High-speed modulation of a compact silicon ring resonator

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Abstract: We demonstrate high speed modulation based on a compact silicon ring resonator operating in depletion mode. Our device features an electrical small signal bandwidth of approximately 19GHz, which is the fastest silicon ring resonator modulator reported to date.

I. INTRODUCTION

As multi-core processor architectures continue to evolve, a set of challenges emerge for the global interconnects in massively multicore platforms. The limited throughput and large power consumption of electrical interconnects become dominant factors limiting the continued scaling of power performance. Silicon photonics satisfies the idea that conventional interconnects could be replaced with a CMOS-compatible intra-chip optical network, based on Silicon-On-Insulator (SOI) nanophotonic integrated circuits. The plasma dispersion effect has been demonstrated as the most effective way to modulate the refraction index in silicon to date [1]. High speed modulation in free carrier depleted silicon-based modulators was demonstrated theoretically by [2,3] and experimentally by [4-8], to operate in the multi-GHz regime

Two of the compulsory functions within any on-chip optical network include the electrical modulation of an optical carrier at the transmitter, and the routing/switching of this signal throughout the entire network. In this paper, a high-speed silicon modulator based on carrier depletion in a reverse-biased p–n junction is demonstrated. In this case, the pn junction is formed in a compact and standard silicon rib waveguide with 300nm width and 200nm height. This results in a very compact modulator with a footprint of less than 100μm^2.

II. DESIGN AND FABRICATION

The ring resonator modulator reported in this paper is based on a 200 nm silicon overlayer SOI with 2 micrometers of buried oxide. The rib waveguide is 300 nm wide and has a 150 nm etch depth which enables single mode transmission for TE polarisation. Modulation is obtained in the waveguide by depleting a vertical pn junction inserted in the waveguide. As shown in Figure 1, the pn junction is asymmetrical in size but also in doping concentration in order to maximize the area of hole depletion that overlaps with the optical mode. The position of the contact electrodes, as well as the highly doped regions, are key to the performance of a reverse biased PN based-modulator because the frequency response is limited by the RC cut off frequency resulting from capacitive effects within the junction and the resistance of the doped regions and metal contacts (Figure2).

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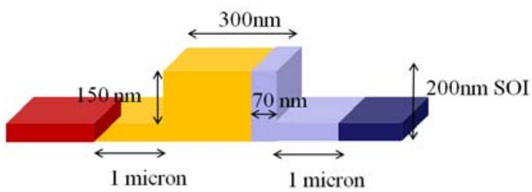

Figure 1: Cross section of the device

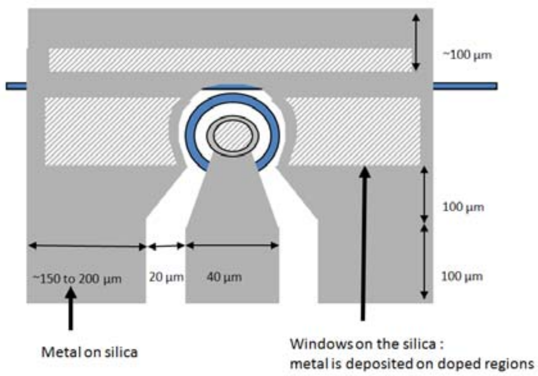

Figure 2: Top view of the device

III. EXPERIMENTAL RESULTS

The optical response of the ring features resonances larger than 10dB around 1580 nm, where the free-spectral range of the 40.2 microns radius ring resonator varies from 2.5 nm at 1520 nm to 3 nm at 1620 nm. The output spectrum of the modulator for decreasing reverse bias is shown in Figure 3 where the modulator exhibited a DC on/off ratio of 5 dB at -10V.

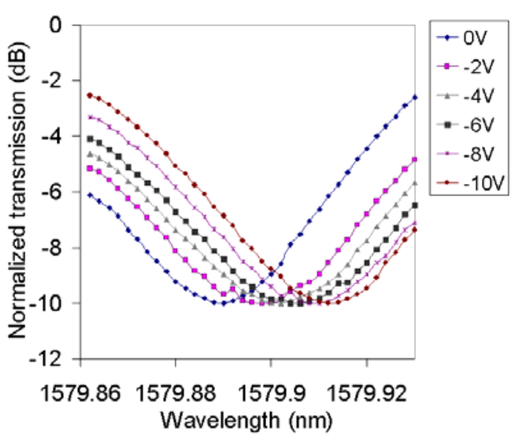

Figure 3: Experimental ring resonator transmission with increasing bias.

These characteristics were measured using electrical probes to provide the bias. Very low values of the reverse current (-1 µA at -10 V) were measured that ensured low electrical power dissipation in the ring resonator. With reverse voltage bias, carrier depletion is responsible for a refractive index change in the waveguide, which results in a red shift of the spectrum. A shift in resonant wavelength of around 20 pm was measured at -10 V.

The frequency response of the modulator was measured using an AC signal generated by an opto-RF vector network analyser (Agilent 86030A). The RF signal was coupled to the ring resonator using ground-signal-ground electrodes. The modulated optical signal was then coupled back to the opto-RF vector network analyser. The normalized optical response as a function of the frequency is given in Figure 4. A 3 dB cut-off frequency of 19 GHz is measured. To the author's knowledge, this is the fastest experimental ring resonator based silicon optical modulator reported to date.

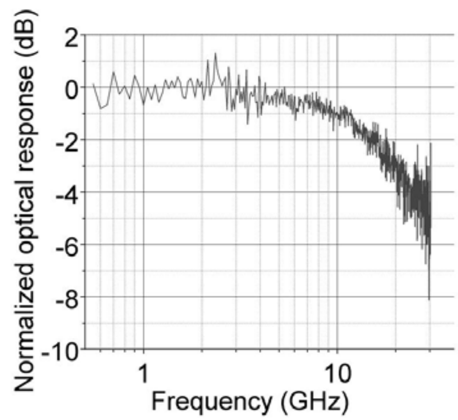

Figure 4: Normalized optical response as a function of frequency.

The fabricated device displays promising figures in terms of frequency of operation. The device suffers non optimal performance due to alignment and electrical activation issues that can be overcome in the next generation of devices by moving towards a process with a self aligned junction and a different impurity selection for the waveguide n-type doping. These improvements will enable greater process control and an increase in device yield.

IV. CONCLUSIONS

In conclusion, we present a high speed ring resonator modulator. The modulation was achieved by carrier depletion in an asymmetric p-n diode structure. The modulator exhibited the DC on/off ratio of 5 dB at -10V, and a 3dB bandwidth of 19 GHz. This is the fastest reported operation of a silicon ring resonator modulator to date.

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