

3-D printing technique accelerates nanoscale fabrication 1000-fold

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A millimeter-scale structure with submicron features is supported on a U.S. penny on top of a reflective surface. Credit: Vu Nguyen and Sourabh Saha

Using a new time-based method to control light from an ultrafast laser,



researchers have developed a nanoscale 3-D printing technique that can fabricate tiny structures 1000 times faster than conventional two-photon lithography (TPL) techniques, without sacrificing resolution.

Despite the high throughput, the new parallelized technique—known as femtosecond projection TPL (FP-TPL)—produces depth resolution of 175 nanometers, which is better than established methods and can fabricate structures with 90-degree overhangs that can't currently be made. The technique could lead to manufacturing-scale production of bioscaffolds, flexible electronics, electrochemical interfaces, microoptics, mechanical and optical metamaterials, and other functional micro- and nanostructures.

The work, reported Oct. 3 in the journal *Science*, was done by researchers from Lawrence Livermore National Laboratory (LLNL) and The Chinese University of Hong Kong. Sourabh Saha, the paper's lead and corresponding author, is now an assistant professor in the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology.

Existing nanoscale additive manufacturing techniques use a single spot of high-intensity light—typically around 700 to 800 nanometers in diameter—to convert photopolymer materials from liquids to solids. Because the point must scan through the entire <u>structure</u> being fabricated, the existing TPL technique can require many hours to produce complex 3-D structures, which limits its ability to be scaled up for practical applications.

"Instead of using a single point of light, we project a million points simultaneously," said Saha. "This scales up the process dramatically because instead of working with a single point that has to be scanned to create the structure, we can use an entire plane of projected light. Instead of focusing a single point, we have an entire focused plane that can be



patterned into arbitrary structures."

To create a million points, the researchers use a digital mask similar to those used in projectors to create images and videos. In this case, the mask controls a <u>femtosecond laser</u> to create the desired light pattern in the precursor liquid polymer material. The high-intensity light causes a polymerization reaction that turns the liquid to solid, where desired, to create 3-D structures.





A stacked 3D ring structure generated by overlapping several projections in 3D space. Arbitrarily complex 3D structures can be generated through this depth-resolved nanoscale 3D printing technique. Credit: Vu Nguyen and Sourabh Saha

Each layer of the fabricated structure is formed by a 35-femtosecond



burst of high-intensity light. The projector and mask are then used to create layer after layer until the entire structure is produced. The liquid polymer is then removed, leaving behind the solid. The FP-TPL technique allows the researchers to produce in eight minutes a structure that would take several hours to produce using earlier processes.

"The parallel two-photon system that has been developed is a breakthrough in nanoscale printing that will enable the remarkable performance in materials and structures at this size scale to be realized in usable components," said LLNL's Center for Engineered Materials and Manufacturing Director Chris Spadaccini.

Unlike consumer 3-D printing that uses particles sprayed onto a surface, the new technique goes deep into the liquid precursor, allowing the fabrication of structures that could not be produced with surface fabrication alone. For instance, the technique can produce what Saha calls an "impossible bridge" with 90-degree overhangs and with more than a 1,000:1 aspect ratio of length to feature size. "We can project the light to any depth that we want in the material, so we can make suspended 3-D structures," he said.

The researchers have printed suspended structures a millimeter long between bases that are smaller than 100 microns by 100 microns. The structure doesn't collapse while being fabricated because the liquid and solid are about the same density—and the production happens so quickly that the liquid doesn't have time to be disturbed.

Beyond bridges, the researchers made a variety of structures chosen to demonstrate the technique, including micro-pillars, cuboids, log-piles, wires and spirals. The researchers used conventional polymer precursors, but Saha believes the technique would also work for metals and ceramics that can be generated from precursor polymers.



"The real application for this would be in industrial-scale production of small devices that may be integrated into larger products, such as components in smartphones," he said. "The next step is to demonstrate that we can print with other materials to expand the material palette."



Overhanging 3D structures printed by stitching multiple 2D projections, demonstrating the ability to print depth-resolved features. The bridge structure, with 90-degree overhangs, is challenging to print using serial scanning TPL techniques. Credit: Vu Nguyen and Sourabh Saha

Research groups have been working for years to accelerate the twophoton lithography process used to produce nanoscale 3-D structures. The success of this group came from adopting a different way of focusing the light, using its time-domain properties, which allowed production of very thin light sheets capable of high resolution—and tiny features.

Use of the femtosecond laser allowed the research team to maintain



enough light intensity to trigger the two-photon process polymerization while keeping the point sizes thin. In the FP-TPL technique, the femtosecond pulses are stretched and compressed as they pass through the optical system to implement temporal focusing. The process, which can generate 3-D features smaller than the diffraction-limited, focused <u>light</u> spot, requires that two photons hit the liquid precursor molecules simultaneously.

"Traditionally, there are tradeoffs between speed and resolution," Saha said. "If you want a faster process, you would lose resolution. We have broken this engineering tradeoff, allowing us to print 1000 times faster with the smallest of features."

At Georgia Tech, Saha intends to continue advancing the work with new materials and further scale-up of the process.

"So far, we have shown that we can do pretty well on speed and resolution," he said. "The next questions will be how well we can predict the features and how well we can control the quality over large scales. That will require more work to understand the process itself."

More information: Scalable submicrometer additive manufacturing. *Science* 2019. <u>science.sciencemag.org/lookup/ ... 1126/science.aax8760</u>

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