Advantage Chapter.

Simone Falco is research associate at the Department of Aeronautics of Imperial College London, U.K.

Zhengyi Fu is director of the State Key Lab of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, and a Cheung Kong Scholar of the Ministry of Education of China.

Wei Ji is assistant professor at State Key Lab of Advanced Technology for Materials Synthesis and Processing, Wuhan University of Technology, Wuhan, China.
Society Awards (continued)

Barnaby Parker currently works for an engineering consultancy (Frazer-Nash Consultancy) as a software engineer supporting a variety of modelling and process streamlining projects.


Jinyong Zhang is professor at the Wuhan University of Technology in the Materials Science and Engineering Department, China.

RICHARD AND PATRICIA SPRIGGS PHASE EQUILIBRIA AWARD honors authors who made the most valuable contribution to phase stability relationships in ceramic-based systems literature in 2018.

“Simple model for particle phase transformation kinetics” in Acta Materialia, 2018; 154 228-236

Raphael M.C.V. Reis is professor of materials engineering at Fluminense Federal University (UFF), Brazil.

Edgar D. Zanotto is professor of materials science and engineering at the Federal University of São Carlos, Brazil, and directs CeRTEV (Center for Research, Technology and Education in Vitreous Materials).

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

Jan Schulteiss currently works as a postdoctoral researcher at TU Darmstadt, Germany. He received his Ph.D. in 2018. In his Ph.D. thesis, Schulteiss investigated the mechanism of polarization reversal in polycrystalline ferroelectric/ferroelastic ceramics. The mechanism was illustrated as a well-defined sequence of switching events physically originating from an interplay between local electric and mechanical fields.

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

Tepppei Okawa is representative director and executive vice president of NGK Spark Plug Co., LTD (Nagoya, Japan). He has been primarily engaged with developments and commercialization of automotive oxygen ceramic sensors for internal combustion engines at the R&D center and Sensor Department. He developed a planar-type wide range oxygen sensor, called UEGO (Universal Air-Fuel Ratio Heated Exhaust Gas Oxygen) sensor. He is an ACerS corporate partner and received a Corporate Environmental Achievement Award from ACerS.

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

Surojit Gupta is associate professor of mechanical engineering at the University of North Dakota. Gupta is an active researcher in sustainable materials, high temperature ceramics and alloys, nanotechnology, additive, and green manufacturing. He is an active member of ACerS, TMS, ASM International, ACS, ASME, and Sigma Xi. Currently, he serves as chair-elect of ACerS Engineering Ceramics Division, and member-at-large of ACS. Gupta has won several awards including Global Young Investigator Award from ACerS ECD, Dean Professorship, Dean’s Outstanding Faculty Award, and ASM/IIM lectureship award.

KARL SCHWARTZWALDER-PROFESSIONAL ACHIEVEMENT IN CERAMIC ENGINEERING (PACE) AWARD honors the past president of the National Institute of Ceramic Engineers, focusing on public attention on outstanding achievements of young persons in ceramic engineering and illustrates opportunities available in the ceramic engineering profession.

Nathan D. Orloff is microwave materials project leader at the National Institute of Standards and Technology in Boulder, Colo., and adjunct faculty at the University of Colorado. He received his Ph.D. in physics

Corporate Technical Achievement Award

recognizes a single outstanding technical achievement made by an ACerS corporate partner in the field of ceramics.

The award recognizes General Electric for the development and commercialization of ceramic matrix composites (CMCs) in aircraft engines.

CMCs offer the high-temperature capability of ceramics with the durability of metals, which allows engines to run hotter with less cooling. These factors have enabled them to deliver higher thrust, with lower emissions and less fuel burn.

GE Aviation produces one LEAP shroud every 12 minutes and recently shipped its 50,000th shroud. With a backlog of over 16,300 LEAP engines valued at more than $230B and over 700 9X engines valued at more than $30B, GE’s ceramic manufacturing engineers have years of work ahead of them. As the cost to manufacture CMCs continues to decrease, GE is revisiting applications for CMCs in large-industrial-gas-turbines and beginning to explore future CMC applications in reusable space and hypersonics.
ics at the University of Maryland. His current focus is on the microwave materials project which has several concurrent activities in different program areas. In thin-film tunable materials, he works on measurements of new low loss tunable dielectrics. Orlaff is an officer of the Colorado Section.

**ACERS/EPDC: ARTHUR FREDERICK GREAVES-WALKER LIFETIME SERVICE AWARD** recognizes an individual who has rendered outstanding service to the ceramic engineering profession and who, by life and career, has exemplified the aims, ideals, and purpose of the Education and Professional Development Council.

Mary R. Reidmeyer is teaching professor emeritus at the Missouri University of Science & Technology in Rolla, Mo. She teaches applied glass forming and oversees the operation of the Materials Science & Engineering Hot Glass Shop. She studied technical glasses with Delbert Day and received a Ph.D. She left academia for a decade to found two companies that provide ceramic product development and testing. Reidmeyer has resumed teaching, advising, and continues to create and innovate outreach activities. She remains active with ACerS St. Louis Section, where she served as officer.

**CERAMIC EDUCATION COUNCIL: OUTSTANDING EDUCATOR AWARD** recognizes truly outstanding work and creativity in teaching, directing student research, or the general educational process of ceramic educators.

Richard K. Brow is Curators’ Professor of Ceramic Engineering and interim director, Center for Biomedical Research at Missouri University of Science and Technology in Rolla, Mo. He received his Ph.D. in ceramic science from The Pennsylvania State University. Currently, his research involves collaborations with several of the younger faculty at S&T to develop glasses for biomedical applications, and he is always looking for opportunities to connect students to the glass industry. Brow serves on the Ceramic and Glass Industry Foundation Board.

**THE AMERICAN CERAMIC SOCIETY 2019 ANNUAL HONORS AND AWARDS BANQUET**

Join us to honor the Society’s 2019 award winners at ACerS Annual Honors and Awards Banquet

Monday, September 30 at MS&T19

6:45 – 7:30 p.m. Reception
7:30 – 10:00 p.m.

Salon EF,
Marriott, Downtown Waterfront

Please note: This year we are providing open seating. You are free to select your table when the doors open at 7 p.m.

Purchase banquet tickets with your conference registration or contact Erica Zimmerman at ezimmerman@ceramics.org.

Tickets must be purchased by noon on September 30, 2019.
Richard M. Fulrath Symposium and Awards

To promote technical and personal friendships between Japanese and American ceramic engineers and scientists

Symposium: September 30, 2019 | 2 – 4:40 p.m.

Check matscitech.org for latest updates.

US Academic
Vilas G. Pol

Engineered ceramic materials for energy storage

Vilas G. Pol is associate professor at Purdue University’s School of Chemical Engineering. Previously, he was a materials scientist at the Department of Energy’s Argonne National Laboratory. Pol has 20 years of research experience in the fields of chemistry, sustainability, energy storage, materials chemistry, engineering and electrochemistry. The Vilas Pol’s Energy Research (ViPER) laboratory at Purdue University focuses its research activities on the development of high-capacity ceramic based electrode materials and engineering for longer cycle life and improved battery safety.

US Industrial
Ronald G Polcawich

Piezoelectric thin film processing, piezoMEMS devices, and an overview of PRIGM, SHRIMP, & AMEBA programs

Ronald G. Polcawich is program manager at DARPA in the Microsystems Technology Office and currently on detail to DARPA from the Micro & Nano Materials & Devices Branch of U.S. Army Research Laboratory, Adelphi, Md. He received a Ph.D. in materials science and engineering from The Pennsylvania State University. As program manager, Polcawich leads the Precise Robust Inertial Guidance for Munitions (PRIGM) program, the SHort-Range Independent Microrobotic Platforms (SHRIMP) program, and A Mechanically Based Antenna (AMEBA) program.

Japan Academic
Manabu Fukushima

Engineering cellular ceramics with modulated pore configurations

Manabu Fukushima is senior research scientist at Structural Materials Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Nagoya, Japan. He received his Ph.D. at Tokyo Institute of Technology. His research interests include controlled microstructural design of porous ceramics for better performance and their technical transfer to industries. He serves as chair of ACerS Engineering Ceramics Division.

Japan Industrial
Keigo Suzuki

Fabrication and characterization of nanoscale dielectrics for the design of advanced ceramic capacitors

Keigo Suzuki is principal researcher at Murata Manufacturing Co., Ltd., Japan. He received his Ph.D. degree in engineering from the Kyoto Institute of Technology. Suzuki has been actively involved in the development of new synthesis methods for ferroelectric and semiconductor oxide nanoparticles, and thin films based on dry and wet processes. His research focuses on development of novel electronic devices based on functional nanoparticles and thin films. He is developing advanced SPM techniques to investigate the nature of nanomaterials in terms of nanoscale for the design of future electronic devices.

