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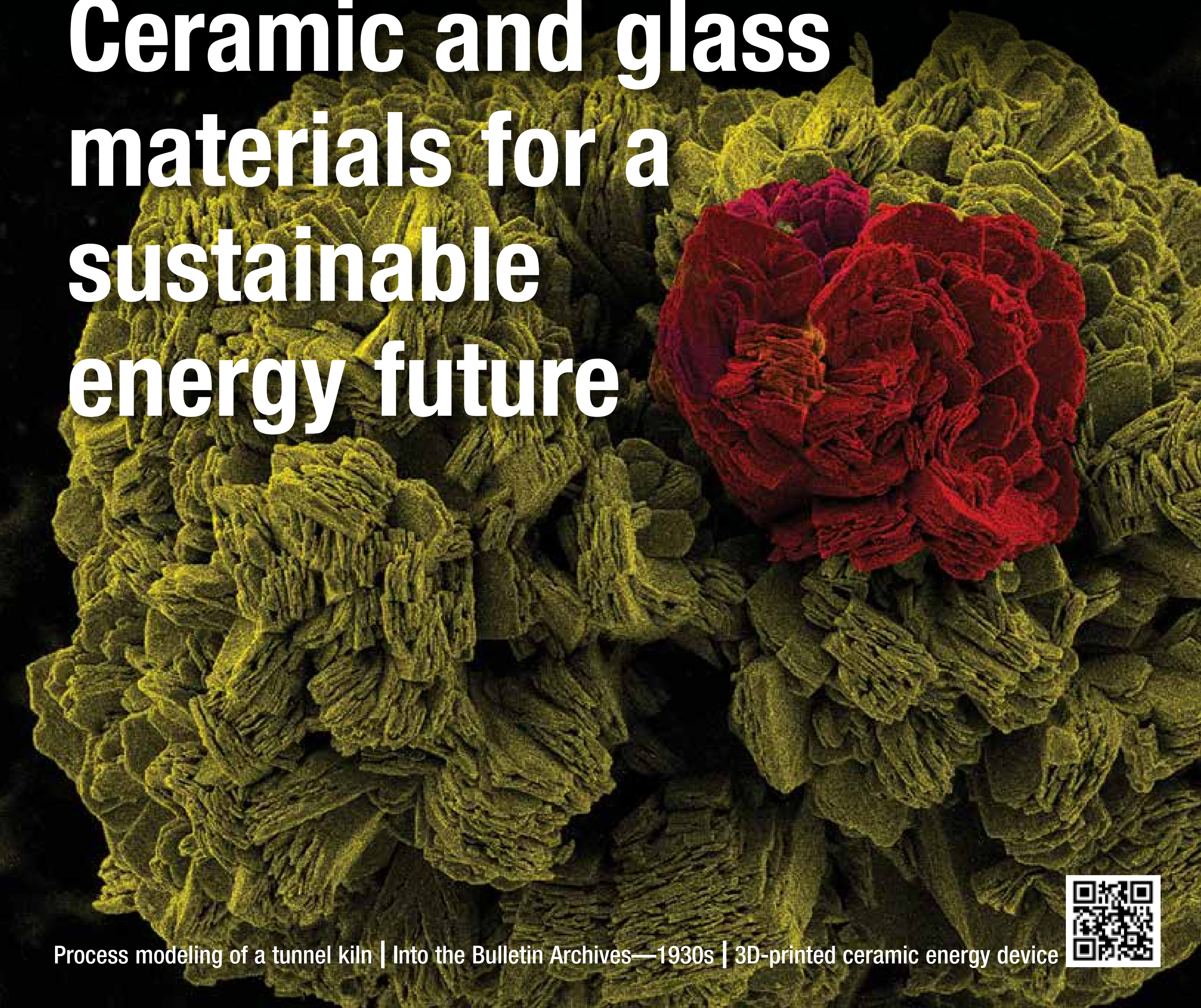
MARCH 2021

Ceramic and glass materials for a sustainable energy future



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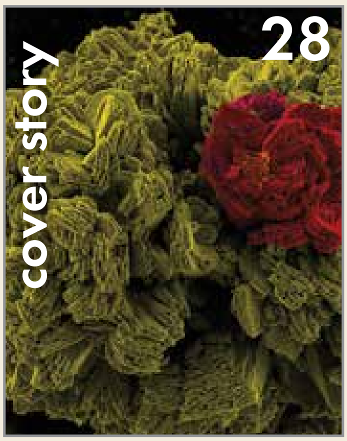

Ceramic and glass materials for a sustainable energy future

Durable ceramic and glass materials underpin advances in electricity generation, energy conversion and storage, and waste disposal.

by Ram Devanathan, Daiwon Choi, Olga Marina, Josef Matyáš, and Suresh Baskaran

Process modeling of a sanitary ware tunnel kiln

Process modeling offers a way to understanding the physics and temperature profile in a tunnel kiln without the need for an expensive experimental setup or significant amounts of time.

by Denny Mathew Alex, Tino Redemann, and Eckehard Specht

Cover image

The cover shows a false-colored scanning electron microscope image of a plutonium oxide aggregate (~100 mm across) formed from calcination of plutonium oxalate. Cracks are visible where gases escaped during calcination.

Credit: Edgar Buck, Pacific Northwest National Laboratory

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As seen on *Ceramic Tech Today*...

Credit: Eike Köhnen, Helmholtz Zentrum Berlin

Researchers detail how they created record-setting perovskite/silicon tandem solar cell

In January 2020, researchers at Helmholtz Zentrum Berlin announced they created perovskite/silicon tandem solar cells with 29.15% power conversion efficiency. A recently published paper details how they fabricated and tested these record-setting cells.

Read more at www.ceramics.org/tandemrecord2020

Also see our ACerS journals...

Key features in the development of unimorph stainless steel cantilever with screen-printed PZT dedicated to energy harvesting applications
By M. I. R. Taborda, C. Elissalde, U. Chung, et al.
International Journal of Applied Ceramic Technology

Revealing the synergy of Sn insertion in hematite for next-generation solar water splitting nanoceramics
By K. C. Bedin, A. L. M. Freitas, A. Tofanello, et al.
International Journal of Ceramic Engineering & Science

Interface engineering of nanoceramic hematite photoelectrode for solar energy conversion
By A. L. M. Freitas, D. N. F. Muche, E. R. Leite, and F. L. Souza
Journal of the American Ceramic Society

Hybrid Li-S pouch cell with a reinforced sulfide glass solid-state electrolyte film separator
By T. Yersak, J. R. Salvador, R. D. Schmidt, and M. Cai
International Journal of Applied Glass Science

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ACSBA7, Vol. 100, No. 2, pp 1– 48. All feature articles are covered in Current Contents.

news & trends

Carbon capture strategy looks to olivine to remove carbon dioxide from the atmosphere

Recent analyses by the Global Carbon Project indicate that all of the canceled plans and home confinement in 2020 compounded into a 7% worldwide drop in fossil carbon emissions from 2019.

"I think it's likely the biggest [drop in emissions] ever," Rob Jackson, Stanford University earth scientist and chair of the Global Carbon Project, says in a *Popular Science* article. "That's the equivalent of taking about 500 million cars off the world's roads for a year."

That is impressive. But when it comes to carbon emissions, it is still not enough.

Simply cutting current and future carbon emissions, even drastically, will not be enough to reverse the damage that has already been done and prevent further climate change and environmental damage. Instead, additional strategies are needed to help humans reverse the trend that they helped to create, and one popular option currently is capture carbon and storage.

These methods and techniques widely vary, from high-tech to entirely natural, but the principle is the same—to capture carbon dioxide formed from industrial processes and fossil fuel-based activities and store it, so that it does not further contribute to atmospheric levels. Some of the strategies even turn that carbon dioxide into a usable product such as fuel (those strategies are termed carbon capture, utilization, and storage).

One industry that certainly has been under a harsh spotlight is the cement industry, due to its 7% contribution to global carbon dioxide emissions. Accordingly, the cement industry has increasingly looked at ways to reduce its negative environmental impact, including not only "greener" cement formulations but also production facilities that capture carbon before it is released into the atmosphere.

Another significant contributor to carbon emissions is the transportation industry, which is estimated to account for 28.2% of carbon emissions in the United States in 2018. In addition to

Olivine, a silicate mineral that is highly abundant on earth—and may be the next big thing in effective and scalable carbon capture and storage techniques.

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

fossil fuel burning vehicles on the roads, air travel accounts for a large amount of those emissions, so many airlines are now similarly looking for ways to reduce their environmental impact.

Again, carbon capture techniques offer a solution. For instance, United Airlines recently announced that it plans to reduce its carbon emissions 100% by 2050 by investing in carbon capture technologies. Its strategy involves a multimillion-dollar investment in a company called 1PointFive, which uses large facilities to literally suck carbon dioxide from the air, a process generally termed direct air capture.

But while such carbon capture solutions generally are seen as a necessary component of our sustainable future, the problem is that these technologies and strategies are often expensive to implement—the economics still are not favorable to encourage and expand their use enough to sufficiently address the problem.

So what is really needed is a strategy that is not only effective at removing carbon dioxide from the air but also is scalable, affordable, and easy to implement across the globe.

A simple green silicate mineral called olivine just might provide the solution, according to a recent initiative called Project Vesta. The Project describes itself as "a nature-based, permanent, scalable, and affordable solution to climate change," and that solution involves using olivine to enhance the earth's natural process of carbon sequestration.

Project Vesta's idea is relatively simple yet clever—mimic the earth's natural process of carbon sequestration but enhance the process, speeding it up to keep pace with human activity. "Our mission is to help reverse climate change by turning a trillion tonnes of CO_2 into rock," the Project's website states.

To understand the project's strategy, it helps to understand the process by which the earth normally sequesters carbon dioxide, called the carbon-silicate cycle or the inorganic carbon cycle. This natural cycle incorporates weathering of rock and volcanic activity, which sequester and release carbon dioxide, respectively—converse processes that roughly balance one another to keep the earth's atmosphere at a relative carbon dioxide status quo.

The basic gist is that weathering of rocks draws carbon dioxide out of the atmosphere and incorporates it into the rocks, which are eventually drawn down into the earth's mantle via movement of the tectonic plates. There, heat and pressure catalyze chemical reactions that release the carbon dioxide, which is then burped back out into the atmosphere during volcanic eruptions, restarting the cycle.

The cycle normally works to balance out the earth's atmospheric carbon dioxide content, but the problem is humans—we have altered the natural landscapes to such an extent and contributed so much additional carbon dioxide to the atmosphere through activities like burning fossil fuels that the earth cannot keep up.

So Project Vesta's idea is to enhance this natural process, essentially jump starting the carbonate-silicate cycle to augment the earth's ability to sequester all that excess carbon dioxide created by human activity. The project's solution—termed coastal enhanced weathering—involves mining, crushing, and spreading a mineral called olivine on beaches.

Thermcraft celebrates its 50th anniversary

Thermcraft was born in January 1971, in a small warehouse space in downtown Winston Salem, N.C. From that small startup operation, Thermcraft progressively grew into a leading international manufacturer of thermal processing equipment, offering industrial and laboratory furnaces, ovens, high-temperature heating elements, insulation, and replacement parts. Thermcraft now resides in a 70,000-square-foot manufacturing and office space located just a few miles from downtown Winston Salem, where it all began. The number one priority at Thermcraft has always been customer service. We look forward to serving the thermal processing industry for another 50 years! 100

"Olivine is a widely abundant volcanic mineral. It makes up over 50% of the Earth's upper mantle, and is the most effective mineral for enabling CO_2 removal through rock weathering," the Project's website states.

During weathering, olivine reacts with water, generating hydroxide ions that react with carbon dioxide in the atmosphere. The bicarbonate that forms from this reaction washes into oceans through the action of waves and precipitates as carbonate onto the ocean floor. There, the carbon dioxide is locked into rock that will eventually be drawn down into the earth via movement of tectonic plates, effectively sequestering carbon dioxide deep in the earth.

Project Vesta is not looking to turn all beaches green with olivine. The project estimates just 2% of shelf seas (oceans on the continental shelf, where there is high mixing of waters) are needed to capture all carbon emissions spewed out by human activity. And at a cost of as little as \$21/tonne—which the project says, at full scale, amounts to less than 10% the cost of other carbon capture strategies—enhanced coastal weathering is economically feasible as well.

Because olivine is one of the most common minerals on earth by volume, supply should not be an issue either. And while mining, crushing, and transporting olivine to beaches will certainly contribute its own carbon emissions, the scaled process, if successful, will more than offset its damage. Project Vesta states that the process is 95% efficient—for every tonne of CO_2 emitted during olivine extraction and transportation, enhanced coastal weathering with that olivine can remove 20 tonnes of CO_2 from the atmosphere.

It all sounds quite promising—but the big question is, will it work?

Project Vesta currently is testing pilot-scale experiments, incrementally adding crushed olivine to a test beach to monitor how it affects the total environment. If they see positive results, the team plans to extend the testing to additional environments to ensure scalability and safety of the strategy, scaling up incrementally and continuing to monitor the effects before eventually rolling out a global strategy.

The project reminds of the current situation with the global pandemic, where the promise of highly effective vaccines is offering a glimmer of hope to restore some sense of balance to the world.

Now, we just have to wait and see if it all pans out.

Find more of the science behind Project Vesta's strategy at https://www.projectvesta.org/science. 100

Recycling robot aims to generate separate material waste streams right at home

More than 90% of discarded plastic around the world is never recycled. And many other materials that are even more recyclable than plastic, such as glass and aluminum, do not achieve the high recycling rates such materials could and should achieve.

Part of the problem is the economics of recycling. While China once imported a vast majority of the world's recyclables, the country enacted import bans in 2018 that wholesale disrupted global recycling supply chains. And in the U.S., the domestic infrastructure to make recycling economically feasible simply is nonexistent in many places.

Another part of the challenge with recycling operations is generating and maintaining individual, high-quality, pure waste streams. The "mixed-use" bins that allow consumers to combine their plastic, glass, aluminum, paper, and more all into one place—called single-stream recycling—are really convenient for consumers, but they introduce major challenges in terms of separating recyclables into their individual constituents.

Due to the current popularity of single-stream recycling, the task of materials separation now most often falls to recycling facilities. And while some use robots equipped with cameras and sensors to achieve this separation, in many areas separating recyclable waste is a manual, imperfect process. That increases the time and cost required to generate separate material waste streams, and it also results in lower quality and thus lower value material waste streams.

Multi-stream recycling, in which different materials are separated and collected individually throughout the entire recycling process, offers a much better alternative in terms of generating valuable and pure material waste streams. Yet multi-stream recycling systems are more complicated and require more coordinated efforts on the parts of consumers, municipalities, and recycling companies. So new solutions are needed to make recycling more effective, solutions that both generate high-quality individual waste streams and make it simple for consumers to comply.

One proposed solution to improving recycling is Lasso, a robotic appliance designed to bring the recycling bin and materials sorting facility right inside consumers' kitchens. Lasso looks like a heavy and somewhat bulky appliance, but Lasso contains cameras, sensors, robotics, and mechanics that together can clean, sort, process, and store recyclable materials, generating high-quality and high-purity material waste streams right at their point of use.

The concept is that a person can simply insert their recyclable into Lasso, and the appliance's cameras and sensors scan the item to determine what it is and if it is recyclable. If it is, Lasso steam cleans the item and then crushes it and stores it in separated individual material bins. If the item is not recyclable or not an accepted material, Lasso simply returns the item.

Initial models of Lasso are set to prepare and store seven different materials—aluminum, steel, two plastics (PET and HDPE), and three colors of glass (clear, brown, and green). A connected smartphone app lets users know when the separate material storage bins within the unit are nearly full so they can schedule a curbside pickup.

Lasso is still in development, but according to a Gizmodo article, the company already has the capital to build the devices and plans to start shipping in September 2022, with planned curbside pickup service starting in San Francisco and expanding to other parts of the U.S.

Like many new technologies, the unit will not be cheap—expect prices of around $3,500 once Lasso is available. The price would be expected to decrease with more widespread adoption, and Lasso CEO Aldous Hicks also hints at other potential solutions as well as expanded capabilities in a Lasso blog post: "Without giving away too much, I can say that the second Lasso model will be able to accept paper and cardboard, plastic film and food scraps. By the time the second model is delivered, Lassos will also be offered as a service model, with an affordable annual service fee rather than an upfront appliance purchase cost. In keeping with a fast-growing technology company, all free cash flow is plowed back into R&D to drive down the costs and bring the follow-on products to market."

Learn more about Lasso at https://www.lassoloop.com.

Credit: Lasso Loop Recycling, YouTube

Lasso is a robotic appliance designed to improve the recycling cycle by bringing multi-stream recycling into the home.

Solid-state battery global markets

By BCC Publishing Staff

The global solid-state battery market was valued at $65.8 million in 2019 and is estimated to reach $391.9 million by 2025, growing at a compound annual growth rate (CAGR) of 35.7% over the forecast period.

Solid-state batteries are among the new generation of advanced battery systems that offer several advantages over the current battery technologies, such as lithium-ion batteries. Their use of solid rather than liquid electrolytes lets these batteries operate at high workable temperatures, charge faster, and store a massive amount of energy in a compact area. However, at this point they are very expensive as compared with other battery types.

