TE-TM Mode Conversion Optical Isolator Employing Halfwave Plate Integrated with Spot-Size Converters

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Abstract: A TE-TM mode conversion optical isolator consists of a nonreciprocal mode converter and a reciprocal mode converter. The reciprocal mode converter is realized by a polyimide halfwave plate inserted into a groove. In order to suppress diffraction loss, a spot-size converter was integrated at both an input facet and an output facet of the halfwave plate. By introducing the spot-size converter, the insertion loss due to the halfwave plate could be reduced to approximately 0.22 dB.

Introduction: In optical communication systems, an optical isolator is indispensable in protecting optical active devices from unwanted reflected light. An optical isolator employing a TE-TM mode conversion comprises nonreciprocal and reciprocal mode converters.[1] Therefore, complicated control of direction of magnetization is needed. To overcome the difficulties associated with the mode-conversion isolator, a hybrid optical isolator with a halfwave plate was proposed.[2] The control of direction of magnetization is required for the nonreciprocal mode converter only. In this paper, the authors report on the TE-TM mode conversion optical isolator which employs the halfwave plate integrated with spot-size converters for suppressing diffraction loss.

Device structure: Figure 1 shows a TE-TM mode conversion optical isolator with a halfwave plate. The optical isolator consists of the $\pi/4$-rad nonreciprocal mode converter and the $\pi/4$-rad reciprocal mode converter. The nonreciprocal mode converter is comprised of the magneto-optic waveguide with a $(CeY)_3Fe_5O_{12}$ (Ce:YIG) guiding layer. An external magnetic field in the longitudinal direction is applied to the magneto-optic waveguide for the nonreciprocal mode conversion. A polyimide halfwave plate is inserted into a groove fabricated in the waveguide as a $\pi/4$-rad reciprocal TE-TM mode converter.[3]

For the forward-traveling light wave, the $-\pi/4$-rad nonreciprocal mode conversion is cancelled by the $+\pi/4$-rad reciprocal mode conversion. Consequently, the polarization state of the output light wave is identical with that of the input light wave. For the backward-traveling wave, on the other hand, the nonreciprocal mode conversion changes its sign to $+\pi/4$ rad. This mode conversion is added to the reciprocal mode conversion, and the whole mode conversion amounts to $\pi/2$ rad. The polarization state of the output light wave is normal to that of the input light wave. Therefore, the device equipped with two polarizers, whose polarization azimuth is identical, at both the input port and the output port acts as an optical isolator. The optical isolator can operate for both TE mode and TM mode depending on the azimuth of the polarizers.

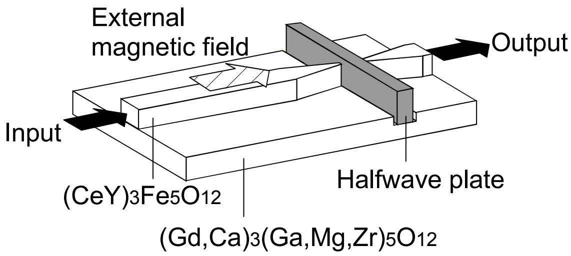


Fig. 1. TE-TM mode conversion optical isolator with Ce:YIG guiding layer.

As can be seen in Fig. 1, the polyimide halfwave plate is inserted into the groove in the magneto-optic waveguide. Propagation through the halfwave plate gives rise to diffraction loss due to the lack of an optical confinement structure. Diffraction loss was calculated when the light wave propagated in a slab waveguide with the groove. Figure 2 shows the calculated diffraction loss depending on the groove width. The refractive index of the polyimide halfwave plate was assumed to be 1.6 at 1.55 μm.[2,3] The thickness of the slab waveguide H was 1.0, 1.5, 2.0, 3.0 and 5.0 μm, respectively. Smaller the thickness H is, larger the diffraction loss is, which is derived from a small optical confinement factor. In consideration of a single-mode condition, however, it is desirable that the magneto-optic waveguide has a small Ce:YIG core. There is a trade-off between the diffraction loss and the single-mode condition.

