

AMERICAN CERAMIC SOCIETY

# bulletin

DECEMBER 2022

## Star power!

How glass and ceramics push us deeper into space



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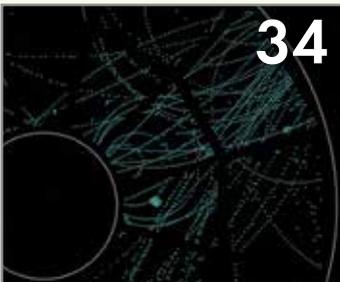
## feature articles



### Star power! How glass and ceramics push us deeper into space

For all that space can throw at a mission, glass and ceramics handle the hazards well. It is no surprise, then, that these materials frequently have a place in space exploration from beginning to end—from launch and return, to all the travel, data collection, and learning in between.

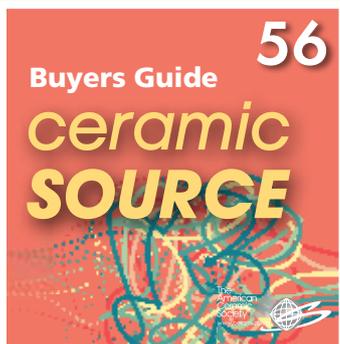
By Leslie Nemo



### Detectors in space: Analyzing cosmic ray tracks in barium phosphate glasses with unknown environmental information

Track-etch detectors allow for precise identification of cosmic rays. This case study explores how one might examine tracks in a detector glass plate for which detailed environmental provenance is unknown.

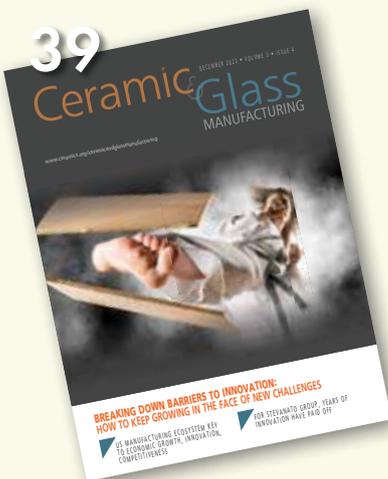
By Nicholas J. Tostanoski, Darren Stohr, and S. K. Sundaram



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Our annual reference and buyer's guide and directory

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Breaking down barriers to innovation: How to keep growing in the face of new challenges

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- US manufacturing ecosystem key to economic growth, innovation, competitiveness
- For Stevanato Group, years of innovation have paid off

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### Cover image

Astronaut David A. Wolf, STS-112 mission specialist, anchored to a foot restraint on the Space Station Remote Manipulator System, carries the Starboard One outboard nadir external camera.

Credit: NASA

**Editorial and Production**

Eileen De Guire, Editor

[edeguire@ceramics.org](mailto:edeguire@ceramics.org)

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**Customer Service/Circulation**

ph: 866-721-3322 fx: 614-899-6109

[customerservice@ceramics.org](mailto:customerservice@ceramics.org)

**Advertising Sales**

**National Sales**

Mona Thiel, National Sales Director

[mthiel@ceramics.org](mailto:mthiel@ceramics.org)

ph: 614-794-5834

**Executive Staff**

Mark Mecklenborg, Executive Director and Publisher

[mmecklenborg@ceramics.org](mailto:mmecklenborg@ceramics.org)

Eileen De Guire, Director of Technical Publications and Communications

[edeguire@ceramics.org](mailto:edeguire@ceramics.org)

Marcus Fish, Director of Development and Industry Relations

Ceramic and Glass Industry Foundation

[mfish@ceramics.org](mailto:mfish@ceramics.org)

Michael Johnson, Director of Finance and Operations

[mjohnson@ceramics.org](mailto:mjohnson@ceramics.org)

Mark Kibble, Director of Information Technology

[mkibble@ceramics.org](mailto:mkibble@ceramics.org)

Andrea Ross, Director of Meetings, Membership and Marketing

[aross@ceramics.org](mailto:aross@ceramics.org)

Erica Zimmerman, Executive Office Manager

[ezimmerman@ceramics.org](mailto:ezimmerman@ceramics.org)

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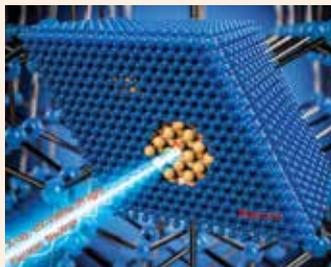


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As seen on *Ceramic Tech Today*...



Credit: Qiaoshi Zeng, Center for High Pressure Science and Technology Advanced Research

**Nanostructured diamond capsules maintain high-pressure samples for materials analysis**

A recent joint project by researchers in China and the United States showed that properties of high-pressure materials can be maintained in free-standing, nanostructured diamond capsules without the support of traditional bulky pressure vessels.

Read more at [www.ceramics.org/diamond-capsules](http://www.ceramics.org/diamond-capsules)

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By R. Calvo and P. Fuierer

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By C. Shao, C. Yu, Y. Jiao, et al.

*International Journal of Applied Glass Science*

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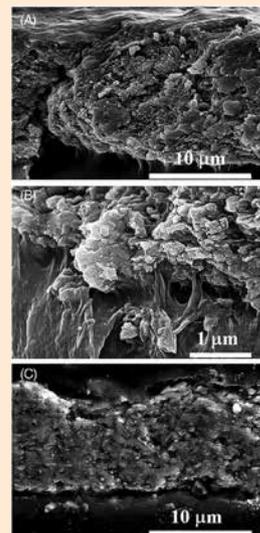
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## Approval of industrial seafloor mining trial elicits scrutiny from marine scientists and journalists

With the rapid expansion of renewable energy technologies and electric vehicle adoption, the mining industry is attracting intense focus from governments worldwide as they consider how to secure the critical materials needed to build these technologies.

While expansion of land-based mineral extraction and processing operations outside of China is a main target in many government plans, some companies push the envelope by exploring the possibility of mining a previously unfathomable location—the deep seabed.

Deep-sea mining is the process of retrieving mineral deposits from the seabed at ocean depths greater than 656 feet (200 meters). Since the 2000s, interest in deep-sea mining has grown as miners search for new mineral sources beyond the depleted or difficult-to-access land-based deposits. To date, the International Seabed Authority (ISA), an autonomous international organization established by the United Nations to govern resources of the deep seabed, has issued 31 exploratory contracts to scope out deep-sea mineral deposits.

But even as the ISA develops regulations to move from exploration to exploitation of deep-sea mineral resources, there is concern in the scientific community that much still remains unknown about the environmental impacts of deep-sea mining. Marine experts stress that if deep-sea mineral exploitation is allowed too soon, it could irreparably harm marine ecosystems.

On Sept. 7, 2022, an announcement by Canadian mining startup The Metals Company (TMC) triggered fresh discussion of these risks. The company said the ISA greenlit a plan submitted by TMC subsidiary Nauru Ocean Resources Inc. (NORI) to perform a trial extraction of polymetallic nodules in the Clarion Clipperton Zone of the Pacific Ocean. It is the first time since the 1970s that such trials will be conducted in this area.

The trial extraction will see NORI's offshore strategic partner, Swiss undersea contractor Allseas, deploy a prototype collector to vacuum polymetallic nodules from three miles under the ocean's surface. Approximately 3,600 tonnes of polymetallic nodules are expected to be collected during the trial, which begins later this month and should conclude in the fourth quarter of 2022.

According to TMC's announcement, the trial will be independently monitored by ocean scientists from a dozen different institutions, who will analyze the impact of the mining submarine and the machinery used to raise the nodules to the surface processing ship. Their assessment will be used by the ISA to determine if full-scale mining is warranted.

An investigative report published by *The New York Times* in August 2022 questions the choice of TMC to conduct this



Canadian mining startup The Metals Company received approval from the International Seabed Authority to conduct a polymetallic nodule extraction trial in the deep sea. Pictured is the Hidden Gem, TMC's surface production vessel.

century's first industrial trial. The report details how TMC's executives spent 15 years gaining influence with the ISA, and how the ISA shared important data with them, including the locations of valuable pieces of seabed that it later reserved for TMC to exploit.

*The New York Times* also raises concerns about how TMC and ISA's relationship undercuts the system meant to provide developing nations a place at the table. In theory, developing nations should get access to data in certain mining areas before companies do. "But the reverse happened: A top executive at the firm got the vital data first, then secured two tiny island nations [Nauru and Tonga] as sponsors," *The New York Times* reports.

With these sponsors—in addition to a sponsorship that TMC secured from the central Pacific island country of Kiribati in 2015—TMC now has rights to three of the seven exploratory contracts issued by the ISA in areas reserved for developing nations.

Regardless of the results from TMC's extraction trial, full-scale mining cannot take place until the ISA finishes developing its extraction regulations. Those regulations will likely be completed sooner than later—Nauru, one of TMC's sponsors, invoked a provision in 2021 that effectively mandates the adoption of extraction regulations by next summer (June 2023). ■

## Shallow-water mining is not the answer to deep-sea mining

Because of the environmental and economic concerns associated with mining mineral deposits on the deep seabed, some companies and countries are considering shallow-water mining instead.

Unlike deep-sea mining, which is defined as mining the seabed at ocean depths greater than 656 feet (200 meters), shallow-water mining is not strictly defined by depth but rather by location. It usually refers to operations that occur on the continental shelf with easier access to the coast.

Proponents of shallow-water mining argue that, in addition to being more accessible than deep seabeds, better knowledge of shallow-water ecosystems and their shorter recovery times makes mining these areas less environmentally and economically risky.

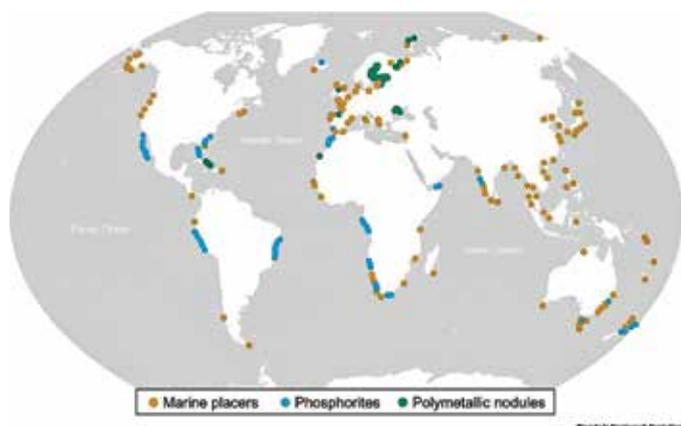
However, a recent open-access paper raises concerns about viewing shallow-water mining as an eco-alternative to deep-sea mining.

The Finland-based authors are Laura Kaikkonen from the University of Helsinki and Baltic Marine Environment Protection Commission and Elina A. Virtanen from the Marine Research Centre at the Finnish Environment Institute.

In their paper, they show how the arguments given above for shallow-water mining rely on scant critical evaluation. Yet numerous shallow-water mining projects are already taking place because, unlike the stringent intergovernmental regulations for deep-sea exploration and exploitation, coastal areas often fall under the jurisdiction of national legislatures.

Take Indonesia, for example. Indonesia is the world's largest exporter of tin and second largest producer of the metal, behind China. As land-based tin resources dwindled, Indonesia turned to dredging tin off the coast of the Bangka-Belitung Islands.

The huge expansion of shallow-water mining operations has heightened tension with fishermen, who say their catches have collapsed due to steady encroachment on their fishing grounds since 2014.



**Overview of the currently known main marine mineral resources (marine placers, phosphorites, and polymetallic nodules) on the continental shelf, which have extraction potential defined by their proximity to the coast and depth of the resource.**

“We used to get at least 10 kilograms in a day. Now, only two kilograms, and sometimes we come back with nothing because the location has been destroyed by an illegal mining site,” a fisherman tells Reuters in an interview.

The evidence of mining’s coastal effects is not just anecdotal. Conservation news site Mongabay reports that the Indonesian Forum for the Environment found tin mining in Bangka has degraded 5,270 hectares (13,022 acres) of coral reef and 400 hectares (988 acres) of mangrove forest.

“Considering the absence of environmental regulation and risks to marine biodiversity, shallow-water mining is not a low-risk solution to overcome the environmental and ethical issues of mining on land and in the deep sea,” Kaikkonen and Virtanen write. Thus, “precautionary conservation measures and systematic comparisons of alternative ways to obtain the required minerals must be taken before seabed mining, be it in the shallow water or in the deep sea, is allowed to proceed.”

The open-access paper, published in *Trends in Ecology & Evolution*, is “Shallow-water mining undermines global sustainability goals” (DOI: 10.1016/j.tree.2022.08.001). ■

## First-of-their-kind drones can 3D print in flight

One benefit of additive manufacturing is the ability to fabricate complex shapes that are difficult to achieve using subtractive methods. But to realize such precision, 3D-printing equipment is generally rooted tightly in place so each layer can be deposited in the desired location. As such, using additive manufacturing to repair objects in difficult-to-access locations, such as at the top of tall buildings, is not convenient because the equipment cannot be transported there easily.

A new technology developed by an international research team would make such repairs not only feasible but desirable.

The team, co-led by drone expert Mirko Kovac of Empa (Dübendorf, Switzerland) and Imperial College London and autonomous manufacturing researcher Robert Stuart-Smith of University College London and University of Pennsylvania, developed a swarm of cooperative, 3D-printing drones that can print materials for building or repairing structures while flying.

The system, called Aerial Additive Manufacturing (Aerial-AM), features two types of drones: BuildDrones, which deposit the materials, and quality-control ScanDrones, which measure the BuildDrones’ output and inform their next manufacturing steps. The drones are fully autonomous in flight, but a human controller can monitor progress and intervene if necessary.

In a paper published in *Nature*, the researchers demonstrated proof-of-concept prints, including a 2.05-meter-high cylinder (72 layers) made of a rapid-curing insulation foam material and a 0.18-meter-high cylinder (28 layers) made of a structural pseudoplastic cementitious material. They developed the latter material themselves so the drones would remain light enough to take flight even while carrying the printing material.



Credit: Nature Video, YouTube

**A newly developed swarm of cooperative, 3D-printing drones can print materials for building or repairing structures while flying.**

It took the drones 300 seconds per layer to construct the cement-like cylinder, or 2.3 hours in total. In an interview with *The Daily Beast*, Stuart-Smith says the drones will get faster and more efficient as the technology is refined, particularly when testing begins outdoors with larger, more powerful drones.

The researchers also simulated builds of cylinders and domes with groups of three and more drones, using beams of light instead of physical materials and taking time-lapse images of the results, to demonstrate how the system could print larger structures.

An Empa press release states the researchers plan to work with construction companies to validate the solutions and provide repair and manufacturing capabilities. ■

## **Glass bead geoengineering to protect sea ice may actually accelerate its loss**

A recent open-access paper written by Melinda Webster at the University of Alaska Fairbanks and Stephen Warren at the University of Washington warns that a proposal to protect Arctic sea ice through geoengineering could ultimately hasten its loss instead.

In 2018, nonprofit organization Ice911 (now called Arctic Ice Project) published an open-access paper on hollow silica glass microspheres that allegedly could be spread on sea ice to increase its albedo (ability to reflect sunlight) and thus help conserve the ice.

When the authors presented their work at the University of Alaska Fairbanks to other scientists working on sea ice, a few expressed doubts about the project's feasibility. For example, oceanographer Seth Danielson noted in a University of Alaska Fairbanks article that using an icebreaker to distribute the beads would decrease the reflectiveness of the pack ice field as the ship broke through, counteracting the purpose of the beads.

The new paper by Webster and Warren confirms some of the hesitations that university researchers expressed following the 2019 presentation.

They begin by critiquing the experimental design used in the 2018 paper. Specifically, they point out that that paper

investigated the albedo of thin ice with no snow cover, “but that surface type occurs on the Arctic Ocean mostly during times of the year when sunlight is minimal and the albedo is therefore irrelevant.”

So, “To estimate the radiative forcing achievable by spreading HGMs [hollow glass microspheres] over the Arctic Ocean, we must consider the various surface types that are largely representative of Arctic sea ice, with their spectral albedos, and how their seasonal cycles relate to the seasonal cycle of sunlight,” they write.

When seasonal differences in the sea ice surface are considered, Webster and Warren found the glass microspheres actually hasten melting.

While the glass microspheres reflect 43% of the incoming sunlight and allow 47% to pass through, the remaining 10% is absorbed. This absorption means the glass microspheres darken any surfaces with an albedo of more than 0.61, such as snow-covered ice.

“The net result is the opposite of what was intended: spreading HGMs would warm the Arctic climate [by an annual average of 3.3–3.5 Wm<sup>-2</sup>] and speed sea-ice loss,” they write.

If nonabsorbing glass microspheres were developed—and could be transported and distributed over the Arctic without contamination—then this method could help cool the climate, Webster and Warren write. However, the challenge then becomes one of quantity. About 360 million tons would be needed for an annual one-time application to cool the climate.

Ultimately, “The use of microspheres as a way to restore Arctic sea ice isn't feasible,” Webster says in a University of Alaska Fairbanks press release. “While science should continue to explore ways to mitigate global warming, the best bet is for society to reduce the behaviors that continue to contribute to climate change.”

The open-access paper, published in *Earth's Future*, is “Regional geoengineering using tiny glass bubbles would accelerate the loss of Arctic sea ice” (DOI: 10.1029/2022EF002815). ■



Credit: Ned Rucell, University of Alaska Fairbanks

**Pictured are the hollow glass microspheres that are meant to protect sea ice but will likely hasten its melting instead.**

## Emerging from the pandemic, glass packaging is set for growth

By Scott Cooper

Since the invention of the automated glass bottle machine in the early 1920s, glass has been a staple to safely store, transport, and enjoy food and beverages.

World events over the decades naturally led to ebbs and flows of the prominence of glass on shelves and in home pantries. In the post-World War II era of the 1950s and '60s, glass had a strong presence in homes as products like milk and beer were delivered in refillable glass bottles, with systems to collect and clean the bottles. The 1970s brought a plastic revolution continuing into the early 2000s, which introduced a culture of “throw away” packaging and decreased the demand for glass. However, in the 2000s, emerging economies such as Brazil, India, China, and the former Soviet Union lifted the overall global demand for packaged food and beverages, and a corresponding increase for glass. Following the Great Recession in 2008, consumers were more price-sensitive, which encouraged mass market beer to shift from glass to aluminum packaging.

Now at the end of 2022, the International Year of Glass, the fundamentals for glass packaging are at the strongest in more than 20 years. This current market power is due to several factors.

First, the COVID-19 pandemic greatly accelerated change in our world—and without a doubt, behavior toward food and beverage consumption as well. As people stayed at home, there was a reinvigoration of cooking and eating well at home. Rather than treating themselves at restaurants, people preferred to indulge at home with higher-end foods, sauces, or cocktails, which tend to be packaged in glass rather than other materials.

Second, a preference for healthier products such as kombuchas, enhanced waters, and low alcohol drinks began before the pandemic and has continued. Glass inherently aligns with brands that project a “better for you” image.

Third, consumers are slowly becoming more aware of the sustainability impact created by their packaging. As reports continue to emerge of the environmental toll from plastic packaging, glass is uniquely positioned as a material because it is truly recyclable.

As the world’s largest manufacturer of glass packaging, O-I has supported these changes in the world. For example, in the last five years, O-I’s North America product mix shifted in



O-I’s new Drinktainer packaging innovation provides restaurants a way to offer drinks to-go.

response to consumer demands from largely beer-focused to greater production of food, nonalcoholic, and spirits products.

The pandemic offered a unique opportunity to successfully pilot and launch a packaging innovation: the Drinktainer. This product is a unique wide-mouth design that can be filled onsite at the brewery or bar and served to-go. It offers the sensory experience of drinking from a wide-mouthed glass while also being functional by being capped and sealed for transport. This design was piloted during the pandemic as restaurants were looking for ways to offer drinks to-go. The Drinktainer is now commercially available with Lagunitas Brewing in Petaluma, Calif., and Blue Moon Brewing in Denver, Co., being just a few who are using this new to-go packaging option.

The challenges of the last three years demonstrated that glass is an essential material in the supply chain of food and beverages. The glass packaging industry strongly persisted through the challenges of those years, and is ready to seize new opportunities in the post-pandemic world.

### About the author

Scott Cooper is Global Glass and Materials Science Group Leader at O-I Glass in Perrysburg, Ohio. Contact Cooper at [scott.cooper@o-i.com](mailto:scott.cooper@o-i.com). ■

# Aerospace ceramics: Global markets to 2026

By BCC Publishing Staff

The global market for aerospace ceramics was valued at \$4.7 billion in 2020, although it was slowed that year by the COVID-19 pandemic. It is estimated to grow at a compound annual growth rate (CAGR) of 12.2% to reach \$8.8 billion in 2026.

The aerospace industry is broken down into three segments: commercial, defense, and space.

- **The commercial segment** refers to aircraft manufactured to cater to demand from airlines, along with business jets, private jets, and cargo planes. It accounts for the largest share of the market due to the use of composites to replace metals and alloys in airline vehicles.

- **The defense segment** includes aircraft such as fighter jets, unmanned air vehicles (UAV), and drones. Though fighter jets are increasingly using composites, the prime driver is exponentially growing demand from UAVs and drones. Unlike the commercial segment, end-users of defense products are mainly government authorities and organizations, which have set budgets allocated at the beginning of a year or deal. As such, demand remains mostly unaffected by environmental and microeconomic factors.

- **The space segment** refers to vehicles designed to transport people as well as materials to space. It is expected to be the fastest growing segment during the forecast period, driven by demand for small satellites for telecommunication, surveillance, and entertainment purposes. The U.S. leads the satellite manufacturing industry, accounting for more than 60% of the global market.

Rising demand for improved fuel efficiency, enhanced performance, and increased safety is driving the aerospace

**Table 1. Properties of some key ceramics. Source: TWI Ltd.**

Ceramic	Melting point (°C)	Density (g/cm <sup>3</sup> )	Strength (MPa)	Coefficient of thermal expansion (× 10 <sup>-4</sup> /°C)	Thermal conductivity (W/mK)	Elastic modulus (GPa)
Beryllium oxide	2,530	3.1	246	7.4	210	400
Alumina	2,050	4.0	455	8	40	380
Zirconia	2,700	5.6	175	10.5	19	140
Aluminum nitride	1,900	3.3	441	4.4	180	320
Silicon nitride	1,900	3.2	210	3	17	175
Boron carbide	2,350	2.5	350	4.3	25	450
Silicon carbide	2,700	3.2	140	4.3	50	210

industry to deploy new, lighter weight, stronger materials that were once considered too costly or too difficult to use for day-to-day production activities. Advanced materials are particularly important in current engine designs. Today's lean-burn engines can reach temperatures up to about 3,800°F.

Geographically, the top players in each region are

- **North America (U.S. and Canada).** The U.S. dominates the regional as well as global aerospace manufacturing industry and also leads in ceramics and composites consumption. The region also leads in the exports of aircraft-related products, with the U.S. contributing more than a 40% share in global exports.

- **Europe.** Several countries in Europe, notably France, Germany, the U.K., and Italy, are home to leading manufacturers and consumers of aero-structures and components made from ceramics and composites. Globally, the region ranks second in terms of aircraft production and exports.

- **Asia-Pacific.** With a growing population, growing disposable income, and increasing defense budgets in the region, the domestic market for airline service and aircraft increased in the last decade in the Asia-Pacific. The regional demand for such products and services are mainly driven by Japan, Australia, Singapore, and South Korea. However, the market in China and India is also growing due to a rising standard of living and high defense expenditures. China globally

**Table 2. Companies and government agencies in the space industry, by top five countries (number). Source: Space-Tech**

Country	Space companies	Government agencies
U.S.	1,741	22
China	147	3
France	170	2
Russia	8	2
Japan	72	1

ranks second in terms of its domestic aviation market and is soon expected to replace the U.S. at the top.

- **Rest of the world (Middle East, Africa, South America).** In the Middle East and Africa, the aerospace manufacturing industry is led by United Arab Emirates and Israel. The South American aerospace industry is led by Brazil, due to the presence of multinational aerospace manufacturer Embraer S.A.

## About the author

BCC Publishing Staff provides comprehensive analyses of global market sizing, forecasting, and industry intelligence, covering markets where advances in science and technology are improving the quality, standard, and sustainability of businesses, economies, and lives. Contact the staff at Helia.Jalili@bccresearch.com.

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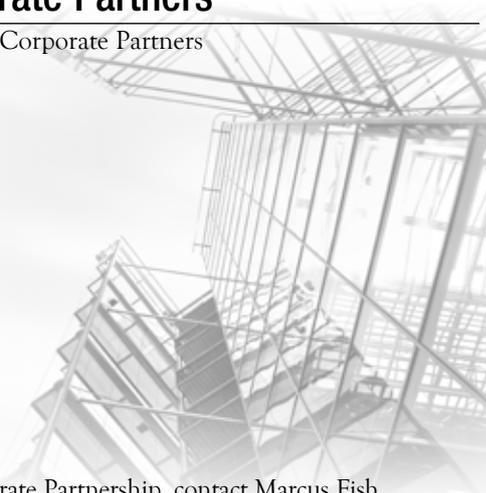
BCC Publishing Staff, "Aerospace ceramics: Global markets to 2026" BCC Research Report AVM218A, October 2021. www.bccresearch.com. ■

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**Angelo Cristante** is development engineer at Vesuvius. He holds a B.S. in materials engineering from the Federal University of Itajuba–Campus Itabira and an M.S. in materials engineering from the School of Engineering of Lorena at University of São Paulo, Brazil. Cristante also has experience in industry–academic collaborative projects both in Brazil and in the United States.

**Cristante**

Cristante joined ACerS in 2020 and has since volunteered for the Book Publishing Subcommittee, Young Professionals Network Steering Committee, and Webinar Subcommittee, as well as the Young Professionals Industry Task Force. He also serves as chair of the Subcommittee on Monolithics of the ASTM Committee on Refractories (C08) and as young professional chair of the Refractories Systems Technology Committee of the Association for Iron & Steel Technology.



**Theresa (Tessa) Davey** is assistant professor in the Fracture and Reliability Research Institute of the School of Engineering at Tohoku University, Japan. She has an M.S. in theoretical physics and an M.S. in extreme conditions physics from Imperial College London, U.K.

**Davey**

Before relocating to Japan in 2017, she completed her Ph.D. and worked as a postdoctoral research associate in the Department of Materials at Imperial College London. She also is undertaking discipline-based educational research, specifically regarding individual-centered education methods to improve equitable access to education.

Davey has been a member of ACerS since 2014, with involvement in the Refractory Ceramics, Engineering Ceramics, and Basic Science Divisions. She was a delegate of the President’s Council of Student Advisors (PCSA) and was the first international PCSA chair in 2016. Since then, she helped establish the United Kingdom and Japan Chapters and served as secretary for both. Davey is a member of the Member Services Committee and recently became chair of the Diversity & Inclusion Subcommittee.

We extend our deep appreciation to Cristante and Davey for their service to our Society! ■

FOR MORE  
INFORMATION:

[ceramics.org](http://ceramics.org)

## ACerS Sections network and present at in-person events

Members of the **Carolinas Section** ► gathered for networking during ACerS Annual Meeting at MS&T in Pittsburgh, Pa., on Tuesday, Oct. 11, 2022. ■



◀ **Colorado Section** members attended the Colorado Center for Advanced Ceramics Conference (CCAC) on Aug. 16–17, 2022, at the Colorado School of Mines. Organized by the graduate students at the Colorado School of Mines, CCAC is one of the largest technical ceramic conferences in the region. The Colorado Section also provided sponsorship for the event. ■

Members of the **New Mexico Section** ► review posters at the 32<sup>nd</sup> Rio Grande Symposium on Advanced Materials on Oct. 24, 2022. ■



### 'Maintaining, repairing, and replacing terra cotta roofs' presented by the Western New York Section

On Sept. 15, 2022, the Western New York Section co-hosted a presentation by Alfred University librarian and university archivist Laurie Lounsberry Meehan on the terra cotta industry. The presentation was followed by a Section leadership meeting and dinner at the Rosebush restaurant in Alfred, N.Y. ■



Laurie Lounsberry Meehan

### Welcome to the newest ACerS Section!

ACerS Board of Directors recently approved a petition to establish the New Jersey/Metro New York/Philadelphia Section of The American Ceramic Society. As a local source of ceramic and glass industry education, information, and interaction, ACerS Sections bring the Society's vast resources directly to our members.

The Section welcomes involvement of students in New Jersey, Metro New York, or the Philadelphia area. To learn more and to get involved with the new Section, contact Marilyn Stoltz at [mstoltz@ceramics.org](mailto:mstoltz@ceramics.org) or the Section officers.

- Chair: Lisa Klein, Rutgers University
- Treasurer: Ryan Sills, Rutgers University
- Secretary: Ashutosh Goel, Rutgers University ■

more  
SOCIETY  
DIVISION  
SECTION  
CHAPTER  
NEWS



**Germany Chapter co-hosts Symposium on Glass, Sept. 22–23, 2022, in Mainz, Germany**

The German Glass Society, SCHOTT AG, and the ACerS Germany Chapter co-hosted the Symposium on Glass, Sept. 22–23, 2022, in Mainz, Germany. Symposium topics included advanced processing, study of glass transitions, and the chemical processing of functional ceramics.

ACerS president Sanjay Mathur (pictured right) was among the eight invited guests. Approximately 60 students, scientists, and industry representatives participated in fruitful discussions during the two-day event. ■



**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](mailto:mmartin@ceramics.org). The deadline is the 30<sup>th</sup> of each month.



Ressler

**Kevin Ressler** joined the CoorsTek executive leadership team in the role of chief commercial officer.



Singh

**Mrityunjay Singh** received the Edward DeMille Campbell Memorial Lecture Award of ASM International.



Varshneya

**Arun Varshneya** will serve as the 58<sup>th</sup> president of the Society of Glass Technology. ■

**Serbia Chapter members attend local ceramics conference**



Members of the ACerS Serbia Chapter attended the Advanced Ceramics and Application Conference in Belgrade, Serbia, on Sept. 26–27, 2022.

**Spain Chapter organizes Ceramics and Vitreous Materials for the 21<sup>st</sup> Century Workshop**

Approximately 25 students and scientists attended the Ceramics and Vitreous Materials for the 21<sup>st</sup> Century Workshop at Instituto de Tecnología Cerámica on Oct. 19, 2022. ■



Spain Chapter treasurer **José Serafin Moya** (left) and chair **Arnaldo Moreno Berto** (right). ▶



## Ceramic Tech Chat: Valerie Wiesner

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 October episode of Ceramic Tech Chat, Valerie Wiesner, research materials engineer at NASA Langley Research Center, shares how she became involved with the materials side of space research, describes working on mitigation strategies to minimize the impact of lunar dust, and gives her thoughts on what to expect from space exploration and travel in the coming years. Check out a preview from her episode, which features Wiesner describing the challenge of lunar dust.

*“Lunar dust is a major problem that can really hinder a lot of the surface operations, whether it’s landing on the surface, establishing a human habitat. The dust is everywhere. It basically coats the moon, and coupled with being under vacuum, and being exposed to UV radiation from the sun, among other things, there are a lot of interesting and really damaging effects that can come from the interactions with lunar surface dust. ... So, we’ve been exploring different ceramic-based coatings that offer wear resistance or abrasion resistance, really, against that lunar dust to try to figure out, ‘Hey, can we improve that performance and ultimately the life and durability of a lot of the components that we have operating to enable our sustainable human presence on the moon?’”*

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



## Bioceramics 32, Venice, Italy, Sept. 20–23, 2022



The American Ceramic Society endorsed the 32<sup>nd</sup> Symposium and Annual Meeting of the International Society for Ceramics in Medicine (Bioceramics 32) held in Venice, Italy, on Sept. 20–23, 2022. During this event, ACerS sponsored a well-attended session on “Antibacterial bioceramics for smart prosthetic applications” with speakers from Italy, Germany, France, India, and other countries. The ACerS Bioceramics Division (represented by Bikramjit Basu, Annabel Braem, and Sadaf Batool) attended. ■

## IN MEMORIAM

Ian Hastings

James Keski

Some detailed obituaries can also be found on the ACerS website, [www.ceramics.org/in-memoriam](http://www.ceramics.org/in-memoriam).

# AWARDS AND DEADLINES



## Announcing the launch of ACerS online Society awards portal

ACerS recently partnered with OpenWater, an online application and review software platform, to provide a streamlined experience for our members to submit Society award nominations. Several notable features include

- Single sign-on using your ACerS login
- Ability to begin, save, complete, and submit nominations
- Option to add collaborators to allow other ACerS members to upload letters of support, signatures, or other documentation
- Online award subcommittee collaboration and judging

Deadline for Society award nominations is **Jan. 15, 2023**. Visit <https://bit.ly/ACerSONlineAwards> to log in and start the award nominations process! ■

## BSD presents first Early Discovery Award

The Basic Science Division's Early Discovery Award recognizes an early career member of ACerS who has demonstrated a contribution to basic science in the field of glass and ceramics.



**Yanhao Dong** is the first awardee of the BSD's Early Discovery Award. Dong is an assistant professor in the School of Materials Science and Engineering at Tsinghua University. He obtained a B.S. in materials science from Tsinghua University; his M.S. in materials science, M.S. in applied mechanics, and Ph.D. in material science all come from The University of Pennsylvania. Previous awards through the Society include the Electronics Division's Edward C. Henry Award and ACerS' Morgan Medal and Global Distinguished Doctoral Dissertation Award. His current research focuses on advanced ceramics for structural and energy applications.

The Early Discovery Award includes an ACerS lifetime membership and a certificate of recognition. ■

## Ceramographic Awardees

### Roland B. Snow Award for Best in Show

*Heart of chromium*—by **Roei Bronschter** and **Wayne D. Kaplan**; Technion Israel Institute of Technology

#### Scanning electron microscopy category

First: *Finding Dory MXene*—by **Nithin Chandran B. S.**, **Anupma Thakur**, and **Babak Anasori**; Indiana University-Purdue University

Second: *Dandelion meadow*—by **Stepan Vorotilo** and **Kseniia Vorotilo**; Drexel Nanomaterials Institute

Third: *Rare earth oxide cornflakes*—by **Christian Stern**, **Doris Sebold**, **Martin Bram**, and **Olivier Guillon**; Forschungszentrum Juelich GmbH

#### Transmission electron microscopy category

First: *Waterfall hidden in deep mountain*—by **Bo Yang**, **Haiyan Wang**, and **Xinghang Zhang**; Purdue University

Second: *Nano cake & goldberries*—by **Jianan Shen**, **James P. Barnard**, and **Haiyan Wang**; Purdue University

Third: *A buried gem*—by **Chao Shen**, **Anyu Shang**, **Haiyan Wang**, and **Xinghang Zhang**; Purdue University

#### Optical microscopy category

First: *Strontium titanate mustang*—by **Hudson Shih**, **Yayoi Takamura**, **Seung SaeHong**; University of California, Davis

Second: *Polycrystal SrTiO<sub>3</sub> galaxy*—by **Chukwudalu Okafor**, **Jürgen Rödel**, and **Xufei Fang**; Technical University of Darmstadt, Germany

Third: *Great white heron 'spotted' on CaF<sub>2</sub>*—by **Alexander Frisch**, **Jürgen Rödel**, and **Xufei Fang**; Technical University of Darmstadt, Germany

#### Undergraduate student contribution

First: *Heart of chromium*—by **Roei Bronschter** and **Wayne D. Kaplan**; Technion Israel Institute of Technology

#### Scanning probe category

First: *Nanoparticle growth in a twisted relationship*—by **M.L. Weber**, **C. Lenser**, **O. Guillon**, and **F. Gunkel**; Forschungszentrum Jülich GmbH & Lawrence Berkeley National Laboratory ■

## Nomination deadline for Division awards: Jan. 15 or Jan. 21, 2023

**Contact:** Karen McCurdy | [kmccurdy@ceramics.org](mailto:kmccurdy@ceramics.org)

Division	Award	Nomination Deadline	Description
AACS	Anna O. Shepard	Jan. 15, 2023	Presented to an individual(s) who has made outstanding contributions to materials science applied to art, archaeology, architecture, or cultural heritage.
BIO	Young Scholar	Jan. 15, 2023	Recognizes excellence in research among current degree-seeking graduate students and post-doctoral research associates.
BIO	Global Young Bioceramicist	Jan. 15, 2023	Recognizes the outstanding young ceramic engineer or material scientist who has made significant contributions to the area of bioceramics, for human healthcare around the world. Nominations are invited for candidates from academia, industry, or government-funded national laboratories around the world.
BIO	Larry L. Hench Lifetime Achievement	Jan. 15, 2023	Presented to a deserving individual(s) in recognition of lifetime dedication, vision, and accomplishments in advancing the field of bioceramics, particularly toward innovation in the field and contribution of that innovation to translation of technology toward clinical use.
BIO	Tadashi Kokubo	Jan. 15, 2023	Presented to a deserving individual(s) in recognition of their outstanding achievement in the field of bioceramics research and development.
BSD	Early Discovery	Jan. 15, 2023	Recognizes an early career member of ACerS who has demonstrated a contribution to basic science in the field of glass and ceramics.
BSD	Robert B. Sosman Award	Jan. 15, 2023	Awarded in recognition of outstanding achievement in basic science that results in a significant impact to the field of ceramics.
Cements	Early Career	Jan. 15, 2023	Recognizes an outstanding early career scientist who is conducting research in the field of cement and concrete in academia, industry, or a government-funded laboratory.
EPDC	Greaves-Walker Lifetime Service Award	Jan. 15, 2023	Presented to an individual who has rendered outstanding service to the ceramic engineering professions and who has exemplified the aims, ideals, and purpose of EPDC.
EPDC	Arthur L. Friedberg Engineering Tutorial and Lecture	Jan. 15, 2023	Given to an individual who has made outstanding contributions to ceramic engineering that relate to the processing or manufacturing of ceramic products. The awardee must be a member of EPDC and ACerS.
EPDC	Outstanding Educator	Jan. 15, 2023	Recognizes truly outstanding work and creativity in teaching and mentoring, in directing student research, or in the general educational process (e.g., lectures, publications on education, workshops, textbooks, short courses, videos, interest lectures) among ceramic/glass educators.
GOMD	Norbert J. Kreidl	Jan. 21, 2023	Recognizes research excellence in glass science. Open to all degree-seeking graduate students (M.S. or Ph.D.) or those who have graduated within a twelve month period of the annual GOMD meeting.
GOMD	George W. Morey	Jan. 21, 2023	Recognizes new and original work in the field of glass science and technology. The criterion for winning the award is excellence in publication of work, either experimental or theoretical, done by an individual.
GOMD	L. David Pye Lifetime	Jan. 21, 2023	Recognizes a lifetime of dedication, vision, and accomplishments in advancing the fields of glass science, glass engineering, and glass art.
GOMD	Stookey Lecture	Jan. 21, 2023	Recognizes an individual's lifetime of innovative exploratory work or noteworthy contributions of outstanding research on new materials, phenomena, or processes involving glass that have commercial significance or the potential for commercial impact.
GOMD	Varshneya-Mauro-Jain Guru-Chela Travel Fund	Jan. 21, 2023	Recognizes the special bond of knowledge, trust, and growth between a teacher ("Guru") and a student ("Che-la"), benefiting both.
MFG	John E. Marquis	Jan. 15, 2023	Presented to the author or authors of a paper on research, engineering, or plant practices related to manufacturing in ceramics and/or glass published in the prior calendar year (2022) in a publication of the Society, which is judged to be of greatest value to the members and to the industry. ■

# STUDENTS AND OUTREACH



FOR MORE  
INFORMATION:

[www.ceramics.org/students](http://www.ceramics.org/students)

## MS&T22 student contest winners

The Material Advantage Student Program sponsored various contests for undergraduate and graduate students during MS&T22 in Pittsburgh, Pa. Thank you to all who helped judge and organize the contests this year, and congratulations to all the student winners.

