Researchers remotely control sequence in which 2-D sheets fold into 3-D structures

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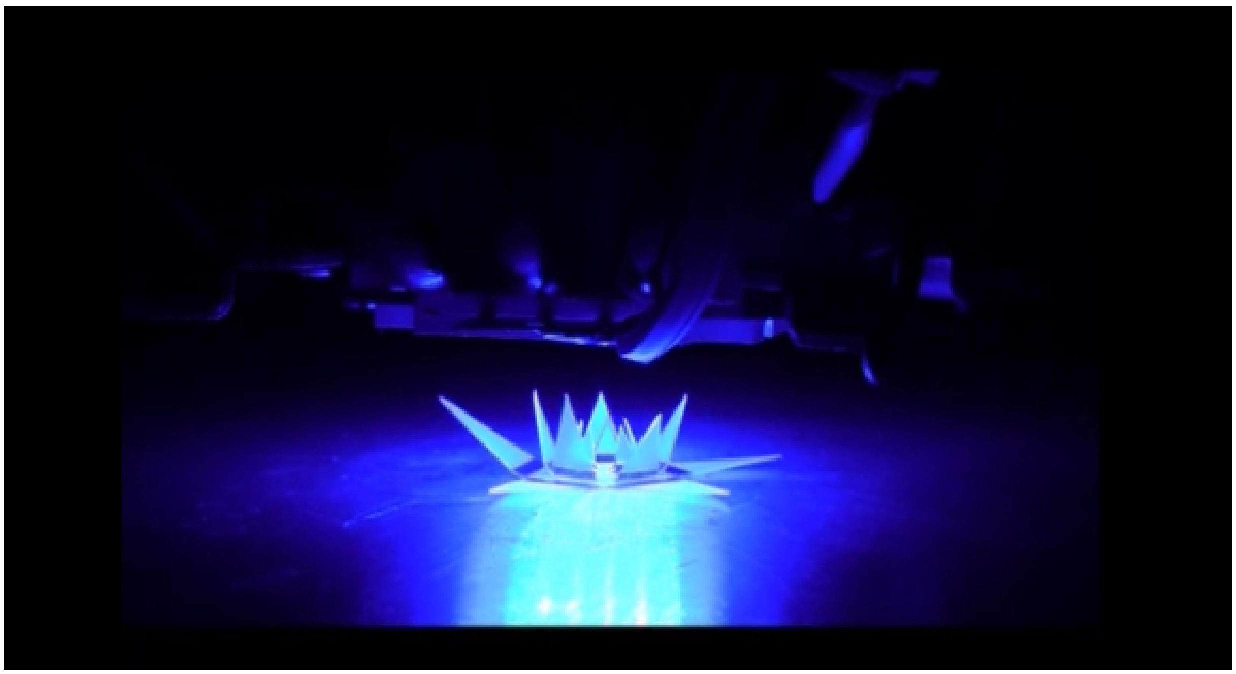

Inspired by origami, North Carolina State University researchers have found a way to remotely control the order in which a two-dimensional (2-D) sheet folds itself into a three-dimensional (3-D) structure.

"A longstanding challenge in the field has been finding a way to control the sequence in which a 2-D sheet will fold itself into a 3-D object," says

Michael Dickey, a professor of chemical and biomolecular engineering at NC State and co-corresponding author of a paper describing the work. "And as anyone who has done origami - or folded their laundry—can tell you, the order in which you make the folds can be extremely important."

"The sequence of folding is important in life as well as in technology," says co-corresponding author Jan Genzer, the S. Frank and Doris Culberson Distinguished Professor of Chemical and Biomolecular Engineering at NC State. "On small length scales, sequential folding via molecular machinery enables DNA to pack efficiently into chromosomes and assists proteins to adopt a functional conformation. On large length scales, sequential folding via motors helps solar panels in satellites and space shuttles unfold in space. The advance of the current work is to induce materials to fold sequentially using only light."

Specifically, the researchers have developed a technique to design and fabricate 2-D materials that can be controlled remotely in order to trigger any of the given folds to take place, in any order.

Dickey and Genzer were early leaders in the field of self-folding 3-D structures. In their landmark 2011 paper, the researchers outlined a technique in which a pre-stressed plastic sheet was run through a conventional inkjet printer to print bold black lines on the material. The material was then cut into a desired pattern and placed under an infrared light, such as a heat lamp.

The printed lines absorbed more energy than the rest of the material, causing the plastic to contract—creating a hinge that folded the sheets into 3-D shapes. By varying the width of the printed lines, or hinges, the researchers were able to change how far—and how quickly—each hinge folds. The technique is compatible with commercial printing techniques, such as screen printing, roll-to-roll printing, and inkjet printing, that are inexpensive and high-throughput but inherently 2-D.

The new advance uses essentially the same technique, but takes advantage of the fact that different colors of ink absorb different wavelengths, or colors, of light.

"By printing the hinges in different colors, we can control the order of the folds by altering the wavelengths of light that shines on the 2-D sheet," Genzer says.

For example, if one hinge is printed in yellow and another hinge is printed in blue, the researchers can make the yellow hinge fold by exposing it to blue light. The blue hinge won't fold, because blue ink doesn't absorb blue light. The researchers can then make the blue hinge fold by exposing the sheet to red light.

In addition, by manipulating the colors of ink, the researchers were also able to get hinges to fold sequentially when exposed to a single wavelength of light. This is possible because some colors will absorb a given wavelength of light more efficiently than others.

"This is a proof-of-concept paper, but it opens the door to a range of potential applications using a simple and inexpensive process," Dickey says.

"Ultimately, people are interested in self-assembling structures for multiple reasons, from shipping things in a flat package and having them assemble on site to having devices self-assemble in 'clean' environments for medical or electronic applications."

The paper, "Sequential Self-folding of Polymer Sheets," is published in the journal *Science Advances*.

More information: "Sequential self-folding of polymer sheets"

Science Advances, advances.sciencemag.org/content/3/3/e1602417

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