The hidden powers of porous copper

ASU researchers discover new way to 3D print porous copper structures, unlocking faster manufacturing for applications in security, energy

By Aisha Kaddi, ASU News
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The most surprising discoveries rarely arrive with a drumroll. They slip into existence quietly, born from familiar materials we've handled a thousand times.

One of those materials is copper, a metal prized for its strength, durability and electrical conductivity — qualities that have made it a staple in electronics, energy systems and manufacturing for decades.

Researchers have long studied how metals can be shaped, printed and adjusted to achieve specific functions. In 2019, supported by a U.S. National Science Foundation grant, Arizona State University manufacturing engineering faculty took that work in a new direction.

Assistant Professor Xiangfan Chen and Associate Professor Bruno Azeredo — in the School of Manufacturing Systems and Networks, part of the Ira A. Fulton Schools of Engineering — set out to develop a method for 3D printing extremely small, complex porous copper structures with applications spanning everything from information security to energy efficiency.

Now that work has come to fruition, and the significance of the research was recognized with the acceptance of a paper describing the findings in Nature Communications, a highly selective journal that publishes research with broad scientific impact.

Lowering the temperature to raise potential

At the time, metal additive manufacturing faced a major limitation: producing complex metal parts required high temperatures and powerful lasers.

“When your process requires high heat and high power just to get started, you automatically exclude a wide class of design choices,” says Binil Starly, school director and a professor of manufacturing engineering in the School of Manufacturing Systems and Networks. “For manufacturers, that limits material behavior and allows for fewer pathways to scale innovative structures into real-world systems.”

Chen and Azeredo set out to determine whether nanostructured metal powders could reduce power and heat requirements to enable the formation of microscale metallic structures.

By studying how metals with nanoscale pores interact with light, the team aimed make metal powders heat and bond more efficiently, lowering sintering temperatures and speeding up the metal printing process.

“In my own research, I had previously learned how to sinter nanoporous powders at low temperatures, but had little clue how to 3D print them at microscales,” Azeredo says. “That all changed when Chen came in and provided a definitive solution.”

Over the following years, Chen and Azeredo’s research expanded beyond printing powders to full three-dimensional structures. Using a fast, high-resolution continuous 3D-printing process — micro continuous liquid interface production, or µCLIP — and with support from a second NSF Future Manufacturing grant, the team created intricate copper components filled with nanoscale pores thousands of times smaller than the width of a human hair.

“I saw this as an opportunity to leverage my expertise in high-resolution 3D printing to bring nanoporous metals into the microscale,” Chen says. “By combining precise architectural control with post-sintering processing, we were able to create metal structures that simply weren’t accessible before.”

After printing copper-polymer structures, the researchers used heat to remove the polymer, leaving behind a solid copper structure. They found that carefully controlling how the copper was heated allowed them to change the internal structure and material behavior. By adjusting the final heating temperature, they could fine-tune how the material performed.

For example, at higher sintering temperatures, the copper became dense, stable and electrically conductive. At lower temperatures, it retained its nanoporous structure, giving it a much larger surface area and heightened chemical reactivity.

From failure to functionality

One day, surrounded by the quiet hum of machinery and the glow of a liquid resin bath, the team made an unexpected discovery.

They observed that when a sintered structure was removed from an airtight chamber, exposure to oxygen in the air triggered rapid oxidation in the highly porous copper, causing the material to break apart and undergo dramatic changes in its properties.

Instead of seeing this fragility as a flaw, the team realized it could be a design opportunity. By engineering materials to intentionally oxidize and fail when exposed to air, they opened the door to new applications in information security and related fields.

“Imagine a tiny network of copper material inside a phone chip,” Chen says. “If someone tries to open the phone to access sensitive information, the chip would react with air — creating a materials design opportunity we can now explore.”

“Think of it as a built-in safeguard. The material itself would become part of the security system,” he says.

The researchers envision copper components that remain stable under normal conditions but rapidly degrade when exposed to air. In secure devices, physically opening a component could trigger the material to destroy itself, protecting the information it carries.

(Video: {https://www.youtube.com/watch?v=jzL6nILGcwE})

Engineering how materials respond

“Instead of dismissing it as a failure, we leaned into it,” Azeredo says. “That moment showed us that porosity could be used not just to enhance performance, but to intentionally design how a material responds to its environment.”

