Silicon-Organic Hybrid (SOH) IQ Modulator for 16QAM at 112 Gbit/s

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Silicon modulators fabricated by scalable, established CMOS technology, promise an answer to today's power consumption challenges. With advanced modulation formats and the resulting higher spectral efficiencies, long-haul applications for silicon modulators come into reach. Energy efficient, high speed modulators were demonstrated as resonant [1] and non-resonant [2] devices. A single-carrier single-polarization data rate of 56 Gbit/s is considered state-of-the-art [3]. Usually, free-carrier dispersion is exploited in silicon modulators.

In contrast, we employ the $\chi^{(2)}$-nonlinearity (Pockels effect) of an organic material. A slot waveguide concentrates both the modulating and the optical field in the slot region which is filled with the organic material. This arrangement leads to a high modulation efficiency. With such a silicon-organic hybrid (SOH) modulator [4] we go beyond quadrature phase-shift keying (QPSK) and show that advanced quadrature amplitude modulation (QAM) formats are feasible. With 16QAM we achieve a record-high single-polarization data rate of 112 Gbit/s.

Our device was fabricated at IMEC using silicon-on-insulator (SOI) wafers and CMOS processes. The Si waveguide (WG) layer has a height 220 nm, Fig. 1(a). A modulation voltage is applied to the slightly doped Si rails via copper electrodes (Cu) and connecting tungsten vias (W), and changes the refractive index in the WG slot (140 nm width, exposed by dry and wet etching during post processing, spin-coated with a polymer M3 containing chromophores, which is commercialized by GigOptix, Inc.). Four such phase modulators control the phases in the arms of two nested Mach-Zehnder interferometers, Fig. 1(b), which are operated in push-pull. Two RF voltages modulate the in-phase (I) and quadrature (Q) components of the optical carrier.

Experimentally, two random data signals (PRBS, 2^{11}-1) were created, amplified (output voltage 5 Vpp), and fed to the chip (a gate field of 0.1V/nm provides a high-conductivity accumulation layer in the connecting slabs [4]). Light at a wavelength of 1546 nm is coupled to and from the chip (30 dB overall insertion loss) via grating couplers (5 dB loss per coupler). The modulated light is received with an optical modulation analyzer. At a data rate of 112 Gbit/s, an 8-tap pre-emphasis filter leads to an error vector magnitude (EVM) of 10% at the receiver, see Fig. 1(c)-(e). The energy consumption of the IQ modulator is 620 fJ/bit assuming a 50 Ω generator and a matched load. The bit-error ratio 7×10^{-4} is well below the limit for hard-decision forward error correction.

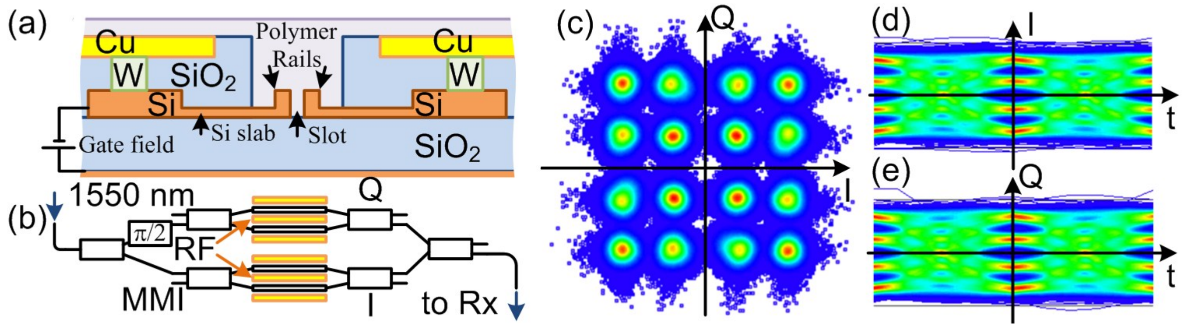

Fig. 1 (a) Cross section of SOH phase modulator (PM) using a $\chi^{(2)}$-nonlinear polymer. (b) Schematic of 4 PMs forming an IQ modulator; grating couplers not shown. (c) 16QAM constellation diagram at 112 Gbit/s. (d, e) I and Q eye diagrams.

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