Japan Industrial
Koichiro Morita

Dielectric material design and lifetime prediction for highly reliable MLCCs

Koichiro Morita is group leader on the development of dielectric materials for multilayer ceramic capacitors (MLCCs) in the R&D Laboratory at Taiyo Yuden Co., Ltd., Japan. Morita received a M.E. from Institute for Advanced Materials Processing, Tohoku University. His research interests focus on MLCCs, including but not limited to dielectric material synthesis, fabrication process control, quality evaluation, and failure analysis.
ACerS Award Lectures

ACerS/EPDC ARTHUR L. FRIEDBERG CERAMIC ENGINEERING TUTORIAL AND LECTURE
Monday, September 30, 2019  |  9–10 a.m.

Kathleen A. Richardson, is Pegasus Professor of Optics and Materials Science and Engineering and Florida Photonics Center of Excellence and professor at CREOL/College of Optics and Photonics at the University of Central Florida in Orlando, Fla.

Redefining material design for next generation optical material

Kathleen A. Richardson is a recognized world leader in infrared glass science research and education. Her group is a leading source of global expertise in the design, fabrication, and characterization of next generation materials for use in infrared components and systems for diverse optical applications.

EDWARD ORTON JR. MEMORIAL LECTURE
MS&T PLENARY SESSION
Tuesday, October 1, 2019  |  8–10:40 p.m.

Minoru Tomozawa, is professor of the Department of Materials Science and Engineering, Rensselaer Polytechnic Institute in Troy, N.Y.

Glass and water: Fast surface relaxation

Minoru Tomozawa received his Ph.D. in metallurgy and materials science at the University of Pennsylvania. His current research interest is in glass and water interaction. His work, found fast surface relaxation, led to a new method of making stronger glass fibers and clarification of various mysteries of glasses such as fatigue limit.

ACerS FRONTIERS OF SCIENCE AND SOCIETY RUSTUM ROY LECTURE
Tuesday, October 1, 2019  |  1–2 p.m.

Jennifer A. Lewis, is the Wyss Professor for Biologically Inspired Engineering in the Paulson School of Engineering and Applied Sciences and a core faculty member of the Wyss Institute at Harvard University in Cambridge, Mass.

Printing architected matter in three dimensions

Jennifer A. Lewis's research focuses on the programmable assembly of functional, structural, and biological materials. She is an elected member of the National Academy of Sciences, National Academy of Engineering, the National Academy of Inventors, and the American Academy of Arts and Sciences.

GLASS AND OPTICAL MATERIALS DIVISION ALFRED R. COOPER AWARD SESSION
Tuesday, October 1, 2019  |  2–4:40 p.m.

COOPER DISTINCTIONED LECTURE

Kathleen Richardson,
University of Central Florida

Function-tailoring strategies for broadband infrared glasses

2019 ALFRED R. COOPER YOUNG SCHOLAR AWARD PRESENTATION

Wataru Takeda,
Coe College

Topological constraint model of high lithium content borate glasses

BASIC SCIENCE DIVISION ROBERT B. SOSMAN AWARD AND LECTURE CENTER
Wednesday, October 2, 2019  |  1–2 p.m.

Yury Gogotsi, is Distinguished University Professor and Charles T. and Ruth M. Bach Professor of Materials Science and Engineering at Drexel University in Philadelphia, Pa. He also serves as director of the A.J. Drexel Nanomaterials Institute.

Nanomaterials born from ceramics: Transformative synthesis of carbons, carbides, and nitrides

Yury Gogotsi received his Ph.D. from Kiev Polytechnic, Ukraine, and a D.Sc. degree from the Ukrainian Academy of Sciences. His research group works on 2D carbides and nitrides (MXenes), nanostructured carbons, and other nanomaterials for energy, water, and biomedical applications.
Solid-state batteries: Unlocking lithium’s potential with ceramic solid electrolytes

By Nathan J. Taylor and Jeff Sakamoto

Recent progress indicates that ceramic materials may soon supplant liquid electrolytes in batteries, offering improved energy capacity and safety.

Widespread adoption of electric vehicles (EV) will require dramatic changes to the energy storage market.

Total worldwide lithium-ion (Li-ion) battery production was 221 GWh in 2018, while EV demand alone is projected to grow to more than 1,700 GWh by 2030. As economies of scale have been met in Li-ion battery production, price at the pack level has fallen and is expected to break $100/kWh within the next few years.

Li-ion batteries are expected to address near-term energy storage needs, with advances in cell chemistry providing steady improvement in cell capacity. Yet Li-ion batteries will eventually approach the practical limits of their energy storage capacity, and the volatile flammable liquid electrolyte in Li-ion cells requires thermal management systems that add cost, mass, and complexity to EV battery packs.

Recent progress demonstrates that Li-ion conducting solid electrolytes have fundamental properties to supplant current Li-ion liquid electrolytes. Moreover, using solid electrolytes enables all-solid-state batteries, a new class of lithium batteries that are expected to reach storage capacities well beyond that of today’s Li-ion batteries. The promise of a safer high-capacity battery has attracted enormous attention from fundamental research through start-up companies, with significant investment from venture capitalists and automakers.

The Li-ion battery

The 1970s marked development of the first Li-ion cathode intercalation materials. Cells with a metallic lithium anode were commercialized in the 1980s, but it was soon discovered that lithium deposits in dendritic structures upon battery cycling. These dendrites eventually grow through the separator, connecting the anode and cathode and causing a dangerous short circuit of the cell. The solution was to replace the lithium anode with a graphite Li-ion host material, thereby producing the modern Li-ion battery.

First introduced by Sony in 1991, the graphite anode is paired with a LiCoO2 cathode and flooded with a liquid organic electrolyte with dissolved lithium salt. The dissolved lithium provides Li-ion transport within the cell. A thin and porous polymer separator prevents physical contact between the anode and cathode while allowing ionic transport between electrodes.

This basic cell structure remains unchanged today, albeit with numerous energy-boosting innovations, including silicon anode additions, electrolyte additives to increase cycle life, and high nickel-content cathodes. These innovations have led to an average of 8% annualized energy density improvement in Li-ion batteries. Despite this progress, the volumetric energy density of Li-ion batteries can only reach a practical limit of about 900 Wh/L at the cell level.

For Li-ion batteries, active cathode and anode powders are mixed with binder and cast on a current collector using doctor blade, reverse comma, or slot die coating. These electrodes are slit into desired dimensions, interleaved with a separator, and either wound—or the case of an 18650 (18 mm diameter; 65 mm length) cylindrical cell—or stacked or folded to produce a prismatic pouch cell. Figure 1 shows 18650 cylindrical wound cells and 10-Ah pouch cells.

For EV applications, cells are arranged into modules, which are placed into a battery pack. For example, a Tesla Model 3 contains more than 4,000 individual cylindrical cells, producing about 80 kWh of storage. Other manufacturers, such as GM, use pouch-type cells, with 288 cells producing 60 kWh of storage in the Chevy Bolt.

Li-ion battery packs contain significant battery management systems to keep cells within a safe operating range. Heat generated within the pack must be removed by cooling systems to protect both the performance and lifetime of Li-ion cells.
Capsule summary

POWERING DOWN

The rise of electric vehicles is expected to demand the majority of lithium-ion battery capacity in the coming years. While the cost of lithium-ion batteries is low, they are reaching their practical limits. This limit pushes innovators to offer new kinds of batteries with higher energy density storage with increased safety.

CHARGING UP

Recent progress demonstrates that solid electrolytes have the properties to supplant current liquid electrolytes in lithium-ion batteries, offering improved safety. Solid electrolytes also enable all-solid-state batteries, a class of batteries that could reach energy storage capacities well beyond that of lithium-ion.

ENERGIZING THE FUTURE

As solid-state battery technology builds momentum toward commercialization, several challenges remain. Manufacturing techniques that leverage scalable processes are needed, as well as solutions to materials challenges such as preventing lithium filament growth and mitigating cathode volume change during cycling.

Generally, temperatures must remain below 60°C to limit the rate of reactions between the electrolyte and electrodes.

Finally, the pack and surrounding structures must be designed to prevent catastrophic failure of the pack in the event of a vehicle crash. These battery management systems lead to a pack cost of about 1.2–1.4 times the cell-level cost.

While the graphite anode enabled the modern Li-ion battery, six atoms of carbon are needed to intercalate one lithium ion, creating the compound C₆Li in a fully charged battery. This requirement limits the theoretical capacity of graphite to 382 mAh/g.

Silicon is a promising replacement with a capacity of 4,200 mAh/g, but the significant (300X) mechanical strain it experiences during cell cycling results in capacity fade over time. Despite these capacity losses, as understanding of silicon lithiation and the effect of particle morphology have advanced, manufacturers have created silicon/graphite composite anodes with gradually increasing silicon levels.

The most energy-dense anode is lithium metal with a capacity of 3,860 mAh/g. While lithium dendrite growth prevents use in liquid electrolyte-based cells, physically stabilizing the lithium metal with a Li-conducting solid electrolyte can prevent dendrite growth and cell failure. Several Li-ion-conducting solid electrolytes are promising for this role.

Solid-state batteries

All solid-state batteries center around the approach of enabling a high-capacity metallic lithium anode, which greatly increases volumetric energy density at the cell level. Figure 2 schematically illustrates both the Li-ion and solid-state battery. Gains over Li-ion in gravimetric energy density, or amount of energy stored per mass, are lower given that solid electrolytes with densities of 1.8–5.0 g/cm³ are replacing organic liquid electrolytes with densities close to 1.0 g/cm³. However, many consumer and automotive applications are increasingly driven by volumetric considerations.

