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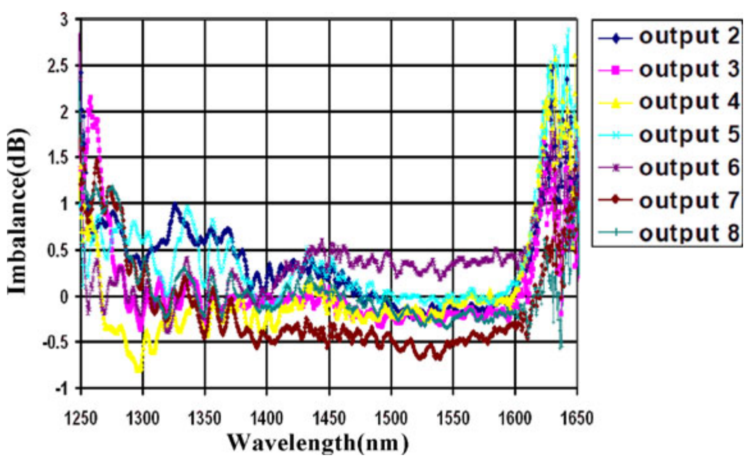

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A Wide Wavelength Range of 1 × 8 Optical Power Splitter With an Imbalance of Less Than ±1.0 dB on Silicon-on-Insulator Technology

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Abstract: A 1 × 8 optical splitter on silicon-on-insulator technology is demonstrated with less than ±1.0 dB imbalance for a wavelength range of 300 nm, in which, a multimode interference (MMI) structure is introduced into an optical power splitter. A comparison is provided for 1 × 2 MMI splitters with and without tapers, a 1 × 2 MMI splitter with tapers is designed, fabricated and measured, which show a wider wavelength range of 300 nm with a lower imbalance of less than ±0.25 dB and a propagation loss of 3 dB.

Index Terms: A 1 × 8 optical power splitter, wider wavelength range, silicon-on-insulator technology.

1. Introduction

Silicon photonic network on chip has become popular as an alternative option for increasing bandwidth, decreasing latency, and reducing power in high performance microelectronics [1]. The splitter is one of the fundamental building elements for the integrated optical circuits as optical power divider [2], combiner [3], attenuator [4], and router [5]. Various splitters are reported [2]–[14]. Among them, MMI splitters receive increasing attention due to very compact and sharply increasing tolerance to fabrication errors compared to the widely-used Y-junction splitters [6]. The MMI is based on this self-imaging principle where the input image is reproduced into multiple images at the output with high uniformity, which also have wide optical bandwidth, low cross talk and polarization independence [7]. Actually, the 1 × N MMI splitters on SOI technology due to high index contrast, low losses, and compatibility with Si electronics and biological samples are reported by many papers [2]–[6], [8]–[12]. However, most of these papers [2]–[6], [8]–[12] focus on the characteristic at a single wavelength of 1550 nm/1310 nm or output number of the splitters.

