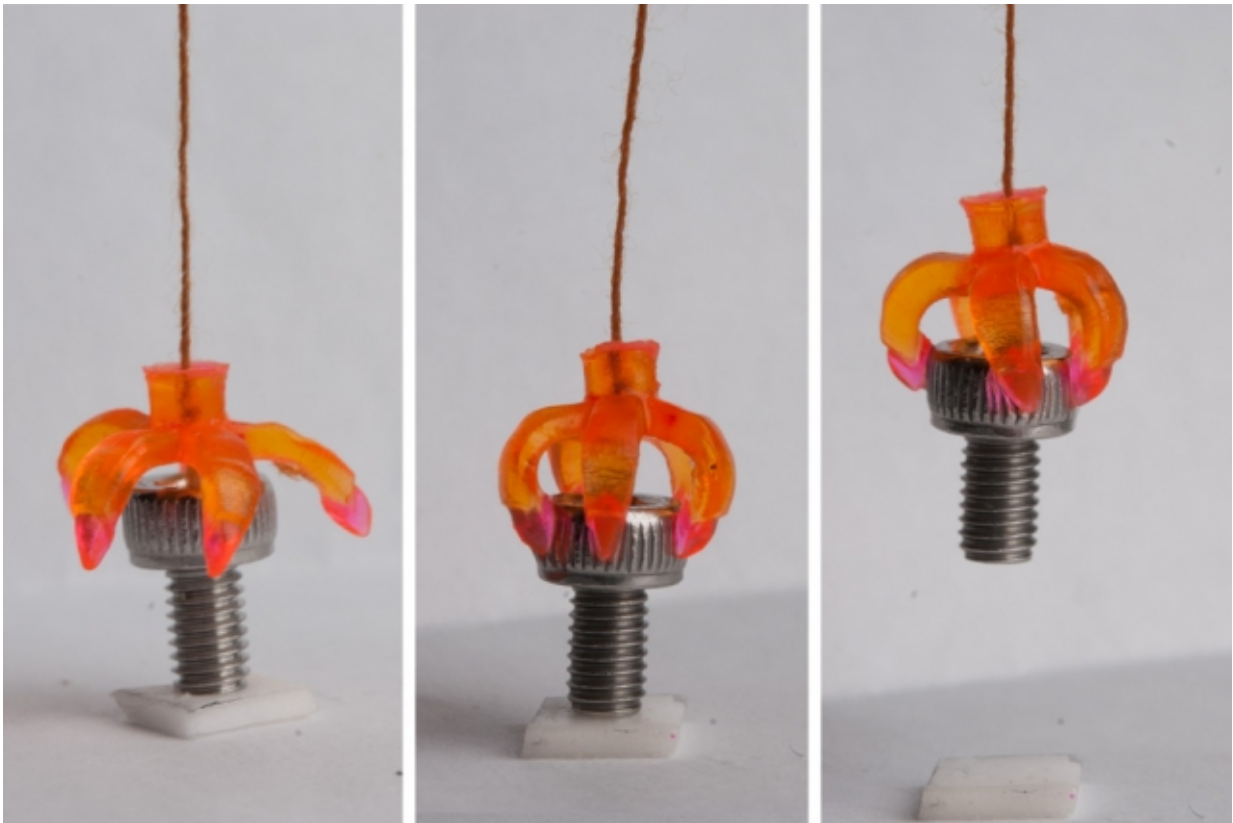


3-D printed structures that 'remember' their shapes

August 26 2016, by Jennifer Chu



In this series, a 3-D printed multimaterial shape-memory minigripper, consisting of shape-memory hinges and adaptive touching tips, grasps a cap screw. Credit: Qi (Kevin) Ge

Engineers from MIT and Singapore University of Technology and

Design (SUTD) are using light to print three-dimensional structures that "remember" their original shapes. Even after being stretched, twisted, and bent at extreme angles, the structures—from small coils and multimaterial flowers, to an inch-tall replica of the Eiffel tower—sprang back to their original forms within seconds of being heated to a certain temperature "sweet spot."

For some structures, the researchers were able to print micron-scale features as small as the diameter of a human hair—dimensions that are at least one-tenth as big as what others have been able to achieve with printable shape-memory materials. The team's results were published earlier this month in the online journal *Scientific Reports*.

Nicholas X. Fang, associate professor of mechanical engineering at MIT, says [shape-memory polymers](#) that can predictably morph in response to temperature can be useful for a number of applications, from soft actuators that turn solar panels toward the sun, to tiny drug capsules that open upon early signs of infection.

