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# Inverse woodpile structure has extremely large photonic band gap

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CHAMPAIGN, Ill. — As many homeowners know, when stacking firewood, pieces should be placed close enough to permit passage of a mouse, but not of a cat chasing the mouse.

*Click photo to enlarge*

Photo by L. Brian Stauffer

Paul Braun, a University Scholar and a professor of materials science and engineering, and Jennifer Lewis, the Thurnauer Professor of Materials Science and Engineering and interim director of the Frederick Seitz Materials Research Laboratory, have created a germanium inverse woodpile structure that has one of the widest photonic band gaps ever reported.

Now, imagine a woodpile where all those mouse passageways are packed with ice, the wood carefully removed, and you have an idea of what the latest photonic structure built by researchers at the University of Illinois looks like.

It's called an inverse woodpile structure, and the U. of I. device is built of germanium, a material with a higher refractive index than silicon.

"Until now, all woodpile structures have been composed of solid or hollow rods in an air matrix," said Paul Braun, a University Scholar and a professor of materials science and engineering at the U. of I. "Our structure is composed of a germanium matrix containing a periodic array of tubular holes, made possible by a unique and flexible fabrication technique."

In a paper accepted for publication in the journal Advanced Materials, and posted on its Web site, Braun and his co-authors describe the fabrication and optical properties of their germanium inverse woodpile structure; a structure with one of the widest photonic band gaps ever reported.

"A wider band gap means there is a broader spectral range where you can control the flow of light," said Braun, who also is affiliated with the university's Beckman Institute, Frederick Seitz Materials Research Laboratory, and Micro and Nanotechnology Laboratory. "In many applications, from low-threshold lasers to highly efficient solar cells, photonic crystals with wide band gaps may be required."

To create their germanium inverse woodpile structure, the researchers first produced a polymer template by using a robotic deposition process called direct-write assembly.

The process employs a concentrated polymeric ink, dispensed as a filament to form the woodpile rods, from a nozzle approximately 1 micron in diameter (a micron is 1 millionth of a meter, approximately 50 times smaller than the diameter of a human hair).

The nozzle dispenses the ink into a reservoir on a computer-controlled, three-axis micropositioner. After the pattern for the first layer is generated, the nozzle is raised and another layer is deposited. This process is repeated until the desired three-dimensional structure is produced.

Next, the researchers deposited a sacrificial coating of aluminum oxide and silicon dioxide onto the entire structure. The coating enlarged the rods and increased the contact area between them. The space between the rods was subsequently filled with germanium.

The researchers then heated the structure to burn away the polymer template. Lastly, the sacrificial oxide coating was dissolved by acid, leaving behind a tiny block of germanium with an inner network of interconnected tubes and channels.

The finished structure – built and tested as a proof of concept – consists of 12 layers of tubes and measures approximately 0.5 millimeters by 0.5 millimeters, and approximately 15 microns thick.

"The direct-write template approach offers new design rules, which allows us to fabricate structures we otherwise could not have made," said co-author Jennifer Lewis, the Thurnauer Professor of Materials Science and Engineering and interim director of the Frederick Seitz Materials Research Laboratory.

"Our technique also can be adopted for converting other polymeric woodpile templates, such as those made by laser-writing or electro-beam lithography, into inverse woodpile structures," Lewis said.

In addition to their potential as photonic materials, the interconnected, inverse woodpile structures could find use as low-cost microelectromechanical systems, microfluidic networks for heat dissipation, and biological devices.

With Braun and Lewis, co-authors of the paper are postdoctoral research associate Florencio García-Santamaria and graduate student Mingjie Xu, both at Illinois; electrical engineering professor Shanhui Fan at Stanford University; and physicist Virginie Lousse at the Laboratoire de Physique du Solide in Belgium.

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