Researchers use 3D printing to make ultrafast graphene supercapacitor

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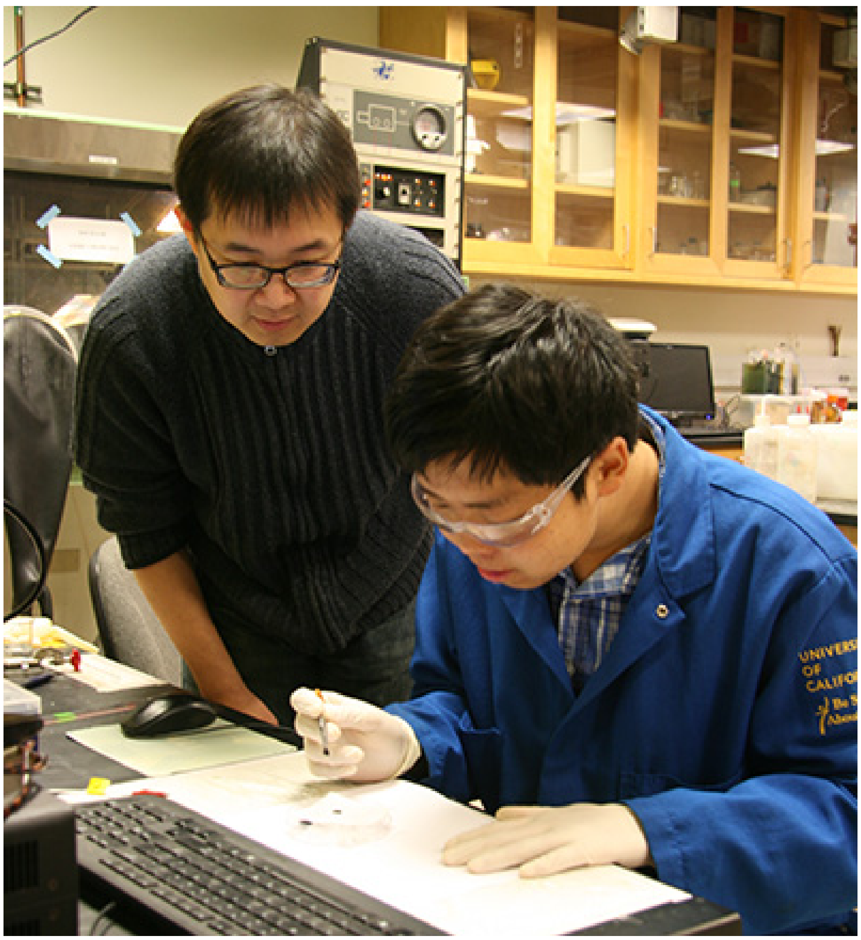

Yat Li (left) and Tianyu Liu worked with researchers at Lawrence Livermore National Laboratory to develop supercapacitors using 3D-printed graphene aerogel electrodes. Credit: T. Stephens

Scientists at UC Santa Cruz and Lawrence Livermore National Laboratory (LLNL) have reported the first example of ultrafast 3D-printed graphene supercapacitor electrodes that outperform comparable electrodes made via traditional methods. Their results open the door to novel, unconstrained designs of highly efficient energy storage systems for smartphones, wearables, implantable devices, electric cars and wireless sensors.

Using a 3D-printing process called direct-ink writing and a graphene-oxide composite ink, the team was able to print micro-architected electrodes and build supercapacitors with excellent performance characteristics. The results were published online January 20 in the journal *Nano Letters* and will be featured on the cover of the March issue of the journal.

"Supercapacitor devices using our 3D-printed graphene electrodes with thicknesses on the order of millimeters exhibit outstanding capacitance retention and power densities," said corresponding author Yat Li, associate professor of chemistry at UC Santa Cruz. "This performance greatly exceeds the performance of conventional devices with thick electrodes, and it equals or exceeds the performance of reported devices made with electrodes 10 to 100 times thinner."

LLNL engineer Cheng Zhu and UCSC graduate student Tianyu Liu are lead authors of the paper. "This breaks through the limitations of what 2D manufacturing can do," Zhu said. "We can fabricate a large range of 3D architectures. In a phone, for instance, you would only need to leave a small area for energy storage. The geometry can be very complex."

Fast charging

Supercapacitors also can charge incredibly fast, Zhu said, in theory requiring just a few minutes or seconds to reach full capacity. In the future, the researchers believe newly designed 3D-printed supercapacitors will be used to create unique electronics that are currently difficult or even impossible to make using other synthetic methods, including fully customized smartphones and paper-based or foldable devices, while at the same time achieving unprecedented levels of performance.

According to Li, several key breakthroughs made these novel devices possible, starting with the development of a printable graphene-based ink. Modification of the 3D printing scheme to be compatible with aerogel processing made it possible to maintain the important mechanical and electrical properties of single graphene sheets in the 3D-printed structures. Finally, the use of 3D printing to intelligently engineer periodic macropores into the graphene electrode significantly enhances mass transport, allowing the device to support much faster charge/discharge rates without degrading its capacity.

"This work provides an example of how 3D-printed materials such as graphene aerogels can significantly expand the design space for fabricating high-performance and fully integrable energy storage devices optimized for a broad range of applications," Li said.

The advantages of graphene-based inks include their ultrahigh surface area, lightweight properties, elasticity, and superior electrical conductivity. The graphene composite aerogel supercapacitors are also extremely stable, the researchers reported, capable of nearly fully retaining their energy capacity after 10,000 consecutive charging and discharging cycles.

"Graphene is a really incredible material because it is essentially a single atomic layer that can be created from graphite. Because of its structure and crystalline arrangement, it has really phenomenal capabilities," said LLNL materials engineer Eric Duoss.

Over the next year, the researchers intend to expand the technology by developing new 3D designs, using different inks, and improving the performance of existing materials.

More information: Cheng Zhu et al. Supercapacitors Based on Three-Dimensional Hierarchical Graphene Aerogels with Periodic Macropores, *Nano Letters* (2016). DOI: 10.1021/acs.nanolett.5b04965

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