There are several notable end users for solid-state batteries, including

- **Medical and healthcare devices:** Initial usage of solid-state batteries in this market segment started with heart pacemakers in the early 1970s. Solid-state batteries now are used in a variety of medical devices, including heart rhythm devices, nerve simulators, implanted sensors for catheters, and pulse generators, among other devices.
- **Electric vehicles:** Currently high cost and degree of complexity for production at commercial scale are acting as impediments to the growth of solid-state batteries in this market segment. Once these challenges are overcome, the solid-state battery industry is expected to grow at a very rapid pace in the long-term future.
- **Consumer electronics:** This segment is among the key potential future markets for solid-state batteries. Solid-state batteries currently are used in several electronics devices, such as radio frequency identification, integrated circuits, and high-end electronics. However, they are seen as a potential replacement for lithium-ion batteries in portable electronics, such as smartphones and laptops, once production can be made cost effective.
- **Industrial:** Scope of the industrial segment for solid-state batteries in this report includes telecom networks and battery backup devices/uninterruptible power supply. For battery backup devices, solid-state batteries are seen as replacements for the current lead acid and lithium-ion batteries used. For telecom and network, growing usage of the Internet of Things for connectivity is expected to create demand for solid-state batteries. However, commercialization in this segment is expected to take longer, possibly till the next decade.
- **Other:** Other end uses for solid-state batteries include energy harvesting, military, and aerospace applications. Currently, solid-state batteries are being used at a limited scale for energy harvesting, but they are suitable for this application due to their high energy density. Military and aerospace segment are considered to be future applications for the solid-state batteries.

Table 1. Types of large and advanced battery systems

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

Publications related to solid-state batteries have risen tenfold in the past two decades, along with a noteworthy upsurge in patent filing activities. Over 2,700 patents were filed between 2000 and 2019, out of which one half comprised from the U.S. and Japan. Toyota leads the number of solid-state battery patents filed by company, accounting for 43% of all patents filed since 2000.

About the author

BCC Publishing Staff comprises expert analysts who are skilled in conducting primary research, secondary research, and data analysis and have decades of combined experience covering a wide range of industries. Contact the staff at analysts@bccresearch.com.

Resource

BCC Publishing Staff, "Solid State Battery: Global Markets" BCC Research Report FCB053A, December 2020. www.bccresearch.com.

Table 2. Global market for solid-state battery, by end user, 2019–2025 ($ millions)

End user	2019	2020	2025	CAGR% 2020–2025
Medical & Healthcare devices	17.8	23.0	105.4	35.6%
Electric Vehicles	19.4	25.2	116.8	35.9%
Consumer Electronics	15.1	19.6	90.5	35.8%
Industrial	5.4	6.9	31.0	35.1%
Others	8.1	10.5	48.2	35.6%
Total	65.8	85.2	391.9	35.7%

By Lisa McDonald

Into the Bulletin Archives—A look back at our 100 years in print

Since May 1922, the *ACerS Bulletin* has served the ACerS community, providing them updates on member news, Division meetings, and the latest research in ceramics and glass.

In celebration of Volume 100 this year, the *Bulletin* editorial team is running a special column in each issue of the 2021 *Bulletin* that looks at the history of the *Bulletin* by decade. This issue highlights the 1930s.

We hope you enjoy following the journey of the *Bulletin* from its early years to today. As an ACerS member, you have access to all 100 years of the *Bulletin* on the *Bulletin Archive Online* at https://bulletin-archive.ceramics.org. 100

Into the *Bulletin* Archives—1930s

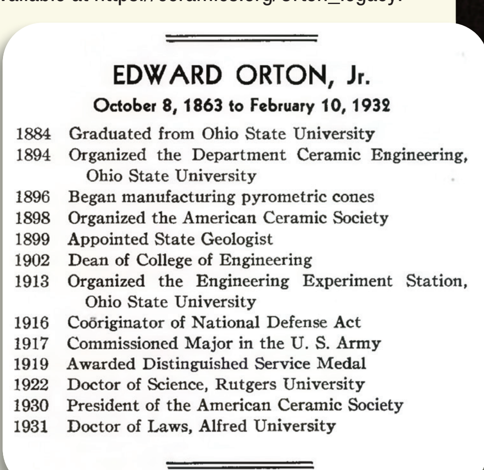
The *Bulletins* of the 1930s followed the format of the 1920s *Bulletins* quite closely. One major difference, though, started in July 1933, when the first paid ads, and an accompanying advertiser's index, began appearing in the magazine. In addition, the July issue also saw the first instance of a buyers' guide for equipment, materials, and services for the ceramics and glass industry. The buyers' guide became a regular feature of each issue in the 1930s.

1930s

Past ACerS president Edward Orton, Jr. (1930–31) died Feb. 10, 1932. Orton was instrumental in organizing the Society in 1898, and he served as the Society's first Secretary from 1899–1917. At the time of his death, Orton was Chairman of Fellows, an honorary ACerS group that was instituted only a little more than one year before his death.

In 1896, Orton began the manufacture of pyrometric cones in the United States. This work is continued by the Edward Orton, Jr., Ceramic Research Foundation, which was established in 1932 by provision of Orton's will.

A detailed obituary for Orton can be found in the March 1932 issue of the *Bulletin*. A look at his legacy is available at https://ceramics.org/Orton_legacy.

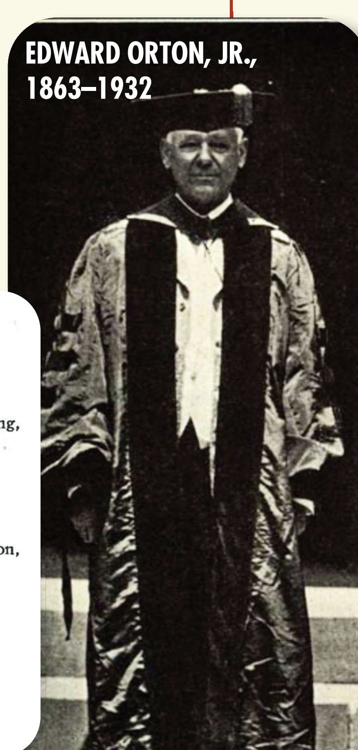


EDWARD ORTON, Jr.

October 8, 1863 to February 10, 1932

1884	Graduated from Ohio State University
1894	Organized the Department Ceramic Engineering, Ohio State University
1896	Began manufacturing pyrometric cones
1898	Organized the American Ceramic Society
1899	Appointed State Geologist
1902	Dean of College of Engineering
1913	Organized the Engineering Experiment Station, Ohio State University
1916	Coöriginator of National Defense Act
1917	Commissioned Major in the U. S. Army
1919	Awarded Distinguished Service Medal
1922	Doctor of Science, Rutgers University
1930	President of the American Ceramic Society
1931	Doctor of Laws, Alfred University

Credit: *ACerS Bulletin* (March 1936) Vol. 15 Iss. 3, pp. 74



EDWARD ORTON, JR., 1863–1932

Credit: *ACerS Bulletin* (March 1936) Vol. 11 Iss. 3, pp. 48

The establishment of the Fellow status in ACerS is one of the most notable stories tracked by the *Bulletin* in the 1930s. The process began in February 1930, when the Society approved Clause 6 of the "Recommendations of the Committee on Classification of Membership," which outlined the terms of Fellow status.[1] In May 1930, the constitutional amendments for Fellow status were adopted by letter ballot,[2] and in December 1930, the first one hundred Fellows met to organize and lay down the specifications and methods by which the Fellowship would grow.[3] Induction of those Fellows, plus 52 nominated in the regular manner, took place during the 33rd Annual Meeting in February 1931.[4]

The Society also announced two major changes to its Divisions structure during the 33rd Annual Meeting.

DIVISIONS OF THE SOCIETY

During the 1930s, the Society had eight Divisions.

- Art
- Refractories
- Enamel
- Terra Cotta
- Glass
- White Wares
- **Materials and Equipment (new)**
- **Structural Clay Products (previously Heavy Clay Products)**

In addition to more serious news, the "Activities of the Society" section included lighthearted banter as well.

PRONUNCIATION OF CERAMIC—"SERAMIC" OR "KERAMIC"?*

Editor of the Sentinel: Mr. Fred Rhead, in his lecture to the Society of Industrial Artists last night, pronounced that word familiar to all of us in the Potteries as "Seramic."

As it is derived from the Greek word "Keramos," is not the correct pronunciation "Keramic," or are both correct, or both used universally?

I shall be glad of a ruling on this point.—*Anglo-American*

New Union's Reply to Trades Council

The question of the pronunciation of "ceramic" is not one for the potter or language expert to decide. The arbiter in these matters is the man-in-the-street. What he finally accepts is the standard.

The French "garahzh" is fast becoming "garrage" (pronounced like "passage") and "vitamin" was originally "vitamine," with various pronunciations.

As regards "ceramic," we have introduced into English a number of Greek words with the initial letter "k," changing this into "c." Now "c" before "e" or "i" is *sibilant*, that is, since the time of the French William the Conqueror. Hence "seramic."

In Anglo-Saxon times, the word would have been pronounced "keramic." Since the Conqueror, the hard sound of "c" before "e" and "i" is denoted by" k", *e.g.*, "cyn" is now "kin" and "cyng" is now "king."

—*T. Murphy*

* From the *Evening Sentinel*, Stoke-on-Trent, June 9 and 14, 1937.

Credit: *ACerS Bulletin* (September 1937) Vol. 16 Iss. 9, pp. 376

One, the Heavy Clay Products Division and the National Brick Manufacturers Association consolidated to become the Structural Clay Products Division, which still exists today. Two, an entirely new Division called the Materials and Equipment Division was formed. President Edward Orton, Jr. explained the impetus for such a Division during his Annual Meeting address.

"Some of you perhaps have not yet sensed fully the need of such a division, reasoning that all the divisions have in the past given place to papers and discussions on such topics, and that under that procedure new materials and new equipment have been brought forcefully to the attention of those most directly concerned with its use. On the other hand, ceramic materials and processes in the nature of the case are of such general use, in so many branches of our art, that members of all divisions should profit from more general diffusion or knowledge concerning them. And no one can successfully deny that the classification and subdivision of knowledge is an inherent part of scientific progress.

The same process which has split our one-time single body into seven divisions is still operating. Who would say that we have not gained by it? Each division now displays more papers, more studies, more discoveries, more pushing back of the frontiers of the unknown, each year than the whole Society did when it was one body. By the lessons of our own experience, as well as the universal testimony of all other organizations, we shall gain by subdividing and specializing in the future as in the past."

–*ACerS Bulletin, Vol. 10., Iss. 4., April 1931*

References

[1]*Bulletin*, April 1930, pp. 110–117.

[2]*Bulletin*, March 1930, pp. 71–74.

[3]*Bulletin*, February 1931, pp. 30–35.

[4]*Bulletin*, April 1931, pp. 89–93.

SOCIETY DIVISION SECTION CHAPTER NEWS

Welcome new ACerS Corporate Partners

ACerS is pleased to welcome its newest Corporate Partners:

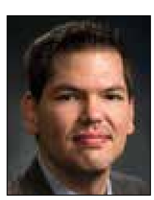
- **GeoCorp**
- **QuantumScape**
- **Silicon Carbide Products**
- **Special Shapes Refractory Company**

ACerS Corporate Partner program offers member companies all the benefits of individual membership plus marketing, recruiting, networking, and education. Employees of corporate partners enjoy cost savings on ACerS' new and expanded online educational training programs about ceramic science, technology, and manufacturing.

To learn how your company can utilize the benefits and gain exposure to a global audience through the Corporate Partnership program, contact Kevin Thompson, membership director, at (614) 794-5894 or kthompson@ceramics.org.

Volunteer spotlight

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



Hubert

Mathieu Hubert earned a M.Chem. from the University of Rennes, France, and a Ph.D. in materials science at the University of Rennes and the University of Arizona. His work focused on chalcogenide glasses and glass-ceramics.

His professional background includes working at CelSian Glass & Solar as a glass scientist and technologist and teaching with the CelSian-NCNG International Glass Technology Course. He joined Corning USA in 2016 and is a development associate, working on new glass products. Additionally, he lectures on glass science and glass technology at Corning Community College.

A member of ACerS since 2011, Hubert has served as a GOMD conference session chair and as lead organizer of the Symposium on Glass Technology and Manufacturing at the 2019 ICG/GOMD conference. Currently, he is program co-chair for the upcoming 2021 GOMD Conference in Vancouver. He also mentors students as part of ACerS PCSA mentoring program.

We extend our deep appreciation to Hubert for his service to our Society!

St. Louis Section/RCD Virtual 56th annual symposium: March 24–25, 2021

The St. Louis Section and the Refractory Ceramics Division of The American Ceramic Society will host the Virtual 56th Annual Symposium on Refractories on the theme "Properties and Performance of Refractory Ceramics—A Tribute to Richard C. Bradt" on March 24–25. Co-program chairs are Kelley Wilkerson and Jeff Smith of Missouri University of Science and Technology. For more information and to register, visit http://bit.ly/2021StLouisRCD.

Frontiers of Ceramics & Glass Webinar Series

MARCH 16
11 A.M. – 12 P.M.

Title: *Raw material variability and manufacturing*

PRESENTER:
WILLIAM M. CARTY– Alfred University
ACerS Manufacturing Division

Free to ACerS members

The ACerS Frontiers of Ceramics and Glass Webinar Series offers free, live webinars for members each month providing valuable technical content in a convenient format. Expert speakers from ACerS Divisions, Sections, and Chapters deliver knowledge on a variety of cutting-edge topics while answering questions from live viewers.

William M. Carty, FACerS, will discuss how raw material variability (e.g., particle size distribution) and powder processing can impact manufacturing control and product consistency from an engineering perspective, such as by offering a potentially new way to look at particle size distribution data.

There is no cost for ACerS members, GGRN, or Material Advantage student members, and members can access previous webinar recordings. The registration fee for nonmembers is $30 and $15 for student nonmembers.

For more information and registration, visit https://ceramics.org/professional-resources/career-development/web-seminars. 100

Names in the news

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

Barsoum

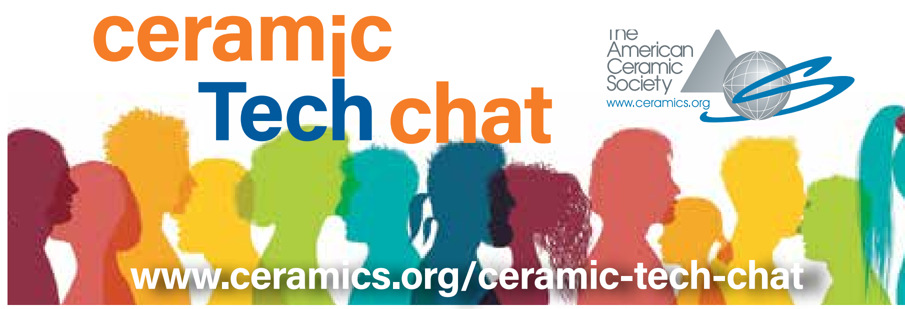
Michel Barsoum, FACerS, Distinguished Professor in the materials science and engineering department at Drexel University, ranked first in the materials science subfield in a citation study led by a Stanford University researcher and published in *PLOS Biology*. The study analyzed 2019 citation metrics from Scopus and excluded self-citations. 100

IN MEMORIAM

William Contardi
Don Frith
Conrad Naber
Masaki Narisawa
John "Jack" Persico
Gerald Rieper
Clarence Shaw

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

more
SOCIETY
DIVISION
SECTION
CHAPTER
NEWS



Ceramic Tech Chat: Greg and Ashley Hilmas

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

In the January episode of Ceramic Tech Chat, dad and daughter duo Greg and Ashley Hilmas, university professor and government research materials engineer, respectively, describe their similar journeys to becoming ceramic engineers, how their career paths diverged after earning their Ph.D.'s, and what it is like working in the same niche field.

Check out a preview from their episode, which features how they each came to be in their current jobs.

AWARDS
AND
DEADLINES

FOR MORE
INFORMATION:

ceramics.org/members/awards

EDiv names best student posters, student oral presentations of EMA 2021

The Electronics Division presented awards for outstanding student work during their 2021 Virtual Electronic Materials and Applications Conference. Congratulations to these students!

Poster Competition EMA 2021

First place

High speed visualization of ferroelectric domains by friction asymmetry
Seongwoo Cho, Korea Advanced Institute of Science and Technology

Second place

Aqueous chemical solution deposition of $Sr_xBa_{1-x}Nb_2O_6$ *thin films*
Viviann Hole Pedersen, Norwegian University of Science and Technology

Third place

Correlating structural changes to the volume fraction of polar nanoregions in quenched $Na_{1/2}B_{1/2}TiO_3 - BaTiO_3$ *ceramics*
Andreas Wohninsland, Technical University of Darmstadt, Germany

Oral Presentation Competition EMA 2021

First place

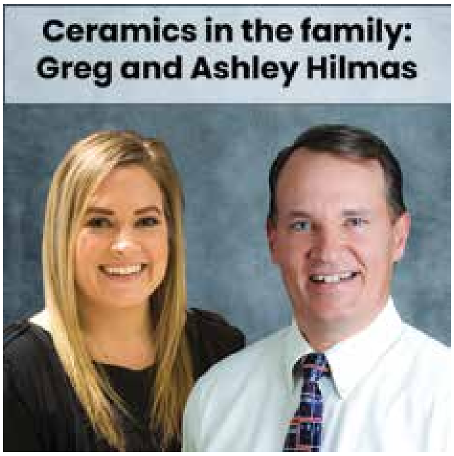
Microstructure quantification and random forest regression models for $Li_4Ti_5O_{12}$ *– Ni property prediction*
William Huddleston, Case Western Reserve University

Greg, FACerS and Curator's Professor of Ceramic Engineering at the Missouri University of Science and Technology:

"After my second postdoc in Michigan, I went to work for a small company called Advanced Ceramics Research in Tucson, Arizona. It was going well, I was really enjoying it, but at the same time things were changing at the company, … and I was starting to think about going elsewhere.