Beyond security applications, this work reflects a broader shift in how engineers think about metals. Rather than compromising between durability and functionality, manufacturers can now develop materials that achieve both goals.

By adjusting processing conditions, engineers can choose between dense, long-lasting copper or highly reactive copper engineered to break down when needed — an unprecedented level of control not possible with traditional manufacturing methods.

Looking ahead, Chen and Azeredo’s work could also lead to advances in energy and sustainable manufacturing. In the medical field, for example, materials designed to safely self-disintegrate could simplify the removal of implanted devices.

More broadly, materials that combine structural strength with controlled reactivity could open new paths toward lightweight, energy-efficient systems.

What began as an effort to improve metal additive manufacturing ultimately revealed how precise control over structure and processing can produce material behaviors beyond the reach of conventional methods.

“For me, this work is about pushing additive manufacturing beyond making shapes to actually programming how materials behave across scales,” Chen says. “Moving forward, I see this as a foundation for designing metals that are not only structurally complex but also responsive, adaptive and intentionally transient, opening up new directions for how we think about functional materials.”

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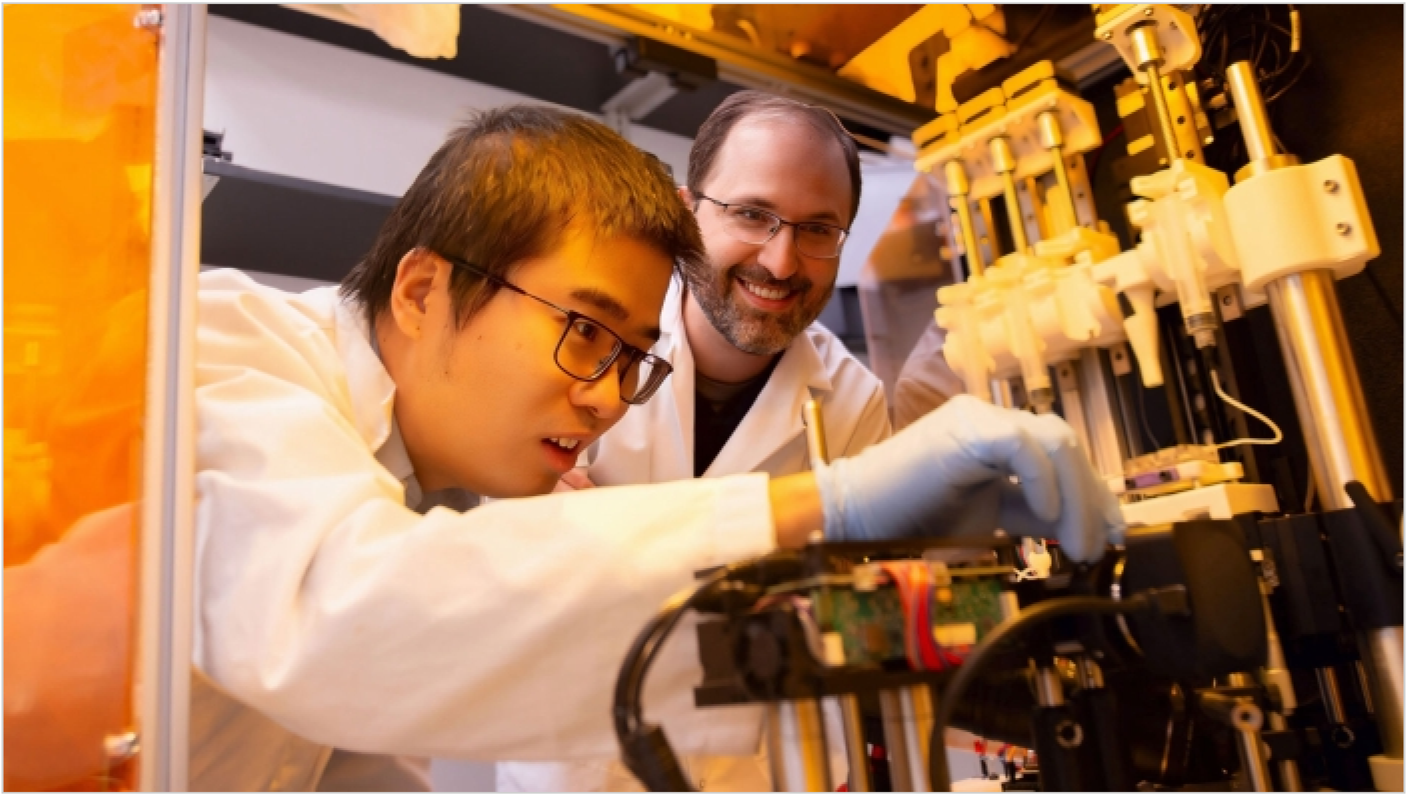
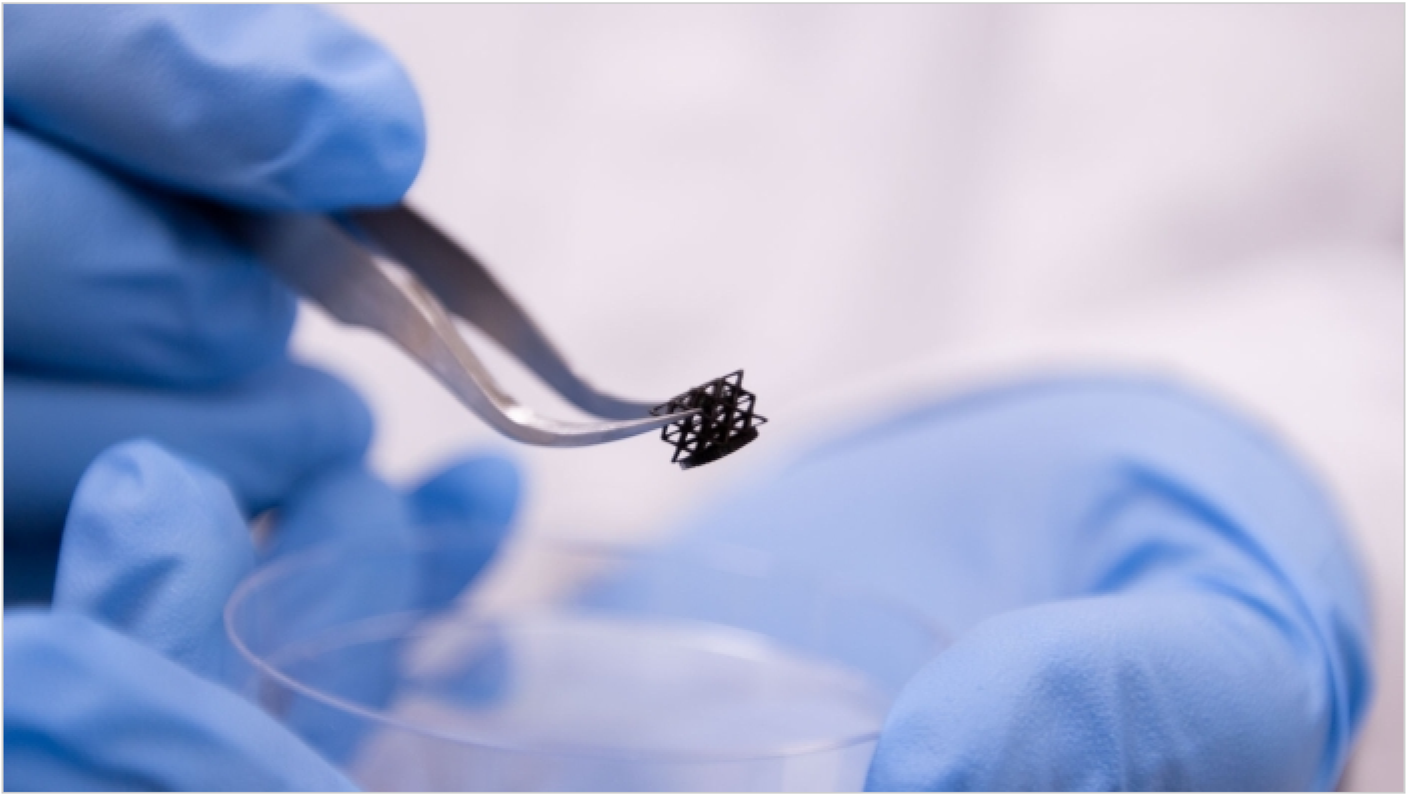
Main image