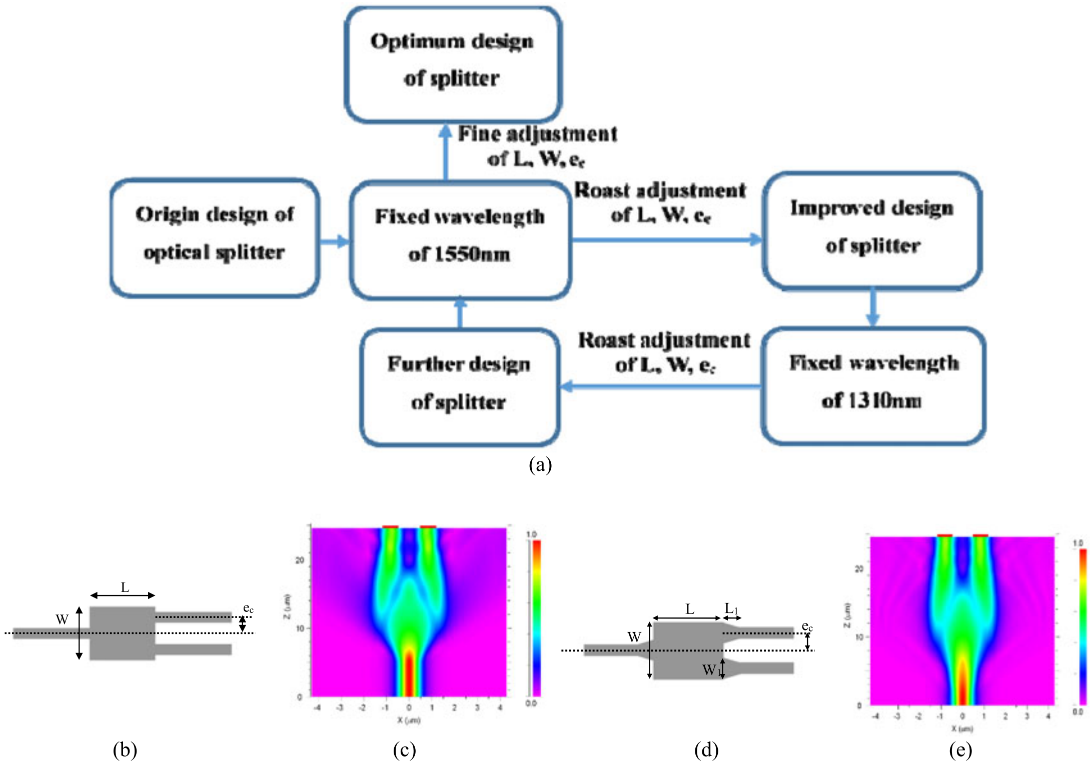

Fig. 1. (a) A process to optimize the design; (b), (c) The structure and Picture of electrical field of 1 × 2 MMI splitter without the tapers; (d), (e) The structure and Picture of electrical field of 1 × 2 MMI splitter with the tapers.

In this manuscript, a MMI splitter is discussed with a lower imbalance for a larger wavelength range. A taper is introduced to mitigate the transition loss between the MMI section and the bus waveguide and enhance the device fabrication tolerance [13], [14]. This will improve the imaging quality in an MMI device and have a lower loss and better imbalance. A comparison is presented for the 1 × 2 MMI splitter with and without tapers using Finite Difference Time Domain (FDTD). The 1 × 2 and 1 × 8 MMI splitters on SOI technology are designed, fabricated and measured.

2. Theoretical Analysis

The simulation of the splitter is performed with FDTD in order to minimize the transition loss and imbalance [15]. It is a complex process to optimize the optical MMI splitter with FDTD by adjusting the design parameters of a splitter (L, W, e_c). We focus the wavelength of 1.55 μm with help of another interesting wavelength of 1.31 μm to execute the optimization. The process is shown in Fig. 1(a), in which, firstly, a wavelength of 1.55 μm is fixed, the design of an optical MMI splitter is improved at a wavelength of 1.55 μm with FDTD by adjusting the parameters of the splitter. Then, last step is repeated at a wavelength of 1.31 μm. Finally, based on the design at a wavelength of 1.31 μm, the structure is optimized at a wavelength of 1.55 μm, again. An optimum design is achieved with L of 3.6 μm, W of 2 μm and e_c of 0.52 μm using the process.

Further, a transition taper is added with L1 of 0.5 μm and W1 of 0.6 μm using FDTD as shown in Fig. 1(b) and (d). The contour mapping of the field for the MMI splitters with and without tapers are shown in Fig. 1(c) and (e) for TE polarization. One can observe that the transition of the MMI splitter with tapers show more mitigatory for the optical power from the input port to the output ports. The simulations show a loss of 2.6 dB and 2.8 dB for a splitter with and without tapers at the wavelength

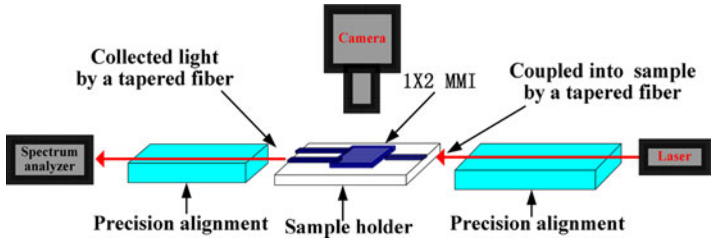

Fig. 2. Experimental setup for the measurements of MMI splitters.