### Material Advantage graduate student poster contest

1<sup>st</sup> place—\$250

**Sien Liu**, The University of Tokyo—*Effect of interfacial microstructure on tensile property and fracture behavior of bicrystal and polycrystal Fe/Ni interface*

2<sup>nd</sup> place—\$150

**David Guirguis**, Carnegie Mellon University—*Quantification of melt pool variability for LPBF additive manufacturing by high-speed imaging*

3<sup>rd</sup> place—\$100

**Matthew Julian**, Institut d'Electronique et des Technologies du numéRique (IETR)—*Structural and dielectric properties relationship in strontium-tantalum based oxide ceramics for DRA applications*

### Material Advantage undergraduate student poster contest

1<sup>st</sup> place—\$250

**Jack Beardshear**, Carnegie Mellon University—*Impact of itaconic acid on the stabilization reaction of poly(acrylonitrile-co-itaconic acid) as examined using solid-state NMR under air and vacuum conditions*

2<sup>nd</sup> place—\$150

**Caitlyn Santiago**, Carnegie Mellon University—*Fabrication of three-dimensional ceramic architectures with micro-scale resolution and near zero shrinkage using aerosol jet printing*

3<sup>rd</sup> place—\$100

**Meddelin Setiawan**, The Pennsylvania State University—*A novel high-energy X-ray diffraction microscopy (HEDM) processing algorithm for reconstructing large 3D intragranular orientation gradients*

### Material Advantage undergraduate student speaking contest

1<sup>st</sup> place—\$500

**Aliya Kaplan**, Virginia Polytechnic Institute and State University—*New ceramic approach to active cooling*

2<sup>nd</sup> place—\$250

**Kira Martin**, University of Illinois at Urbana-Champaign—*Material characterization of TiN films motivated by time and energy resolved mass spectroscopy*

3<sup>rd</sup> place—\$150

**Abigail Stanlick**, Iowa State University—*Little known nylon: Nylon 5,9 synthesis and scientific importance*

4<sup>th</sup> place—\$100

**Christopher Barns**, West Chester University of Pennsylvania—*Structural phase patterning of MoS<sub>2</sub>*

### Material Advantage Ceramic Mug Drop Contest—Organized by Keramos

Winner—\$100 and trophy

**Mitchell Lensing**, Colorado School of Mines

Most aesthetic mug—\$50

**Mitchell Lensing**, Colorado School of Mines

### Material Advantage Ceramic Disc Golf Contest—Organized by Keramos

Winner—\$100 and trophy

**Victoria Rambo**, Virginia Polytechnic Institute and State University

Most aesthetic disc—\$100

**Makayla Gamiel**, Missouri University of Science and Technology

### Material Advantage Social Media Contest

\$100

**Caitlyn Santiago**, Carnegie Mellon University

\$100

**Nolan Clark**, McMaster University ■

## ACerS student tours resume at MS&T 2022, courtesy of Almatris, Inc.

As a conclusion to a successful MS&T 2022 conference, nine graduate and undergraduate students were given the opportunity to tour Almatris, Inc.'s Leetsdale, Pa., manufacturing plant. This tour was organized by the ACerS President's Council of Student Advisors (PCSA) and is the first physical tour the PCSA hosted since MS&T 2019. Students from seven universities from across the globe attended. Special thanks are extended to Marilyn Kunka, Leslie Beiter, Bill Smith, John Holloway, and the entire Almatris Leetsdale team.

The tour began with an overview of Almatris' global structure and product portfolio. While the Leetsdale Almatris location is primarily involved in grinding tabular and calcined alumina to controlled sizes for customer needs, Almatris is a global leader in premium alumina with a wide range of specialty materials. The Almatris team answered questions ranging from alumina logistics to the development of new product lines, and attending students were immediately able to learn about the differences between sourcing laboratory-scale and industrial-scale quantities of material. Few tour participants had ever measured supplies by the railcar-load!

After meeting the Almatris team and learning about the company structure, the tour proceeded to the factory floor.

Here, students saw how aluminum oxide balls from Almatris' Bauxite, Arkansas, location are crushed and milled to size, characterized, and bagged for shipment. Coming from mostly research environments, the high degree of automation in Almatris' operations was eye-opening to many tour participants.

The highlight of the tour was Almatris' ball mills, some of the largest in the world, which are employed to produce alumina powder of tightly controlled particle sizes. Toward the end of the tour, students saw the product testing, characterization, and quality control labs, an environment many of the student researchers found more familiar.

These student tours at MS&T are a critical event for broadening students' understanding of the ceramics industry. By interacting with current professionals in the industry and seeing large-scale manufacturing in operation, students learn about ceramics in a way that can be impossible in a laboratory or a classroom. The PCSA is proud to resume this aspect of our conference programming. We hope many of our readers can

attend the ACerS Student Tour at MS&T 2023, and would like to again thank Almatris, Inc. for hosting student attendees and providing this opportunity.

The MS&T 2022 ACerS Student Tour was organized in partnership with The American Ceramic Society and the Programming Committee of the PCSA. ■



## ACerS' evolving mentor programs

The Education and Professional Development Council (EPDC) created the EPDC Mentor Program Subcommittee in 2021 to manage and create new mentor programs based upon the framework of the PCSA's long running and successful Student Mentor Program.

The EPDC Mentor Program Subcommittee launched a new Faculty Mentor Program this year to provide more opportunities for our academic-focused ACerS members. Several Faculty Mentor Program participants were matched and will officially continue their mentor relationship at least through the end of 2022. For this upcoming year, the EPDC Mentor Program Subcommittee put together a **new Industry Mentor Program** to cater to even more of ACerS membership. We encourage all who are interested to sign up for one or more of the mentor programs offered.

The ACerS Mentor Programs are designed to equip participants with the insight, tools, and connections necessary to make a lasting impact in their future career. Many mentor program participants choose to return each program year to take on a new mentee and/or continue with an existing mentee.

Some of the 2022 mentor program participants, along with some of ACerS leadership, gathered during ACerS Annual Meeting at MS&T22. Pictured, from left, are Sanjay Mathur, Victoria Blair, and Monica Ferraris.



We gathered together some of the 2022 mentor program participants, along with some of ACerS leadership, during ACerS Annual Meeting at MS&T this year, and we hope to do the same at the Annual Meeting at MS&T23 as well.

Be sure to visit [www.ceramics.org/mentorship](http://www.ceramics.org/mentorship) to sign up for the 2023 mentor programs! ■

# CERAMIC AND GLASS INDUSTRY FOUNDATION

## CGIF scholarship recipient does not give up on his goals—or his family

Beaming in front of a royal blue curtain on the Zoom call, one cannot help but think of a magician when speaking with CGIF scholarship recipient Devon Woodfine. A quick glance upon his impressive email signature implies he really is a magician, or perhaps Woodfine simply mastered the art of being the hardest worker in the room. Let us go with the latter.

Born and raised in South Los Angeles—or South Central—Woodfine grew up in a single-parent household with an emphasis on the importance of education.

“Ever since I was a kid, education has always been a big push in my family to obtain and I’ve always had an interest in STEM,” Woodfine says. “I’m big into manga and comics, so my favorite characters in those are usually the scientist or gadget guy, so I knew I was gonna get into engineering or something or like computer science.”

Woodfine is a rising junior at California State Polytechnic University, Pomona, where he studies mechanical engineering. Last fall, Woodfine received \$5,000 through the National Society of Black Engineers (NSBE) on behalf of the CGIF and ACerS.

In 2019, Woodfine assumed the head of his household and now serves as the primary caregiver for his mother, who became chronically ill when Woodfine was still in high school. Woodfine says this scholarship allowed him to pay off most of his tuition for this year.



“I’m truly grateful that the (CGIF) selected me as the winner this year,” Woodfine says.

In the future, Woodfine aspires to attend graduate school, earn his Ph.D., and create his own startup company, but he also considers delving right into the engineering industry.

“I’m thinking of doing product design for maybe a fan corporation in Silicon Valley, but I’m also open to working in the biomedical space,” Woodfine says.

Woodfine recognizes that materials science can play a crucial role in protecting the environment from harmful substances.

“From plastics to biodegradable materials used for the consumer market, medical devices [are] made from biocompatible tissue,” Woodfine says. “And weather resistant batteries for electric vehicles are all problems materials science will solve in the upcoming years that will revolutionize how we imagine life.”

Last year, Woodfine served as a pilot manufacturing intern at Edwards Lifesciences in Irvine. This summer, he worked as a process informatics intern at Pfizer. He also serves as vice president of NSBE at Cal Poly Pomona. While the list of achievements goes on for Woodfine, family is still at the forefront of his life.

“You can’t just give up, because there’s somebody depending on you,” Woodfine says. “My mom was in that situation with me where I’m probably sure there were days that she didn’t want to go forward but she had to do it because she had a son to take care of, so it’s like—it’s paying it forward.” ■

SAVE THE DATE  
OCT. 1-5, 2023

MS&T 23  
MATERIALS SCIENCE & TECHNOLOGY

Technical Meeting and Exhibition

GREATER COLUMBUS  
CONVENTION CENTER  
COLUMBUS, OH USA

[MATSCITECH.ORG](https://MATSCITECH.ORG)

## Kicking cancer to the curb: A review of ceramics and glasses for cancer diagnosis and therapy

The use of ceramic and glass materials for cancer diagnosis and therapy is a growing area of interest.

Currently, cancer typically is treated through surgical removal of the tumor followed by chemotherapy and/or radiotherapy to destroy any remaining pieces. However, chemotherapy can trigger severe side effects caused by inherent off-target toxicity of the drugs, while radiotherapy can damage nearby healthy cells. Thus, new methods are needed for early detection and targeted treatment of cancer.

Researchers from The University of Hong Kong, Southern University of Science and Technology (China), University College London (U.K.), and Columbia University (U.S.) wrote a 26-page paper overviewing the main ceramics and glasses being explored for cancer detection and treatment, including their properties and possible applications.

### Materials for cancer diagnosis and therapy

Among the ceramics used in cancer diagnosis and therapy, the phosphate family is widely explored. Calcium phosphates are the major inorganic constituents of biological hard tissues, such as bones and teeth, and therefore offer inherent biocompatibility.

#### Ceramics in cancer diagnosis and therapy

##### Diagnostic functions

- Optical imaging
- Ultrasound imaging
- Computed tomography
- Magnetic resonance imaging
- Single-photon emission computed tomography
- Multimodal imaging

##### Therapy approaches

- Chemotherapy
- Hyperthermia
- Gene therapy
- Photodynamic therapy
- Radiation therapy



**Pink ribbon for Breast Cancer Awareness Month, which takes place in October.**

Credit: Angiola Harry, Unsplash

Nanostructured amorphous calcium phosphate, hydroxyapatite, and calcium-deficient hydroxyapatite are frequently used because they are easy to make from aqueous solutions using a simple precipitation method. In recent decades, tricalcium phosphate became more attractive as well due to its biodegradability.

Bioactive glasses for medical applications are mainly composed of varying proportions of silica, calcium oxide, sodium oxide, and phosphorous pentoxide. The specific properties of these glasses are often modified by controlling their synthesis at the nanometer scale.

Doping ceramics and glasses with magnetic ions (e.g.,  $\text{Fe}^{2+}/\text{Fe}^{3+}$ ,  $\text{Mn}^{2+}$ ,  $\text{Gd}^{3+}$ ) allows the materials to be used for magnetic targeting, magnetic-induced treatment guidance, and magnetic hyperthermia.

### Development of ceramic-based cancer theranostics

Theranostics (**therapy + diagnostics**) is a novel concept that entails the use of nanoparticles in a single system for both molecular sensing/imaging and therapy for cancer.

Though there are a few single-component nanoparticle systems that may be used for theranostics, such systems have major limitations and have not been vigorously pursued. Instead, composite or hybrid nanoparticles hold the

greatest promise for cancer detection and treatment.

Mesoporous silica nanoparticle-based theranostics are one much studied system due to their potential as carriers for either imaging contrast agents or therapeutic agents. Calcium phosphates are of interest in theranostics as well because they may provide stimuli-triggered drug release resulting from pH-dependent dissolution.

### Challenges and future opportunities

Though there are substantial reports on biological studies performed in vitro and in animal models, the authors found very few clinical trials on either single-component or hybrid ceramic theranostics. Bringing ceramic-based theranostics to clinical trial or commercialization will involve the following steps.

- Consider both short-term and long-term toxicity of the potential theranostic materials. Currently, most reports present only short-term biological test results.
- Improve the targeting ability of theranostics and thereby ensure sufficient dosage. Fortunately, there exists a body of knowledge on tumor-specific targeting ligands, targeting efficiency, and mechanisms to overcome targeting barriers. This knowledge provides a framework for future studies.
- Develop new methods for clinical use that achieve detection and/or therapy function in the body. According to the authors, a “good percentage” of published detection and therapy methods are not applicable or usable when the theranostics are at the targeted tissue site in the body.

• Formulate controllable and reproducible synthesis processes for theranostics. Because hybrid ceramics are the most promising systems for theranostics, manufacturers must ensure precise control of the synthesis parameters to avoid batch-to-batch variations.

The paper, published in *Journal of the Korean Ceramic Society*, is “Hybrid ceramics-based cancer theranostics” (DOI: 10.1007/s43207-022-00217-w). ■

## Injection molding may offer path to high-throughput manufacturing of transparent ceramics

In a recent open-access paper, German researchers showed that transparent magnesium aluminate spinel ceramics can be shaped and structured using conventional injection molding machinery.

Fabrication of transparent ceramics typically involves casting powders from water-based solutions or pressing raw powders followed by a sintering process. This approach only produces simple geometries; more complex structures require time-consuming post-processing steps such as grinding, polishing, or etching.

Some studies on additive manufacturing of transparent ceramics have taken place, but these methods are not suited for mass-market manufacturing.

Powder injection molding is a well-known method for manufacturing small, complex-shaped inorganic components. It involves mixing metal or ceramic powders with polymeric binders and then pushing the heated mixture under pressure into a die cavity, where it cools and is subsequently ejected. The composite then undergoes heat treatments to remove the polymeric binder and achieve final density.

The authors of the recent paper come from Albert Ludwig University of Freiburg and include colleagues from Karlsruhe Institute of Technology. They describe using a two-step debinding process followed by sintering and hot isostatic pressing to fully densify their transparent ceramics. Notably, no sintering aids were used because “it has been shown repeatedly” that dopants can affect the final properties of a transparent ceramic, they write.

Without further post-processing steps, the magnesium aluminate spinel ceramics achieved high optical transmissions of up to 84% and high surface quality with a roughness of less than 20 nm. Additionally, the researchers could create the ceramics in a variety of sizes, from macroscopic components with wall thicknesses up to 4 mm down to microstructured components with single micrometer resolution.



**Example of an injection molded transparent ceramic shaped like a gear. Scale bar: 5 mm.**

The open-access paper, published in *Advanced Science*, is “Injection molding of magnesium aluminate spinel nanocomposites for high-throughput manufacturing of transparent ceramics” (DOI: 10.1002/advs.202204385). ■

## Thermoformed boron-based ceramics may offer new frontier in customized electronic components

In a recent paper, Northeastern University (Boston, Mass.) researchers demonstrate how the proper microstructure can allow a ceramic to be formed via a method traditionally reserved for plastics and sheet metals.

Thermoforming involves heating a sheet-shaped material to a pliable temperature and then laying it over a mold using pressure or vacuum forming methods. It is useful for fabricating parts that require large-scale designs and shorter production runs.

The typically brittle nature of ceramics keeps it from being formed via thermoforming methods. However, the Northeastern University researchers successfully demonstrated that certain ceramics can be formed via thermoforming.

Their ceramic matrix composite (CMC) consists of highly oriented hexagonal boron nitride (hBN) particles within a boron oxide matrix. They explain that the atomic structure of hBN gives it high thermal anisotropy, which allows the CMC to quickly transmit heat and flow effectively during the molding process.

To fully harness this innate property of hBN, the researchers used a vibration-assisted casting method they previously developed to align high volume fractions

of hBN particles (60 vol%) in a liquid photoresin. They then subjected the dense particle suspension to vibration energies during a tape casting process to further fluidize and shear align the hBN in-plane to a high degree.

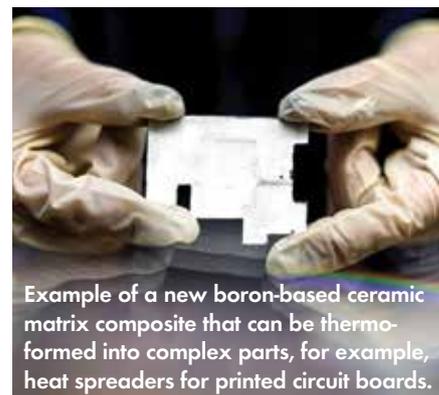
Following tape casting, the researchers applied ultraviolet light to the suspension to polymerize the photoresin, locking in the oriented hBN particles. Finally, they subjected the samples to pressureless sintering in oxygenated environments to grow a matrix of boron oxide that replaced the polymeric matrix and engulfed the hBN.

The researchers characterized the CMC’s flow regimes into a phase diagram and determined the optimal flow properties for thermoforming occurred between 500–700°C. With this knowledge, they thermoformed the boron-based CMC to a variety of molds and feature sizes, achieving feature sizes as small as 200 µm at 700°C.

To demonstrate the potential of ceramic thermoforming on the electronics field, they compared the cooling performance of an incumbent aluminum heat sink against a press-fit, thermoformed CMC on a Raspberry Pi computer. When the heat sinks were normalized by height, the CMC showed a cooling advantage 10× over the aluminum.

According to a Northeastern University press release, the researchers are now developing the thermoformed CMC via their startup, Fourier LLC.

The paper, published in *Advanced Materials*, is “Thermoformable boron nitride based all-ceramics” (DOI: 10.1002/adma.202203939). ■



**Example of a new boron-based ceramic matrix composite that can be thermoformed into complex parts, for example, heat spreaders for printed circuit boards.**

# Star power!

## How glass and ceramics push us deeper into space

By Leslie Nemo



Astronaut David A. Wolf, STS-112 mission specialist, anchored to a foot restraint on the Space Station Remote Manipulator System, carries the Starboard One outboard nadir external camera.

Tucked into museums, private collections, and even archaeological sites are some nondescript tubes with bubbly, blemish-filled glass inside. Though it would be easy to write off the old instruments as unimpressive, the assortment of these strange devices scattered over Europe represent some of the world's earliest known telescopes—the first instruments people used to bring stars, planets, and outer space closer to home, even if only for an evening.

Credit: NASA

# Star power! How glass and ceramics push us deeper into space



Credit: Michael Koney

**Figure 1. Marvin Bolt, first-ever curator of science and technology at The Corning Museum of Glass before his retirement in 2020, peers through an early telescope made around 1650 CE. The telescope is part of the Astronomisch-Physikalisches Kabinett collection in Kassel, Germany.**

The oldest telescopes available today date to the early- and mid-17<sup>th</sup> century, not long after the technology itself was born (Figure 1).<sup>1</sup> And even though it took a while for telescope users to focus the tubes on the skies—the earliest versions were meant for surveying landscapes and monitoring enemies as they approached—glass has been integral to the collecting and focusing of light as long as the devices have been around.

The earliest iterations were full of imperfections from inconsistent raw materials and rudimentary processing situations. Glass quality did not see a significant boost until the late 1600s with leaded varieties, which fostered mass production of telescopes. Lens design and glass types continued to evolve, eventually leading to borosilicate compositions, which still features in the world's largest and most ambitious space exploration projects.<sup>2</sup>

Even as we venture into space instead of only watching it from home, glass and the exploration of our universe have stayed inextricably linked. Ceramics, too, have wound their way into the technologies that get us closer and closer to the rest of our universe due to their ability to withstand the extreme environments found in space.

Temperatures in space run a range that is difficult to comprehend—spots near the poles of the moon can drop to  $-424^{\circ}\text{F}$

or  $-253^{\circ}\text{C}$ ,<sup>4</sup> while reentering the Earth's atmosphere can generate temperatures over  $4,800^{\circ}\text{F}$  or  $2,649^{\circ}\text{C}$ .<sup>5</sup> A mission and all of its precious cargo must handle temperature changes within this spectrum, all while withstanding battery from other destructive forces.

For example, in low-Earth orbit, which extends about 1,000 kilometers off Earth's surface,<sup>6</sup> the atmosphere consists of about 96% atomic oxygen.<sup>7</sup> These highly reactive single oxygen atoms can erode spacecraft exteriors, and so pose a threat to the satellites located in low-Earth orbit, as well as the International Space Station (ISS). Radiation exposure is an issue as well, both in Earth's immediate area and deeper into space. Over time, cumulative bombardment by high-energy subatomic particles can wear down equipment.<sup>8</sup> If a particle strikes an electrical circuit just right, computers and communication systems can crash.

For all that space can throw at a mission, glass and ceramics handle the hazards well. Ceramics are often good insulators and can protect internal heat-sensitive materials and instruments. Additionally, many glass and ceramic materials have good thermal stability, meaning there is minimal expansion, contraction, or warping when they undergo extreme temperature shifts. Both also are fairly chemically stable and can withstand atomic oxygen and radiation better than, say, aluminum<sup>9</sup> or silicon.<sup>10</sup> Plus, in the vacuum that is space, materials can outgas, meaning molecules come off and drift away. Overall mass drops, and the particles could land on instruments aboard the craft, clouding operations. Glass and ceramics largely resist this kind of vacuum-induced loss.

Glass and ceramics also hold strong appeal in the space industry for a seemingly-minor but fairly important reason: The materials have a long track record. Research and design for space missions is expensive and time-consuming. Whatever goes past Earth's atmosphere must endure every condition it might meet and, in many cases, needs to ensure the wellbeing of human passengers.

"People who design space vehicles are fairly conservative for obvious reasons," says Sylvia Johnson, retired chief materials technologist for the Entry Systems and Technology Division at NASA Ames Research Center, in an interview. "If a material has been proven not just by testing but by [for example] landing on Mars, that gives a lot more confidence."

Glass has hundreds of years of proven space imaging utility. And when it comes to launching equipment into space, use of ceramics to mitigate high temperatures has a history stretching back to 1981, when the Space Shuttle first launched. Portions of the craft that saw the highest temperatures were protected by ceramic tiles designed by University of Washington engineer James Mueller and his team. (Apollo mission heat shields had fiberglass-reinforced epoxy components, where the epoxy composite was designed to ablate away as it deflected heat from the astronauts during reentry.<sup>11</sup>)

For all these reasons, glass and ceramic materials frequently have a place in space exploration from beginning to end—from launch and return, to all the travel, data collection, and learning in between (Figure 2).

## GLOBAL MARKETS FOR CERAMICS IN SPACE

Expanding space programs and operations, including the current commercial space travel boom, ensure a strong future for ceramic space markets. For North America alone, the market for space operation ceramics was valued at \$158.2 million in 2020 and is predicted to reach \$902.9 million in 2026. Though North America, the United States in particular, represents the largest space ceramic market, other global markets are growing as well. European, Asian-Pacific, and Chinese markets should reach \$473.7 million, \$438 million, and \$150.4 million by 2026, respectively. Learn more about these markets in the "Business and Market View" column on page 7.<sup>3</sup> ■

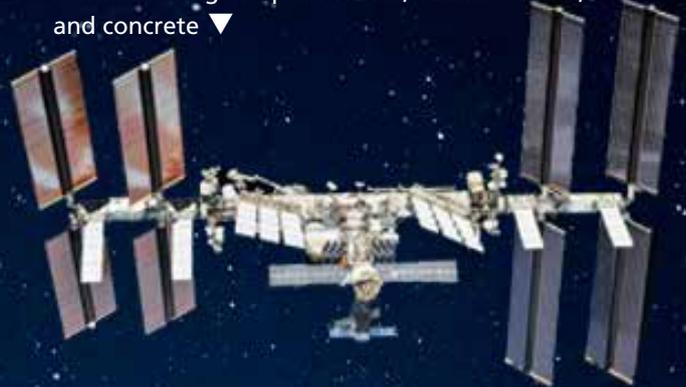
## Offworld exploration

Lunar and Martian regolith for 3D printing components in space ▼



## International Space Station

- Microgravity experimentation on glasses
- Manufacturing of optical fibers, turbine blades, and concrete ▼



## Satellites

- Glass-fiber and carbon-fiber-reinforced polymers for structural elements
- Ceramic coatings for thermal and radiation protection
- Silicate glasses and gallium arsenide for solar panels
- Gallium nitride and silicon carbide circuitry
- Chalcogenide phase-change materials for photonic applications



## Exit and reentry from space

- Ceramic coatings and composite structural elements for thermal protection systems
- Concrete-based pads for launch complexes
- Fiber-reinforced ablative materials and ultrahigh-temperature ceramics for thermal protection during reentry



## Ground-based observations

Glass and glass-ceramics for lenses and mirrors ▶



Figure 2. Glass and ceramic materials play a role in space exploration from beginning to end—from launch and return to all the travel, data collection, and learning in between.

# Star power! How glass and ceramics push us deeper into space



**Figure 3.** Thomas Werner, head of the Extremely Large Telescope project, pictured with the 500<sup>th</sup> ZERODUR mirror blank for the M1 primary mirror.



**Figure 4.** Inside the Operations and Checkout Building high bay at NASA's Kennedy Space Center, technicians dressed in clean-room suits have installed a back shell tile panel onto the Orion crew module and now are checking the fit next to the middle back shell tile panel.

## LOOKING BEYOND OUR ATMOSPHERE: GROUND-BASED TELESCOPES

Though telescopes have progressed from the warped, speckled tubes of several centuries ago, the instruments—whether on land or in the skies—still rely on glass. The material provides an ultrasmooth, durable mirror blank for metal coatings, such as aluminum, that collect light in the telescope. The seven 27.5-foot-diameter blanks making up the primary reflector in the Giant Magellan Telescope (GMT), for example, are made of E6 low expansion borosilicate glass.<sup>12</sup>

Not only is borosilicate glass relatively affordable compared to other glass options for the project, but it can withstand chemical erosion. Every few years, the telescope lenses for the GMT will get new aluminum coatings to make sure the reflective surface is in good condition. Removing the remnants of the previous coating calls for strong acids and bases to dissolve it away. Borosilicate glass can handle the chemical exposure.

The assembly of each mirror starts with the Ohara Corporation glass manufacturer shipping lumps of the glass from their production site in Japan to the University of Arizona's Richard F. Caris Mirror Lab. There, the research team selects which glass blocks to melt into a honeycomb-shaped mold. The hexagonal pattern, which is reinforced by silicon carbide bolts, means the final product is a fraction of the weight of a traditional solid-glass mirror. Once in place on the GMT—a project projected to cost \$1 billion dollars<sup>13</sup>—the mirrors will help produce images with 10 times the clarity of the Hubble Space Telescope from the Las Campanas Observatory in the Chilean Andes.<sup>14</sup>

Glass-ceramics, a newer class of materials, are also making their way into telescopes. Across the Atlantic in Germany, Schott is manufacturing a suite of 949 hexagonal mirror blanks using its trademark ZERODUR glass-ceramic for the European Southern Observatory's Extremely Large Telescope (Figure 3),<sup>15</sup> which will sit in the Atacama Desert, also in Chile.<sup>16</sup> Mirror production started in 2020 and will extend into 2024. Before making their way to the \$1.3 billion dollar telescope, the glass-ceramic hexagons will go to Safran Reosec for polishing.

## 3, 2, 1...LAUNCHING INTO SPACE

When it comes to getting a spacecraft through the atmosphere and back again, ceramics are core to the heat-protective elements.

"If we're talking about something that's intended to be reused with little or minimal TPS [thermal protection system] refurbishment, then we're looking at ceramic-based systems, almost universally," says Marc Rezin, senior project manager on NASA's Artemis and Orion programs, in an interview.

Some of what is in use today is an evolved version of the rigid ceramic tiles that coated parts of the Space Shuttle, with new renditions including alumina fibers as well as the silica fibers that were in the original shuttle ceramics.

Ceramics also withstand impacts from debris better than other thermal protection systems, which is why ceramic tiles are on the back shell of the Orion spacecraft. The craft is not designed for multiple trips. But Rezin and his colleagues chose ceramic tiles for the back half of Orion because the material



**Figure 5. Aerial view of the Kennedy Space Center Launch Complex 48. Launch Complexes 39A and 39B are both visible behind the pad.**

Credit: Ben Smegelsky, NASA

can withstand encounters with micrometeoroids—a meteoroid fragment smaller than a grain of sand<sup>17</sup>—and space debris from defunct, human-made objects (Figure 4).

It might seem counterintuitive to praise the durability of a material that is typically thought of as brittle and could be susceptible to crack propagation, Rezin says. But in space, the collisions occur at such high speed, the porous portions of a ceramic thermal protection system take in the energy of collisions and the cracks do not spread like they would in other settings.

“The rigid fiber-based tiles are pretty darn good at absorbing the micrometeorite hits,” Rezin says. As the sheer volume of debris in space continues to grow, there is a chance for ceramic protection systems and their ability to withstand strikes to grow in popularity too, he adds.

The Space Shuttle tile technology also helped inspire a new ceramic-based TPS called TUFROC that “is like a Space Shuttle tile that can go to an even higher temperature,” says Jay Feldman, high-temperature reusable materials project manager at the Thermal Protection Systems branch of NASA Ames, in an interview.

TUFROC, which is used on the leading edge of the wings of the Space Force’s X-37B vehicle,<sup>18</sup> has two layers: A shuttle-like tile sits below a composite material made of a silicon oxycarbide matrix with embedded carbon fibers. The carbon-heavy outside reradiates heat while the underlying tile insulates whatever material it covers.<sup>19</sup>

Oftentimes, the composite is capped with a black glass made of tetraboronsilicide and borosilicate glass.<sup>20</sup> A range of surface treatments between the composite and the glass ensure that the thermal expansion of the two materials more closely align. Without those coatings, the glass could pop off with enough use or thermal shock, Feldman says.

Though TUFROC has a complex production process, it is generally easier to fabricate than carbon-carbon composites or carbon-silicon carbide. It has already started to be adopted by

companies, for example, Boeing; a derivative is in use by the Sierra Nevada Corporation.

As corporate interest in TUFROC shows, a growing private space industry also means that reusable ceramic thermal protection systems are seeing an increase in demand. Companies around the world are developing reusable mission equipment. Tokyo-based ispace wants to land its first moon lander by the end of 2022 and eventually shuttle materials between the moon and Earth.<sup>21</sup> Meanwhile, SpaceX’s HLS Starship was chosen last year by NASA to bring astronauts from the Orion spacecraft to the moon and back using a system that is meant to eventually become reusable.<sup>22</sup>

Those hoping for cost-efficient shields on their reusable spacecrafts get help from Feldman and AMA Incorporated research scientist Adam Caldwell. Feldman and Caldwell help private industry get a handle on what thermal protection systems are available, how to access them, and, if need be, how to manufacture them.

Currently, a fair number of companies are asking the last question—how to make their own ceramic TPS—because sourcing TPS components has become increasingly challenging. A given tile might have alumina fibers, silica fibers, and aluminum borosilicate fibers.

“Actually turning [the fibers] into a porous ceramic tile is not trivial, and there’s a very limited number of places where they can do that successfully,” Feldman says. “There are not enough sources and given the growth in the industry, it’s become very difficult for folks to source these materials.”

Besides thermal protection systems, ceramics have an important role in the support structure beneath rockets. Concrete is the standard launch pad material. A version called Fondu Fyre, produced by Allied Mineral Products, served as the basis for Kennedy Space Center’s Shuttle Launch Pads 39A and 39B,<sup>23</sup> which launched missions ranging from Apollo to the Space Shuttle.<sup>24</sup>

# Star power! How glass and ceramics push us deeper into space

Though the Fondu Fyre has since been removed, NASA used another concrete-based pad for a new launch complex built at Kennedy in 2020, the first new one built since the 1960s (Figure 5).<sup>25</sup> Along with a four-foot-thick concrete pad, Launch Complex 48 includes a small basin to capture water from a sound suppression system and an area where fuel tankers containing propellants can be stored on site. The pad was specifically designed to host a wide range of different propellant types—a feature that caters to commercial spaceflight.

For decades, NASA experimented with Martyte, an epoxy with embedded ceramics, as a thermal protective coating on launch pads. Even in the 1960s, Martyte held appeal for the way the resin burned away and kept the launch surface cooler in the face of extreme heat from rocket exhaust.<sup>26</sup> As recently as 2020, SpaceX also relied on Martyte as a protective covering for underlying concrete pads.<sup>27</sup>

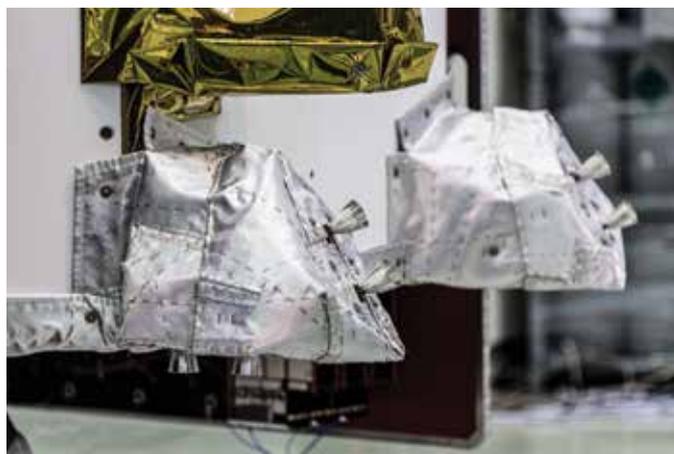
At least one company turned to graphene to make launches possible. Orbex, a launch service company with offices in the U.K. and Denmark, developed a reusable launch vehicle where the main structure and its tanks are a carbon fiber and graphene composite.<sup>28</sup> The relatively small system—62 feet tall and can carry a payload just shy of 400 pounds—should take off for the first time from the company testing site in Scotland later in 2022.<sup>29</sup>

## SAFETY AND OPERATIONS IN SPACE

After launch, mission equipment still relies on glass and ceramics for durability, protection, and the key instruments needed to execute the program goals.

