Tiny lasers get a notch up

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Tiny disk-shaped lasers as small as a speck of dust could one day beam information through optical computers. Unfortunately, a perfect disk will spray light out, not as a beam, but in all directions. New theoretical results, reported in the Optical Society (OSA) journal *Optics Letters*, explain how adding a small notch to the disk edge provides a single outlet for laser light to stream out.

To increase the speed of computers and telecommunication networks, researchers are looking to replace electrical currents with beams of light that would originate from small semiconductor lasers. However, shrinking lasers down to a few micrometers in size is not easy. The typical laser builds up its concentrated light beam by bouncing light rays, or modes, back and forth inside a reflective cavity. This linear design is not practical for microlasers. Instead, scientists discovered in 1992 that they could get light amplification by having rays bounce around in a circle inside a small flat disk. These light rays are called "whispering gallery modes" because they are similar to sound waves that travel across a room by skimming along a curved wall or ceiling.

The problem is that a disk is rotationally invariant, so there is no preferred direction for the amplified light to escape. Many microlaser designs end up shooting light out in multiple directions within the plane of the disk. "The experimentalists have a holy grail of unidirectional emission in microlasers," says Martina Hentschel of the Max Planck Institute for the Physics of Complex Systems. In the past few years, some progress has been made with so-called spiral microlasers, which have a tiny notch that resembles the outer opening of a snail shell.

Certain experiments have shown that light tends to propagate in a single direction from the notch. But other experiments have not been so lucky. In order to understand these contrasting results, Hentschel and her colleague Tae-Yoon Kwon have performed a systematic study of spiral microlasers using a state-of-the-art theoretical description.

Physicists typically treat the light rays trapped inside a cavity as if they were billiard balls bouncing off walls, Hentschel explains. Some light rays escape, but those rays that just barely graze the inside surface are fully reflected back into the cavity (this being the same effect that channels light beams along optical fibers). Unfortunately, this simple "billiard" model is not sufficient for explaining spiral microlasers, Hentschel says.

Hentschel and Kwon therefore chose a more sophisticated model based on the electromagnetic wave and laser equations. This framework allowed the researchers to control what part of the semiconductor material would be excited, or "pumped," to a light-emitting state. Numerical calculations showed that the two whispering gallery modes inside a spiral cavity—one traveling clockwise, the other counterclockwise—are coupled together, but only one of these modes is able to escape out through the spiral's notch. To maximize this unidirectional emission, the researchers found that the notch size should be roughly twice the wavelength of the light. Moreover, the pumping needs to be confined to the rim of the spiral, specifically the outer 10 percent. These parameters could aid in the design of better-collimated microlasers. "The optimal geometry and boundary pumping is very useful to know for an experimentalist," Hentschel says.

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