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Silicon-Organic Hybrid (SOH) Devices for Optical Signal Processing

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Abstract: Silicon-organic hybrid (SOH) integration allows overcoming insufficient nonlinear optical properties of silicon-on-insulator waveguides. We discuss 100 Gbit/s electro-optic modulation and demonstrate 120 Gbit/s all-optical signal processing with SOH devices.

OCIS codes: (130.4310) Nonlinear; (130.2790) Guided waves; (160.4330) Nonlinear optical materials; (190.3270) Kerr effect; (190.4710) Optical nonlinearities in organic materials

1. Introduction: SOH waveguides

Silicon-on-insulator (SOI) is a promising material system for dense on-chip integration of both silicon photonic and electronic devices, thereby overcoming the electronic bottleneck in short-reach high-volume data interconnects. However, certain devices are difficult to realize when relying solely on the intrinsic properties of silicon: Because of crystal symmetry, the material does not exhibit an appreciable second-order nonlinear optic effect. Silicon electro-optic modulators can therefore only be realized using free-carrier dispersion, and bandwidths of 30 GHz have been achieved in devices of 1 mm active length [1]. In addition, third-order nonlinear interaction in silicon nanophotonic waveguides is impeded by two-photon absorption and requires measures to remove free carriers [2].

These limitations can be overcome by combining SOI waveguides with dedicated low-index cladding materials [3]. In particular, organic materials offer the possibility to engineer their optical properties as desired by modifying their molecular structure. In this paper, we discuss electro-optic modulation and Kerr-type ultrafast all-optical signal processing in integrated silicon-organic hybrid (SOH) devices.

2. Second-order nonlinearities: Electro-optic modulators

Figure 1(a) shows a cross section of an electro-optic SOH waveguide. The waveguide core consists of two silicon strips on a SiO_2 buffer layer and is covered by a low-index electro-optic cladding material (EO). Field discontinuities at the core-cladding interfaces provide strong interaction of the guided mode with the electro-optic material, see field plot in Fig. 1(a). Both Si strips and the adjacent thin slabs are doped and connected to aluminum electrodes. A voltage applied to the electrodes induces a large electric field in the narrow gap between the strips. The design shows potential for efficient electro-optic modulation at more than 100 GHz in 1.2 mm long devices [4]. The conductive Si slabs can be replaced by photonic crystal (PhC) structures. Fig. 1(b) shows a schematic of an SOH-PhC-based Mach-Zehnder modulator. By appropriate design, the optical group velocity in the PhC-sections can be reduced to 4 % of the vacuum speed of light with flat dispersion over an optical bandwidth of 1 THz. For 1V modulation amplitude, a bandwidth of 78 GHz is predicted for 80µm long PhC sections, allowing for 100 Gbit/s transmission [5].

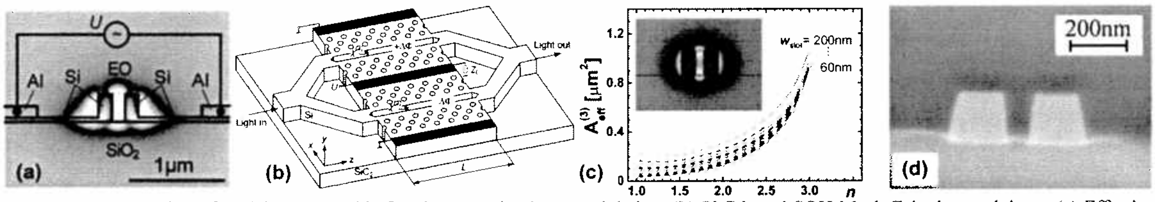

Fig. 1 (a) Cross section of an SOH waveguide for electro-optic phase modulation. **(b)** PhC-based SOH Mach-Zehnder modulator. **(c)** Effective area as a function of the linear refractive index n of the nonlinear cover material. Strip width w and waveguide height h optimized for fixed slot widths w_{slot}. *Inset:* Field plot of the horizontal E-field component. **(d)** Cross section of fabricated slot waveguide functionalized with organic film.

3. Third-order nonlinearities: All-optical signal processing

For all-optical signal processing, the optical mode has to be confined to a small effective area within the nonlinear cover material. This can be achieved by using slot waveguides [6]. By optimizing the waveguide dimensions, effective cross sections smaller than $0.1\,\mu m^2$ can be obtained, see Fig. 1(c) [7]. We functionalized SOI strip waveguides by molecular beam deposition of an amorphous organic film of DDMEBT (derivative 2 in [9], nonlinear index $n_2 \approx 2 \times 10^{-17} m^2/W$). These waveguides exhibit nonlinearities of $\gamma = 10^5\,W^{-1}km^{-1}$ at $\lambda = 1.55\,\mu m$ and were used in a proof-of-principle experiment to demonstrate all-optical demultiplexing of a 120 Gbit/s data stream to 10 Gbit/s [8].

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