### *Durable materials protect key components*

Though space machinery includes everything from helicopters to space vehicles, satellites are the devices that market analysts predict will drive most of the coming growth in the aerospace ceramics sector.<sup>3</sup> More specifically, versions meant to look back at Earth for data collection on weather, agriculture, water, and other planetary systems will see the largest increase in deployments.



Credit: European Space Agency

**Figure 6. Close-up of a set of thrusters on the BepiColombo Mercury Transfer Module that will carry the two science orbiters—the Mercury Planetary Orbiter and the Mercury Magnetospheric Orbiter—to the innermost planet. The silver/white thermal blanket is covered with Nextel, a ceramic cloth known for its heat-resistant properties, which will allow the thrusters to be exposed directly to the sun.**

Satellites, which stay closer to home and provide services for humans on Earth, are growing in popularity. OneWeb plans to offer global internet access with a network of 648 already launched low-Earth orbit satellites, while SpaceX's satellite internet service, Starlink, is available in 32 countries.<sup>30</sup> Some of these satellites—and the equipment used to get them in orbit—turn to glass-fiber (GFRPs) and carbon-fiber-reinforced polymers (CFRPs).

At Beyond Gravity, the space-oriented segment of the Swiss technology group RUAG, both materials are popular for crafting lightweight but durable space structures. The company produces payload fairings (the protective elements around a spacecraft payload that pop off at the final destination) for clients such as rocket manufacturer United Launch Alliance. They also make satellite bodies and dispensers, which is a sort of tube that carries multiple satellites at once and releases them into orbit.

Beyond Gravity already made CFRP-based dispensers for aforementioned OneWeb and recently signed a contract for a similar order that is reported to be the largest so far for the company.<sup>31</sup> Beyond Gravity will make satellite dispensers for Amazon's Project Kuiper, which also aims to create broadband access via a net of satellites around the world.

To balance weight and durability in their products, Beyond Gravity often manufactures structures with a kind of CFRP sandwich. Thin layers of the composite material house an inner substance, often aluminum, shaped into a honeycomb. Aluminum is a more affordable material compared to CFRP, but the latter material provides enough stiffness that the company can trust products like a dispenser will hold onto its cargo until the exact right moment. The stiffness also means the company can scale up the length of a dispenser fairly easily with CFRP and accommodate a larger number of satellites, says Luca Luzzatto, materials and processes engineer with Beyond Gravity, in an interview.

The company also can trust that the CFRP will not expand or contract severely as products cycle through temperature extremes during deployment, such as from  $-150^{\circ}\text{C}$  to  $150^{\circ}\text{C}$ . GFRPs can also work well for parts of equipment where radiowaves need to be transmitted through the craft exterior, Luzzatto says.

Repeatedly manufacturing CFRPs for space equipment requires product control. Inspections—some physical, some chemical, some destructive, and some simply observational—ensure that batches of CFRP are up to standard and not struggling with defects, such as pockets of included air or foreign objects stuck in the composite. With each batch that is made, Beyond Gravity will create designated testing samples for more invasive inspections, such as the compression strength of the product or its tensile properties. If the ordered product happens to need bits cut away for, say, doors or other openings, the team will apply the same tests to the scraps as well because they are part of the larger CFRP pieces that will go to customers. The team will also examine the CFRP interior via ultrasound to see if any empty areas are in the polymer and to generally make sure the entire composite is homogenous.

Satellite missions that go farther and for longer may demand materials designed for longer-lasting durability, says Adrian Tighe, senior materials and processes engineer in the Directorate of Technology, Engineering and Quality at the European Space Agency, in an interview. Ceramic coatings are a popular form of protection against changing temperatures and the space environment as a whole.

Tighe worked on BepiColombo, a two-satellite system that will arrive at Mercury in 2025. For this and other systems like the ESA Solar Orbiter heading toward the sun, extreme heat could melt a craft body made of aluminum. Thin spray-on ceramic coatings, provided by companies such as Germany-based CeraNovis or U.S.-based Cerakote, tolerate the temperature changes better and protect the underlying materials (Figure 6).

On BepiColombo, a white ceramic layer covers the craft's antenna and edges of the solar array to help deflect solar radiation. The coating, which consists of a water glass binder, alumina, and hexagonal boron nitride mix developed by Ceranovis GmbH, required nearly two years of testing to ensure it would not crack and would retain the reflective white color, Tighe says. Tests included ultraviolet light exposure and time in a vacuum chamber oven. Mirrored glass can also serve as a guard against rising temperatures—panels of the material on the side of a craft reflect solar radiation and radiate heat.

Solar power is a primary power source for spacecraft,<sup>32</sup> and glass plays a crucial role in these components. Borosilicate<sup>33</sup> and aluminosilicate<sup>34</sup> glasses still dominate coverings for solar panels, often enhanced with cerium or cerium dioxide to protect solar cells from electron, proton, and ultraviolet radiation.<sup>35</sup> The doping with other species also can keep the glass from growing darker over the course of a mission, Tighe says. Excelitas is one of the few manufacturers of cerium-doped coverglass.

Gallium arsenide is another dependable solar cell material for space applications because the material absorbs a wider bandwidth of light and is more resistant to gamma radiation. The Hubble Space Telescope received GaAs solar cells in 2002, as did the Orion spacecraft and the Mars helicopter Ingenuity. This last craft has GaAs solar panels from SolAero Technologies,<sup>36</sup> which is now owned by EMCORE RocketLab. The parent company still makes GaAs solar arrays for satellite, along with Nano Avionics.

#### Advanced materials keep operations running

Aboard spacecrafts, ceramics have found their way into the electronic components. Ever since the Apollo era,<sup>37</sup> silicon chips have been the go-to circuitry option for space missions. But silicon has its limits, and increasingly far-flung missions are pushing them. Typically, silicon stops working as a semiconductor around 250°C and, therefore, needs enclosed spaces

## CHALCOGENIDE PHASE-CHANGE MATERIALS: CHANGING OUR APPROACH TO AEROSPACE PHOTONICS

By Lisa McDonald

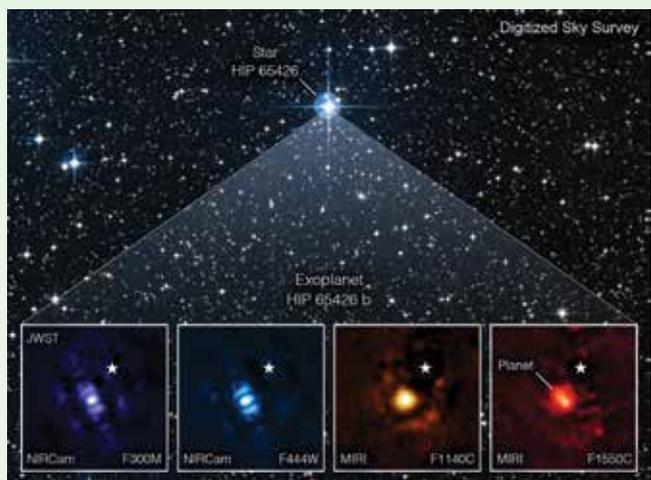
As we continue to push the limits of space exploration and travel, demands on next-generation space systems will increase while being constrained by lean SWaP-C (size, weight, power, and cost) budgets. Realizing subsystems that meet such performance demands requires novel photonic material platforms. Chalcogenide phase-change materials (PCMs) such as GeSbTe, GeSbSeTe, and SbTe demonstrate great potential to fulfill these needs.

Chalcogenide PCMs have the ability to repeatedly switch between two distinct, nonvolatile solid phases: crystalline and amorphous, where the crystalline phase demonstrates high conductivity and reflectivity and the amorphous phase demonstrates low conductivity and reflectivity. There is widespread use of chalcogenide PCMs in commercial nonvolatile memory devices. However, investigations into its potential photonic applications—such as tunable filters, active metaoptics, and switchable fiber-optics—picked up rapidly in the past decade.<sup>a</sup>

The small size, weight, and power metrics of chalcogenide PCMs promise reconfigurable optical systems that are ultracompact, lightweight, energy-efficient, and have rugged characteristics, which are highly prized in the space industry. Possible future applications of chalcogenide PCMs in space applications include

- Photonic integrated circuits, such as used for high-speed communications and sensing;
- LIDAR and imaging spectroscopy components, for example, spatial light modulators, beam steerers, and tunable filters;
- Deep-space imaging, including autofocus/real-time phase-corrective lenses and planar adaptive optics; and

<sup>a</sup>L. Martin-Monier, C. C. Popescu, L. Ranno, et al., "Endurance of chalcogenide optical phase change materials: a review," *Optical Materials Express* 2022, **12**(6): 2145–2167.

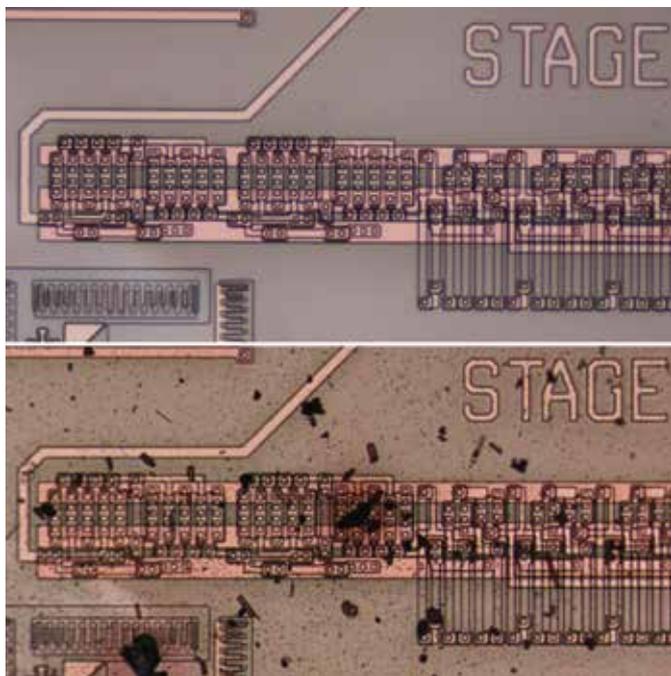


**Image of a gas giant exoplanet by the James Webb Space Telescope, as seen through four different light filters. Space-based exoplanet imaging requires real-time wavefront corrections to lessen the effects of thermal gradients, optical imperfections, and diffraction issues. Chalcogenide PCMs could be used to simplify the correction system.**

- Satellite temperature management/thermal homeostasis, such as tunable/dynamic thermal emission control.

To advance commercialization of optical PCM devices, improving cycle lifetime is a main focus. While endurance and failure mechanisms are extensively characterized for PCMs in electronic applications, much effort is still required to fully validate optical PCM longevity. ■

## Star power! How glass and ceramics push us deeper into space



Credit: NASA

**Figure 7. Integrated silicon carbide circuit before (above) and after (below) testing in Venus atmospheric conditions.**

on a craft that shield the electronics from high heat. Though space agencies successfully designed silicon chips for Mars missions in the past, space environments like that of Venus—which reaches 460°C and includes sulfuric acid clouds that are tens of kilometers deep<sup>38</sup>—are beyond the abilities of silicon.

Gallium nitride-based materials, on the other hand, could open new avenues in space applications. GaN can handle a wider range of temperatures and often needs less active cooling compared to silicon devices. Plus, GaN is inherently radiation-resistant (though how it withstands radiation is still not completely understood).<sup>39</sup>

Despite some unknowns concerning GaN durability, ESA plans to use GaN in several upcoming projects. GaN circuits will be used in the Hisdesat telecom satellites launching in 2023 and 2024.<sup>40</sup> The Biomass satellite, launching in 2023 to conduct a census of all trees on Earth, will feature GaN-based radiofrequency amplifiers. Two companies—United Monolithic Semiconductors and OMMIC—have made ESA’s European Preferred Part list for manufacturing GaN circuits and semiconductor processes.

Silicon carbide could one day work its way into spacecraft circuitry as well. NASA’s Glenn Gas Sensors team and Glenn Physical Sensors team expect the temperature and radiation-resistant nature of silicon carbide will lead to future electronics that need less protective equipment.<sup>41</sup> Reducing weight dedicated to temperature control reduces the launch cost—or, alternatively, increases the number of instruments that can fit on a given satellite.

In 2017, the Glenn Research Center reported testing the first silicon carbide circuit that could withstand Venus-like conditions without any protective or temperature-controlling equipment (Figure 7).<sup>42</sup> The chip lasted nearly 22 days inside the Glenn Extreme Environments Rig,<sup>43</sup> an apparatus that sim-

ulates the heat and pressure environment of Venus. The experiment only ended because other planned work forced the lab to shut the rig down. A research team at the KTH Royal Institute of Technology also assembled several prototype versions of silicon carbide circuits and showed they can operate at 500°C.<sup>44</sup>

Typically, a spacecraft also carries aboard lenses and other optical equipment. While a smaller satellite with a shorter lifespan might opt for straightforward lenses like what is used on Earth, radiation-resistant glass that will not take on a brown tint during a mission is the current standard material for most advanced systems.

“If it’s a billion-dollar mission, it’s worth getting a more resistant glass,” Tighe says.

This “rad-hard” glass is offered by Schott as well as the Ohara Corporation. Optical benches—the bars that support cameras and lenses within a telescope—are often made of ceramic, for example, silicon carbide and silicon nitride. The extreme thermal stability of the ceramic keeps the mounted instruments steady, leading to higher-resolution measurements from the equipment.

There are some unexpected uses for ceramics in mission technologies as well. The ESA Aeolus satellite, for example, emits laser pulses to create a Doppler effect, measuring how long it takes the light bursts to come back to the device for a sense of how wind and moisture is moving in the atmosphere. The laser pulses are magnified by optical lenses in the satellite, with one of the mirrors being two pieces of sintered silicon carbide and a silicon alloy.<sup>45</sup> The mirror and the manufacturing process came from a partnership between EADS-Astrium and Boostec.

### SPACE-BASED MANUFACTURING: ISS EXPERIMENTS AND BENEFITS OF MICROGRAVITY FABRICATION

Oftentimes, the final destination of a payload is not far-flung planets but the U.S. National Laboratory aboard the ISS. Since the living and research station first started operating in 2000, astronauts have conducted more than 3,000 experiments aboard the international destination,<sup>46</sup> with glass experimentation occurring even before the ISS on a space shuttle in the 1980s.<sup>47</sup>

On Earth, material flaws such as unintentional density gradients or unwanted depositions often show up because of the influence of gravity. To learn if removing some of gravity’s pull leads to final products with fewer errors, companies and research teams have taken experiments onto the ISS, which flies in low-Earth orbit. Though drop towers and parabolic flights can create the lower-gravity situations available on Earth, the conditions only last for a few seconds or a few minutes. Any extended period of time in a semiweightless state has to happen off Earth’s surface.

Most of what is investigated on the ISS relates to what happens in microgravity—in other words, how chemical, biological, and physical processes occur when there is less of Earth’s constant pull acting on the materials. Private companies may participate in experiments aboard the ISS, and some have had a chance to examine what kinds of glasses can be formed in such unique conditions.

Materials Development, Inc. (MDI) is one such company. The instrumentation and research company dedicates a lot of its earthbound work to providing universities, national laboratories, and private companies with containerless processing systems. Using sound waves or gas pressure, the devices levitate and heat small samples of material. Eliminating contact between the sample and any other surfaces ensures that these materials, which are generally no larger than 3 millimeters across, do not react with other materials. Lack of contact with, say, containers or furnace elements also lets researchers experiment with structure and properties. For example, operators can supercool fluids that are not so easily quenched in full-gravity environments.

In its experiments onboard the ISS, MDI turns to similar technologies for its own investigations—in particular, creating glass out of atypical compositions. The company currently has two projects aboard the ISS that, in short, look to expose compounds to unusually high temperatures and study how the materials change. Sent to the ISS via SpaceX, the MDI study samples make their way to the Japanese Aerospace Exploration Agency's electrostatic levitation furnace.<sup>48</sup> Like the levitation instruments that MDI assembles on Earth, the JAXA device keeps samples from touching other materials during heating or cooling—except these experiments take place in microgravity. Current experimental materials include calcium or magnesium aluminate as well as titanates.

"They're reluctant glass formers, but they make interesting glasses," says Rick Weber, founder and president of MDI in a Ceramic Tech Chat podcast.<sup>49</sup>

Astronauts and the MDI team assess how the thermal-physical properties of the liquids change as temperatures rise and fall. Actual manipulation of the furnace happens from a station in Japan while Weber and his team communicate with astronauts and the control team about what experimental stages should happen next. Any glass made in the process will come back to Earth for MDI to examine further.

"You really don't know until you run a particular sample the kinds of things you might encounter," Weber says. Also, the ISS experiences communications outages roughly once every hour. Experiments have to be timed so that materials do not reach ideal temperatures right as the communication cuts out. Though the MDI team pushes liquids to extreme temperatures and situations that might not be accessible on Earth, Weber thinks that exploring phase formation in the limit of microgravity will be valuable for eventually designing functional, not just experimental, glasses.

Companies also are exploring space manufacturing of materials meant to be shipped back and used on Earth. Research indicates that manufacturing glass or ceramic products such as optical fibers without the interference of gravity could lead to final products with fewer defects.

The results of ISS testing have been encouraging. Several bouts of testing in the past decade showed that ZBLAN optical fibers can be made more uniform in space manufacturing settings. In July 2022, FOMS, Inc. and Mercury Systems sent another batch of material to test ZBLAN optical fiber production on the ISS.<sup>50</sup>



**Figure 8. Full-scale prototype of the LIFE habitat.**

Credit: Sierra Space

Redwire operates two production systems on the ISS. The ceramic manufacturing module 3D prints ceramic goods and ran its first proof-of-concept test in 2021 by making turbine disks out of layered blades, often called blisks.<sup>51</sup> The company also operates an industrial crystal-growing facility.

ISS manufacturing experimentation has even included concrete production. The Pennsylvania State University and chemical company BASF had concrete samples mixed on the ISS to see what the final microstructure looked like.<sup>52</sup>

Though the ISS houses experiments for now, the craft was not designed for full-scale manufacturing. NASA announced that the facility will likely be retired after 2030.<sup>53</sup> Private companies, however, plan to replace what will be lost when the ISS is brought down—including Sierra Space. By 2027, the company plans to have a space manufacturing research module up and running. Called the Large Integrated Flexible Environment, or LIFE, habitat (Figure 8), the center will be part of a commercial space station called Orbital Reef that Sierra Space is creating with Blue Origin.

Early products coming out of Sierra Space facilities will likely be small pieces of technical equipment that could most benefit from space-based construction. The finer and more miniaturized a piece of technology is, the greater the impact a single flaw has on its functionality, explains Jonathan Volk, senior manager of in-space manufacturing and advanced materials for Sierra Space, in an interview.

For example, manufacturing a graphene-based semiconductor could involve laying down the carbon via a chemical vapor deposition process. Any hiccups or jolts during the deposition process could impact the semiconductor functionality because the graphene is one atomic-layer thick. As it turns out, the wafer-thin goods that could most benefit from flawless production also make for lightweight and relatively inexpensive payloads.

Booming growth in the communications technologies market makes it an appealing sector for manufacturing develop-

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ment as well. The previously mentioned fiber optics market is set to reach \$13.7 million by 2026, nearly 40% higher than the same market in 2022.<sup>3</sup> Graphene semiconductors could reach a market value of about \$70 million by 2030.<sup>54</sup>

The LIFE habitat, which will combine living quarters, a kitchen, a garden, and production space, will account for about 80% of the volume of the ISS and could possibly manage crystal growth and ceramic stereolithography. Down the line, other more energy-intensive processes might become part of the Sierra Space offerings, such as furnaces similar to the one JAXA runs on the ISS.

“The idea of supporting a furnace that can reach any melting point of any material known to man at this point is going to have some design challenges,” Volk says in an interview.

## RETURNING TO EARTH

When a given mission, whether experiment or expedition, is complete, spacecrafts often will return to Earth. During reentry, the vehicle exterior reaches extreme temperatures due to adiabatic compression and friction.

Early spacecraft relied on sacrificial, or “ablativ,” layers to withstand these temperatures, for example, the Apollo series of spacecraft featured ablative heat shields. These layers consisted of materials that vaporized upon extreme heating, helping to deflect and carry away the heat.<sup>55</sup> Most ablative materials are made of polymers, sometimes with fiberglass reinforcement, but the foundation supporting the ablative portion can be ceramic based, says Peter Marshall, research scientist with Analytical Mechanics Associates (AMA) Incorporated working with the Thermal Protection Materials branch at NASA Ames, in an interview.

## ULTRAHIGH-TEMPERATURE CERAMICS ‘LEAD’ THE WAY IN HYPERSONIC VEHICLE DEVELOPMENT

By Lisa McDonald

Imagine traveling between New York City and London in less than two hours rather than the current average of seven. That fantasy may not be so unreal if hypersonic aircraft are successfully developed.

“Hypersonic” refers to speeds that exceed five times the speed of sound. While intercontinental ballistic missiles easily reach such speeds, the fastest sustainable speeds achieved to date by aircraft are just over three times the speed of sound (~2,200 mph accounting for altitude).<sup>a</sup>

Aerodynamic heating is one of the biggest challenges to developing aircraft capable of hypersonic speeds. This heating is produced by friction and compression processes as a high-speed solid body passes through the air, particularly along sharp-shaped structures like wings and nose cones. It also affects space shuttles during reentry into the atmosphere.

To protect against this heat, missiles, which are intended for single use over a short time span, rely on ablative (sacrificial) layers that vaporize to carry away the extreme heat. In contrast, aircraft and space shuttles, which ideally are reusable over longer time spans, may use ablative layers but more so rely on insulating layers that can withstand repeated exposure to extremely high temperatures.

Current materials used for thermal protection systems, such as reinforced carbon-carbon, offer protection up to about 1,650°C (~3,000°F).



Georgia-based startup Hermeus is one company looking to advance commercialized hypersonic travel. It is developing a 20-passenger hypersonic airliner called Halcyon (rendering shown above) in collaboration with government agencies.

Credit: Hermeus, Flickr (CC BY 2.0)

However, as aircraft and space shuttles are developed to travel at faster speeds, they will require protection from temperatures between 2,000–3,000°C (~3,600–5,400°F).<sup>b</sup>

Ultrahigh-temperature ceramics (UHTCs) are an emerging class of materials of interest for use in the leading edges of hypersonic vehicles. UHTCs are most often defined as compounds with melting/decomposition temperatures above 3,000°C. Borides, carbides, and nitrides of early transition metals, such as ZrB<sub>2</sub>, HfB<sub>2</sub>, ZrC, HfC, TaC, and HfN, are prime examples of UHTCs.

Reports of UHTC synthesis date back to the late 1800s, but technological interest in these materials grew dramatically during the space race in the late 1950s and 1960s; interest renewed in the late 1980s. Today, knowledge of UHTC

synthesis, processing, densification, thermo-mechanical properties, and oxidation advanced significantly thanks to abundant research conducted during the past 30 years.<sup>c</sup>

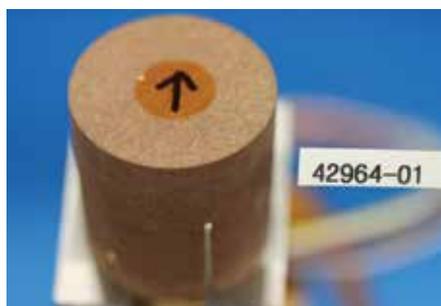
Most characterization and testing of UHTCs is carried out under ambient conditions due to the difficulties of testing materials in extreme environments. Of the testing that has occurred in relevant environments, much of it is restricted or classified. However, it is known that monolithic UHTCs often fail during testing due to thermal shock, limiting their practical use. Instead, groups are now exploring composites consisting of UHTC matrices reinforced by continuous and/or chopped fibers due to their improved fracture toughness and noncatastrophic failure behavior.<sup>d</sup> ■

<sup>a</sup>“NASA Armstrong fact sheet: SR-71 Blackbird,” NASA, 23 Feb. 2014. <https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-030-DFRC.html>

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Credit: NASA

**Figure 9. Heat shield thermocouple plug with ceramic insulator along the sidewall.**

Some form of ablative material will be on the Mars Sample Return Earth Entry Vehicle. The job of this particular craft is spelled out in its name: to bring samples of Mars' surface, as collected by the Perseverance rover, back for research.<sup>56</sup>

One candidate ablative system is the 3D Medium Density Carbon Phenolic (3DMCP). This particular mission is looking for an ablator with higher density and more mechanical strength, which the engineering team thinks will likely be found in the woven structure of 3DMCP.

"I think that these 3D weaves for carbon fiber really also leveraged a lot of our best past experience for pre-woven C/SiC or C/C or some of the other full ceramic systems," Marshall says.

The thickness of the 3DMCP and the kind of matrix embedded in the fibers can be customized for each application, which is a departure from standard materials that change little but are applied to a range of projects.

"We're heading in the direction of being able to tailor TPS. So rather than a monolithic, we may have a multilayer TPS material, depending on mission needs," says Mairead Stackpoole, chief of the Thermal Protection Materials Branch of NASA Ames, in an interview.

Nowadays, creating reusable shuttles is a focus for government and privately funded aerospace initiatives. As such, materials that can withstand repeated exposure to extremely high temperatures without burning up are needed, and ultrahigh-temperature ceramics are one solution (see sidebar: *Ultrahigh-temperature ceramics lead the way in hypersonic vehicle development*).

The reentry period also serves as an invaluable opportunity to collect data on what exactly a craft is exposed to as it careens back through our atmosphere.



Credit: P. Carril, ESA

**Figure 10. Artist impression of a lunar base concept, featuring solar arrays for energy generation, greenhouses for food production, and habitats shielded with regolith.**

"Those environments cannot be fully replicated on the ground with our test facilities," says Jose Santos, aerospace flight systems engineer in the Thermal Protection Materials Branch of NASA Ames, in an interview.

When it comes to researching what a potential reentry system might look like, the gold standard simulation is a model that predicts environmental conditions based on real-life measurements collected during flight. Ceramic-based TPS components can ensure the readings captured on reentry are accurate.

For example, reentry temperature measurements are often made with onboard thermocouples (Figure 9). To ensure the highest-quality temperature reading possible, the wires may be sheathed in ceramic tubes that are typically 99% or more alumina, Santos says.

Recently, Santos and his colleagues looked to further miniaturize the thermocouples and their insulator systems to increase accuracy and reduce footprint. Additive manufacturing technologies might be the solution, although so far, finding a supplier has proved challenging, Santos says.

### STAYING IN SPACE: MOON BASES, MARS COLONIES, AND BEYOND

Even in the instances where a mission will not return to Earth, ceramics are key to developing spacecrafts that can go the

distance and keep people functioning on other planets (Figure 10).

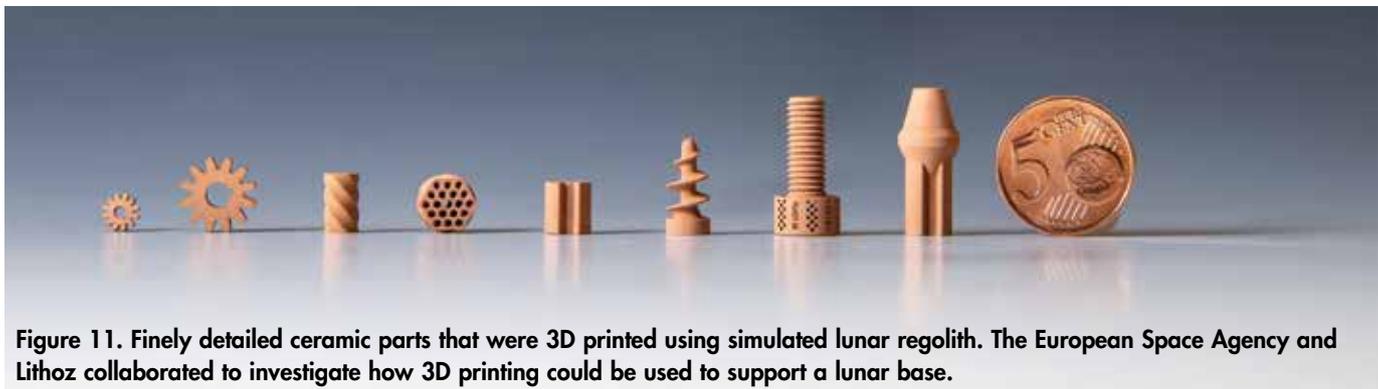
Both NASA and ESA are investigating moon bases where astronauts would live for longer periods on the lunar surface. But an extended stay requires supplies and equipment—everything from housing to tools to replacement vehicle parts. What if components were made from regolith, the surface material covering whatever satellite rock or planet humans are on? If that were possible, missions could launch smaller payloads, and the raw material certainly would be plentiful.

"For Mars, it is not only a wish, but it's almost a necessity," says Advenit Makaya, advanced manufacturing engineer at the European Space Research and Technology Centre of the European Space Agency, in an interview. "It takes a long time to go there and takes a long time to come back. You want to make the most of the time you have there."

The need to produce components in space pushes companies and space agencies to test different manufacturing methods with simulated regolith. Missions to potential base areas show that the minerals on extraterrestrial surfaces are fairly similar to what is on Earth, save differences in proportions and chemical compositions, Makaya says.

But in-space manufacturing will lack

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**Figure 11. Finely detailed ceramic parts that were 3D printed using simulated lunar regolith. The European Space Agency and Lithoz collaborated to investigate how 3D printing could be used to support a lunar base.**

Credit: European Space Agency

the mineral refinement processes we use on Earth. Mining and purifying regolith would consume too much energy and infrastructure. Besides, any water found on the planets will have to be dedicated to more pressing needs such as human consumption or fuel production, not manufacturing. Any astronauts assembling

components and structures from regolith will be working with essentially raw material and all its varieties and complexities.

While terms like “lunarcrete” might be thrown around to communicate the intended purpose or durability of regolith products, Makaya says vocabulary meant to make extraterrestrial construction sound like Earth-based construction materials will never be a perfect fit.

For now, researchers working with simulated regolith use renditions mimicking specific attributes of the complex original. Work concerned with seismic activity will study a simulant focused on replicating particle size distribution, Makaya says, while experimentation with a manufacturing process that essentially aims to melt the regolith into a kind of glass will rely on a mockup with the right chemical composition.

Makaya and his ESA colleagues studied simulated regolith alongside Lithoz, a 3D ceramics printing company. More specifically, the team tested lithography-based ceramic manufacturing with a regolith simulant developed by the European Astronaut Center,<sup>57</sup> containing ingredients such as silicon dioxide, aluminum oxide, and calcium oxide (Figure 11).<sup>58</sup> The production process involves a mixed ceramic and polymer material that is 3D printed.<sup>59</sup> The polymer acts as a kind of glue that keeps ceramic particles together. Debinding, or the burning out, of the polymer leaves behind a ceramic structure that needs sintering to completely densify. The sample screws, nuts, and bolts the ESA and Lithoz team printed were too fragile, Makaya says, but the team is investigating alternative applications such as mesh screens or filters.

## CLEANING UP OUR ATMOSPHERE: TACKLING THE ISSUE OF SPACE DEBRIS

The return of a spacecraft is not always considered—equipment has historically been left to circulate our planet on its own, creating a lot of garbage in near-Earth orbit. Everything from broken equipment to paint flecks to abandoned launch vehicle components are circulating and threatening the duration or safety of active missions. The Department of Defense Space Surveillance Network tracks 27,000 pieces of trash, and that is only a small fraction of what is floating around.<sup>a</sup> As Alexandra Navrotsky and Megan Householder wrote in a recent review article, “we have done a remarkable job gumming up the Earth with our refuse. We are doing an equally remarkable job gumming up near space with all sorts of remnants from satellites and rockets.”<sup>b</sup>

The ESA Cleansat program intends to reduce the hazards of obsolete devices with a range of tactics, including “Design for Demise.” The assembly premise aims to construct crafts and satellites that incinerate as they reenter Earth’s atmosphere, avoiding space waste and incoming debris. A candidate “Design for Demise” material could be CFRP or GFRP.

ESA testing of possible components that would perform as desired and burn up on reentry has included electronics cards and battery housing made of GFRP and a CFRP magnetorquer (a satellite component that aligns the craft with Earth’s magnetic fields).<sup>c</sup> The latter piece of equipment is generally made out of other materials that let it withstand reentry. In Germany, a hypersonic plasma wind tunnel subjected the GFRP and CFRP components to a simulation of atmospheric reentry conditions and several-thousand-degree-Celsius heat.<sup>d</sup> The CFRP magnetorquer, which was provided by Portugal-based LusoSpace,<sup>e</sup> burned up nicely. ■

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<sup>b</sup>Alexandra Navrotsky and Megan Householder. “New worlds, new chemistry, new ceramics.” *Int J Ceramic Eng Sci.* 2021; 3: 252–266. <https://doi.org/10.1002/ces2.10104>

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## ‘SPACE’ FOR EXPLORATION

As the timelines and production schedules of various missions indicate, space missions take years and even decades to execute. The money and testing required to get people and equipment farther than ever before takes time—but when information such as the exact mineral composition of Earth’s only satellite or the precise depth of a far-away planet’s gassy clouds come back to us, the investment in carefully assembling spacecrafts and space equipment is worth it. The far-flung gear is, in a way, extensions of ourselves. It serves essentially as our ears, eyes, hands, noses, and mouths in new places.

Even if it takes decades (or longer) for humans to set foot on these far-off places, we can thank glass and ceramics for getting there first and helping make each extreme environment that much more intriguing and accessible. ■

## SAMPLING OF COMPANIES PRODUCING OR PURCHASING FOR SPACE APPLICATIONS

COMPANY	LOCATION	PRODUCTS
Amazon	Seattle, Wash., USA	Satellite production and launch
BASF	Ludwigshafen, Germany	Chemical company
Blue Origin	Kent, Wash., USA	Space flight equipment
Boeing	Chicago, Ill., USA	Space flight equipment
Boostec	Bazet, France	Silicon carbide for scientific instruments
Ceranovis GmbH	Saarbruecken, Germany	Industrial coatings
EMCORE	Alhambra, Calif., USA	GaAs solar cells for satellites
Excelitas	Waltham, Mass., USA	Glass for solar cells
FOMS, Inc	San Diego, Calif., USA	Fiber optic manufacturing in space
Kyocera Corporation	Kyoto, Japan	Ceramic components for satellites, space observation, and astronomy
Lithoz GmbH	Vienna, Austria	Ceramic 3D printing with simulated regolith
Iusospace	Lisbon, Portugal	Space equipment engineering
Materials Development, Inc	Evanson, Ill., USA	Space experimentation
MDA	Brampton, Ontario, Canada	Satellite components
Mercury Systems	Andover, Mass., USA	Aerospace and defense, including ZBLAN fiber production
Nano Avionics	Vilnius, Lithuania	Solar arrays
Ohara Corporation	Rancho Sanata Margarita, Calif. and Branchburg, N.J., USA	Manufacturing glass for telescopes
OMMIC	Limeil-Brévannes, France	Semiconductors
OneWeb	London, United Kingdom	Internet satellites
Redwire	Jacksonville, Fla., USA	Space manufacturing
Rocketlab	Long Beach, Calif., USA	Carbon-fiber-reinforced polymer facesheets for satellites, GaAs solar cells
Safran Reosec	Saint-Pierre-du-Perray, France	Optical technologies/polishing glass for telescopes
Schott	Mainz, Germany	Glass-ceramics for mirrors, cerium-doped glass for solar panels
Sierra Nevada Corporation	Sparks, Nev., USA	Space flight equipment
Sierra Space	Broomfield, Colo., USA	Space manufacturing and experimentation
SpaceX	Hawthorne, Calif., USA	Rockets, satellites, and vehicles
United Monolithic Semiconductors	Ulm, Germany	Semiconductors

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# Detectors in space: Analyzing cosmic ray tracks in barium phosphate glasses with unknown environmental information

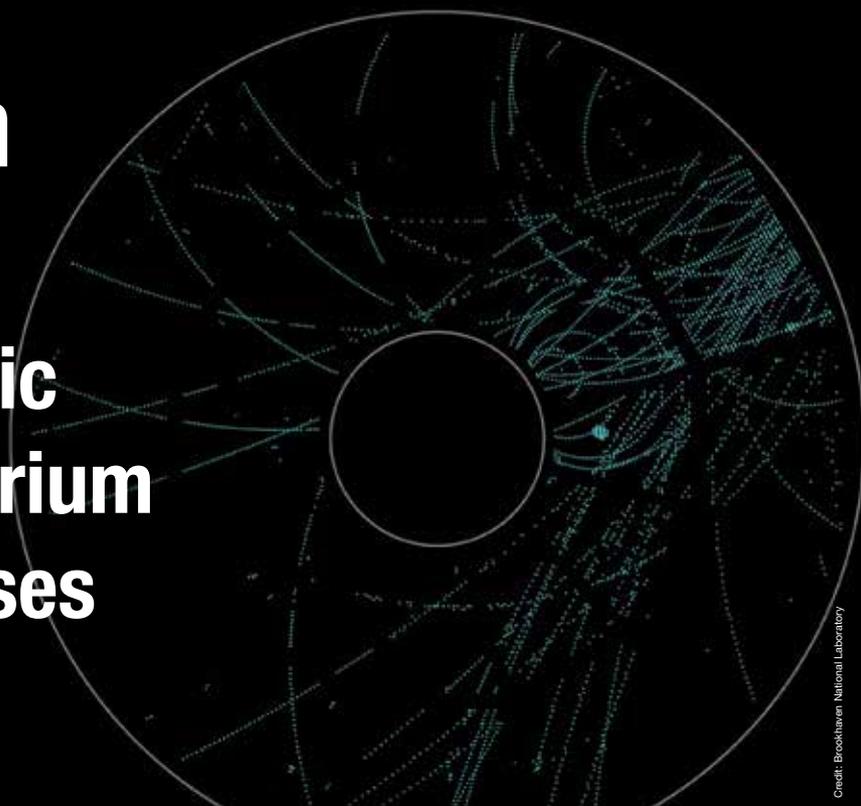


Figure 1. Example of cosmic rays traversing through the STAR detector in the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. The straighter paths indicate faster moving particles while the curved paths indicate slower moving particles. This information allows researchers to determine particle charge information.

