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Integration of an Optical Waveguide Isolator by Wafer Direct Bonding

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1. Introduction

In optical communication systems, an optical isolator is of great importnace in order to protect active devices from unwanted reflected light and to stabilize oscillation of semiconductor laser diode. An optical waveguide isolator has been strongly required for the integration of the other optical components. In particualr, the use of nonreciprocal phase shift in an optical waveguide isolator has an advantage that phase matching is not necessary between two orthogonally polarized modes and complicated control of magnetization [1,2]. Magnetic garnet films such as Ce:YIG (Ce-substituted yttrium iron garnet) are suitable for an integrated optical waveguide isolator because of their large Faraday rotation and low optical loss at 1.3μm and 1.55μm [3]. In the present work, we report on an intergreted optical waveguide isolator by wafer direct bonding between the InGaAsP and Ce:YIG. The optical isolation ratio of the fabricated device is discussed.

2. Experiments

A schematic structure of the integrated optical isolator is shown in Fig. 1. The layer structure of multi-mode section of the optical isolator is Ce:YIG/InGaAsP/InP, and the rest part of the device is air/InGaAsP/InP. The upper cladding layer, Ce:YIG was contacted to multi-mode section using a wafer direct bonding process, which is crucial in integrating the waveguide isolator. The semiconductor waveguide and Ce:YIG magnetic film were cleaned using Trichloroethylene, Acetone, Methanol in order. After cleaning, the surfaces of the InGaAsP and Ce:YIG wafer were treated by O_2 plasma for 30 seconds at 100W RF power under 0.3 Torr. Bonding between InGaAsP and Ce:YIG was strengthened by heat treatment at 220°C in the ambience of Ar for 120 min. In order to measure isolation ratio, a unidirectional external magnetic field is applied to the multimode section of the optical isolator. The direction of the magnetic field is transverse to the light propagation and is the film plane for nonreciprocal phase shift.

3. Result and Discuss

In order to construct an optical isolator, a wafer direct bonding technique has been used. The crystallographic property of InP and GGG($Gd_3Ga_5O_{12}$) is similar to that of InGaAsP and Ce:YIG, respectively. The bonding between InP and a commercially available mirror polished GGG has been investigated. Fig. 2 shows a cross sectional image of the bonded wafer between the InP and GGG. From the Fig. 2, the wafer direct bonding is likely to be successful without an air gap between the bonded layers. The air gap between the magnetic garnet film and semiconductor layer is known to give rise to the rapid reduction of nonreciprocal phase shift [4]. In order to measure isolation ratio, an external magnetic field was applied to the device fabricated using wafer direct bonding between InGaAsP and Ce:YIG, an MMI(multi-mode interference) waveguide optical isolator. The applied magnetic field was found to cause the nonreciprocal phase shift of the traveling wave in the multi-mode section, which has been designed to make the maximum intensity for a forward propagating wave. However, for a backward reflected wave, the focal point of the multi mode section is not located at the waveguide for nonreciprocal phase shift. Therefore, the output in the backward direction has been relatively smaller intensity than that of the forward direction. The isolation ratio was measured through the variation of the intensity by reversing the external magnetic field direction, since reversing the direction of magnetic field is equivalent to reversing the wave propagating direction. The intensities of the outputs in the forward and backward directions are shown in Fig. 3. For the forward and backward directions, the intensities were measured to be -37.8 dBm and -40.7dBm, respectively. Our results, therefore, demonstrate the MMI waveguide optical isolator with isolation ratio of 2.9 dB using a wafer direct bonding technique.

4. Summary

An integrated waveguide optical isolator by wafer direct bonding has been studied. The isolation ratio was found to be 2.9dB in our device. We found that wafer direct bonding between the InP and GGG is effective for the integration of a waveguide optical isolator.

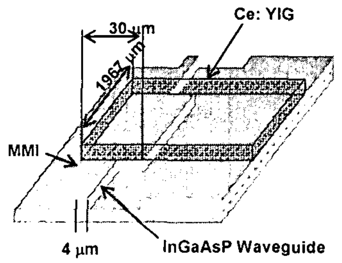

Fig. 1. The schematic structure of the optical isolator.

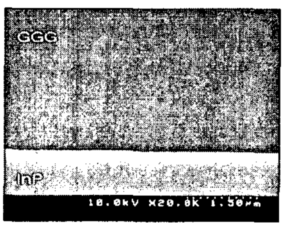

Fig. 2. SEM image of bonded sample between InP and GGG

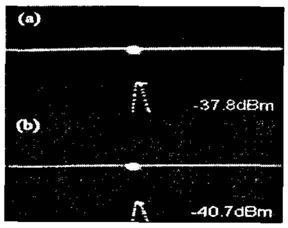

Fig. 3. Near field pattern and intensity of output from waveguide (a) forward direction (b) backward direction

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