A silicon-based tunable multimode interferometer using the thermo-optic effect

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***Abstract*— A silicon-based tunable and compact 2x2 multimode interferometer with 594.5x9µm size has been designed and experimentally demonstrated. The thermo-optic effect is exploited to achieve electro-optical tunability demonstrating above 10dB cross-talk between output ports.**

Keywords-Integrated; Multimode interferometer; silicon photonics; thermo-optic effect

I. INTRODUCTION

Tunable couplers are important devices for optical integrated circuits allowing a high accurate setting of any splitting ratio. In this case, tunable MMI are very attractive due to their intrinsic properties like high theoretical bandwidth and low fabrication tolerances. On the other hand, SOI (Silicon-On-Insulator) platform offers the possibility of mass-manufacturing as well as cost-effective integration with CMOS electronics. Many works in these devices has been reported. In [1], an InGaAsP MMI was demonstrated with 504µm x 18µm dimensions but a poor cross talk (~5.7dB). Also, in [2], a polymer-based photonic MMI (510µm x 10µm) was reported. However, to our knowledge, no work on silicon photonic tunable MMI has been demonstrated so far.

In this work we propose a highly compact silicon-based tunable 2x2 multimode interferometer (MMI). We achieve MMI tunability using the thermo-optic effect, conveniently setting up a titanium heater on the surface. The designed silicon device exhibits a switching crosstalk of 13dB with an MMI structure length of 594.5µm. Such reduce dimensions allow our device to be a promising candidate for on-chip integration.

II. DEVICE STRUCTURE AND THEORETICAL ANALYSIS

The proposed MMI is composed for a multimode waveguide and two outputs and inputs ports provided by tapers. These tapers allow not only minimizing return losses, but also having bigger self-images into the multimode waveguide which benefits the thermo-optic effect to achieve the necessary length for the required phase shift. First of all, the passive MMI was designed as a single photonic cross coupler, as it can be observed in Figure 1. In this passive device, our design parameters are L_{MMI}=594.5 µm and W_{MMI}=9 µm.

The proposed design is based on a π radians phase shift of one of the two folded images at the center of the MMI (at $L_{MMI}/2$). This phase shift results in an interference pattern shifting on the propagation direction, from the original to the new, like a mirrored image. Thermo-optic effect is achieved through an electrode over the waveguide surface in one of two folded images to bring the phase shifting. One can see the self-images distribution in [3].

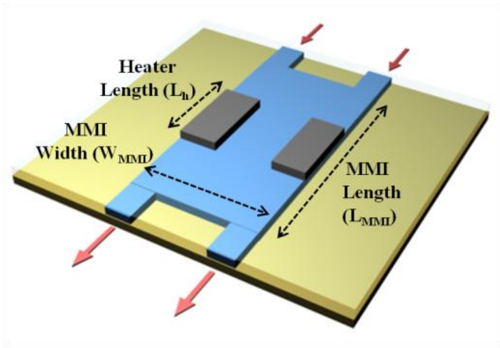

Figure 1. Schematic of the tunable MMI.

The key of this device is that the refractive index must only be changed in a localized place in the device. We can find the relationship between the phase and the index change through next expression:

$$\Delta\varphi = k \cdot \Delta n \cdot L_h \quad (1)$$

where L_h is the heater length over the waveguide to get the optimal phase shift, induced by a localized temperature shift on the waveguide, and k=2π/λ is the wavelength number[4]. This temperature dependence is given for the thermal coefficient of the material (silicon in our case). Finally, we can define the index change as:

$$\Delta n = \frac{\delta n}{\delta T} \cdot \Delta T \quad (2)$$

In our case, working with silicon, the thermal coefficient is $1.84 \cdot 10^{-4}$ / ºC. We focused on getting the optimal index change for an MMI as small as possible. With our material, a index change with thermo-optic effect around $\Delta n = 10^{-2}$ can be obtained. Thus, once known the index change and the desired phase shift (π radians), we can obtain the necessary length through (1)-(2) equations to finally get the mirrored pattern interference. The theoretical obtained L_h is 77.5 µm.

