Nanoscale ripples provide key to unlocking thin material properties in electronics

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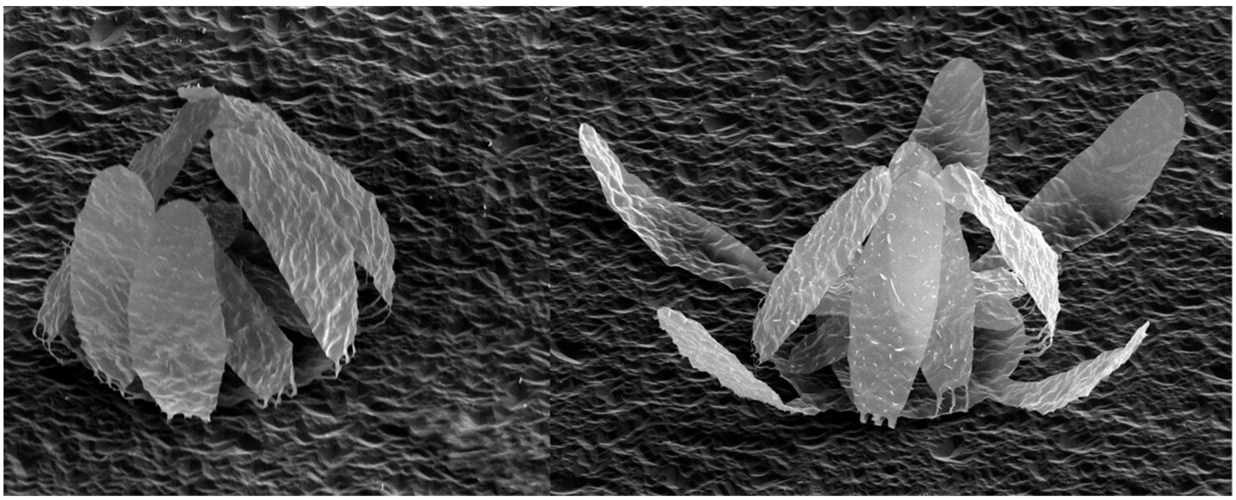


An electron micrograph shows nanometer-thick kirigami structures that highlight the advantages of using rippled metamaterials as structural films. The incorporation of rippled metamaterials allows for enhanced control over the final three-dimensional architecture. Image Credit: Jian Zhou.

When materials are created on a nanometer scale—just a handful of atoms thick—even the thermal energy present at room temperature can cause structural ripples. How these ripples affect the mechanical properties of these thin materials can limit their use in electronics and other key systems.

