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IMEC advance hints at all-optical add-drop multiplexers

As bit rates in the optical backbone speed past 40 Gbits/s per wavelength, there is a fundamental problem with the front-end optical-to-electronic conversion process. As Roel Baets, head of the photonics research group at **IMEC**, points out, you can do the optical-to-electronic conversion at 10 Gbits/s, and you can think of ways to do it at 40 Gbits/s. But to convert a single optical pulse train at over 40 Gbits/s to electronic pulses is a daunting prospect at the least. A better approach, were it possible, would be to demultiplex the bit stream optically, producing several lower-rate bit streams that could then be converted.

Such a demultiplexer would require an optical switching device capable of synchronous operation at over 100 Gbits/s—something that had been heretofore only speculation. But a recently-described breakthrough at the University of Karlsruhe, in collaboration with IMEC, Lehigh University, and ETH Zurich, has demonstrated optical demultiplexing at these speeds.

The problem, according to Baets, is basically one of searching for a non-linear optical material. That statement may require some explanation. In ordinary materials, the refractive index is independent of the amount of light energy passing through the material. So if you superimpose two light pulses in a silicon waveguide, for instance, you get the superposition of the two pulses out the other end, in just the same way that you would have recovered either of the pulses independently.

But imagine there were a material that was not linear with respect to light energy—a material that changed its refractive index based on the light-energy density in the material. In such a material, one light pulse could change the way a second pulse propagated.

In fact, some organic materials have just this property. But the change in refractive index is only useful at very high energy densities. The researchers reasoned that if they created a silicon slotted waveguide with a very narrow slot—on the order of 100 nm wide—and then deposited such a nonlinear organic material inside the waveguide, they would have created a very fast optical switch.

The device works as follows, according to Baets. You direct an optical data-pulse stream—at 170 Gbits/s in this case--into the waveguide. At the same time, you superimpose a stream of clock pulses, of the same pulse-width but at one quarter the frequency, and in-phase with the data pulse stream. When a data pulse coincides with a clock pulse, the increase in optical energy alters the refractive index of the optical material.

Now it gets interesting. It's a property of slotted waveguides that if the optical wave is polarized so that the e-filed is horizontal, the field will be stronger in the lower-index material. When pulses coincide and change the refractive index of the organic material, the light wave in effect moves the light back and forth between the organic material inside the waveguide and the silicon ridges that define the edges of the waveguide. In this way, with further cleverness, the waveguide passively extracts the data pulses that coincide with the clock pulses—every fourth pulse--from the rest of the data pulse train. That is a time-domain demultiplexer.

The demonstration chip simply split off every fourth bit from the data bit-stream. But it's not hard to visualize the same fundamental switching mechanism as the heart of a full N-way demultiplexer, an add-drop multiplexer, or even a more complex optical signal-processing component.

Baets said that the project could only have been accomplished with the collaboration of the photonics research teams from IMEC and Karlsruhe, the participation of the Lehigh and ETH organizations, and with access to the deep sub-micron **photonics shuttle service** that IMEC now offers to non-commercial projects. The combination of extremely fine silicon slotted waveguides and organic material was necessary to the experiment.

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