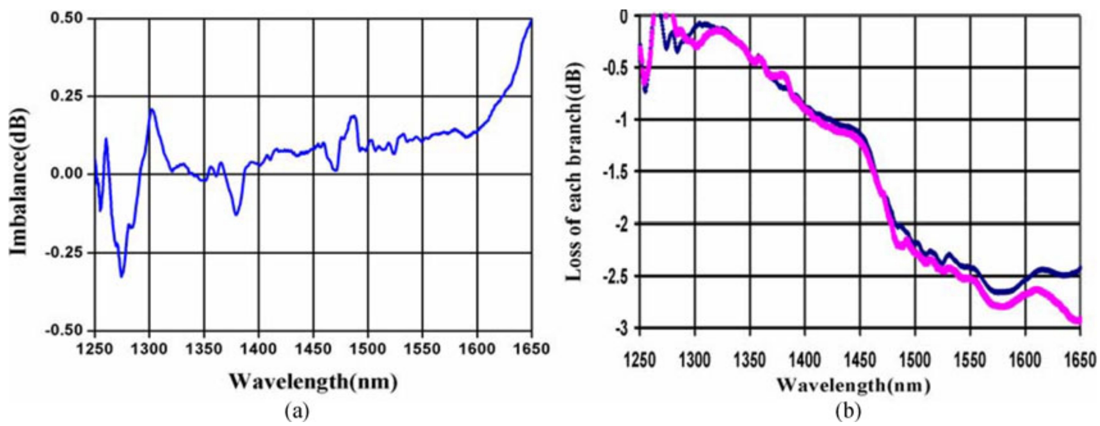

Fig. 3. (a) Imbalance versus the wavelength and (b) Loss versus the wavelength of 1 × 2 MMI beam splitter with the tapers for TE polarization mode (pink and deep blue line for two different outports, respectively).

of 1.55 μm under TE polarization mode, respectively, which confirm that the use of tapers on the input and output waveguides of the MMI reduces the backward reflection and then decreases the radiation losses [16].

3. Fabrication and Measurement of the MMI Splitters

In order to evaluate the MMI splitters, the 1 × 2 and 1 × 8 MMI splitters are fabricated on SOI technology, which are fabricated on SOI unibond 200 nm wafer manufactured by SOITEC with 400 nm of Si on a 1 μm buried oxide (BOX) layer in a commercial facility. The thick oxide of 1 μm is sufficient to reduce the substrate leakage losses and consequently to optically isolate the waveguide circuit from the substrate. Thinning steps with oxidation and etching are used to reduce the silicon thickness to 200 nm.

The fabricated MMI splitters are measured using a set-up as show in Fig. 2, in which, the sample is mounted on a XYZ translational stage. Light from a source is coupled to a polarization maintaining fiber and directed through a polarization controller. Then, the light is coupled into the sample by a tapered fiber. After passing through the sample, the light is collected by a tapered fiber and transmitted to a spectrum analyzer. The input and output tapered fibers are mounted on XYZ micrometer stages for precision alignment with respect to the sample. A linear infrared camera with a microscope objective is used to observe the light diffracted at the side wall of the waveguides during the measurement.

Based on the above simulation, a 1 × 2 MMI splitter with the tapers is designed and fabricated. The measurement results for TE polarization mode are shown in Fig. 3. One can observe the splitter with the tapers has a large wavelength range of 300 nm from 1300 nm to 1600 nm with