By Nicholas J. Tostanoski, Darren Stohr, and S. K. Sundaram

While traveling to distant star systems in a reasonable time period is currently beyond our capabilities, there are other ways for us to learn about far-away stars and planets.

Cosmic rays are heavily ionized particles from outside our solar system that travel through space at nearly the speed of light (Figure 1). Analyzing the composition of cosmic rays can provide a rich source of information on the chemical evolution of the universe.

Track-etch detectors allow for precise identification of cosmic rays. These detectors consist of glasses that are marked when cosmic rays pass through them. These cone-shaped marks, or “tracks,” trace the trajectory that the particles took through the glass and are revealed via chemical etching.<sup>1</sup>

Interest in tracking cosmic rays in glass dates back to the late 1980s. Price et al.<sup>2,3</sup> identified phosphate glasses as good materials for track-etch detectors because of their increased sensitivity due to low bond strength. Wang et al.<sup>3</sup> performed a systematic study of phosphate glasses free of uranium and identified BP-1, a barium phosphate glass with composition  $58\text{P}_2\text{O}_5-21\text{BaO}-11\text{SiO}_2-10\text{Na}_2\text{O}$  mol%,<sup>1</sup> as the best choice for the application.

In the 1990s, the U.S.-Russian collaborative TREK cosmic ray experiment used BP-1 on the external surface of the

Russian Mir space station to help identify and quantify the elemental abundance of ultra-heavy nuclei and isotopes in galactic cosmic radiation.<sup>4</sup> However, currently, literature related to examination of the TREK track-etch detectors is inadequate, due in part to lack of knowledge about the environment during the experiment.

Temperature and pressure during irradiation exposure in long-term space missions play a critical role in determining the charge resolution of the glass.<sup>5</sup> Unfortunately, no information is known about the temperature and pressure of the local BP-1 environment before, during, or after the TREK experiment. Additionally, after the experiment, the samples were placed in storage with unknown environmental conditions. These unknowns affect the ability of researchers to analyze tracks multiple decades after the conclusion of the TREK experiment.

Our study shows how one might examine tracks in a detector glass plate for which detailed environmental provenance is unknown.

## Experimental procedure

In theory, and limitedly reported in literature, glass track-etch detectors can be analyzed using optical and electron microscopy techniques, where hydrofluoric acid (HF) reveals tracks in the glass.

In our study, we used a JEOL JSM-7800F (JEOL, Tokyo, Japan) scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) to analyze the BP-1 in both secondary (SE) and backscattered (BSE) imaging modes, and EDS for elemental analysis. BP-1 was cross-sectioned, ground, and polished.

Samples underwent additional chemical etching using 40–45 vol% HF for two minutes and 49–51 vol% HF for five minutes at room temperature. These ranges were chosen because Price et al.<sup>5</sup> and Randhawa et al.<sup>6</sup> concluded 48 vol% HF was the most suitable etchant to reveal etch pits under SEM.

An electrical conducting gold coating was applied.

## Results and discussion

Interaction of cosmic rays with a bulk glass would potentially result in local chemical and structural changes along the narrow, cone-shaped etch trajectory. It is suspected such changes could be viewed using BSE imaging modes, where elemental and compositional changes would be observed and made clear by lack of a specific element along the trajectory.

The BP-1 cross-section was examined using SEM-EDS point, line, and map scans. A line scan was used in the region between the apex of paired etched conical features running through the midpoint, on the border, and within the bulk, as shown in Figure 2.

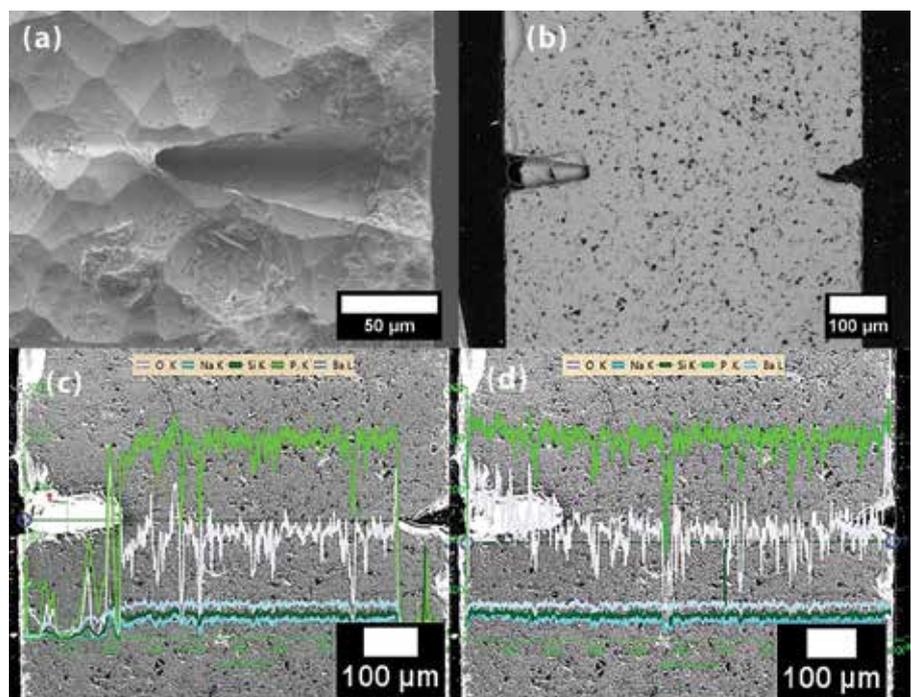
Analysis resulted in no measurable elemental intensity variations or structural changes. It is suspected that a narrow trajectory connecting the paired etched conical features would be highlighted through additional etching; however, further etching resulted in no visible trajectories or observable changes between etched conical features.

We suspect the BP-1 was initially etched, due to conical features on the as-received sample. We do not see any damage along the trajectory. This observation may be attributed to healing over extended time or removal of the damaged layer during sample preparation.

## Conclusion

Our investigation did not reveal any structural changes or narrow tracks in BP-1, suggesting such compositional changes are beyond the sensitivity of the instrument or perhaps the damage healed with time. Unfortunately, we lack access to new pristine and exposed glasses for comparison.

Our results underline the challenges in determining how cosmic radiation



**Figure 2.** SEM of (a) as-received etched SE image of fracture surface and (b) polished and further etched BSE image featuring paired etched conical features. SEM-EDS line scan (c) between the apex and (d) on the border of the paired etched conical features.

influences glass structure when environmental information before, during, and after the experiment is unknown. However, despite these challenges, it is important to pursue research in this area because understanding and developing means to study glass from track-etch detectors will assist scientists in determining what lies beyond our solar system.

## Acknowledgments

The authors would like to thank James E. Martinez from NASA Lyndon B. Johnson Space Center, Houston, Texas, for supplying the BP-1 samples. The authors would like to acknowledge Brookhaven National Laboratory for allowing permission to include the cosmic ray image. Nicholas Tostanoski acknowledges teaching assistant support from the Inamori School of Engineering. S.K. Sundaram acknowledges support from Kyocera Corporation in the form of Inamori Professorship.

## About the authors

Nicholas J. Tostanoski, Darren Stohr, and S. K. Sundaram are Ph.D. candidate, scanning electron microscopist, and Inamori Professor of Materials Science & Engineering, respectively, in the Inamori School of Engineering at The New York State College of

Ceramics, Alfred University, N.Y. Contact Tostanoski at njt2@alfred.edu.

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# Global themes 'steel' the show at ACerS 124<sup>th</sup> Annual Meeting at MS&T22 in Pittsburgh

All photos (Credit: ACerS)

Following last year's challenges with pandemic-related travel restrictions, the 2022 Materials Science & Technology technical meeting and exhibition, held October 9–12 in Pittsburgh, Pa., saw a resurgence in attendance.

In addition to renewed attendance, this year welcomed a new collaboration between the MS&T partners and commercial exhibition firm Event Partners. Event Partners sold and managed the full exhibition at MS&T22, as well as co-located two commercial exhibitions within the conference: The Advanced Materials Show and the first-ever Nanotechnology Show.

"Being able to welcome so many people—including international members!—to an in-person conference after two years of mostly virtually meetings was a gratifying way to wrap up ACerS 2022 conference schedule," says Mark Mecklenborg, ACerS executive director. "The energy was especially noticeable during our student events and in the co-located Advanced Materials Show and Nanotechnology Show exhibitions during MS&T22. We look forward to continuing this success at MS&T2023 in Columbus, Ohio."

Below are highlights from ACerS 124<sup>th</sup> Annual Meeting at MS&T22.

## EMBRACING THE GLOBAL NATURE OF ACERS

In the past few years, ACerS international members faced challenges attending the Annual Meeting due to pandemic-



Incoming ACerS president Sanjay Mathur, left, accepts the ceramic gavel from outgoing ACerS president Beth Dickey during the Annual Business Meeting on Monday, Oct. 10.

related travel restrictions. Fortunately, attendance from outside the United States witnessed a boost this year as countries around the world continue to ease their travel requirements, with 53 countries outside the U.S. represented.

ACerS newly seated president Sanjay Mathur highlighted the importance of ACerS international members throughout his time at the conference. As director of the Institute of Inorganic Chemistry at the University of Cologne in Germany, he personally knows the challenges that international members may face engaging with the Society.

During his term as president, Mathur plans to "refocus and reframe" the role of international members within ACerS, with talent pool, topical diversity, and global partners serving as guiding topics for future initiatives.

"I think 2023 is going to be a turning point," he said during the Annual Business Meeting on Monday, Oct. 10.

This year already witnessed a notable expansion of ACerS globally with the first-ever Pan American Ceramics Congress and Ferroelectrics Meeting of Americas, held July 24–28 in Panama City, Panama.



On Saturday, Oct. 8, the 2022–23 delegates of the President's Council of Student Advisors met for their annual business meeting. This year's cohort consists of 46 students from 28 universities, representing eight countries.



ACerS women past presidents at the Annual Awards banquet. From left: Dana Goski (2020–21), Marina Pascucci (2010–11), Beth Dickey (2021–22), Sylvia Johnson (2018–19), Katherine Faber (2006–07), and Kathleen Richardson (2014–15).



Andrew Wereszczak (left) and Jeffrey Swab (right) organized a symposium to recognize the contributions of George Quinn (center) to the field of structural ceramics and glasses.

## GLASS FEATURES IN SEVERAL AWARD LECTURES AS IYOG WINDS DOWN

This year witnessed countless thoughtful and informative presentations on glass in honor of it being the United Nations International Year of Glass. Several distinguished speakers added to this repertoire by giving glass-themed award lectures during ACerS Annual Meeting.

Monday morning kicked off with the Arthur L. Friedberg Ceramic Engineering Tutorial and Lecture by Rutgers University Distinguished Professor Lisa Klein. She shared how her introduction to glass involved studying glass in moon rocks before going on to explain her experience synthesizing glasses via sol-gel processing.

On Tuesday morning, Rensselaer Polytechnic Institute associate dean for research and graduate programs Liping Huang delivered the Cooper Session Distinguished Lecture on how new approaches to glass formation can uncover previously “hidden” glasses. That afternoon, Mathur delivered the Edward Orton Jr. Memorial Lecture on ceramic and glass particles for precision drug delivery.

In addition to the glass-focused lectures, other award talks covered emerging ceramics of interest. Drexel Distinguished University and Charles T. and Ruth M. Bach Professor Yury Gogotsi delivered the Frontiers of Science and Society Rustum Roy Lecture on MXenes,

while Missouri Science and Technology Curators’ Professor of Ceramic Engineering William G. Fahrenholtz discussed ultrahigh-temperature ceramics during the Robert B. Sosman Lecture.

## STUDENT ENGAGEMENT SHOWS SIGNS OF RECOVERY FOLLOWING PANDEMIC-RELATED SLOWDOWNS

Student engagement was an oft-quoted example of the pandemic’s effects, with professors citing difficulties encouraging camaraderie among students without in-person activities. Fortunately, numerous activities and competitions during ACerS Annual Meeting provided students a chance to meet face to face. View a full list of student award winners at <https://bit.ly/MST22studentwinners>.

Visit the ACerS Flickr page for more photos from ACerS Annual Meeting at MS&T22. Next year, ACerS 125<sup>th</sup> Annual Meeting at MS&T23 will take place in Columbus, Ohio, from October 1–5. ■



The Ceramic and Glass Industry Foundation launched its newest program GLOW (Glass Learning Opportunities Workshop) during MS&T22 at the Pittsburgh Glass Center on Wednesday, Oct. 12.



A mug shatters during the Material Advantage Ceramic Mug Drop Contest, organized by Keramos, on Tuesday, Oct. 11. The winner of the contest was Mitchell Lensing of the Colorado School of Mines.



Attendees explored the two commercial exhibitions during MS&T between conference sessions.



## Ceramics for space exploration: Development of in situ resource utilization technologies

In the past decade, there has been a resurgence of interest in space exploration, both from the commercial sector and government agencies. However, as mission concepts and proposed projects become more ambitious, breakthrough technologies that can reduce the cost of space exploration need to be developed.

In situ resource utilization (ISRU) is one area of space technology that will be critical in the future. Currently, all space exploration missions require every necessary resource to be brought along in the initial launch. For crewed missions, these resources include the propellant, life support, and power systems for the initial and return journey.

ISRU technologies allow necessary resources to be created at the destination or along the way, overcoming the requirement of bringing these resources along from the start. But these technologies must operate in extreme environments while remaining efficient and reliable. So, ceramic materials are at the core of many of these ISRU technologies.

For example, in 2020, NASA included the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) aboard the Mars-destined Perseverance rover. MOXIE is a technology demonstration unit designed to show that oxygen can be produced from the carbon dioxide-rich Martian atmosphere.

MOXIE generates oxygen using solid oxide electrolysis operating at approximately 800°C. The ceramic electrolyte in MOXIE is scandia-stabilized zirconia (ScSZ).<sup>1</sup> ScSZ was selected for its superior ionic conductivity at operating temperatures.

However, ScSZ is not as thermally stable and mechanically robust compared to more traditional zirconias, such as yttria-stabilized and magnesia-stabilized zirconias.<sup>2</sup> As a result, the thermal design for MOXIE incorporates novel ceramic insulation to avoid large thermal gradients that could accelerate degradation of the ScSZ electrolyte. The insulation



**Figure 1. Prototype induction heating testbed for melting lunar regolith simulants in a graphite crucible.**

includes a ceramic aerogel composite consisting of silica fiber-reinforced amorphous silica as well as titania powder, which provides infrared opacifiers to limit radiative thermal losses.<sup>3</sup>

In 2021, MOXIE successfully performed the first extraterrestrial ISRU experiment and produced about 50 grams of oxygen, paving the way for a large-scale unit that could support oxygen production for propellant use.<sup>1</sup>

Moving to the human side of space exploration, NASA established the Artemis program in 2017 with the long-term goal of creating a permanent lunar settlement and supporting future crewed missions to Mars. ISRU technologies are critical to Artemis because they lower the cost of establishing and maintaining a lunar settlement.

Lunar regolith (soil) is comprised of mostly oxides of silicon, iron, calcium, and aluminum, along with other metals at lower concentrations.<sup>4</sup> This composition makes it a great resource for producing oxygen for life support and propellant use and metals for construction purposes.

There are several competing processes for reducing lunar regolith, such

as carbothermal reduction and molten regolith electrolysis. Both processes involve melting lunar regolith, which produces a complex, corrosive silicate melt at extremely high temperatures (>1,500°C). Handling and stable containment of this melt, as well as any reduced molten metals, is a complicated materials challenge.

My doctoral research, funded by NASA's Space Technology Mission Directorate, will focus on identification of ceramics that can survive the extreme environment of lunar regolith processing. I am just getting started on this work, but I am optimistic that we can identify and develop ceramics that will enable ISRU technologies to operate long-term on the lunar surface to support a new generation of space exploration.

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*Kevin Yu is a Ph.D. student in Katherine Faber's research group at the California Institute of Technology. He previously worked at the Jet Propulsion Laboratory as a materials and process engineer prior to starting graduate school. In his free time, he enjoys working on his car and watching sports. ■*

# Ceramic & Glass

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## MANUFACTURING

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## **BREAKING DOWN BARRIERS TO INNOVATION: HOW TO KEEP GROWING IN THE FACE OF NEW CHALLENGES**

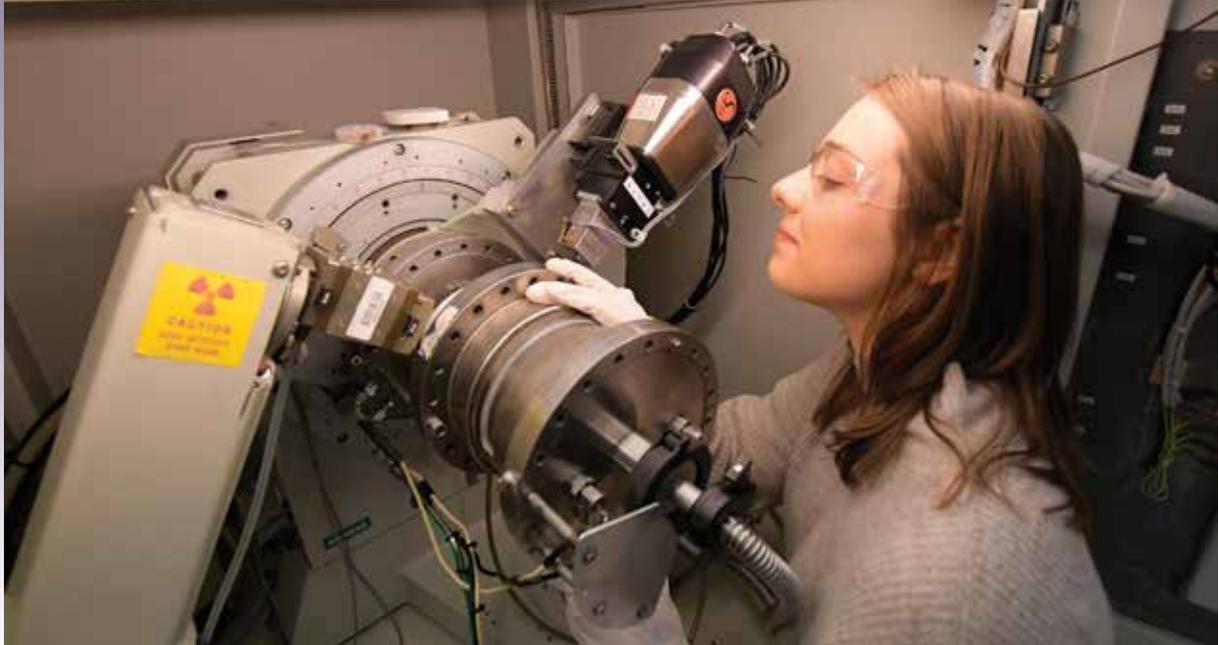
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edeguire@ceramics.org

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The American Ceramic Society

550 Polaris Pkwy., Suite 510

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# INDUSTRY NEWS

## ARDAGH BEGINS ONSITE SOLAR POWER PROJECTS

Ardagh Group S.A. started construction of three solar projects in the Netherlands. The installations will supply renewable, onsite-generated electricity to Ardagh's Dongen, Moerdijk, and Oss facilities and are part of the company's strategy to use 100% renewable electricity by 2030. The Netherlands is the first country where Ardagh will supply all its production facilities with onsite-generated energy via large-scale solar installations. The company says its overall strategy is built on a combination of onsite, near-site, and offsite renewable electricity projects.

In Europe, Ardagh plans to replace 14,500 MWh of electricity consumption from the grid.



CerAMing holds numerous patents around the layer-wise slurry deposition printing process.

## LITHOZ ACQUIRES GERMAN 3D-PRINTING STARTUP CERAMING

Lithoz GmbH announced the acquisition of Germany-based CerAMing, the patent holder of the layer-wise slurry deposition ceramic 3D printing process. Founded in 2019 in Berlin, CerAMing is a spinoff of the Federal Institute for Materials Research and Testing. With the acquisition, Lithoz says it now has a complete "all-from-one-source portfolio" of complementary, market-relevant processes in 3D printing for advanced ceramics.

## SOLAR FAÇADE PANEL PLANT OPENS IN GERMANY

Envelon opened a solar panel production facility at the headquarters of the Grenzebach Group in the Bavarian town of Hamlar, Germany. Envelon has been part of the Grenzebach Group, which has more than 20 years of experience producing photovoltaic systems, since 2021. The company says the facility has solar façade panel production capacity of up to 300,000 square meters per year and will help the company meet significant demand from China and the United States. Envelon is a supplier of photovoltaic façades and building envelopes.



Grenzebach is consolidating production of Envelon photovoltaic building façades in Hamlar, Germany.

Orora has a goal of 60% recycled content for glass beverage containers by 2025.



## ORORA OPENS \$25M GLASS RECYCLING PLANT

Glass packaging provider Orora began operating a new \$25 million glass beneficiation plant in South Australia that will significantly increase the recycled content in its manufactured glass products. Construction was supported by \$8 million in grant funding from the Australian government. The plant has the capacity to produce a maximum of 150,000 tonnes of furnace-ready, recycled glass each year, with 100% of it to be used by Orora to produce glass packaging for its customers across the beverage industry.

## STRATEGIC MATERIALS ACQUIRES GLASS RECYCLER

Strategic Materials, Inc. announced it acquired Kansas City, Mo.-based Ripple Glass. SMI says the acquisition will accelerate its plan to expand glass collection programs and increase glass recovery rates across North America. All Ripple Glass employees were retained by the company. SMI says it is North America's largest glass recycler, with nearly 50 locations in the United States, Canada, and Mexico. Ripple Glass, founded in 2009, provides passive solutions for post-consumer and post-industrial glass throughout the Midwest and operates a glass processing facility in Kansas City.



SMI says it plans to reproduce the Ripple Glass collection model nationwide.

Schott reduced its carbon emissions despite an increase in energy consumption.



## SCHOTT REACHES MILESTONES IN GREEN ENERGY PLAN

Specialty glass manufacturer Schott says it achieved the first milestones in its plan to become a climate neutral producer by 2030, by switching to 100% green electricity and making a 60% reduction in carbon emissions. Schott says it relies on renewable energies purchased through independently verified green electricity certificates and on power purchase agreements, which are contracts with operators of renewable energy plants, such as wind farms. "We are investing a mid-double-digit million-euro amount to achieve our climate targets," says Jens Schulte, head of Schott's zero carbon program.

## RWE AGREES TO BUY CON EDISON CLEAN ENERGY UNIT

RWE AG signed a purchase agreement with Con Edison, Inc. to acquire all shares in Con Edison Clean Energy Businesses, Inc. The purchase will include 3 gigawatts of operating capacity and a development pipeline of more than 7 GW. The companies say they agreed on a purchase price of \$6.8 billion. When completed, the purchase will make RWE the second-largest solar operator in the United States. Germany-based RWE says it has earmarked up to 15 billion euro for investment in the U.S. as part of its growth strategy there.



RWE has a project pipeline of more than 24 GW in onshore wind, solar, and batteries in the U.S.

Saint-Gobain wants to reduce its direct and indirect carbon dioxide emissions by 33% by 2030.



## SAINT-GOBAIN CO<sub>2</sub> REDUCTION TARGETS GAIN INDEPENDENT APPROVAL

Saint-Gobain says the Science Based Targets initiative approved its greenhouse gas emission reduction targets, confirming they are consistent with the organization's net-zero standard and the Paris Climate Agreement. The Science Based Targets initiative is a collaboration of CDP Worldwide, the United Nations, the World Resource Institute, and the World Wildlife Fund that independently evaluates corporate targets for transitioning to a low-carbon economy. Saint-Gobain says it is the first company in its sector worldwide to receive the approval since the standard was introduced at the end of last year.

# BREAKING DOWN BARRIERS TO INNOVATION: HOW TO KEEP GROWING IN THE FACE OF NEW CHALLENGES

By David Holthaus



Saint-Gobain engineers developed durable ceramic rollers to reduce downtime in the hot-stamping process. *Credit: Saint-Gobain*

Innovation is essential for manufacturers to grow market share, develop new products, improve efficiency, and increase revenue and profits. But given the economic conditions of our time, fostering and maintaining a culture of innovation can get lost in the crush of meeting day-to-day operational challenges.

A global pandemic, supply chain disruptions, a labor shortage, and inflationary cost increases have converged to make the operating environment difficult, with the risk that developing new products and new technologies may become lesser priorities.

So how does a manufacturer keep growing, changing, and innovating in the face of these pressures? It begins with staying close to the customer.

"It starts with customer discovery, listening, and being empathetic," says Brandon Cornuke. "There's opportunity there."

Cornuke is vice president of strategy and innovation at Cleveland-based Magnet, part of the National Institute of Standards and Technology's Manufacturing Extension Partnership. He consults with

manufacturers, entrepreneurs, and other organizations to help bring new ideas to fruition.

Innovation, he says, is a catch-all term that can lose its meaning, but at its root, it is about creating new value by constantly solving problems that move the business forward. It usually does not involve world-changing ideas but incremental changes that lead to growth. That starts with connecting with the customer.

"You really have to find ways to solve problems for your customers," he says. "Any customer segment that has a problem should be someone you can focus on and do your best to listen to."

That is how the product development process starts at Superior Technical Ceramics. Based in St. Albans, Vermont, privately owned STC has been in the ceramic materials business since 1898. As a small manufacturer, it prides itself on customer service and technical innovation.

Research and development at STC begins with "sitting down with our customers and talking about what direction they see their com-

panies going and what they need from us," says Kelleen Loewen, vice president of sales and marketing at STC. That could be new shapes, new products, or new technologies.

"You have to listen to find out what's coming down the pipeline," she says.

The same holds true at big manufacturers. Saint-Gobain is a 44-billion-euro company that employs more than 166,000 people around the world. It operates eight research centers globally, where engineers are responsible for about 400 patents a year.

"Innovation is central to everything we do as a company," says Adam Stevenson, director of research for specialty grains and powders at Saint-Gobain's North American research and development hub in Northborough, Mass. "The biggest key to having a good innovation program is working very closely with your customers."

That is where Saint-Gobain's development work begins.

"The more you can be hand-in-hand with your customers, understanding their problems, understanding their pain points, and understanding the directions they want to go, then you can develop the R&D programs that answer those problems," Stevenson says.

An example is the company's work with automobile manufacturers who are striving to make lighter-weight vehicles, particularly for the electric vehicle market. Hot stamping emerged as a manufacturing process for the vehicle frame and can result in lightweight steel that retains its durability and strength. However, the hot stamping process can result in contamination and damage to the ceramic rollers that convey the steel through the process, and that can cause production downtime.

Working with the auto manufacturers and Tier 1 suppliers, Saint-Gobain engineers developed specialty rollers that mitigate contamination and weakening, allowing for significantly longer lifetimes in the furnaces and fewer problems in the hot-stamping operation, Stevenson says.

That is the kind of innovation that falls under the category of "near-in" or incremental innovation—making something a little better or a little faster.

"That is the majority of what organizations do, about 70% of the time," Cornuke says.

He adds that about 20% of innovation falls in the second tier—finding a new market for a product, or delivering a product differently or more efficiently. The final 10% of innovations typically have a much longer horizon—new customers, new products, new sales channels.

Saint-Gobain has a team of engineers and material scientists dedicated to projects in that final category, termed "Horizon 3 projects," which may not produce results for five to 10 years, Stevenson says.

"These are high risk-reward efforts," he says. "These are megatrends you want to hitch yourself to, but there's a huge amount of transition risk."

Indeed, that is the top barrier to innovation in Cornuke's experience, particularly among manufacturers that do not have the huge R&D budget that a company the size of Saint-Gobain does.

"The number one barrier among small manufacturers we work with is aversion to risk," he says. "They have people on the payroll and products to get out the door. Taking a risk is hard for them to do."

For the last two to three years, STC has been producing at its capacity, spending most of its time managing orders from current customers, Loewen says. But in 2023, it will focus on where it can find production capacity it can fill and assess potential customers for that work. The sales and marketing team will work closely with the manufacturing side to assess sales inventory and operations, planning budgets, and determining where there is room to grow, she says.

The company also made a recent acquisition that provided additional capacity. At the end of 2020, it closed on the purchase of Santa, Ana-Calif.-based IJ Research, a manufacturer specializing in sapphire-to-metal brazed hermetic assemblies. STC will look to expand the markets of that division, Loewen says.



Brandon Cornuke

Even large manufacturers can be averse to the risks of innovation. It is the major barrier internally to innovation at Saint-Gobain, Stevenson says.

"Anytime you enter into a major development program, there's a risk-reward that you have to balance," he says. "You have to find ways to reduce the risk or make sure the business has the tolerance."

That tolerance can begin with leadership that values risk-taking and makes it part of a corporate culture, Cornuke says.

"It helps to have a leader who supports risk taking with smart steps and smart investment," he says. "You can't succeed if you don't have a leader who says we're going to support risk-taking and we're not going to crucify people who don't succeed."

Accepting, even celebrating, failure should be part of the culture, he says.

"That's anathema to small organizations, or really any organization," he says. "You have to find a way to say we tried this and we learned."

Saint-Gobain's advanced ceramic materials division serves markets including aerospace, automotive, energy, and semiconductors.  
Credit: Saint-Gobain



Other barriers to innovation include finding labor and talent.

"It's very hard to find engineers and technical people," Loewen says. "It seems all of these people were around four or five years ago, but they're nowhere to be found now."

Supply chain constraints are slowing innovation as well. Some manufacturers are asking their customers to order much farther in advance, and many are "reshoring" their suppliers domestically to shorten the supply chain.

A Bank of America survey of 3,000 companies found that the COVID-19 pandemic accelerated a shift in manufacturing to the U.S. and Europe and away from China. Seventy-five percent of the respondents said they were reshoring operations to their home bases or to neighboring countries. However, that is not always possible, and doing so can be costly. Bank of America projected that shifting production that is not meant for China out of China would cost \$1 trillion over five years.

Innovation also requires constant assessment of the dynamics of the economy to spot where new opportunities may lie. STC, for example, is looking to grow its business among oil and gas producers as the rising cost of energy is expected to stimulate production. A huge market for ceramic manufacturers—aerospace—was down in 2020 and 2021 as the pandemic hampered travel, but the sector has

rebounded, and jet engine manufacturers are expected to ramp up production. GE Aerospace, for example, one of the world's biggest jet engine makers, recently reported a 24% increase in its third quarter revenue from a year ago.

Other industries ripe for innovation include anything to do with the hydrogen economy, semiconductors, electric vehicle batteries, and businesses in human health and security, such as antimicrobial surfaces, Stevenson says.

The long-term move toward the decarbonization of industry is another trend that will demand innovation.

"There's a massive number of industrial processes that will need ancillary changes," Stevenson says.

He points out that research and development is just one part of the innovation system. Sales and marketing and purchasing are critical cogs in the innovation machine too, as they understand what the internal and external customer needs are.



Adam Stevenson

Innovation requires doing new things and doing things differently, and the path can be full of obstacles.

"Innovation is a messy process," Stevenson says. "You fundamentally have to accept failure along the way. There's a lot of behaviors that you have to build into an innovative culture. One of them is understanding that it's a messy process. But ultimately it's exceptionally rewarding." ▀

## US MANUFACTURING ECOSYSTEM KEY TO ECONOMIC GROWTH, INNOVATION, COMPETITIVENESS

By Devon Bistarkey

*Devon Bistarkey is a strategic communications lead in the Office of the Undersecretary of Defense for Acquisition and Sustainment.*

*The complete version of this article was originally published on the U.S. Department of Defense website, [www.defense.gov](http://www.defense.gov).*

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Approaching an era where automation and cognitive computing seamlessly connect to smart factories, supply chains are entering into a fourth industrial revolution known as Industry 4.0. This transformation, through advanced digital technologies across engineering and manufacturing, is set to bring the U.S. manufacturing ecosystem to the forefront of modernization—and with it, a demand for a sustained pipeline of talent and strong domestic manufacturing centers.

“America’s manufacturing ecosystem has been a vital engine of economic growth, innovation, and competitiveness for over 200 years—and has played a critical role in developing and driving the technologies that sustain our national security,” says Bill LaPlante, undersecretary of defense for acquisition and sustainment. “Today, the U.S. is in a technological and economic race to maintain its manufacturing edge, particularly as it concerns critical defense systems, such as satellites, advanced munitions and communications technologies.”

Advanced manufacturing is changing the nature of manufacturing—creating new, technically advanced and higher-paying positions.

Known manufacturing chokepoints across sectors—including skilled labor, machine tools, critical chemicals and a reliance on foreign resources—are impacting operational readiness.

The Defense Department is taking decisive action to combat these challenges to achieve two imperatives: to maintain capability and capacity to sustain legacy systems, and to expand and modernize manufacturing capabilities to build tomorrow’s defense systems. This effort requires significant investment in American workers and infrastructure, including \$372 million in the president’s fiscal 2023 budget to strengthen the nation’s supply chains through domestic manufacturing.



Department of Defense Office of Small Business programs director Farooq Mitha, right, visited the LIFT Manufacturing Innovation Institute in Detroit in March. *Credit: Devon Bistarkey*

The Industrial Base Analysis and Sustainment program within the Department’s Acquisition and Sustainment office is leading multiple projects designed to increase industrial manufacturing capability, supply chain capability and resiliency, and workforce development.

With 64 active and planned projects in key defense industrial base sectors, program efforts assemble a coalition of stakeholders and public-private partnerships designing, building, and producing critical technologies and chemicals to ensure warfighters maintain enduring advantages. Defense-critical sectors at the focus of these efforts include workforce, castings and forgings, microelectronics, batteries, kinetics, and critical chemicals.

Addressing the threat that an aging and shrinking manufacturing workforce poses to U.S. national security, IBAS invested approximately \$130 million across 16 unique workforce-related projects since the launch of its National Imperative for Industrial Skills initiative in 2020.

The model’s key principles emphasize identifying industry needs and driving collaboration with education, as well as looking at mutual reliance on like facilities, equipment, and processes driven by relevant industry needs. This approach focuses on developing a deeper and sustained collaboration among all levels of education (K–12, two-year post high school, and four-year post high school) and industry (small and medium manufacturers, large original equipment manufacturers), as well as nonprofit and governmental support activities.

One flagship IBAS effort working to address critical machine tool needs in support of defense manufacturing is America’s Cutting Edge program, which launched in March 2020. The effort combines the scientific expertise of the Department of Energy’s Oak Ridge National Laboratory; the research and teaching expertise of the University of Tennessee, Knoxville; and the workforce development leadership of the Institute for Advanced Composites Manufacturing Innovation to revitalize the U.S. machine tool sector through transformative thinking, technology, and training.

Through ACENet, an associated network of regional machine tool innovation and workforce development hubs in Florida, North Carolina, Tennessee, Texas, and West Virginia, the Defense Department is working to increase efficiency of existing machine tools while developing skills and training for next-generation machine tools for composites and metals. These initiatives include establishing efforts to rapidly train the next generation of machine tool designers and operators. ▀

## For Stevanato Group, years of innovation have paid off

By David Holthaus

When the COVID-19 pandemic emerged, the race was on to not only develop a vaccine but to find ways to distribute it around the world. As drugmakers unexpectedly developed vaccines in a matter of months, the next critical step was to figure out how to contain, store, and safely ship massive quantities of the drugs so they could be administered at clinics, doctors' offices, hospitals, and drive-through sites everywhere.

For Italy-based Stevanato Group, a producer of pharmaceutical glass containers, it was an opportunity to respond to a global health crisis, expand its already growing business, and improve on an innovation the firm had developed a few years earlier that could accelerate the vaccine shipping and distribution network.

The company was one of the first to market a full range of ready-to-use glass vials for the pharmaceutical industry. Previously, drug manufacturers had to clean and sterilize glass vials before they could start filling the containers. It is an expensive and time-consuming process that demands resources that could be put to better use elsewhere in the pharmaceutical development process.

