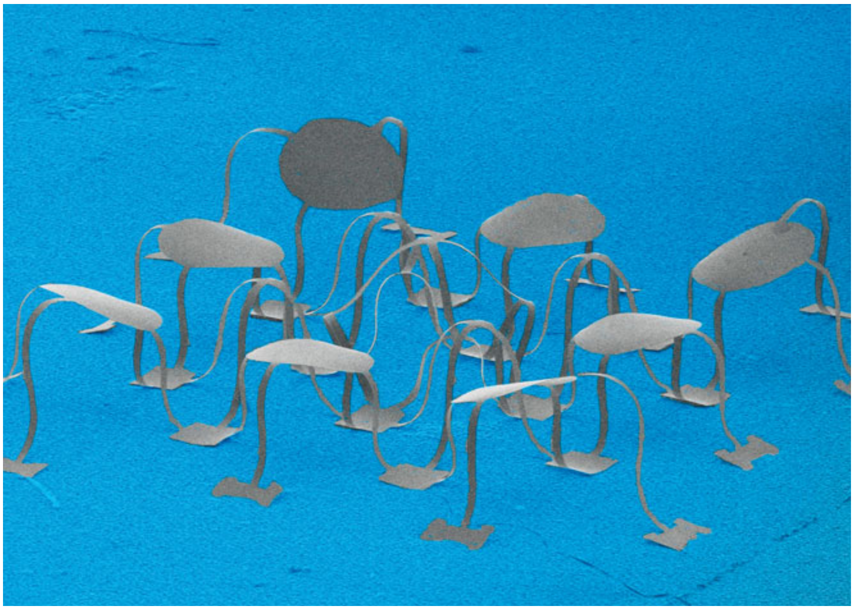
Compressive buckling converts 2D microstructures and nanostructures into 3D

A fundamental limitation in the microfabrication industry is the inherent planarity (two-dimensional [2D] nature) of most commercial lithographic processes. Meanwhile, demand for three-dimensional (3D) microarchitectures for use in biomedical devices, electronics, and energy storage is increasing. In the January 9 issue of *Science* (DOI: 10.1126/science.1260960; p. 154), John Rogers of the University of Illinois at Urbana-Champaign and Yonggang Huang of Northwestern University have reported a scalable, commercially viable technique for the controlled fabrication of electronics-grade silicon 3D "pop-up" microarchitectures.

"The concept of origami is very popular these days in engineering," said Rogers, lead author of the study; "unfortunately it does not scale down very effectively." Therefore, instead of selectively forming creases, as in traditional origami, Rogers lithographically patterns attachment points between thin ribbons made of silicon, or other materials, and a stretched elastomer sheet. This leads to controlled buckling as the elastomer compresses. David Gracias, a professor at The Johns Hopkins University, who was not involved in the work, said, "The paper reports a beautiful combination of modeling and experiments, and the study has scientific, technological, and even aesthetic appeal."

The attachments are formed on the silicon strip by lithographically defined selective exposure to ozone, producing patterns of surface hydroxyl terminations. Meanwhile, the silicone elastomer sheet is stretched to a large strain (>70%) and ozone-treated to uniformly hydroxylate its surface. On contact, the silicon covalently bonds to the elastomer only at the lithographically defined regions. Upon release of the strain, the elastomer compresses, thereby producing silicon 3D microarchitectures in a "pop-up" process. For fun, Rogers notes, "We can build prototypes of our structures at the macroscale, to quickly explore designs and gain a better intuitive feel for the geometries, by using automated paper cutters and glue."



Mesoscale network of silicon "tent" and "tilted table" structures. Each tabletop is about 500 µm wide. Image credit: J. Rogers, University of Illinois at Urbana-Champaign.

Over 40 unique structures are reported, including multilevel or "hierarchical" geometries. To Rogers, determining the range of topographies that can be achieved "is an interesting mathematical challenge. For example, you can't make a sphere but you could make a basket. So you can decrease the width of the ribbons and increase their density to get close to a sphere." This is where Huang comes in. He has developed a computer model for prediction of 3D structures. Huang's program can rapidly test combinations of 2D strip geometries and attachment points, saving the time and expense of fabrication. In many cases, the predicted structures differ from the experimentally observed structures by less than 10%.

Composite 3D architectures were also fabricated, including a mechanically tunable inductor with polyimide-encapsulated metal conducting layers. The ability to incorporate electronics-grade dielectrics, metals, and semiconductors is a defining aspect of this work. While techniques such as 3D printing are compatible with certain ceramics, polymers, and metals, the technique described by Rogers and Huang is completely compatible with advanced electronic and optoelectronic materials and device designs.

Rogers envisions a role for these 3D structures in the biomedical field as well. "The ability to fabricate high performance silicon sensors in these 3D, porous geometries make it an attractive type of 'active,' or 'electronic,' scaffold for tissue cultures. These platforms offer the potential for monitoring the growth and behavior of cells by collecting thermal and electronic data and measuring stresses and strains. We believe that we will also be able to stimulate their behaviors."

Gracias foresees wide-ranging potential applications for the structures due to their inherent integration of device-grade silicon and flexible substrates. "This concept could be used to create a variety of wearables, implants, and flexible analog devices," Gracias said. The future of microdevices is looking (pop-) up!

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