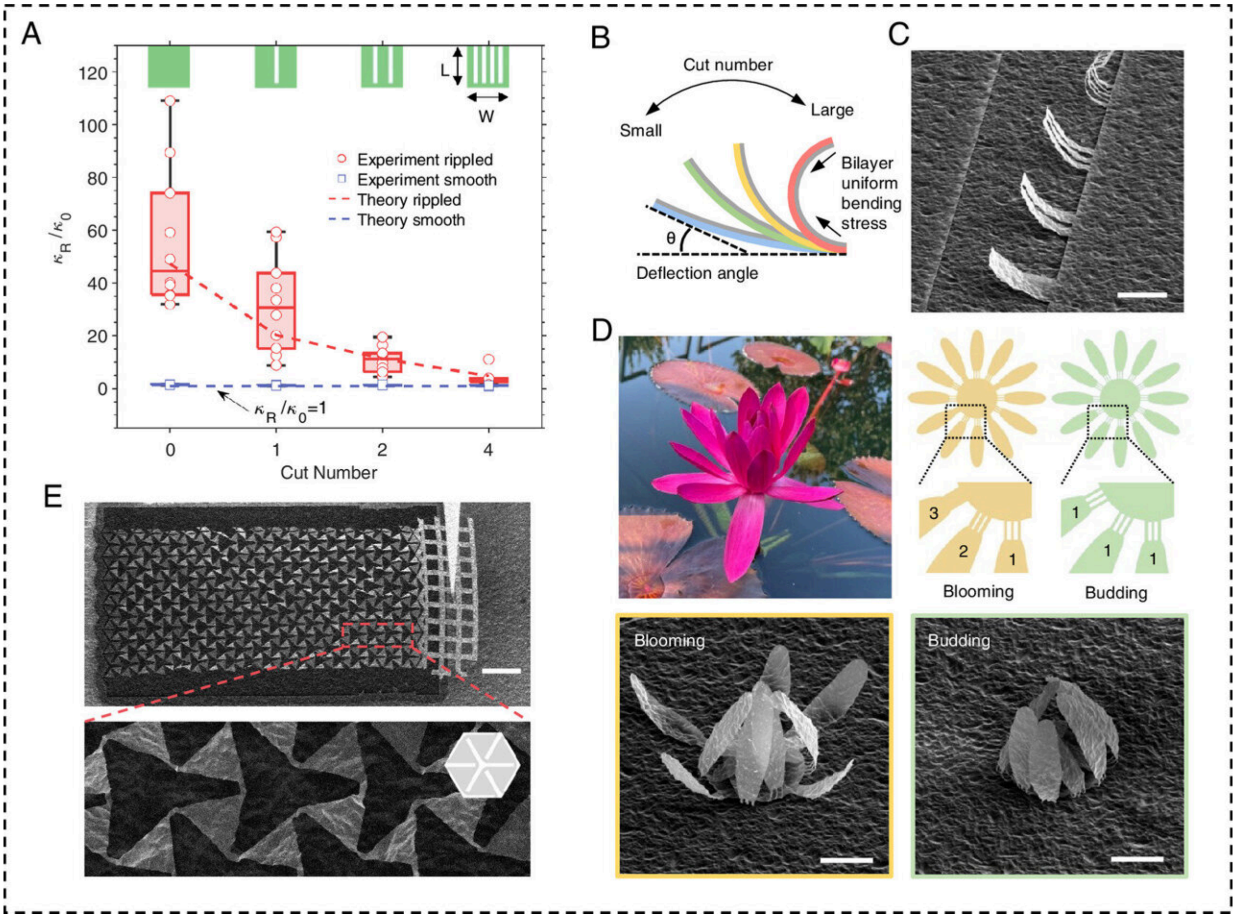
New research validates theoretical models about how elasticity is scale-dependent—in other words, the elastic properties of a material are not constant, but vary with the size of the piece of material.

Assistant Professor Jian Zhou, Ph.D. '18, collaborated with researchers from Argonne National Laboratory, Harvard University, Princeton University and Penn State University for a recently published paper in the *Proceedings of the National Academy of Sciences.*

Using a semiconductor manufacturing process, the team created alumina structures 28 nanometers thick (more than 1,000 times thinner than the diameter of a human hair) on the silicon wafer with thermal-like static ripples, then tested them with lasers to measure their behavior. To remove possible stress to the material that could affect the results, cantilevers held the wafers during testing.

The results matched with theories proposed by the research group led by noted Harvard Professor David R. Nelson, one of the contributors to this new study.

"This is the first time we can characterize precisely what the ripple effect is on thin film," said Zhou, a faculty member at the Thomas J. Watson College of Engineering and Applied Science's Department of Mechanical Engineering.



Tailorable mechanical properties of rippled films through cutting. Credit: *Proceedings of the National Academy of Sciences* (2025). DOI: 10.1073/pnas.2425200122

Knowing the effects of ripples is important because microelectronics, micromechanical devices, microscopic robots and other devices could be fabricated from thin films, leading to innovations in medicine, computing and other technologies.

In a lighthearted moment, Zhou and his collaborators employed the knowledge they gained to bend the material into nanoscopic flowers.

"Once we know more about the mechanical properties, we can create better structures like micro-robotics with precise control over the geometries we want," he said. "For example, I can introduce real-time controlled actuations where initially it's one shape, and when we apply some excitation, it can be something else—like a Transformer."

More information: Jian Zhou et al, Rippled metamaterials with scale-dependent tailorable elasticity, *Proceedings of the National Academy of Sciences* (2025). DOI: 10.1073/pnas.2425200122

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