Stevanato's innovation, which it calls EZ-fill, provides drug makers with clean, sterilized glass containers that are ready to use and can be easily integrated into the drug manufacturer's processes.

"Everything that has to do with the cleaning and sterilization of the vials we do ourselves," says Riccardo Butta, president of Stevanato's Americas division. "What we ship to customers is ready to be filled."

"It was a major innovation for the market," he says. "It cuts down the cost of goods for our customers and makes life simpler for them."

The shipping process also avoids glass-to-glass contact, a critical factor in the transportation of vials, as it lowers the risk of scratches and other defects.

"We've increased the quality of the product we send to our customers," he says.

The availability of the ready-to-use innovation allowed Stevanato Group to quickly respond to the demands of vaccine makers during the pandemic and cut the time to market for their life-saving drugs.

It also led to record sales, as the Group saw revenue grow 27.5% in 2021 to 843.9 million euro. Nearly 15% of the Group's overall revenue in 2021 came from its COVID-related business, it says.



At the Technology Excellence Center in Boston, Stevanato researchers test container performance and conduct chemical analysis. *Credit: Stevanato Group*

Stevanato Group is a rapidly expanding international company that sees innovation as a pillar of its growth strategy.

In late 2021, the company broke ground on the construction of a huge manufacturing facility, its first in the U.S., in Fishers, Ind., just north of Indianapolis. The \$145-million facility will support the expansion of its ready-to-use technology and put the company closer to its customers in North America.



Riccardo Butta

Central Indiana is developing a life sciences sector, building on the presence of healthcare companies there, such as Eli Lilly and Roche. The presence of Indiana University and Purdue University is also helpful to recruit engineering and scientific talent, Butta says. And it is closer to Stevanato's home base in Northern Italy than the West Coast.

"The time zone is important," Butta says. "Six hours to Italy is important, as opposed to nine or more from California."

The Indiana site is expected to begin operating in 2023. The plant will be a key piece of the Group's North America footprint, allowing it to serve its customers from the design and product development phase through manufacturing and commercialization.

One of those customers is the U.S. government. Earlier this year, the company announced a \$95-million agreement with the Department of Health and Human Services' Biomedical Advanced Research and Development Authority (BARDA) to expand capacity at the Indiana plant and provide priority access to BARDA vaccine and drug development partners.

The agreement “further confirms our strategic approach in the United States to invest and broaden our product offering,” says Franco Stevanato, the company’s executive chairman.

The manufacturing facility will work closely with researchers who do design and scientific analysis at Stevanato’s Technology Excellence Center in Boston, which it opened in 2020.

Located in the rapidly developing Seaport District of Boston, the R&D lab tests the impact of powerful drugs on glass containers. It also gathers data on the impact of the filling process on the formulations, and analyzes different types of container-closure systems, all of which are designed to help their pharmaceutical company customers minimize their time to market as they scale up and commercialize new drugs.

“The cost of these drugs is going up, so it becomes more critical for us to have the right quality,” Butta says. “Some drugs are very aggressive to the glass. We need to look for solutions for that so the container is not affected by the chemical properties of the drug.”

Boston was chosen as the site for the lab partly to overcome one of the chief obstacles to innovation—finding the right talent.

“There’s a lot of competition for talent,” Butta says. “Here there is the talent that we need.”

Greater Boston, including Cambridge, home of Harvard University, is a biotech hub, with companies such as Boston Scientific, Sanofi, Pfizer, and Novartis maintaining operations there.

“Many of our customers are here with their development centers,” Butta says. “It’s being embedded in the right ecosystem.”

Stevanato is innovating to increase the speed at which it can assemble and inspect its products.

“Speed gives you lower cost on everything,” Butta says.

The company is also employing artificial intelligence in the inspection process, allowing for its products to be more efficiently inspected for defects without human intervention.



Researchers at Stevanato’s Boston R&D center use high-resolution analysis to detect microscopic particles in glass. Credit: Stevanato Group

Founded in 1949, Stevanato Group accelerated its expansion in recent years. What began as a family-owned company, went public in 2021, raising \$672 million in its initial public offering on the New York Stock Exchange.

Earlier this year, it announced the acquisition of a facility in China, where it will employ 270 people to produce its EZ-fill syringes and vials and grow its presence in that market. And in May of this year, it announced the construction of another manufacturing facility in Italy that will employ 190 people when it begins operating in the second half of 2023.

The company is also innovating beyond its core product of pharmaceutical-grade glass vials. It is manufacturing an auto-injector that allows patients to administer their own drugs. It is also manufacturing a small, wearable, infusion device that can be programmed for a range of medications.

These innovations contributed to the company’s announcement that it is raising its revenue expectations for the full year 2022, even as revenue from its COVID-related business decreases as the global vaccine push tapers off.

A little more than year after going public, “We have met or exceeded our financial targets while advancing our long-term strategic goals,” Franco Stevanato says. ▀



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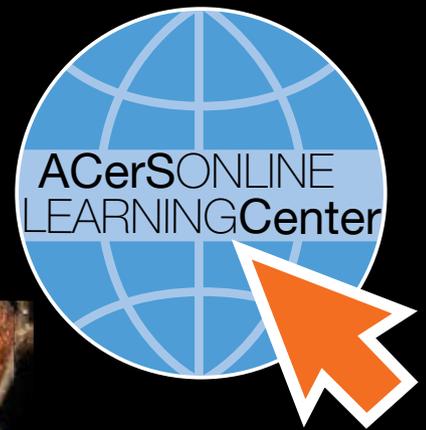
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## Calendar of events

### November 2022

**30–Dec 2** ASEAN Ceramics – IMPACT Forum Hall 4, Bangkok, Thailand; <https://asean-ceramics.com/thailand/#thai-about>

### December 2022

**7–9** ➔ 7<sup>th</sup> Highly-functional Ceramic Expo Tokyo – Makuhari Messe, Chiba, Japan; <https://www.ceramics-japan.jp/en-gb.html>

### January 2023

**17–20** EMA 2023: Basic Science and Electronic Materials Meeting – DoubleTree by Hilton Orlando at Sea World Conference Hotel, Orlando, Fla.; <https://ceramics.org/EMA23>

**22–27** 47<sup>th</sup> International Conference and Expo on Advanced Ceramics and Composites (ICACC 2023) – Hilton Daytona Beach Oceanfront Resort, Daytona, Fla.; <https://ceramics.org/ICACC23>

### March 2023

**28–30** 56<sup>th</sup> Annual St. Louis Section / Refractory Ceramics Division Symposium on Refractories – Hilton St. Louis Airport Hotel, St. Louis, Mo.; <https://ceramics.org/event/56th-annual-st-louis-section-refractory-ceramics-division-symposium-on-refractories>

### May 2023

**17–19** ➔ 8<sup>th</sup> Highly-functional Ceramic Expo Osaka – INTEX Osaka, Osaka, Japan; <https://www.ceramics-japan.jp/en-gb.html>

**30–June 1** MagForum 2023 – Grand Hotel Dino, Baveno, Lake Maggiore, Italy; <http://imformed.com/get-informed/forums/magforum-2023>

### June 2023

**4–9** ACerS Glass & Optical Materials Division Annual Meeting (GOMD 2023) – Hotel Monteleone, New Orleans, La.; <https://ceramics.org/gomd2023>

**5–8** ACerS 2023 Structural Clay Products Division & Southwest Section Meeting in conjunction with the National Brick Research Center Meeting – Omni Austin Hotel Downtown, Austin, Texas; <https://ceramics.org/SCPD2023>

### August 2023

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

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

### September 2023

**26–29** ➔ Unified International Technical Conference on Refractories (UNITECR) with 18<sup>th</sup> Biennial World-wide Congress on Refractories – Kap Europa, Frankfurt am Main, Germany; <https://unitecr2023.org>

### October 2023

**1–5** ACerS 125<sup>th</sup> Annual Meeting with Materials Science & Technology 2023 – Columbus Convention Center, Columbus, Ohio; <https://matscitech.org/MST23>

### November 2023

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

### July 2024

**14–19** International Congress on Ceramics – Hotel Bonaventure, Montreal, Canada; [www.ceramics.org](http://www.ceramics.org)

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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Lubrizol Performance Coating OH  
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Refractory Minerals Co Inc PA  
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FELDCO Intl CA  
 Zibo Guangtong Chemical Co Ltd China

**Cutting Tools**

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 Astro Met Advanced Ceramics Inc OH  
 Cerakote Ceramic Coatings OR  
 CeramTec North America Corp SC  
 CoorsTek CO  
 Dianamic Abrasive Products Inc MI  
 Ferro Ceramic Grinding Inc MA  
 New Tech Ceramics Inc IA  
 NGK Spark Plug Co Ltd Japan  
 PremaTech Advanced Ceramics MA  
 Rauschert Industries Inc GA  
 RocCera LLC NY  
 Thermocarbon FL  
 Xiamen Unipretec Ceramic Technology Co Ltd China  
 Zibo Guangtong Chemical Co Ltd China

**Cylinders**

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 Cerakote Ceramic Coatings OR  
 CoorsTekCO  
 Creatz3D Ceramics Singapore  
 Ferrotec Ceramic Products China  
 Morgan Technical Ceramics Auburn CA  
 Strem Catalog, by Ascensus Specialties MA  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China

**Dies**

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 North Star Equipment Inc WA  
 Petro Mold Company PA  
 Ram Products Inc OH  
 Refractron Technologies Corp NY  
 Xiamen Unipretec Ceramic Technology Co Ltd China  
 Zircoa Inc OH

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 CeramTec North America Corp SC  
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 Ferro Ceramic Grinding Inc MA  
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 Creatz3D Ceramics Singapore  
 Inducerceramic Canada  
 Maryland Ceramic & Steatite Co Inc MD  
 Rauschert Industries Inc GA  
 Refractron Technologies Corp NY  
 Robocasting Enterprises LLC NM  
 Starfire Systems Inc NY  
 Valley Design Corp MA  
 Zhengzhou Mission Ceramic Products Co Ltd China

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 Aremco Products Inc NY  
 Astro Met Advanced Ceramics Inc OH  
 Bharat Heavy Electricals Ltd India  
 Cerlase France  
 CoorsTek CO  
 Elan Technology GA  
 Ferro Ceramic Grinding Inc MA  
 Israel Ceramic & Silicate Inst Israel  
 Keeling & Walker Ltd UK  
 Morgan Advanced Materials CA  
 Ortech Inc CA  
 Petro Mold Company PA  
 P-Ker Engineering NY  
 Precision Ceramics FL  
 PremaTech Advanced Ceramics MA  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Schott North America Inc NY  
 Starfire Systems Inc NY  
 Technical Products Inc WI  
**TevTech LLC MA See ad on page 99**  
 Valley Design Corp MA  
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 Zibo Guangtong Chemical Co Ltd China

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 Blasch Precision Ceramics Inc NY  
 Capovani Brothers Inc NY  
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 Dow High Temp Furnaces India  
 Elcon Precision LLC CA  
 FCT Ingenieurkeramik GmbH Germany  
 Ferrotec Ceramic Products China  
 Inducerceramic Canada  
 Precision Ceramics FL  
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 Blasch Precision Ceramics Inc NY  
 Ceramco Inc NH  
 CeramTec North America Corp SC  
 CeramTec-ETEC Germany  
 CerCo LLC OH  
 Creatz3D Ceramics Singapore  
 Dow High Temp Furnaces India  
 Du-Co Ceramics Company PA  
 Elcon Precision LLC CA  
 EZG Manufacturing Inc OH  
 FCT Ingenieurkeramik GmbH Germany  
 Ferro Ceramic Grinding Inc MA  
 Ferrotec Ceramic Products China  
 GE Global Research NY  
 Inducerceramic Canada  
 Industrial Ceramic Products Inc OH  
 Jyoti Ceramic Industries Pvt Ltd India  
 McDanel Advanced Ceramic Technologies LLC PA  
 Morgan Advanced Materials CA  
 Morgan Technical Ceramics Auburn CA  
 NGK Spark Plug Co Ltd Japan  
 Precision Ceramics FL  
 PremaTech Advanced Ceramics MA  
 Rauschert Industries Inc GA  
 Silicon Carbide Products Inc NY  
 SINTX Technologies UT  
 Sonya Ceramics (Export Division) India  
 Xiamen Unipretec Ceramic Technology Co Ltd China  
 Zhengzhou Mission Ceramic Products Co Ltd China

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 Bharat Heavy Electricals Ltd India  
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 CerCo LLC OH  
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 Diamorph AB UK  
 Indo US MIM Tec India  
 Matexcel NY  
 Ortech Inc CA  
 Rauschert Industries Inc GA  
 Starfire Systems Inc NY  
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 Actech Precision Ceramic (HK) Limited China  
 CeraNova Corp MA  
 Cerinnov France  
 Cerlase France  
 CerPoTech AS Norway  
 Creatz3D Ceramics Singapore



**Coherent CA See ad on page 63**

Israel Ceramic & Silicate Inst Israel  
 Morgan Technical Ceramics Auburn CA  
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Precision Ceramics FL  
Technology Assessment and Transfer Inc (TA&T) MD

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Cerlase France  
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**Nitride Products**

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AdTech Ceramics TN  
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Advanced Ceramics Manufacturing AZ  
Beijing Cerametek Materials Co Ltd China  
Blasch Precision Ceramics Inc NY  
FCT Ingenieurkeramik GmbH Germany  
Ferro Ceramic Grinding Inc MA  
Induceramic Canada  
Momentive Performance Materials Inc NY  
NEVZ-Ceramics Close JSC Russia

NGK Spark Plug Co Ltd Japan  
North American Hогanas PA  
O'Keefe Ceramics Inc CO  
Precision Ceramics FL  
Precision Ferrites and Ceramics Inc CA  
Saint-Gobain Ceramics & Plastics MA  
Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA  
Silicon Carbide Products Inc NY  
Treibacher Industrie AG Austria  
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nGimat LLC KY  
PremaTech Advanced Ceramics MA

Suntech Advanced Ceramics (Shenzhen) Co Ltd China  
Surnet Corp MA  
Technology Assessment and Transfer Inc (TA&T) MD  
Toto Ltd Japan

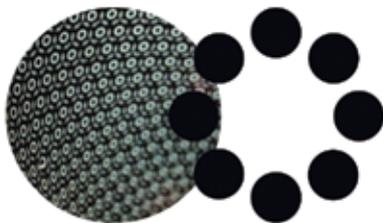
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Astro Met Advanced Ceramics Inc OH  
Beijing Cerametek Materials Co Ltd China  
Blasch Precision Ceramics Inc NY  
Ceramac Inc NH  
CeramTec North America Corp SC  
CeramTec-ETEC Germany  
CerPoTech AS Norway  
Du-Co Ceramics Company PA  
FELDCO Intl CA  
Ferro Ceramic Grinding Inc MA  
Hunter Chemical LLC PA  
Imerys Fused Minerals Murg GmbH Germany  
Innovnano - Advanced Materials SA Portugal  
Jyoti Ceramic Industries Pvt Ltd India  
Keeling & Walker Ltd UK  
Matexcel NY  
MSE Supplies AZ  
Nanocerox UT  
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Polymer Innovations Inc CA  
Rauschert Industries Inc GA  
Refractron Technologies Corp NY  
Robocasting Enterprises LLC NM  
Superior Technical Ceramics CorpVT  
**Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD**

See ad on page 83

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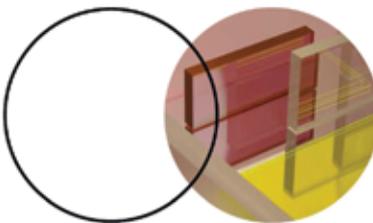
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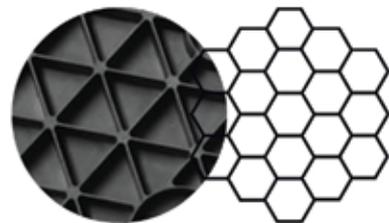
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 Industrial Ceramic Products Inc OH  
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 Morgan Technical Ceramics Auburn CA  
 Ortech Inc CA  
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 PremaTech Advanced Ceramics MA  
 Rauschert Industries Inc GA  
 Refractron Technologies Corp NY  
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 Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA  
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 Ferrotec Ceramic Products China  
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 CoorsTek CO  
 Custom Processing Services PA  
 Diamorph AB UK  
 FCT Ingenieurkeramik GmbH Germany  
 FELDCO Intl CA  
 Ferrotec Ceramic Products China  
 Free Form Fibers NY



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 Precision Ceramics FL  
 Precision Ferrites and Ceramics Inc CA  
 PremaTech Advanced Ceramics MA  
 Rauschert Industries Inc GA  
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 Silicon Carbide Products Inc NY  
 Starfire Systems Inc NY  
 Technology Assessment and Transfer Inc (TA&T) MD  
**TevTech LLC MA See ad on page 99**  
 Zhengzhou Mission Ceramic Products Co Ltd China

**Silicon Nitride Products**

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 Morgan Advanced Materials CA  
 O'Keefe Ceramics Inc CO  
 Precision Ceramics FL  
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 Ortech Inc CA  
 Rauschert Industries Inc GA  
 Superior Technical Ceramics Corp VT  
 Zhengzhou Mission Ceramic Products Co Ltd China

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 Creatz3D Ceramics Singapore  
 Ferrotec Ceramic Products China  
 Israel Ceramic & Silicate Inst Israel  
 nGimat LLC KY  
 Precision Ferrites and Ceramics Inc CA  
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 SINTX Technologies UT  
 Surmet Corp MA

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 Akron Porcelain & Plastics Co OH  
 Aremco Products Inc NY  
 Associated Ceramics & Technology Inc PA  
 Astro Met Advanced Ceramics Inc OH  
 Blasch Precision Ceramics Inc NY  
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 CoorsTek CO  
 Du-Co Ceramics Company PA  
 Dunhua Zhengxing Abrasive Co Ltd China  
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 Elcon Precision LLC CA  
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 Jyoti Ceramic Industries Pvt Ltd India  
 McDanel Advanced Ceramic Technologies LLC PA  
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 Progressive Technology Inc CA  
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**Wear-Resistant Parts**

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 Advanced Ceramics Manufacturing AZ

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 Astro Met Advanced Ceramics Inc OH  
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 Progressive Technology Inc CA  
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 Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA  
 Silicon Carbide Products Inc NY  
 Starfire Systems Inc NY  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China  
 Superior Technical Ceramics Corp VT  
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 Astro Met Advanced Ceramics Inc OH  
 Beijing Cerametek Materials Co Ltd China

Bharat Heavy Electricals Ltd India  
 Ceramco Inc NH  
 CeramTec North America Corp SC  
 CeramTec-ETEC Germany  
 CoorsTek CO  
 Creatz3D Ceramics Singapore  
 EBL Products Inc CT  
 ENrG Inc NY  
 FCT Ingenieurkeramik GmbH Germany  
 Ferro Ceramic Grinding Inc MA  
 Ferrotec Ceramic Products China  
 Imerys Fused Minerals Murg GmbH Germany  
 Inducerceramic Canada  
 Innovnano - Advanced Materials SA Portugal  
 International Ceramic Engineering MA  
 Israel Ceramic & Silicate Inst Israel  
 Jyoti Ceramic Industries Pvt Ltd India  
 Lithoz GmbH NY  
 McDanel Advanced Ceramic Technologies LLC PA  
 Morgan Advanced Materials CA  
 MSE Supplies AZ  
 Nanoe France  
 NEVZ-Ceramics Close JSC Russia  
 Nyacol Nano Technologies Inc MA  
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 RocCera LLC NY  
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 Saint-Gobain NorPro OH  
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 Superior Technical Ceramics Corp VT  
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 Ceramic Arts Network OH  
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 StudioLX - Home Decor IL  
 Tethon 3D NE  
 Viridis3D LLC MA

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 RISE Research Institutes of Sweden RISE Glass Sweden  
 StudioLX - Home Decor IL  
 Viridis3D LLC MA

**Lighting**

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 Viridis3D LLC MA

**Ornamental Artware**

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 StudioLX - Home Decor IL  
 Viridis3D LLC MA

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 North Star Equipment Inc WA  
 Peter Puggger Mfg Inc CA  
 Petro Mold Company PA  
 Ram Products Inc OH  
 Sheffield Pottery MA  
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 FELDCO Intl CA  
 GMA Industries Inc MI  
 Imerys Refractory Minerals GA  
 Kyanite Mining Corp VA  
 Prince Minerals Inc (Prince International Corporation) TX  
 Saint-Gobain Abrasives MA

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 Washington Mills NY

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 Saint-Gobain NorPro OH

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 Denka Corp NY  
 Momentive Performance Materials Inc NY  
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 AluChem Inc OH  
 APF Recycling Inc OH  
 Baikowski Malakoff Inc NC  
 Denka Corp NY  
 Electro Abrasives Corp NY  
 Fusion Ceramics Inc OH  
 Hindalco Industries Limited India  
 Maryland Refractories Co OH  
 Nabaltec AG Germany  
 Nanoe France



**PIDC (Pacific Industrial Development Corporation) MI** See ad on page 69

Prince Minerals Inc (Prince International Corporation) TX  
 Refractory Minerals Co Inc PA  
 Sauereisen Inc PA

**Alumina, Fused**

Alteo NA LLC OH  
 APF Recycling Inc OH  
 Denka Corp NY  
 Electro Abrasives Corp NY  
 GMA Industries Inc MI  
 Imerys Refractory Minerals GA  
 Lithoz GmbH NY  
 McDanel Advanced Ceramic Technologies LLC PA  
 Nanoe France  
 Prince Minerals Inc (Prince International Corporation) TX  
 Washington Mills NY

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 APF Recycling Inc OH  
 BassTech Intl NJ

Bosai Minerals Group Co Ltd China  
 Electro Abrasives Corp NY  
 GMA Industries Inc MI  
 Imerys Refractory Minerals GA  
 Washington Mills NY

**Alumina, Fused White**

Alteo NA LLC OH  
 APF Recycling Inc OH  
 Electro Abrasives Corp NY  
 Imerys Refractory Minerals GA  
 Sauereisen Inc PA  
 Washington Mills NY

**Alumina, High-Purity**



**3D ceram CT** See ad on page 73

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 Alteo NA LLC OH  
 AluChem Inc OH  
 APF Recycling Inc OH  
 Applied Ceramics Inc CA  
 Associated Ceramics & Technology Inc PA  
 Baikowski Malakoff Inc NC  
 CARBO Texas  
 CoorsTek CO  
 Creatz3D Ceramics Singapore  
 Denka Corp NY  
 International Ceramic Engineering MA  
 Ipsen Ceramics IL  
 Lithoz GmbH NY  
 Materion Advanced Materials NY  
 Materion Ceramics AZ  
 Nanoe France  
 PIDC (Pacific Industrial Development Corporation) MI  
 Pred Materials International Inc NY  
 Prince Minerals Inc (Prince International Corporation) TX  
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 Valley Design Corp MA  
 Xiamen Unipretec Ceramic Technology Co Ltd China

**Alumina, Hydrated**

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 Alteo NA LLC OH  
 Denka Corp NY  
 Fusion Ceramics Inc OH  
 Hindalco Industries Limited India  
 Nanoe France  
 PIDC (Pacific Industrial Development Corporation) MI  
 Prince Minerals Inc (Prince International Corporation) TX  
 RE Carroll Inc PA

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- Almatis Inc PA
- Alteo NA LLC OH
- Associated Ceramics & Technology Inc PA
- Baikowski Malakoff Inc NC
- CoorsTek CO
- Denka Corp NY
- Hindalco Industries Limited India
- Imerys Refractory Minerals GA
- Nanoe France
- PIDC (Pacific Industrial Development Corporation) MI
- Prince Minerals Inc (Prince International Corporation) TX
- Trinity Ceramic Supply Inc TX
- Wesbond Corp DE

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- AluChem Inc OH
- Baikowski Malakoff Inc NC
- Denka Corp NY
- Hindalco Industries Limited India
- Nabaltec AG Germany
- Nanoe France
- Prince Minerals Inc (Prince International Corporation) TX

**Alumina, Single Crystal**

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- Nanoe France
- Prince Minerals Inc (Prince International Corporation) TX

**Alumina, Tabular**

- Almatis Inc PA
- Alteo NA LLC OH
- AluChem Inc OH
- APF Recycling Inc OH
- Denka Corp NY
- GrainBound LLC PA
- Imerys Refractory Minerals GA
- Nanoe France
- Prince Minerals Inc (Prince International Corporation) TX
- Sauereisen Inc PA

**Alumina, Zirconia Toughened**

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- Applied Ceramics Inc CA
- Associated Ceramics & Technology Inc PA
- CerCo LLC OH
- Denka Corp NY
- Innovnano - Advanced Materials SA Portugal
- Nanocerox UT
- Nanoe France
- PicoParts Ltd Israel
- PIDC (Pacific Industrial Development Corporation) MI
- Prince Minerals Inc (Prince International Corporation) TX
- Rauschert Industries Inc GA
- Sauereisen Inc PA
- Washington Mills NY
- Xiamen Innovacera Advanced Materials Co Ltd China
- Zircoa Inc OH

**Aluminum & Compounds**

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- BassTech Intl NJ
- Denka Corp NY
- Hindalco Industries Limited India
- Leico Industries Inc NJ
- Refractory Minerals Co Inc PA
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- Valley Design Corp MA
- Xiamen Unipretec Ceramic Technology Co Ltd China

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 Haiku Tech Inc FL  
 Hexion Inc OH  
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 Sauereisen Inc PA  
**U.S. Borax Inc | Rio Tinto IL** See ad on page 71

**Boron & Compounds**

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 Electro Abrasives Corp NY  
 FELDCO Intl CA  
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**U.S. Borax Inc | Rio Tinto IL** See ad on page 71

**Boron Carbide**

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 Custom Processing Services PA  
 Denka Corp NY  
 Dunhua Zhengxing Abrasive Co Ltd China  
 Electro Abrasives Corp NY  
 FELDCO Intl CA  
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 Precision Ceramics FL  
 Reade Advanced Materials RI  
 Saint-Gobain Ceramics & Plastics MA  
 Xiamen Unipretec Ceramic Technology Co Ltd China

**Cadmium & Compounds**

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 FELDCO Intl CA  
 GFS Chemicals Inc OH  
 Hunter Chemical LLC PA

**Calcium & Compounds**

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 Denka Corp NY  
 GFS Chemicals Inc OH  
 Prince Minerals Inc (Prince International Corporation) TX

**Calcium Aluminates**

Almatis Inc PA  
 CerPoTech AS Norway  
**Gorka Cement Poland** See ad on page 107  
 Mineral Research Processing France  
 nGimat LLC KY  
 Sauereisen Inc PA

**Calcium Carbonate**

Arkema Inc PA  
 Fusion Ceramics Inc OH  
 Prince Minerals Inc (Prince International Corporation) TX  
 RE Carroll Inc PA  
 Unimin Corp CT

**Calcium Silicate**

Fusion Ceramics Inc OH  
 Mineral Research Processing France  
 Sauereisen Inc PA

**Carbon Fibers**

Goodfellow Corp PA

**Carbons, Carbon Black**

Cancarb Limited Canada

**Carbons, Diamond**

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**Cements**

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 ESL ElectroScience PA  
 Gwent Electronic Materials Ltd UK

**Cements, Refractory**

Almatis Inc PA  
 Aremco Products Inc NY  
 Diamorph AB UK



**Gorka Cement Poland** See ad on page 107

Kerneos Inc VA  
 Mineral Research Processing France  
 Sauereisen Inc PA  
 Unifrax I LLC NY

**Cerium & Compounds**

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 GFS Chemicals Inc OH  
 nGimat LLC KY  
 PIDC (Pacific Industrial Development Corporation) MI

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See ad on page 83

#### Cerments

Gorka Cement Poland

See ad on page 107

#### Chamotte

Imerys Refractory Minerals GA

#### Chrome & Compounds

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 Atlantic Equipment Engineers NJ  
 CerPoTech AS Norway  
 Hunter Chemical LLC PA  
 Monofrax LLC NY  
 North American Hoganäs PA

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 Imerys GA  
 Laguna Clay Co CA  
 Sheffield Pottery MA  
 Tethon 3D NE  
 Unimin Corp CT

#### Cobalt & Compounds

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 Ceramic Color & Chemical Mfg Co PA  
 CerPoTech AS Norway  
 FELDCO Intl CA  
 Fusion Ceramics Inc OH  
 Goodfellow Corp PA  
 Hunter Chemical LLC PA  
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 Atlantic Equipment Engineers NJ  
 Beijing Cerametek Materials Co Ltd China  
 Ceramic Color & Chemical Mfg Co PA  
 CerPoTech AS Norway  
 Goodfellow Corp PA  
 Matexcel NY  
 Shoen Chemical Inc Japan

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 Euro Support Advanced Materials The Netherlands  
 Gwent Electronic Materials Ltd UK  
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See ad on page 83

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 Powder Processing & Technology LLC IN  
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 MemPro Materials Corp  
 Thermal Products Co Inc GA  
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 Wesbond Corp DE

**Fibers, Glass**

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**Mo-Sci Corp MO** **See ad on page 97**  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Schott North America Inc NY  
 Unifrax I LLC NY

**Fluorides**

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**Frit**

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 RISE Research Institutes of Sweden RISE Glass Sweden  
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 Aremco Products Inc NY  
 Beijing Cerametek Materials Co Ltd China  
 CoorsTek CO  
 Matexcel NY  
 Momentive Performance Materials Inc NY  
 Semco Carbon OH  
 Superior Graphite Co IL  
**TeVTech LLC MA** **See ad on page 99**

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 Goodfellow Corp PA  
 MSE Supplies AZ  
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 CerPoTech AS Norway  
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 Goodfellow Corp PA  
 Kyanite Mining Corp VA  
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 Prince Minerals Inc (Prince International Corporation) TX

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 GFS Chemicals Inc OH  
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Goodfellow Corp PA

**Lithium & Compounds**

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 CerPoTech AS Norway  
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 MSE Supplies AZ  
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**Magnesia, Fused**

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 GFS Chemicals Inc OH  
 Goodfellow Corp PA  
 Pred Materials International Inc NY  
 Prince Minerals Inc (Prince International Corporation) TX  
 Atlantic Equipment Engineers NJ  
 BassTech Intl NJ  
 CerPoTech AS Norway  
 Fusion Ceramics Inc OH  
 Goodfellow Corp PA  
 nGimat LLC KY  
 Prince Minerals Inc (Prince International Corporation) TX  
 RE Carroll Inc PA

**Metallic Salts**

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**Metallizing Compounds**

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 Gwent Electronic Materials Ltd UK  
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**Microspheres, Hollow**

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**Molybdenum & Compounds**

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 CerPoTech AS Norway  
 Elcon Precision LLC CA  
 GFS Chemicals Inc OH

**Nanomaterials**

Agostyx OR



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**Cerion Nanomaterials NY** See ad on page 75  
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 Innovnano - Advanced Materials SA Portugal  
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 MSE Supplies AZ  
 Nanocerox UT  
 nGimat LLC KY  
 Nyacol Nano Technologies Inc MA  
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**TevTech LLC MA** See ad on page 99

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 FELDCO Intl CA  
 GFS Chemicals Inc OH  
 Hunter Chemical LLC PA  
 Matexcel NY  
 Shoei Chemical Inc Japan

**Niobium & Compounds**

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 FELDCO Intl CA  
 Leico Industries Inc NJ

**Organic Precursors**

Agostyx OR  
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**Pastes, Conductor**

Aremco Products Inc NY  
 Haiku Tech Inc FL  
 Polymer Innovations Inc CA  
 Sauereisen Inc PA  
 Shoei Chemical Inc Japan

**Phosphates**

Arkema Inc PA  
 BassTech Intl NJ  
 nGimat LLC KY  
 Refractory Minerals Co Inc PA  
 Sauereisen Inc PA

**Piezoelectric Compositions**

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 AVX Corp SC  
 CerPoTech AS Norway  
 Polymer Innovations Inc CA  
 Sparkler Ceramics Pvt Ltd India

**Pigments**

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 Fusion Ceramics Inc OH  
 Hunter Chemical LLC PA  
 Mason Color Works Inc OH  
 Sauereisen Inc PA  
 Wistra GmbH Germany

**Plaster, Gypsum**

Sheffield Pottery MA

**Plaster, Industrial**

Sheffield Pottery MA

**Potassium & Compounds**

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 PIDC (Pacific Industrial Development Corporation) MI

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GFS Chemicals Inc OH  
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 MSE Supplies AZ  
 Nanocerox UT



**PIDC (Pacific Industrial Development Corporation) MI**  
 See ad on page 69

Pred Materials International Inc NY  
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**Refractory Oxides**

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 Hunter Chemical LLC PA  
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 PIDC (Pacific Industrial Development Corporation) MI

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**Sand, Glass**

Covia OH  
 Fusion Ceramics Inc OH  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 U.S. Silica Co MD

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 Maryland Refractories Co OH  
 U.S. Silica Co MD  
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 Nanocerox UT  
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**Selenium & Compounds**

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 FELDCO Intl CA  
 Pred Materials International Inc NY

Outside back cover

**Semiconducting Powders**



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**SiAlON Powder**

Pred Materials International Inc NY

**Silica**

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 Denka Corp NY  
 Ipsen Ceramics IL  
 Maryland Refractories Co OH  
 Momentive Performance Materials Inc NY  
 Nanocerox UT  
 Saint-Gobain Ceramics & Plastics MA  
 Sauereisen Inc PA  
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 U.S. Silica Co MD

**Silica, Fused**

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 BassTech Intl NJ  
 Bosai Minerals Group Co Ltd China  
 Centerline Technologies MA  
 Industrial Ceramic Products Inc OH  
 Ipsen Ceramics IL  
 Momentive Performance Materials Inc NY  
 Technical Glass Products Inc Ohio  
 Valley Design Corp MA

**Silicates**

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 Denka Corp NY  
 Nanocerox UT  
 Sauereisen Inc PA

**Silicon & Compounds**

Agostyx OR  
 Atlantic Equipment Engineers NJ  
 Elkem Metals Inc PA  
 FELDCO Intl CA  
 McDanel Advanced Ceramic Technologies LLC PA  
 Reade Advanced Materials RI  
 Valley Design Corp MA

**Silicon Carbide**

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 Applied Ceramics Inc CA  
 Atlantic Equipment Engineers NJ  
 BassTech Intl NJ  
 Beijing Cerametek Materials Co Ltd China  
 Bullen OH  
 Cancarb Limited Canada  
 CerCo LLC OH  
 CoorsTek CO  
 Custom Processing Services PA  
 Electro Abrasives Corp NY  
 FELDCO Intl CA  
 Goodfellow Corp PA  
 Imerys Refractory Minerals GA  
 Momentive Performance Materials Inc NY  
 North American Hoganas PA  
 Ortech Inc CA

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Pred Materials International Inc NY  
 Rauschert Industries Inc GA  
 Saint-Gobain Ceramics & Plastics MA  
 Starfire Systems Inc NY  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China  
 Superior Graphite Co IL  
 Texters Technical Ceramics Inc Canada  
 Treibacher Industrie AG Austria  
 Valley Design Corp MA  
 Washington Mills NY

**Silicon Nitride**



**3D ceram CT**      See ad on page 73

Alteo NA LLC OH  
 Applied Ceramics Inc CA  
 Atlantic Equipment Engineers NJ  
 Bullen OH  
 CerCo LLC OH  
 CoorsTek CO  
 Creatz3D Ceramics Singapore  
 Denka Corp NY  
 FELDCO Intl CA  
 Goodfellow Corp PA  
 International Ceramic Engineering MA  
 McDanel Advanced Ceramic Technologies LLC PA  
 North American Hoganas PA  
 Ortech Inc CA  
 Pred Materials International Inc NY  
 Rauschert Industries Inc GA  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China  
 Texters Technical Ceramics Inc Canada  
 Xiamen Unipretec Ceramic Technology Co Ltd China

**Sodium & Compounds**

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 Covia OH  
 GFS Chemicals Inc OH  
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**Spheres, Ceramic**

Saint-Gobain NorPro OH

**Spheres, Glass**

Imerys Refractory Minerals GA  
**Mo-Sci Corp MO**      See ad on page 97  
 RISE Research Institutes of Sweden RISE Glass Sweden

**Strontium & Compounds**

Alfa Aesar Johnson Matthey MA  
 BassTech Intl NJ  
 CerPoTech AS Norway  
 Fusion Ceramics Inc OH  
 GFS Chemicals Inc OH  
 nGimat LLC KY  
 Strem Catalog, by Ascensus Specialties MA

**Superabrasives**

Alteo NA LLC OH  
 Diamond Industrial Tools Inc IL  
 Dianamic Abrasive Products Inc MI  
 Saint-Gobain Ceramics & Plastics MA

**Superconducting Powders**

Alfa Aesar Johnson Matthey MA  
 nGimat LLC KY

**Tantalum Metal Powder**

Leico Industries Inc NJ

**Tantalum Oxide**

CerPoTech AS Norway  
 FELDCO Intl CA  
 PIDC (Pacific Industrial Development Corporation) MI