Solid-state batteries also offer significant simplification over Li-ion batteries at the pack level, where individual cells are connected. Solid-state batteries do not require significant thermal management systems, as battery performance improves as temperature increases.

Ionic conductivity of solid electrolytes increases with increasing temperature, along with maximum charge and discharge rates. As a result, maximum operating temperature of a solid-state cell is only limited by that of lithium, which melts at 180°C. Additionally, elimination of the flammable liquid electrolyte of Li-ion alleviates design considerations of catastrophic cell or pack-level failure. In total, solid-state batteries offer significant mass and volume savings at the pack level, translating to increased pack capacity.

Because the graphite anode used in modern Li-ion batteries has a low potential compared to lithium (0.20 V), lithium metal-based solid-state batteries can be drop-in replacements for Li-ion batteries, offering higher volumetric energy capacity with similar voltage and performance.

Solid electrolytes

Solid electrolytes have been investigated for batteries since the discovery of fast sodium-ion conduction in 8-Al₂O₃ by Ford Motor Company in the 1960s. In the mid-1990s, attention turned to lithium solid electrolytes when the first thin-film batteries using radio frequency magnetron sputtered lithium phosphorous oxynitride (LiPON) were introduced. Thin-film batteries consist of a LiPON solid electrolyte layer under 10 μm with a thin layer of cathode and lithium metal anode.

The capacity of thin-film batteries is limited by ionic transport in the cathode. If cathode thickness is increased beyond 10 μm, lithium diffusion rate within the cathode limits the ability to access the full cathode capacity. Ideally, the solid-state cathode emulates a Li-ion cathode that is a three-dimensional blend of electrolyte and cathode particles to increase areal loading.

Nevertheless, thin-film batteries show excellent capacity retention over tens of thousands of cycles. However, this technology cannot fundamentally provide the storage of bulk-type Li-ion batteries needed for consumer electronics or EV applications. More recently, multiple Li-ion solid electrolytes have emerged with conductivities that are competitive with liquid electrolytes.

Figure 1. (a) Typical formats for Li-ion cells: wound cylindrical 18650 (left) and pouch cells (right). (b) Cross section of 18650 battery shows electrode layers.
Requirements of solid electrolytes

Successful solid-state battery commercialization will require solid electrolytes with a unique combination of properties. First, solid electrolytes must have lithium ionic conductivities over 0.1 mS/cm to be viable liquid electrolyte replacements. Second, the electrolyte must also be stable against lithium metal, one of the most electropositive elements. The electrolyte must either be chemically stable to lithium reduction or form a passivating reaction layer. Third, the electrolyte must form low-resistance interfaces (<1 Ω·cm<sup>2</sup>) to ensure low internal cell resistance. Forming low-resistance interfaces presents significant challenge at the alkali metal interface, where atmosphere reacted surface layers, reduced oxides, and nonuniform wetting can contribute to significant interface resistance. Fourth, the electrolyte must have a strength and fracture toughness high enough to prevent lithium filament propagation through the electrolyte. Fifth, the electrolyte must be stable at the anode and cathode potentials. Current state-of-the-art Li-ion cathodes operate at or below 4.5 V, so the cathode must resist electron or hole injection over the entire 0–4.5 V versus the Li/Li<sup>+</sup> operating range.

Types of solid electrolytes

Polymer solid electrolytes have low ionic conductivities and typically operate at increased temperature (60°C–80°C) to take advantage of increased ionic transport at these temperatures. While polymers are easily processed, their mechanical properties are generally insufficient to stabilize the lithium metal anode. Thus, most attention has focused on inorganic solid electrolytes (Figure 3). Sulfide solid electrolytes have some of the highest conductivities of solid electrolytes. While there are multiple chemistries, the Li<sub>2</sub>S–P<sub>2</sub>S<sub>5</sub> system is most popular. Electrolytes in the Li<sub>2</sub>S–P<sub>2</sub>S<sub>5</sub> system can be glassy, crystalline, or partially crystalline. Undoped, Li<sub>2</sub>S–P<sub>2</sub>S<sub>5</sub> electrolytes have poor electrochemical stability with lithium, but doped variants have increased stability. One advantage of sulfide electrolytes is the ductile nature of particles, which compress to form compacts with good electrochemical bridging between particles at room temperature or below 400°C. Accordingly, sulfide electrolytes are the most easily processed inorganic solid electrolytes. However, with some sulfide electrolyte compositions, reactivity with water vapor in air can be a challenge, releasing H<sub>2</sub>S and degrading the electrolyte. As such, they are usually processed under argon or extremely low humidity dry room atmospheres.

A second class of inorganic solid electrolytes is oxide-based. A few types exist, but garnet Li<sub>1</sub>La<sub>3</sub>Zr<sub>2</sub>O<sub>12</sub> (LLZO) has emerged as the most popular. Oxide solid electrolytes have fair ionic conductivities at room temperature and the broadest electrochemical window and highest chemical stability toward lithium.

Critical current density

Additionally, the elastic moduli and fracture toughness of oxide materials are the highest of all solid electrolytes, favorable to physical stabilization of the lithium metal anode and long-term cell lifetimes. Although they have the most favorable combination of electrochemical properties, sintering temperatures of 1,000°C–1,300°C are required to produce dense electrolytes with high ionic conductivity.

First discovered by Weppner et al. in 2007, LLZO has a garnet crystal structure and is a lithium-conducting oxide electrolyte. The low-conductivity tetragonal room temperature structure can be aliovalently doped to stabilize the high-conductivity cubic phase. Typical dopants are Al<sup>3+</sup> or Ga<sup>3+</sup> on the 24d Li site or Ta<sup>5+</sup> or Nb<sup>5+</sup> on the 16a site, with aluminum, tantalum, and gallium remaining the most popular due to chemical stability toward metallic lithium. LLZO has a high ionic conductivity up to 1 mS/cm at 25°C and low electronic conductivity of about 10<sup>−12</sup> S/cm. The electrochemical window of LLZO extends beyond 5 V, enabling next-generation high-voltage cathode materials. Recent research within our group shows that LLZO exhibits many of the criteria to produce a practical solid electrolyte to enable use of lithium metal electrodes. LLZO powders can be produced through a solid-state reaction method and scaled to kilogram batch sizes.

One approach is to use rapid induction hot pressing, a technique developed at the University of Michigan in which uniaxial force is applied to a die contained within an induction heating coil. The high heating rates enabled by induction heating rapidly eliminate porosity, limiting lithium volatilization to maintain stoichiometry. With this process, relative densities up to 99% have been achieved in under 10 minutes.

Critical current density

Faster charge or discharge rates put additional demand on the battery. At low charge rates or current densities (mA/cm<sup>2</sup>), lithium passes stably from the lithium metal electrode into the solid electrolyte. At high current densities,
lithium metal filaments or dendrites form along grain boundaries or directly within electrolyte grains.

In solid electrolytes, resistance to dendrite or lithium filament formation appears to be closely correlated with current density, or total cell current divided by the electrolyte cross-sectional area. Consequently, there should be a critical current density (CCD) at which the cell fails due to lithium metal penetration. At current densities below this critical value, stable charging is possible.

A typical test of CCD is stepped constant current plating of lithium using a symmetric cell, with lithium electrodes on either side of a solid electrolyte. Upon application of a current, lithium at one electrode is oxidized and enters the solid electrolyte. At the other electrode, lithium ions are reduced to form lithium metal and plate the electrolyte surface. Upon reversal of the applied current, lithium can be stripped back and plated in its original position.

In a CCD test, current is increased in increments until steady-state ohmic resistance of the cell drops, indicating that lithium has shorted or partially shorted the cell. Figure 4 illustrates the DC profile for a typical CCD test. A sudden drop in cell voltage indicates a drop in cell resistance due to lithium metal short circuit. Figure 4c shows a lithium dendrite on the electrolyte surface after anode removal.

Early Li/LLZO cells had CCD values less than 0.1 mA/cm², reflecting a 30-hour charge cycle for an equivalent Li-ion replacement battery. A CCD of this magnitude would limit charging speeds to values unacceptable for today's applications.

These early demonstrations also suffered from poor contact between the lithium electrode and LLZO electrolyte, manifesting as high interfacial resistance. While metals do not typically wet oxides well, some groups established that thin metal or metal oxide coatings could dramatically improve the wetting of lithium metal on LLZO. However, these coatings may not be amenable to largescale manufacturing.

Elemental analysis of the native LLZO surface reveals a thin layer of Li₂CO₃ on LLZO, resulting from reaction with water vapor and CO₂ in air. This Li₂CO₃ layer occludes the LLZO surface, preventing facile lithium migration into the LLZO. Simple heat treatment in an inert environment can decompose the surface layer, revealing pristine LLZO that is easily wet by metallic lithium. As a result, the typical lithium interfacial resistance falls to below 5 Ω·cm², and homogenous coverage of LLZO by lithium dramatically increases CCD values.

