Asymmetric-ration Optical Power Couplers Based on Nano-Pixel Structure

Yu Han [O], Zanhui Chen, Wenying Li, Haisong Jiang, and Kiichi Hamamoto

I-EggS (Interdisciplinary Graduate School of Engineering Sciences), Kyushu Univ.

E-mail: han.yu.926@s.kyushu-u.ac.jp

1. Introduction

One typical optical power coupler is the Y-branch waveguide that has an input waveguide and two output waveguides. Symmetric Y-branch 3-dB couplers (output power ratio 1:1) are wavelength-independent and have been studied to some extent in the past [1]. In contrast, couplers with an asymmetric splitting ratio still have difficulties that are not easily addressed for practical applications. In the asymmetric Y-branch waveguides, the cross-section of the input waveguide is different from those of the output waveguides, so that it is difficult to realize optical mode-matching among the waveguides. This may cause a high coupling loss from the input waveguide to the output waveguides. Therefore, a coupler with an asymmetric splitting-power-ratio design, in addition to a compact footprint and low excess loss is urgently needed. In this work, we proposed 1:9 and 1:99 optical power couplers based on inverse designed nano-pixel. Both couplers occupy a compact area of 2.88 × 2.88 μm^2 with a low excess loss of 0.68 (1:9) / 0.41 dB (1:99) and a wide wavelength operation range of 1500-1600 nm.

2. Inversely designed asymmetric-ration optical couplers

Inverse design approach is employed to realize the desired splitting ratio in the two output waveguides [2]. A compact footprint is finally optimized as occupying a square area of only 2.88 × 2.88 μm^2 as schematically shown Fig. 1. There are totally 576 circular air holes randomly located in this area. These holes are with an identical diameter of 90 nm. The width of the input waveguide is 500 nm for both couplers. In order to collect all the output light, the output waveguide is 1.3 μm-wide for both couplers. Though the output waveguides are wider than that of the input, the output waveguides are possible to be connected with a 500 nm-wide waveguide in future by adding a mode converter based on nano-pixel structure. The beam couplers are constructed on a 100 nm Si high-mesa waveguide. The fabrications and applications of the 100 nm Si high-mesa waveguides have been described in Ref. 3.

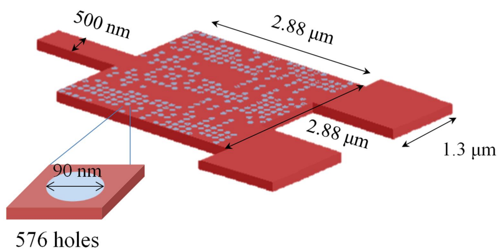

Fig. 1 Schematic diagram of the couplers

The light propagation in the finally optimized couplers was simulated by using finite difference time domain (FDTD) method at the wavelength of 1550 nm. Figures 2(a) and (b) show the simulated optical filed in the device with a splitting ratio of 1:9 and 1:99, respectively. The excess loss α is as low as 0.41 and 0.68 dB for the 1:9 and 1:99 coupler, respectively. Here, α is defined as $\alpha = -10*log_{10}\,[(P_{output1} + P_{output2}) \,/\, P_{in}]$, where $P_{output1}$ and $P_{output2}$ is the output power of the output waveguide and P_{in} the input power at the input waveguide.

One critical technological parameter with the largest contribution to the coupler performance is the sizes of the holes (pixels). Therefore, the influence of the hole diameters on the splitting ratio has been simulated. We find that the variation of the splitting ratio is sufficiently low in the range of 80-100 nm. The splitting ratio is 1:97.5 and 1:8.6 at the diameter of 80 nm, and 1:97.1 and 1:8.6 at 100 nm.

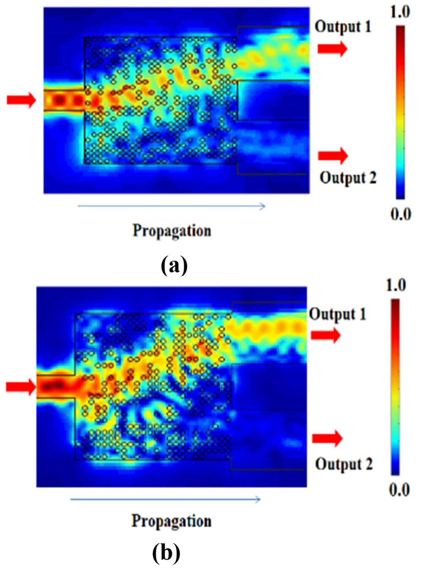

Fig. 2 Simulated light propagation in the optimized couplers (a) Split power ratio of 1 (output 1):9 (output 2) and (b) 1(output 1):99 (output 2) at the wavelength of 1550 nm.

Another important factor for the coupler application is wavelength dependent performance shift. According to our simulations, that the device has a low wavelength dependent excess loss in the range of 1500-1600 nm as shown in Fig. 3. This ability proves a broadband application in future integrated photonic circuits.

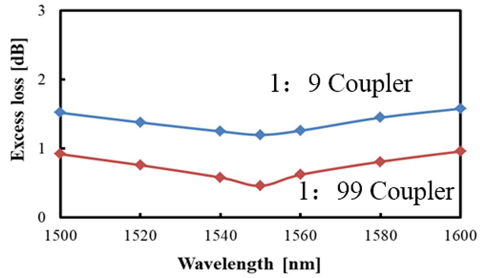

Fig. 3 Excess loss versus wavelength

3. Conclusions

We have designed ultra-compact optical power couplers with a split power ratio 1:9 and 1:99. The two couplers utilize the same area, and the different ratio is controlled by optimizing positions of the circular nano-pixels. The simulated excess loss is 0.68 and 0.41 dB for the 1:9 and 1:99 couplers, respectively. Fabrication tolerance and wavelength dependent performance shift are examined, and the results show that the couplers have a high tolerance and a broadband application window. The results reveal the promising potential of the couplers to be applied in integrated photonic circuits.

Acknowledgment

This work has been financially supported in finance by SECOM Science and Technology Foundation

Reference

[1] H. Sasaki and I. Anderson, IEEE J. Quantum Electron. 14 (11), 883–892 (1978).
[2] K. Xu, et al, Opt. Lett. 42, 855–858 (2017).
[3] Y. Han, et al, Appl. Opt., DOI. 391604 (2020).