Silicon Photonic Modulator Using Mode Conversion with Asymmetric Sidewall Bragg Gratings

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***Abstract*— An asymmetric sidewall grating allows to operate a Bragg modulator in reflection without circulator and with less than 1.5 dB on-chip loss. An asymmetric Y-junction directs the incident TE0 mode to the grating, while the reflected TE1 mode is goes to the drop port.**

Keywords—Silicon photonic modulator, Bragg grating, Y-junction.

I. INTRODUCTION

Silicon photonic modulator is one of the key components in optical interconnects. Mach-Zehnder interference (MZI) [1], micro-ring resonator [2], Bragg grating [3], or a combination of these structures [4-5] have been proposed as modulators. MZI modulators provide a wide optical bandwidth and offer small pulse chirp, but they have a large footprint and require high power. Micro-ring modulators (MRMs) present compact footprint and low power consumption, but the drawback of resonance-based modulator is their sensitivity to temperature that increase on thermal control. Bragg grating modulator offer a compromise between all these performance requirements but, up to now there has been little effort to improve Bragg grating modulator. Bragg modulators present the largest optical bandwidth when operated in reflection which is a major hurdle considering the lack of on-chip circulators [6].

In this paper, we propose a novel design of Bragg grating modulator in which a half-period offset between sidewall gratings is introduced. Fig. 1 shows the configuration of the suggested modulator with asymmetric sidewall Bragg grating (ASBG). It has three main parts: an asymmetric Y-junction, a taper, and an ASBG in multi-mode rib waveguide. The ASBG introduces modes coupling between the forward propagating fundamental transverse electric (TE0) and backward TE1 modes [7]. Because of this mode conversion, the reflected power can be directed to the drop port of the asymmetric Y-junction, eliminating the use of circulator. We present an asymmetric Y-junction design that introduces only 1.5 dB on chip loss. A p-n junction is introduced to modulate the grating response through carrier depletion. In the analysis below, we optimize the position of the p-n junction in order to maximize the overlap between the two optical modes and the depletion region.

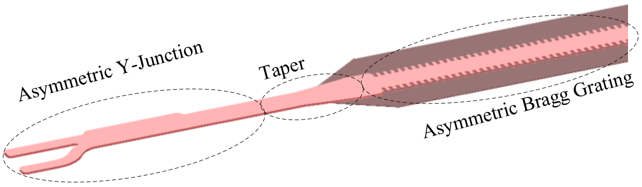

Fig. 1. Configuration of the proposed modulator.

II. ASYMMETRIC Y-JUNCTION AND BRAGG GRATING

An ideal asymmetric Y-junction (Fig.2 (a)) should operate as follows: when the TE0 mode is excited in the input arm, all of power couples to the TE0 mode of the multi-mode waveguide (MMW). On the other hand, when the power is reflected in the TE1 mode, all of the reflected power goes into the drop arm of Y-junction. The proposed Y-junction consists of two arms with different widths, a multi-mode interference (MMI) section, and an output MMW. Width of the input and drop arms are 650 nm and 490 nm, respectively. Width and length of MMI are 1.38 µm and 4.3 µm, respectively, with a 50 nm distance before the start of the MMI. The width of the MMW is 1.14 µm. Fig. 2 (b) shows the electrical field distribution and transmission spectrums when the fundamental TE0 mode is excited at the input port (simulations are done with Lumerical FDTD). Transmission into the TE0 mode of the MMW is around 85 percent. Fig. 2 (c) shows the power transmitted into the input and drop port when the reflected TE1 mode is excited at the through port. It shows that more than 83 percent of the reflected power is coupled to the fundamental mode TE0 mode in the drop port, while only 4 percent goes into the input port. Therefore, the Y-junction provides good isolation and little loss to retrieve the reflected light. The results confirm that the input power and the reflected power are almost isolated by the proposed Y-junction. Fig. 2 (b) and (c) show that the spectrums are almost constant over the whole C-band.

In an ASBG, the half-period offset between two sidewall gratings introduces a π-phase shift. Hence, unlike symmetric gratings, coupling coefficient between the fundamental forward and backward modes is zero and there is no back reflection. On the other hand, the coupling coefficient between an odd and an even mode can be different from zero if the phase matching condition is satisfied, for example $\lambda/\Lambda=(n_0+n_1)/2$, where n_0 and n_1 are the average effective index of the forward TE0 mode and