I got a call from my first postdoc advisor at the University of Michigan, John Holmes, and he said, 'Hey, do you know this university in Rolla, Missouri? … They're looking for [a junior faculty member] with expertise in mechanical properties of ceramics, and I gave them your name and contact information.'

So, I look back on it and I think, 'Okay, maybe I can do this.' But frankly, I didn't know. I didn't know if I did enjoy teaching. I didn't know if I'd really be good at it or not. And 22 years later, I love teaching."



Ashley, research materials engineer at the Air Force Research Laboratory (AFRL):

"I don't think I would have the job I have today without ACerS President's Council of Student Advisors (PCSA). So I was able to meet Dr. Lisa Rueschhoff, who is also AFRL, through PCSA. We became pretty close. She invited me out to do a seminar at AFRL about my work when I was in grad school. And it was while I was there giving the seminar, someone from the team I'm on now was like 'Hey, we have a position open. You should apply. I think you could be a decent candidate.' And so if I didn't go give that seminar, would I have known about the job? Who really knows, I guess. But ACerS definitely played an instrumental role."

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

Second place

Role of grain boundary refinement and nano-precipitates in enhancing the flux pinning of superconducting Nb_3Sn
Jacob Rochester, The Ohio State University

Third place

Design of new lead-free antiferroelectric $(1-x)NaNbO_3 - xSrSnO_3$ compositions guided by first-principles calculations
Maohua Zhang, Technical University of Darmstadt, Germany

more AWARDS AND DEADLINES

ECD best poster winners from ICACC 2020

The Engineering Ceramics Division has announced the best posters from the ICACC 2020 meeting held last January in Daytona Beach, Fla. The awards were presented virtually during ICACC 2021 in February. Congratulations to the authors of these award-winning posters.

First place awards

Growth of high purity zone-refined boron carbide single crystals by laser diode floating zone method, **Michael Straker**, Morgan State University, Md.; **Ankur Chauhan, Kevin J. Hemker, Mekhola Sinha, W. Adam Phelan,** Johns Hopkins University, Baltimore, Md.; **M. Chandrashekhar**, University of South Carolina, S.C.; **Michael Spencer**, Morgan State University, Md.

DFT study of the impact of impurities in SiC bulk and grain boundaries, **Matt Guziewski, Shawn P. Coleman**, US Army Research Laboratory, Md.; **Cassidy Atkinson, Pamir Alpay**, University of Connecticut

Atomic layer deposition of ultra-high temperature ceramics as hydrogen environmental barrier coatings for nuclear thermal propulsion, **Sarah Bull, Theodore Champ, Charles Musgrave, Alan W. Weimer**, University of Colorado; **Cynthia Adkins, Robert O'Brien**, Idaho National Lab; **William W. McNeary**, National Renewable Laboratory, Colo.

Second place award

Biomass derived carbons and PDC functionalized carbon composite for electrochemical energy storage, **Shakir Bin Mujib**, Kansas State University; **Beatriz Vessalli**, Centro de Tecnologia da Informação Renato Archer (CTI), Brazil; **Waldir Bizzo**, University of Campinas – UNICAMP, Brazil; **Talita Mazon**, CTI, Brazil; **Gurpreet Singh**, Kansas State University

Third place awards

Processing and characterizing Al-doped boron carbide bulk ceramic, **Qirong Yang, Eric Gronske, Chawon Hwang, Richard A. Haber**, Rutgers University, N.J.

Hydrothermal sintering: a low temperature densification process of ceramics, **Lucas Villatte, Sylvie Bordere, Dominique Bernard, Marie-Anne Dourges, Alain Largeteau, Catherine Elissalde, Graziella Goglio**, Institut de la Chimie et de la Matière Condensée de Bordeaux, France

Trustee awards

Processing and mechanical characterization of ice-templated alumina-epoxy composites, **Justine Marin, Sashanka Akurati, Dipankar Ghosh**, Old Dominion University, Va.

Mechanical properties of spark plasma sintered B_4C, **Ruslan Kuliiev, Nina Orlovskaya**, University of Central Florida; **Holden Hyer, Yongho Sohn**, University of Central Florida

Partial amorphization and phase control of cobalt nickel sulfide for an efficient oxygen evolution reaction, **Sungwook Mhin**, Korea Institute of Industrial Technology

Electric potential change of glasses by polishing with thermally oxide silicon, **Ryo Fukuzaki, Seiichi Suda**, Shizuoka University, Hamamatsu, Japan

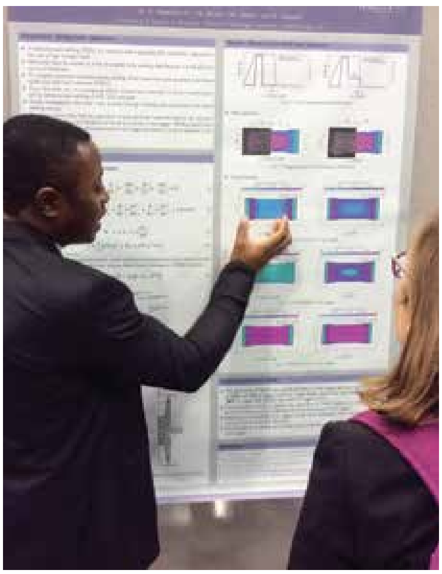
Take note of fast-approaching award deadlines

While **January 15** was the deadline for most award nominations to be submitted, there are four prestigious Division awards that have later deadlines. Award eligibility for each can be found at www.ceramics.org/awards.

Contact: Erica Zimmerman | Member engagement manager | ezimmerman@ceramics.org | 614.794.5821

Division	Award	Nomination Deadline	Description
GOMD	**Alfred R. Cooper Scholars Award**	May 15	This award recognizes undergraduate students who have demonstrated excellence in research, engineering, and/or study in glass science or technology. The recipient receives a plaque, $500, and a complimentary registration to ACerS Annual Meeting at MS&T21.
Electronics	**Edward C. Henry Award**	May 15	This award is given annually to an outstanding paper reporting original work in the Journal of the American Ceramic Society or the Bulletin during the previouscalendar year on a subject related to electronic ceramics. The author(s) will be presented with a plaque and $500 (split among authors).
Electronics	**Lewis C. Hoffman Scholarship**	May 15	The purpose of this $2,000 tuition award is to encourage academic interest and excellence among undergraduate students in ceramics/materials science and engineering. The 2021 essay topic is "Artificial intelligence and data mining in electroceramics."
Basic Science	**Graduate Excellence in Materials Science (GEMS)**	March 15 (submit abstracts) Aug. 15 (Apply for GEMS award)	The award is open to graduate students making oral presentations in any symposium at ACerS Annual Meeting at MS&T21. To be eligible for these awards, submit your abstracts to MS&T2021 at https://www.matscitech.org/MST21.

STUDENTS AND OUTREACH



The 2019–2020 class of PCSA delegates' "Day in the Life (DITL)" video project. Individual video stories may be viewed at www.instagram.com/acerspcsa.

Apply today for 2021–22 ACerS PCSA class

The President's Council of Student Advisors (PCSA) is the student-led committee of The American Ceramic Society composed of ceramic and glass focused students. The PCSA is looking for dedicated and motivated undergraduate and graduate students to get involved and to help advance ACerS into the future. Interested students should visit www.ceramics.org/applypcsa to learn more and how to apply. Application deadline is **March 26, 2021.**

ACerS Associate Membership and Young Professionals Network

The Society offers one year of Associate Membership at no charge for recent graduates who have completed their final degree. To receive the benefits of membership in the world's premier membership organization for ceramics and glass professionals, visit www.ceramics.org/associate.

Also, consider joining ACerS Young Professionals Network once you have become an ACerS member. ACerS YPN is designed for members who have completed their degree and are 25 to 40 years of age. YPN gives young ceramic and glass scientists access to invaluable connections and opportunities. Visit www.ceramics.org/ypn for more information, or contact Yolanda Natividad, member engagement manager, at ynatividad@ceramics.org.

ACerS GGRN—Graduate student membership for ceramic and glass students

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

GGRN members receive all ACerS individual member benefits plus special events at meetings, and free webinars on targeted topics relevant to the ceramic and glass graduate student community.

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

FOR MORE INFORMATION:

ceramics.org/students

CERAMICANDGLASSINDUSTRY FOUNDATION

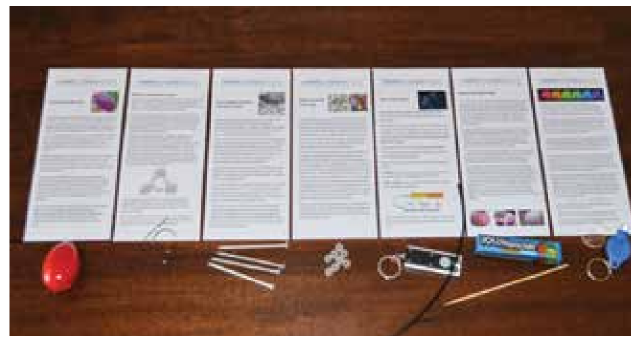
CGIF introduces a new materials science teaching resource

The Ceramic and Glass Industry Foundation, building on lessons developed by Mary Reidmeyer, FACerS, of Missouri University of Science and Technology, recently launched a new educational resource. The Mini Materials Demo Kit is a collection of seven simple demonstrations for use practically anywhere by parents, teachers, and students who are using online and at-home teaching resources.

The lessons are written for a wide age-range of learners and the whole family can have fun learning about such topics as:

- The science of Silly Putty®
- What is fiber optics?
- Magic color beads and UV light
- How are glass fibers made?
- What is fluorescence?
- What is a shape memory alloy?
- Does heating an aluminum nail make it harder?

Our larger Materials Science Classroom Kit is intended for use in the classroom. Five of the nine lessons are for the teacher to demonstrate; the remaining four are for students to perform in small groups with assistance from the teacher.



The new Mini Materials Demo Kit is intended for use virtually anywhere by students to gain hands-on experience and knowledge, and the lessons are written in such a way that they can be meaningful to elementary, middle, or high school students.

The Mini Materials Demo Kit provides interesting activities to be done at home or in the classroom and can be purchased for only $49; quantity discounts are available for orders of five or more. Donations to supply kits to those with limited resources can be made at https://myacers.ceramics.org/donate.

For more information on both the Materials Science Classroom Kit and the new Mini Materials Demo Kit, visit https://ceramics.org/sciencekits or contact Belinda Raines at braines@ceramics.org. 100

research briefs

Scientists probe secrets of ancient mummy painting

Researchers from the University of Utah, Boise State University, and Idaho National Laboratory, in collaboration with the Walters Art Museum in Baltimore, Maryland, investigated the pigment used to paint a mummy portrait from Roman Imperial Egypt.

Mummification practices such as mummy masks and opulent tombs often are associated with famous Egyptian rulers like King Tut. But mummification practices continued in Egypt even after it became part of the Roman empire in 30 BCE. From the first to third century CE, those mummies were often accompanied by portraits of the deceased, called mummy portraits, that depicted the physical likeness of the person preserved inside.

Many unanswered questions still remain about mummy portraits, the people they depicted, and the cultural context in which these works of art, life, and death were created. Today, more than 1,000 mummy portraits are known to exist, preserved thousands of years after they were created, offering a potentially rich source of information about the culture and people at this time in history.

Credit: University of Utah

Researchers used X-ray analysis to determine the chemical and structural composition of pigment used in the above mummy portrait from Roman Imperial Egypt.

For their open-access study, the researchers investigated a portrait called *Portrait of a Bearded Man*, which depicts a curly-haired bearded man dressed in a toga notable for its purple markings.

"Since the purple pigment occurred in the clavi—the purple mark on the toga that in Ancient Rome indicated senatorial or equestrian rank—it was thought that perhaps we were seeing an augmentation of the sitter's importance in the afterlife," Glenn Gates, co-author and conservation scientist at the Walters Art Museum, where the portrait resides, says in a University of Utah release.

In addition to the potential cultural significance of the purple markings in the portrait, the pigment itself caught the team's eye because it contained "unusually large, rough gem-like purple particles embedded in the purple paint," they write in the paper. Those particles spanned as much as 3 mm in diameter, whereas most ancient paint particles typically measured 20–50 µm.

While the most valued type of ancient purple dye comes from snails, the pigment in the painting seemed to be different. So the team took an incredibly up close and detailed look at one 50-µm pigment particle carefully extracted

Research News

World's largest 3D printer to cut wind turbine blade costs by half

The University of Maine received a $2.8 million government grant to develop a 3D printing solution to create large, recyclable, segmented wind blade molds. In 2019, the university commissioned the largest polymer 3D printer in the world to compliment its wind blade testing facility, which is the second largest in the U.S. The university also will collaborate with Oak Ridge National Laboratory, which received a $4 million award to better control mold surface temperatures. TPI Composites and Siemens Gamesa are partnering with the University of Maine on the project to transition the additive manufacturing solution into real-world applications. For more information, visit https://www.windpowermonthly.com.

Laser-writing method quickly converts a single starting material to circuit components

By controlling the power and other properties of a narrow beam of laser light as it scanned the surface of a thin film of molybdenum disulfide, researchers at the Air Force Research Laboratory and University of Dayton selectively modified the composition, crystallinity, and electronic properties of the film, transforming microscopic regions of the film into the three basic types of materials needed to build circuitry—a conducting phase (MoO_2), an insulator (MoO_3), and a semiconducting phase (2H-MoS_2). They used the laser-writing method to make resistors, capacitors, and other circuit components and fabricated an ammonia sensor with a detection limit below the part-per-million level. For more information, visit https://cen.acs.org/index.html.

from the painting by using energy-dispersive X-ray fluorescence (XRF) techniques to identify its elemental composition.

Results showed that the pigment particle contained lead, aluminum, titanium, silicon, potassium, iron, sulfur, and chromium. Yet analysis revealed no bromine, ruling out many of the commonly known sources of purple in ancient paintings, including snails and lichens.

Further chemical analysis with energy-dispersive X-ray spectroscopy confirmed the XRF results and indicated the particle was mostly organic. Specifically, the results indicated that the pigment was likely an organic lake pigment, "an organic dye affixed to an amorphous hydrated alumina substrate through the use of a potash alum mordant, potassium aluminum sulfate, $KAl(SO_4)_2 12H_2O$, used for dying since 1000 BCE," the authors write in the paper.

Elementally, the results suggested that the pigment was consistent with plant and insect sources, which were common sources of color in ancient works of art. However, the team was intrigued by the fact that sampling from different areas of the pigment particle revealed it had a heterogenous composition, surprising because organic lake pigments were previously thought to be amorphous.

Accordingly, further analysis with atom probe tomography—a technique that can determine the spatial distribution of elements in other materials but has not been previously applied to an organic pigment—revealed an interface between two phases of a tiny sample of the pigment particle.

Using focused ion beam milling, the team carved out an even tinier portion of the already tiny particle, exposing a 100-μm^2 cross-section of the pigment particle. Closer inspection with transmission electron microscopy revealed geology-like stratigraphy in the sample cross-section, again surprising because ancient lake pigments were thought to be amorphous.

The sample contained three distinct layers consisting of different elemental makeups and crystalline characteristics. Larger lead-based particles and crystallites were predominant in the outer layer, suggesting "growth was favored over nucleation" when the pigment formed, the authors write in the paper. The inner layer instead contained smaller crystallites, "suggesting nucleation was favored over crystal growth." The middle layer was heterogeneous, sort of like a gradient area between the two.

So what does it mean? "All of these reported findings point to a close association between the purple pigment particle and ancient dye practice and technology," the authors write. In other words, the findings suggest how an ancient artist may have formed such a pigment.

In the press release, University of Utah materials scientist Darryl Butt explains the findings may indicate that when Egyptian dyers produced red dye in lead vats, a sludge may have developed inside the vat that was a purplish color. "Or, they were very smart and they may have found a way to take their red dye, shift the color toward purple by adding a salt with transition metals and a mordant [a substance that fixes a dye] to intentionally synthesize a purple pigment. We don't know," he adds.

The open-access paper, published in *International Journal of Ceramic Engineering & Science*, is "Microstructural and chemical characterization of a purple pigment from a Faiyum mummy portrait" (DOI: 10.1002/ces2.10075).

Nanodiamonds measure thermal conductivity in living cells

Osaka University researchers created a device from fluorescent nanodiamonds coated with a heat-releasing polymer called polydopamine. When irradiated with laser light, the nanodiamonds emit light while the polymer heats up. Since the fluorescence of the nanodiamonds depends on their temperature, the researchers were able to use this fluorescence to calculate the rate of heat flow from the device to its surroundings. They tested the hybrid device by placing it inside two types of biological cells, and they found that the polymer heated up more in cells with a low thermal conductivity than in those with a higher thermal conductivity. For more information, visit https://physicsworld.com.