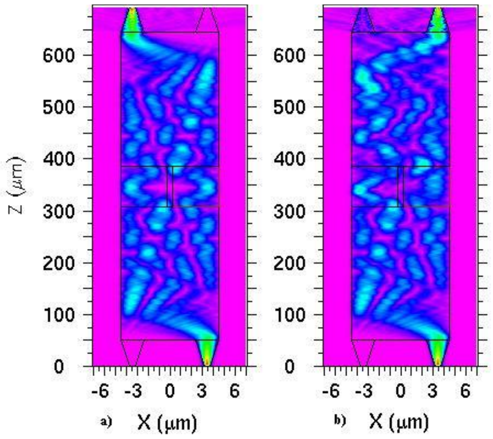

Figure 2. Simulated MMIs: a) Passive MMI b) Active MMI with the phase shift.

On the other hand, L_h has also been optimized via the beam propagation method (BPM) starting from the theoretical value obtained previously. In Figure 2 it can be observed the obtained mirrored pattern interference changing the index in one of the two folded images. In this case, the obtained heater length is L_h=79.5µm. which allow a simulated index change of 0.024. So, good agreement is found between the theoretical and simulations results.

III. Experimental Results

The tunable MMI was fabricated by using e-beam lithography, inductive coupled plasma etching and metal evaporation. A heater over one of the two self-images was placed at the device center. . The MMI tunability was analyzed by measuring the variation of output power for an applied voltage. Figure 3 shows the obtained results for each port and inset shows a SEM image with a detail of MMI ports. From these results, we can determinate the voltage, and therefore the necessary electric current, to get the desired index change. Furthermore, the resistance of the heater can be obtained.

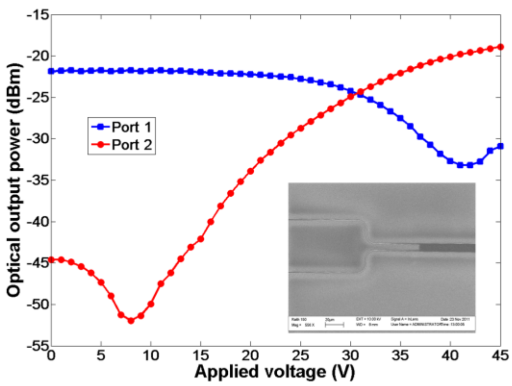

Figure 3. Measured output coupled power for each port as a function of the applied voltage. Coupling losses of 20dB from grattings have been estimated (vertical coupling).

The electrical current is 1.855 mA measured in the desired point in which the voltage reached is 42 V. In this case the device shows a power consumption of around 77mW. Due to this high power consumption, we made a design feedback to optimize the structure allowing a new less electrical power consumption tunable MMI.

One approach to reduce the power consumption is to minimize the required index change. The idea to get a minimum index change is to increment the heater's length (L_h). To make this as efficiently as possible is necessary to increment the two folded images size. We used a taper on the input (and output) achieving a bigger size on the two folded images and then optimizing the size and location heater. In this way, as it shown in Figure 4, the effective index shift was reduced from 0.024 to 0.015. On the other hand, if MMI size is modified (694.5µm x 9.75µm) having optimized heaters, the required index change can be reduced to 0.013, thus decreasing the power consumption.

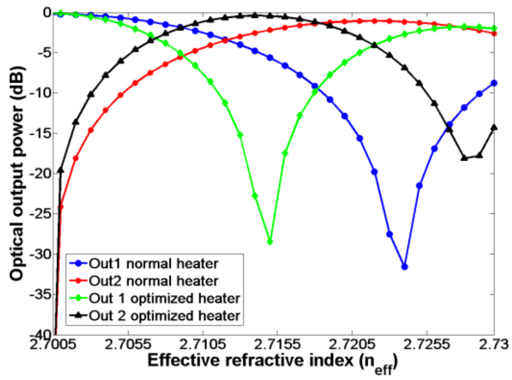

Figure 4. power to output ports for both length of shift index region.

IV. Conclussions

We have demonstrated a very compact (594.5µm x 9µm) silicon-tunable MMI based on thermo-optic effect. Furthermore, we have described an approach to reduce the power consumption through the optimization of the heater size over the self-images, reducing the required index change to make possible the tunable effect. Optimum performance has been achieved with a heater length of 127.5 µm and maximum input port size of 3.5 µm for a minimum power consumption keeping device coupling properties.

Acknowledgment

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