Design of a Waveguide-Type Polarization Beam Splitter Incorporating Trenches Filled with Low-Refractive Index Material

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Abstract. *We propose a waveguide-type polarization beam splitter (PBS) incorporating trenches filled with low-refractive index material, which exhibits a low insertion loss of less than 2 dB and a high polarization extinction ratio of more than 20 dB over a wide wavelength range from 1525-1630 nm.*

Introduction

The concept of a waveguide-type polarization beam splitter (PBS) is very promising because such a device could be easily integrated with other circuits. A silica-based waveguide-type PBS which utilizes waveguide birefringence and which is dependent on the core-width has been reported [1]. This device exhibited low-insertion loss and a high polarization extinction ratio. Silica-based waveguides have been very popular in the field of passive optical components because they offer low fiber-to-chip coupling losses and low propagation losses. However, these devices require the use of long waveguide arms because the waveguide birefringence is low. PBS devices fabricated using silicon-on-insulator waveguides have also been studied [2]. Since they feature large waveguide birefringence which depends on the rib width, the size of these devices can be more compact than silica-based designs. However, it is difficult to achieve a high polarization extinction ratio and a low coupling loss between single mode fibers without mode-size conversion when using a silicon-based waveguide-type PBS.

We have proposed and fabricated a compact silica-based PBS [3] by including trenches filled with low-refractive index material with a refractive index of 1.3335. This device exhibited a high polarization extinction ratio around the center wavelength. In this paper, we have optimized such a PBS structure which incorporates trenches in order to obtain a high polarization extinction ratio over a wide wavelength range, and we have confirmed the transmission characteristics of the PBS that we designed by using simulations based on the beam propagation method (BPM).

Design of PBS

Our proposed PBS structure with trenches filled with low-refractive index material is shown in Fig. 1. It has a Mach-Zehnder interferometer (MZI) configuration, and consists of two 3-dB couplers and two waveguide arms with trenches of different lengths. We used multimode interference (MMI) devices as a 3-dB coupler, and the trenches were introduced along both sides of the core. Because of the local laterally-enhanced optical confinement, the propagation constants of the embedded waveguides containing low-refractive index material strongly depend on the polarization. Therefore, the size of such a PBS can be reduced. To balance the light intensities in both waveguide arms, we inserted trenches into both of them. The straight trenches were inserted gradually into the core to reduce the junction loss between the conventional waveguide and the low-refractive index material embedded waveguide.

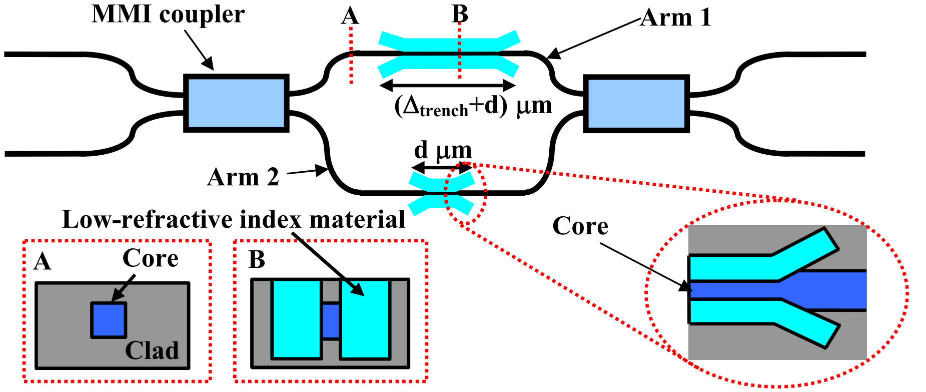

Fig. 1. Schematic configuration of our proposed PBS

The wavelength dependences of the effective refractive indices for both the conventional waveguides and the low-refractive index material embedded waveguides are shown in Fig. 2. The value of the difference in optical pass-length between the two waveguide arms *Δ(nL)* changes according to the wavelength because the effective refractive index of a low-refractive index material embedded waveguide depends on the wavelength. Therefore, we can't obtain a high polarization extinction ratio over a broad wavelength range with this configuration.

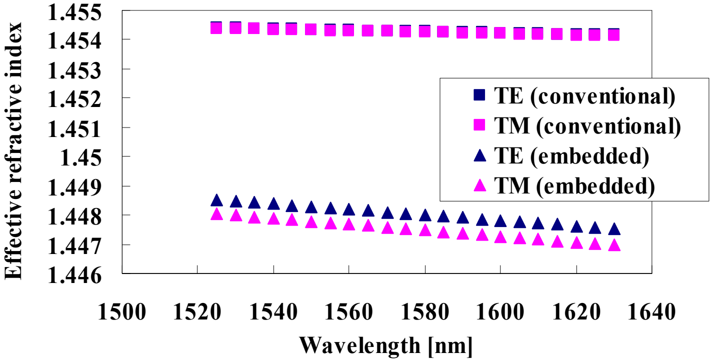

Fig. 2. Wavelength dependences of the effective refractive indices of both conventional waveguides and low-refractive index material embedded waveguides with mesa widths of 3.0 µm.