Decommissioned wind turbine blades get a second wind through reuse and recycling

Wind turbines last an average of 25 years. When it comes time to decommission a turbine, the blades pose a problem.

"About 85% of turbine component materials—such as steel, copper wire, electronics, and gearing—can be recycled or reused. But the blades are different as they are made up of fiberglass (a composite material)," a blog post by the Union of Concerned Scientists explains. "The mixed nature of the blade material makes separating the plastics from the glass fibers to recycle into a workable fiberglass material difficult—and the strength needed for the blades means they are also physically challenging to break apart."

Currently, the vast majority of turbine blades that reach end-of-use are either stored in various places or taken to landfills because there are few options for recycling. However, such an approach is not sustainable, especially when you consider the amount of material that is expected to be discarded in the coming years. Turbine blades average around 50 meters (164 feet) in length, with size expected to increase, and the U.S. alone is expected to decommission about 8,000 blades each year for the next four years.

Numerous companies have started investigating ways to decommission turbine blades sustainably. For example, Washington state-based startup Global Fiberglass Solutions developed a method to break down blades and press them into pellets and fiber boards for use in flooring and walls. In December 2020, GE Renewable Energy announced a multiyear agreement with Veolia North America to develop the first U.S. wind turbine blade recycling program of its kind.

These initiatives are needed, but breaking down turbine blades and turning them into new products is not the only way to recycle the blades. Repurposing wind turbine blades in their current form is the goal of researchers at the Cork Institute of Technology in Cork, Ireland.

Wind turbines play an essential role in renewable energy. Companies and organizations are working to make the decommissioning of blades a sustainable process.

Their Re-Wind project, which is supported by scientists from the Queen's University Belfast (Northern Ireland) and the Georgia Institute of Technology (U.S.), aims to repurpose wind turbine blades for a variety of civil engineering projects. The collaboration has investigated the feasibility of repurposing wind turbine blades since 2016, and this year they are set to debut their first two large-scale demonstrations to test the potential.

The first demonstration involves building a footbridge in Ireland using two wind turbine blades as replacements for steel girders, which are the main horizontal supports. Onshore wind management company Everun donated two decommissioned blades to the project this past December, and the Re-Wind collaborators expect to finish the bridge by May and install it in June.

The second demonstration, called "Blade Pole," is a collaboration with an electric power company to repurpose wind blades as large, high-voltage electrical transmission towers. The idea will be tested by installing three decommissioned blades as power towers on a wind farm in Kansas this summer. While the blades will not be connected to the electric grid for the initial trial run, Re-Wind engineers plan to study the structure's durability to determine if the idea is sound.

"We've got all the theory and calculations, but of course, as engineers, we also want to make sure that this works before putting live wires on it," says Larry Bank, Re-Wind team lead and research faculty member at Georgia Tech, in a Grist Magazine article.

Beyond these two projects, the Re-Wind team has numerous other ideas for repurposing wind turbine blades, including laying blades horizontally along stretches of coastlines to act as wake brakes, using blades to build better noise barriers for highways, and cutting up blades for use in affordable housing.

"What I'd love to do is turn it [Re-Wind] into a blade waste brokerage business," Angela Nagle, civil engineering Ph.D. student at the University College Cork, says in the Grist Magazine article.

Learn more about the Re-Wind team's projects and research by visiting the collaboration's website at https://www.re-wind.info. 100

Clay tiles restore coral reefs

During the global-scale coral bleaching event in 2014–2017, more than 75% of global reefs experienced mass heat stress and nearly 30% reached mortality levels, according to the NOAA Office for Coastal Management. Early in 2020, scientists reported another mass bleaching event, this one larger in scale and second only to the year 2016 in intensity.

The extreme bleaching extremely worries scientists because once corals die, reefs rarely come back. And without coral reefs, many marine animals will lose their homes, coastal communities will lose protection from flooding, and people who rely on reef fisheries for food and income will go hungry, among other adverse events. So restoring coral reefs damaged by bleaching as well as ocean acidification and pollution is an important task for marine researchers.

Among the numerous approaches to restoration, one method called structural restoration involves introducing artificial structures into areas where the reef was lost due to disturbances such as blast fishing, boat grounding, dredging, and landslides. In such circumstances, the seafloor is reduced to rubble or sand, and coral cannot attach to these loose surfaces. The artificial structures provide a solid surface on which the coral can attach.

To create these artificial structures, marine scientists and architects at the University of Hong Kong explored using 3D printing to fabricate structurally complex clay tiles. They initially considered using concrete or metal, but they decided on terracotta clay because it is more environmentally friendly.

In July 2020, the researchers seeded the almost 2-foot-wide hexagonal tiles with three species of coral fragments (Acropora, Platygyra, and Pavona) and then planted 128 tiles at three different sites in Hong Kong's Hoi Ha Wan Marine Park. They chose this marine park because, in 2018, Typhoon Mangkhut destroyed nearly 80% of the coral reefs in the Hoi Ha Wan bay, which is home to 60 species of coral reefs as well as 120 fish species.

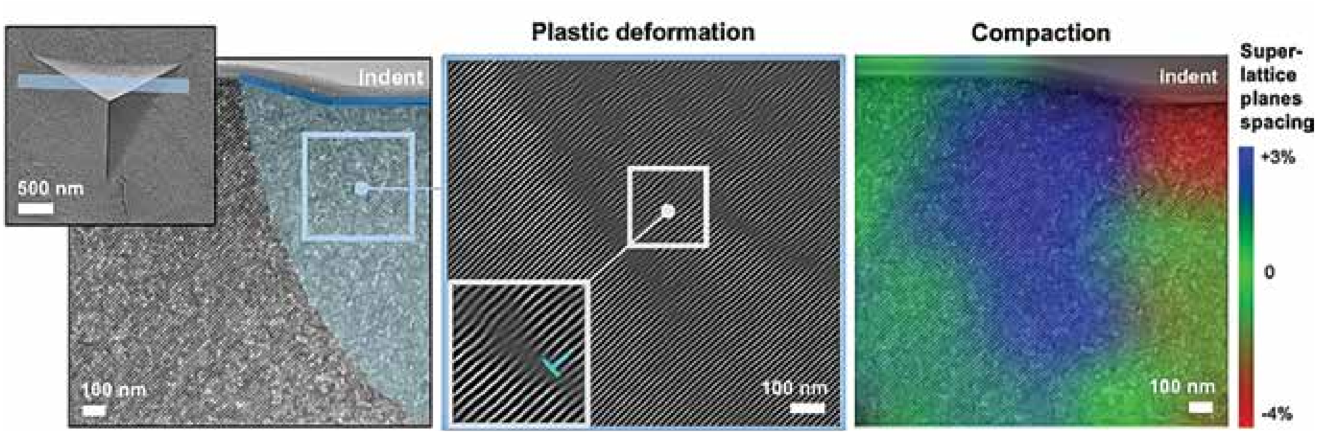
After two months, the scientists observed that 100% of the coral on the tiles still thrived. They plan to continue monitoring the site for the next one and a half years.

A video on this research is available at https://www.youtube.com/watch?v=G7VR08z99iU. 100

Credit: South China Morning Post, YouTube

A marine scientist tracks the progress of coral growing on a 3D-printed clay tile.

Designing on the nanoscale: Strong and deformable organically linked supercrystals



Organically linked supercrystals are an emerging type of nanocomposite that could have uses in next-generation electronics and as biomimetic structural materials. The above images come from a recent paper exploring the deformation mechanisms of such materials.

Researchers led by Gerold Schneider, professor of materials mechanics at the Hamburg University of Technology in Germany, explored creating organically linked supercrystals and investigated their properties.

Supercrystalline materials are one emerging approach to nanocomposite design. These materials consist of highly ordered, 3D assemblies of nanoparticles that are segmented into unit cells, i.e., the simplest repeating unit in a crystal, much larger than in ordinary inorganic crystals. Typically, the nanoparticles are assembled by interfacing with an ultrathin organic layer, which allows the composite to exhibit valuable inorganic and organic properties.

Thanks to this combination of nanosized building blocks and their periodic arrangement, supercrystals can feature a variety of functional properties, which give them great potential as structural bioinspired materials. In addition, supercrystals feature a quasi-isotropic mechanical behavior, meaning their mechanical properties have the same value when measured in different directions, in contrast to high-aspect-ratio layered structures.

Despite these advantages, researchers have struggled to fabricate organically linked supercrystals with good mechanical properties. That situation changed in 2016, when the researchers led by Schneider published a letter in *Nature Materials* detailing how they created organically linked supercrystals using oleic acid and iron oxide nanoparticles.

Their organically linked supercrystals exhibited exceptional quasi-isotropic mechanical properties because of the size of the nanoparticles. "The main difference from the approaches used thus far is the adjusted size of the nanoparticles in a close-packed supercrystal, such that monolayers of oleic acid molecules on the surface of the nanoparticles can bridge the tetrahedral and octahedral sites," they write. "This requirement is fulfilled for particle diameters smaller than 16 nm."

When this bridging occurs, the weak van der Waals interactions that typically hold the unit cells together become overridden by a network of covalent bonds, resulting in a shift from soft matter to strong inorganic-organic nanocomposites.

The organically linked supercrystal demonstrated exceptional elastic modulus of up to about 60 GPa, bending strength of up to about 630 MPa, and hardness of up to about 4 GPa. "To our knowledge these are the highest combined values of elastic modulus, strength and nanohardness ever reported for a synthetic bioinspired organic/inorganic nanocomposite, and similar to microcantilever beam and micropillar strengths and moduli values of enamel," the researchers write. (Since that study, the researchers increased these properties even more through further process optimization.)

In a new open-access study published in January 2021, the researchers explored the deformation behavior of their organically linked supercrystal. They chose this property because, if the supercrystal proved to be both mechanically strong and deformable, it would be ideal for electronic applications, especially next-generation stretchable or bendable devices.

They performed nanoindentation experiments to measure elastic modulus and hardness of the organically linked supercrystals, and the measurements allowed them to subsequently assess the nanocomposite's deformation behavior. In addition, they used a combination of atomic force microscopy, scanning electron microscopy, and transmission electron microscopy to visualize the supercrystalline structure, defects, and deformations.

Based on the experimental measurements, microscopy observations, and some accompanying finite element simulations, the researchers concluded that supercrystals, much like ordinary crystals, accommodate plastic deformation in the form of pileups, dislocations, and slip bands.

"The classic shear theories of crystalline materials are found to describe well the behavior of supercrystalline nanocomposites, which result to feature an elastoplastic behavior, accompanied by compaction," they write.

Ultimately, the researchers believe the good mechanical properties and ability to deform plastically means organically linked supercrystals can find applications as robust components for batteries and sensors, as well as biomimetic structural materials and bioimplants. At this point, though, the supercrystals' ductility and fracture toughness still need to be enhanced to reach the mechanical behavior desirable for flexible devices. But this study already unveils what can be achieved with crosslinked and noncrosslinked oligomers, and it defines the path toward further optimization.

The 2016 paper, published in *Nature Materials*, is "Organically linked iron oxide nanoparticle supercrystals with exceptional isotropic mechanical properties" (DOI: 10.1038/nmat4553).

The 2021 open-access paper, published in *Science Advances*, is "Defects and plasticity in ultrastrong supercrystalline nanocomposites" (DOI: 10.1126/sciadv.abb6063).

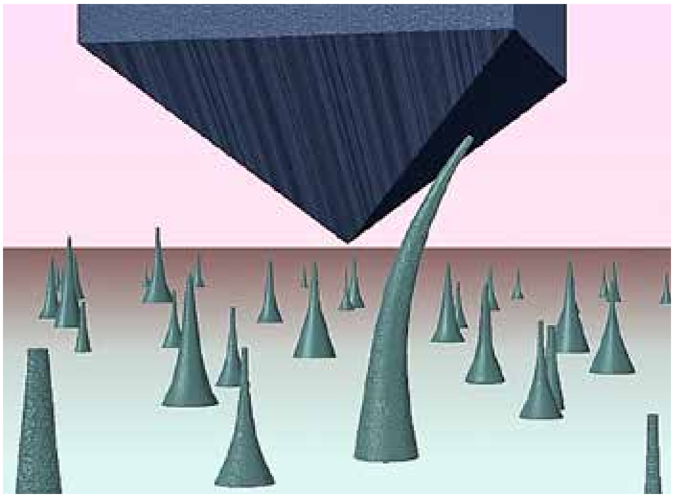
Bendable single-crystalline diamonds hold potential for next-generation electronics

An international team of researchers led by associate professor Yang Lu at the City University of Hong Kong are pushing the boundaries on creating nanodiamonds that can deform elastically.

Diamond has numerous desirable characteristics that would make it useful in electronics. However, modulating the material's electronic properties to desired specification is extremely difficult because of diamond's rigid crystalline structure.

One way to change a material's electronic properties is through strain engineering, or by deforming a material's lattice structure. In 2018, the researchers made headlines when they demonstrated that diamond nanoneedles could undergo fully reversible elastic deformation.

They accomplished this feat by using a nanoindenter diamond tip to bend the diamond nanoneedles, which they observed with a scanning electron microscope. They then combined the real-time bending experiment videos with finite element method analysis to determine that single-crystalline nanodiamonds can achieve maximum local tensile strains up



A schematic diagram showing the "push to bend" nanomechanical test on a diamond nanoneedle. After an international team of researchers demonstrated this property in 2018, they continued studying the phenomenon and published a follow-up paper in January 2021.

to 9%, which is well above the 0.1%–0.35% strain recorded for bulk diamonds in the past.

In a CityU press release, Lu described the team's feelings as "extremely exciting," but he noted that this study was only the beginning of the research that could take place. In the almost three years since then, Lu and his colleagues investigated the phenomenon further, and in January 2021 they published a follow-up study that more fully explores the possibility of using single-crystalline diamonds in functional electronic devices.

They microfabricated bridge-shaped single-crystalline diamond samples and then uniaxially stretched them in a well-controlled manner. As in the 2018 paper, they combined real-time videos with density functional theory calculations to determine the tensile strain performance.

They determined that the diamond bridges demonstrate a highly uniform, large elastic deformation of about 7.5% strain across the whole gauge section of the specimen, rather than deforming in a localized area. After optimizing the sample geometry and microfabrication process, they increased the maximum uniform tensile strain up to 9.7%, a value that surpassed the maximum local value in the 2018 study.

Of course, the goal of deforming the diamond is to change its electrical properties. So the researchers followed up the tensile strain experiments by investigating how the elastic straining affected the diamond's bandgap.

Using both calculations and experiments, they concluded that the bandgap generally decreases as the tensile strain increases, with the largest bandgap reduction being a drop from about 5 eV to 3 eV at around 9% strain along a specific crystalline orientation [101].

In addition, their calculations suggest with tensile strains larger than 9% along a specific crystalline orientation [111], the bandgap could transition from being indirect to direct, meaning it would serve more efficiently in optoelectronic applications.

"I believe a new era for diamond is ahead of us," Lu says in a CityU press release.

The 2018 paper, published in *Science*, is "Ultralarge elastic deformation of nanoscale diamond" (DOI: 10.1126/science.aar4165).

The 2021 paper, published in *Science*, is "Achieving large uniform tensile elasticity in microfabricated diamond" (DOI: 10.1126/science.abc4174). 100

Researchers grow graphene nanoribbons for lower cost at higher yield

Researchers led by the Moscow Institute of Physics and Technology (MIPT) in Russia developed an alternative synthesis method for graphene nanoribbons.

Out of all carbon allotropes, graphene nanoribbons are one family that does not receive as much attention. Graphene nanoribbons are finite strips of graphene with width less than 50 nm. The two most common edge geometries of graphene nanoribbons—zigzag and armchair—impart the nanoribbon with noticeably different electronic properties. The zigzag geometry, in which atoms along the edge come from the same sublattice, give the nanoribbon conducting properties. The armchair geometry, in which atoms along the edge come from two different sublattices, give the nanoribbon semiconducting properties that are valuable for electronics.

Graphene nanoribbons typically are created using a bottom-up synthesis approach because it provides more control over the edge geometry, and it more easily allows production of nanoribbons with narrow widths on the order of a few nanometers. The synthesis commonly involves on-surface chemical reactions that occur in two stages. In the first stage, halogen-containing molecules are adsorbed on a gold substrate, at which point substrate-assisted dehalogenation and aryl–aryl coupling of monomers into polymeric structures occurs. In the second stage, the polymeric structures are thermally transformed into graphene nanoribbons via cyclodehydrogenation and planarization.

There are several drawbacks to this synthesis process. For one, the process is quite costly due to the gold substrate and the ultrahigh vacuum conditions needed to facilitate effcient aryl–aryl coupling (<10^{-9} mbar). In addition, very few nanoribbons are produced at a time, so material output is comparatively low for the price. Fortunately, recent advances in chemical vapor deposition techniques have opened the door to address some of these drawbacks, and that is what the researchers of the recent study did.

The MIPT researchers, as well as colleagues from Skolkovo Institute of Science and Technology and the A.M. Prokhorov General Physics Institute of the Russian Academy of Sciences, developed the approach based on their previous work growing graphene nanoribbons inside single-walled carbon nanotubes, which served to constrain ribbon width.

"To form surface assisted bottom-up graphene nanoribbons, we used the same setup with modified synthesis parameters and a different substrate and precursor molecules," say Elena Obraztsova and Pavel Fedotov, head and senior researcher, respectively, at the MIPT Laboratory of Nanocarbon Materials, in an email.

