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Surface Micromachining in Optical Isolator Employing Nonreciprocal Radiation Mode Conversion

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1. Introduction

In optical communication systems, an optical isolator is indispensable in protecting optical active devices from unwanted reflected light. We have studied an optical isolator, employing a nonreciprocal phase shift, fabricated by wafer bonding technique [1]. The isolator was comprised of a magneto-optic waveguide with a magnetic garnet / GaInAsP / InP structure. By using the nonreciprocal phase shift, an optical isolator employing a nonreciprocal radiation mode conversion was proposed [2]. It is considered that an optical isolator employing the nonreciprocal radiation mode conversion can be constructed with a magneto-optic waveguide which has a semiconductor guiding layer. In order to enhance the nonreciprocal phase shift, a lower cladding layer with a lower refractive index material is effective.

In this paper, we report on surface micromachining for enhancement of the nonreciprocal phase shift in the optical isolator employing the nonreciprocal radiation mode conversion.

2. Device Structure

Figure 1 shows the optical isolator, employing the nonreciprocal radiation mode conversion, fabricated by wafer bonding. A Ce-substituted yttrium iron garnet (Ce:YIG) was connected with a GaInAsP guiding layer by wafer bonding technique. Faraday rotation coefficient of Ce:YIG was approximately –4500 deg/cm at a wavelength of 1.55 μm. The nonreciprocal phase shift occurs in TM modes traveling in a magneto-optic waveguide where the magnetization is aligned transversely to the light propagation direction in film plane. By adjusting waveguide parameters, propagation constants of TE-like and TM-like modes satisfy a following relationship:

$$\beta^{y}_{11b} < \beta^{x}_{c} < \beta^{y}_{11f} \qquad (1)$$

where β^{y}_{11f}, β^{y}_{11b} denote the propagation constants of forward and backward traveling TM-like waves, respectively, and β^{x}_{c} denotes the cutoff of a TE-like wave. In this case, only the backward traveling TM-like waves are coupled to the TE-like radiation waves so that this device acts as a TM-mode optical isolator.

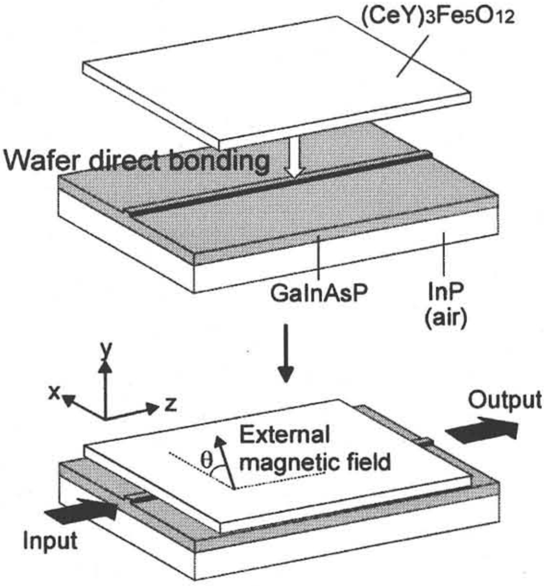

Figure 1 Optical isolator employing nonreciprocal radiation mode conversion

The optical isolator with the magnetic garnet / GaInAsP / InP (or air) waveguide was designed at a wavelength of 1.55 μm. Figure 2 shows the calculated nonreciprocal phase shifts in the magneto-optic waveguide with the Ce:YIG / GaInAsP / InP (or air) structure. In case of the air cladding layer, the maximum nonreciprocal phase shift is more than twenty times larger than that of the waveguide with the InP cladding layer. Larger nonreciprocal phase shifts can be attributed to the increase in the electromagnetic field penetrating into the Ce:YIG cladding layer.

Figure 3 shows the relationship between a rib height and a rib width in order to satisfy Eq. (1). When the rib height is 59 nm in the magneto-optic waveguide with the InP cladding layer, the rib width for the isolator operation ranges between 3.96 and 4.03 μm (with a tolerance of 70 nm). In case of the air cladding layer, on the other hand, when the rib height is 90 nm, the tolerance of the rib width for the isolator operation is approximately 530 nm, seven times larger than that in the optical isolator with the Ce:YIG / GaInAsP / InP waveguide.

