Three-Dimensional Photonic Crystals Shine

In work that could improve solar cells and LEDs, researchers have, for the first time, made practical working devices out of three-dimensional photonic crystals.

By Katherine Bourzac

For the first time, researchers have made high-quality three-dimensional photonic crystals and used them to make a highly efficient light-emitting diode (LED). Three-dimensional photonic crystals promise to boost the performance of just about any optical device, be it a display, a solar cell, or an efficient lightbulb—but until now, no one had been able to make them using commercially viable methods or workable materials. Researchers at the University of Illinois at Urbana-Champaign are now working on solar cells based on the structures.

Photonic crystals can control the absorption, emission, and movement of light in a very precise way based on their structure. They've been a hot area of research since the late 1980s. So far, it's only been practical to make flat, two-dimensional photonic crystals. These control the movement of light very well in two dimensions, but not perfectly in the third. Still, they've been very successful. A company called Luxtera, for example, has developed ways of building photonic-crystal-based optical interconnects directly onto computer chips. Bringing optical signals closer to computer processors helps speed data transmission, and using photonic crystals helps keep the size of these links compact. Luminus has focused on LEDs, for which the crystals help improve light output, making these devices brighter and more power-efficient.

However, three-dimensional photonic crystals would make even better optical devices. "The key advantage is, you can really control the propagation of light in all dimensions," says Paul Braun, professor of materials science and engineering at the University of Illinois. Braun is leading the work on three-dimensional photonic crystals, and his group is also working on making solar cells from the crystals.

Making these structures is tricky. Photonic crystal structures vary, but they're often made by drilling nanoscale holes, rods, and other features into a material. Patterning a flat slab of material with the necessary nanoscale structures to make a two-dimensional photonic crystal is a relatively simple process. It's far more difficult to get that kind of patterning into a thick chunk of material to make a three-dimensional structure without degrading the material. And the kinds of photonic crystals that are most useful—those that can actively convert between electrical signals and optical ones, in addition to precisely manipulating the flow of light—are the hardest to make because material flaws are introduced during the process. This light-to-electricity and back conversion is critical in LEDs, solar cells, and optical data interconnects for computing.

The University of Illinois group made high-quality three-dimensional photonic crystals by growing them on a template, from the bottom up, rather than by trying to introduce the nanoscale patterns into hunks of material. The researchers start by making the template, stacks of packed nanoscale spheres. They then put the template inside a vapor-deposition chamber and flow in a series of gases containing gallium and arsenide. The materials get deposited onto the template and grow around it. It's like filling up a box of ping-pong balls with water: the material that's flowed in fills the spaces between the spheres. Then they chemically remove the spheres, leaving behind a three-dimensional photonic crystal—a hunk of crystalline gallium arsenide that's riddled with nanoscale holes.
Gallium arsenide is used to make optical devices such as photodetectors, but making it into three-dimensional photonic crystals has not been possible before. Not only were the Illinois researchers able to make a three-dimensional photonic crystal out of the material, they were also able to use it to make an LED that's driven by an electrical current.

“I've been waiting a long time for someone to accomplish what [the Illinois group] has accomplished,” says Eli Yablanovitch, a professor of electrical engineering and computer science at the University of California, Berkeley. In the late 1980s, Yablanovitch did some of the foundational work on photonic crystals, advancing the idea that certain designs can emit light in a very controlled way that's useful for LEDs.

Yablanovitch says it's difficult to predict what will result from this work, and when, because no one has made practical three-dimensional photonic crystals before. “Some of the most compelling applications are already being filled by two-dimensional photonic crystals,” he says. If it becomes as easy to make three-dimensional photonic crystals as it is to make their flat counterparts already in products, they would always be the first choice, says Yablanovitch.

The technology is probably still several years away from commercialization, says Braun.

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