Demonstration of Rib Waveguide Based 1x12 Multimode Interference Optical Beam Splitter on Silicon-on-Insulator

David Kwong, Yang Zhang, Amir Hosseini, *Student Member*, *IEEE,* YaZhao Liu and Ray T. Chen, *Fellow, IEEE*

Abstract— **We present a compact silicon nanomembrane based 1x12 multimode interference coupler (MMI) fabricated on Silicon On Insulator (SOI) that exhibits low loss and high uniformity at 1550nm wavelength.**

I. INTRODUCTION

On-chip optical interconnects are a possible solution to the challenges facing copper interconnects as scaling of high performance integrated circuits (IC) continues. Efficient optical beam splitters are a key component in photonic integrated circuits (PICs) that will be used to implement such an optical network. Multimode interference (MMI) couplers have the advantage of compact size, low loss, stable splitting ratio, low cross talk and imbalance, large optical bandwidth, ease of production, and good fabrication tolerances [1]. As one of the largest uses of MMI couplers is for power splitters; the power distribution at the output ports has been thoroughly investigated and it can be shown that the resolution and contrast of the images determine the uniformity and insertion loss of the MMI device [2]. Particularly for MMI couplers with large number of outputs, the output uniformity is usually poor and the insertion loss is high [3].

The majority of MMI couplers based on SOI have used a ridge waveguide structure. This has the disadvantage of requiring large input and output waveguide dimensions, as well as large radius bends for low loss propagations [4]. Ultimately, the overall device size is increased and this limits their use in ultra-compact PICs. Furthermore, implementation with electronics using conventional CMOS processing is also simplified [5]. Until recently, few devices employing a rib waveguide structure for the input and output have been presented. Acoleyen et al have shown an optical phased array based on cascaded 1x2 MMI couplers [6]. In this paper, we demonstrate a single stage optical beam splitter with large number of outputs that avoids multiple insertion loss by using a 1x12 MMI on SOI with a rib waveguide structure.

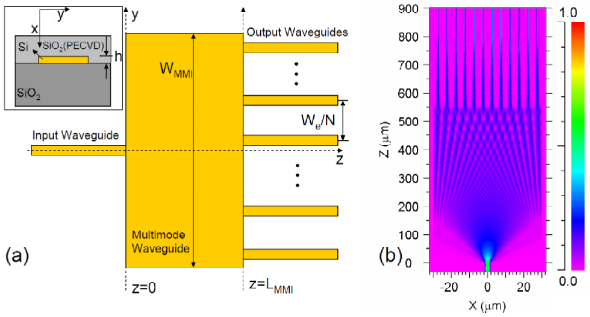

Figure 1-(a) Schematic of a 1XN MMI beam splitter. Inset is cross section schematic of the SOI based waveguiding structure. n_{Si}=3.47, n_{SiO2}=1.45, $n_{PECVD(SiO2)}$=1.46. (b) BeamPROP simulation of 1x12 MMI beam splitter showing equal power distribution at the single mode output after tapering.

II. OPERATION PRINCIPLES

MMI devices operate based on the phenomenon of self imaging in multimode waveguides whereby an input field profile is reproduced in single or multiple images at periodic intervals along the propagation direction of the guide [Soldano95]. From Figure 1, the multimode waveguide consists of a core with refractive index n_c and width W_{MMI}, length L_{MMI}, and N output ports. The multimode section can support a maximum of N+1 modes. From MMI theory, the propagation constant β_p can be approximated as $\beta_p \approx \beta_0 - p(p-2)/3L_\pi$, where L_π is the beat length of the two lowest order modes and defined as $L_\pi = \pi/(\beta_p - \beta_0) \approx 4n_{eff}W_e^2/3\lambda_0$, where n_{eff} is the effective refractive index of the fundamental mode in the multimode section. Generally, an N-fold image of the input is formed at $L_{MMI}=3rL_\pi/N$, but in the case of a symmetric excitation to the center of the multimode waveguide, the length of the MMI becomes $L_{MMI}=3rL_\pi/4N$ where r is an integer [7, 8].

We performed a simulation of our MMI device using Rsoft's BeamPROP software based on the beam propagation method to determine its performance. When we fix the width of the MMI W_{MMI}=60μm, the theoretical prediction of the MMI length is L_{MMI}=550.4μm. We have also chosen the input waveguide width, and hence the output waveguide with as well, to be W_W=2.5μm as it coincides with the mode diameter of our lensed fiber for optical testing. As can be seen from Figure 2, our simulation confirms our theoretical prediction.

