3D-printed superconductor achieves record performance with soft matter approach

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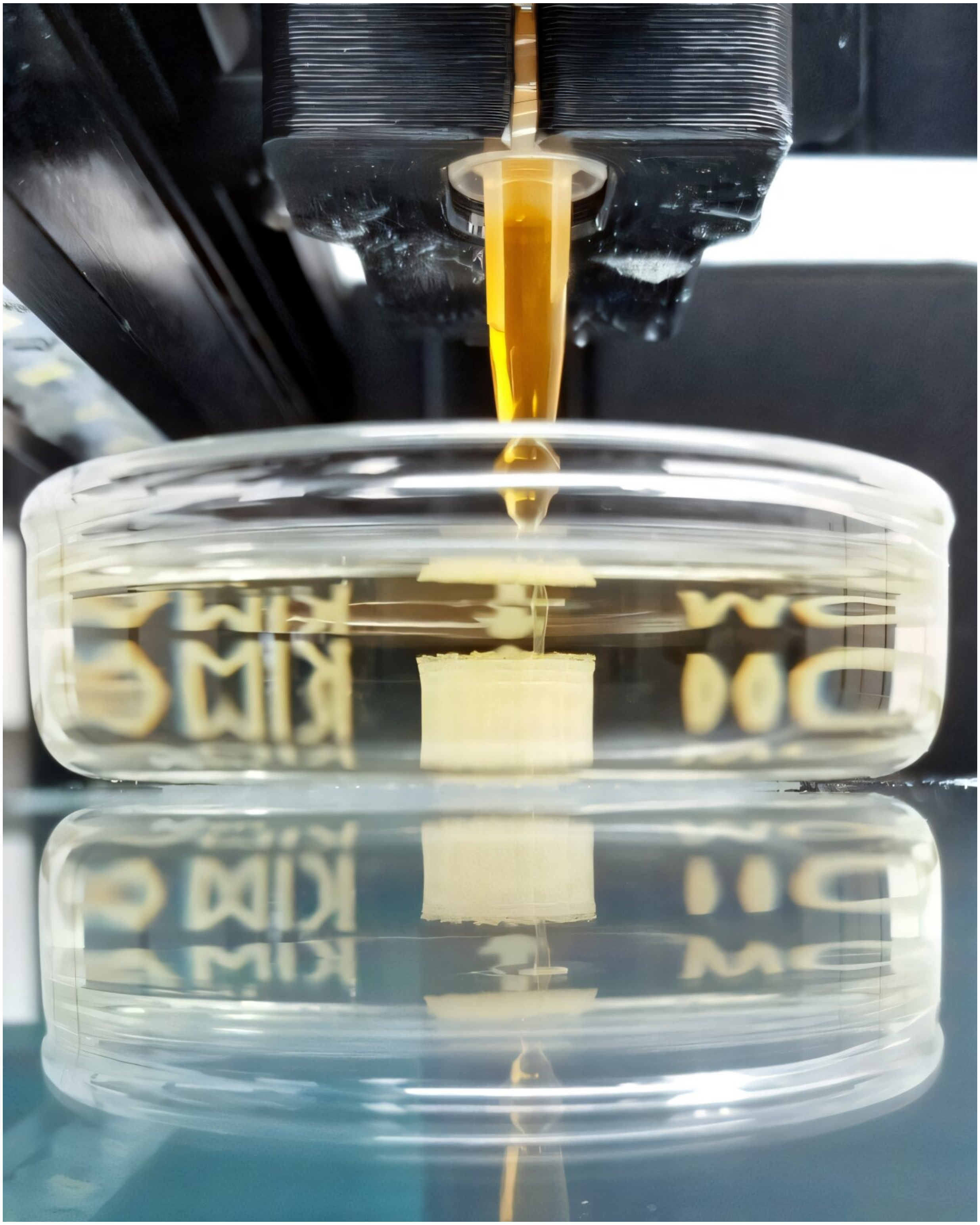

A copolymer-inorganic nanoparticle ink is deposited during the 3D printing process, where it self-assembles before being heat-treated into a crystalline superconductor. Credit: Wiesner Group/Provided

Nearly a decade after they first demonstrated that soft materials could guide the formation of superconductors, Cornell researchers have achieved a one-step, 3D printing method that produces superconductors with record properties.

The advance, detailed in *Nature Communications*, builds on years of interdisciplinary work led by Ulrich Wiesner, the Spencer T. Olin Professor in the Department of Materials Science and Engineering, and could improve technologies such as superconducting magnets and quantum devices.

Wiesner and colleagues reported in 2016 the first self-assembled superconductor using block copolymers—soft, chain-like molecules that naturally arrange themselves into orderly, repeating nanoscale structures. By 2021, the group found that these soft material approaches could produce superconducting properties on par with conventional methods.

The new study produces enhanced properties using a copolymer-inorganic nanoparticle ink that self-assembles as it is 3D printed; heat treatments then convert the printed material into a porous crystalline superconductor. The approach represents a major departure from traditional 3D printing methods of porous materials, which often involve synthesizing porous materials separately, converting them into powders, mixing them with binders and then re-processing them through heat treatments.

Cornell's scalable, "one-pot" process skips a number of those steps to create superconducting materials with structure at three different scales: At the atomic scale, the atoms line up into a crystalline lattice; block copolymer self-assembly directs the formation of mesostructured lattices; and 3D printing leads to macroscopic lattices, including coils or helices for different applications.

"This has been a long time in the making," said Wiesner, who is also a professor in the Department of Design Tech. "What this paper shows is that not only can we print these complex shapes, but the mesoscale confinement gives the materials properties that were simply not achievable before."

The study's most striking result came when the researchers printed a niobium-nitride material. Thanks to its nanostructured porosity, the 3D-printed superconductor displayed an upper critical magnetic field of 40 to 50 Tesla, the highest confinement-induced value ever reported for this compound superconductor. The property is key for functioning in strong superconducting magnets, such as those used in MRI imaging.

"We've mapped this superconducting property onto a macromolecular design parameter that goes into the synthesis of the material. That's something no one has shown before," Wiesner said. "The map tells us which polymer molar mass is needed to achieve a specific superconductor performance, a remarkable correlation."

The work was made possible by graduate students Fei Yu, who developed and tested the printing inks, and Paxton Thetford, who solved the chemistry of working with unusually small block copolymers. Major contributions also came from Bruce van Dover, the Walter S. Carpenter Jr. Professor in the Department of Materials Science and Engineering; as well as Sol Gruner, professor emeritus, and Julia Thom-Levy, professor and chair, both of the Department of Physics in the College of Arts and Sciences.

Looking ahead, the researchers hope to explore alternative superconducting compounds. The study highlighted that the method can be applied to other transition metal compounds, such as titanium nitride, and to 3D structures that are difficult to achieve with conventional processes. And the porous architecture produces record surface areas for compound superconductors, which could prove valuable for designing next-generation quantum materials.

"I'm very hopeful that as a new research direction, we'll make it easier and easier to create superconductors with novel properties," Wiesner said.

"Cornell is unique in bringing together chemists, physicists and materials scientists to push this field forward. This study demonstrates just how much potential there is in soft matter approaches to quantum materials."

More information: Fei Yu et al, Hierarchically ordered porous transition metal compounds from one-pot type 3D printing approaches, *Nature Communications* (2025). DOI: 10.1038/s41467-025-62794-8

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