"We ultimately want to use body temperature as a trigger," Fang says. "If we can design these polymers properly, we may be able to form a drug delivery device that will only release medicine at the sign of a fever."

Fang's coauthors include former MIT-SUTD research fellow Qi "Kevin" Ge, now an assistant professor at SUTD; former MIT research associate Howon Lee, now an assistant professor at Rutgers University; and others from SUTD and Georgia Institute of Technology.

Ge says the process of 3-D printing shape-memory materials can also be thought of as 4-D printing, as the structures are designed to change over the fourth dimension—time.

"Our method not only enables 4-D printing at the micron-scale, but also

suggests recipes to print shape-memory polymers that can be stretched 10 times larger than those printed by commercial 3-D printers," Ge says. "This will advance 4-D printing into a wide variety of practical applications, including biomedical devices, deployable aerospace structures, and shape-changing photovoltaic solar cells."

Need for speed

Fang and others have been exploring the use of soft, active materials as reliable, pliable tools. These new and emerging materials, which include shape-memory polymers, can stretch and deform dramatically in response to environmental stimuli such as heat, light, and electricity—properties that researchers have been investigating for use in biomedical devices, soft robotics, wearable sensors, and artificial muscles.



A shape-memory Eiffel tower was 3-D printed using projection microstereolithography. It is shown recovering from being bent, after toughening on a heated Singapore dollar coin. Credit: Qi (Kevin) Ge

Shape-memory polymers are particularly intriguing: These materials can switch between two states—a harder, low-temperature, amorphous state, and a soft, high-temperature, rubbery state. The bent and stretched shapes can be "frozen" at room temperature, and when heated the materials will "remember" and snap back to their original sturdy form.

To fabricate shape-memory structures, some researchers have looked to 3-D printing, as the technology allows them to custom-design structures with relatively fine detail. However, using conventional 3-D printers, researchers have only been able to design structures with details no smaller than a few millimeters. Fang says this size restriction also limits how fast the material can recover its original shape.

"The reality is that, if you're able to make it to much smaller dimensions, these materials can actually respond very quickly, within seconds," Fang says. "For example, a flower can release pollen in milliseconds. It can only do that because its actuation mechanisms are at the micron scale."

Printing with light

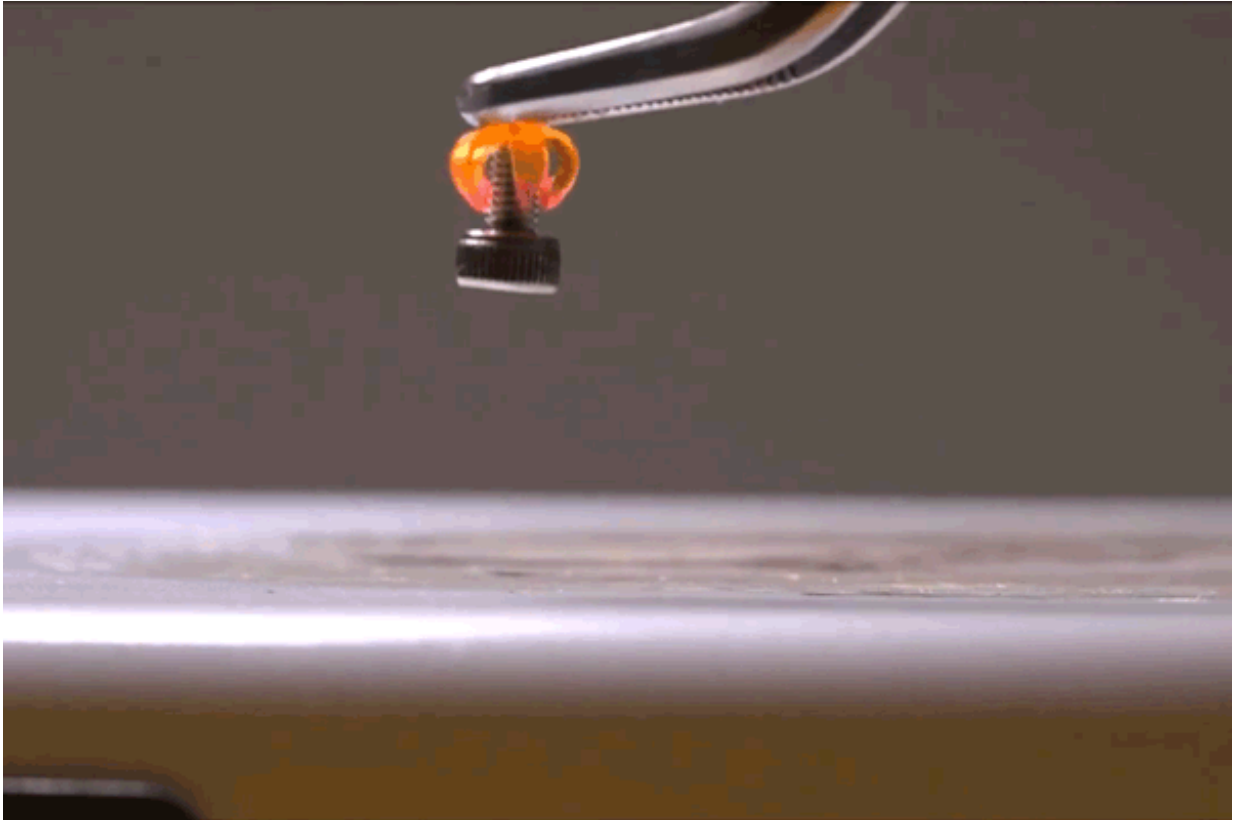
To print shape-memory structures with even finer details, Fang and his colleagues used a 3-D printing process they have pioneered, called microstereolithography, in which they use light from a projector to print patterns on successive layers of resin.

