Researchers at Illinois, led by Paul Braun, a professor of materials science and engineering and of chemistry, have demonstrated the first optoelectronically active 3D photonic crystal. Photo: L. Brian Stauffer

In an advance that could open new avenues for solar cells, lasers, metamaterials, and more, researchers at the University of Illinois have demonstrated the first optoelectronically active 3D photonic crystal.

“We've discovered a way to change the three-dimensional structure of a well-established semiconductor material to enable new optical properties while maintaining its very attractive electrical properties,” says Paul Braun, a professor of materials science and engineering and of chemistry who led the research effort.

The team published its advance in *Nature Materials*.

Photonic crystals are materials that can control or manipulate light in unexpected ways thanks to their unique physical structures. Photonic crystals can induce unusual phenomena and affect photon behavior in ways that traditional optical materials and devices can’t. They are popular materials of study for applications in lasers, solar energy, LEDs, metamaterials, and more.

However, previous attempts at making 3D photonic crystals have resulted in devices that are only optically active—that is, they can direct light—but not electronically active, so they can’t turn electricity to light or vice versa.

The Illinois team’s photonic crystal has both properties.

“With our approach to fabricating photonic crystals, there’s a lot of potential simultaneously,” says Erik Nelson, a former graduate student in Braun’s lab who now is a postdoctoral researcher at Harvard University. “With our approach to fabricating photonic crystals, there’s a lot of potential simultaneously,” says Erik Nelson, a former graduate student in Braun’s lab who now is a postdoctoral researcher at Harvard University.

To create a 3D photonic crystal that is both electronically and optically active, the researchers started with a template of gallium arsenide (GaAs), a widely used semiconductor, through the template, filling in the gaps between the spheres.

The GaAs grows as a single crystal from the bottom up, a process called epitaxy. Epitaxy is common in industry to create 2D films of single-crystal semiconductors, but Braun’s group developed a way to apply it to an intricate 3D structure.

“The key discovery here was that we grew single-crystal semiconductor through this complex template,” says Braun, who;
Using an epitaxial approach, researchers developed a 3D photonic crystal LED, the first such optoelectronic device. Image: Eric Nelson

is affiliated with the Beckman Institute for Advanced Science and Technology and with the Frederick Seitz Materials Research Laboratory at Illinois. "Gallium arsenide wants to grow as a film on the substrate from the bottom up, but it runs into the template and goes around it. It's almost as though the template is filling up with water. As long as you keep growing GaAs, it keeps filling the template from the bottom up until you reach the top surface."

The epitaxial approach eliminates many of the defects introduced by top-down fabrication methods, a popular pathway for creating 3D photonic structures. Another advantage is the ease of creating layered heterostructures. For example, a quantum well layer could be introduced into the photonic crystal by partially filling the template with GaAs and then briefly switching the vapor stream to another material.

Once the template is full, the researchers remove the spheres, leaving a complex, porous 3D structure of single-crystal semiconductor. Then they coat the entire structure with a very thin layer of a semiconductor with a wider bandgap to improve performance and prevent surface recombination.

To test their technique, the group built a 3D photonic crystal LED—the first such working device.

Now, Braun's group is working to optimize the structure for specific applications. The LED demonstrates that the concept produces functional devices, but by tweaking the structure or using other semiconductor materials, researchers can improve solar collection or target specific wavelengths for metamaterials applications or low-threshold lasers.

"From this point on, it's a matter of changing the device geometry to achieve whatever properties you want," Nelson says. "It really opens up a whole new area of research into extremely efficient or novel energy devices."

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