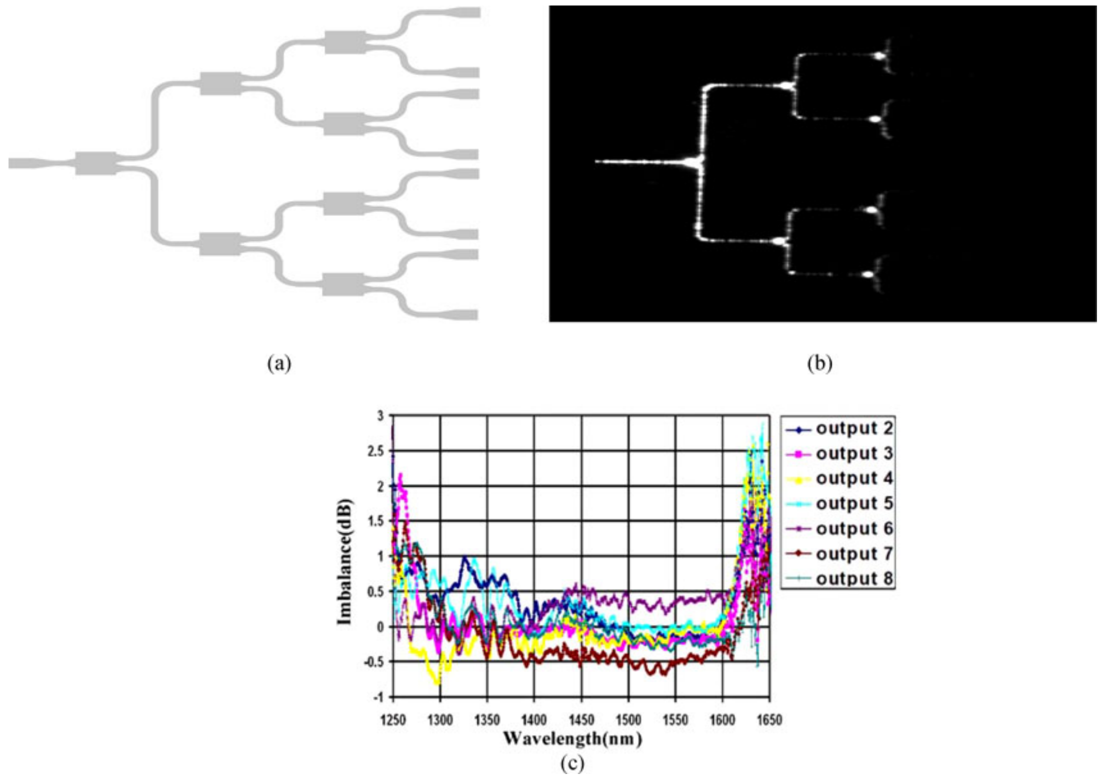

Fig. 4. (a) 1 × 8 MMI splitter, (b) The near infrared image of a working 1 × 8 MMI splitter, (c) Imbalance with the wavelength for 1 × 8 MMI splitter for TE polarization mode.

an imbalance of less than ±0.25 dB in Fig. 3(a), and 3 dB bandwidth of 400 nm in Fig. 3(b). This means the MMI splitters are suitable for a lower scale of integration to distribute the optical signal. Moreover, from Fig. 3(b), the loss at the wavelength of 1.55 μm is about 2.5 dB, which is close to the value of calculation, and the loss decreases with the longer wavelength due to Rayleigh scattering.

Based on the above 1 × 2 MMI splitter, a 1 × 8 MMI splitter with the tapers is designed as show in Fig. 4(a), which include 7 MMI, 21 tapers and 28 bends. Moreover, there are tapers on the in/output ports to improve the coupling with the fibers. The measured results are shown in Fig. 4(b) for TE polarization. In which, output1 is as the reference port for the other seven output ports, one can observe that the imbalance of each branch is almost less than ±1.0 dB for the spectral range of the wavelength from 1.3 μm to 1.6 μm. This means our design has a nicer balance for every branch with a wavelength spanning of 300 nm, although there are some little fluctuations on some branches for some wavelengths due to the fabrication imperfection. The measured loss for each branch is less than 6.74 dB at the wavelength of 1.55 μm.

4. Conclusion

In this paper, a 1 × 2 MMI splitter with the tapers is discussed, designed and fabricated with an optical wavelength range of 400 nm for an imbalance of less than ±0.25 dB and a propagation loss of less than 3 dB. A 1 × 8 MMI splitter with the tapers on SOI technology is demonstrated with an imbalance of less than ±1.0 dB dB for an optical wavelength range of 300 nm. The 1 × 8 MMI splitter, including the tapers, occupies a footprint of less than ~2000 × 200 μm^2.

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