Instead of a gold substrate, they placed a common nickel foil in a glass tube together with a solid precursor (10,10′-dibromo-9,9′-bianthracene molecules, or DBBA). They sealed the tube under moderate vacuum conditions (10^{-3} mbar) and then placed it in a quartz tube reactor, where it was subjected to the two-stage annealing process.

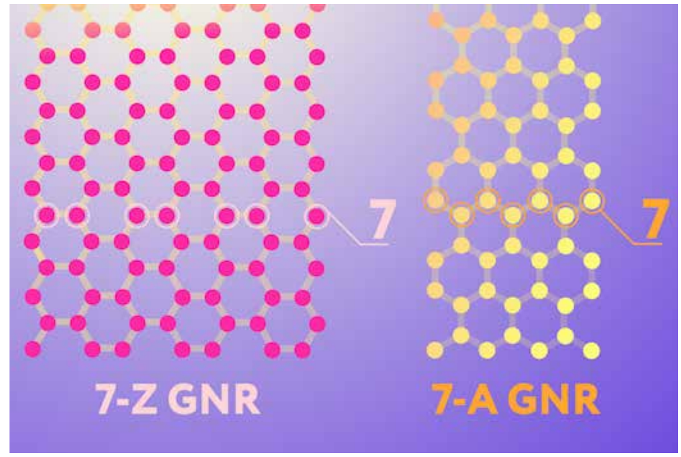
Multiwavelength Raman spectroscopy testing revealed the graphene nanoribbons produced using the new method compared in quality to graphene nanoribbons fabricated using conventional methods that require ultrahigh vacuum conditions and a gold substrate.

In addition, the nanoribbons grew as thick films that could be separated into multiple ribbons, in contrast to the thin films produced by conventional ultrahigh vacuum processes. Obraztsova and Fedotov say this difference in film thickness is because they optimized the setup to produce thick films rather than monolayers. For example, instead of a careful dose of DBBA molecules used in conventional setups, their process requires DBBA molecules in excess.

The researchers now are working on optimizing the synthesis parameters to produce not only seven-atom armchair graphene nanoribbons but also graphene nanoribbons of different types, by using other molecules besides DBBA.

"In our future studies, we are planning to examine the optical properties of different types of semiconducting graphene nanoribbons," Obraztsova and Fedotov say. "Our goal is to register characteristic Raman, UV-Vis-IR optical absorption, and photoluminescence that are fingerprints of particular type of graphene nanoribbons."

The paper, published in *The Journal of Physical Chemistry C*, is "Excitonic photoluminescence of ultra-narrow 7-armchair graphene nanoribbons grown by a new 'bottom-up' approach on a Ni substrate under low vacuum" (DOI: 10.1021/acs.jpcc.0c07369). 100



Two nanoribbon edge configurations. The pink network of carbon atoms is a ribbon with zigzag (Z) edges, and the yellow one has so-called armchair (A) edges. Note that while nanoribbons come in many different widths, the ones in the image are by convention both considered to be seven atoms wide.

Potential of potassium carbonate as flux in continuous steel casting

Credit: Primetals Technologies, YouTube

In continuous steel casting, ceramic powders help keep the liquid metal from oxidizing. Potassium carbonate may serve as an alternative and less expensive material from which to make powders.

Two researchers from Shinagawa Refractories Co. in Okayama, Japan, investigated the potential of potassium carbonate as flux in continuous steel casting.

In continuous steel casting, liquid steel is poured from a furnace ladle through a small, refractory-lined distributer called a tundish and into the mold, where the metal cools and solidifies into its final form.

Ceramics are used to line the ladle, tundish, and mold to protect against corrosion and decomposition. However, ceramics also are used in the continuous casting process in the form of powders spread on top of the liquid metal.

"The liquid steel must be protected from exposure to air: if not, then oxygen will react to form detrimental oxide inclusions in the steel," explains an article by TA Instruments. Thus, special powders are continuously fed on the surface of the liquid metal during casting to prevent this oxidation from occurring.

These powders mainly consist of calcium oxide (CaO) and silicon dioxide (SiO_2). The powder's melting point and viscosity are adjusted using flux compositions such as sodium oxide, lithium oxide, and fluorine.

Unfortunately, "the choice of flux is narrow due to the soaring price of Li_2O raw material," the researchers write in their article. Their solution? To examine potassium oxide (K_2O), another alkali metal oxide, as an alternative flux composition.

In their study, they chose to use potassium carbonate as a source of potassium oxide because it "is easy to use without limits for composition design."

However, potassium carbonate is known for deliquescence, which is the tendency of a solid to absorb moisture from the air and dissolve in it. Such a property is detrimental in steel casting because "if the raw material absorbs moisture in the production process in the factory, it will solidify in the raw material hopper or adhere to production facilities such as mixers or belt conveyors, which impedes productivity."

To prevent deliquescence, Okada and Ito investigated whether potassium carbonate could be converted to a stable mineral by mixing and heating it with other raw materials used in casting powder. Specifically, they investigated four commonly used casting powder materials—silica, calcium carbonate, Portland cement, and alumina—as possibilities.

They mixed the potassium carbonate with each raw material at a weight ratio of 1:1 and then heated the mixture in an electric furnace at 800°C for 30 minutes. After the samples were removed from the furnace and left in the atmosphere, the researchers measured weight change with elapsed time.

The samples mixed and heated with silica, Portland cement, and alumina all showed a large weight increase and were wet after nine days, indicating that deliquescence occurred. However, the sample mixed with calcium carbonate showed a small weight increase and stayed dry, so the researchers focused on this composition.

The researchers believe that deliquescence was prevented because a new crystal structure formed when the potassium carbonate and calcium carbonate combined, namely $K_2Ca(CO_3)_2$—and they confirmed the existence of this crystal structure in the fired sample using XRD analysis.

The rest of the article mainly details their attempts to identify the best way to manufacture $K_2Ca(CO_3)_2$, including by modifying melting temperature and weight ratio. They tested the resulting powder by throwing it on hot molten metal at 1,500°C, and the test showed "no problem of moisture absorption and exhibited good melt behavior."

In the conclusion, they close by stating, "Since the only component other than K_2O in this material is CaO, which is the main component of mold powder and tundish powder, $K_2Ca(CO_3)_2$ is considered to be a solution for adding K_2O to the composition of mold powder and tundish powder."

The paper, published in *Journal of the Technical Association of Refractories, Japan*, is "Prevention of potassium carbonate deliquescence." (Original title: 炭酸カリウムの潮解抑制. Translated from Taikabutsu, January 2019, pg. 9.) 100

Laser-based process allows direct creation of 3D glass structures

Researchers in France explored the use of two-photon polymerization to 3D print glass.

Polymerization is a process of reacting monomer molecules together in a chemical reaction to form polymer chains or 3D networks. Researchers have exploited photopolymerization-induced phase separation of hybrid resins or hybrid ceramic precursors that can undergo both the photopolymerization reaction and a sol-gel process to create transparent silica parts.

However, "The common approach in these works … is to create multiple two-dimensional (2D) slices and then stack these slices to form 3D objects. This layer-by-layer process has numerous limitations: manufacturing time, mechanical anisotropy properties, shrinkage, shear stress, robust implementation time of layers of constant thickness, need for the creation of supports for complex parts and their elimination in a post-processing operation, etc.," the researchers write.

They argue that most of these drawbacks are linked to the layer-by-layer procedure. Direct creation of 3D structures would therefore overcome these limitations, and that is exactly what two-photon polymerization offers.

"[In two-photon polymerization], polymerization is activated by the simultaneous absorption of two photons of an intense laser radiation, only taking place at high laser intensity within a spatially localized focal spot in the monomer with a photosensitive initiator," they write. "Then, with the [two-photon polymerization] technique, it is possible to polymerize volumes inside the polymer liquids contrary to the conventional one-photon-based process (such as stereolithography), in which polymerization takes place only on the liquid surface or close to it."

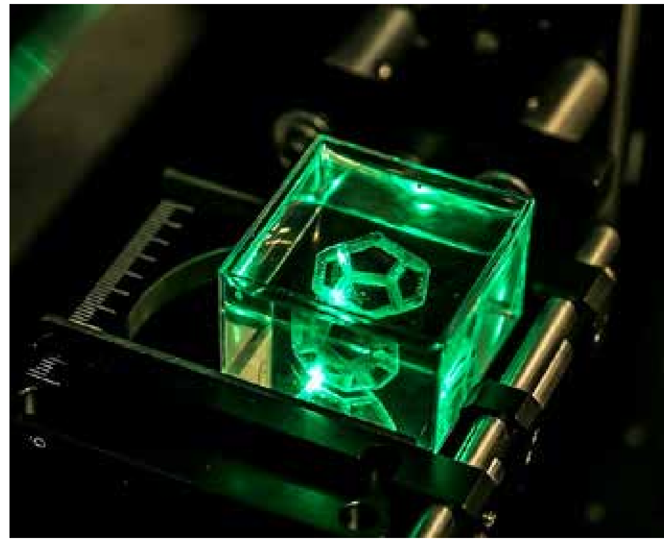
To test the potential of 3D printing glass through two-photon polymerization, the researchers mixed a high-viscosity transparent resin and loaded it with silica nanoparticles until the dispersion reached 50 wt. % of nanoparticles of silica. A photoinitiator (1 wt. %) then was added to absorb the laser light and initiate two-photon polymerization.

The researchers used a commercial femtosecond diode pumped ytterbium amplified laser to trigger two-photon polymerization of the dispersion. Then, the solidified structures were rinsed with isopropyl alcohol and underwent thermal post-treatments to transform the polymerized green parts into silica glass.

The final silica glass parts did not show any cracks or breakages, and the measured density of the samples was 2.18 g/cm^3, which is close to the theoretical value of amorphous silica. These results illustrate that the researchers "optimized the thermal post-treatments and showed the importance of them on the success of the global process."

A press release by The Optical Society notes that the researchers are working to make the technique more practical and reduce cost by experimenting with less expensive laser sources, for example. However, the results already show that "Our approach could potentially be used to produce almost any type of 3D glass object," Laurent Gallais, researcher and associate professor at the Fresnel Institute and École Centrale de Marseille, says.

The paper, published in *Optics Letters*, is "3D printing of silica glass through a multiphoton polymerization process" (DOI: 10.1364/OL.414848). 100



Credit: Laurent Gallais, The Fresnel Institute and École Centrale de Marseille

A picture of the developed 3D printing laser system based on two-photon polymerization. The laser source is a commercial femtosecond diode pumped ytterbium amplified laser.

Ceramic and glass materials for a sustainable energy future

By Ram Devanathan, Daiwon Choi, Olga Marina, Josef Matyáš, and Suresh Baskaran

Durable ceramic and glass materials underpin advances in electricity generation, energy conversion and storage, and waste disposal.

Global energy use is expected to rise 50% by 2050 due to population growth and increase in per capita energy use.[1] Concerns about the influence of burgeoning energy consumption on climate change drive interest in sustainable energy technologies that produce minimal environmental impact, avoid resource depletion, and are economically viable and socially beneficial.

Solar, wind, water, bioenergy, nuclear, geothermal, hydrogen, and fuel cell technologies have important roles to play in paving the path to sustainable development. Given the variability of wind and solar power, advances in energy storage are crucial to support increased adoption of renewable electricity generation and the reliability of the electric grid.

Ceramic and glass materials are ubiquitous in energy technologies because of their unique properties, such as high temperature stability, wear and corrosion resistance, thermal and electrical insulating properties, superconductivity, and radiation tolerance. These materials find uses in thermal barrier coatings, photovoltaic cells, solar cell substrates, thermoelectrics, batteries, supercapacitors, fuel cells, solid oxide electrolysis cells, refractories, electrical insulators, superconducting magnets, gas turbine components, fission reactor fuel, fusion reactor structures and blankets, and wasteforms for safe, long-term immobilization of nuclear waste.

Given the sheer diversity of these applications, we focus this brief overview on recent developments in selected energy technologies in which ceramic and glass materials are proving indispensable.

Electrochemical energy storage

Ceramics play a vital role in energy storage and conversion devices widely used in portable electronic devices, electric vehicles, and stationary storage to support the rapid growth of renewable energy. This field is currently dominated by lithium-ion batteries driven by the adoption of environmental norms and regulatory support.[2]

The discovery of novel ceramic electrodes and ionic conductors with suitable crystal structure, chemical stability, electronic/ionic conductivity, particle size, and grain boundary enabled the commercialization of lithium-ion, sodium-ion, and sodium–sulfur batteries. Among various lithium-ion battery chemistries, the layered lithium nickel manganese cobalt oxide cathode (NMC: $LiMO_2$, where M=Ni, Mn, or Co) is forecasted to grow at a higher rate than other chemistries due to higher energy/power density at lower cost with better thermal stability than commercial $LiCoO_2$ (LCO), $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ (NCA), $LiMn_2O_4$ (LMO), $LiNi_{0.5}Mn_{1.5}O_4$ (LNMO), and $LiFePO_4$ (LFP).[3]

As an original NMC cathode, $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ (NMC-111), also known as "1-1-1," has been developed as one of the most successful lithium-ion cathodes. Subsequently, the NMC family grew in diversity through the composition of $N_xM_yC_z$ cathodes (x:y:z = 4:3:3, 5:3:2, 6:2:2, 8:1:1, and $x + y + z = 1$). To meet the requirements for future automotive markets (electric, hybrid electric, and plug-in hybrid electric vehicles), progress toward NMC with a high nickel content (> 70%), high capacities of more than 200 mAh/g, and voltage of about 3.8 V vs. Li/Li^+ is inevitable. However, the challenge is that higher nickel content in NMC aggravates surface-related degradations, including surface phase transformation, transition metal dissolution, lattice oxygen release, and electrolyte decomposition. Therefore, in recent years, battery manufacturers are actively transitioning from polycrystalline to single-crystal nickel-rich material to reduce internal surfaces (Figure 1).

The tuning of microstructure and particle morphology[4] to optimize high-Ni NMC is promising because intergranular fracture disrupts the electronic/ionic conduction pathway and dramatically increases particle surface area. In addition, higher electrode compact density (>3.8 g/cm^3 for NMC electrodes) is possible with the single-crystal particles because they are less prone to cracking during pressing. Higher density can be realized through control of calcination conditions including temperature, duration, atmosphere, lithium/metal ratio, and post surface treatments. These research advances are pivotal to realizing enhanced cycling stability, energy density, and other desired electrochemical properties.

Meet a PNNL STEM Ambassador: Charmayne Lonergan

Charmayne Lonergan is a materials scientist at Pacific Northwest National Laboratory in Richland, Washington, whose work focuses on the vitrification of nuclear waste. She also is part of the PNNL STEM Ambassador program, which trains PNNL staff members on how best to convey the impact and relevance of their work to various audiences.

Lonergan talked about her experience becoming a STEM Ambassador on the seventh episode of ACerS podcast Ceramic Tech Chat, a preview of which is below.

"I think I was actually one of the first ambassadors that went through the program. But basically, we took our projects … and we basically [answered], 'What is a glass, why is it useful for trapping nuclear waste, what are the things that we kind of care about.' And those were more designed to be able to go to a classroom or, what we often do, which was setup somewhere on campus and have a display.

The biggest thing that I've realized people didn't know that our outreach has done, which is when we talk about waste vitrification, or you know, trapping waste in glass, containing waste in glass, immobilizing, whatever you'd like to call it, a lot of people think that it's like the waste is a soda and we're pouring it into a bottle and then capping it. And what actually is happening is the waste is the color of the bottle. You're mixing the waste with the chemicals of the frit and you're turning it into the glass. So, it's not something being poured into a vessel and trapped, it's becoming part of the vessel, and it's one solid piece. And hence why that's so robust, and we can feel confident that we won't have appreciable amounts of radioactive or harmful things released into the environment over hundreds of thousands of years."

Learn more about PNNL's STEM Ambassador program at https://www.pnnl.gov/stem-outreach. And listen to Lonergan's whole interview—plus all of our other Ceramic Tech Chat episodes—at https://ceramictechchat.ceramics.org/974767. 100

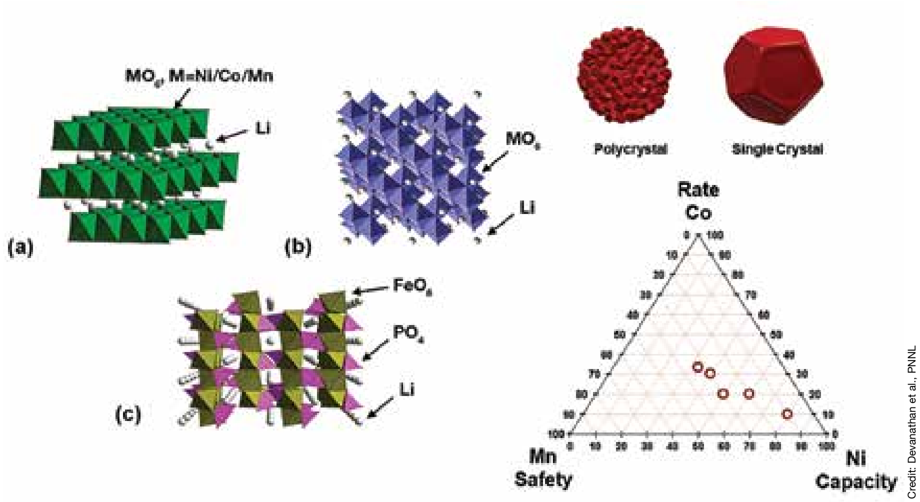


Figure 1. Crystal structures of cathode materials. (a) Layered structure ($LiMn_xNi_yCo_zO_2$), (b) Spinel structure ($LiMn_2O_4$), and (c) olivine structure ($LiFePO_4$). The polycrystal and single crystal morphologies and a representation of compositions of interest are also shown.