**Terbium Oxide**

Alfa Aesar Johnson Matthey MA  
 C&L Development Corp CA  
 CerPoTech AS Norway  
 Leico Industries Inc NJ  
 Nanocerox UT

**Thickening Agents**

Lubrizol Performance Coating OH

**Thick-Film Materials**

CerPoTech AS Norway  
 ESL ElectroScience PA  
 New Tech Ceramics Inc IA  
 Polymer Innovations Inc CA  
 Shoen Chemical Inc Japan

**Thin-Film Materials**



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Cerakote Ceramic Coatings OR  
 CerPoTech AS Norway  
 FELDCO Intl CA  
 Innovnano - Advanced Materials SA Portugal  
 Materion Advanced Materials NY  
 New Tech Ceramics Inc IA  
 Strem Catalog, by Ascensus Specialties MA  
 Valley Design Corp MA

**Tin & Compounds**

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 CerPoTech AS Norway  
 FELDCO Intl CA  
 Goodfellow Corp PA  
 Trinity Ceramic Supply Inc TX

**Titanium & Compounds**

APF Recycling Inc OH  
 Atlantic Equipment Engineers NJ  
 C&L Development Corp CA  
 FELDCO Intl CA  
 Goodfellow Corp PA  
 Leico Industries Inc NJ  
 Matexcel NY  
 Nanocerox UT  
 North American Hoganas PA  
 TAM Ceramics NY

**Titanium Carbide**

Atlantic Equipment Engineers NJ  
 Beijing Cerametek Materials Co Ltd China  
 FELDCO Intl CA  
 Jilin Changyu Advanced Materials Co, Ltd China  
 North American Hoganas PA  
 Reade Advanced Materials RI

**Titanium Diboride**

Dunhua Zhengxing Abrasive Co Ltd China  
 FELDCO Intl CA  
 Momentive Performance Materials Inc NY  
 New Tech Ceramics Inc IA  
 North American Hoganas PA

Pred Materials International Inc NY  
 Surmet Corp MA

**Titanium Dioxide**

BassTech Intl NJ  
 Beijing Cerametek Materials Co Ltd China  
 FELDCO Intl CA  
 Fusion Ceramics Inc OH  
 Nanocerox UT  
 nGimat LLC KY  
 Pred Materials International Inc NY

**Titanium Nitride**

Atlantic Equipment Engineers NJ  
 FELDCO Intl CA  
 North American Hoganas PA  
 Pred Materials International Inc NY

**Tubes**

Technical Glass Products Inc Ohio

**Tungsten Carbide**

Associated Ceramics & Technology Inc PA  
 Atlantic Equipment Engineers NJ  
 C&L Development Corp CA  
 Centerline Technologies MA  
 Custom Processing Services PA  
 FELDCO Intl CA  
 Jilin Changyu Advanced Materials Co, Ltd China  
 MSE Supplies AZ  
 North American Hoganas PA  
 PicoParts Ltd Israel  
 Pred Materials International Inc NY

**Tungsten Oxide**

CerPoTech AS Norway  
 FELDCO Intl CA

**Uranium & Compounds**

Wistra GmbH Germany

**Vanadium & Compounds**

Atlantic Equipment Engineers NJ  
 CerPoTech AS Norway  
 FELDCO Intl CA

**Wetting Agents**

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**Yttria**

APF Recycling Inc OH  
 Associated Ceramics & Technology Inc PA  
 Bullen OH  
 CoorsTek CO  
 ESL ElectroScience PA  
 Innovnano - Advanced Materials SA Portugal  
 Nanocerox UT  
 nGimat LLC KY  
 North American Hoganas PA  
 PIDC (Pacific Industrial Development Corporation) MI  
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 Washington Mills NY

**Yttrium & Compounds**

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**American Elements Inc CA**  
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Nanocerox UT  
nGimat LLC KY  
PIDC (Pacific Industrial Development Corporation) MI

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Leico Industries Inc NJ  
Prince Minerals Inc (Prince International Corporation) TX  
RE Carroll Inc PA  
Sauereisen Inc PA  
**TevTech LLC MA**

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### Zinc Borate

**U.S. Borax Inc | Rio Tinto IL**

See ad on page 71

### Zinc Oxide

American Chemet Corp IL  
FELDCO Intl CA  
Fusion Ceramics Inc OH  
nGimat LLC KY  
Prince Minerals Inc (Prince International Corporation) TX  
Sauereisen Inc PA  
uttam industries India

### Zirconia

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C&L Development Corp CA  
Creat3D Ceramics Singapore  
Custom Processing Services PA  
Innovnano - Advanced Materials SA Portugal  
International Ceramic Engineering MA  
Leico Industries Inc NJ  
Nanocerox UT  
Nanoe France  
nGimat LLC KY  
Ortech Inc CA  
PIDC (Pacific Industrial Development Corporation) MI  
PremaTech Advanced Ceramics MA  
Rauschert Industries Inc GA  
Saint-Gobain Ceramics & Plastics MA  
Sauereisen Inc PA  
Suntech Advanced Ceramics (Shenzhen) Co Ltd China  
TAM Ceramics NY  
Washington Mills NY  
Xiamen Unipretec Ceramic Technology Co Ltd China  
Zibo Guangtong Chemical Co Ltd China  
Zircoa Inc OH

### Zirconia, Engineering-Grade

Creat3D Ceramics Singapore  
Innovnano - Advanced Materials SA Portugal  
Leico Industries Inc NJ  
McDanel Advanced Ceramic Technologies LLC PA  
Nanoe France  
Zibo Guangtong Chemical Co Ltd China  
Zircoa Inc OH

### Zirconia, High-Purity

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CARBO Texas  
CoorsTek CO  
Creat3D Ceramics Singapore  
Innovnano - Advanced Materials SA Portugal  
International Ceramic Engineering MA  
Nanocerox UT  
Nanoe France  
Sauereisen Inc PA  
Zibo Guangtong Chemical Co Ltd China

### Zirconia, Refractory-Grade

McDanel Advanced Ceramic Technologies LLC PA  
Nanoe France

Washington Mills NY  
Zircoa Inc OH

### Zirconium & Compounds

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C&L Development Corp CA  
CerPoTech AS Norway  
FELDCO Intl CA  
Goodfellow Corp PA  
Innovnano - Advanced Materials SA Portugal  
Luxfer MEL Technologies NJ  
Monofrax LLC NY  
PIDC (Pacific Industrial Development Corporation) MI  
Saint-Gobain Ceramics & Plastics MA  
Zibo Guangtong Chemical Co Ltd China

### Zirconium Carbide

Cancarb Limited Canada  
Jilin Changyu Advanced Materials Co, Ltd China  
North American Hoganas PA

### Zirconium Carbonate

C&L Development Corp CA  
Zibo Guangtong Chemical Co Ltd China

### Zirconium Diboride

North American Hoganas PA  
North American Hoganas PA

## CLAY & NATURAL MINERALS

### Bauxite

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Bosai Minerals Group Co Ltd China  
Fluid Energy Processing & Equipment Co PA  
Hindalco Industries Limited India  
Imerys Refractory Minerals GA  
Prince Minerals Inc (Prince International Corporation) TX

### Bentonite

Custom Processing Services PA  
Reade Advanced Materials RI  
Trinity Ceramic Supply Inc TX  
Vanderbilt Minerals LLCCT

### Borax



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See ad on page 71

### Chromite

Prince Minerals Inc (Prince International Corporation) TX

### Clays, Ball

Covia OH  
Fusion Ceramics Inc OH  
Imerys GA  
Old Hickory Clay Co KY  
Sheffield Pottery MA  
Sibelco Benelux Belgium  
Trinity Ceramic Supply Inc TX  
Unimin Corp CT

### Clays, China

Fusion Ceramics Inc OH  
Imerys GA

Old Hickory Clay Co KY  
Sheffield Pottery MA  
Sibelco Benelux Belgium  
Vanderbilt Minerals LLC CT

### Clays, Enamel

Old Hickory Clay Co KY  
RISE Research Institutes of Sweden RISE Glass Sweden  
Sibelco Benelux Belgium  
Vanderbilt Minerals LLC CT

### Clays, Engobe

Imerys GA  
Old Hickory Clay Co KY  
Sheffield Pottery MA  
Sibelco Benelux Belgium  
Vanderbilt Minerals LLC CT

### Clays, Fire or Refractory

Aalsey Refractories Co MO  
Christy Minerals LLC MO  
Endicott Clay Products Company NE  
Furnace Products & Services Inc PA  
Imerys Refractory Minerals GA  
Maryland Refractories Co OH  
Old Hickory Clay Co KY  
Peter Pugger Mfg Inc CA  
Riverside Refractories Inc--Allied Mineral Products AL  
Sheffield Pottery MA  
Sibelco Benelux Belgium

### Clays, Glaze

Imerys GA  
Old Hickory Clay Co KY  
Peter Pugger Mfg Inc CA  
Sheffield Pottery MA  
Sibelco Benelux Belgium  
Vanderbilt Minerals LLC CT

### Clays, Stoneware

Christy Minerals LLC MO  
Old Hickory Clay Co KY  
Peter Pugger Mfg Inc CA  
Sheffield Pottery MA  
Sibelco Benelux Belgium

### Cordierite

Maryland Ceramic & Steatite Co Inc MD  
Mason Color Works Inc OH  
Reade Advanced Materials RI  
Refratechnik Ceramics GmbH Germany  
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### Diatomaceous Earth

Reade Advanced Materials RI

### Dolomite

Fusion Ceramics Inc OH  
Sibelco Benelux Belgium  
Trinity Ceramic Supply Inc TX

### Feldspar

Avalon Advanced Materials Inc Canada  
Fusion Ceramics Inc OH  
Imerys GA  
Prince Minerals Inc (Prince International Corporation) TX  
Sheffield Pottery MA  
Sibelco Benelux Belgium  
Trinity Ceramic Supply Inc TX

### Flint

Christy Minerals LLC MO  
Fusion Ceramics Inc OH  
Sheffield Pottery MA

**Forsterite**

Du-Co Ceramics Company PA  
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See ad on page 83

**Kaolin**

Arkema Inc PA  
 Bosai Minerals Group Co Ltd China  
 CARBO Texas  
 Covia OH  
 Christy Minerals LLC MO  
 Fusion Ceramics Inc OH  
 Imerys GA  
 Imerys Refractory Minerals GA  
 M&M Clays Inc GA  
 Old Hickory Clay Co KY  
 RE Carroll Inc PA  
 Reade Advanced Materials RI  
 Sheffield Pottery MA  
 Trinity Ceramic Supply Inc TX  
 U.S. Silica Co MD  
 Vanderbilt Minerals LLC CT

**Kyanite**

Kyanite Mining Corp VA

**Lime & Limestone**

Prince Minerals Inc (Prince International Corporation) TX  
 RE Carroll Inc PA

**Lithium Minerals**

Avalon Advanced Materials Inc Canada  
 Fusion Ceramics Inc OH

**Magnesite**

APF Recycling Inc OH  
 Bosai Minerals Group Co Ltd China  
 Fluid Energy Processing & Equipment Co PA  
 Imerys Refractory Minerals GA

**Mica**

Imerys GA

**Montmorillonite**

Reade Advanced Materials RI  
 Vanderbilt Minerals LLC CT

**Mullite**

Christy Minerals LLC MO  
 Imerys Refractory Minerals GA  
 International Ceramic Engineering MA  
 Kyanite Mining Corp VA  
 Pred Materials International Inc NY  
 Reade Advanced Materials RI  
 Texers Technical Ceramics Inc Canada  
 Washington Mills NY

**Nepheline Syenite**

Covia OH  
 Fusion Ceramics Inc OH  
 Sheffield Pottery MA  
 Sibelco Benelux Belgium  
 Trinity Ceramic Supply Inc TX

**Olivine**

Prince Minerals Inc (Prince International Corporation) TX  
 Sibelco Benelux Belgium

**Pyrite**

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 Washington Mills NY

**Pyrophyllite**

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 Vanderbilt Minerals LLC CT

**Quartz**

Applied Ceramics Inc CA  
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 Goodfellow Corp PA  
 Imerys GA  
 International Ceramic Engineering MA  
 Momentive Performance Materials Inc NY  
 Multi Lab UK  
 Prince Minerals Inc (Prince International Corporation) TX  
 Sibelco Benelux Belgium  
 Technical Glass Products Inc Ohio

**Rutile**

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 Prince Minerals Inc (Prince International Corporation) TX

**Sapphire**

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 Centerline Technologies MA  
 Goodfellow Corp PA  
 International Ceramic Engineering MA  
 MSE Supplies AZ

**Silica**

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 Centerline Technologies MA  
 Imerys GA  
 Imerys Refractory Minerals GA  
 Maryland Refractories Co OH  
 Prince Minerals Inc (Prince International Corporation) TX  
 Sibelco Benelux Belgium  
 Trinity Ceramic Supply Inc TX  
 U.S. Silica Co MD

**Soda Ash**

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 RE Carroll Inc PA

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 Trinity Ceramic Supply Inc TX

**Steatite**

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 International Ceramic Engineering MA

**Steatite**

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 Cancarb Limited Canada  
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 Somany Ceramics Ltd India

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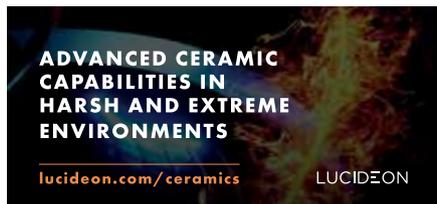
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 CoorsTek CO  
 Edward Orton Jr Ceramic Foundation OH  
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 H&M Analytical Services Inc NJ  
 Hindalco Industries Limited India  
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 Israel Ceramic & Silicate Inst Israel  
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**Lucideon UK**

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 Micron Inc DE  
 NSL Analytical Services Inc OH  
 OPF Enterprises TX  
 Particle Technology Labs IL  
 Quantachrome Instruments FL  
 Refractory Consulting Services OH  
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 Cerakote Ceramic Coatings OR  
 Ceralink Inc NY  
 Cerion Nanomaterials NY  
 Elan Technology GA  
 Elcon Precision LLC CA  
 GrainBound LLC PA  
 H&M Analytical Services Inc NJ  
 Hitech Materials Pty Ltd NSW  
 Imerys GA  
 Inst for Applied Materials-Ceramics in Mechanical Engineering Karlsruhe Inst of Technology Germany  
 International Ceramic Engineering MA  
 Lithoz GmbH NY



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 North American Hoganas PA  
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 O'Keefe Ceramics Inc CO  
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 Schott North America Inc NY  
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 Polymer Innovations Inc CA  
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 Centerline Technologies MA  
 Elan Technology GA  
 Electrosciences Ltd UK  
 Gwent Electronic Materials Ltd UK  
 Haiku Tech Europe BV The Netherlands  
 Haiku Tech Inc FL



Harrop Industries Inc OH See ad on page 58



I Squared R Element Co NY See ad on page 79

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 Verity Technical Consultants LLC OH  
 Wistra GmbH Germany

**Environmental**

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 Air Force Civil Engineer Center FL  
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 Refrac Systems AZ  
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 Thermal Products Co Inc GA  
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**Kilns**

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FCT Systeme GmbH Germany  
 Lucideon UK  
 Nabertherm Inc DE  
 OPF EnterprisesTX

**Litigation**

H&M Analytical Services Inc NJ  
 Lucideon UK  
 Particle Technology Labs IL  
 Refractory Consulting Services OH  
 Spontaneous Materials CO  
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 Cerinnov France  
 CoorsTek CO  
 Custom Processing Services PA  
 Cyclonaire Corp NE  
 Endicott Clay Products Company NE  
**Ingredient Masters Inc OH** See ad on page 101  
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 Jenike & Johanson Inc MA  
 Laserage Technology Corp IL  
 Lucideon UK  
 Maryland Ceramic & Steatite Co Inc MD  
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Verity Technical Consultants LLC OH  
 Wistra GmbH Germany

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 Bharat Heavy Electricals Ltd India  
 BuzzMac Intl LLC ME  
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 Elan Technology GA  
 Fluid Energy Processing & Equipment Co PA  
 Geller Microanalytical Laboratory Inc MA  
 GrainBound LLC PA  
 H&M Analytical Services Inc NJ  
 Hindalco Industries Limited India  
 Hitachi High-Tech America Inc MD  
 Hitech Materials Pty Ltd NSW  
 Hysitron Inc MN  
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 Jenike & Johanson Inc MA  
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 Lucideon UK  
 Matexcel NY  
 Micromeritics Instrument Corp GA  
 Nol-Tec Systems Inc MN  
 NorECs AS Norway  
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 Particle Technology Labs IL  
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 Ram Products Inc OH  
 Spontaneous Materials CO  
 Tethon 3D NE

**Nuclear Materials**

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 Dunhua Zhengxing Abrasive Co Ltd China  
 NSL Analytical Services Inc OH

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Spontaneous Materials CO  
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**Professional Engineer**

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Optimization - Klug Systems NY  
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Fosbel Inc OH  
Hitech Materials Pty Ltd NSW  
Industrial Ceramic Products Inc OH  
Ipsen Ceramics IL  
JTF Microscopy Services LLC NY  
Laguna Clay Co CA  
Lucideon UK  
Maryland Refractories Co OH  
NSL Analytical Services Inc OH  
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Viridis3D LLC MA  
Wistra GmbH Germany

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AVEKA MN  
CelSian Glass & Solar BV The Netherlands  
Ceralink Inc NY  
Cerion Nanomaterials NY  
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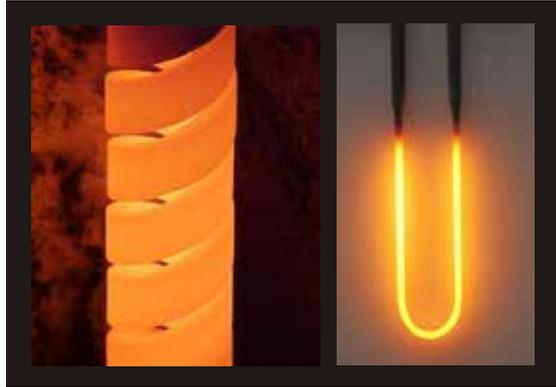


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See ad on page 99

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See ad on page 58

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 Materials Research Furnaces Inc NH  
 Nabertherm Inc DE  
**Oxy-Gon Industries Inc NH** See ad on page 89  
 Paragon Industries LP TX  
 PSH Kilns & Furnaces Canada  
 RD Webb Company Inc MA  
 Recco Furnaces CA  
 Seco/Warwick Corp PA  
 The Furnace Source LLC CT  
 Thermcraft Inc NC  
 Trent Inc PA  
 Verder Scientific Inc PA  
 Winner Technology Korea  
 Wyssmont Co NJ

**Furnaces, Gas**

Aadvanced Machinery Inc MI  
 Ceramic Services Inc PA  
 Ceritherm France  
 Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
 HED Intl Inc NJ  
 Keith Co CA  
 L&L Kiln Mfg Inc NJ  
**Centorr Vacuum Industries NH** See ad on page 87  
 Materials Research Furnaces Inc NH  
 McGill AirClean OH  
 Nabertherm Inc DE  
 Recco Furnaces CA  
 Seco/Warwick Corp PA  
 Swindell Dressler Intl Co PA  
 The Furnace Source LLC CT  
 Thermcraft Inc NC  
 Wyssmont Co NJ

**Furnaces, Glass-Melting**

Applied Test Systems Inc PA  
 Carbolite Gero UK  
 Ceradyne Inc a 3M Co KY  
 CM Furnaces Inc NJ



**Deltech Inc (Deltech Furnaces) CO** Inside front cover  
**Deltech Kiln and Furnace Design LLC CO** See ad on page 77  
 Furnace Products & Services Inc PA  
 General Glass Equipment Co NJ  
 Magneco Metrel Inc IL  
 Nabertherm Inc DE  
 Paragon Industries LP TX  
 PSH Kilns & Furnaces Canada  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Verder Scientific Inc PA

**Furnaces, High-Temperature**

Applied Test Systems Inc PA  
 Cancarb Limited Canada  
 Capovani Brothers Inc NY  
 Carbolite Gero UK  
 Centorr Vacuum Industries NH  
 Ceritherm France  
 CM Furnaces Inc NJ

Cober Muegge LLC CT  
 Dalmia Inst of Scientific & Industrial Research India  
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 FCT Systeme GmbH Germany  
 Furnace Products & Services Inc PA  
**Gasbarre Products Inc PA** See ad on page 95  
 Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
 HED Intl Inc NJ  
 Lucifer Furnaces Inc PA  
 Materials Research Furnaces Inc NH  
 Nabertherm Inc DE



**Oxy-Gon Industries Inc NH** See ad on page 89  
 Plansee SE MA  
 PSH Kilns & Furnaces Canada  
 Quintus Technologies LLC OH  
 RD Webb Company Inc MA  
 Seco/Warwick Corp PA  
 Swindell Dressler Intl Co PA  
 The Furnace Source LLC CT



**Thermcraft NC** See ad on page 89  
 Verder Scientific Inc PA  
 Winner Technology Korea

**Furnaces, Laboratory**

Carbolite Gero UK  
 Capovani Brothers Inc NY



**Centorr Vacuum Industries NH** See ad on page 87  
 CM Furnaces Inc NJ  
 Cober Muegge LLC CT  
**Deltech Inc (Deltech Furnaces) CO** Inside front cover  
**Deltech Kiln and Furnace Design LLC CO** See ad on page 79  
 FCT Systeme GmbH Germany  
 Harper International NY  
**Centorr Vacuum Industries NH** See ad on page 87  
 Lucifer Furnaces Inc PA  
 Materials Research Furnaces Inc NH  
 Nabertherm Inc DE  
**Oxy-Gon Industries Inc NH** See ad on page 89  
 RD Webb Company Inc MA  
 RocCera LLC NY  
 The Furnace Source LLC CT  
 Verder Scientific Inc PA  
 Winner Technology Korea

**Furnaces, Vacuum**

Applied Test Systems Inc PA  
 AVS Inc MA  
 Capovani Brothers Inc NY  
 Centorr Vacuum Industries NH  
 Cober Muegge LLC CT  
 FCT Systeme GmbH Germany  
**Gasbarre Products Inc PA** See ad on page 95  
 Goceram AB Sweden  
 Materials Research Furnaces Inc NH  
 Nabertherm Inc DE



**Oxy-Gon Industries Inc NH** See ad on page 89  
 RocCera LLC NY  
 Seco/Warwick Corp PA  
 The Furnace Source LLC CT  
 Verder Scientific Inc PA

**Heating Elements**

Applied Test Systems Inc PA



**Centorr Vacuum Industries NH** See ad on page 87  
 CM Furnaces Inc NJ  
 Hotek Alliance Ltd China



**I Squared R Element Co NY** See ad on page 79  
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 Lucifer Furnaces Inc PA  
 Materials Research Furnaces Inc NH  
**Oxy-Gon Industries Inc NH** See ad on page 89  
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 Recco Furnaces CA  
 Seco/Warwick Corp PA  
 Thermal Products Co Inc GA  
 Thermcraft Inc NC  
 Trent Inc PA  
 Verder Scientific Inc PA  
 Winner Technology Korea

**Humidification Systems**

CM Furnaces Inc NJ

**Kilns**

Applied Test Systems Inc PA  
 Carbolite Gero UK  
 Ceramic Services Inc PA  
 Ceritherm France

Detroit Process Machinery MI  
 FCT Systeme GmbH Germany  
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**Harrop Industries Inc OH** See ad on page 58  
 HED INTl Inc NJ  
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**L&L Special Furnace Co Inc PA** See ad on page 87  
**Centorr Vacuum Industries NH** See ad on page 87  
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 Laguna Clay Co CA  
 Lucifer Furnaces Inc PA  
**Mohr Corp MI** See ad on page 85  
 Nutec Bickley Mexico  
 PSH Kilns & Furnaces Canada  
 RD Webb Company Inc MA  
 Recco Furnaces CA  
 RocCera LLC NY  
 Swindell Dressler Intl Co PA  
 Takasago Industry Co Ltd Japan  
 Thermcraft Inc NC  
 Wistra GmbH Germany

**Kilns, Bell**

Carbolite Gero UK  
 Ceramic Services Inc PA  
 Ceritherm France  
 Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
 HED INTl Inc NJ  
 Keith Co CA  
 L&L Kiln Mfg Inc NJ  
**Centorr Vacuum Industries NH** See ad on page 87  
 Lucifer Furnaces Inc PA  
 Nabertherm Inc DE  
 Nutec Bickley Mexico  
 PSH Kilns & Furnaces Canada  
 Recco Furnaces CA  
 Swindell Dressler Intl Co PA  
 Takasago Industry Co Ltd Japan  
 Thermcraft Inc NC

**Kilns, Box**

Advanced Machinery Inc MI  
 American Art Clay Co Inc IN  
 Applied Test Systems Inc PA  
 Carbolite Gero UK  
 Ceramic Services Inc PA  
 Ceritherm France  
 CM  
 Furnaces Inc NJ  
 Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
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 Keith Co CA  
 L&L Kiln Mfg Inc NJ  
**Centorr Vacuum Industries NH** See ad on page 87  
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Lucifer Furnaces Inc PA  
Nabertherm Inc DE  
Nutec Bickley Mexico  
Takasago Industry Co Ltd Japan  
Thermcraft Inc NC  
Verder Scientific Inc PA

**Kilns, Conveyor**

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Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
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Keith Co CA  
Lucifer Furnaces Inc PA  
Nabertherm Inc DE  
Nutec Bickley Mexico  
Recco Furnaces CA

**Kilns, Elevator**

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Ceritherm France  
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**Harrop Industries Inc OH** See ad on page 58  
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L&L Kiln Mfg Inc NJ  
**Centorr Vacuum Industries NH** See ad on page 87  
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Nabertherm Inc DE  
Nutec Bickley Mexico  
Recco Furnaces CA  
Swindell Dressler Intl Co PA  
Takasago Industry Co Ltd Japan

**Kilns, Envelope**

Ceritherm France  
**Harrop Industries Inc OH** See ad on page 58  
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Keith Co CA  
L&L Kiln Mfg Inc NJ  
**Centorr Vacuum Industries NH** See ad on page 87  
Nabertherm Inc DE  
PSH Kilns & Furnaces Canada  
Recco Furnaces CA  
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**Kilns, Periodic (Batch)**

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Ceritherm France  
CM Furnaces Inc NJ  
Cober Muegge LLC CT  
FCT Systeme GmbH Germany  
Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
HED INTl Inc NJ  
Keith Co CA  
L&L Kiln Mfg Inc NJ

**Centorr Vacuum Industries NH** See ad on page 87  
Lucifer Furnaces Inc PA  
Nabertherm Inc DE  
RD Webb Company Inc MA  
Recco Furnaces CA  
Swindell Dressler Intl Co PA  
Takasago Industry Co Ltd Japan  
Thermcraft Inc NC

**Kilns, Pusher Plate**

Ceritherm France  
CM Furnaces Inc NJ  
Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
HED INTl Inc NJ  
Ipsen Ceramics IL  
Keith Co CA  
Lucifer Furnaces Inc PA  
Recco Furnaces CA

**Kilns, Roller Hearth**

Ceramic Services Inc PA  
Ceritherm France  
Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
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Keith Co CA  
Lucifer Furnaces Inc PA  
Nutec Bickley Mexico  
Swindell Dressler Intl Co PA  
Takasago Industry Co Ltd Japan  
Wistra GmbH Germany

**Kilns, Rotary**

Ceritherm France  
CM Furnaces Inc NJ



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Fives North American Combustion Inc OH  
Furnace Products & Services Inc PA  
Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
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Lucifer Furnaces Inc PA  
Nutec Bickley Mexico  
Raymond Bartlett Snow-Schneck Processing IL  
Thermcraft Inc NC  
Verder Scientific Inc PA

**Kilns, Shuttle**

Basic Machinery Co Inc NC  
Ceramic Services Inc PA  
Ceritherm France  
CM Furnaces Inc NJ  
Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
HED INTl Inc NJ  
Keith Co CA  
L&L Kiln Mfg Inc NJ  
**Centorr Vacuum Industries NH** See ad on page 87  
Lucifer Furnaces Inc PA  
Nabertherm Inc DE  
Nutec Bickley Mexico  
Recco Furnaces CA  
Swindell Dressler Intl Co PA  
Takasago Industry Co Ltd Japan

Thermcraft Inc NC  
Wistra GmbH Germany

**Kilns, Test/Lab**

American Art Clay Co Inc IN  
Applied Test Systems Inc PA  
Carbolite Gero UK  
Ceramic Services Inc PA  
CM Furnaces Inc NJ  
Cober Muegge LLC CT  
FCT Systeme GmbH Germany  
Harper International NY  
**Harrop Industries Inc OH** See ad on page 58  
Keith Co CA  
L&L Kiln Mfg Inc NJ  
**Centorr Vacuum Industries NH** See ad on page 87  
Lucifer Furnaces Inc PA  
Nabertherm Inc DE  
Nutec Bickley Mexico  
Paragon Industries LP TX  
PSH Kilns & Furnaces Canada  
RD Webb Company Inc MA  
Recco Furnaces CA  
Takasago Industry Co Ltd Japan  
Thermcraft Inc NC  
Verder Scientific Inc PA

**Kilns, Tunnel (Continuous)**

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Basic Machinery Co Inc NC  
Ceramic Services Inc PA  
Ceritherm France  
CM Furnaces Inc NJ  
Cober Muegge LLC CT  
**Deltech Inc (Deltech Furnaces) CO** Inside front cover  
Euro Support Advanced Materials The Netherlands  
Harper International NY



**Harrop Industries Inc OH** See ad on page 58  
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Nutec Bickley Mexico  
Recco Furnaces CA  
Swindell Dressler Intl Co PA  
Takasago Industry Co Ltd Japan  
Wistra GmbH Germany

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**Harrop Industries Inc OH** See ad on page 58  
Keith Co CA  
Recco Furnaces CA

**Microwave Systems**

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Ceralink Inc NY  
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**Process/Quality Control Systems**

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General Glass Equipment Co NJ  
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**Pyrometric Cones/Plaques**

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Edward Orton Jr Ceramic Foundation OH  
Industrial Ceramic Products Inc OH  
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Trinity Ceramic Supply Inc TX

**Sensors, Temperature**

Datapaq Inc NH  
Penn Tool Co NJ  
Zibo Guangtong Chemical Co Ltd China

**Thermocouples & Accessories**

**AdValue Technology LLC AZ** See ad on page 67  
American Art Clay Co Inc IN  
American Isostatic Presses OH  
CM Furnaces Inc NJ  
Datapaq Inc NH  
**Gasbarre Products Inc PA** See ad on page 95  
**Harrop Industries Inc OH** See ad on page 58  
Keith Co CA  
Leico Industries Inc NJ  
Materials Research Furnaces Inc NH  
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Quintus Technologies LLC OH  
Recco Furnaces CA  
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**EDUCATION & RESOURCES**

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Brick Industry Assn VA  
Glass Mfg Industry Council OH  
Indian Ceramic Society India  
International Centre for Diffraction Data PA  
Journal of the American Ceramic Society OH  
SAMPE CA  
The American Ceramic Society OH

**Books**

APC International Ltd PA  
Bharat Heavy Electricals Ltd India  
Journal of the American Ceramic Society OH  
SAMPE CA  
Sheffield Pottery MA

**Continuing Education**

**Alfred University NY** See ad on page Inside back, 40, 91  
Arizona State University AZ

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 JTF Microscopy Services LLC NY  
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 Tethon 3D NE

### Degree Programs, ABET Accredited



**Alfred University NY** See ad on page Inside back, 40, 91  
 Case Western Reserve University OH  
 Massachusetts Inst of Technology MA  
 Missouri University of Science and Technology MO  
 Rensselaer Polytechnic Inst NY

### Degree Programs, Ceramic



**Alfred University NY** See ad on page Inside back, 40, 91  
 Fraunhofer Institute for Ceramic Technologies and Systems  
 IKTS Germany  
 Massachusetts Inst of Technology MA  
 Missouri University of Science and Technology MO

### Degree Programs, Glass Engrg Science



**Alfred University NY** See ad on page Inside back, 40, 91  
 Fraunhofer Institute for Ceramic Technologies and Systems  
 IKTS Germany

### Degree Programs, Materials Science

**Alfred University NY** See ad on page Inside back, 40, 91  
 Arizona State University AZ  
 Case Western Reserve University OH  
 Fraunhofer Institute for Ceramic Technologies and Systems  
 IKTS Germany  
 Massachusetts Inst of Technology MA  
 Missouri University of Science and Technology MO  
 Rensselaer Polytechnic Inst NY

### Employment Services

SAMPE CA

### Publications

American Ceramic Society Bulletin OH  
 American Scientific Publishers CA  
 Chemical Abstracts Service OH  
 GrainBound LLC PA  
 Indian Ceramic Society India  
 Journal of the American Ceramic Society OH

### Ultrasonic Transducers

Piezo by Graco OH

## ■ ELECTRICAL/ELECTRONIC CERAMICS

### Antennas, Dielectric

Euro Support Advanced Materials The Netherlands  
 O'Keefe Ceramics Inc CO

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### Capacitors

Associated Ceramics & Technology Inc PA  
 AVX Corp SC  
 Euro Support Advanced Materials The Netherlands  
 Induceric Canada  
 Murata Manufacturing Co Ltd Japan

### Ceramic-Brazed Assemblies

AdTech Ceramics TN  
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 Induceric Canada  
 Morgan Technical Ceramics Auburn CA  
 Precision Ferrites and Ceramics Inc CA

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 CerPoTech AS Norway  
 ESL ElectroScience PA  
 Master Bond Inc NJ  
 NorECs AS Norway

### Crystals

Induceric Canada  
 Kyocera International Inc CA  
 Momentive Performance Materials Inc NY  
 MSE Supplies AZ  
**TeVTech LLC MA** See ad on page 99

### Dielectrics

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 AVX Corp SC  
 Centerline Technologies MA  
 CerPoTech AS Norway  
 ENrG Inc NY  
 ESL ElectroScience PA  
 Euro Support Advanced Materials The Netherlands  
 Gwent Electronic Materials Ltd UK  
 Morgan Advanced Materials CA  
 NGK Spark Plug Co Ltd Japan  
 Pacific Ceramics Inc CA  
 Advanced Ceramic Technology CA

### Ferrites & Ferromagnetics

Ferro Ceramic Grinding Inc MA  
 Pacific Ceramics Inc CA  
 Precision Ferrites and Ceramics Inc CA  
 Spontaneous Materials CO

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 Euro Support Advanced Materials The Netherlands  
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### Fuel Cells, Solid Oxide

AdTech Ceramics TN  
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 Bharat Heavy Electricals Ltd India  
 Cancarb Limited Canada  
 CerPoTech AS Norway  
 ENrG Inc NY

ESL ElectroScience PA  
 Euro Support Advanced Materials The Netherlands  
 Gwent Electronic Materials Ltd UK  
 Morgan Technical Ceramics Auburn CA  
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### High-Voltage Insulators

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 Du-Co Ceramics Company PA  
 Elcon Precision LLC CA  
 Morgan Technical Ceramics Auburn CA  
 Precision Ferrites and Ceramics Inc CA  
 Xiamen Innovacera Advanced Materials Co Ltd China

### Hybrid Circuits & Packages

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 Xiamen Innovacera Advanced Materials Co Ltd China

### IC Packages

AdTech Ceramics TN  
 Kyocera International Inc CA  
 NGK Spark Plug Co Ltd Japan

### Insulators, Electrical/Electronic

Accuratus Corp NJ  
 AdTech Ceramics TN  
**AdValue Technology LLC AZ** See ad on page 67  
 Akron Porcelain & Plastics Co OH  
 Blasch Precision Ceramics Inc NY  
 Ceramco Inc NH  
 CeramTec North America Corp SC  
 CerCo LLC OH  
 Du-Co Ceramics Company PA  
 ER Advanced Ceramics Inc OH  
 ESL ElectroScience PA  
 Federal-Mogul MI  
 Ferro Ceramic Grinding Inc MA  
 Maryland Ceramic & Steatite Co Inc MD  
 Materion Ceramics AZ  
 Morgan Technical Ceramics Auburn CA  
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 P-Ker Engineering NY  
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 Sonya Ceramics (Export Division) India  
 Superior Technical Ceramics Corp VT  
 Toto Ltd Japan  
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### Magnets

Spontaneous Materials CO

### Microwave Packages

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 Kyocera International Inc CA  
 Precision Ferrites and Ceramics Inc CA

### Multilayer Ceramic Capacitors

Euro Support Advanced Materials The Netherlands  
 Murata Manufacturing Co Ltd Japan

### Multilayer Ceramics, AIN

AdTech Ceramics TN  
 NEVZ-Ceramics Close JSC Russia  
 Xiamen Innovacera Advanced Materials Co Ltd China

**Multilayer Ceramics, Custom**

AdTech Ceramics TN  
 EBL Products Inc CT  
 ENrG Inc NY  
 Euro Support Advanced Materials The Netherlands  
 Piezo by Graco OH  
 Xiamen Innovacera Advanced Materials Co Ltd China

**Piezoelectrics**

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 AVX Corp SC  
 EBL Products Inc CT  
 Meggitt Piezo Technologies IN  
 Morgan Advanced Materials CA  
 Sparkler Ceramics Pvt Ltd India

**Resistors, Thick-Film**

ESL ElectroScience PA  
 Murata Manufacturing Co Ltd Japan

**Resonators**

AVX Corp SC  
 Murata Manufacturing Co Ltd Japan  
 NGK Spark Plug Co Ltd Japan

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See ad on page 83

**RF Components**

AdTech Ceramics TN  
 Advanced Ceramic Technology CA  
 Advanced Energy CO  
 Murata Manufacturing Co Ltd Japan  
 Precision Ferrites and Ceramics Inc CA

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See ad on page 83

**Semiconductors**

Cancarb Limited Canada  
 Elcon Precision LLC CA  
 Momentive Performance Materials Inc NY  
 NEVZ-Ceramics Close JSC Russia  
 Semiconductor Energy Laboratory Co Ltd Japan  
 Toto Ltd Japan

**Sensors**

AdTech Ceramics TN  
 AVX Corp SC  
 Bullen OH  
 CeramTec North America Corp SC  
 EBL Products Inc CT  
 ENrG Inc NY  
 Gwent Electronic Materials Ltd UK  
 Murata Manufacturing Co Ltd Japan  
 Neoptix Canada  
 Optocon AG Germany  
 Piezo by Graco OH  
 Quality Thermistor Inc ID  
 Sparkler Ceramics Pvt Ltd India  
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**Spark Plugs**

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 CerCo LLC OH  
 Federal-Mogul MI  
 Gwent Electronic Materials Ltd UK  
 NGK Spark Plug Co Ltd Japan

**Substrates, Alumina**

Accuratus Corp NJ

**Substrates, Alumina**

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 AdTech Ceramics TN

Bullen OH  
 Centerline Technologies MA  
 CeramTec North America Corp SC  
 CoorsTek CO  
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 Ferro Ceramic Grinding Inc MA  
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 NEVZ-Ceramics Close JSC Russia  
 NGK Spark Plug Co Ltd Japan  
 Ortech Inc CA  
 Saint-Gobain NorPro OH  
 Toto Ltd Japan  
 Valley Design Corp MA  
 Xiamen Innovacera Advanced Materials Co Ltd China

**Substrates, Aluminum Nitride**

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 AdTech Ceramics TN  
 Bullen OH  
 Centerline Technologies MA  
 CoorsTek CO  
 Laserage Technology Corp IL  
 MSE Supplies AZ  
 NEVZ-Ceramics Close JSC Russia  
 Ortech Inc CA  
 Starfire Systems Inc NY  
 Valley Design Corp MA  
 Xiamen Innovacera Advanced Materials Co Ltd China

**Substrates, Glass**

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 Bullen OH  
 Centerline Technologies MA  
 Laserage Technology Corp IL  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Saint-Gobain Recherche France  
 Valley Design Corp MA

# New Advanced Research Capabilities at Alfred, NY

## Ultrafast Materials Science and Engineering Laboratory (U-Lab)

- Femtosource Scientific XL 500 (FEMTOLASERS Produktions GmbH, Fernkornigasse, Austria) - Pulse energy of 500 nJ, pulse duration less than 50 fs, and repetition rate of 5.1 MHz

## Terahertz Science and Engineering Laboratory (T-Lab)

- Terahertz time-domain spectroscopy and imaging (THz-TDS; Teraview TPS Spectra 3000, Teraview, Cambridge, UK)
- Custom hybrid scanner THz system at 100 & 280GHz, Terasense Group, Inc.