The researchers first create a model of a structure using computer-aided design (CAD) software, then divide the model into hundreds of slices, each of which they send through the projector as a bitmap—an image file format that represents each layer as an arrangement of very fine pixels. The projector then shines light in the pattern of the bitmap, onto a liquid resin, or polymer solution, etching the pattern into the resin, which then solidifies.

"We're printing with light, layer by layer," Fang says. "It's almost like how dentists form replicas of teeth and fill cavities, except that we're doing it with high-resolution lenses that come from the semiconductor industry, which give us intricate parts, with dimensions comparable to the diameter of a human hair."

The researchers then looked through the scientific literature to identify an ideal mix of polymers to create a shape-memory material on which to print their light patterns. They picked two polymers, one composed of long-chain polymers, or spaghetti-like strands, and the other resembling more of a stiff scaffold. When mixed together and cured, the material can be stretched and twisted dramatically without breaking.

What's more, the material can bounce back to its original printed form, within a specific temperature range—in this case, between 40 and 180 degrees Celsius (104 to 356 degrees Fahrenheit).



Credit: Massachusetts Institute of Technology

The team printed a variety of structures, including coils, flowers, and the miniature Eiffel tower, whose full-size counterpart is known for its intricate steel and beam patterns. Fang found that the structures could be stretched to three times their original length without breaking. When they were exposed to heat within the range of 40 C to 180 C, they snapped back to their original shapes within seconds.

"Because we're using our own printers that offer much smaller pixel size, we're seeing much faster response, on the order of seconds," Fang says. "If we can push to even smaller dimensions, we may also be able to push their response time, to milliseconds."

"This is a very advanced 3-D printing method compared to traditional nozzle or ink-jet based printers," says Shaochen Chen, professor of nano-engineering at the University of California at San Diego, who was not involved in the research. "The method's main advantages are faster printing and better structural integrity."

Soft grip

To demonstrate a simple application for the shape-memory structures, Fang and his colleagues printed a small, rubbery, claw-like gripper. They attached a thin handle to the base of the gripper, then stretched the gripper's claws open. When they cranked the temperature of the surrounding air to at least 40 C, the gripper closed around whatever the engineers placed beneath it.

"The grippers are a nice example of how manipulation can be done with soft materials," Fang says. "We showed that it is possible to pick up a small bolt, and also even fish eggs and soft tofu. That type of soft grip is probably very unique and beneficial."

Going forward, he hopes to find combinations of polymers to make shape-memory materials that react to slightly lower temperatures, approaching the range of human body temperatures, to design soft, active, controllable drug delivery capsules. He says the material may also be printed as soft, responsive hinges to help solar panels track the sun.

"Very often, excessive heat will build up on the back side of the solar cell, so you could use [shape-memory materials] as an actuation mechanism to tune the inclination angle of the solar cell," Fang says. "So we think there will probably be more applications that we can demonstrate."

More information: Qi Ge et al. Multimaterial 4D Printing with

Tailorable Shape Memory Polymers, *Scientific Reports* (2016). [DOI: 10.1038/srep31110](https://doi.org/10.1038/srep31110)

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