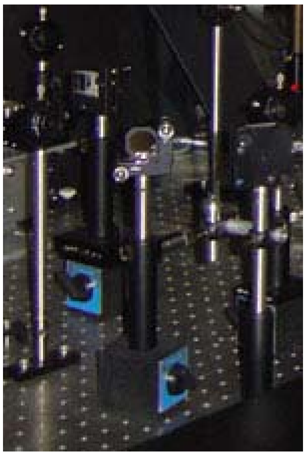
Physics Department | Center For Optical Technologies | Lehigh University



Prof. Ivan Biaggio

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Organics for Nonlinear Optics:

Molecules

Solid State

- Devices -

Silicon-Organic-Hybrid Integrated Devices for All Optical Switching

Our development of a high-quality supramolecular assembly of small molecules with a large third-order optical nonlinearity represents a new, flexible organic material for integrated nonlinear optics.

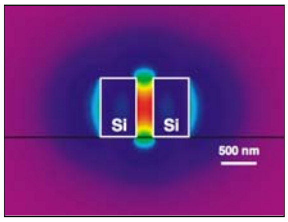
One the best ways to control the propagation of a tightly focused optical mode in an organic material is not to build a waveguide using the material itself, but to combine the materail with silicon-waveguiding technology so that the silicon (transparent at telecommunication wavelengths!) will be responsible for controllilng the optical mode and its propagation, while the organic will be responsible for the nonlinear optical effects.

Silicon processing technology has developed to the extent that millimeter-scale devices are routinely fabricated with nanometer precision in modern high-volume complementary metal oxide-semiconductor (CMOS) lines, making silicon-on-insulator (SOI) one of the most attractive platform for photonic circuits or integrated optics.

By designing appropriate SOI waveguide geometries and exploiting the large refractive index difference between silicon and an organic material it is possible to combine the best of two worlds: Mature CMOS processing to fabricate the waveguides that control the optical mode, and flexible organic chemical engineering for designing nonlinear optical materials that efficiently mediate light-light interaction. It is especially useful to design the SOI waveguide in such a way that the overlap between optical mode and organic cover layer and the optical intensity in the organic are maximized.

The SOH waveguide structure was designed at the University of Karlsruhe. Its structure is shown in the Figure to the right. It consists of a silicon slotted waveguide that is surrounded by a nonlinear organic cladding. Three unique advantages combine to make this system the best candidate for integrated nonlinear optics on a chip:

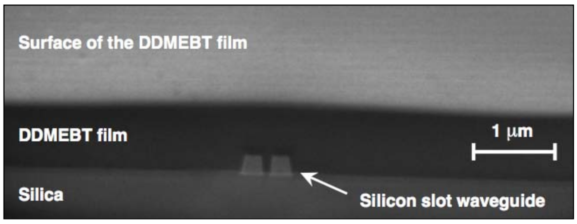
- The organic material can be developed independently from the silicon waveguide for optimum nonlinear optical properties.
- The silicon waveguide can be optimized essentially independently from the organic material.
- A slotted geometry can be chosen to create an optical mode that is guided by the silicon, but that has maximum optical intensity inside the organic material.



Cross-section of a silicon-on-insulator waveguide to control the optical mode and localize it in the organic material. In the figure, the light is horizontally polarized and electromagnetic boundary conditions lead to the large intensity in the slot.

The SOH structure was fabricated by first producing the SOI slot waveguide and then covering it with the organic layer by molecular beam deposition. The slotted waveguides were produced on a 200 mm CMOS line using 193 nm deep UV lithography and Clorine-based reactive ion etching at Ghent University in Belgium. The thickness of the SOI device layer (waveguide height) was 220 nm, and the buried oxide was 2 micrometers thick. The figure below shows a cross-section of the final SOH waveguide.

Vapor deposition of our DDMEBT film organic material in high vacuum makes it possible to perfectly and homogeneously fill the less than 200 nm wide slot between the silicon ridges where the optical mode is concentrated. This property is the key that allowes us to realize a highly functional SOH device.