## 3D-Printing of Materials

- Lithoz CeraFab 8500-Lithography-Based Ceramic Manufacturing System (LCM)

## Gyrotron Laboratory (G-Lab)

- Gyrotron - 95 GHz/10 kW system (Bridge 12 Technologies, LLC)

- a. Nicholas J. Tostanoski (BS '18, PhD '22) examines the femtosecond laser system at U-Lab.  
 b. A view of sample holder of THz-TDS at T-Lab  
 c. Nicholas J. Tostanoski (BS '18, PhD '22) loads a glass sample for THz measurements.  
 d. Nathaniel L. Skeele (BS/BA '22) adjusts settings of dual-camera THz scanner at T-Lab.  
 e. Lithoz CeraFab 8500 at Alfred  
 f. 95 GHz/10 kW Gyrotron at G-Lab



Contact: Prof. S. K. Sundaram, Inamori Professor of Materials Science and Engineering, Phone: (607) 871-2789; Fax: (607) 871-2354; E-mail: [sundaram@alfred.edu](mailto:sundaram@alfred.edu) Inamori School of Engineering

The Sundaram Group

**Substrates, Other**

Accuratus Corp NJ  
 Akron Porcelain & Plastics Co OH  
 Bullen OH  
 Centerline Technologies MA  
 CoorsTek CO  
 Du-Co Ceramics Company PA  
 ENRG Inc NY  
 Materion Ceramics AZ  
 MSE Supplies AZ  
 NGK Spark Plug Co Ltd Japan  
**Trans-Tech Inc a subsidiary of  
 Skyworks Solutions Inc MD** See ad on page 83  
 Valley Design Corp MA

**Substrates, Silicon Carbide**

Bullen OH  
 Centerline Technologies MA  
 Ferro Ceramic Grinding Inc MA  
 Ortech Inc CA  
 Toto Ltd Japan  
 Valley Design Corp MA

**Superconductors, High-Temperature**

ENRG Inc NY  
 Xiamen Innovacera Advanced Materials Co Ltd China

**Tapes**

Du-Co Ceramics Company PA  
 ESL ElectroScience PA  
 Euro Support Advanced Materials The Netherlands  
 Haiku Tech Europe BV The Netherlands  
 Haiku Tech Inc FL  
 Maryland Ceramic & Steatite Co Inc MD

**Thermistors**

AVX Corp SC  
 Gwent Electronic Materials Ltd UK  
 Murata Manufacturing Co Ltd Japan  
 Quality Thermistor Inc ID

**Transducers**

APC International Ltd PA  
 CSC Force Measurement Inc MA  
 EBL Products Inc CT  
 Meggitt Piezo Technologies IN  
 Neoptix Canada  
 Piezo by Graco OH  
 Sparkler Ceramics Pvt Ltd India  
 Technisonic Research Inc CT

**Transformers**

Grand Power Systems formally Warner Power LLC MI  
 RoMan Manufacturing MI

**Ultrasonic Ceramics**

APC International Ltd PA  
 EBL Products Inc CT  
 Meggitt Piezo Technologies IN  
 Piezo by Graco OH

**Varistors**

AVX Corp SC  
 Kyocera International Inc CA

**FABRICATING & FINISHING****Abrasives**

Allied High Tech Products Inc CA  
 Diacut Inc CO  
 Diamond Industrial Tools Inc IL  
 Dianamic Abrasive Products Inc MI  
 Dunhua Zhengxing Abrasive Co Ltd China  
 Dynacut Inc PA  
 Electro Abrasives Corp NY  
 Engis Corp IL  
 FELDCO Intl CA  
 Jet Edge Waterjet Systems MN  
 Reade Advanced Materials RI  
 Saint-Gobain Abrasives MA  
 Sigmadiamant Spain  
 Stahl USA Inc WI  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China  
 Washington Mills Electro Minerals Co NY

**Brickmaking Equipment**

Basic Machinery Co Inc NC  
 EZG Manufacturing Inc OH  
 Laeis GmbH Luxembourg  
 Stedman Machine Co IN

**Casting Equipment, Pressure**

American Isostatic Presses OH  
 Cerinnov France  
 Cerlase France  
 Dorst America Inc PA  
 HED Intl Inc NJ  
 Laguna Clay Co CA  
 Maryland Ceramic & Steatite Co Inc MD

**Casting Equipment, Tape**

Haiku Tech Europe BV The Netherlands  
 Haiku Tech Inc FL  
 HED Intl Inc NJ

**CNC Mills**

Elcon Precision LLC CA  
 Liberty Machinery Co IL  
**OptiPro Systems LLC NY** See ad on page 93  
 Penn Tool Co NJ  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China

**Coating Equipment**

Agostyx OR  
 Allied High Tech Products Inc CA  
 Cerakote Ceramic Coatings OR  
 Dynacut Inc PA  
 Haiku Tech Europe BV The Netherlands  
 Haiku Tech Inc FL  
 Liberty Machinery Co IL

**Cold-End Coatings, Glass**

RISE Research Institutes of Sweden RISE Glass Sweden

**Controllers**

Dorst America Inc PA  
 General Glass Equipment Co NJ  
 Laguna Clay Co CA  
 Rockwell Automation Inc WI

**Cutting Equipment**

Basic Machinery Co Inc NC  
 Diamond Industrial Tools Inc IL  
 General Glass Equipment Co NJ  
 Haiku Tech Inc FL  
 Jet Edge Waterjet Systems MN  
 Liberty Machinery Co IL  
**OptiPro Systems LLC NY** See ad on page 93  
 Penn Tool Co NJ  
 Sigmadiamant Spain  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China

**Cutting Tools**

Diacut Inc CO  
 Dynacut Inc PA  
 Engis Corp IL  
 Jet Edge Waterjet Systems MN  
 New Tech Ceramics Inc IA  
 Penn Tool Co NJ  
 Sigmadiamant Spain

**CVD Equipment**

Advanced Energy CO  
 Capovani Brothers Inc NY  
 Centorr Vacuum Industries NH  
 Liberty Machinery Co IL  
 Strem Catalog, by Ascensus Specialties MA

**Deburring Equipment**

Engis Corp IL  
 Liberty Machinery Co IL  
**Mohr Corp MI** See ad on page 85  
 Penn Tool Co NJ

**Diamond Drills**

Diamond Industrial Tools Inc IL  
 Dianamic Abrasive Products Inc MI  
 Greenlee Diamond Tool Co IL  
 Mitsubishi Materials Corporation Japan

**Diamond Hones**

Diamond Industrial Tools Inc IL  
 Dianamic Abrasive Products Inc MI  
 Engis Corp IL  
 Greenlee Diamond Tool Co IL  
 Saint-Gobain Abrasives MA  
 Stahl USA Inc WI

**Diamond Saw Blades**

Allied High Tech Products Inc CA  
 Aremco Products Inc NY  
 Comtrust Architectural Mesh Co Ltd China  
 Diacut Inc CO  
 Diamond Industrial Tools Inc IL  
 Dianamic Abrasive Products Inc MI  
 Dynacut Inc PA  
 Engis Corp IL  
 Greenlee Diamond Tool Co IL  
 LECO Corp MI  
 Liberty Machinery Co IL  
 Saint-Gobain Abrasives MA  
 Texers Technical Ceramics Inc Canada

**Diamond Saws**

Allied High Tech Products Inc CA  
 Aremco Products Inc NY  
 Capovani Brothers Inc NY  
 Diacut Inc CO  
 Dynacut Inc PA  
 Greenlee Diamond Tool Co IL  
 Liberty Machinery Co IL

**Diamond Tools**

Diamond Industrial Tools Inc IL  
 Dianamic Abrasive Products Inc MI  
 Engis Corp IL  
 Greenlee Diamond Tool Co IL  
 LECO Corp MI  
 Mitsubishi Materials Corporation Japan  
 Penn Tool Co NJ  
 Saint-Gobain Abrasives MA  
 Sigmadiamant Spain

**Dicing Equipment**

Aremco Products Inc NY  
 Capovani Brothers Inc NY  
 Diacut Inc CO

Diamond Industrial Tools Inc IL  
 Dynacut Inc PA  
 Liberty Machinery Co IL

**Dies**

**Gasbarre Products Inc PA** See ad on page 95  
 Ram Products Inc OH

**Dressing Wheels, Diamond**

Diacut Inc CO  
 Diamond Industrial Tools Inc IL  
 Dianamic Abrasive Products Inc MI  
 Dynacut Inc PA  
 Engis Corp IL  
 Greenlee Diamond Tool Co IL

**Electroplating Equipment**

Haiku Tech Inc FL  
 Liberty Machinery Co IL  
 Penn Tool Co NJ

**Extruders**

Aadvanced Machinery Inc MI  
 American Art Clay Co Inc IN  
 Basic Machinery Co Inc NC  
 Detroit Process Machinery MI  
 Dorst America Inc PA  
 Ipsen Ceramics IL  
 Laguna Clay Co CA  
**Mohr Corp MI** See ad on page 85  
 North Star Equipment Inc WA  
 Peter Puggger Mfg Inc CA

**Feeders**

**Ingredient Masters Inc OH** See ad on page 101  
 Isoform Ltd UK  
**Mohr Corp MI** See ad on page 85  
 Wyssmont Co NJ

**Forming Equipment**

American Isostatic Presses OH  
 ARBURG GmbH + Co KG Germany  
 Dorst America Inc PA  
 HED INTl Inc NJ  
 Ipsen Ceramics IL  
 Isoform Ltd UK  
 Lithoz GmbH NY  
**Mohr Corp MI** See ad on page 85  
 Quintus Technologies LLC OH  
 Ram Products Inc OH

**Glass Finishing Equipment**

General Glass Equipment Co NJ  
 Liberty Machinery Co IL  
 Lithoz GmbH NY



**OptiPro Systems LLC NY** See ad on page 93

**Glass Forming Equipment**

General Glass Equipment Co NJ

**Glass Shear Spray**

RISE Research Institutes of Sweden RISE Glass Sweden

**Glass Supplies**

Ipsen Ceramics IL

**Grinders, Centerless**

Diamond Industrial Tools Inc IL  
 Liberty Machinery Co IL  
 Precision Ferrites and Ceramics Inc CA  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China

**Grinders, Cylindrical**

Diamond Industrial Tools Inc IL  
 Liberty Machinery Co IL  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China

**Grinders, Finished Product**

DCM Tech MN  
 Ipsen Ceramics IL  
 Liberty Machinery Co IL  
**OptiPro Systems LLC NY** See ad on page 93  
 Stahli USA Inc WI

**Grinding Wheels**

Allied High Tech Products Inc CA  
 Diacut Inc CO  
 Diamond Industrial Tools Inc IL  
 Dynacut Inc PA  
 Engis Corp IL  
 Greenlee Diamond Tool Co IL  
 Penn Tool Co NJ  
 Sigmadiamant Spain  
 Stahli USA Inc WI

**Hydraulic Systems**

Isoform Ltd UK  
 Ram Products Inc OH

**Injection-Molding Equipment**

ARBURG GmbH + Co KG Germany  
 Goceram AB Sweden

**Mohr Corp MI**

Rockwell Automation Inc WI  
 Suntech Advanced Ceramics (Shenzhen) Co Ltd China

**Jigging Equipment**

Cerinnov France  
 Ram Products Inc OH

**Lapping Equipment**

Allied High Tech Products Inc CA  
 Capovani Brothers Inc NY  
 Diamond Industrial Tools Inc IL  
 Dynacut Inc PA  
 Engis Corp IL  
 Liberty Machinery Co IL  
**OptiPro Systems LLC NY** See ad on page 93  
 Sigmadiamant Spain  
 Stahli USA Inc WI

**Lapping Supplies**

Allied High Tech Products Inc CA  
 Diamond Industrial Tools Inc IL  
 Dunhua Zhengxing Abrasive Co Ltd China  
 Engis Corp IL  
 FELDCO Intl CA  
 Stahli USA Inc WI

**Laser Scrubbers**

Centerline Technologies MA  
 Cerlase France  
 Laserage Technology Corp IL

**Machining Equipment**

Dynacut Inc PA  
 Ferro Ceramic Grinding Inc MA  
 International Ceramic Engineering MA  
 Liberty Machinery Co IL

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 Hole dia: 0.8mm

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 www.optipro.com/optisonic

**OptiPro Systems LLC NY**  
Penn Tool Co NJ  
Stahli USA Inc WI

See ad on page 93

**Mandrels, Diamond**

Diacut Inc CO  
Diamond Industrial Tools Inc IL  
Dianamic Abrasive Products Inc MI  
Engis Corp IL  
Greenlee Diamond Tool Co IL

**Molds, Case**

Petro Mold Company PA  
Ram Products Inc OH

**Molds, Ceramic-Forming**

Akron Porcelain & Plastics Co OH  
Cerinnov France  
Cerlase France  
Goceram AB Sweden  
Ipsen Ceramics IL  
Isoform Ltd UK  
Laeis GmbH Luxembourg  
Laguna Clay Co CA  
Petro Mold Company PA  
Ram Products Inc OH  
Viridis3D LLC MA

**Molds, Models**

Petro Mold Company PA  
Ram Products Inc OH  
Viridis3D LLC MA

**Plasma Etching Systems**

Advanced Energy CO  
Capovani Brothers Inc NY  
Liberty Machinery Co IL

**Pneumatic Systems**

Cyclonaire Corp NE  
**Ingredient Masters Inc OH**  
Ram Products Inc OH  
Young Industries Inc PA

See ad on page 101

**Polishing Equipment**

Allied High Tech Products Inc CA  
Capovani Brothers Inc NY  
Diamond Industrial Tools Inc IL  
Dynacut Inc PA  
Engis Corp IL  
LECO Corp MI  
Liberty Machinery Co IL  
**OptiPro Systems LLC NY**  
Penn Tool Co NJ  
Sigmadiamant Spain  
Stahli USA Inc WI

See ad on page 93

**Polishing Powder & Supplies**

Baikowski Malakoff Inc NC  
C&L Development Corp CA  
Dianamic Abrasive Products Inc MI  
Engis Corp IL  
Sigmadiamant Spain  
Stahli USA Inc WI

**Presses, Compacting**

Detroit Process Machinery MI  
Digital Press Inc PA  
Dorst America Inc PA  
**Gasbarre Products (PTX Pentronix) PA**

See ad on page 95



**Gasbarre Products Inc PA** See ad on page 95  
**Mohr Corp MI** See ad on page 85  
Quintus Technologies LLC OH



**Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD** See ad on page 83

**Presses, Dry**

Advanced Machinery Inc MI  
Dorst America Inc PA  
**Gasbarre Products Inc PA** See ad on page 95  
Maryland Ceramic & Steatite Co Inc MD  
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

**Presses, Extrusion**

Dorst America Inc PA  
Maryland Ceramic & Steatite Co Inc MD  
**Mohr Corp MI** See ad on page 85  
Peter Puggler Mfg Inc CA

**Presses, Hot**

American Isostatic Presses OH  
Centorr Vacuum Industries NH  
FCT Ingenieurkeramik GmbH Germany  
FCT Systeme GmbH Germany  
Materials Research Furnaces Inc NH  
**Oxy-Gon Industries Inc NH** See ad on page 89  
Refrac Systems AZ

**Presses, Hot Isostatic**

American Isostatic Presses OH  
AVS Inc MA  
FCT Ingenieurkeramik GmbH Germany  
Quintus Technologies LLC OH

**Presses, Hydraulic**

Advanced Machinery Inc MI  
ARBURG GmbH + Co KG Germany  
AVS Inc MA  
Capovani Brothers Inc NY  
Digital Press Inc PA  
Dorst America Inc PA  
**Gasbarre Products Inc PA** See ad on page 95  
Laeis GmbH Luxembourg  
Materials Research Furnaces Inc NH  
**Mohr Corp MI** See ad on page 85  
Ram Products Inc OH

**Presses, Isostatic**

Advanced Machinery Inc MI  
American Isostatic Presses OH  
Capovani Brothers Inc NY  
Cerinnov France  
Cerlase France  
Detroit Process Machinery MI  
Dorst America Inc PA  
**Gasbarre Products (PTX Pentronix) PA** See ad on page 95



**Gasbarre Products Inc PA** See ad on page 95  
Haiku Tech Europe BV The Netherlands  
Haiku Tech Inc FL  
Isoform Ltd UK  
**Mohr Corp MI** See ad on page 85  
Quintus Technologies LLC OH  
RocCera LLC NY  
Suntech Advanced Ceramics (Shenzhen) Co Ltd China

**Presses, Other**

ARBURG GmbH + Co KG Germany  
Isoform Ltd UK

**Presses, Pressure Casting**

Cerlase France  
Dorst America Inc PA  
Peter Puggler Mfg Inc CA  
Ram Products Inc OH

**Presses, Refractory Shapes**

Laeis GmbH Luxembourg

**Presses, Rotary**

Advanced Machinery Inc MI

**Presses, Rotary**

Materials Research Furnaces Inc NH

**Presses, Tile (Ceramic)**

Laeis GmbH Luxembourg  
Peter Puggler Mfg Inc CA

**Pug Mills**

Advanced Machinery Inc MI  
Basic Machinery Co Inc NC  
Dorst America Inc PA  
**Mohr Corp MI** See ad on page 85  
Peter Puggler Mfg Inc CA  
Sheffield Pottery MA  
Young Industries Inc PA

**PVD Equipment**

Capovani Brothers Inc NY  
Liberty Machinery Co IL  
Teeter Marketing Services LLC FL

**Roofing Tile Machinery**

Laeis GmbH Luxembourg

**Setting Equipment**

Basic Machinery Co Inc NC

**Slab Rollers**

North Star Equipment Inc WA

**Spray Booths**

Treibacher Industrie AG Austria

**Sputtering Equipment**

Advanced Energy CO  
Capovani Brothers Inc NY  
FCT Ingenieurkeramik GmbH Germany

**Superabrasives**

Diamond Industrial Tools Inc IL  
Dynacut Inc PA

Engis Corp IL  
Greenlee Diamond Tool Co IL  
Liberty Machinery Co IL  
Teeter Marketing Services LLC FL

### Surface Modification Systems

Teeter Marketing Services LLC FL

### Tilemaking Equipment

Basic Machinery Co Inc NC  
Peter Pugger Mfg Inc CA  
Ram Products Inc OH

### Tools, Modeling

Sheffield Pottery MA  
Viridis3D LLC MA

### Turning Machines, Insulator

Liberty Machinery Co IL

### Ultrasonic Machining Equipment

Bullen OH  
International Ceramic Engineering MA  
Liberty Machinery Co IL



OptiPro Systems LLC NY

See ad on page 93

### Used Equipment

Aadvanced Machinery Inc MI  
Basic Machinery Co Inc NC  
Capovani Brothers Inc NY  
Cerinnov France  
Diamond Industrial Tools Inc IL  
Dorst America Inc PA  
Dynacut Inc PA  
Liberty Machinery Co IL  
**Mohr Corp MI**  
Ram Products Inc OH  
Viridis3D LLC MA

See ad on page 85

### Vibratory Finishing Equipment

Capovani Brothers Inc NY  
Liberty Machinery Co IL  
Penn Tool Co NJ  
Rockwell Automation Inc WI

### Weighing/Scales

Optimation - Klug Systems NY

### Wheels, Cutoff & Grinding

Diacut Inc CO  
Diamond Industrial Tools Inc IL  
Dianamic Abrasive Products Inc MI  
Dynacut Inc PA  
Engis Corp IL  
Greenlee Diamond Tool Co IL  
LECO Corp MI  
Liberty Machinery Co IL  
Penn Tool Co NJ

### Wheels, Diamond

Aremco Products Inc NY  
Diacut Inc CO  
Diamond Industrial Tools Inc IL  
Dianamic Abrasive Products Inc MI  
Dynacut Inc PA

Engis Corp IL  
Greenlee Diamond Tool Co IL  
LECO Corp MI  
Sigmadiamant Spain  
Stahli USA Inc WI

## GLASS PRODUCTS

### Automotive Glass

Arkema Inc PA  
RISE Research Institutes of Sweden RISE Glass Sweden  
Saint-Gobain Recherche France  
Schott North America Inc NY

### Beads/Spheres

Bekeson Glass LLC MS  
Ceradyne Inc a 3M Co KY  
Maryland Ceramic & Steatite Co Inc MD



Mo-Sci Corp MO

See ad on page 97

### Bioglass

Ceradyne Inc a 3M Co KY  
Matexcel NY



Mo-Sci Corp MO

See ad on page 97

RISE Research Institutes of Sweden RISE Glass Sweden  
Specialty Glass Inc FL

### Borosilicate Glass

Bekeson Glass LLC MS  
Bullen OH  
Elan Technology GA  
Garg Process Glass India Pvt Ltd India  
RISE Research Institutes of Sweden RISE Glass Sweden  
Schott North America Inc NY  
Specialty Glass Inc FL  
Valley Design Corp MA

### Chemically Strengthened Glass

Arkema Inc PA  
Garg Process Glass India Pvt Ltd India  
RISE Research Institutes of Sweden RISE Glass Sweden  
Saint-Gobain Recherche France  
Saxon Glass Technologies Inc NY  
Schott North America Inc NY  
Vesuvius SC

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 Cerinnox France  
 Owens-Illinois Inc OH  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Saint-Gobain Recherche France  
 Vesuvius SC

**Fibers, Continuous**

Saint-Gobain Recherche France  
 Verity Technical Consultants LLC OH

**Fibers, Optical**

Adamant Co Ltd Japan  
 Corning Incorporated NY  
 Optocon AG Germany  
 Schott North America Inc NY

**Flat & Safety Glass**

Arkema Inc PA  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Saint-Gobain Recherche France  
 Vesuvius SC

**Fused Silica Glass**

Accuratus Corp NJ  
 Arkema Inc PA  
 Bullen OH  
 Ferro Ceramic Grinding Inc MA  
 Imerys Refractory Minerals GA  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Valley Design Corp MA

**Glass-Ceramics**

Accuratus Corp NJ  
 Advanced Ceramic Technology CA  
 Arkema Inc PA  
 Bekeson Glass LLC MS  
 Bullen OH  
 Certase France  
 Elan Technology GA  
 Ivoclar Vivadent Inc Principality of Liechtenstein  
 Petro Mold Company PA  
 PremaTech Advanced Ceramics MA  
 Schott North America Inc NY  
 Specialty Glass Inc FL  
 StudioLX - Home Decor IL  
**TevTech LLC MA** See ad on page 99  
 Texers Technical Ceramics Inc Canada  
 Valley Design Corp MA  
 Xiamen Innovacera Advanced Materials Co Ltd China

**Glass-to-Metal Seals**

Bekeson Glass LLC MS  
 Elan Technology GA  
 ESL ElectroScience PA  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Schott North America Inc NY  
 Specialty Glass Inc FL

**Laboratory & Technical Glass**

Arkema Inc PA  
 Garg Process Glass India Pvt Ltd India  
 LECO Corp MI  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Saxon Glass Technologies Inc NY  
 Schott North America Inc NY  
 Specialty Glass Inc FL  
**TevTech LLC MA** See ad on page 99

**Laminated Glass**

Arkema Inc PA  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Vesuvius SC

**Laser Glasses**

Cerinnox France  
 Israel Ceramic & Silicate Inst Israel  
 RISE Research Institutes of Sweden RISE Glass Sweden

**Lenses**

**TevTech LLC MA** See ad on page 99

**Lighting**

Osram Sylvania Inc MA

**Manufacturing**

Bekeson Glass LLC MS

**Mirrors**

Valley Design Corp MA

**Optical & Optoelectronic Ceramics**

NEVZ-Ceramics Close JSC Russia  
 Specialty Glass Inc FL  
**TevTech LLC MA** See ad on page 99  
 Vesuvius SC

**Optical Substrates**

Bullen OH  
 FELDCO Intl CA  
 Schott North America Inc NY  
 Specialty Glass Inc FL  
 Valley Design Corp MA  
 Vesuvius SC

**Optical Thin Films**

Agostyx OR  
 FELDCO Intl CA  
 Schott North America Inc NY  
**TevTech LLC MA** See ad on page 99

**Solar**

Ceradyne Inc a 3M Co KY  
 FELDCO Intl CA  
**TevTech LLC MA** See ad on page 99  
 Texers Technical Ceramics Inc Canada  
 Vesuvius SC

**Specialty Glass**

Bekeson Glass LLC MS  
 Ceradyne Inc a 3M Co KY  
 Corning Incorporated NY  
 Fusion Ceramics Inc OH  
 Garg Process Glass India Pvt Ltd India  
 Israel Ceramic & Silicate Inst Israel  
 Keeling & Walker Ltd UK  
 Refrac Systems AZ  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Saint-Gobain Recherche France  
 Saxon Glass Technologies Inc NY  
 Schott North America Inc NY  
 Specialty Glass Inc FL  
 Vesuvius SC

**Technical Glass**

Bekeson Glass LLC MS  
 Ceradyne Inc a 3M Co KY  
 Elan Technology GA  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Saxon Glass Technologies Inc NY  
 Schott North America Inc NY  
 Specialty Glass Inc FL  
 Vesuvius SC

**Tubing & Rod**

**AdValue Technology LLC AZ** See ad on page 67  
 Garg Process Glass India Pvt Ltd India  
 Morgan Advanced Materials CA  
 Specialty Glass Inc FL

**LABORATORY EQUIPMENT & SUPPLIES****Chemicals**

Agostyx OR  
 Arkema Inc PA  
 Bayville Chemical Supply Co Inc NY  
 Lubrizol Performance Coating OH  
 Nanofilm OH  
 RocCera LLC NY

**Colorimeters**

HunterLab VA

**Density Measurement Instruments**

Hitachi High-Tech America Inc MD  
 Micromeritics Instrument Corp GA  
 Particle Technology Labs IL  
 Penn Tool Co NJ  
 Quantachrome Instruments FL  
 RocCera LLC NY

**Detectors**

Control Instruments Corp NJ  
 Penn Tool Co NJ  
 Rockwell Automation Inc WI  
 Siemens Process Industries and Drives GA

**Dimension Measurement Instruments**

CSC Force Measurement Inc MA  
 Penn Tool Co NJ

**Dryers**

Applied Test Systems Inc PA  
 B&P Littleford MI  
 Ceramic Services Inc PA  
 Cober Muegge LLC CT  
 Detroit Process Machinery MI  
 EIRICH Machines Inc IL  
 Goceram AB Sweden  
 Recco Furnaces CA  
 Wyssmont Co NJ

**Fiberoptic Illuminators**

Carl Zeiss Microimaging Inc NY

**Glass Testing Instruments**

**Mo-Sci Corp MO** See ad on page 97  
 RISE Research Institutes of Sweden RISE Glass Sweden  
 Taber Industries NY

**Glassware**

**AdValue Technology LLC AZ** See ad on page 67  
 Garg Process Glass India Pvt Ltd India  
 RISE Research Institutes of Sweden RISE Glass Sweden

**Glossimeters**

Horiba Instruments Inc CA

**Hardness Measurement Instruments**

Allied High Tech Products Inc CA  
 Buehler Ltd IL  
 Carl Zeiss Microimaging Inc NY  
 LECO Corp MI  
 Nanoscience Instruments AZ  
 Penn Tool Co NJ  
 Taber Industries NY

**Hot Plates**

RocCera LLC NY  
 Zhengzhou Mission Ceramic Products Co Ltd China

**Lab Crucibles**

**AdValue Technology LLC AZ** See ad on page 67  
 Ceramco Inc NH

CoorsTek CO  
 Materion Ceramics AZ  
 McDanel Advanced Ceramic Technologies LLC PA  
 Robocasting Enterprises LLC NM  
 Xiamen Innovacera Advanced Materials Co Ltd China  
 Zhengzhou Mission Ceramic Products Co Ltd China

#### Lab Furnace Tubes

**AdValue Technology LLC AZ** See ad on page 67  
 Carbolite Gero UK  
 McDanel Advanced Ceramic Technologies LLC PA  
 Nabertherm Inc DE  
 Xiamen Innovacera Advanced Materials Co Ltd China  
 Zhengzhou Mission Ceramic Products Co Ltd China

#### Lab Furnaces

Aadvanced Machinery Inc MI  
 American Isostatic Presses OH  
 Applied Test Systems Inc PA  
 AVS Inc MA  
 Carbolite Gero UK



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[www.centorr.com](http://www.centorr.com)

**Centorr Vacuum Industries NH** See ad on page 87  
 Ceramic Services Inc PA  
 CM Furnaces Inc NJ  
 CSC Force Measurement Inc MA  
**Deltech Inc (Deltech Furnaces) CO** Inside front cover  
 Detroit Process Machinery MI  
**Centorr Vacuum Industries NH** See ad on page 87  
 Lucifer Furnaces Inc PA  
 Materials Research Furnaces Inc NH  
 Nabertherm Inc DE  
**Oxy-Gon Industries Inc NH** See ad on page 89  
 Paragon Industries LP TX  
 RD Webb Company Inc MA



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**TevTech LLC MA** See ad on page 99  
 The Furnace Source LLC CT  
 Thermcraft Inc NC  
 Trent Inc PA  
 Verder Scientific Inc PA  
 Zhengzhou Mission Ceramic Products Co Ltd China

#### Light Sources

Allied High Tech Products Inc CA  
 Carl Zeiss Microimaging Inc NY  
 Spectronics Corp NY

#### Mechanical Property Measurement Instruments

Applied Test Systems Inc PA  
 Buehler Ltd IL  
 BuzzMac Intl LLC ME  
 CSC Force Measurement Inc MA  
 Nanoscience Instruments AZ  
 TA Instruments DE  
 Taber Industries NY

#### Microscopes, Hot Stages

Carl Zeiss Microimaging Inc NY  
 Dalmia Inst of Scientific & Industrial Research India  
 TA Instruments DE

#### Microscopes, Interference

Buehler Ltd IL  
 Carl Zeiss Microimaging Inc NY

#### Microscopes, Other

**AdValue Technology LLC AZ** See ad on page 67  
 Allied High Tech Products Inc CA  
 Carl Zeiss Microimaging Inc NY  
 Nanoscience Instruments AZ  
 TA Instruments DE

#### Microscopes, Polarizing

Buehler Ltd IL  
 Carl Zeiss Microimaging Inc NY  
 JTF Microscopy Services LLC NY

#### Microscopes, Reflected Light

Allied High Tech Products Inc CA  
 Buehler Ltd IL  
 Carl Zeiss Microimaging Inc NY  
 LECO Corp MI

#### Microscopes, Scanning Electron

Hitachi High-Tech America Inc MD  
 Nanoscience Instruments AZ  
 SEMTech Solutions Inc MA

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**Mixers, Vacuum**

Applicon Co IN  
EIRICH Machines Inc IL  
Netzsch Premier Technologies LLC PA  
Peter Pugger Mfg Inc CA

**Mixing Equipment**

Advanced Machinery Inc MI  
B&P Littleford MI  
Carolina Material Technologies NC  
Custom Processing Services PA  
Detroit Process Machinery MI  
EIRICH Machines Inc IL  
ER Advanced Ceramics Inc OH  
General Glass Equipment Co NJ

**Glen Mills Inc NJ** See ad on page 105

Goceram AB Sweden  
Hockmeyer Equipment Corp NC  
Laguna Clay Co CA

Lancaster Products PA  
Mixer Systems Inc WI

**Mohr Corp MI** See ad on page 85

Netzsch Premier Technologies LLC PA  
OPF Enterprises TX  
Peter Pugger Mfg Inc CA  
Resodyn Acoustic Mixers Inc MT  
Young Industries Inc PA

**Nozzles**

CerCo LLC OH  
Dunhua Zhengxing Abrasive Co Ltd China  
Maryland Ceramic & Steatite Co Inc MD

**Packaging & Packaging Equipment**

Basic Machinery Co Inc NC

Tempo Plastic CA

**Pneumatic Systems**

Applicon Co IN  
Carolina Material Technologies NC  
Cyclonaire Corp NE  
Nol-Tec Systems Inc MN  
Reed Gunite & Shotcrete Equipment CA  
Velco GmbH Germany  
Young Industries Inc PA

**Process Control Equipment**

Control Instruments Corp NJ  
 Datapaq Inc NH  
 General Glass Equipment Co NJ  
**Ingredient Masters Inc OH** See ad on page 101  
 McGill AirClean OH  
 Nol-Tec Systems Inc MN  
 Norcross Viscosity Controls MI  
 Optimization - Klug Systems NY  
 Ram Products Inc OH  
 Rockwell Automation Inc WI  
 Siemens Process Industries and Drives GA

**Pulverizers**

Aadvanced Machinery Inc MI  
 Applicon Co IN  
 Basic Machinery Co Inc NC  
 Fritsch GmbH - Milling and Sizing Germany  
 Fritsch Milling & Sizing Inc NC  
**Glen Mills Inc NJ** See ad on page 105  
 Mixer Systems Inc WI  
 Stedman Machine Co IN  
 Williams Patent Crusher & Pulverizer Co Inc MO  
 Wyssmont Co NJ

**Pumps**

ER Advanced Ceramics Inc OH  
 Ram Products Inc OH  
 Reed Gunitite & Shotcrete Equipment CA

**Pumps, Concrete**

Reed Gunitite & Shotcrete Equipment CA

**Scale Systems**

CSC Force Measurement Inc MA  
 Mettler-Toledo Inc OH  
 Nol-Tec Systems Inc MN  
 Optimization - Klug Systems NY

