Topological origami and kirigami techniques applied experimentally to metamaterials

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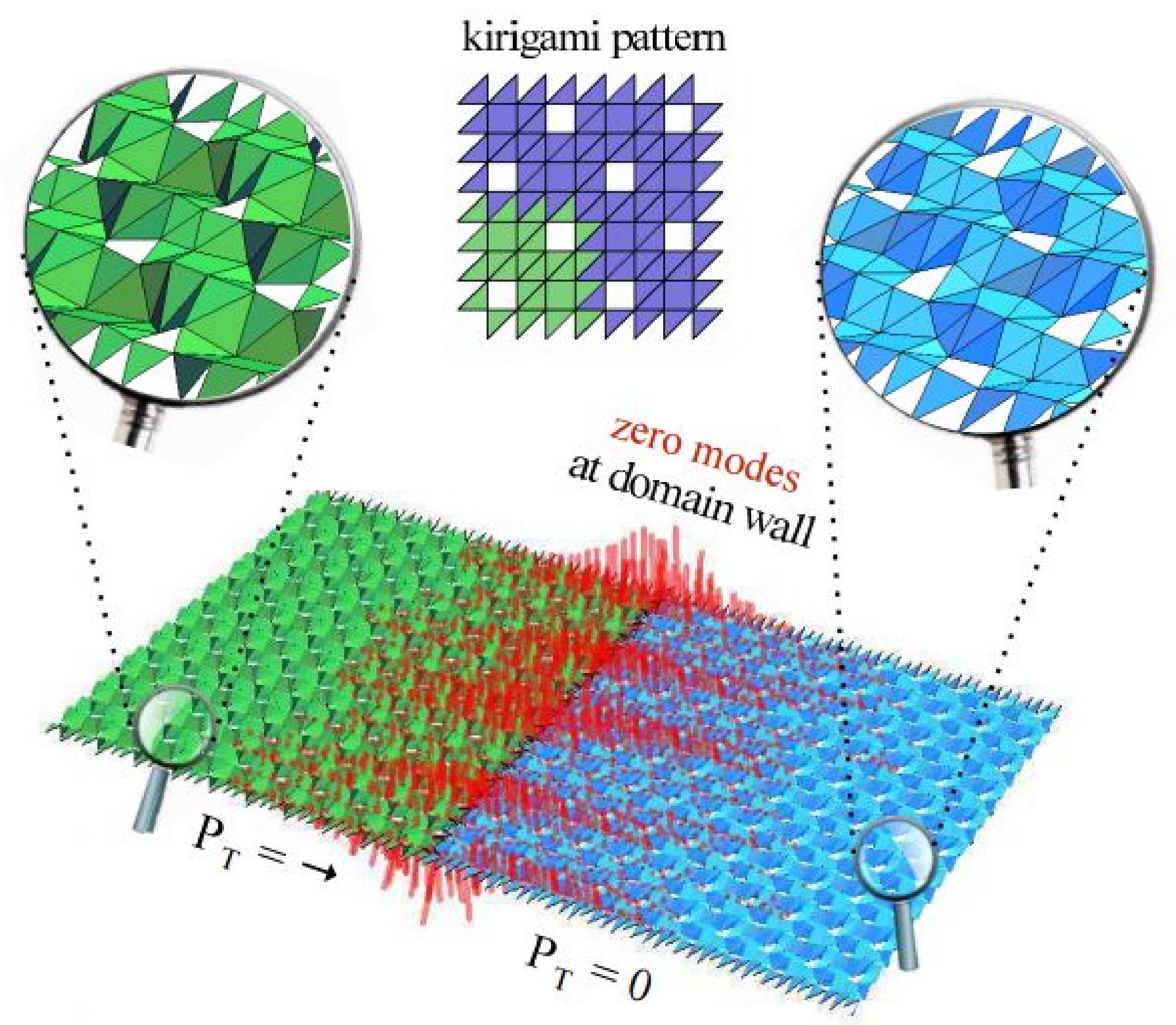

Topologically protected zero mode (red) in a kirigami heterostructure. Credit: arXiv:1508.00795 [cond-mat.soft]

(Phys.org)—A team of researchers with members from Universiteit Leiden in the Netherlands, Cornell University and the University of Massachusetts has developed for the first time metamaterials that are based on topological origami and kirigami techniques. In their paper published in *Physical Review Letters*, the team describes their techniques and the benefits of such materials.

Over the past several years as researchers have looked for new ways to create metamaterials—those that are artificial that have well-defined, tunable properties—they have become increasingly interested in the Japanese arts of origami (paper folding) and kirigami (paper folding and cutting). Thousands of years of working with paper has led to constructs that exhibit remarkable properties, (it has also been noted that the ancient art could lead to the creation of metamaterials with properties such as Poisson ratio, curvature and states that could be tuned using nothing but geometric criteria) which modern researchers would like to apply to new metamaterial development efforts. In this new endeavor, the researchers used their knowledge of origami to construct a metamaterial that has the properties of being soft along one edge, while remaining stiff on the other—two distinct topological phases while being made from a just single base material.

The work by the team was an extension of research done two years ago by a team at the University of Pennsylvania that came up with the idea of "topological mechanics" which was itself based on topological states seen in quantum mechanics. That led to the discovery that simple mechanical structures could be created that were polarized, which in this sense, meant soft along one side and hard along another.

The researchers report that their metamaterial was made by hooking plastic four-sided units together via hinges, which resulted in a single long, but thin rectangular structure. Squishing the structure from the ends caused it to buckle in a uniform way leading to the formation of hills and valleys—the folds slowly transitioned from soft at one end to rigid at the other. The team notes that bigger versions of the material could be made but only by applying kirigami techniques, i.e. cutting out certain sections. They suggest other materials could be created using similar techniques for mechanical or industrial applications.

More information: Bryan Gin-ge Chen et al. Topological Mechanics of Origami and Kirigami, *Physical Review Letters* (2016). DOI: 10.1103/PhysRevLett.116.135501 , On *Arxiv*: arxiv.org/abs/1508.00795

ABSTRACT
Origami and kirigami have emerged as potential tools for the design of mechanical metamaterials whose properties such as curvature, Poisson ratio, and existence of metastable states can be tuned using purely geometric criteria. A major obstacle to exploiting this property is the scarcity of tools to identify and program the flexibility of fold patterns. We exploit a recent connection between spring networks and quantum topological states to design origami with localized folding motions at boundaries and study them both experimentally and theoretically. These folding motions exist due to an underlying topological invariant rather than a local imbalance between constraints and degrees of freedom. We give a simple example of a quasi-1D folding pattern that realizes such topological states. We also demonstrate how to generalize these topological design principles to two dimensions. A striking consequence is that a domain wall between two topologically distinct, mechanically rigid structures is deformable even when constraints locally match the degrees of freedom.

kirigami-techniques-experimentally.html