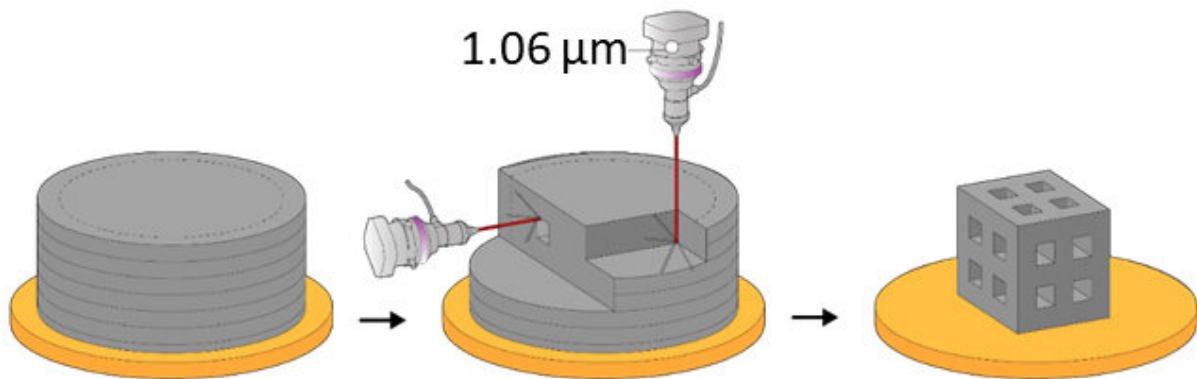


Lab creates conductive 3-d carbon blocks that can be shaped for applications

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Rice University scientists have layered laser-induced graphene and built a prototype that shapes the resulting 3-D blocks into sophisticated shapes. The foam offers new possibilities for energy storage and flexible electronic sensor applications. Credit: Tour Group/Rice University

Rice University scientists have developed a simple way to produce conductive, three-dimensional objects made of graphene foam.

The squishy solids look and feel something like a child's toy but offer new possibilities for energy storage and flexible electronic sensor applications, according to Rice chemist James Tour.

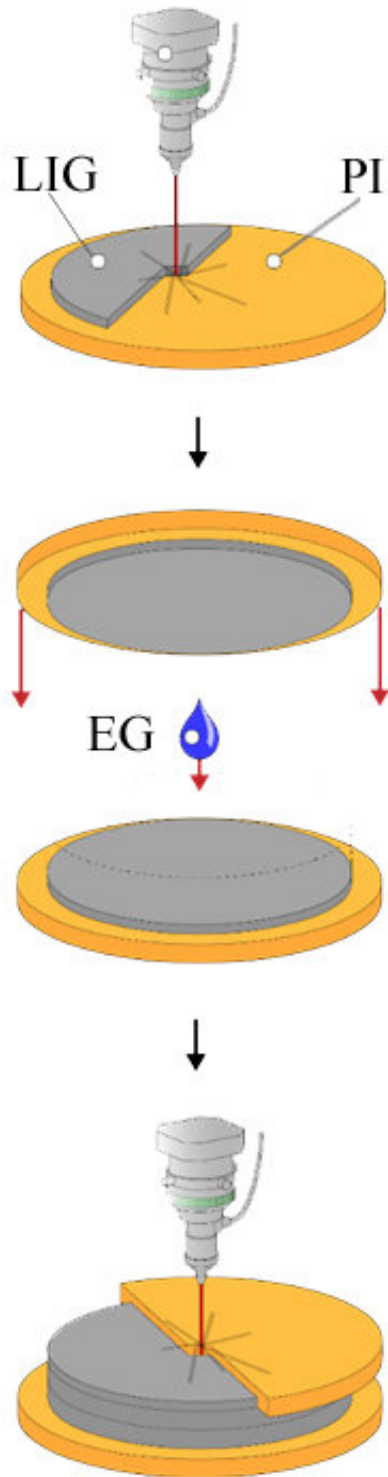
The technique detailed in *Advanced Materials* is an extension of

groundbreaking work by the Tour lab that produced the first laser-induced [graphene](#) (LIG) in 2014 by heating inexpensive polyimide plastic sheets with a laser.

The laser burns halfway through the plastic and turns the top into interconnected flakes of 2-D carbon that remain attached to the bottom half. LIG can be made in macroscale patterns at room temperature.

The lab extended its technique to create LIG on wood and even food, but 3-D objects of pure graphene were less practical until now, Tour said.

"Now we have built a prototype machine that lets us make graphene foam into 3-D objects through automated successive layering and laser exposure," Tour said. "This truly brings graphene into the third dimension without furnaces or the need for metal catalysts, and our process is easily scaled."