Fundamental research, such as the role of LLZO surface chemistry at the lithium metal interface, has significantly improved properties like CCD, which is an important performance metric for solid-state cell commercialization. Another area of investigation is the role of defects in mechanical properties in limiting CCD.

One study showed that lithium can preferentially plate at grain boundaries in polycrystalline LLZO. Coarsening the microstructure decreases the areal number average grain boundaries and increases CCD in kind. Figure 5 illustrates recent fundamental LLZO research that has aided understanding of cell interfaces and failure mechanisms.

In a more practical demonstration, LLZO with an optimized lithium interface and grain size was recently cycled for over 100 cycles at a current density (1.0 mA/cm²) and capacity equivalent to a 3-hour charge of a Li-ion cell.

Solid-state batteries: Unlocking lithium’s potential with ceramic solid electrolytes

Recent LLZO basic science progress

After this extended cycling, no degradation at the lithium interface or short circuiting was observed, offering promise for LLZO-based solid-state cells with equivalent or better lifetime than Li-ion cells.

Remaining challenges

Lithium dendrites

Despite the aforementioned progress on increasing CCD through understanding of lithium metal interface chemistry and mechanics, lithium dendrites remain a challenging roadblock to solid-state battery commercialization.

Early fundamental models predicted that a separator material with over 2X the shear modulus of lithium (4.5 GPa) would be resistant to dendrite growth. In practice, however, most solid electrolytes show lithium dendrite growth despite shear moduli many times that of lithium. The mode of lithium filament propagation is still unclear and may take different forms. Lithium has been observed preferentially plating at grain boundaries within polycrystalline electrolytes, but filaments have also been observed within grains and within single crystal specimens.

Careful management of the lithium interface and plating parameters have demonstrated current densities representative of real-world charging conditions. In spite of this progress, dendrite growth is still the major factor in solid-state cell cycling lifetime. As a more fundamental understanding of lithium filament growth in solid electrolytes develops, solid-state batteries are expected to continue to increase in power performance and lifetime. As CCD increases with temperature, early commercial cells may fully operate or charge at increased temperature (50°C–80°C) to prevent dendrite formation, with the added benefit of lower cell internal resistance.

Composite cathode

While the properties and understanding of solid electrolytes have greatly improved, significant challenges remain in constructing a cathode. In a conventional Li-ion cathode, active particles are cast with a conductive carbon onto a current collector bound by a polymeric binder, commonly PVD. Once the cell is filled with liquid electrolyte, active particles can be supplied with lithium ions and electrons through the electrolyte and carbon phase, respectively. Replicating this structure with solid-state materials remains more challenging.

Composite cathodes must be developed with active materials connected with a continuous ionic and electronic 3D percolating network. Early work cosintering active materials and common electrolytes shows that deleterious solid-state chemical reactions occur at the interface between the two phases, hindering Li-ion transport. As sulfide or polymer electrolytes can be densified without extensive thermal processing, they may be more ideal than oxide electrolytes to limit solid-state reactions within the composite cathode.

Most Li-ion active cathode materials have significant volume change upon cycling. In response to lithium intercalation or deintercalation, the unit cell of the cathode swells or contracts. For today’s state-of-the-art Li-Ni-Mn-Co layered oxide cathode, volume decreases about 3.4% for full discharge.

In a composite cathode with a rigid sintered electrolyte phase, active materials may be physically constrained such that they cannot easily change volume. This situation may be alleviated by adding a compliant phase to take up this volume change.
change. Similarly, solid–solid electrochemical interfaces within the cathode could lose contact due to repeated cycling stresses, resulting in capacity loss.

Manufacturing
As the technical challenges facing solid-state battery technology are resolved, the largest remaining roadblock to widespread adoption is a low-cost manufacturing strategy.

Li-ion batteries are produced in large quantities with well-established manufacturing technologies. The cost of a typical polymeric separator in a Li-ion battery is about $1/m², so it may be difficult for a ceramic solid electrolyte to compete as a drop-in replacement. However, solid-state batteries can be cost-competitive with Li-ion batteries if a holistic approach to cell manufacturing can be realized. Significant opportunity remains for the ceramic industry to lend manufacturing and quality control expertise to develop solid-state battery technology.

With Li-ion pack prices projected to fall below $100/kWh, competitive solid-state battery manufacturing must use scalable processes. Roll-to-roll processing is ideal, given its low cost and the large existing capital investment. Additionally, roll-to-roll processing offers high-volume controlled application of discrete layers 5–150 µm in thickness.

Due to the high sensitivity of lithium battery materials to residual water, dry rooms with controlled dewpoints of -40°C or less are an important component of manufacturing and represent a significant cost. In Li-ion manufacturing, battery electrodes typically are cast, dried, and calendared in atmosphere before moving to a controlled environment for assembly and electrolyte filling. Many solid-state battery materials have similar or higher moisture sensitivity than Li-ion materials, which may extend the need for controlled atmosphere to the entire manufacturing process.

Unlike Li-ion batteries, solid-state batteries based on oxide solid electrolytes require a sintering step to produce ionically conducting electrolyte layers. Careful attention must be taken during sintering to achieve dense materials while retaining good electrochemical performance. Li₂O volatilization is significant at densification temperatures (1,000°C–1,300°C), requiring lithium reservoirs or over-lithiated starting materials. Another approach to prevent Li₂O loss is rapid thermal processing or hot-pressing of materials to avoid lithium loss.

One additional concern during manufacturing is electrolyte thickness. While the electrolyte is an important component of the cell architecture, it does not contribute to storage capacity of the battery. As such, there is significant pressure to reduce the separator thickness.

Energy-dense cell designs require a separator less than 50 µm in thickness, with less than 20 µm being ideal. An added benefit of reduced separator thickness is reduced raw material cost. Forming defect-free dense ceramic films at this thickness is challenging but within the scope of current tape-casting and densification technology.

Conclusions
Transportation is expected to demand the majority of Li-ion manufacturing capacity in the next few years. While the costs of Li-ion batteries have fallen dramatically, there is still need for higher energy density storage with increased safety. Recent progress has shown some solid electrolytes have a combination of properties to reliably integrate the lithium metal anode into batteries. With a lithium metal anode, solid-state batteries offer much higher energy densities than Li-ion batteries and reduced pack-level cooling and monitoring.

As solid-state battery technology builds momentum toward commercialization, many challenges remain. Chiefly, as solid-state technology scales-up, manufacturing techniques must be developed that leverage scalable processes, such as slurry casting and roll-to-roll processing. Material challenges also remain, including preventing lithium filament shorting of cells and mitigating issues arising from the cathode volume change during cycling.

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By David W. Richerson

Education outreach shares the magic of ceramic and glass materials with the next generation—and everyone can find a way to participate.

Education outreach is critical to recruit the next generation of ceramic and glass scientists and engineers—but it also provides a fun science experience to youth that just might inspire a STEM career.

Recognizing the importance of education outreach, ACerS established an Education Committee around 1991 at the behest of then ACerS president Bob Egan. I was part of this team of motivated individuals who assembled and met at the Annual Meeting, where we defined goals and a strategy and began forming an action plan.

The Committee chose two primary areas of focus: outreach to the community and continuing education to members. We implemented continuing education by helping develop National Institute of Ceramic Engineers (NICE) short courses to be offered in conjunction with annual meetings. I prepared a course on structural ceramics and recruited Richard Mistler, Ilhan Aksay, and Bryan McEntire to join me in a course on fabrication of ceramics. We later added other courses, such as sintering.

The Committee’s first outreach project was to assemble a Ceramic Demonstration Kit that could be used by individuals and distributed to Sections, student groups, and universities. Mark Glasper, who was ACerS communications director at that time, worked closely with the Committee to assemble and distribute kits.

The first kits contained about 12 items, including a space shuttle tile, a catalytic converter substrate, and a superconductor demonstration set (Figure 1). I still have one of the first kits and have used it extensively over the years at the University of Utah and visits to schools and various community organizations.

Once the committee assembled the kits, we provided training seminars to Sections at annual meetings to encourage use of the kits.

The committee initiated and implemented many other outreach activities with ACerS support: Ceramic Science and Engineering Day at a high school in Westerville, Ohio; visits of high school teachers and students to the Expo at the ACerS Annual Meeting; broad distribution of periodic tables; and an ACerS traveling museum exhibit.

The traveling museum exhibit was titled The Magic of Ceramics and included 10 large display cases containing various ceramic and
glass applications. The exhibit covered topics such as electrical and electronic ceramics, optical ceramics and glass, structural ceramics and composites, automotive ceramics (including magnetic and piezoelectric), and beautiful ceramic and glass art.

The exhibit was part of the ACerS centennial celebration and traveled around the United States for three years, visiting nine different cities. In each city, we trained local members and Sections to conduct tours and outreach activities. The exhibit introduced hundreds of thousands of people to ceramics and glass.

After touring, the traveling museum exhibit was set up for a couple of years at ACerS headquarters in Westerville, Ohio.

Because the exhibit represented such an excellent cross-section of uses of ceramics and glass, and because I had photographs of all the items in the exhibit, I offered to write an outreach book to be published by ACerS.

This book would be different than anything ACerS had published previously. First, it would have to be in color and written at a level understandable by the general public. Second, it would have to be much less expensive than the technical volumes normally published by ACerS.

