Vapor Deposition of Organic Molecules for Ultrafast All-Optical Switching on Silicon

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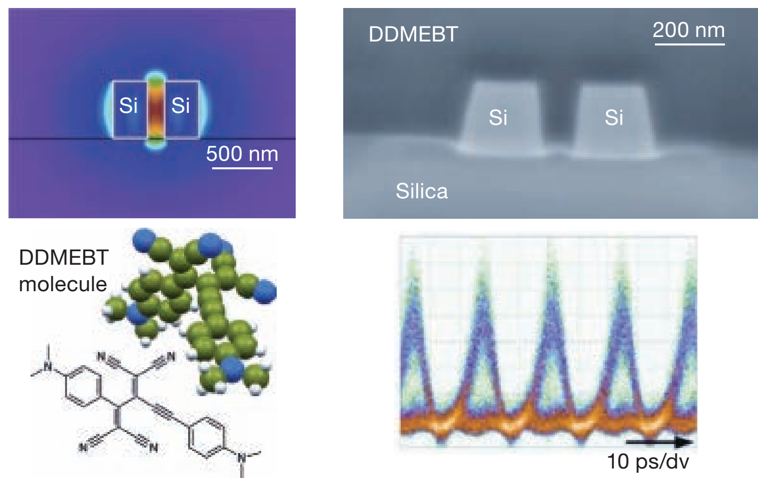
Organic molecules with extended electron conjugation offer a third-order off-resonant nonlinear optical response that is practically instantaneous, and they could allow for the mediation of light-light interaction at femtosecond speeds. The main challenge for applications is the necessity to develop a solid-state organic material that not only reflects the high optical nonlinearities of its molecular components, but that also has a high optical quality and can be easily and efficiently combined with current integrated optics technology.

One of the most commercially interesting and cost-effective technologies available is the silicon-on-insulator platform, which can deliver integrated optics structures with nanometer precision in modern high-volume complementary metal-oxide–semiconductor (CMOS) lines. We have demonstrated a reliable and efficient new way of combining the best features of organic nonlinear optical materials with the silicon photonics platform and thus obtaining ultra-fast all-optical switching capabilities.

This work built on recent research on a new family of small organic molecules that can maintain an exceptionally high third-order nonlinearity with shrinking size and create a dense supramolecular assembly with a low refractive index, a high third-order susceptibility, and a high optical quality.[1,2]

We used the organic nonlinear optical molecule DDMEBT (2-[4-(dimethylamino)phenyl]-3-{[4-(dimethylamino)phenyl]ethynyl}buta-1,3-diene-1,1,4,4-tetracarbonitrile)) and molecular beam deposition to cover a silicon slot waveguide.[2,3] The molecules filled the nanometer scale slot completely and homogeneously, realizing an ideal structure that uses the passive silicon waveguide to control a narrow optical mode (diameter ~100 nm) inside the organic nonlinear optical material. In this geometry, most of the optical power travels outside the silicon, with a high optical intensity in the organic cladding that can be maintained over macroscopic propagation lengths, leading to enhanced nonlinear optical effects while at the same time minimizing the intensity in the silicon and the related two-photon absorption.



(Left) Illustration of the optical mode guided by a silicon-on-oxide slot waveguide (optical polarization is horizontal) and of the nonlinear optical organic molecule used for the organic cladding.[2] (Right) Scanning electron microscope image of the cross-section of the fabricated SOH waveguide and eye diagram of the 42.7 Gbit/s signal demultiplexed out of a 170.8 Gbit/s signal.[3,4]

The resulting silicon-organic-hybrid (SOH) nonlinear optical waveguide combines the best of two worlds: the flexibility of organic chemistry for functional nonlinear optical properties and the ability of silicon nanophotonics to create very high-quality optical waveguiding circuitry. The third-order optical nonlinearity in the organic then provides what silicon cannot: all-optical switching at very high data rates without two-photon absorption and free carrier generation. The SOH system provides higher intensities in the organic than could be obtained by creating an organic waveguide by other means and is potentially the best way to mediate light-light interaction and enable all-optical switching applications in integrated optics.

We measured a record nonlinearity coefficient of $\gamma \approx 100\ W^{-1}m^{-1}$ in a 4-mm-long SOH waveguide that was used for all-optical demultiplexing of 170.8 Gbit/s to 42.7 Gbit/s in the 1.55 µm telecommunication window.[3,4] This is a key step forward toward the development of more complex and flexible photonic integrated circuits that incorporate active functionality. ▲

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