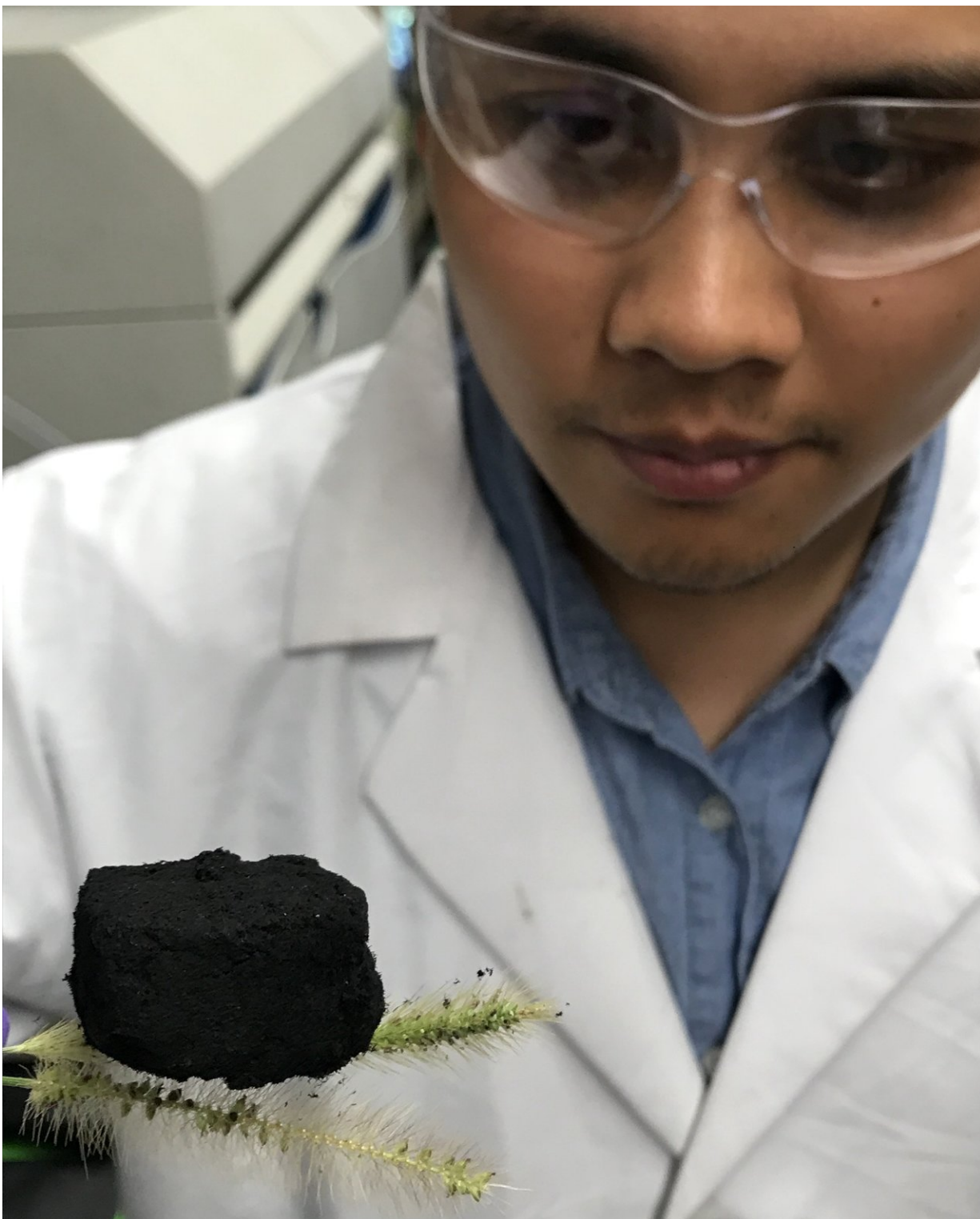
Rice University scientists are making 3-D laser-induced graphene (LIG) foam through an automated process that begins by turning the top layer of a polyimide (PI) sheet into graphene (top), stacking another layer on top (center) with

ethylene glycol (EG) as a binder and then burning the top layer's PI into graphene as well (bottom). The process is repeated as necessary to build up a 3-D block that can be shaped. Credit: Tour Group/Rice University

The new method is based on laminated object manufacturing, in which layers of a material are assembled and then cut to shape. In this case, the bottom LIG layer remains attached to its polyimide base. A second layer is coated with ethylene glycol and placed facedown on the first, like a jelly sandwich. Its polyimide top is then burned into graphene; the process is repeated until the block is complete.

The [ethylene glycol](#) binder is evaporated away on a hot plate, and any remaining polyimide can be removed in a furnace. That leaves a pristine, spongy carbon block, said Duy Xuan Luong, a Rice graduate student and co-lead author of the paper. The Rice lab stacked up to five layers of foam and then used a custom-built fiber lasing system on a modified 3-D printer to mill the block into complex shapes.

The lab assembled proof-of-concept lithium-ion capacitors that used 3-D LIG as both anodes and cathodes. The anode's gravimetric capacity of 354 milliamp hours per gram neared the theoretical limit of graphite, while the cathode's capacity exceeded the average capacity of other carbon materials. Full test cells retained about 70 percent of their capacity after 970 charge-discharge cycles.



Rice University graduate student Duy Xuan Luong suspends a three-dimensional block of laser-induced graphene atop two willows. The lab uses an industrial

laser to transform inexpensive polyimide plastic into graphene foam at room temperature, and then binds the sheets to produce lightweight, conductive 3-D graphene. Credit: Rice University

"This is excellent performance in these new-generation lithium-ion capacitors, which capture the best properties of lithium-ion batteries and capacitor hybrids," Tour said.

The researchers then infused a block of 3-D LIG with liquid polydimethylsiloxane through its 20- to 30-nanometer pores. This created a stronger, still-flexible, conductive material without changing the original foam's shape. From this material, they made a flexible sensor that accurately recorded the pulse from the wrist of a volunteer and said further calibration of the device would let them extract blood pressure from the pulse waveform.

More information: Duy Xuan Luong et al, Laminated Object Manufacturing of 3D-Printed Laser-Induced Graphene Foams, *Advanced Materials* (2018). [DOI: 10.1002/adma.201707416](https://doi.org/10.1002/adma.201707416)

Provided by Rice University

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