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Nonlinear Optics - How Bricks And Snow Could Show Us A Superfast Internet

By *News Account*
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The next time an overnight snow begins to fall, take two bricks and place them side by side a few inches apart in your yard. In the morning, the bricks will be covered with snow and barely discernible. The snowflakes will have filled every vacant space between and around the bricks.

What you will see, says Ivan Biaggio, an associate professor of physics at Lehigh University, resembles a phenomenon that, when it occurs at the smallest of scales on an integrated optical circuit, could hasten the day when the Internet works at superfast speeds.

Biaggio is part of an international team of researchers that has developed an organic material with an unprecedented combination of high optical quality and strong ability to mediate light-light interaction and has engineered the integration of this material with silicon technology so it can be used in optical telecommunication devices.

The material, composed of small organic molecules with high nonlinear optical susceptibilities, mimics the behavior of the snowflakes covering the bricks when it is deposited into the slot, or gap, that separate silicon waveguides that control the propagation of light beams on an integrated optical circuit.

Just as the snowflakes, being tiny and mobile, fill every empty space between the two bricks, Biaggio says, the molecules completely and homogeneously fill the slot between the waveguides. The slots measure only tens of nanometers wide; 1 nm is one one-billionth of a meter, or about the width of a dozen carbon atoms.

"We have been able to make thin films by combining the molecules into a material that is perfectly transparent, flat, and free of any irregularities that would affect optical properties," says Biaggio.

The slot between the waveguides is the region where most of the light guided by the silicon propagates. By filling the slot, say Biaggio and his collaborators, the molecules add an ultra-fast all-optical switching capability to silicon circuitry, creating a new ability to perform the light-to-light interactions necessary for data processing in all-optical networks.

The nanophotonic device obtained in this way, says the group, has demonstrated the best all-optical demultiplexing rate yet recorded for a silicon-organic-hybrid device.

Multiplexing is the process by which multiple signals or data streams are combined and transmitted on a single channel, thus saving expensive bandwidth. Demultiplexing is the reverse process.

In tests, the novel hybrid device was able to extract every fourth bit of a 170-gigabit-per-second telecommunications data stream and to demultiplex the stream to 42.7 gigabits per second.

Biaggio's group is part of an international collaboration that includes scientists from the Institute of Photonics and Quantum Electronics at the University of Karlsruhe in Germany, the Photonics Research Group at Ghent University in Belgium, and the Laboratory for Organic Chemistry at the Swiss Federal Institute of Technology (ETH) in Zurich. Biaggio is affiliated with Lehigh's Center for Optical Technologies (COT). Another group member, Bweh Esembeson, earned a Ph.D. in physics from Lehigh earlier this year and is now an applications engineer with Thorlabs Inc. in New Jersey.

The silicon-organic-hybrid device and its breakthrough properties were presented for the first time as a postdeadline contribution at a meeting of the optical telecom industry last spring and at several other scientific conferences, and Biaggio's group published an article titled "A High-optical Quality Supramolecular Assembly for Third-order Integrated Nonlinear Optics" in the October 2008 issue of Advanced Materials.

A nonlinear optical answer to bandwidth demand

As Internet users demand greater bandwidth for ever faster communications, scientists and engineers are working to increase the speed at which information can be transmitted and routed along a network. They are hoping to achieve a major leap in velocity by designing circuits that rely solely on light-waves process data.

At present, data must be converted back and forth from optical signals to electrical signals for managing its progress within the optical telecommunication network. This limits the flexibility and the speed of optical telecommunication. All-optical circuits, experts say, could unleash the full potential of optical telecommunication and data processing.

All-optical circuits require nonlinear optical materials with good optical quality. A nonlinear optical response occurs in a material when the intensity of light alters the properties of the material through which light is passing, affecting, in turn, the manner in which the light propagates.

Biaggio's group is working with a small organic molecule called DDMEBT that possesses one of the strongest nonlinear optical responses yet observed when compared to its relatively small size. The molecule can condense from the vapor phase into a bulk material. The high, off-resonant bulk nonlinearity and large-scale homogeneity of this material, says Esembeson, represent a unique combination not often found in an organic material.

"Between high optical nonlinearity in a molecule and ability to actually fabricate a bulk plastic with excellent optical quality, there is always a compromise," he says.

The DDMEBT bulk material possesses 1,000 times the nonlinearity of silica glass. This organic material, however, is difficult to flexibly structure into nanoscale waveguides or other optical circuitry. Silicon, on the other hand, is structurally suited to the dense integration of components on photonic circuit devices. And silicon technology is mature and precise. It enables the creation of waveguides whose nanoscale flatness facilitates the control of light propagation.

"With pure silicon," says Biaggio, "you can build waveguides that enable you to control light beam propagation, but you cannot get ultrafast light-to-light interaction. Using only silicon, people have achieved a data switching rate of only 20 to 30 gigabits per second, and this is very slow.

"We need higher-speed switching to achieve a higher bit rate. Organic materials can do this, but they are not terribly good for building waveguides that control propagation of tightly confined light beams."

To combine the strengths of the DDMEBT and the silicon, Biaggio and his collaborators have fashioned silicon-organic hybrid (SOH) waveguides where silicon waveguides are covered with DDMEBT.

"We have combined the two approaches," he says. "We start from a silicon waveguide designed to guide the light between two silicon ridges . Then we use molecular beam deposition to fill the space between the ridges with the organic material [DDMEBT], creating a dense plastic with high optical quality and high nonlinearity where the light propagates.

"We combine the best of both technologies."

One of the group's singular achievements, he says, is the filling-in process.

"The key question was whether we could put the DDMEBT between the two silicon strips. There is a lot of research in this area, but no one had been able to make an organic material completely and homogeneously cover such a silicon structure, so that it spreads out and fills all the spaces. Homogeneity is necessary to prevent light scattering and losses.

We now achieved this by using a molecular structure that decreases inter-molecular interactions and promotes the formation of a homogeneous solid state. We then heated the molecules to a vapor phase and used a molecular beam to deposit the molecules on top of the silicon structure. The molecules were able to homogeneously fill the nanometer scale slot between the silicon ridges and to cover the whole structure we needed to cover.

"Our collaborators in Karlsruhe, who have state-of-the-art equipment for characterizing optical communications systems, were able to reliably switch individual bits out of a 170 gigabits per second data stream, which is impressive, but the organic material would be able to support even faster data rates"

The researchers summed up their achievements:

"To the best of our knowledge, this is the first time that nonlinear SOH [silicon-organic hybrid] slot waveguides were used in high-speed optical communication systems. We believe that there is still a large potential for improving the conversion efficiency and the signal quality."

A description of this material was published on the *Nature Photonics* Web site March 15.

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