In order to circumvent the diffraction loss, a spot-size converter was introduced into the waveguide at both an input facet and an output facet of the halfwave plate as shown in Fig. 1. The spot-size converter was designed in order to minimize the diffraction loss at 1.55 μm. The strip height and the strip width were assumed to be 0.80 μm and 1.0 μm, respectively. The thickness of the halfwave plate was assumed to be 20 μm in the light of the thickness of the polyimide halfwave plate. In consideration of the calculated diffraction loss, the taper length and taper width were determined to be 300 μm and 0.25 μm, respectively. Figure 3(a) shows the propagation characteristics of the TE mode through the halfwave plate without the spot-size converter. The propagation loss due to the insertion of the halfwave plate without the spot-size converter was more than 20 dB. When the halfwave plate was integrated with the spot-size converter, the propagation loss was reduced to approximately 1.48 dB. Moreover, when the spot-size converter was covered by an SiO_2 cladding layer, the propagation loss was reduced to approximately 0.22 dB. Figure 3(b) shows the propagation characteristics of the TE mode through the halfwave plate integrated with the spot-size converter covered by the SiO_2 cladding layer. By introducing the spot-size converter at both facets of the halfwave plate, the magneto-optic waveguide satisfies not only a single-mode condition but also a small diffraction loss.

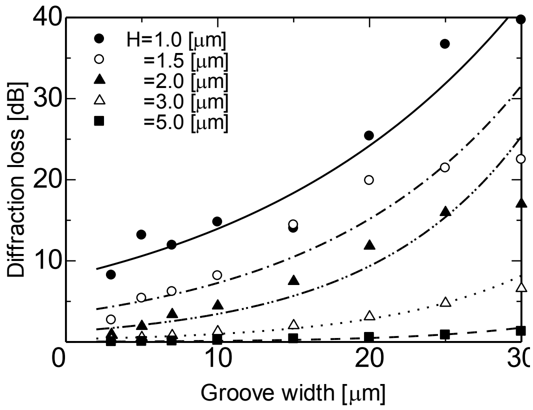
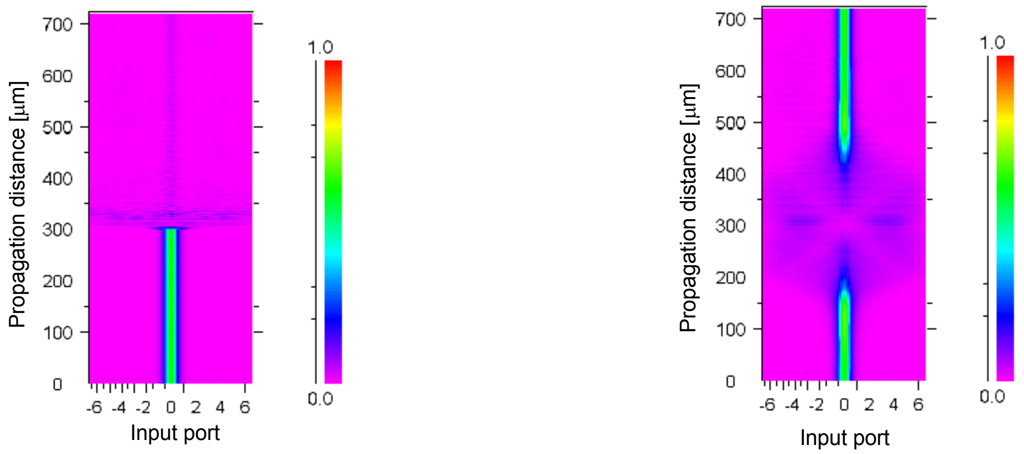


Fig. 2. Calculated diffraction loss depending on groove width.



(a) (b)

Fig. 3. Propagation characteristics of the TE mode (a) without a spot-size converter and (b) with a spot-size converter covered by a SiO_2 cladding layer.

Conclusion: We discussed an optical isolator employing a TE-TM mode conversion. The reciprocal mode converter was realized by a polyimide halfwave plate integrated with a spot-size converter. By introducing the spot-size converter for an input facet and an output facet of the halfwave plate, the propagation loss due to the halfwave plate could be reduced to approximately 0.22 dB.

References

1. J. P. Castera and G. Hepner, *IEEE Trans. Magn.* **MAG-13**, pp.1583-1585, (1977).
2. N. Sugimoto, H. Terui, A. Tate, Y. Katoh, Y. Yamada, A. Sugita, A. Shibukawa, and Y. Inoue, *J. Lightwave Technol.* **14**, pp.2537-2546, (1996).
3. S. Ando, T. Sawada, and Y. Inoue, *Electron. Lett.* **29**, pp.2143-2145, (1993).