THE PRACTICAL POLARITON LASER

New design could be key to on-chip optical interconnects

Lasers have largely replaced the copper wiring of old to speedily stream bits among servers in large data centers. Engineers have long dreamed that they could use lasers to do the same within the servers’ data-congested processors, too. One problem standing in their way is that even the most efficient lasers need an awful lot of current before they light up. But a new kind of device, the polariton laser, could light the way using merely a trickle of electrons. Until recently, however, the device has worked only in an impractical environment.

Now, researchers at the University of Michigan have built the first polariton laser that both runs on electricity and operates at room temperature. It emits coherent light when provided with a current of only 169 amperes per square centimeter. A similar structure operating as an ordinary laser would take more than 250 times as much current, and even the best gallium nitride laser, enhanced with quantum dots, requires at least 1000 A/cm² before it starts lasing.

The difference comes from the way the device works. In a conventional laser, incoming current raises electrons to a higher energy state; once a majority are in that state, they can suddenly drop to a lower state and emit photons, an action known as stimulated emission. In contrast, a polariton laser works via the stimulated scattering of polaritons—quasiparticles that combine an electron, a hole, and a photon and that can exist only within a crystal. When energy is pumped into the system, the polaritons absorb it, then quickly release it as photons. Unlike with electrons in conventional lasers, the majority of polaritons don’t have to be excited before lasing can begin, so the so-called lasing threshold—the energy required to start the process—is much lower.

“Forty years, we’ve had one kind of coherent light source—the laser,” says Pallab Bhattacharya, professor of electrical engineering at Michigan, who reported the work in June in Physical Review Letters. “This coherent light source is based on a completely different physical principle.”

Polariton lasers were first described in 1996. In the years that followed, researchers developed several versions that used the light from other lasers as an energy source. Last year, Bhattacharya’s group and a separate team of Southampton, in England, who was not involved in the work.

The difference in the physics also means the device can be switched on and off much faster than conventional lasers. That capability for fast modulation, plus the lower power requirements, points to a use in optical communications, such as across a computer chip, or as part of an optical memory system.

Bhattacharya says that success with this laser came from a fundamental change to the design. Previous attempts used a vertical structure, in which the lasing material was sandwiched between two sections of distributed Bragg reflectors, with the light eventually emerging from the top of the laser. The reflectors were alternating layers of material with different indices of refraction that reflected photons back into the lasing cavity. The structure required 20 to 25 pairs of alternating layers, however, which increased electrical resistance. Pumping in more energy to overcome the resistance disrupted the polaritons and destroyed the lasing effect.

This time, Bhattacharya used a horizontal lasing cavity 690 nanometers long, not much bigger than the wavelength of the light it would emit. The cavity is capped at either end with distributed Bragg reflectors built of alternating layers of silicon dioxide and titanium dioxide, five on one end and six on the other. The gallium nitride lasing material sits on top of a layer of indium aluminum nitride, which acts as a barrier, preventing photons from leaking out of the bottom; air acts as a barrier on the top. Instead of the kilo-ohms of resistance in the previous design, this device has only 10 ohms. “That is really the turning point,” Bhattacharya says.

The new laser is very simple to fabricate, according to Bhattacharya, which he says could speed commercial versions. He’s experimenting with other materials to get emissions at longer wavelengths; this laser emits in the ultraviolet, whereas most optical communications rely on the near infrared. But, he says, for chipmakers faced with a data bottleneck in processors and other complex chips, any working device would prove valuable, no matter what the wavelength. “If you put a laser on silicon, anybody will take any color they can get.”

—Neil Savage