The Society stepped up to this challenge—and the result was the book “The Magic of Ceramics.”

In addition to the Society, students also stepped up to the challenge of ceramics outreach. They expanded use of demonstration kits, wrote curriculum materials, and developed classroom experiments to provide hands-on experience in materials science and engineering for middle school and high school teachers and students. These projects evolved into the Materials Science Classroom Kits that are supported today by the Ceramic and Glass Industry Foundation (CGIF).

**My experience with education outreach**

Now that you have the background, I can get to the important question—how can you participate?

I will share my journey through education outreach to provide some inspiration and examples.

As materials science and engineering students assumed leadership in outreach activities, I changed my personal focus to local projects. My concern was that K–12 students were not getting enough exposure to science and were not going into STEM fields. My goal was to find one fun and meaningful activity that would fit into the curriculum for each grade level.

Through substitute teaching, my wife learned that earth science was part of the 2nd and 4th grade curriculum, but that many of the teachers had no background in earth science and were uncomfortable teaching the subject.

I have been interested in minerals and fossils since elementary school, so I began receiving invitations from teachers to visit their classes. Within a few years, I was visiting as many as 20 classes per year and had prepared study modules on minerals and fossils that I could leave with each class. Figure 2 shows a portion of one of these study modules that illustrates various types of fossils. Such modules are easy to assemble and can be used over and over.

To check what is taught in each grade in your town, go to the website for your local school district. If you have children or grandchildren in school, talk to their teachers and ask if some portion of the science curriculum could be enhanced.

Over the years, I developed an outreach partnership with the Geology and Geophysics Department at the University of Utah. One of the professors was working on a National Science Foundation (NSF) proposal to gather data on carbon dioxide from human compared to natural sources, which became known as the UTES program.

I joined the program to design outreach and year-long partnerships in schools, starting projects on energy and air quality in 5th and 6th grades. These projects are another science-based activity that anyone in the ceramic and glass fields could easily take into school classes. Part of the approach I have used is discussion about energy efficiency, air pollution, and how materials play an important role in solving these issues.

When the UTES program ended, I contacted Lynnette Madsen at NSF and recommended a small program to continue efforts with 5th and 6th grade classes. This suggestion resulted in the Materials Science and Engineering for a Sustainable Future program (NSF grant DMR-0652634). Over a period of about five years, I developed year-long partnerships with several schools.

At these schools, I visited classes at the beginning of the school year and talked with students about sources of
How can you participate in ceramics and glass education outreach?

pollution in the Salt Lake Valley, where bad air often results from inversion layers. I would challenge students to study issues of energy production (which in Utah was mostly burning coal) and sources of air pollution and then to plan and implement projects to reach out to their parents, communities, and even the governor and legislators.

Students at one school, Morningside Elementary, were so effective that they got bills introduced and passed in the legislature and even got the governor to declare special days, such as “Change a Light” (switch from incandescent to fluorescent and LED), “Stop Idling,” and “Clean the Air” days (Figure 3).

Morningside students on the Stop Wasting Energy Everywhere Today (SWEET) team also met with Jane Goodall when she visited Salt Lake City (Figure 4). Morningside classes won the state Community Problem Solving award seven years in a row and went on to win top honors at the national level. One year, they won the Presidential Award and were invited to Washington, D.C.

Subsequent to the NSF program, I conducted an energy and air quality program in 5th and 6th grade classes in Tucson, Ariz., through Advanced Ceramics Research Foundation funding from the U.S. Department of Labor. Figure 5 illustrates one of the hands-on activities at the Gallego School in this program.

You may think that such activities would take a great deal of my time, but that was not the case. I typically visited a class about six times during the year and then joined them on some outreach activities, such as visits to the governor and legislature.

The key was finding a great teacher as a partner. Anyone can have an important impact on science education with relatively small time commitment by simply partnering with a motivated teacher. The teacher I worked with at Morningside Elementary went on to lead state-wide restructuring of the curriculum, so the small NSF program had a significant long-term impact on science education.

In support of the 6th grade outreach activities, I organized city-wide venues where students could communicate what they were learning. These included art exhibits on energy and air quality and an annual Library Square Festival of Science and Art, where I partnered with about a dozen other community and university organizations.

I also became active in the Utah Alliance for Science, Math, and

Figure 2. One example of various fossil study modules used in 4th grade classes.

Figure 3. Members of the Morningside Elementary Get Really Energy Efficient Now (GREEN) team meeting with then Utah governor John Huntsman Jr., who supported the students’ “Change a Light, Save the World” initiative.

Figure 4. Morningside Elementary Stop Wasting Energy Everywhere Today (SWEET) team students with their teacher and Jane Goodall. The students presented at a press conference for Goodall.
Technology Education, where I met other individuals that led to collaborations.

Another personal goal is to extend career opportunity information to middle school and high school students. I have visited several classes and participated in various career day activities using the Ceramic Demonstration Kit. Anyone in materials science can easily do this—the first time may be a little intimidating, but then it is easy, fun, and effective. The kids really respond to hands-on activities.

My largest outreach effort with high school students resulted when Anil Virkar, then department chair for the Materials Science and Engineering Department at the University of Utah, asked me to plan and propose a program to NSF.

I partnered with faculty from each engineering department at the university, and together we proposed a program in which student teams in each department would plan hands-on activities and demonstrations (following the idea of the Ceramic Demonstration Kit). The goal was to inform high school students about career opportunities in engineering and to ultimately reach the governor’s goal to double the number of engineering students at the University of Utah.

NSF funded the program—not only did it greatly increase knowledge and interest of high school teachers and students in science and engineering, but it also stimulated a life-long enthusiasm of participating university professors and students in science outreach. Figure 6 shows a demonstration with a space shuttle tile at a high school class.

**Now, it is your turn**

So how can you participate?

The easiest way is to support students through the CGIF by distributing Materials Science Classroom Kits to teachers and schools in your town. You can help as an individual or by encouraging your company or local ACerS Section to be a sponsor. Visit www.foundation.ceramics.org for more information.

If you have a little extra time and enthusiasm, you can host a materials science workshop at a local school. Or maybe a local school already has a summer science program, such as the Summer Research Institute at Conrad Weiser High School in Robesonia, Pa. Such programs might be very happy to integrate a Materials Science Classroom Kit into their program, especially if you can offer involvement of one or more persons working in the ceramics and glass field.

Use your imagination to come up with your own ideas for outreach—visit the school classes of your children or grandchildren; volunteer a career day presentation at a local middle school; organize an art competition or exhibit with a school or local library, using categories such as pollution control, energy efficiency (lighting, power generation), recycling, or the role of ceramics and glass in architecture; volunteer to be a science fair mentor or judge.

CGIF outreach manager Belinda Raines (braines@ceramics.org) can help and give you other ideas about how to help.

My experience is that outreach projects are fun and personally satisfying, but one always wonders if these projects have a lasting influence on the students.

Early this year, I received an answer to that question. My local community council passed a resolution to establish a Sustainability Task Force with a goal of achieving 100% renewable energy by 2032. One of the people that showed up for the organizational meeting was a young lady who had been a member of the GREEN team at Morningside Elementary. She had gone on to obtain degrees in chemistry and biology and had continued her involvement in environmental stewardship—what a satisfying experience!

If you are interested or motivated to start an outreach effort in your town but are nervous about getting started, I am happy to talk with you. I can also share a copy of one of my NSF reports that describes step-by-step the visits to 5th and 6th grade classes, simple in-class projects, and some of the outreach projects implemented by students.

**About the author**

David W. Richerson is retired from the Materials Science and Engineering Department at the University of Utah; currently manager of minerals at the Natural History Museum of Utah. Contact Richerson at richersond@aol.com.

**Figure 5. Students at Gallego School in Tucson, Arizona showing their toothpick and marshmallow models that demonstrate the combustion of methane.**

**Figure 6. The Materials Science and Engineering outreach team demonstrates the heat resistance of a space shuttle tile from the Ceramic Demonstration Kit.**
The Ceramic and Glass Industry Foundation (CGIF) offers a number of outreach programs to inspire the next generation of ceramic and glass scientists and engineers—and there are a number of ways you can get involved!

**Materials Science Classroom Kit sponsorship program**

For the last several years, the CGIF has facilitated sponsorship of Materials Science Classroom Kits to teachers who, due to limited resources, are unable to purchase a kit for their classroom. Through a donation of only $250, a teacher on our waiting list or a teacher of your choosing can receive a Materials Science Classroom Kit, which is accompanied by “The Magic of Ceramics” book by David Richerson.

The current version of our Materials Science Classroom Kit facilitates learning and inspires students to pursue further studies in materials science. Fun, hands-on lessons and activities introduce middle and high school students to the basic classes of materials: ceramics, composites, metals, and polymers. The Materials Science Classroom Kit complies with Next Generation Science Standards and is highly regarded as the best of its kind.

**Grant support for student outreach projects**

Because the CGIF was created to attract, inspire, and train the next generation of ceramic and glass professionals, the Foundation provides financial support for projects and activities that help fulfill the CGIF mission. Approved projects are directly related to introducing students to ceramic and glass science. The CGIF grants allow organizations and groups to develop or extend existing efforts to grow the base of ceramic and glass education, training, or outreach. In 2018, the CGIF provided over $87,000 to 12 recipients.

