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Ride the Light

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Teaching silicon new photonic tricks promises a huge boost in getting data out of a computer

In his lab at Sun Microsystems' San Diego Physical Sciences Center, Ashok Krishnamoorthy is surrounded by big numbers: looming powerful computers that can crank through a trillion operations per second. But what commands his attention these days is something very small: a prototype silicon chip, only a few millimeters on a side, that works like a magic gateway between muscle-bound computers.

Although still a hatchling, this so-called silicon photonic chip, devised by a Carlsbad, Calif. startup called Luxtera, could mark the beginning of a new Internet era when computers will be able to tap into huge reserves of data, no matter where they are situated, as easily as they now retrieve data from their own hard drives. "It will mean that distance truly won't matter anymore," says Arno Penzias, a Nobel laureate and one of Luxtera's venture backers. "Wherever you are, you can share in all the world's information."

Big promises come in small packages. Luxtera's chip is neatly hidden inside a component that looks like a gold-covered mint wafer. Metal pins along three sides both secure the piece to a circuit board and deliver streams of bits to the silicon device. On the fourth side of the component is a plug that resembles a telephone jack. Krishnamoorthy slides a bundle of fiber-optic threads into the plug. One thread is attached to a laser.

As the pins deliver bits sent from another computer, the laser pumps a steady stream of light into the chip. Inside, a modulator works like a tiny shutter, imprinting the bits onto the incoming laser light. The light signals do a victory lap in the device, then head out on a path that runs parallel to the one they came in on. The signals spill onto an optical fiber, then travel another 20 meters before reaching a detector, a chip that transforms the light signals back into electrical ones. "We've been working with Luxtera for almost a year now," says Krishnamoorthy. "I have personally tested the modulators to 10 gigabits a second." That's fast enough to send a DVD movie in four seconds.

Silicon photonics aims to solve what has become one of the huge bottlenecks in the information age, the movement of data in and out of computers. For the past 40 years computer chips have grown faster as designers have marched steadily to the drumbeat of Moore's Law, roughly doubling the number of transistors on a swatch of silicon every two years. By shortening the distance electrons travel, they've made chips go faster. But like an automobile pulling out of the driveway, electrons that venture outside a chip must follow some path--usually copper--to reach their next destination. Intel's top-of-the-line Pentium 4 runs at 3.7 gigahertz and relies on a souped-up "bus" that is about a quarter of that speed.

Designers have invented clever shortcuts for electrons, like Sun's recent approach for nudging separate chips closer together and zapping data between them. But radically improved performance calls for the use of photons, or particles of light, which are 250,000 times lighter than electrons and can fly in close formation, squeezing lots of data into a small space. Telephone companies spent the 1990s ripping out copper lines and replacing them with optical fiber and expensive networking gear to turn digital signals into light waves. This was never a cheap trick, though, depending on compound semiconductors such as indium phosphide and gallium arsenide, which don't enjoy the mass-manufacturing economies of silicon, the mainstay of the computing universe.

"Silicon always wins," points out Cary Gunn, a cofounder and vice president of Luxtera. If optical devices could be built in silicon, the cost of communicating data would fall.

Silicon is finicky about light. Tickle compound semiconductors with enough electrons and they spit back photons (the telecom industry uses them for its optical magic). In the 1980s Eli Yablonovitch, now a professor at UCLA, invented something called photonic crystals, which manipulate light much like transistors shuffle electrons around. Key to building useful photonic crystals, however, was carving tiny structures into semiconductors.

In the late 1990s, after nine years in the Air Force, Gunn wound up in graduate school at the California Institute of Technology working with Axel Scherer, one of the world's experts in building very tiny electronic and photonic structures. By then the enormous manufacturing muscle of the silicon chip industry had pushed the size of key chip components down to roughly 100 nanometers--a quarter of the wavelength of infrared light, which is widely used by the telecom industry. Only at these tiny dimensions can engineers manipulate the electrons buzzing within silicon to change its photonic properties. "That turned the corner," says Yablonovitch, who cofounded Luxtera with Gunn and Scherer. The challenge was to train silicon to modulate laser light fast enough to keep up with the data pouring in from computers.

Scores of inventions had to fall into place. (All told, Luxtera has filed for more than 75 patents; 15 have been issued so far.) The central idea of the modulator depends on the fact that light travels at different speeds through different materials. (Put a pencil in a glass of water and the pencil looks bent because light travels more slowly through water than through air.) Light traveling through silicon usually moves only a third as fast as it would in a vacuum. At the nanoscale level, Luxtera engineers figured out how to tune silicon by applying voltage and thus make light move more sluggishly.

Within the Luxtera chip, light is split along two paths, and the twin beams are nudged out of synch with each other by the modulator, acting upon incoming data. When the beams recombine, they either make a bigger wave or cancel each other out. This way the modulator stamps data onto the light.

Figuring out how to funnel as much light as possible from a laser into the tiny modulator structure is another part of Luxtera's secret sauce. The company also saved enormous trial-and-error time by using a complex modeling program built by two Caltech undergraduates that simulates how light and electrons interact in three dimensions. (They sold it to Luxtera in exchange for founder's equity.)

The timing of the telecom bust helped, too. In November 2001 Luxtera's venture capitalist tapped chip industry veterans, including Alexander Dickinson, who got his start with optical devices at Bell Labs. Minutes after Dickinson signed the papers that gave Luxtera $7 million in seed capital, Gunn bought $2 million worth of test equipment for $200,000 in a fire-sale auction at Nortel. Since then Luxtera has raised another $24 million in venture funding.

That 10 gigabits a second is only a starting point, says Dickinson. Adding light signals of different wavelengths, like creating extra channels, will multiply performance. Shrinking component sizes will also speed the modulator.

Intel researchers are working feverishly on their own silicon photonic components, including modulators, which operate at 4 gigabits a second. Those could be commercial devices by the end of the decade. Last December the Defense Advanced Research Projects Agency kicked off a four-year program to build integrated electronic-photonic devices. "This is potentially a very disruptive technology," says Jagdeep Shah, who manages the Darpa program. "We're sort of like at the early stage of integrated circuits."

Essential to holding down costs is using the same manufacturing tools and factories used to make cheap PC chips. Luxtera is relying on Freescale Semiconductor to build its chips, and in the past 12 months Freescale has been sliding Luxtera's designs right into the standard manufacturing line for the PowerPC chips that go into a range of devices, including Apple computers. David Mothersole, chief technology officer of Freescale's networking business, expects to be making samples for Luxtera's first customers by the end of this year. Although the startup plans to make money by selling its chips to computer systems manufacturers, its director of marketing, Gabriele Sartori, is a staunch advocate of spreading the new technology through licensing.

Luxtera's growing fan club also includes Michael Fister, formerly with Intel and now chief executive of Cadence Design Systems, the leading maker of chip-design software tools. "Demand for high-speed interconnects is strong," he says. "There's good reason to be intrigued with this technology, and Luxtera is definitely worth watching."

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