Microscopic 'sunflowers' for better solar panels

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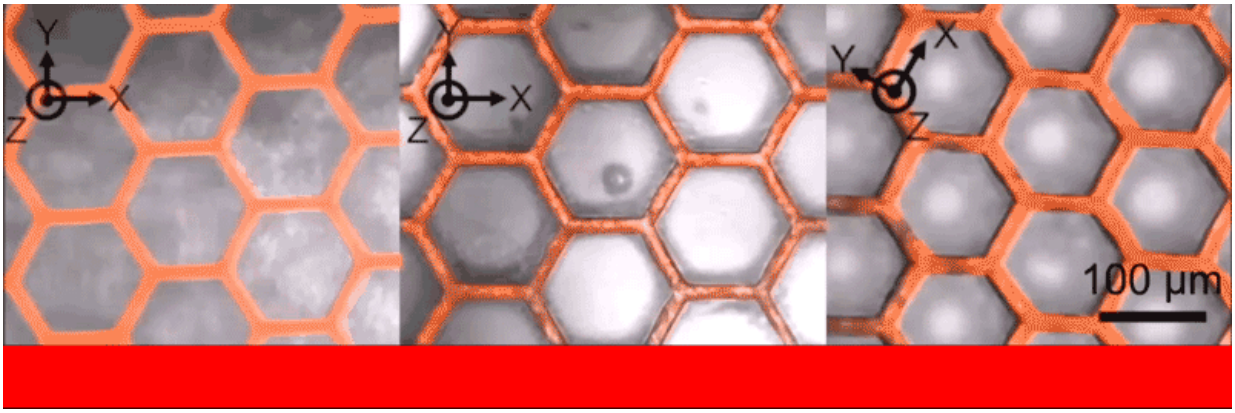

Liquid crystal elastomers deform in response to heat, and the shape they take depends on the alignment of their internal crystalline elements, which can be determined by exposing them to different magnetic fields during formation. Credit: Wyss Institute at Harvard University

The pads of geckos' notoriously sticky feet are covered with setae—microscopic, hairlike structures whose chemical and physical composition and high flexibility allow the lizard to grip walls and ceilings with ease. Scientists have tried to replicate such dynamic microstructures in the lab with a variety of materials, including liquid crystal elastomers (LCEs), which are rubbery networks with attached liquid crystalline groups that dictate the directions in which the LCEs can move and stretch. So far, synthetic LCEs have mostly been able to

deform in only one or two dimensions, limiting the structures' ability to move throughout space and take on different shapes.

Now, a group of scientists from Harvard's Wyss Institute for Biologically Inspired Engineering and John A. Paulson School of Engineering and Applied Sciences (SEAS) has harnessed magnetic fields to control the molecular structure of LCEs and create microscopic three-dimensional polymer shapes that can be programmed to move in any direction in response to multiple types of stimuli. The work, reported in *PNAS*, could lead to the creation of a number of useful devices, including solar panels that turn to follow the sun for improved energy capture.

"What's critical about this project is that we are able to control the molecular structure by aligning liquid crystals in an arbitrary direction in 3-D space, allowing us to program nearly any shape into the geometry of the material itself," said first author Yuxing Yao, who is a graduate student in the lab of Wyss Founding Core Faculty Member Joanna Aizenberg, Ph.D.

The microstructures created by Yao and Aizenberg's team are made of LCEs cast into arbitrary shapes that can deform in response to heat, light, and humidity, and whose specific reconfiguration is controlled by their own chemical and material properties.The researchers found that by exposing the LCE precursors to a magnetic field while they were being synthesized, all the liquid crystalline elements inside the LCEs lined up along the magnetic field and retained this molecular alignment after the polymer solidified. By varying the direction of the magnetic field during this process, the scientists could dictate how the resulting LCE shapes would deform when heated to a temperature that disrupted the orientation of their liquid crystalline structures. When returned to ambient temperature, the deformed structures resumed their initial, internally oriented shape.

Such programmed shape changes could be used to create encrypted messages that are only revealed when heated to a specific temperature, actuators for tiny soft robots, or adhesive materials whose stickiness can be switched on and off. The system can also cause shapes to autonomously bend in directions that would usually require the input of some energy to achieve. For example, an LCE plate was shown to not only undergo "traditional" out-of-plane bending, but also in-plane bending or twisting, elongation, and contraction. Additionally, unique motions could be achieved by exposing different regions of an LCE structure to multiple magnetic fields during polymerization, which then deformed in different directions when heated.

Micropillars made of a light-responsive liquid crystal elastomer (LCE) re-orient themselves to follow light coming from different directions, which could lead to more efficient solar panels. Credit: Wyss Institute at Harvard University

The team was also able to program their LCE shapes to reconfigure themselves in response to light by incorporating light-sensitive cross-linking molecules into the structure during polymerization. Then, when the structure was illuminated from a certain direction, the side facing the light contracted, causing the entire shape to bend toward the light. This type of self-regulated motion allows LCEs to deform in response to their environment and continuously reorient themselves to autonomously follow the light.

Additionally, LCEs can be created with both heat- and light-responsive properties, such that a single-material structure is now capable of multiple forms of movement and response mechanisms.

One exciting application of these multiresponsive LCEs is the creation of solar panels covered with microstructures that turn to follow the sun as it moves across the sky like a sunflower, thus resulting in more efficient light capture. The technology could also form the basis of autonomous source-following radios, multilevel encryption, sensors, and smart buildings.

"Our lab currently has several ongoing projects in which we're working on controlling the chemistry of these LCEs to enable unique, previously unseen deformation behaviors, as we believe these dynamic bioinspired structures have the potential to find use in a number of fields," said Aizenberg, who is also the Amy Smith Berylson Professor of Material Science at SEAS.

"Asking fundamental questions about how Nature works and whether it is possible to replicate biological structures and processes in the lab is at the core of the Wyss Institute's values, and can often lead to innovations that not only match Nature's abilities, but improve on them to create new materials and devices that would not exist otherwise," said Wyss Institute Founding Director Donald Ingber, M.D., Ph.D., who is also the Judah Folkman Professor of Vascular Biology at Harvard Medical School and the Vascular Biology Program at Boston Children's Hospital, as well as Professor of Bioengineering at SEAS.

More information: Yuxing Yao el al., "Multiresponsive polymeric microstructures with encoded predetermined and self-regulated deformability," *PNAS* (2018).
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