Krista Carlson, assistant professor at University of Utah, received funding for a six-course science workshop, “The Hidden World of Glass,” for teens at the Girls Transition Center, a secure residential treatment program for young women ages 12–18. Carlson developed the program to bring hands-on science activities to youth in secure facilities who are typically unable to participate in traditional science laboratory experiments.

Carlson explained, “I think a lot of our societal issues could be solved by increasing the access people have to education and hands-on experiences. By bringing these activities into these facilities, we could potentially inspire the next generation of scientists who can create positive change in the world.”

For more information on any of the Foundation’s outreach activities or any volunteer opportunities, please contact Belinda Raines at braines@ceramics.org. If you would like to support CGIF programs through a donation, please visit our website at https://foundation.ceramics.org/give.
Attendees had the chance to experience not one but two conferences in mid-July. The 2nd Global Forum on Advanced Materials and Technologies for Sustainable Development (GFMAT-2) and the 4th International Conference on Innovations in Biomaterials, Biomanufacturing and Biotechnologies (Bio-4) took place in tandem July 21–26, 2019 in Toronto, Canada.

More than 360 people, including 50 students, from 31 countries traveled to Toronto to attend GFMAT-2 and Bio-4. This year marks the first time the two conferences were held jointly.

The combined conference opened Sunday night with a welcome reception, and began in earnest Monday morning with plenaries given by five distinguished scientists from around the world—Serena Best (University of Cambridge, U.K.), Mrityunjay Singh (Ohio Aerospace Institute, U.S.), Xingdong Zhang (Sichuan University, China), Claude Delmas (Bordeaux Institute of Condensed-Matter Chemistry, France), and Robert Pilliar (University of Toronto, Canada). After each plenary, conference organizing chair Tatsuki Ohji presented the speakers with commemorative ceramic plates.

On Tuesday, the Bio conference held a symposium in honor of Delbert E. Day, a luminary in the field of glass for healthcare applications. The symposium provided researchers a forum in which to discuss work similar and related to research conducted by Day, and to talk about how their personal relationships with Day have influenced them far beyond just research.

In addition to the plenaries and Day symposium, numerous technical sessions provided looks into a wide array of topics, including eco-materials, innovative processing, and energy storage on the GFMAT side, and biomaterials for medical devices and dentistry on the Bio side.

On Tuesday night, about 50 people presented at the poster session, hosted by the Global Graduate Researcher Network. During the Thursday night conference dinner, three students were awarded the Student Poster Awards sponsored by Mo-Sci: Andrey Tikhonov (Lomonosov Moscow State University), Natsuki Okajima (National Institute of Technology, Toyama College), and Ilknur Eryilmaz (Institut national de la recherche scientifique INRS).

JOIN US FOR THE ACeRS 121ST ANNUAL MEETING!

Technical Meeting and Exhibition

www.ceramics.org   |   American Ceramic Society Bulletin, Vol. 98, No. 7

SEPTEMBER 29 – OCTOBER 3, 2019
MATSCITECH.ORG
JOIN US FOR THE ACeRS 121ST ANNUAL MEETING!

THE MS&T PARTNERSHIP BRINGS TOGETHER SCIENTISTS, ENGINEERS, STUDENTS, SUPPLIERS, AND MORE TO DISCUSS CURRENT RESEARCH AND TECHNICAL APPLICATIONS, AND TO SHAPE THE FUTURE OF MATERIALS SCIENCE AND TECHNOLOGY. REGISTER NOW TO TAKE PART IN THE LEADING FORUM ADDRESSING STRUCTURE, PROPERTIES, PROCESSING, AND PERFORMANCE ACROSS THE MATERIALS COMMUNITY.

PLENARY LECTURES
TUESDAY, OCTOBER 1 | 8–10:40 a.m.
ASM/TMS DISTINGUISHED LECTURESHIP IN MATERIALS AND SOCIETY
Carolyn Hansson, professor of materials engineering, University of Waterloo, Canada
The challenge of 100 year service-life requirement

ACeRS EDWARD ORTON JR. MEMORIAL LECTURE
Minoru Tomozawa, professor, Department of Materials Science and Engineering, Rensselaer Polytechnic Institute, USA
Glass and water: Fast surface relaxation

AIST ADOLF MARTENS MEMORIAL STEEL LECTURE
Wolfgang Bleck, chair, Department of Ferrous Metallurgy, IEHK Steel Institute, RWTH Aachen University, Germany
The fascinating variety of new manganese alloyed steels

ACeRS SHORT COURSES
SATURDAY, SEPTEMBER 28
9 a.m. – 4:30 p.m. SINTERING OF CERAMICS, day 1

SUNDAY, SEPTEMBER 29
8 a.m. – Noon
INTRODUCTION TO MACHINE LEARNING FOR MATERIALS SCIENCE
9 a.m. – 2:30 p.m.
SINTERING OF CERAMICS, day 2

THURSDAY, OCTOBER 3
8 a.m. – 4:30 p.m.
Electrocermics in modern technology: Applications and impact, day 1

FRIDAY, OCTOBER 4
8 a.m. – Noon
Electrocermics in modern technology: Applications and impact, day 2

HOTEL INFORMATION
RESERVATION DEADLINE: SEPTEMBER 6, 2019
For best availability and immediate confirmation, make your reservation online at matscitech.org/mst19.
PORTLAND MARRIOTT DOWNTOWN WATERFRONT
– ACeRS HQ | $209 plus tax/night single or double
MAX light rail
Included with your MS&T registration is a pass for the Portland MAX Light Rail, which will get you back and forth from your hotel to the conference.

#MST19
The MS&T partnership brings together scientists, engineers, students, suppliers, and more to discuss current research and technical applications, and to shape the future of materials science and technology. Register now to take part in the leading forum addressing structure, properties, processing, and performance across the materials community.
SPECIAL EVENTS

SUNDAY, SEPTEMBER 29
5 – 6 p.m.  MS&T WOMEN IN MATERIALS SCIENCE RECEPTION
5:30 – 7:30 p.m.  ACerS PCSA & KERAMOS RECEPTION

MONDAY, SEPTEMBER 30
8:30 a.m. – 6 p.m.  ACerS BASIC SCIENCE DIVISION CERAMOGRAPHIC EXHIBIT AND COMPETITION
1 – 2 p.m.  ACerS 121ST ANNUAL MEMBERSHIP MEETING
5 – 6 p.m.  MS&T PARTNERS’ WELCOME RECEPTION
6:45 – 7:30 p.m.  ACerS ANNUAL HONOR AND AWARDS BANQUET RECEPTION
7:30 – 10 p.m.  ACerS ANNUAL HONOR AND AWARDS BANQUET

TUESDAY, OCTOBER 1
7 a.m. – 6 p.m.  ACerS BASIC SCIENCE DIVISION CERAMOGRAPHIC EXHIBIT & COMPETITION
10 a.m. – 6 p.m.  EXHIBITION SHOW HOURS
11 a.m. – 1 p.m.  GENERAL POSTER SESSION WITH PRESENTERS
Noon – 2 p.m.  MS&T FOOD COURT
1 – 6 p.m.  GENERAL POSTER VIEWING
4 – 6 p.m.  EXHIBITOR NETWORKING RECEPTION
4:45 – 5:45 p.m.  GENERAL POSTER SESSION WITH PRESENTERS

WEDNESDAY, OCTOBER 2
7 a.m. – Noon  ACerS BASIC SCIENCE DIVISION CERAMOGRAPHIC EXHIBIT & COMPETITION
9:30 a.m. – 2 p.m.  GENERAL POSTER SESSION WITH PRESENTERS
9:30 a.m. – 2 p.m.  EXHIBITION SHOW HOURS
Noon – 2 p.m.  MS&T FOOD COURT

THURSDAY, OCTOBER 3
7 a.m. – Noon  ACerS BASIC SCIENCE DIVISION CERAMOGRAPHIC EXHIBIT & COMPETITION

ACerS LECTURES AND AWARDS

MONDAY, SEPTEMBER 30
8:10 – 8:55 a.m.  ACerS NAVROTSKY AWARD FOR EXPERIMENTAL THERMODYNAMICS OF SOLIDS
– Alexander Beutl, Institute of Inorganic Chemistry–Functional Materials, University of Vienna, Althanstraße, Austria, A novel apparatus for coulometric titrations in lithium containing systems
9 – 10 a.m.  ACerS/EPDC ARTHUR L. FRIEDBERG CERAMIC ENGINEERING TUTORIAL AND LECTURE
– Kathleen Richardson, University of Central Florida, USA, Redefining material design paradigms for next generation optical materials
2 – 4:40 p.m.  ACerS RICHARD M. FULRATH AWARD SESSION
– Manabu Fukushima, National Institute of Advanced Industrial Science and Technology, Japan, Engineering cellular ceramics with modulated pore configurations
– Keigo Suzuki, Murata Manufacturing Co. Ltd., Japan, Fabrication and characterization of nanoscale dielectrics for the design of advanced ceramic capacitors
– Ronald Polcawich, U.S. Defense Advanced Research Projects Agency (DARPA), USA, Piezoelectric thin film processing, PiezoMEMS devices, and an overview of PRIGM, SHRIMP, & AMEBA programs
– Koichiro Morita, Taiyo Yuden Co. Ltd., Japan, Dielectric material design and lifetime prediction for highly reliable MLCCs
– Vilas Pol, Purdue University, USA, Engineered ceramic materials for energy storage

