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Silica-Based 2x2 Multimode Interference Couplers with Arbitrary Power Splitting Ratio

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1 Introduction

In integrated optical circuits, couplers are indispensable components for splitting or combining optical signals. Several configurations have been proposed to realize integrated optical couplers, including directional couplers, Y branches, and multimode interference (MMI) couplers. Among these, MMI couplers are attractive, because of their less wavelength and polarization sensitivity and good tolerance to fabrication errors [1].

However, an ordinary 2×2 MMI couplers can only realize fixed ratios. Angled MMI couplers capable of any power splitting ratio have been realized in silica on silicon materials [2]. Nevertheless, it is not easy to design integrated circuits with these couplers, because their input and output waveguides are tilted at an angle, which determine the splitting ratio.

In this paper, we propose and demonstrate a novel MMI coupler configuration that enables us to realize an arbitrary splitting ratio.

2 Design and Fabrication

Figure 1(a) shows the basic configuration of our proposed MMI coupler. In the middle of the MMI region, there is a gap filled with cladding. The function of the coupler is the same as the Mach-Zehnder interferometer (MZI) shown in Fig. 1(b), which consists of two 2×2 couplers connected by two arms. The left half (region A) and the right half (region C) of the MMI coupler are designed so that each functions as a 2×2 coupler, while the middle region (region B) acts as the MZI arms. Light injected into one of the input waveguides is divided into two lightwaves by region A. They both pass through region B to region C; one via the core and the other via the cladding. Since the core has a higher refractive index than the cladding, each lightwave experiences a different phase shift. The two lightwaves are recombined by region C, and extracted from the output waveguides. The power splitting ratio k of the coupler is given by

$$k = \cos^2\left(\frac{\theta}{2}\right), \quad (1)$$

where θ is a phase difference induced in region B. Therefore we can design the power splitting ratio by changing the gap length. When the refractive index difference Δ is 0.75%, a splitting ratio of 0 % to 100% can be realized with a gap length of less than 100 μm.

We fabricated the proposed MMI couplers using planar lightwave circuit (PLC) technologies. The core thickness was 6 μm, and the refractive index difference was 0.75 %. The length of the MMI region and the width were 3.0 mm and 0.025 mm, respectively. Figure 2 shows the excess losses and power splitting ratios of the fabricated coupler, as a function of the gap length. We realized a power-splitting ratio of 0 % to 100 %. However, the longer the gap region was, the larger the excess loss became, because of radiation at the gap. When the splitting ratio was 100 %, the excess loss was about 1.7 dB.

To suppress the radiation loss at the gap, we developed a divided gap design, as shown in Fig. 3. Since radiation loss at the gap increases superlinearly with respect to the gap length, the loss can be improved by dividing the gap into several sections. We set the unit gap length and the gap spacing at 5 and 25 μm, respectively. Figure 4 shows the excess losses and power splitting ratios of the fabricated coupler with divided gaps. Power splitting ratios of 0-100 % can be realized with an excess loss of better than 1 dB.

3 Conclusion

We have proposed a novel MMI coupler for use as an arbitrary ratio power splitter. It is possible to change the power splitting ratio of the coupler by changing the length of the gap at the center of the MMI region. The couplers we fabricated with a divided-gap-design could provide any power splitting ratio with an excess loss of less than 1 dB.

References

[1] L. B. Soldano and E. C. M. Pennings, J. Lightwave Technol., vol. 13, no. 5, pp. 615-627, 1995.

[2] Q. Lai, M. Bachmann, W. Hunziker, P. A. Besse, H. Melchoir, Electron. Lett., vol. 32, no. 7, pp. 1576-1577, 1996.

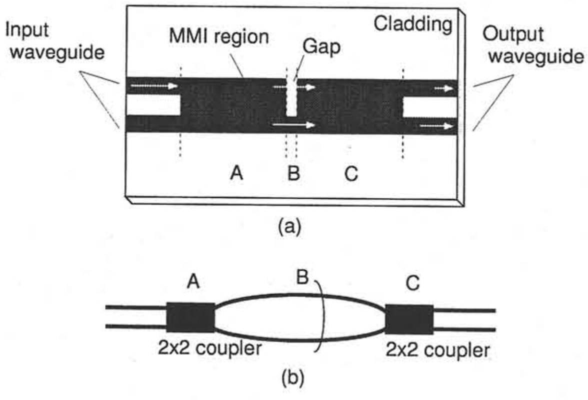

Figure 1: (a) A schematic configuration of our proposed MMI coupler with an arbitrary splitting ratio, (b) A Mach-Zehnder interferometer with the same function as the MMI coupler.

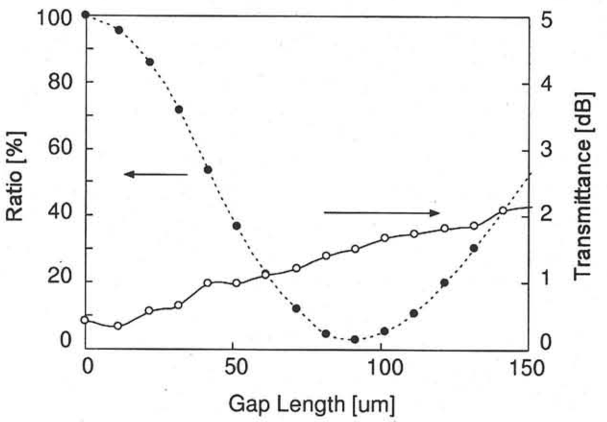

Figure 2: Power splitting ratio and excess loss of MMI coupler fabricated with a single gap.

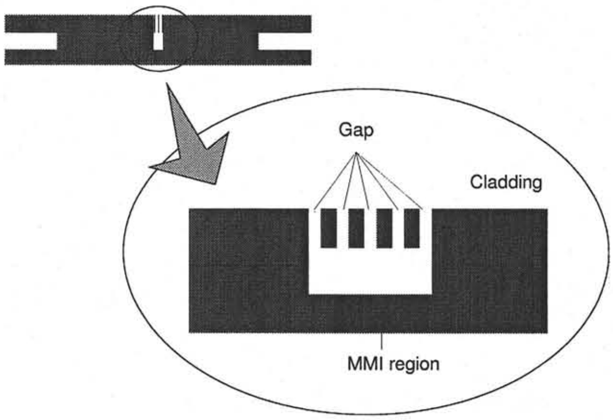

Figure 3: Divided gap design to suppress gap radiation loss.

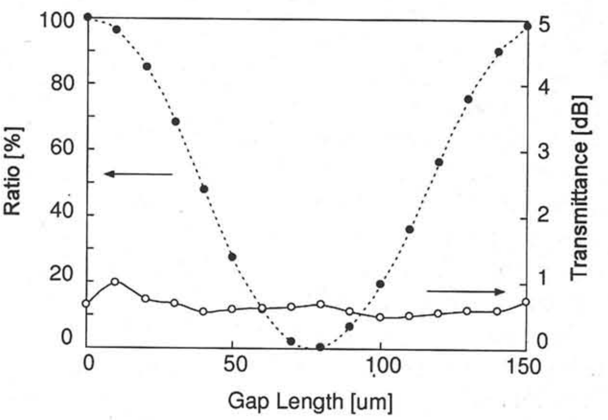

Figure 4: Power splitting ratio and excess loss of MMI coupler fabricated with divided gap design.