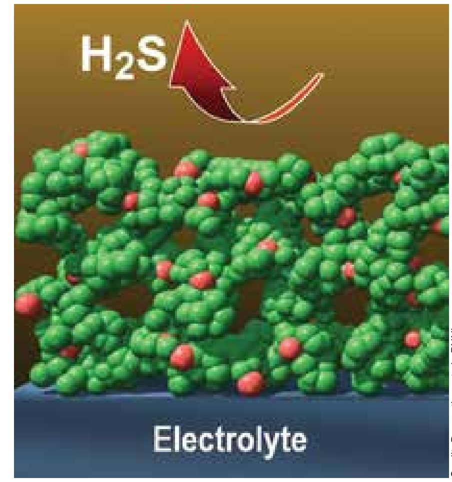


Figure 2. Schematic representation of a new class of high performing, electrically conductive, and catalytically active ceramic electrodes that tolerate carbon and sulfur.

Solid oxide fuel cells, electrolyzers, and oxygen separation

Ceramics are the main constituents of solid oxide fuel cells (SOFC), which are devices that directly convert chemical energy stored in fuels (e.g., H_2, CH_4, NH_3, and CO) to electrical energy via electrochemical reactions, and high-temperature solid oxide electrolysis cells (SOEC), which are devices that convert water vapor and renewable electricity to green fuel (hydrogen).[5] High-temperature electrolysis is a most promising technology for large scale energy storage and production of synthetic fuels in the zero-carbon economy via CO_2 electrolysis or co-electrolysis with steam to chemicals, such as CO, synthesis gas, methanol, dimethyl ether, and formic acid.

The all-solid state SOFC and SOEC devices are comprised of a ceramic oxygen ion- or proton-conducting electrolyte, a ceramic oxygen electrode, and a ceramic or ceramic-metal composite hydrogen electrode. This arrangement requires that the thermal expansion coefficients of a fully dense electrolyte and highly porous electrodes must match at the interfaces without forming any interfacial compounds on sintering or operation to produce the maximum electrochemical performance. The solid electrolyte must possess an adequate ion conductivity; be chemically stable in both oxidizing and reducing environments; and chemically, thermally, and mechanically stable during thermal cycling and operation. The ionic transference number of the electrolyte must be close to unity.

The most commonly used oxygen-ion conducting electrolytes are scandia- or yttria-doped zirconia (YSZ), gadolinia- or samaria-substituted CeO_2, and (La,Sr)(Mg,Ga)O_3. These electrolytes all exhibit high oxygen ion conductivity above 600°C, thus making SOFCs and SOECs suitable for operation at high temperatures, 600–1,000°C. Proton-conducting electrolytes, barium cerates, $BaCe_{0.9}Y_{0.1}O_{3-\delta}$, and barium zirconates, $BaZr_{0.9}Y_{0.1}O_{3-\delta}$, exhibit high conductivity in a lower temperature range of 400–600°C, but they are highly refractory, with poor sinterability below 1,600°C. By using multiple dopants, such as cerium, yttrium, and ytterbium, the sintering properties of the zirconates were recently significantly improved, yielding a relative density of 95%.[6]

Steam electrolysis in SOEC or fuel oxidation in SOFC takes place on a hydrogen electrode, typically a nickel-YSZ or nickel-ceria cermet. However, highly electrically conductive ceramics also are being used as the electrodes and the interconnects. Pacific Northwest National Laboratory developed a new class of high performing electrically conductive and catalytically active ceramic electrodes, such as lanthanum-doped $SrTiO_3$ – ceria and yttrium-doped chromite-ceria composites, that unlike metal electrodes also offer redox, carbon, and sulfur tolerance (Figure 2). The opposite electrode, where the oxygen reduction or oxygen evolution reaction takes place, is often made of the ceramics with the perovskite structure: (La,Sr)MnO_3, (La,Sr)(Co,Fe)$_3$, or doped nickelates.

Because of limited metal stability at high temperatures in dual gas environments, ceramics are being investigated for use as an interconnect. Acceptor-doped lanthanum chromites and calcium- and transition metal-doped yttrium chromites were identified as promising ceramic interconnects to potentially overcome technical limitations of metals. In addition, highly stable ceramic composite membranes based on mixed ionic-and electronic-conducting ceramics are receiving increasing attention due to their potential applications for high-purity oxygen production, oxyfuel combustion, hydrogen/syngas production, coal gasification, and waste recovery.

Nuclear fission and fusion reactors

Ceramic science and technology have a crucial role to play in advancing nuclear fission power, which provided 55% of the carbon-free clean electricity generated in the United States in 2019. Because nuclear reactors operate at full capacity most of the time and their output can be ramped up and down, they can be used to balance the intermittency of renewable energy.

The typical fuel used in light water reactors is UO_2, a fluorite structured ceramic. Plutonium–uranium mixed oxide is an alternative fuel that powers about 10% of France's nuclear reactors. These oxides are ideal for the extreme environment of a nuclear reactor because of their high melting temperature (2,865°C for UO_2), radiation tolerance, ability to retain fission products, and chemical and dimensional stability. There is interest in increasing the fuel burnup to improve the economics and extend the operating cycle. It is essential to understand the effects of high fuel burnup on the fuel pellet microstructural stability, formation of noble metal phases from the aggregation of metallic fission products (palladium, ruthenium, rhodium, technetium, and molybdenum), gaseous fission product transport and release, and internal pressure on the cladding.[7]

In addition to actinide oxides, silicon carbide (SiC), a strong, durable, and radiation resistant ceramic with good thermal conductivity, is of considerable interest to the nuclear energy community. SiC is being investigated as an accident-tolerant cladding material. SiC also serves as a pressure vessel and barrier to fission product release in the TRi-structural ISOtropic (TRISO) particle fuel proposed for advanced reactors that are safer by design, able to quickly ramp output to balance renewables, and produce less waste. Micro and small modular versions of advanced reactors are being considered for deep space missions, powering military bases, and providing electricity and heat to remote communities.

SiC-based composites also are promising candidates for fusion reactor structural applications because of their low induced radioactivity and ability to withstand thermal shock and neutron damage.[8] Nuclear fusion powers the sun. Deuterium-tritium fusion has the potential to power human civilization for centuries without long-lived nuclear waste if it can be harnessed. However, recreating controlled fusion on earth is challenging due to the need for durable materials that can survive the harsh environment for years. In a fusion reactor, materials at the plasma interface are regularly exposed to extreme operating conditions, such as high temperatures, large heat loads, neutron bombardment, and surface erosion by ions. Ceramic–ceramic and ceramic–metal composites are well suited to this challenge. In addition to structural applications, ceramics and composites are needed for uses as plasma-facing materials, insulators, superconductors, and tritium breeding blankets in fusion reactors.

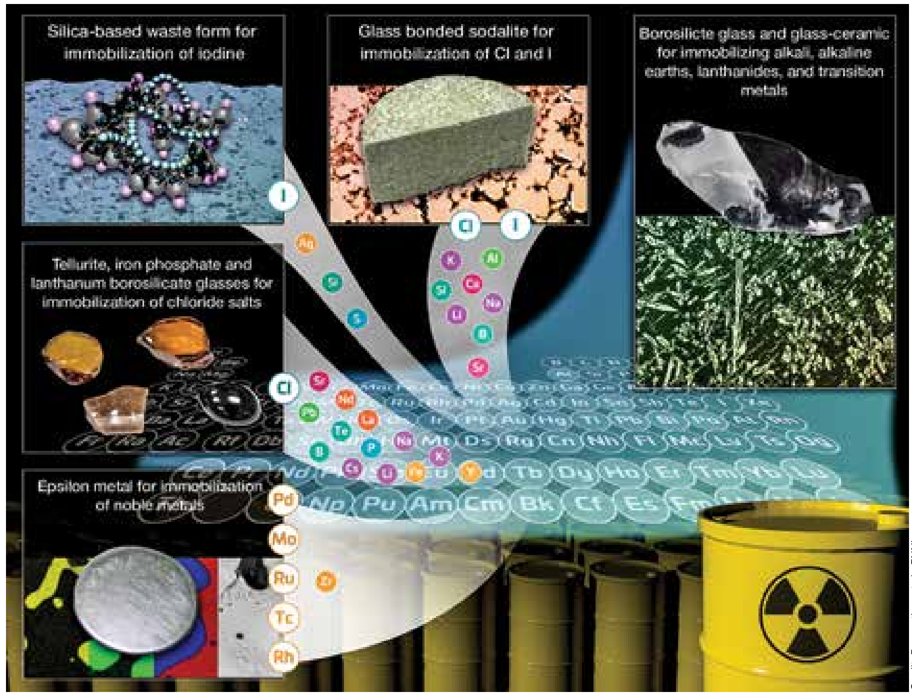


Figure 3. Illustration of ceramics and glasses being considered for immobilization of nuclear waste.

Immobilization of nuclear waste in glasses and ceramics

The increased use of nuclear power and the associated reprocessing of spent nuclear fuel would produce nuclear waste of varied composition and quantity. This new waste, together with radioactive waste from past activities, requires effective and safe nuclear waste management. Chemically and mechanically durable ceramics, such as pyrochlore, zircon, and Synroc, glass-ceramics, and glasses are needed to develop waste forms with high waste loading for safe and long-term storage (Figure 3).

Borosilicate glass is accepted throughout the world as universal waste form for immobilization of radioactive waste. The advantage of its versatility comes from the fact that the glass structure can accommodate almost all the elements of the periodic table. However, this benefit comes with the cost of low waste loadings for some components such as molybdenum, lanthanides, noble metals (e.g., palladium, ruthenium, and rhodium), and halogens (chlorine and iodine) because of their limited solubility in the glass. Glass-ceramics[9] offer the option to incorporate these components at high loadings into specific durable crystalline phases by tailoring the chemistry and cooling rates. Lead tellurite, iron phosphate, lanthanum borosilicate glasses, and glass-bonded sodalite exhibit high chloride salt loadings. A high iodine-loaded and durable silica-based waste form can be produced by consolidation of silver-functionalized silica aerogel sorbent by simultaneous application of fast heating rates to temperatures above 1,000°C and pressures up to 210 MPa.[10] There is considerable potential to tailor glasses and ceramics for specific waste streams.

Outlook

The growing focus on sustainable development worldwide will drive energy and materials technology developments. The need for lower emissions, higher efficiency, and improved materials performance will push the operating envelope for materials to more extreme conditions. Innovations in ceramics and glasses will drive advances in energy conversion and storage, hydrogen and fuel cell technology, next-generation fission and fusion nuclear reactors, and environmental remediation.

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References

[1]International Energy Outlook 2019, U. S. Energy Information Administration, Washington DC (2019).

[2]Z. Yang et al., "Electrochemical energy storage for green grid," *Chem. Rev.*, **111**[5], 3577–3613 (2011).

[3]W. Li et al., "High-nickel layered oxide cathodes for lithium-based automotive batteries," *Nature Energy*, **5**[1], 26–34 (2020).

[4]Y. Bi et al., "Reversible planar gliding and microcracking in a single-crystalline Ni-rich cathode," *Science*, **370**[6522], 1313 (2020).

[5]O. A. Marina et al., "Electrode performance in reversible solid oxide fuel cells," *J. Electrochem. Soc.*, **154**, B452–B459 (2007).

[6]B. Hu et al, "Solid oxide electrolysis for hydrogen production: From oxygen ion to proton conducting cells," *ECS Transactions*, **85**[10], 13–20 (2018).

[7]M. Tonks et al., "Unit mechanisms of fission gas release: Current understanding and future needs," *J. Nucl. Mater.*, **504**, 300–317 (2018).

[8]T. Koyanagi et al. "Recent progress in the development of SiC composites for nuclear fusion applications," *J. Nucl. Mater.*, **511**, 544–555 (2018).

[9]J. Crum et al., "Cold crucible induction melter studies for making glass ceramic waste forms: A feasibility assessment," *J. Nucl. Mater.*, **444**[1-3], 481–492 (2014).

[10]J. Matyáš et al., "Silica-based waste form for immobilization of iodine from reprocessing plant off-gas streams.", *J. Nucl. Mater.*, **476**[1], 255–261 (2016).

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Process modeling of a sanitary ware tunnel kiln

By Denny Mathew Alex, Tino Redemann, and Eckehard Specht

Process modeling offers a way to understand the physics and temperature profile in a tunnel kiln without the need for an expensive experimental setup or significant amounts of time.

Bricks, roof tiles, vitrified clay pipes, and sanitary wares are all ceramic products that need to be fired at a high temperature to get their robust characteristics. Tunnel kilns are the apparatus in which such firing often takes place.

Tunnel kilns can be described as a rectangular chamber with a height of more than 3 meters, width of almost 2 meters, and length of more than 100 meters. The temperatures in the tunnel kiln can reach more than 1,000°C, depending on the product being fired.

Generally, a tunnel kiln has three different sections, namely the preheating zone, the firing zone, and the cooling zone. Unfired products are fed through the entrance and into the preheating zone on kiln cars. In the preheating zone, the unfired ceramic products are heated to more than 600°C by the hot gases coming from the firing zone. In the firing zone, the preheated ceramic products are heated to more than 1,000°C by combustion of fossil fuels, mainly natural gas. Finally, in the cooling zone, the fired ceramic products are cooled by air, which is supplied from the exit of the tunnel kiln. Throughout the process, the ceramic products move in a direction opposite to that of the gas all along the tunnel kiln, which makes the working of the tunnel kiln similar to that of a counter-current heat exchanger.

As ceramic products move through a tunnel kiln, they undergo extreme temperature fluctuations. The temperature profile of the ceramic product is the most important parameter that determines the quality of the final fired ceramic product. So, the main aim of industry is to keep the temperature profile of the ceramic product as it is, irrespective of the production rate.

Sections of this article were previously published at the European Conference on Industrial Furnaces and Boilers. See reference 6 for full citation.

Experimental investigation of a ceramic product's temperature profile as it moves through a tunnel kiln is a very energy intensive and expensive process. First, construction of a scaled experimental tunnel kiln setup for understanding the process is very expensive. Second, even if a scaled experimental setup is constructed, the time needed to undertake experiments is quite long because the experimental measurements are recorded after achieving steady state working condition.

Therefore, a process model helps in understanding the physics happening in the tunnel kiln without the need for an expensive experimental setup or significant amounts of time. Once a process model for the tunnel kiln is developed, it also can be used to predict the behavior when it has different operating conditions, like change in production rate or when a different material for the kiln car is used.

Kiln description and measurements

We developed a process model for an industrial tunnel kiln that produces sanitary wares such as wash basins and water closets (Figure 1). The unfired sanitary wares are kept on kiln cars with the help of furniture, and the kiln car moves along the tunnel kiln on rail tracks. In the preheating zone, there are a set of preheating burners that supply combustion gas and a set of nozzles that supply fresh air all along the preheating zone. In the firing zone, there are burners that use natural gas for the combustion to bring the temperature of the ceramic product above 1,000°C, and the produced combustion gas is mixed with the preheated air coming from the cooling zone. Cooling air from the exit of the tunnel is supplied to the entrance of the kiln, and fast cooling air also is supplied at different locations in order to get a high cooling rate at the required location. All along the cooling zone there are airways between the inner wall and outer wall of the tunnel kiln. The air that is forced through the airways takes out heat from the inner wall, which is heated due to solid-solid radiation from the fired sanitary wares. This method of cooling along the cooling zone is known as indirect cooling.

The tunnel kiln that we modeled is almost four decades old and does not have measuring devices such as mass flowmeters installed to get information regarding combustion air or fast cooling air. Hence, measurements had to be done manually with the help of a Pitot tube, an anemometer, and a thermocouple. After the measurements, mass balance of the gas was obtained, which showed that the amount of gas coming out through the exhaust is more than what is supplied. This difference is called false air, and it is the air which gets sucked into the tunnel kiln, particularly at the unclosed entrance of the tunnel kiln because of the extraction of the exhaust gas by the blower.

To measure the temperature profile of the sanitary ware along the tunnel kiln, a test kiln car with thermocouple enclosed in a ceramic tube was sent through the kiln.

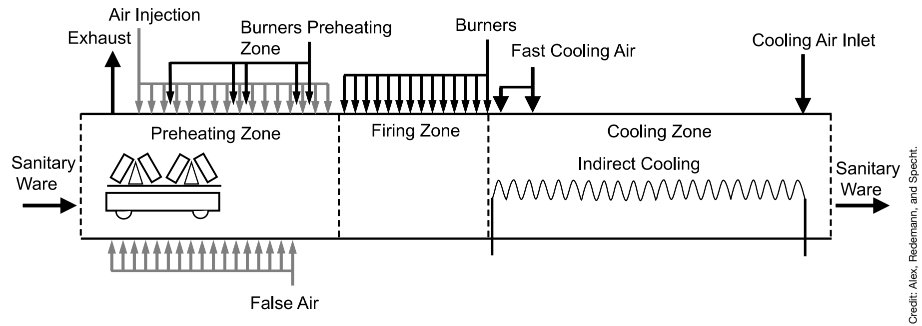

Figure 1. Schematic of the tunnel kiln used in this study.