TUESDAY, OCTOBER 1
1 – 2 p.m.  ACerS FRONTEIRS OF SCIENCE AND SOCIETY—RUSTUM ROY LECTURE
– Jennifer Lewis, Harvard University, USA, Printing architected matter in three dimensions
2 – 4:40 p.m.  ACers GOMD ALFRED R. COOPER AWARD SESSION
Cooper Distinguished Lecture
– Kathleen Richardson, University of Central Florida, USA, Function-tailoring strategies for broadband infrared glasses
2019 Alfred R. Cooper Young Scholar Award Presentation
– Wataru Takeda, Coe College, USA, Topological constraint model of high lithium content borate glasses

WEDNESDAY, OCTOBER 2
1 – 2 p.m.  ACerS BASIC SCIENCE DIVISION ROBERT B. SOSMAN LECTURE
– Yury Gogotsi, Drexel University, USA, Nanomaterials born from ceramics: Transformative synthesis of carbons, carbides and nitrides

Organizers:

Co-Sponsored by:
Organized by ACerS Engineering Ceramics Division, the 44th International Conference and Exposition on Advanced Ceramics and Composites (ICACC) will be held January 26–31, 2020, in Daytona Beach, Fla. As one of the largest international meetings on emerging ceramic materials and technologies, ICACC20 promises a strong technical program that includes 18 symposia, five focused sessions, and three special symposia covering a variety of topics. ICACC has a strong history in attracting thought leaders and renowned experts on the latest research and developments on advanced structural and functional ceramics.

The technical program will include areas of research, development, engineering, and applications of advanced structural ceramics, composites, and other emerging materials and technologies. The technical program includes topics such as mechanical behavior and performance of ceramics and composites; advanced ceramic coatings for structural, environmental, and functional applications; developments in armor ceramics; bioceramics and biocomposites; advanced materials for rechargeable energy storage; applications and developments of porous ceramics; machine learning; geopolymers and sustainable materials; and much more. Peruse the complete technical program on the next page to see the wide range of symposia topics.

ICACC20 is also a lucrative opportunity for exhibitors looking to connect with decision makers. If you have not already secured your booth space, check out the details on the next page on how to put your company in front of this audience.

We look forward to seeing you in Daytona Beach, Florida, in January 2020!

Valerie Wiesner  
Program chair, ICACC 2020  
NASA Glenn Research Center  
E-mail: valerie.l.wiesner@nasa.gov  
Follow @icaccchair on Twitter for updates

Hilton Daytona Beach Resort  
100 North Atlantic Ave.,  
Daytona Beach, FL 32118  
Phone: 1-386-254-8200

Rates: One to four occupants: $180 USD  
U.S. government employee: Prevailing rate

Mention The American Ceramic Society to obtain the special rate.  
Room rates are effective until December 20, 2019 and are based on availability.

TENTATIVE SCHEDULE OF EVENTS

Sunday, January 26, 2020  
Conference registration 2 – 7 p.m.  
Welcome reception at Hilton 5:30 – 7 p.m.

Monday, January 27, 2020  
Conference registration 7 a.m. – 6 p.m.  
Opening awards ceremony and plenary session 8:30 a.m. – Noon  
Companion coffee 9 – 10:30 a.m.  
Lunch on own Noon – 1:20 p.m.  
Concurrent technical sessions 1:30 – 5:30 p.m.  
Young Professional Network, GGRN, student mixer 7:30 – 9 p.m.

Tuesday, January 28, 2020  
Conference registration 7:30 a.m. – 6 p.m.  
Concurrent technical sessions 8:30 a.m. – Noon  
Lunch on own Noon – 1:20 p.m.  
Concurrent technical sessions 1:30 – 6 p.m.  
Exhibits and poster session A, including reception 5 – 8 p.m.

Wednesday, January 29, 2020  
Conference registration 7:30 a.m. – 5:30 p.m.  
Concurrent technical sessions 8:30 a.m. – Noon  
Lunch on own Noon – 1:20 p.m.  
Concurrent technical sessions 1:30 – 5 p.m.  
Exhibits and poster session B, including reception 5 – 7:30 p.m.

Thursday, January 30, 2020  
Conference registration 7:30 a.m. – 6 p.m.  
Concurrent technical sessions 8:30 a.m. – Noon  
Lunch on own Noon – 1:20 p.m.  
Concurrent technical sessions 1:30 – 5 p.m.  
Last night reception 5:30 – 6:30 p.m.

Friday – January 31, 2020  
Conference registration 8 a.m. – Noon  
Concurrent technical sessions 8:30 a.m. – Noon

OFFICIAL NEWS SOURCES
**EXHIBITION INFORMATION**

Reserve your booth today for the premier international advanced ceramics and composites expo. Connect with decision makers and influencers in government labs, industry, and research and development fields. ICACC20 is your destination to collaborate with business partners, cultivate prospects, and explore new business opportunities.

**Exhibit hours**
Tuesday, January 28, 2020, 5–8 p.m.
Wednesday, January 29, 2020, 5–7:30 p.m.

**Exposition location**
Ocean Center Arena, 101 North Atlantic Avenue, Daytona Beach, FL

Exhibit space is filling up fast. To reserve your booth, visit [www.ceramics.org/icacc2020](http://www.ceramics.org/icacc2020) or contact Mona Thiel at mthiel@ceramics.org or 614-794-5834.

### ICACC20 TECHNICAL PROGRAM

| S1 | Mechanical Behavior and Performance of Ceramics and Composites |
| S2 | Advanced Ceramic Coatings for Structural, Environmental, and Functional Applications |
| S3 | 17th International Symposium on Solid Oxide Cells (SOC): Materials, Science and Technology |
| S4 | Armor Ceramics – Challenges and New Developments |
| S5 | Next Generation Bioceramics and Biocomposites |
| S6 | Advanced Materials and Technologies for Rechargeable Energy Storage |
| S7 | 14th International Symposium on Functional Nanomaterials and Thin Films for Sustainable Energy Harvesting, Environmental, and Health Applications |
| S8 | 14th International Symposium on Advanced Processing and Manufacturing Technologies for Structural and Multifunctional Materials and Systems (APMT14) |
| S9 | Porous Ceramics: Novel Developments and Applications |
| S10 | Modeling, Genome, Informatics, and Machine Learning |
| S11 | Advanced Materials and Innovative Processing Ideas for Production Root Technologies |
| S12 | On the Design of Nano-laminated Ternary Transition Metal Carbides/Nitrides (MAX Phases) and Borides (MAB Phases), and their 2D counterparts (MXenes, MBenes) |
| S13 | Development and Applications of Advanced Ceramics and Composites for Nuclear Fission and Fusion Energy Systems |
| S14 | Crystalline Materials for Electrical, Optical, and Medical Applications |
| S15 | 4th International Symposium on Additive Manufacturing and 3D Printing Technologies |
| S16 | Geopolymers, Inorganic Polymers, and Sustainable Materials |
| S17 | Advanced Ceramic Materials and Processing for Photonics and Energy |
| S18 | Ultra-High Temperature Ceramics |
| FS1 | Bio-inspired Processing of Advanced Materials |
| FS2 | Image-based Characterization and Modelling of Ceramics by Nondestructive Examination Techniques |
| FS3 | Molecular-level Processing and Chemical Engineering of Functional Materials |
| FS4 | Green Technologies and Ceramic/Carbon Reinforced Polymers |
| FS5 | Materials for Thermoelectrics |

**Exhibitor** | **Booth**
--- | ---
3DCeram Sinto Inc. | 318
AdValue Technology, LLC | 216
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AVS, Inc. | 307
Centorr Vacuum Industries | 200
Ceramics Expo | 311
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Fritsch Milling & Sizing, Inc. | 219
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Nordson SONOSCAN | 302
Oxy-Gon Industries, Inc. | 215
Praxair Surface Technologies | 217
Reserved | 210
Springer Nature | 107
Tev Tech | 206
Thermcraft, Inc. | 303

9th Global Young Investigator Forum

4th Pacific Rim Engineering Ceramics Summit

Special Focused Session on Diversity, Entrepreneurship, and Commercialization
EMA 2020 is designed for researchers, engineers, technologists, and students interested in basic science, engineering, and applications of electroceramic materials. Speakers include an international mix of university, industrial, and federal laboratory participants exchanging information and ideas on the latest developments in theory, experimental investigation, and applications of electroceramic materials.

Students are highly encouraged to participate in the meeting. Prizes will be awarded for the best oral and poster student presentation.

Please join us in Orlando, Florida, to participate in this unique experience!

ORGANIZING COMMITTEE

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SCHEDULE OF EVENTS

TUESDAY, JANUARY 21, 2020
Conference registration 5 – 6:30 p.m.

