LIGHT FROM SILICON

Lasers and microprocessors could be made on the same chip

By Neil Savage

HOLY GRAIL Data has become a creature of light. The high-bandwidth transmissions that link computers across the Internet are possible only because lasers can send vast numbers of signals through tiny glass fibers. But silicon, the stuff of memory and microprocessors, has little to do with it.

Instead, for bits to become illuminated, silicon circuits must first connect to separate lasers made of more exotic and expensive compound semiconductors. If silicon emitted a useful amount of light, the microprocessors and memory could export data directly as light, simplifying circuit boards and speeding computation by avoiding the data bottleneck that copper interconnects are becoming. Indeed, silicon lasers might even speed signals, such as the all-important clock pulse, within microprocessors.

Since the early days of the laser in the 1960s, physicists have known they could squeeze a few photons out of silicon. But they accomplished little more than that until 1990, when work by British researcher Leigh Canham provided the first glimmer of hope that the speed of the microprocessor could be married to the huge bandwidth of optics. In a burst of excitement, as many as 100 research groups around the world tried to stimulate silicon to produce more light, but for years they managed to get no more than about 1 percent of the energy they poured in to come out as photons.

Silicon has an indirect bandgap. That means the energy states of the charge carriers—negative electrons and positive electron deficiencies called holes—don't match well, and when they combine, they're much more likely to produce a vibration than a photon, making more heat than light. So optoelectronics are instead made from costly compound semiconductors, such as gallium arsenide. And because the crystalline structure of gallium arsenide is different from that of silicon, they don't fit together on the same chip.

But the dream of silicon-laser-powered computing and communications is closer than ever. Salvatore Coffa, research director of soft computing, silicon optics, and postsilicon technologies for STMicroelectronics NV, in Geneva, says STM will sell the world's first commercial device based on silicon light emission by the middle of this year. An optocoupler the company has in mind would use a silicon light-emitting diode (LED) to convert an electrical signal into light, and then back, to link two circuits with different voltages.

Coffa's research group, in Catania, Italy, has made LEDs that convert 15 percent of the electrons injected into them into photons, an external quantum efficiency in the same range as that of gallium arsenide. They emit 1 mW of light per square millimeter of silicon, which Coffa calls "really bright." With fine-tuning to optimize such characteristics as output and lifetime, these LEDs could also compete in microdisplays or solid-state lighting, he claims.

The silicon in the LEDs consists of nanocrystals, tiny clumps measuring only a few nanometers across. Their size changes the physics, so the silicon is more likely to emit light. Coffa's group dopes these "quantum dots" with ions of rare earths; which rare earth is used determines the color of the light.

Philippe M. Fauchet, chairman of electrical and computer engineering at the University of Rochester, in New York, says Coffa's work seems promising, and a commercial product could really stimulate the field. But an LED doesn't have the power, directionality, and narrow spectrum of a laser. Fauchet believes a silicon laser, if it can be created, would be necessary for optical interconnects on a chip. "In my group, we are working very hard on this," he says. "It is not so easy, of course."

But Coffa sees a light at the end of the tunnel, and it's coming from silicon. "I will be very surprised if you don't see the first prototype of the laser in a year from now," he says. He's not promising, though, that a silicon laser will ever be good enough to provide an optical interconnect.

Cautions another scientist working on silicon lasers, Lorenzo Pavesi of Italy's Università di Trento in Povo: "It could take months, or years, or even forever."■

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ride at moderately high temperatures of from 300 to 500 °C and pressures of 200 to 500 megaPascals (about 2000–5000 atmospheres). The work is still preliminary. But so far, the researchers have succeeded in producing only small shards of gallium nitride a couple of millimeters across and a centimeter or so long.

At the GE Global Research Center in Niskayuna, N.Y., researchers are pursuing a technique similar to Mitsubishi's, but with even higher temperatures and pressures: 600 to 1000 °C and 500 to 2000 megaPascals (5000–20 000 atmospheres). They have been able to produce single-crystal gallium nitride substrates 1–2 mm thick with an area of 15 by 18 mm^2. Researchers have made considerable progress, says Mark P. D'Evelyn, manager of GE Global's Ceramic Processing Laboratory, and have measured defect densities less than 200/cm^2. But much more work remains before the product is ready to be commercialized.

Meanwhile, ATMI Inc., in Danbury, Conn., is using an approach similar to Sumitomo's, but with a starting substrate of sapphire instead of gallium arsenide. ATMI scientists grow the desired thickness of gallium nitride, then remove the sapphire to leave a free-standing layer of single-crystal gallium nitride. The company has begun to sell engineering quantities of 50-mm wafers with uniform dislocation densities of 10^6/cm^2. An advantage of the uniformity, says Allan Salant, the company's manager of development engineering, is that laser diodes built on its wafers are not restricted in device size or location.

In total, the number of companies and research institutions developing gallium nitride substrates has climbed to more than 20. And the rate at which the technology is advancing is testimony to the importance of this material. At this time, there is little doubt that we will have commercial quantities of low-dislocation-density gallium nitride substrates in the near future. The questions are only by what methods and from whom. ■