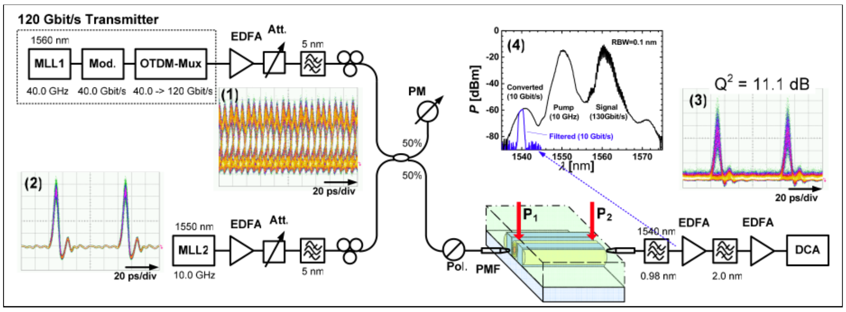


Scanning electron microscope picture of the cross section of the vapor deposited organic film (consisting of DDMEBT molecules) an the silicon waveguide. The ability of the organic material to homogeneously fill the slot between the waveguides is a key feature of our material and of its deposition process.

The SOH waveguide was characterized by our collaborators at the University of Karlsruhe. It showed record nonlinearities in the 1.55 micrometers telecommunication window, with a record nonlinearity coefficient of 100 W/m, almost two orders of magnitude larger than optimized holey silica fibers, and an off-resonant response that is practically instantaneous. In addition, the organic cover material does not significantly affect the losses of the waveguide.

We believe that with the fabrication of this waveguide and the successful demonstration of its capabilities we achieved an important step towards the development of complex silicon-based photonic integrated circuits. An early demonstration of demultiplexing of a 120 Gbit/s data stream was the subject of a postdeadline paper that was accepted at OFC in 2008.

New results then appeared in March 2009 in Nature Photonics, which demonstrated all-optical demultiplexing of a 170.8 Gbit/s data stream to 42.7 Gbit/s in a 4 mm long silicon-organic hybrid waveguide, the fastest silicon photonic all-optical signal processing shown to date.



Setup for the all-optical demultiplexing experiment using four-wave mixing (University of Karlsruhe); Data was modulated on a 120 Gbit/s stream at one wavelength. A 10 Ghz control signal at another wavelength was used to all-optically demultiplex the incoming signal, generating a 10 Gbit/s output signal at a third wavelength that was made up of every 12th bit of the original data stream. The eye diagrams of the input signal and of the demultiplexed signal show the quality of the demultiplexing operation. More details can be found here.

Press release:

- **New organic material may speed Internet access:** Eurekalert, Google list.

Related press releases:

- **Researchers approach quantum limit in third-order nonlinear light-light interaction:** Eurekalert, Google list.

References:

- C. Koos, P. Vorreau, T. Vallaitis, P. Dumon, W. Bogaerts, R. Baets, B. Esembeson, I. Biaggio, T. Michinobu, F. Diederich, W. Freude, J. Leuthold, "All-optical high-speed signal processing with silicon-organic hybrid slot waveguides," Nature Photonics advance online publication 15 March 2009.
- B. Esembeson, M. L. Scimeca, I. Biaggio, T. Michinobu, F. Diederich, "A High Optical Quality Supramolecular Assembly for Third-Order Integrated Nonlinear Optics," Adv. Mater. **19**, 1-4 (2008).
- C. Koos, P. Vorreau, P. Dumon, R. Baets, B. Esembeson, I. Biaggio, T. Michinobu, F. Diederich, W. Freude, J. Leuthold, "Highly Nonlinear Silicon Photonics Slot Waveguide," Optical Fiber Commun. Conf. (OFC 2008), Postdeadline paper PDP25, San Diego, 24-29 February 2008.

See also:

- High Optical Quality Organic Films for Third Order Nonlinear Optics.
- Organic molecules for third-order nonlinear optics.

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