The kiln outer wall temperature was measured with an infrared thermometer.

Model description

Figure 2 depicts the cross-section of the tunnel kiln. On the kiln car, a layer of mineral wool is used to reduce the heat that is taken up by the kiln car. Even though the amount of heat conducted to the kiln car is reduced by the mineral wool layer, the top part of the kiln car also undergoes a temperature fluctuation throughout its journey along the tunnel kiln. The part of the kiln car that undergoes this temperature fluctuation is called the thermal active layer of the kiln car.

On the kiln car, support rods carry the furniture on which the sanitary wares are placed. Here onward the term "solid" represents both the sanitary ware and furniture because both of them have the same physical properties and temperature all along the tunnel kiln. At the exit of the kiln, cold air is blown into the kiln, which gets heated up as it travels through the cooling zone toward the firing zone. This preheated air mixes with the combustion gas produced after the combustion of natural gas. This gas mixture then moves through the preheating zone, where it is again mixed with the combustion gas and with air from the burners and air from the injection nozzles. The gas exits the tunnel kiln at the entrance, where a blower extracts it to the recuperator. The kiln car and the solid move in a direction opposite to the gas, making the tunnel kiln as a counter-current heat exchanger with three flows.

From the gas, heat flows to the solid by convection and radiation. The gas also transfers heat to the kiln car by convection

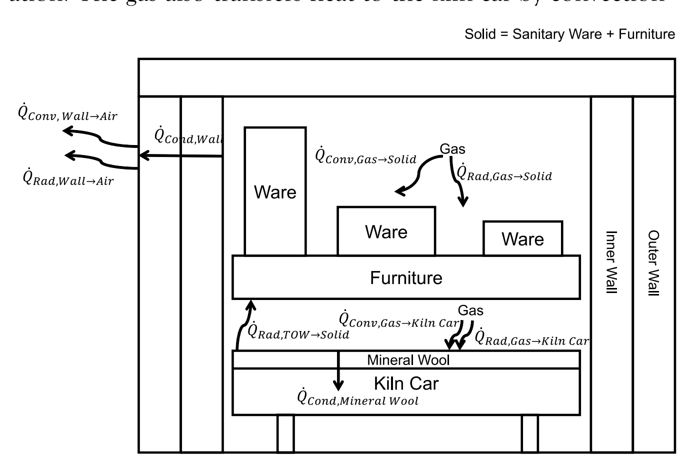

Figure 2. Schematic of the cross-section of the tunnel kiln used in this study.

and radiation, which is then conducted through the mineral wool and finally to the kiln car. The kiln car exchanges heat with the solid through radiation. The inner wall temperature is assumed to be that of the gas temperature, and heat is conducted through the inner and outer wall, which is then lost to the surrounding air by natural convection and radiation. Heat is extracted in the cooling zone from the solid, kiln car, and gas as a result of cooling air being supplied through the airways.

Nomenclature

Symbol

$\dot{Q}$	Heat flow rate, W
$\dot{M}$	Mass flow rate, kg/s
$\dot{H}$	Enthalpy flow rate, W
L	Length of the section where mass flow rate of gas is constant, m
c	Specific heat capacity, J/(kg K)
T	Temperature, K
dx	Small section length, m
α	Overall heat transfer coefficient, W/(m^{2}K)
A	Area, m^2
R	Resistance, K/W
ode	Ordinary differential equation

Index

E	Entity
Conv	Convection
Cond	Conduction
Rad	Radiation
p	Constant Pressure

Ordinary differential equations are developed with the idea that the change in enthalpy of the solid, gas, and kiln car is equal to the net heat flow for each segment of the tunnel kiln, giving rise to equation (1).

$$d\dot{H}_E = d\dot{Q}_{Net} \tag{1}$$

Ordinary differential equations that incorporate all the dependencies of different heat flows, which in turn affect the temperature of the gas, solid, and kiln car, are given below. "L" is the length of the segment of the tunnel kiln where the mass flow rate of the gas is constant.

The different overall heat transfer coefficients between solid, gas, kiln car, and outside air can be obtained by solving the resistance network (Figure 3).[1] Standard Nusselt functions for flow over spheres were used in order to find the convective heat transfer coefficients.

Model validation and results

The ordinary differential equation (2), (3), and (4) are solved using MATLAB "ode" solver[2] and the boundary conditions are the inlet temperatures of the solid and the kiln car. For the gas, the boundary condition is the inlet temperature of cooling air at the end of the tunnel kiln. Temperature profiles of the solid, gas, and kiln car, which are numerically obtained, are depicted in Figure 4, along with the measured temperature profile of the solid. The temperature profile of the solid, which is measured and numerically obtained, has almost the same profile, making the process model a good tool for representing the actual process. The thermal active layer of the kiln car is assumed to be 43% of the total kiln car, such that the outlet temperature of the kiln car, which is numerically simulated, is similar to what is measured.

The temperature profiles for the measured outer wall temperature and numerically obtained outer wall temperature are almost the same, which suggests that the process model represents the tunnel kiln working, with all the physics happening inside it. Analysis of the convective, radiative, and overall heat transfer coefficients between the solid and the gas suggest that the dominat-

Gas temperature

$$\dot{M}_{Gas} c_{p,Gas} L \frac{dT_{Gas}}{dx} = -\begin{bmatrix} -\alpha_{Gas\to Solid} A_{Solid} (T_{Gas} - T_{Solid}) - \alpha_{Gas\to Kiln\ Car} A_{Kiln\ Car} (T_{Gas} - T_{Kiln\ Car}) \\ -\dot{Q}_{Indirect\ Cooling,Gas} - 2\alpha_{Gas\to Air} A_{Wall} (T_{Gas} - T_{Air}) \end{bmatrix} \tag{2}$$

Solid temperature

$$\dot{M}_{Solid} c_{Solid} L \frac{dT_{Solid}}{dx} = \begin{bmatrix} \alpha_{Gas\to Solid} A_{Solid} (T_{Gas} - T_{Solid}) + \alpha_{Kiln\ Car\to Solid} A_{Kiln\ Car} (T_{Kiln\ Car} - T_{Solid}) \\ -\dot{Q}_{Indirect\ Cooling,Solid} - \dot{Q}_{Endothermic\ Reaction} \end{bmatrix} \tag{3}$$

Kiln car temperature

$$\dot{M}_{Kiln\ Car} c_{Kiln\ Car} L \frac{dT_{Kiln\ Car}}{dx} = \begin{bmatrix} \alpha_{Gas\to Kiln\ Car} A_{Kiln\ Car} (T_{Gas} - T_{Kiln\ Car}) - \alpha_{Kiln\ Car\to Solid} A_{Kiln\ Car} (T_{Kiln\ Car} - T_{Solid}) \\ -\dot{Q}_{Indirect\ Cooling,Kiln\ Car} \end{bmatrix} \tag{4}$$

ing mode of heat transfer between the solid and gas is by radiation, and the convective heat transfer is really low when compared with the radiative heat transfer coefficient. The reason for the high radiative and low convective heat transfer coefficients is the low velocity of gas in the tunnel kiln.

Parameter variation

In parameter variation, the deviation of the firing curve from the reference firing curve is depicted when the parameter is increased or decreased from the reference process. The reference process is the process that is validated, and the modeled firing curve is the reference firing curve. The process parameters can be divided into two categories: Specific and General (Table 1). General parameters mean the parameters that are present in a tunnel kiln irrespective of the ceramic it produces. Specific parameters mean the parameters in the tunnel kiln under study for developing the process model.

Understanding how the process reacts to changes in the process parameter value is important for the development of an energy efficient tunnel kiln because it helps to choose the parameter with the maximum potential to reduce energy consumption. Mass flowrate of the kiln car and combustion air in firing zone were the parameters determined to have a favorable impact on the energy consumption, and they are discussed below.

Combustion air in firing zone

Figure 5a depicts the variation of the firing curve when the combustion air, which is supplied in the firing zone, is changed with respect to the reference mass flowrate of the combustion air (100%). The reference case is the simulation that is validated with the measurement results (Figure 4). The mass flowrate of combustion air is reduced in such a way that it always ensures there is complete combustion. From the graph it is clearly visible the firing temperature increases with the decrease in combustion air, and vice versa. Figure 5b shows the possible reduction in the fuel when the amount of combustion air is reduced so as to achieve the reference firing curve. Maximum saving of fuel achieved by reduction of the combustion air is around 17%.

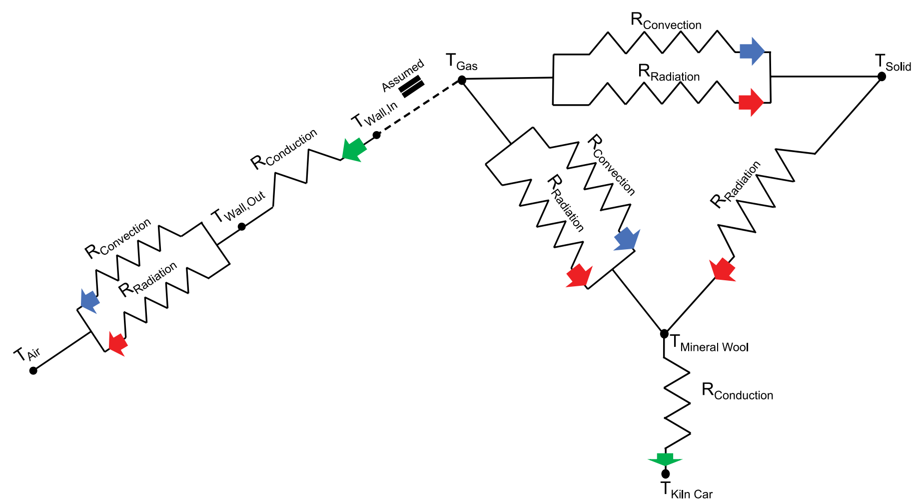

Figure 3. The resistance network of the tunnel kiln. The different overall heat transfer coefficients between solid, gas, kiln car, and outside air can be obtained by solving this network.

Mass flowrate of kiln car

A reduction of kiln car mass has a positive effect on the firing curve. It means the temperature in the firing zone is increased and hence a reduction of the fuel is necessary to bring the temperature to the reference temperature. Figure 6 illustrates the decrease in fuel to maintain the reference temperature profile.

Implications for process management

In this article, we explained the process modeling of a sanitary ware tunnel kiln and discussed the amount of energy savings possible with the process model. The amount of energy savings mentioned in the article is applicable to the kiln under study; the savings will vary on a case-by-case basis. Process modeling can be considered as a tool with many purposes, whether for achieving short-term or long-term targets. For example, pursuing a reduction in the amount of energy so as to reduce a company's operational costs during the fiscal year can be considered a short-term goal. On the other hand, the aim of achieving a

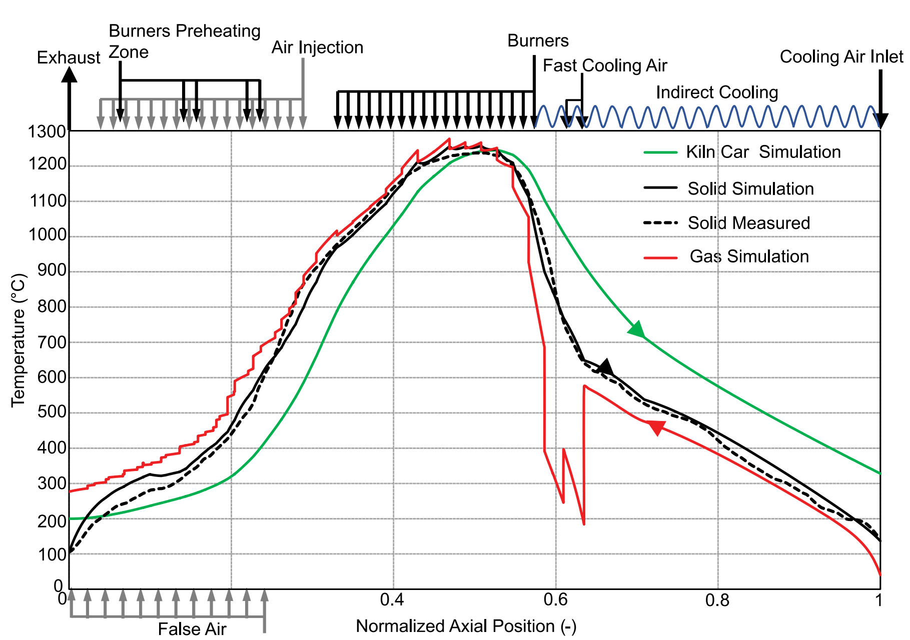

Figure 4. The temperature profiles of the solid, gas, and kiln car, along with the measured temperature profile of the solid.

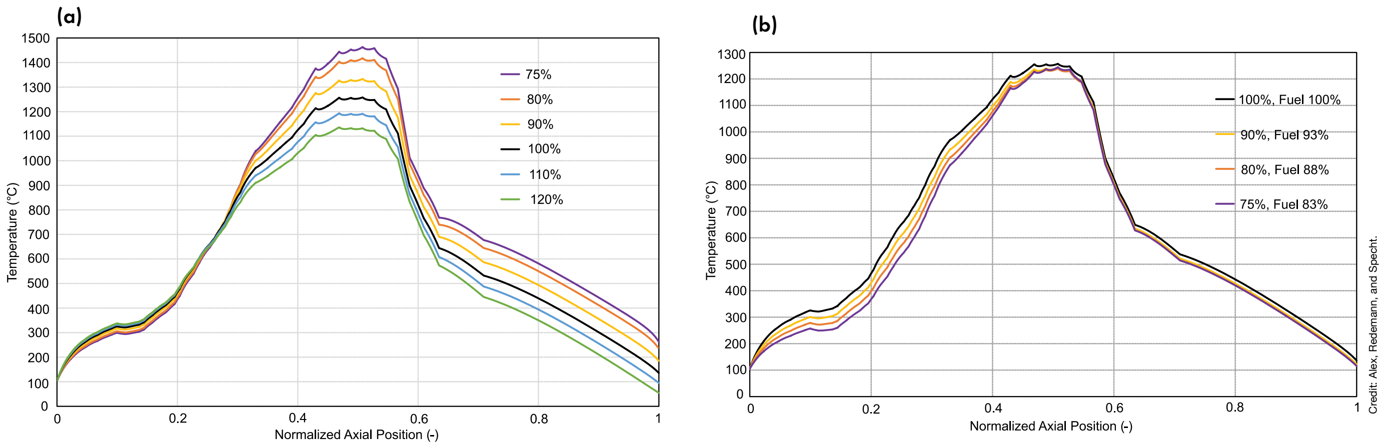

Figure 5. a) Variation of the firing curve when the combustion air is changed with respect to the reference mass flowrate of the combustion air. b) Possible reduction in the fuel when the amount of combustion air is reduced so as to achieve the reference firing curve.

carbon neutral process by 2050 can be considered a long-term goal for the company. The explanation on how the company can use process modeling as a tool is explained in the three subsections below.

Optimize tunnel kiln process

From the simulation, it is observed that a reduction in the combustion air increases the temperature in the firing zone; thus, a reduction of fuel is necessary to keep the firing curve stable. A reduction of 17% in fuel was necessary to achieve the reference firing curve. The reduction of fuel also reduces CO_2, which amounts to a reduction of 375 tonnes of CO_2 per year. Implementing the above change to the tunnel kiln does not involve any cost because it is only required to reduce the air supplied for combustion. There are many advantages to this implementation:

a) Reduction in the cost of fuel in the present situation and in the future.

Many countries are implementing a carbon tax, which will make the fuel more expensive.

b) Reduction in the amount of CO_2 produced, so as to achieve the forthcoming climate target (By 2030: At least 55% cuts in greenhouse gas emissions from 1990 levels).[3]

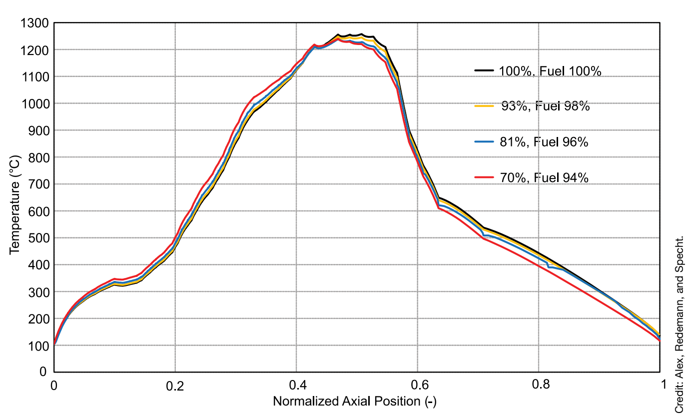

Figure 6. Graph illustrating the decrease in fuel to maintain the reference temperature profile

Optimize investment

From the simulation result shown in Figure 6, a reduction in the kiln car mass reduces the amount of fuel by almost 6% and also the indirect cooling has to be decreased by 23%. The decrease in the indirect cooling means the amount of air supplied in the cooling zone and this decrease translates to the reduction of electricity consumption. To get the benefits stated above, an overhaul of the kiln cars is necessary and translates to investment by the company. A decision in this situation is made by keeping in mind the return of investment set by the company guidelines. Modeling of the tunnel kiln enables the company to better understand whether the investment will help in saving energy and reducing the operational cost.