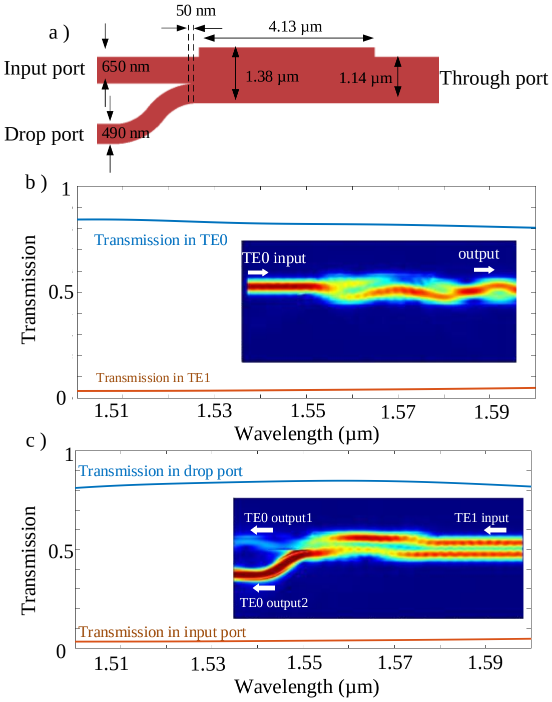

Fig. 2. (a) Schematic of the asymmetric Y-branch, (b) Transmission in TE0 and TE1 mode when the TE0 mode is excited in the input port. Inner figure shows the field distribution. (c) Transmission to the input port and the drop port when the power in TE1 mode is excited in through port 3D. Inner figure shows the field distribution.

the backward TE1 mode, respectively and Λ is the grating period. The asymmetric grating, shown in Fig. 3 (a), are designed with 50% duty cyle corrugations, Λ=310 nm in a ridge waveguide with a width of 800 nm, a ridge height of 130 nm and a 90 nm slab height. The lateral corrugation is 500 nm. A simulation of the UV lithography effect on proposed design (black curve in Fig. 3 (a)) shows that the middle width is increased to 1.018 μm, the corrugation acquire a sinusoidal shape with a depth of 300 nm. We simulated the spectral response of the ASBG with lithography effect. Because of memory limitation, we simulated only 50 periods. Fig. 3 (b) shows the spectrum of transmission and reflection for various modes when the power is incident in the TE0. It is seen that most of the reflection occurs in the TE1 mode (the reflectivity will be much larger as the number of period increases).

III. BRAGG GRATING MODULATOR

In Fig. 1 the taper length is 10 μm to convert from the strip waveguide to the ridge waveguide. Because of the odd TE1 mode, the optimum position of the pn junction is offset from the waveguide center. Fig. 4 shows the variation of refractive index for TE0 and TE1 modes as function of the p-n junction location for reverse bias of 6 V. The effective index modulation of TE0 mode reduces when the offset increases while it increases for TE1. This results in a Bragg wavelength modulation that is maximum for an offset of 285 nm. A calculation of optical modulation amplitude (OMA) showed that it should be possible to obtain an OMA=2.95 dB, for a detuning of 4.38 nm, for a grating having a κl=10 (3 dB bandwidth 8.69 nm, L=252 μm).

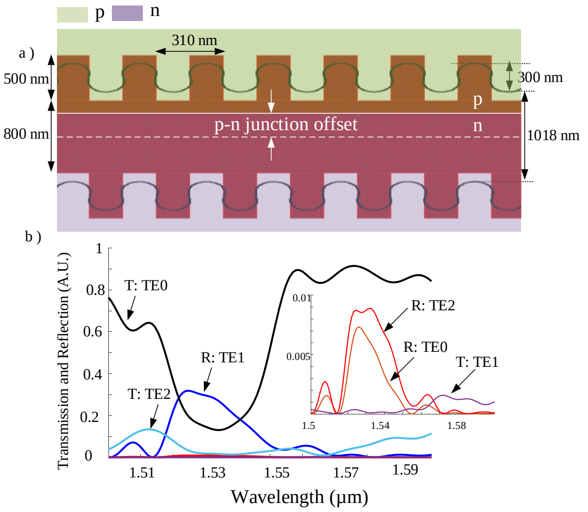

Fig. 3. (a) Configuration of asymmetric Bragg grating (b) Transmission and reflection of ASBG in different modes. In (a), black curve shows the lithography effect. T: Transmission, R: Reflection.

IV. CONCLUSION

A silicon photonic Bragg modulator with asymmetric structures was investigated. Results show that it could be used in reflection without circulators for high speed operation.

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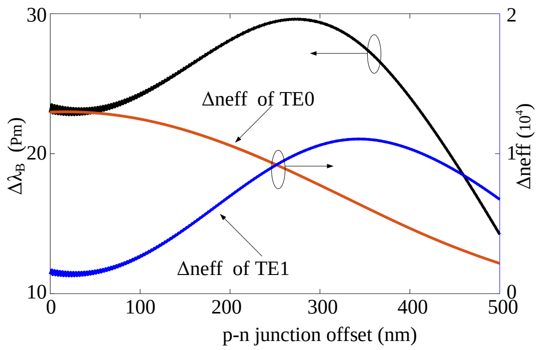

Fig. 4. Tuning of Bragg wavelength and variation of refractive index of TE1 and TE0 modes as function of p-n junction location.