We solved this problem by taking the wavelength dependence of the effective refractive index into account. From Fig. 2, we can assume that the wavelength dependence of the effective refractive index decreases almost linearly as a function of wavelength. The conditions in which the PBS has a broad bandwidth are expressed by

$$n1_{TE}(\lambda)(\Delta_{trench}+\Delta L)-n2_{TE}(\lambda)\Delta_{trench}=m\lambda, \tag{1}$$

$$n1_{TM}(\lambda)(\Delta_{trench}+\Delta L)-n2_{TM}(\lambda)\Delta_{trench}=\left(n+\frac{1}{2}\right)\lambda, \tag{2}$$

where $n1_{TE(TM)}$ and $n2_{TE(TM)}$ respectively express the effective refractive indices of TE(TM) mode for a conventional waveguide and a low-refractive index material embedded waveguide (whose values depend on the wavelength), Δ_{trench} is the difference in length between the trenches in the two waveguide arms, ΔL is the difference in length between the two waveguide arms, λ is the wavelength of the incident light, and m and n are integers. From (1) and (2), the optimum values for Δ_{trench} and ΔL can be determined. However, it is difficult to set the parameters in order to completely satisfy (1) in relation to (2) because the slopes of the effective refractive indices of TE and TM mode as a function of wavelength for a low-refractive index material embedded waveguide do not share the same values. Although we can adjust these by changing the mesa width, they are not independently controllable. Therefore, we obtained a wide bandwidth by making a small sacrifice in terms of the extinction ratio by designing the parameters such that the values of m and n almost become integers.

Simulation results

We optimized the parameters and confirmed the characteristics of the wavelength dependence by using a two dimensional (2D) beam propagation method (BPM). ΔL was 3.59 μm. The mesa width was 3 μm. The birefringence of a waveguide fabricated using trenches filled with low-refractive index material is shown in Fig. 3, and it can be seen that it depends strongly on the mesa width. Smaller mesa widths exhibit larger birefringence; therefore, this enables the use of shorter waveguide arms. However, the difference between the slopes of the effective refractive indices between TE and TM modes as a function of wavelength for a low-refractive index embedded waveguide becomes larger and therefore narrows the working bandwidth. Moreover, narrow mesa widths are difficult to fabricate. Therefore, we determined that the mesa width should be 3 μm, Δ_{trench} was 764 μm, and the straight length of the shorter trench, d was 10 μm. The length of the longer trench, including the taper parts, was less than 1130 μm. The transmission characteristics are shown in Fig. 4.

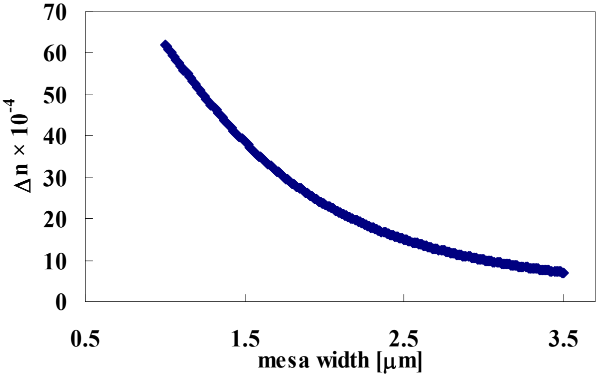

Fig. 3. Birefringence of a low-refractive index material embedded waveguide as a function of mesa width.

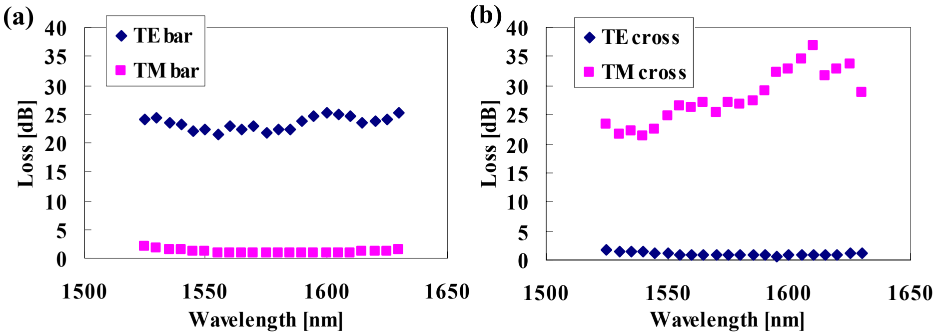

Fig. 4. Wavelength dependence of transmission characteristics.
(a) through-path. (b) cross-path.

The insertion loss was less than 2 dB. The polarization extinction ratio was greater than -20 dB over a wide wavelength range from 1525-1630 nm for both polarizations. Although the trench length becomes longer, higher polarization extinction ratios can be obtained by widening the mesa width.

Conclusion

We improved the wavelength-dependence of a PBS incorporating trenches filled with low-refractive index material by taking the wavelength-dependence of the effective refractive index into account. We confirmed that a PBS fabricated using our proposed design method exhibited a low insertion loss of less than 2 dB and a high polarization extinction ratio of more than 20 dB over a wide wavelength range from 1525 to 1630 nm by making 2D BPM simulations.

References

[1] Y. Hashizume, R. Kasahara, T. Saida, Y. Inoue and M. Okano, "Integrated polarization beam splitter using waveguide birefringence dependence on waveguide core width," Electron. Lett., vol. 25, no. 25, pp. 1517-1518, 2001.

[2] T. K. Liang and H. K. Tsang, "Integrated polarization beam splitter in high index contrast silicon-on-insulator waveguides," IEEE Photon. Technol. Lett., vol. 17, no. 2, pp. 393-395, 2005.

[3] J. Ito, Y. Ikuma, K. Iwamoto and H. Tsuda, "Compact polarization beam splitter using trenches filled with low-refractive index material," in Proceedings of the APLS 2008, 2008, pp.181.