III. DEVICE FABRICATION

We fabricated 1x12 MMIs (W_{MMI}=60μm, L_{MMI}=550.4μm) with W_W =2.5μm. In the case of W_W=2.5μm MMI, the output waveguides were tapered down to 0.5μm for single mode

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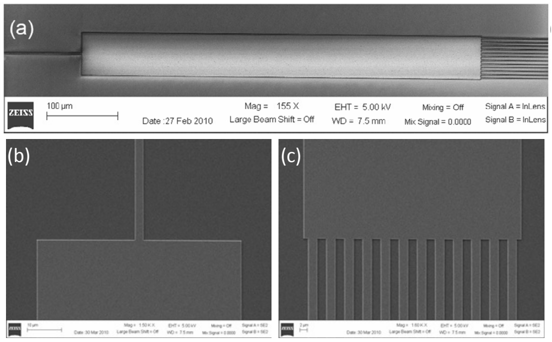

Figure 3-(a) SEM picture of 1x12 MMI, (b) input with W_W =2.5µm, (b) output with W_W =2.5 µm.

operation. The MMIs were fabricated on commercially available SOI from SOITEC with 3µm buried oxide layer (BOX) and 250nm top silicon layer. The silicon was first oxidized to create a top oxide layer that serves as a hard mask for the silicon etch.

The MMIs were patterned using a JEOL JBX600 electron beam lithography system. A nickel liftoff step was used to invert the pattern, and subsequently transferred to the top silicon layer via an HBr/Cl_2 based reactive ion etching (RIE). A subsequent piranha clean has the dual purpose of providing a clean sample, but more importantly, removing the nickel etch mask. Afterwards, a 1µm film of plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide was deposited for the top cladding using the Plasmatherm 790 system. The refractive index of the PECVD $Si0_2$ film was found to be $n_{PECVD(Si02)}$=1.46.

Figure 2 shows SEM pictures of the fabricated 1x12 MMI. These pictures were taken following the silicon RIE etch and prior to PECVD silicon dioxide deposition.

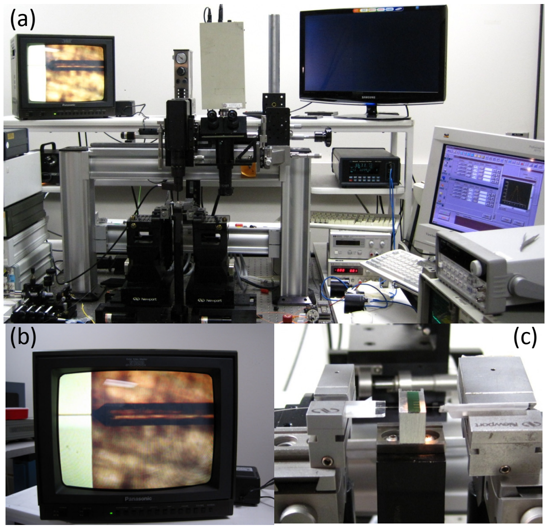

Figure 2-(a) Optical test setup showing auto-aligner with camera to monitor coupling and top mounted IR camera (b) close-up of video screen to monitor coupling. (c) Sample mounted with fiber coupled to input and output.

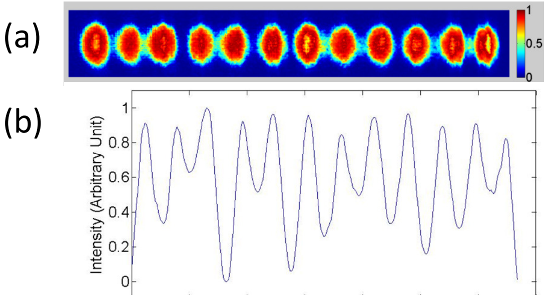

Figure 4-(a) Near field image of 1x12 MMI output (b)) Intensity profile of output channels.

IV. EXPERIMENTAL RESULTS

A six-axis automated aligner system was used to couple TE polarized light from a polarization maintaining lensed fiber (PMF) with a 2.5µm output mode diameter into the input waveguide by a precision in movement of 50nm, as shown in Figure 3. A CCD camera connected to a 100X lens captured the top-down near field images of the cleaved output waveguides' facets. Figure 4(a) and (b) show this near field image and intensity profile, respectively. To determine the uniformity, we used 10log(I_{max}/I_{min}), where I_{max} and I_{min} are the maximum and minimum intensities of the MMI output channels, respectively and calculated a value of 0.8dB.

V. CONCLUSION

An optical beam splitter with a large number of outputs has been successfully demonstrated using a 1x12 MMI fabricated on SOI with a rib waveguide based structure.

VI. ACKNOWLEDGEMENT

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