Carbon neutral tunnel kiln process

Results showed the convective heat transfer coefficient is lower than that of the radiative heat transfer. A high heat transfer coefficient means better heat transfer between the gas and the solid, and hence a reduction in the usage of fuel. For increasing the convective heat transfer between the gas and the solid, circulation systems[4] can be retrofitted to the tunnel kiln. The circulation systems are fitted on the ceiling of the tunnel kiln and help increase the velocity of the gas at a particular section of the tunnel kiln, which can be decided with the help of the results from the simulation. The retrofitting of a tunnel kiln helps the existing infrastructure to be used in the future.

Table 1. List of tunnel kiln parameters (mass flowrate)

General	Specific
Kiln car	Fuel in preheating zone
Cooling air	Combustion air in preheating zone
Fast cooling air	Air injection in preheating zone
Fuel in firing zone	Amount of indirect cooling
Combustion air in firing zone	

The kiln car is considered as a major contributor for energy loss. The future kiln can be envisaged as one without kiln cars.[5] In the current situation, energy required for reaching temperatures of more than 1,000°C is achieved by combustion of fossil fuels, mainly natural gas. Choosing a fuel for combustion that has less of a carbon footprint, like biogas or hydrogen produced from power-to-gas systems or electricity from renewable energy, is a sensible move toward a carbon neutral process. Process modeling helps to study the viability of the above solutions and to adopt the solutions that are best suited for achieving the goal of being climate friendly by 2050.

About the authors

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References

[1] Specht, E., *Heat and mass transfer in thermoprocessing*, Vulkan Verlag, 2017

[2] MATLAB, Choose an ODE Solver. https://www.mathworks.com/help/matlab/math/choose-an-ode-solver.html (accessed 20 January 2021)

[3] 2030 Climate Target Plan https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en (accessed 20 January 2021)

[4] Redemann, T., Specht, E., "Mathematical model to investigate the influence of circulation system on the firing of ceramics," *Infub 11 – 11th European Conference on Industrial Furnaces and Boilers*, Porto, Portugal. *Energy Procedia* 120, 620–627 (2017).

[5] Redemann, T., Specht, E., "Development of new concepts for an energy efficient firing of ceramics by 2050," *Infub 12 – 12th European Conference on Industrial Furnaces and Boilers*, Porto, Portugal, 2020 (Online).

[6] Alex, D.M., Redemann, T., Specht, E., "Development of process model for the manufacturing of sanitary ware in tunnel kiln," *Infub 12 – 12th European Conference on Industrial Furnaces and Boilers*, Porto, Portugal, 2020 (Online).

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Technical sessions	9:30 a.m. – 5:30 p.m.
Exhibit reception and posters	5:00 p.m. – 7:00 p.m.
Thursday, Sept. 16, 2021	
Exhibits	9:30 a.m. – 4:30 p.m.
Technical sessions	8:00 a.m. – 5:00 p.m.
Banquet	7:00 p.m. – 10:00 p.m.
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S30: High temperature superconductors: Materials, technologies, and systems

Ceramics for Environmental Systems

S31: Advanced functional materials, devices, and systems for environmental conservation, pollution control, and critical materials

S32: Ceramics for enabling environmental protection: Clean air and water

S33: Photocatalysts for energy and environmental applications

S34: Glass and ceramics for nuclear waste treatment and sequestration

Biomaterials, Biotechnologies, and Bioinspired Materials

S35: Advanced additive manufacturing technologies for bio-applications; materials, processes, and systems

S36: Advanced multifunctional bioceramics and clinical applications

S37: Material and technology needs for medical devices, sensors, and tissue regeneration

S38: Nanotechnology in medicine

S39: Biomimetics and bioinspired processing of advanced materials

Special Topics

S40: 6th International Richard M. Fulrath Symposium, "Frontiers of ceramics for a sustainable society"

S41: Advancing the global ceramics community: fostering diversity in an ever-changing world

S42: Young Investigator Forum: Next-generation materials for multifunctional applications and sustainable development, and concurrent societal challenges in the new millennium

ACerS virtual meetings start the year strong with Electronic Materials and Applications (EMA 2021)

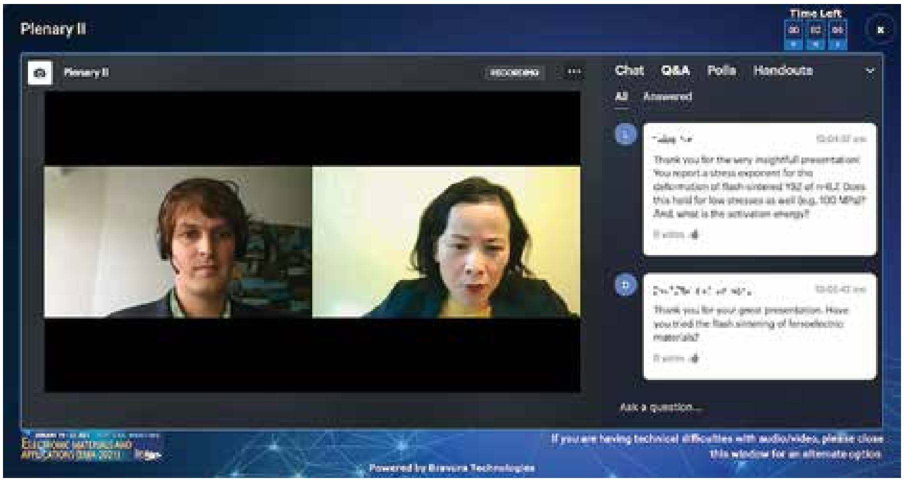
With the nascent rollout of vaccines now taking place, hopes are high that some in-person meetings could take place near the end of the year. Until then, ACerS will continue to hold meetings virtually for the safety of attendees—just as ACerS did for the 12th annual Electronic Materials and Applications Conference on Jan. 19–22, 2021.

ACerS Electronics Division and Basic Science Division usually host the EMA conference each year in Orlando, Fla. However, attendance at the virtual conference remained strong with a record 441 registrations, including 167 students, from 29 countries and close to 400 presentations.

"We are very happy that the virtual EMA2021 last week was well received. We are delighted to see the record participation and active engagements of the attendees at the live Q&A, special events, and networking events during the virtual meeting, and we look forward to meeting everyone again in person next year at Orlando," says Claire Xiong, Electronics Division co-chair and associate professor of materials science and engineering at Boise State University.

The conference included two plenary lectures presented on Tuesday and Wednesday morning. Despina Louca from the University of Virginia opened the conference with a plenary talk on emergent properties in oxides and semimetals, with a special emphasis on magnetoresistive systems. Haiyan Wang from Purdue University discussed a different material phenomenon during her plenary talk on Wednesday—field-induced mass transport in flash-sintered, high-temperature ceramics.

Numerous student events took place during EMA 2021, starting with a poster session on Tuesday evening. Because of the virtual format, students uploaded recordings of themselves presenting their posters. On Thursday evening, winners of the poster and oral competitions were announced during a special award session.



Credit: ACerS

Wednesday plenary speaker Haiyan Wang from Purdue University (right) answers questions from the audience following her presentation. Organizing co-chair Wolfgang Rheinheimer from Technische Universität Darmstadt, Germany, (left) moderated the session.

First place in poster and oral competitions went to Seongwoo Cho (Korea Advanced Institute of Science and Engineering) and William Huddleston (Case Western Reserve University), respectively, for their presentations on high-speed visualization of ferroelectric domains (Cho) and assessment of multifunctional performance of $Li_4Ti_5O_{12}$–Ni anode composites (Huddleston).

On Wednesday, ACerS President's Council of Student Advisors sponsored a career panel for students to ask questions of electroceramic career professionals. Questions covered a wide variety of topics, including work/life balance, dealing with funding uncertainty, and finding your own research topic following graduation. Panelists pointed attendees to ACerS Young Professionals Network as a way to connect with other students and young professionals in the ceramic and glass community, and to find professional development training opportunities.

The last event of the conference was the ever-popular Failure Symposium on Friday night, where scientists share their experiences with failure on their road to success. However, instead of the usual presentations, this year the Failure Symposium was conducted in the format of a pub quiz, where attendees were split into teams and quizzed on famous historical material failures and previous Failure Symposiums.

The recordings from EMA 2021 will be available through March 31, 2021. If you did not attend the live event, you can still register at https://ceramics.org/event-subpage/ema-2021-registration to view the nearly 400 presentations.

Plan to join us next year for EMA 2022 in Orlando, Fla., Jan. 18–21, 2022. We look forward to seeing everyone in person again! 100

Calendar of events

March 2021

9 IMFORMED: Mineral Recycling Forum 2021 – VIRTUAL EVENT ONLY; http://imformed.com/get-imformed/forums/mineral-recycling-forum-2021

15–17 China Refractory Minerals Forum 2021 – VIRTUAL EVENT ONLY; http://imformed.com/get-imformed/forums/china-refractory-minerals-forum-2020

24–25 56th Annual St. Louis Section/Refractory Ceramics Division Symposium on Refractories – VIRTUAL EVENT ONLY; https://ceramics.org/event/56th-annual-st-louis-section

24–29 ➨ 2nd Global Forum on Smart Additive Manufacturing, Design and Evaluation (SmartMADE) – Osaka University, Nakanoshima Center, Japan; http://www.jwri.osaka-u.ac.jp/~conf/Smart-MADE2021

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

April 2021

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

May 2021

3–7 6th International Conference on Competitive Materials and Technology Processes (ic-cmtp6) – Hunguest Hotel Palota, Miskolc-Lillafüred, Hungary; www.ic-cmtp6.eu

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

June 2021

7–9 ACerS 2021 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Omni Austin Hotel Downtown, Austin, Texas; https://ceramics.org/event/acers-2021-structural-clay-products-division-southwest-section-meeting-in-conjunction-with-the-national-brick-research-center-meeting

22–23 ceramitec conference 2021 – Messe München; Munich, Germany; https://www.ceramitec.com/en/trade-fair/ceramitec-conference

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

July 2021

18–23 Materials Challenges in Alternative & Renewable Energy 2021 (MCARE 2021) combined with the 4th Annual Energy Harvesting Society Meeting (EHS 2021) – Hyatt Regency Bellevue Bellevue, Wash.; https://ceramics.org/mcare2021

August 2021

31–Sept 1 6th Ceramics Expo – Cleveland, Ohio; https://ceramics.org/event/6th-ceramics-expo

September 2021

14–17 17th Biennial Worldwide Congress Unified International Technical Conference on Refractories – Hilton Chicago, Chicago, Ill.; https://ceramics.org/unitecr2021

October 2021

12-15 ➨ International Research Conference on Structure and thermodynamics of Oxides/carbides/nitrides/borides at High Temperature (STOHT) – Arizona State University, Ariz.; https://mccormacklab.engineering.ucdavis.edu/events/structure-and-thermodynamics-oxidescarbidesnitridesborides-high-temperatures-stoht2020

17–21 ACerS 123rd Annual Meeting with Materials Science & Technology 2021 – Greater Columbus Convention Center, Columbus, Ohio; https://ceramics.org/mst21

December 2021

12–17 14th Pacific Rim Conference on Ceramic and Glass Technology (PACRIM 14) – Hyatt Regency Vancouver, Vancouver, British Columbia, Canada; www.ceramics.org/PACRIM14

January 2022

18–21 Electronic Materials and Applications 2022 (EMA 2022) – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla; https://ceramics.org/ema2022

23–28 46th International Conference and Expo on Advanced Ceramics and Composites (ICACC2022) – Hilton Daytona Beach Oceanfront Resort, Daytona Beach, Fla.; https://ceramics.org/icacc2022

July 2022

24–28 Pan American Ceramics Congress and Ferroelectrics Meeting of Americas (PACC-FMAs 2022) – Hilton Panama, Panama City, Panama; https://ceramics.org/PACCFMAs

Dates in RED denote new event in this issue.

Entries in BLUE denote ACerS events.

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

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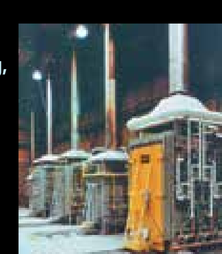

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Minda Zou
Guest columnist

Advanced manufacturing of protonic ceramic energy devices via laser 3D printing

Protonic ceramic energy devices (PCEDs), including protonic ceramics-based membrane reactors, hydrogen-permeable membranes, fuel cells, and electrolysis cells, are energy conversion and/or storage devices working under intermediate temperature (400–700°C). These devices, along with the discovery of ceramics exhibiting high proton conductivity, have attracted substantial interest.[1]

However, conventional manufacturing techniques for PCEDs commonly suffer from the challenges of the small active area, simple geometry, and low surface area/volume ratio, hindering the practical applications of PCEDs. Furthermore, conventional manufacturing techniques usually involve complicated steps. For example, the fabrication of planar protonic ceramic fuel cells requires multiple steps (e.g., tape casting, screen-printing, punching, cofiring, post-firing, sealing, and stacking), which are poorly reproducible and time-consuming as well as potential high cost.

Additive manufacturing, also called 3D printing, is a group of emerging advanced manufacturing technologies that are capable of fabricating highly precise and complex geometries. The AM techniques provide new possibilities for tackling the aforementioned challenges and issues for the manufacturing of PCEDs.

Additive manufacturing begins with a 3D model designed by computer-aided design software. The models are digitally sliced into sequential cross-sectional layers. Afterward, the computer-controlled deposition for the slices is performed by printing in a layer upon layer manner to build up 3D objects.

Since its origination in the 1980s, various additive manufacturing technologies, including 3D inkjet printing, stereolithography, selective laser sintering/melting, laminated object manufacturing, direct energy deposition, and fused deposition modeling, have been developed.[2] In recent years, researchers devoted considerable attention to 3D printing of ceramics for biotechnology, optical and energy devices, and medical applications due to the merits of reduced material waste, accurate fabrication, reproducible and straightforward process, controllable microstructure, and personalized design. However, 3D printing of ceramics also encounters the challenges existing in conventional ceramic processing. For instance, it is difficult to achieve crack-free parts via rapid sintering and to fulfill high precision because of the heavy use of additives (e.g., solvents, organic dispersants, and binders) and significant shrinkage after firing.

Our group recently developed a novel laser 3D printing (L3DP) system,[3] which is an integration of microextrusion-based additive manufacturing and laser processing (e.g., rapid sintering, rapid drying, precise cutting, and precise polishing). The L3DP technique exhibits the capability to fabricate protonic ceramic parts with various controllable microstructures and complex geometries, such as cylinders, tubes with sealed endings, pellets, cones, single unit of fuel cells, and microchannel membranes.

My current research takes advantage of our L3DP technique and focuses on the fabrication of protonic ceramic-based microchannel membrane reactors and fuel cells for renewable energy applications, including direct methane conversion to generate value-added chemicals (e.g., benzene) and electricity, and electrochemical hydrogen production and separation. The manufacturing challenges for microchannel devices by conventional techniques, such as undesired pressure tightness, delamination, and poor shape retainability, can be readily addressed with our L3DP method.[4] The custom-designed microchannel membrane reactors can offer the advantages of significantly reduced device size and greatly enhance catalytic performance compared to their conventional counterparts due to the large surface-area-to-volume ratio. Therefore, it is feasible to develop cost-effective, portable, and high-efficient PCEDs via the L3DP technique.

I feel excited to perform research in this field as it is promising for addressing the global energy crisis and environmental issues caused by heavy use of fossil fuels.

References

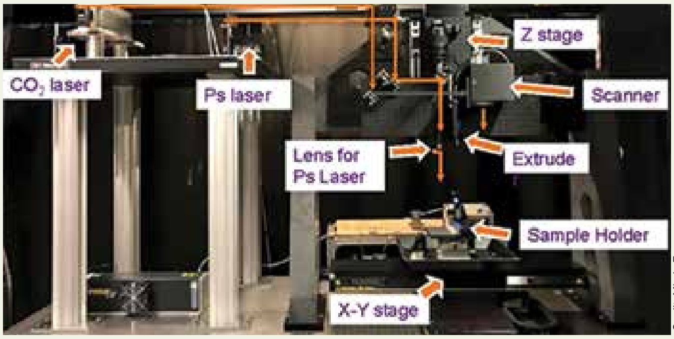
[1]Meng, Y. et al. "Review: recent progress in low-temperature proton-conducting ceramics." *Journal of Materials Science* 54.13 (2019): 9291–9312.

[2]Chen, Z. et al. "3D printing of ceramics: A review." *Journal of the European Ceramic Society* 39.4 (2019): 661–687.

[3]Mu, S. et al. "A novel laser 3D printing method for the advanced manufacturing of protonic ceramics." *Membranes* 10.5 (2020): 98.

[4]Hong, Y. et al. "Fabricating ceramics with embedded microchannels using an integrated additive manufacturing and laser machining method." *Journal of the American Ceramic Society* 102.3 (2019): 1071–1082.

Minda Zou is a Ph.D. candidate in the Department of Materials Science and Engineering at Clemson University. His research focuses on additive manufacturing of protonic ceramic energy devices and their applications for the production of electricity and value-added chemicals. Outside of research, he enjoys hiking, photography, and playing tennis. 100



Credit: Minda Zou

Figure 1. The home-made L3DP system for the advanced manufacturing of protonic ceramic energy devices.