WEDNESDAY, JANUARY 22, 2020
Conference registration 7:30 a.m. – 6 p.m.
Plenary session 1 8:30 – 9:30 a.m.
Concurrent technical sessions 10 a.m. – 5:30 p.m.
Poster session set up 12:30 – 5 p.m.
Lunch on own 12:30 – 2 p.m.
Coffee break 3:30 – 4 p.m.
Poster session & reception 5:30 – 7:30 p.m.
Basic Science Division tutorial 7:40 – 8:45 p.m.

THURSDAY, JANUARY 23, 2020
Conference registration 7:30 a.m. – 6 p.m.
Plenary session 2 8:30 – 9:30 a.m.
Concurrent technical sessions 10 a.m. – 5:30 p.m.
Lunch on own 12:30 – 20 p.m.
Coffee break 3:30 – 4 p.m.
Student & young professionals reception 5:30 – 6:30 p.m.
Conference dinner 7 – 9 p.m.

FRIDAY, JANUARY 24, 2020
Conference registration 7:30 a.m. – 4 p.m.
Concurrent technical sessions 8:30 a.m. – 5 p.m.
Lunch on own 12:30 – 2 p.m.
Failure: The greatest teacher 3:30 – 5 p.m.
new products

The Helios Hydra DualBeam delivers four different ions as the primary beam, allowing researchers and engineers to easily switch between ion species in less than 10 minutes without sacrificing performance. Previously, the application of different beams required researchers to transfer the sample between instruments or conduct lengthy, complicated source exchanges. Now, the beam can be applied to the sample directly after initial milling, vastly reducing transfer and processing time.

Thermo Fisher Scientific Inc. (Waltham, Mass.)
1-800-556-2323
www.thermofisher.com

Bricking Solutions’ new rolling work platform offers 25% more productivity

Bricking Solutions introduces its Rolling Work Platform for improved safety and efficiency during maintenance of horizontal vessels. Coupled with a hydraulic jack system, the Rolling Work Platform is erected in as little as 30 minutes and adjusts to maintain a level working surface in less than 20 minutes, even while operating in vessels with an incline of up to 20 degrees. Compared to traditional rolling scaffolds, the platform offers 25% increased productivity.

Bricking Solutions, Inc. (Monroe, Wash.)
1-360-794-1277
www.brickingsolutions.com

Buzz screw feeder offers viable alternatives to upgrading handscoop operations

Ingredient Masters introduces the Buzz Screw Feeder, a compact, lightweight, and portable dispenser designed to bridge the gap between expensive automated screw feeders and laborious hand scooping of dry materials. Using a simple cordless drill, the Buzz Screw Feeder dispenses most dry bulk materials quickly, precisely, and easily. Available in two sizes, the Buzz Screw Feeder 175 Series can dispense at a rate of up to 1.25 cubic feet per minute, while the 250 Series is capable of up to 3.45 cubic feet per minute.

Ingredient Masters, Inc. (Batavia, Ohio)
513-231-7432
www.ingredientmasters.com

Buehler introduces Mosaic diamond grinding discs for sample preparation

Buehler introduced the Mosaic line of diamond grinding discs (DGD) for superb material removal in the grinding process of sample preparation. The Mosaic DGDs are available with a magnetic backing and come in 8", 10", or 12" discs in 120, 220, 320, 400, and 1,000 grit sizes. This is Buehler’s fifth line of DGDs in the grinding consumable offering, and the Mosaic DGD is especially suited for demanding laboratories working with heavy duty metals or durable materials.

Buehler (Lake Bluff, Ill.)
1-847-295-6500
www.buehler.com

ROSS skid-mounted high shear powder induction & mixing system

The ROSS Model HSM-405SC-25 is an inline high shear rotor/stator mixing system incorporating solids/liquid injection manifold (SLIM) technology. Unlike conventional eductors, the unique SLIM rotor/stator generates a powerful vacuum without the aid of external pumps and pulls powders directly into the mix chamber, promoting instantaneous wet out under high shear conditions.

Charles Ross & Son Company (Hauppauge, N.Y.)
1-800-243-7677
www.mixers.com
Calendar of events

September 2019

2–6 Materials Research Society of Serbia Annual Conference YUCOMAT 2019 and 11th IISS World Round Table Conference on Sintering – Herceg Novi, Montenegro; www.mrs-serbia.org.rs

4–6 3rd Annual Energy Harvesting Society Meeting (EHS19) – Falls Church Marriott Farview Park, Falls Church, Va.; www.ceramics.org/ehs2019


23–25 Annual conference of the Serbian Ceramic Society – Belgrade, Serbia; www.serbianceramicsociety.rs/index.htm

29–Oct. 3 MS&T19 combined with the ACerS 121st Annual Meeting – Portland, Ore.; www.matscitech.org

October 2019

7–11 4th International Conference on Rheology and Modeling of Materials – Bukk, Hotel Palota at Miskolc-Lillafüred, Hungary; www.ic-rmmconf.eu


27–31 ➤ PACRIM 13: 13th Pacific Rim Conference on Ceramic and Glass Technology – Okinawa Convention Center, Ginowan City, Okinawa, Japan; www.ceramics.org/pacrim13

28–31 ➤ 80th Conference on Glass Problems – Greater Columbus Convention Center, Columbus, Ohio; www.glassproblemsconference.org

November 2019


December 2019

1–6 2019 MRS Fall Meeting – Hynes Convention Center, Boston, Mass.; www.mrs.org/fall2019

Dates in RED denote new entry in this issue.
Entries in BLUE denote ACerS events.
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Nanostructured ceramic materials have attracted much research interest over the past few decades as they often exhibit distinct functionalities due to their small crystallite size and large surface area compared to their bulk counterparts. For example, ceramic nanoparticles allow production of dense materials with high mechanical strength and transparency, and large surface area aids catalysts and rechargeable batteries by providing more reaction sites and shorter diffusion distances.

To thoroughly understand the effect of interfaces on properties of nanostructured materials, studying their thermodynamics is crucial. At interfaces, atoms are coordinated by fewer neighboring atoms than in bulk, resulting in atomic bonds that are not fully satisfied. These unsatisfied bonds give rise to interface instability, defined as interfacial energy, which is the energy required to produce one unit area of surface or grain boundary.

Although interfacial energies of ceramic materials are typically on the order of a few joules per square meter, as particles become smaller than 100 nm, surface area roughly translates to at least 2,500 m²/mol. Navrotsky et al. showed the energy arising from this large surface area gives transition metal oxide nanoparticles different redox equilibria and phase stability from those of bulk metal oxides.¹

From a design perspective, interfacial energies can be manipulated by introducing dopants that segregate to interfaces and better satisfy the local atomic bonds.² This change in interfacial energies can significantly impact properties of nanostructured materials, as demonstrated by Bokov et al., who synthesized dense nanocrystalline yttria stabilized zirconia with improved toughness by using a rare-earth metal as a dopant.³

Inspired by these studies, my research in Prof. Ricardo Castro’s group at the University of California, Davis, has focused on interfacial energies of nano-LiMn₂O₄, a cathode material for Li-ion batteries, to address the increasing energy demand within society. It has been suggested that the use of nanoparticles in batteries can effectively improve battery capacity and power.⁴ However, aforementioned interfacial energies of LiMn₂O₄ nanoparticles can adversely affect the phase and structural stability of the cathode, and therefore the reversibility of Li-ion insertion and extraction in batteries, resulting in a shortened cycle life. The goal of my project is to design a highly stable nanoparticle cathode by quantifying the interfacial energies of LiMn₂O₄ nanoparticles and tuning those energies via doping.

One of the major challenges in studying nanoparticle interfaces is the fabrication of pure, homogeneous materials, as any contamination can drastically affect interface properties. To avoid contamination, I developed a bench-top flame spray pyrolysis (FSP) reactor (Figure 1), which enables clean, scalable, one-step synthesis of LiMn₂O₄ nanoparticles with crystallite size of about 30 nm. On the synthesized nano-LiMn₂O₄, I measured the exothermic heat released during grain growth of the nanoparticles as they are heated up to approximately 800°C using a differential scanning calorimeter. It is critical that grain growth is the only process taking place, rather than additional processes such as redox reaction of metals or water desorption, in order to reliably attribute the heat effect solely to interfacial area change during grain growth. Based on the measured heat of grain growth combined with data on crystallite size change and interfacial area change during the process, surface and grain boundary energies of the nanoparticles are derived, providing further insight into the stability of the nanocathode.

I will be presenting this work with more details at MS&T in Portland, Oregon, this October, proposing a novel thermodynamic strategy for stabilizing cathode nanoparticles. Future work includes mechanical properties and impedance measurements on undoped and doped LiMn₂O₄ for the comprehensive analysis on the effect of dopant. See you in Portland!

References


Kimiko Nakajima is a Ph.D. candidate in materials science and engineering at the University of California, Davis. In addition to her current research on interfaces of engineered ceramic nanoparticles, she is interested in biominerals because “Nature is far ahead of humanity technologically, efficiently synthesizing self-healing ceramic materials with such intricate structures!”
SUBMIT YOUR ABSTRACT!

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