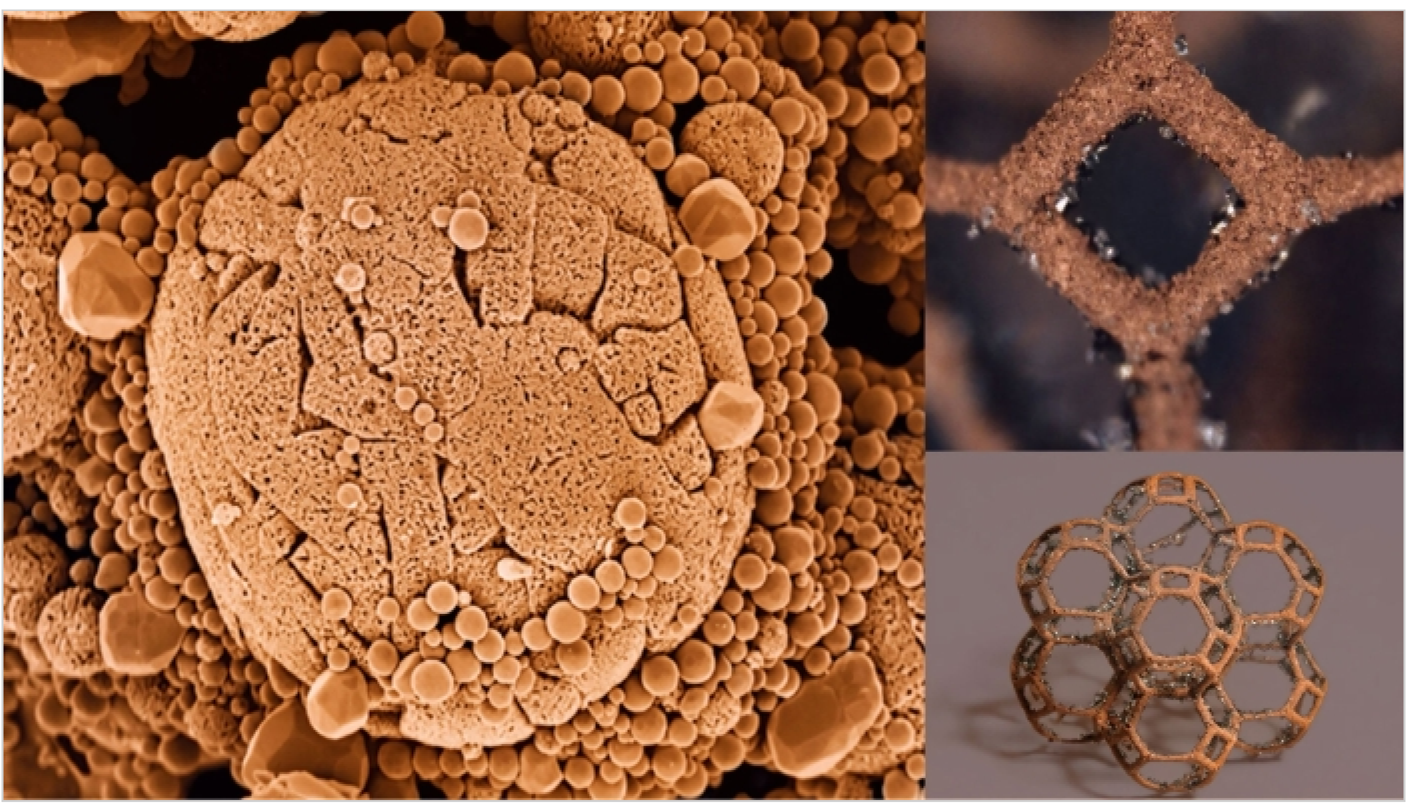


Assistant Professor Xiangfan Chen (left) and Associate Professor Bruno Azeredo, manufacturing engineering faculty members in the School of Manufacturing Systems and Networks, part of the Ira A. Fulton Schools of Engineering at Arizona State University, are pictured observing a 3D printer in the Advanced Manufacturing and Functional Device Laboratory located in the Technology Center on the ASU Polytechnic campus. Photo by Aisha Kaddi/ASU

Text image(s)



The 3D-printing technology developed in Chen’s group enables fabrication of centimeter-scale metallic structures with microscale resolution. This lattice-like architecture is central to governing material behavior, durability and performance in advanced manufacturing and engineered materials. Photo by Aisha Kaddi/ASU



Hierarchical copper structures are organized across many size scales, from nanoscale features to centimeter-scale forms. High-resolution microscope images reveal that the smallest details are created through a low-temperature heating process, while the larger structures are shaped by 3D printing. Photo collage courtesy of Xiangfan Chen/ASU