High-Speed Electro-Optic Modulator Design for Electronic Photonic Integrated Circuits

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The development of future electronic-photonic integrated circuits based on silicon technology critically depends on the availability of CMOS-compatible high-speed modulators that enable the interaction of electronic and optical signals. Very recently an optoelectronic modulator based on a MOS structure has been proposed [1] operating at 1GHz speed. In this paper, we propose a Si/SiO_2 high-index contrast waveguide modulator based on a split ridge-waveguide that operates under forward biased conditions and shows corner frequencies of up to 24 GHz.

A schematic layout of the proposed modulator is shown in Fig.1. Fig.1(a) shows a conventional Mach-Zehnder arrangement, and Fig. 1(b) shows the most important sub-component of the modulator. We use a split-ridge waveguide, i.e. the high-index ridge is separated from the high-index slab via a thin low index layer (see Figure 1(b)). By adjusting thickness d_1 and d_2, we can obtain single-mode operation and optical power well confined in the ridge section. The p^+in^+-diodes in both arms of the Mach-Zehnder modulator are biased in series and a static current is driven through both arms, ensuring that the thermo-optic effects in both arms are balanced to a large degree. The RF-signal is capacitively-coupled to the diodes out of phase via the even mode of a coplanar transmission line, see Fig.1a. The carrier lifetime in the intrinsic section can be varied over a wide range using doping or ion implantation [2]. For short carrier lifetimes, the electric field can be increased to a level where the current flow gets close to saturation and the carriers drift at the saturation velocity $v_s = 10^7$cm/s in silicon.

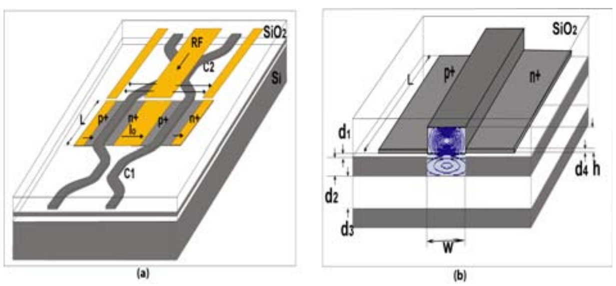

Fig. 1. (a) Externally-biased Mach-Zehnder modulator with coplanar RF-feeder, (b) Split-ridge waveguide pin-phase modulator with single mode intensity profile.

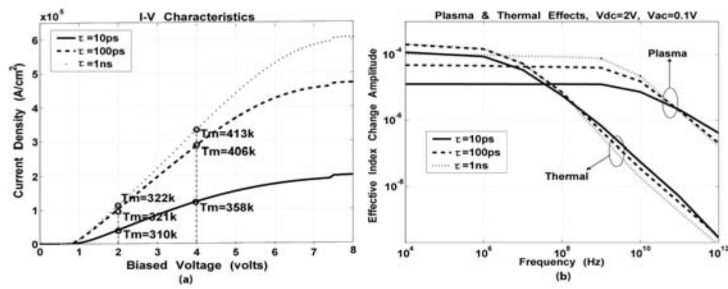

Fig. 2. (a) Modulator I-V-characteristics and maximum device temperature Tm at different operating points and carrier lifetimes τ =10ps (solid), 100ps (dashed), 1ns (dotted); (b) Effective index change due to plasma and thermal effects for τ =10ps (solid), 100ps (dashed), 1ns (dotted).

Detailed two-dimensional simulations with simulator MEDICI have been carried out for a device with dimensions: d_1 = 100nm, d_2 = 350nm, d_3 = 2μm, d_4 = 100 nm, h = 550 nm and w= 1μm assuming longitudinal homogeneity. The static I-V characteristics are shown in Fig. 2(a) for the three different carrier lifetimes. For voltages greater than 6V the current strongly saturates. The heat is efficiently removed from the device via the metal contacts and the thin slab-Si layer (see Fig.1b).

The AC characteristics of the device are determined by computing the small signal modulation transfer function between effective index change in the phase modulator section and the applied voltage. The modulation speed of a pin-diode depends critically on the carrier recombination time and drift velocity where the drift effect dominates the modulation speed because $\tau_{Recom}/\tau_{drift}$ is in the order of 5-10. The simulations gave carrier velocities $v \approx 8\times10^6$cm/s, 2.4×10^6cm/s and 2.4×10^6 cm/s for τ=10ps, 100ps, and 1ns, corresponding to 3dB frequencies [3] $f_{3dB}^{drift} = 2.2/2\pi\tau_{drift}$ = 28GHz, 3GHz, 2.6GHz with τ_{drift}= w/v, which matches the resulting corner frequencies from the simulations rather well, see Fig. 2(b): 24GHz, 4GHz, and 3GHz. Numerical simulations show that the modulator can be biased with a DC-power consumption of $P_{DC} = V_{DC} \cdot I_{DC} = 500mW$, operating at a bias voltage $V_{DC} = 2V$ for a 1mm long section. At a modulation frequency $f = 10$GHz, with amplitude (half peak-to-peak) $V_{AC} = 1V$ a dissipated microwave power of 76mW and a figure of merit to be FOM=0.5V·cm at a wavelength of 1.55 μm is obtained with a total static loss of about 4 dB.

References:

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