**Screens & Screening Equipment**

Aadvanced Machinery Inc MI  
 Basic Machinery Co Inc NC  
 Cleveland Vibrator Co OH  
 Control Instruments Corp NJ  
 Detroit Process Machinery MI  
 Fritsch GmbH - Milling and Sizing Germany  
 Fritsch Milling & Sizing Inc NC  
**Glen Mills Inc NJ** See ad on page 105  
 JADCO Manufacturing, Inc PA  
 Midwestern Industries Inc OH  
**Mohr Corp MI** See ad on page 85  
 Siccio Engineering Works India

**Separators**

Fritsch GmbH - Milling and Sizing Germany  
 Midwestern Industries Inc OH  
 Williams Patent Crusher & Pulverizer Co Inc MO

**Shredders**

Basic Machinery Co Inc NC  
 Fritsch GmbH - Milling and Sizing Germany  
**Glen Mills Inc NJ** See ad on page 105  
 Stedman Machine Co IN  
 Williams Patent Crusher & Pulverizer Co Inc MO

**Single-Wafer Packs**

Tempo Plastic CA

**Size Reduction Equipment**

AVEKA MN  
 Basic Machinery Co Inc NC  
 Custom Processing Services PA  
 EIRICH Machines Inc IL  
 ER Advanced Ceramics Inc OH  
 Fluid Energy Processing & Equipment Co PA

Fritsch GmbH - Milling and Sizing Germany  
**Glen Mills Inc NJ** See ad on page 105  
 Lancaster Products PA  
 Netzsch Premier Technologies LLC PA  
 Raymond Bartlett Snow-Schneck Processing IL  
 Stedman Machine Co IN  
 Union Process OH  
 Williams Patent Crusher & Pulverizer Co Inc MO  
 Wyssmont Co NJ

**Spray Dryers**

Aadvanced Machinery Inc MI  
 Arch Maintenance Services GA  
 AVEKA MN  
 Detroit Process Machinery MI  
 Dorst America Inc PA  
 Eian Technology GA  
 Euro Support Advanced Materials The Netherlands  
**Mohr Corp MI** See ad on page 85  
 Spray Drying Systems Inc MD

**Storage Equipment**

Basic Machinery Co Inc NC

**Storage Equipment**

Cyclonaire Corp NE

**Substrate Wafer Trays**

Tempo Plastic CA

**Used Equipment**

Aadvanced Machinery Inc MI  
 American Isostatic Presses OH  
 Detroit Process Machinery MI  
 Dorst America Inc PA



**Mohr Corporation**  
 Ceramic Machinery and Factory Liquidations  
 www.mohrcorp.com

**Mohr Corp MI** See ad on page 85  
 Reed Gunitite & Shotcrete Equipment CA

**Vacuum Cleaning Systems**

Carolina Material Technologies NC

**Ventilating Equipment**

American Art Clay Co Inc IN

**Vibrators**

Carolina Material Technologies NC  
 Cleveland Vibrator Co OH  
 Optimization - Klug Systems NY  
 Rockwell Automation Inc WI

**Vibrators, Bin**

Carolina Material Technologies NC  
 Cleveland Vibrator Co OH  
 Cyclonaire Corp NE

**Weighing Equipment**

Carolina Material Technologies NC  
 CSC Force Measurement Inc MA  
 Cyclonaire Corp NE  
 Mettler-Toledo Inc OH  
 Nol-Tec Systems Inc MN  
 Optimization - Klug Systems NY  
 Rockwell Automation Inc WI  
 Siemens Process Industries and Drives GA

**Weighing/Scales**

Optimization - Klug Systems NY

**Wire Cloth**

Midwestern Industries Inc OH

**PLANT CONSTRUCTION, DESIGN & ENGINEERING**

**Brick Production**

Basic Machinery Co Inc NC  
 Laeis GmbH Luxembourg  
 Swindell Dressler Intl Co PA

**Casting Plants**

Dorst America Inc PA  
 ER Advanced Ceramics Inc OH

**Ceramic Production**

Agostyx OR  
 Cerinnov France  
 Cerlase France  
 GrainBound LLC PA  
 Lucideon UK  
 Maryland Ceramic & Steatite Co Inc MD  
 Riedhammer GmbH Germany  
**Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD** See ad on page 83  
 Viridis3D LLC MA

**Combustion Systems**

Air Products PA  
 Swindell Dressler Intl Co PA

**Decals & Decorating**

Cerinnov France  
 Cerlase France  
 Gwent Electronic Materials Ltd UK

**Drying & Firing**

Basic Machinery Co Inc NC  
 Ceramic Services Inc PA



**Harrop Industries Inc OH** See ad on page 58  
 Swindell Dressler Intl Co PA  
 Wistra GmbH Germany

**Electronic Materials Production**

Haiku Tech Europe BV The Netherlands  
 Haiku Tech Inc FL  
**Trans-Tech Inc a subsidiary of Skyworks Solutions Inc MD** See ad on page 83

**Environmental Control**

Cyclonaire Corp NE  
 Mixer Systems Inc WI  
 Nol-Tec Systems Inc MN  
 RoboVent MI  
 Rockwell Automation Inc WI  
 Saint-Gobain NorPro OH  
 Tri-Mer Corp MI

**Fabrication Shops**

Maryland Ceramic & Steatite Co Inc MD

**Glass Production**

CelSian Glass & Solar BV The Netherlands  
 General Glass Equipment Co NJ  
 Optimization - Klug Systems NY

RISE Research Institutes of Sweden RISE Glass Sweden  
Schott North America Inc NY  
Tri-Mer Corp MI

### Inspection Systems

CSC Force Measurement Inc MA  
Fosbel Inc OH  
Rockwell Automation Inc WI  
Siemens Process Industries and Drives GA

### Laboratories

Activation Laboratories Ltd Canada

### Optical-Fiber Production

Ocean Optics Inc FL

### Refractory Production

ER Advanced Ceramics Inc OH  
Fosbel Inc OH  
Laeis GmbH Luxembourg  
Laguna Clay Co CA  
Swindell Dressler Intl Co PA

### Structural Ceramics Production

CerCo LLC OH  
Maryland Ceramic & Steatite Co Inc MD  
Swindell Dressler Intl Co PA  
Takasago Industry Co Ltd Japan  
**TeVtech LLC MA**

See ad on page 99

### Tile Production

Laeis GmbH Luxembourg  
LIXIL Corporation Japan  
Peter Pugger Mfg Inc CA

### Whiteware Production

LIXIL Corporation Japan  
Ram Products Inc OH  
Swindell Dressler Intl Co PA

## ■ PORCELAIN ENAMEL

### Appliances

Roca Sanitario SA Spain  
Zenith China

### Architectural Units

Roca Sanitario SA Spain  
Zenith China

### Ceramic Coatings, Thermal Protection

Agostyx OR  
Cerinnov France  
Cerlase France  
**Trans-Tech Inc a subsidiary of  
Skyworks Solutions Inc MD**  
Zenith China

See ad on page 83

### Porcelain

Riedhammer GmbH Germany

## ■ REFRACTORIES

### Acid

Allied Mineral Products Inc OH  
Magneco Metrel Inc IL  
Pacific Refractories Ltd India  
Vitcas Ltd UK

### Aggregate

Christy Minerals LLC MO  
Furnace Products & Services Inc PA  
Magneco Metrel Inc IL  
Maryland Refractories Co OH

## Alumina

Advanced Ceramic Technology CA  
Allied Mineral Products Inc OH  
Associated Ceramics & Technology Inc PA  
Astral Material Industrial Co Ltd China  
Baikowski Malakoff Inc NC  
Bucher Emhart Glass SA Switzerland  
Ceramco Inc NH  
CeramTec-EETEC Germany  
Dalmia Inst of Scientific & Industrial Research India  
Du-Co Ceramics Company PA  
Elcon Precision LLC CA  
ER Advanced Ceramics Inc OH  
Fosbel Inc OH  
General Material Industrial Co China  
GrainBound LLC PA  
IPS Ceramics LTD UK  
Ipsen Ceramics IL  
Magneco Metrel Inc IL  
Maryland Refractories Co OH  
Materion Ceramics AZ  
Pacific Refractories Ltd India  
Plibrico Company IL  
Precision Ferrites and Ceramics Inc CA  
Rath Inc DE  
Refractory Minerals Co Inc PA  
RHI US Ltd NY  
Riverside Refractories Inc-Allied Mineral Products AL  
Selee Corp NC  
Sunrock Ceramics Co IL  
Texers Technical Ceramics Inc Canada  
Wistra GmbH Germany  
Xiamen Innovacera Advanced Materials Co Ltd China  
Zircar Refractory Composites Inc NY

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### Anchors

Associated Ceramics & Technology Inc PA  
Magneco Metrel Inc IL

### Arches, Suspended

Fosbel Inc OH  
Ipsen Ceramics IL  
Merkle International Inc IL

### AZS

Bucher Emhart Glass SA Switzerland  
Fosbel Inc OH  
Magneco Metrel Inc IL  
Monofrax LLC NY  
RHI US Ltd NY

### Backwalls

Fosbel Inc OH  
Merkle International Inc IL

### Basic

Allied Mineral Products Inc OH  
Furnace Products & Services Inc PA  
Magneco Metrel Inc IL  
RHI US Ltd NY

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**Blankets**

Associated Ceramics & Technology Inc PA  
Morgan Thermal Ceramics GA  
RHI US Ltd NY  
Thermal Products Co Inc GA  
Unifrax I LLC NY  
Zircar Refractory Composites Inc NY

**Boards**

Agni Fiber Boards Pvt Ltd India  
Morgan Thermal Ceramics GA  
RHI US Ltd NY  
Saint-Gobain Ceramics & Plastics MA  
Thermal Products Co Inc NY  
Unifrax I LLC NY



Zircar Ceramics Inc NY  
Zircar Refractory Composites Inc NY

**Brick**

APF Recycling Inc OH  
Cancarb Limited Canada  
General Material Industrial Co China  
HarbisonWalker Intl PA  
IFB Insulating Firebrick Inc PA  
Morgan Thermal Ceramics GA  
Pacific Refractories Ltd India  
RHI US Ltd NY  
Sunrock Ceramics Co IL  
Wistra GmbH Germany

**Brick, Acid-Resisting**

Pacific Refractories Ltd India  
Vitcas Ltd UK

**Brick, Fireclay**

Allied Mineral Products Inc OH  
Alsey Refractories Co MO  
Pacific Refractories Ltd India  
RHI US Ltd NY  
Vitcas Ltd UK

**Carbon**

Astral Material Industrial Co Ltd China  
Cancarb Limited Canada  
Pacific Refractories Ltd India  
Riedhammer GmbH Germany

**Castable**

Allied Mineral Products Inc OH  
Alsey Refractories Co MO  
Aremco Products Inc NY  
Cancarb Limited Canada  
Capital Refractories Ltd UK  
Furnace Products & Services Inc PA  
HarbisonWalker Intl PA  
Industrial Ceramic Products Inc OH  
Magneco Metrel Inc IL  
Pacific Refractories Ltd India  
Plibrico Company IL  
Plibrico Japan Co Ltd Japan  
Reno Refractories Inc AL  
RHI US Ltd NY  
Riverside Refractories Inc--Allied Mineral Products AL  
Selee Corp NC  
Vitcas Ltd UK  
Zircar Refractory Composites Inc NY

**Cements**

Allied Mineral Products Inc OH  
Aremco Products Inc NY  
Capital Refractories Ltd UK  
Dalmia Inst of Scientific & Industrial Research India  
Furnace Products & Services Inc PA

**Gorka Cement Poland**

See ad on page 107

Kerneos Inc VA  
Plibrico Company IL  
Reno Refractories Inc AL  
Unifrax I LLC NY  
Vitcas Ltd UK

**Clay Flux**

Furnace Products & Services Inc PA  
Peter Puggler Mfg Inc CA  
RHI US Ltd NY

**Coatings**

Allied Mineral Products Inc OH  
Aremco Products Inc NY  
Elcon Precision LLC CA  
Fosbel Inc OH  
Furnace Products & Services Inc PA  
Fusion Ceramics Inc OH  
Gwent Electronic Materials Ltd UK  
Induceramic Canada  
Magneco Metrel Inc IL  
Plibrico Japan Co Ltd Japan  
Rath Inc DE  
Riverside Refractories Inc--Allied Mineral Products AL  
Starfire Systems Inc NY  
Thermal Products Co Inc GA  
Unifrax I LLC NY  
Vitcas Ltd UK  
Zibo Guangtong Chemical Co Ltd China  
Zircar Refractory Composites Inc NY  
ZYP Coatings Inc TN

**Cordierite**

Advanced Ceramic Technology CA  
Akron Porcelain & Plastics Co OH  
Astral Material Industrial Co Ltd China  
CoorsTek CO  
Du-Co Ceramics Company PA  
ER Advanced Ceramics Inc OH  
Industrial Ceramic Products Inc OH  
IPS Ceramics LTD UK  
Maryland Refractories Co OH  
Rauschert Industries Inc GA  
Saint-Gobain Ceramics & Plastics MA

**Crucibles**

**AdValue Technology LLC AZ** See ad on page 67  
Allied Mineral Products Inc OH  
APC International Ltd PA  
Aremco Products Inc NY  
Blasch Precision Ceramics Inc NY  
Bucher Emhart Glass SA Switzerland  
Ceramico Inc NH  
CeramTec-ETEC Germany  
Furnace Products & Services Inc PA  
Industrial Ceramic Products Inc OH  
Ipsen Ceramics IL

LECO Corp MI  
Magneco Metrel Inc IL  
Materion Ceramics AZ  
McDanel Advanced Ceramic Technologies LLC PA  
Progressive Technology Inc CA  
Selee Corp NC  
Silicon Carbide Products Inc NY  
Zhengzhou Mission Ceramic Products Co Ltd China  
Zircar Inc OH

**Dead-Burned**

Fluid Energy Processing & Equipment Co PA

**Fiber Products**

Allied Mineral Products Inc OH  
Furnace Products & Services Inc PA  
LECO Corp MI  
Thermal Products Co Inc GA  
Unifrax I LLC NY  
Vitcas Ltd UK



Zircar Ceramics Inc NY

**Filters, Molten Metal**

Akron Porcelain & Plastics Co OH  
Induceramic Canada  
Industrial Ceramic Products Inc OH  
Selee Corp NC

**Foundry**

Allied Mineral Products Inc OH  
Blasch Precision Ceramics Inc NY  
Capital Refractories Ltd UK  
Fosbel Inc OH  
Industrial Ceramic Products Inc OH  
Ipsen Ceramics IL  
LECO Corp MI  
Magneco Metrel Inc IL  
Plibrico Company IL  
Riverside Refractories Inc--Allied Mineral Products AL  
Selee Corp NC  
Silicon Carbide Products Inc NY  
Zircar Refractory Composites Inc NY

**Fused Cast**

Fosbel Inc OH  
Furnace Products & Services Inc PA  
Monfrax LLC NY  
Saint-Gobain Ceramics & Plastics MA

**Fused Spinel Refractories**

Dalmia Inst of Scientific & Industrial Research India

**Glass Furnace**

**Delttech Inc (Delttech Furnaces) CO** Inside front cover  
Diversified Controls & Systems NY  
Fosbel Inc OH  
Furnace Products & Services Inc PA  
HarbisonWalker Intl PA  
Ipsen Ceramics IL  
Magneco Metrel Inc IL  
RHI US Ltd NY  
RISE Research Institutes of Sweden RISE Glass Sweden  
Vesuvius SC

**Graphite**

Applied Ceramics Inc CA

Furnace Products & Services Inc PA  
Riedhammer GmbH Germany

### Grog

Alsey Refractories Co MO  
Maryland Refractories Co OH

### Gunning

Allied Mineral Products Inc OH  
Blastcrete Equipment Co AL  
Capital Refractories Ltd UK  
Fosbel Inc OH  
Plibrico Company IL  
Plibrico Japan Co Ltd Japan  
Reno Refractories Inc AL  
Riverside Refractories Inc—Allied Mineral Products AL  
Unifrax I LLC NY  
Velco GmbH Germany

### High-Alumina

Advanced Ceramic Technology CA  
Allied Mineral Products Inc OH  
Applied Ceramics Inc CA  
Astral Material Industrial Co Ltd China  
Blasch Precision Ceramics Inc NY  
Bucher Emhart Glass SA Switzerland  
Ceramco Inc NH  
CeramTec-ETEC Germany  
Custom Processing Services PA  
Dalmia Inst of Scientific & Industrial Research India  
ER Advanced Ceramics Inc OH  
Fosbel Inc OH  
IPS Ceramics LTD UK  
Ipsen Ceramics IL  
LECO Corp MI  
Magneco Metrel InclL  
Maryland Refractories Co OH  
Monofrax LLC NY  
Plibrico Company IL  
Plibrico Japan Co Ltd Japan  
Precision Ferrites and Ceramics Inc CA  
Rath Inc DE  
RHI US Ltd NY  
Riedhammer GmbH Germany  
Riverside Refractories Inc—Allied Mineral Products AL  
Selee Corp NC  
Sunrock Ceramics Co IL  
Tethon 3D NE  
Xiamen Innovacera Advanced Materials Co Ltd China  
Zhengzhou Mission Ceramic Products Co Ltd China  
Zircar Refractory Composites Inc NY

### Insulating Brick

Dalmia Inst of Scientific & Industrial Research India  
Furnace Products & Services Inc PA  
General Material Industrial CoChina  
IFB Insulating Firebrick Inc PA  
Laguna Clay Co CA  
PSH Kilns & Furnaces Canada  
RHI US LtdNY  
Riedhammer GmbH Germany  
Zircoa Inc OH

### Insulation

Agni Fiber Boards Pvt Ltd India  
Capital Refractories Ltd UK  
Du-Co Ceramics Company PA  
Furnace Products & Services Inc PA  
General Material Industrial Co China  
HarbisonWalker Intl PA  
Inducericam Canada  
Plibrico Company IL  
Plibrico Japan Co Ltd Japan  
PSH Kilns & Furnaces Canada  
Rath Inc DE

Reno Refractories Inc AL  
RHI US Ltd NY  
Thermal Products Co Inc GA  
Unifrax I LLC NY  
Vesuvius SC  
Wistra GmbH Germany



Zircar Ceramics Inc NY  
Zircar Refractory Composites Inc NY



Zircar Zirconia Inc NY

### Insulation Board

Agni Fiber Boards Pvt Ltd India  
Thermal Products Co Inc GA  
Unifrax I LLC NY  
Zircar Refractory Composites Inc NY

### Insulation Slabs, Calcium Silicate

Furnace Products & Services Inc PA  
Zircar Refractory Composites Inc NY

### Insulation Slabs, Vermiculite

IFB Insulating Firebrick Inc PA

### Insulation, Microporous

Furnace Products & Services Inc PA  
Thermal Products Co Inc GA  
Unifrax I LLC NY

### Kiln Car Insulation

Thermal Products Co Inc GA

### Kiln Furniture

Advanced Ceramic Technology CA  
American Art Clay Co Inc IN



Blasch Precision Ceramics Inc NY See ad on page 109

Ceramco Inc NH  
Inducericam Canada  
Industrial Ceramic Products Inc OH  
Ipsen Ceramics IL  
L&L Kiln Mfg Inc NJ  
Laguna Clay Co CA  
Magneco Metrel Inc IL

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 PSH Kilns & Furnaces Canada  
 RHI US Ltd NY  
 Saint-Gobain Ceramics & Plastics MA  
 Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA  
 Selee Corp NC  
 Silicon Carbide Products Inc NY  
 Sunrock Ceramics Co IL  
 Texers Technical Ceramics Inc Canada  
 Zircar Refractory Composites Inc NY  
 Zircoa Inc OH

### Magnesite

Allied Mineral Products Inc OH  
 Astral Material Industrial Co Ltd China  
 Dalmia Inst of Scientific & Industrial Research India  
 Fluid Energy Processing & Equipment Co PA  
 Furnace Products & Services Inc PA  
 RHI US Ltd NY  
 Riedhammer GmbH Germany

### Monolithic

Allied Mineral Products Inc OH  
 Blasch Precision Ceramics Inc NY  
 Cancarb Limited Canada  
 Ceramco Inc NH  
 Furnace Products & Services Inc PA  
 Magneco Metrel Inc IL  
 Plibrico Company IL  
 Plibrico Japan Co Ltd Japan  
 RHI US Ltd NY  
 Riverside Refractories Inc—Allied Mineral Products AL  
 Saint-Gobain Ceramics & Plastics MA  
 Selee Corp NC  
 Zili USA LLC PA

### Mortars

Allied Mineral Products Inc OH  
 Aisey Refractories Co MO  
 CoorsTek CO  
 Monofrax LLC NY  
 Pacific Refractories Ltd India  
 Plibrico Company IL  
 Plibrico Japan Co Ltd Japan  
 Refratechnik Ceramics GmbH Germany  
 Reno Refractories Inc AL  
 RHI US Ltd NY  
 Riverside Refractories Inc—Allied Mineral Products AL  
 Vitcas Ltd UK

### Mullite

Advanced Ceramic Technology CA  
 Akron Porcelain & Plastics Co OH  
 Allied Mineral Products Inc OH  
 Astral Material Industrial Co Ltd China  
 Atlantic Equipment Engineers NJ  
 Bharat Heavy Electricals Ltd India  
 Bucher Emhart Glass SA Switzerland  
 Ceramco Inc NH  
 CeramTec-ETEC Germany  
 Dalmia Inst of Scientific & Industrial Research India  
 ER Advanced Ceramics Inc OH  
 Fosbel Inc OH  
 General Material Industrial Co China  
 Industrial Ceramic Products Inc OH  
 IPS Ceramics LTD UK  
 Magneco Metrel Inc IL  
 McDanel Advanced Ceramic Technologies LLC PA  
 Reade Advanced Materials RI  
 RHI US Ltd NY  
 Robocasting Enterprises LLC NM  
 Unifrax I LLC NY

### Nozzles

Advanced Ceramic Technology CA

Blasch Precision Ceramics Inc NY  
 Blastcrete Equipment Co AL  
 CeramTec-ETEC Germany  
 FELDCO Intl CA  
 Industrial Ceramic Products Inc OH  
 Jyoti Ceramic Industries Pvt Ltd India  
 LECO Corp MI  
 Magneco Metrel Inc IL  
 Reed Gunite & Shotcrete Equipment CA  
 Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA  
 Silicon Carbide Products Inc NY  
 Xiamen Innovacera Advanced Materials Co Ltd China  
 Zircoa Inc OH

### Paper

Strem Catalog, by Ascensus Specialties MA  
 Thermal Products Co Inc GA  
 Unifrax I LLC NY

### Plastic

Allied Mineral Products Inc OH  
 Capital Refractories Ltd UK  
 Maryland Ceramic & Steatite Co Inc MD  
 Plibrico Company IL  
 Plibrico Japan Co Ltd Japan  
 RHI US Ltd NY  
 Riverside Refractories Inc—Allied Mineral Products AL

### Precast Shapes

Allied Mineral Products Inc OH  
 Blasch Precision Ceramics Inc NY  
 Bucher Emhart Glass SA Switzerland  
 Capital Refractories Ltd UK  
 Ceramco Inc NH  
 CeramTec-ETEC Germany  
 Fosbel Inc OH  
 Industrial Ceramic Products Inc OH  
 Magneco Metrel Inc IL  
 Plibrico Company IL  
 Plibrico Japan Co Ltd Japan  
 RHI US Ltd NY  
 Riverside Refractories Inc—Allied Mineral Products AL  
 Selee Corp NC  
 Silicon Carbide Products Inc NY  
 Zircar Refractory Composites Inc NY

### Ramming Mixes

Allied Mineral Products Inc OH  
 Aisey Refractories Co MO  
 Monofrax LLC NY  
 Plibrico Company IL  
 Plibrico Japan Co Ltd Japan  
 RHI US Ltd NY  
 Riverside Refractories Inc—Allied Mineral Products AL  
 Selee Corp NC

### Rods

Actech Precision Ceramic (HK) Limited China  
**AdValue Technology LLC AZ** See ad on page 67  
 Blasch Precision Ceramics Inc NY  
 CerCo LLC OH  
 Du-Co Ceramics Company PA  
 Industrial Ceramic Products Inc OH  
 LECO Corp MI  
 McDanel Advanced Ceramic Technologies LLC PA  
 Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA  
 Silicon Carbide Products Inc NY

### Rollers

Keith Co CA  
 Recco Furnaces CA  
 Riedhammer GmbH Germany  
 Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA

### Saggers

**AdValue Technology LLC AZ** See ad on page 67  
 Blasch Precision Ceramics Inc NY  
 Ceramco Inc NH  
 IPS Ceramics LTD UK  
 Ipsen Ceramics IL  
 LECO Corp MI  
 Magneco Metrel Inc IL  
 Selee Corp NC  
 Sunrock Ceramics Co IL

### Setters

**AdValue Technology LLC AZ** See ad on page 67  
 Blasch Precision Ceramics Inc NY  
 Ceramco Inc NH  
 Industrial Ceramic Products Inc OH  
 Ipsen Ceramics IL  
 LECO Corp MI  
 Magneco Metrel Inc IL  
 Maryland Ceramic & Steatite Co Inc MD  
 Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA  
 Selee Corp NC  
 Sunrock Ceramics Co IL

### Silica

Allied Mineral Products Inc OH  
 Astral Material Industrial Co Ltd China  
 Blasch Precision Ceramics Inc NY  
 Bucher Emhart Glass SA Switzerland  
 Dalmia Inst of Scientific & Industrial Research India  
 Fosbel Inc OH  
 Ipsen Ceramics IL  
 Maryland Refractories Co OH  
 RHI US Ltd NY  
 Selee Corp NC  
 Sibelco Benelux Belgium

### Silicon Carbide

Allied Mineral Products Inc OH  
 Astral Material Industrial Co Ltd China  
 Bharat Heavy Electricals Ltd India  
 Blasch Precision Ceramics Inc NY  
 Cancarb Limited Canada  
 CoorsTek CO  
 Custom Processing Services PA  
 Electro Abrasives Corp NY  
 Fosbel Inc OH  
 IPS Ceramics LTD UK  
 Magneco Metrel Inc IL  
 Momentive Performance Materials Inc NY  
 Plibrico Company IL  
 Plibrico Japan Co Ltd Japan  
 Precision Ferrites and Ceramics Inc CA  
 Reade Advanced Materials RI  
 Riedhammer GmbH Germany  
 Saint-Gobain Performance Ceramics & Refractories & Hexoloy SiC Materials MA  
 Selee Corp NC  
 Silicon Carbide Products Inc NY  
 Xiamen Innovacera Advanced Materials Co Ltd China

### Specialty

Allied Mineral Products Inc OH  
 Aisey Refractories Co MO  
 Blasch Precision Ceramics Inc NY  
 Bucher Emhart Glass SA Switzerland  
 Ceramco Inc NH  
 CeramTec-ETEC Germany  
 CoorsTek CO  
 Goceram AB Sweden  
 Industrial Ceramic Products Inc OH  
 Magneco Metrel Inc IL  
 McDanel Advanced Ceramic Technologies LLC PA

Refrac Systems AZ  
Riverside Refractories Inc—Allied Mineral Products AL

### Spheres, Ceramic

Piezo by Graco OH

### Tap Hole Clays

Cancarb Limited Canada  
Riverside Refractories Inc—Allied Mineral Products AL  
Vitcas Ltd UK

### Textile



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**Boron Nitride · High Purity Powders**  
**Laser Marker · Laser Machining**

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<http://www.cerinnov.com>  
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Cerinnov specializes in the manufacturing of production and decoration machines for the ceramic and glass industries: shaping and decorating machines, laser marking, engineering, turn-key plants for tableware, tools, and after sales services.



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Cerion's position in the market is enabled by three strategic competitive advantages: deep and demonstrated capability in a) precision design and customization of both nanoparticle size and technical attributes, b) robust processes to scale materials from prototype to low and high-volume production rates, and c) industry-leading, cost-effective manufacturing systems and production capacities.

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<http://www.cerix-ceramics.de>  
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CERIX grow platform GmbH is a start-up company from Robert Bosch GmbH. We produce high-tech ceramics for various markets and offer functional components for sensors, medical products, consumer goods, automotive components, and industrial products made of alumina and zirconia. CIM in combination with in-mold labelling and 3D printing enable us to manufacture complex functional components with the highest degree of precision.

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Cerlase is an officially certified R&D center. Primary research lines are lasers for ceramics, glass and metal (sintering, melting, cutting), shaping processes for ceramics, decoration (laser sintering, total transfer, heat decal), and heat treatment.

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**XIAMEN UNIPRETEC CERAMIC TECHNOLOGY CO LTD** +86 592-551-0319  
No 151 Yuehua Rd Huli District Xiamen  
Fujian 361006 China

http://www.unipretec.com  
info@unipretec.com

Unipretec is a professional manufacturer for advanced ceramics. Our materials include alumina ceramic, zirconia ceramic, boron nitride, and machinable glass ceramic. We aim to provide high quality products and solutions for our customers.

**YOUNG INDUSTRIES INC** +1 570-546-3165  
16 Painter St Fax: +1 570-546-1888  
Muncy PA 17756

http://younginds.com  
mktinfo@younginds.com

Designs and manufactures process equipment, including size reduction and classification, mixing and blending, air pollution control, and pneumatic conveying systems. Operations include national sales network and engineering services.

**ZENITH** +1 573-889-6795  
No 416 Jianye Rd S Jinqiao Area  
Pudong Shanghai China 201206

http://www.miningplant.org  
info@miningplant.org

We hold "Pursuing the Zenith Technology and Quality" as our management concept all the time. In addition to our full efforts, we rely on world-leading absorbing, crushing, and powder processing technology; advanced management; and a quality control system.

**ZHENGZHOU MISSION CERAMIC PRODUCTS CO LTD** +86 371-5668-9683  
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Zhengzhou Henan 450000 China

http://www.msccera.com  
frank@msccera.com

We are a professional manufacturer of high purity alumina (99.7%) and zirconia tubes, rods, plates, balls, crucibles, boats, nozzles, and other custom-made special parts. Large quantity in stock, with very competitive prices.

**ZIBO GUANGTONG CHEMICAL CO LTD** +86 136-9765-7735  
No 27 London Rd Fax: +86 532-8676-6180  
Qingdao Free Trade Zone  
Qingdao Shandong 266555 China

http://www.gtchems.com  
sales@gtchems.com

Zibo Guangtong Chemical is one of the leading manufacturers in China for diacids, diols, and zirconia products. Main products are zirconium compounds, including zirconium oxychloride (CAS No.: 7699-43-6), zirconium dioxide (CAS No.: 1314-23-4), and zirconium carbonate.

**ZILI USA LLC**  
149 Nichol Ave No 2  
McKees Rocks PA 15136

http://www.zilialutech.com  
jsun@ziliref.com

Zili USA is a subsidiary of Zhejiang Zili Alumina Materials Co Ltd, specializing in high-purity alumina materials development and manufacturing. Its products include tabular alumina, low sodium alumina, reactive alumina, and calcined alumina. With warehouses situated in the states, Zili has fully stocked inventories ready for shipment.

Products are widely used in refractories, including sliding gate, purging plug brick, nozzles, well blocks, as well as kiln furniture, electronic industries, petrochemical industries, and ceramic industries.



**ZIRCAR CERAMICS INC** +1 845-651-0441  
100 N Main St  
Florida NY 10921

http://www.zircarceramics.com

Zircar's broad product range includes Alumina, Alumina-Silica and other refractory oxide fiber materials, heating elements, plus furnace insulation custom assemblies and accessories. They offer only the highest quality products in a wide variety of forms, shapes and sizes. Besides their standard product line, Zircar custom manufactures many one of a kind products to satisfy customers' unique needs including furnace insulation, heating components and high temperature systems.

**ZIRCAR REFRACTORY COMPOSITES INC** +1 845-651-2200  
PO Box 489 Fax: +1 845-651-1515  
Florida NY 10921

http://zrci.com  
sales@zrci.com

ZIRCAR Refractory Composites, Inc., produces a comprehensive line of advanced high performance ceramic-ceramic composite materials and related products. Our materials are used around the world in the most demanding thermal, structural and electrical insulating applications ranging in temperatures from 600°C (1,112°F) to 2,200°C (3,992°F). For over thirty years, we have been a problem-solver working with our customers to resolve their thermal management problems. We have developed products that have become industry standards for induction melting, forging and heat treating applications, investment casting, glass processing, hot pressing, and high temperature electrical applications.



**ZIRCAR ZIRCONIA INC** +1 845-651-3040  
PO Box 287 Fax: +1 845-651-0074  
Florida NY 10921

http://www.zircarzirconia.com  
sales@zircarzirconia.com

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**ZIRCOA INC** +1 440-248-0500  
31501 Solon Rd Fax: +1 440-248-8864  
Solon OH 44139

http://zircoa.com  
sales@zircoa.com

Zircoa tailors and manufactures zirconia products to meet extreme conditions in temperature, mechanical stress, and corrosion required to improve industrial processes. Examples of our products include a unique granular zirconia; crucibles for investment casting; refractories for steel, powder metallurgy, glass, quartz, crystal growth, and carbon black; beads and grinding media for dispersion and milling; dies for extrusion of nonferrous metals and other forming methods; and components for oil and gas.

**ZSCHIMMER & SCHWARZ** +1 478-454-1942  
70 Georgia Hwy 22 W Fax: +1 478-453-8854  
Milledgeville GA 31061

http://zschimmer-schwarz.com  
pcuthbertz@windstream.net

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11 Na 22.98976928 Sodium	12 Mg 24.305 Magnesium											13 Al 26.9815386 Aluminum	14 Si 28.0855 Silicon	15 P 30.973762 Phosphorus	16 S 32.065 Sulfur	17 Cl 35.453 Chlorine	18 Ar 39.948 Argon
19 K 39.0983 Potassium	20 Ca 40.078 Calcium	21 Sc 44.955912 Scandium	22 Ti 47.887 Titanium	23 V 50.9415 Vanadium	24 Cr 51.9961 Chromium	25 Mn 54.938045 Manganese	26 Fe 55.845 Iron	27 Co 58.933195 Cobalt	28 Ni 58.6934 Nickel	29 Cu 63.546 Copper	30 Zn 65.38 Zinc	31 Ga 69.723 Gallium	32 Ge 72.64 Germanium	33 As 74.9216 Arsenic	34 Se 78.96 Selenium	35 Br 79.904 Bromine	36 Kr 83.798 Krypton
37 Rb 85.4678 Rubidium	38 Sr 87.62 Strontium	39 Y 88.90585 Yttrium	40 Zr 91.224 Zirconium	41 Nb 92.90638 Niobium	42 Mo 95.96 Molybdenum	43 Tc (98.0) Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.9055 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.8682 Silver	48 Cd 112.411 Cadmium	49 In 114.818 Indium	50 Sn 118.71 Tin	51 Sb 121.76 Antimony	52 Te 127.6 Tellurium	53 I 126.90447 Iodine	54 Xe 131.29 Xenon
55 Cs 132.9054 Cesium	56 Ba 137.327 Barium	57 La 138.90547 Lanthanum	72 Hf 178.49 Hafnium	73 Ta 180.948 Tantalum	74 W 183.84 Tungsten	75 Re 186.207 Rhenium	76 Os 190.23 Osmium	77 Ir 192.222 Iridium	78 Pt 195.084 Platinum	79 Au 196.966569 Gold	80 Hg 200.59 Mercury	81 Tl 204.3833 Thallium	82 Pb 207.2 Lead	83 Bi 208.9804 Bismuth	84 Po (209) Polonium	85 At (210) Astatine	86 Rn (222) Radon
87 Fr (223) Francium	88 Ra (226) Radium	89 Ac (227) Actinium	104 Rf (267) Rutherfordium	105 Db (268) Dubnium	106 Sg (271) Seaborgium	107 Bh (272) Bohrium	108 Hs (270) Hassium	109 Mt (276) Meitnerium	110 Ds (281) Darmstadtium	111 Rg (286) Roentgenium	112 Cn (285) Copernicium	113 Nh (284) Nihonium	114 Fl (289) Flerovium	115 Mc (288) Moscovium	116 Lv (293) Livermorium	117 Ts (294) Tennessine	118 Og (294) Oganesson

58 Ce 140.116 Cerium	59 Pr 140.90766 Praseodymium	60 Nd 144.242 Neodymium	61 Pm (145) Promethium	62 Sm 150.36 Samarium	63 Eu 151.964 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.92535 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.93032 Holmium	68 Er 167.259 Erbium	69 Tm 168.93023 Thulium	70 Yb 173.054 Ytterbium	71 Lu 174.967 Lutetium
90 Th 232.0377 Thorium	91 Pa 231.03689 Protactinium	92 U 238.02891 Uranium	93 Np (237) Neptunium	94 Pu (244) Plutonium	95 Am (243) Americium	96 Cm (247) Curium	97 Bk (247) Berkelium	98 Cf (251) Californium	99 Es (252) Einsteinium	100 Fm (257) Fermium	101 Md (286) Mendelevium	102 No (289) Nobelium	103 Lr (262) Lawrencium

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