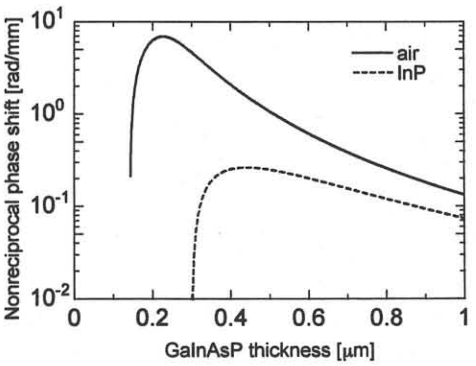

Figure 2 Calculated nonreciprocal phase shift at a wavelength of 1.55 μm

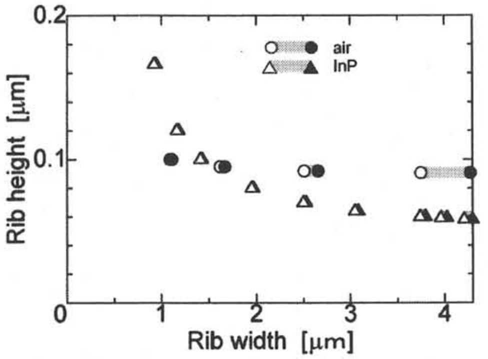

Figure 3 Relationship between rib height and rib width for isolator operation

3. Experimental Results

Figure 4 shows the experimental procedure of the surface micromachining for fabricating the GaInAsP rib waveguide with the air cladding layer. A GaInAsP guiding layer and an AlInAs sacrificial layer were grown on an n-InP substrate by metal organic vapor phase epitaxy. The rib waveguide was formed by use of reactive ion etching with CH_4:H_2 gas. The rib width was 2 μm. A cavity beside the rib waveguide was also fabricated by use of reactive ion etching with CH_4:H_2 gas. The AlInAs sacrificial layer was etched by H_2SO_4:H_2O_2:H_2O (1:1:5) [3]. The magneto-optic waveguide would be obtained by wafer bonding between a Ce:YIG cladding layer and the GaInAsP guiding layer.

Figure 5 shows the SEM image of the GaInAsP rib waveguide with air bridge structure. Light waves at 1.55 μm were launched into the GaInAsP rib waveguide with 1-mm-long air bridge structure. Near field pattern observed at the output facet indicated that the light waves could be guided in the waveguide.

4. Conclusions

Surface micromachining was investigated to fabricate a magneto-optic waveguide with an air cladding layer in an optical isolator employing a nonreciprocal radiation mode conversion. The GaInAsP rib waveguide with the air bridge structure was successfully obtained.

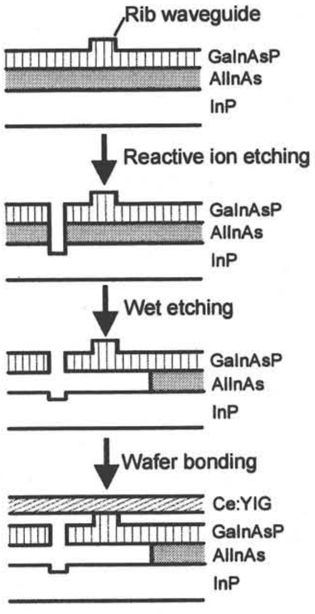

Figure 4 Experimental procedure of surface micromachining

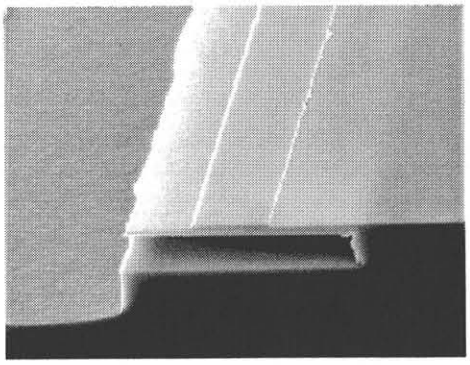

Figure 5 SEM image of GaInAsP rib waveguide with bridge structure

Acknowledgments

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