Resonance characteristics of disk resonators for TE mode isolators

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***Abstract*— A TE mode optical isolator was proposed by depositing and crystallizing Ce:YIG on a disk cavity. Resonance characteristics were obtained from the fabricated device. Resonance characteristics were maintained even after Ce:YIG was deposited and crystallized.**

***Keywords*— Optical isolator, TE mode, Disk resonator type optical isolator**

I. INTRODUCTION

In recent years, data traffic has increased with the rapid development of networks such as 5G, and further speeding up and large-capacity transmission are required. Therefore, stable operation of semiconductor lasers used as the light source is essential, and the contribution of optical isolators suitable for integration is important. Waveguide isolators fabricated with magneto-optical garnets formed on Si platforms by direct bonding [1],[2], adhesive bonding [3], and deposition [4] have been demonstrated.

Non-reciprocal resonators composed of MO materials and ring waveguides can reduce the size of optical isolators. Non-reciprocal ring resonators were reported theoretically [5],[6] and experimentally [2],[4].

Since most semiconductor lasers emit transverse-field (TE) polarized light, it is necessary to develop waveguide optical isolators that can operate in the TE mode. One approach to achieve this is to integrate waveguide TE-TM mode converters (polarization rotators) and non-reciprocal phase shifters for the TM mode [3]. Another approach is to realize a non-reciprocal phase shifter in TE mode [7]. The non-reciprocal phase shifter in TE mode requires the formation of a horizontally asymmetric waveguide structure that coincides with the main electric field direction of the propagating light.

In this paper, we propose a new structure for an optical isolator operating with TE mode light using a disk resonator. In addition, we reported the fabrication of disk resonators necessary for optical isolator operation and the obtained resonance characteristics.

II. OPERATING PRINCIPLE

Unlike ring resonators, in which light propagates through both the inner and outer sidewalls, disk resonators allow light to propagate and resonate using only the outer sidewalls [8].

Figure 1(a) shows a schematic of the proposed new optical isolator. The nonreciprocal phase shift is brought about in the waveguide with a magneto-optical material placed asymmetrically with respect to the electric field of the lightwave. As shown in the Fig. 1(b), lateral asymmetry can be obtained by using a magneto-optical material for the clad covering the disk resonator, so that a non-reciprocal phase shift of TE mode light can be obtained. Since the clockwise propagation mode and the counterclockwise propagation one have different propagation constants to the disk resonator due to the non-reciprocal phase shift, it can be operated as an optical isolator.

In this study, Ce:YIG crystallized by the contact epitaxial method is used as the magneto-optical material covering the disk resonator.

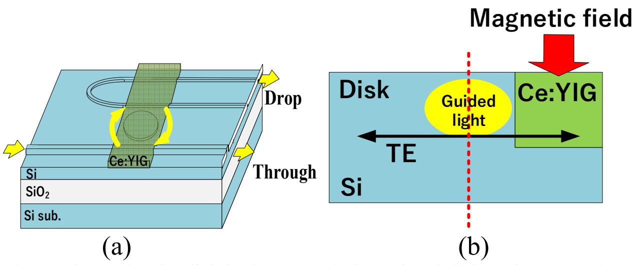


Fig.1.Schematic of a disk isolator consisting of a Si disk and Ce:YIG layer

III. DEVICE AND ANALYSIS OF SI DISK RESONATOR

Figures 2(a) and (b) shows a cross sectional view of waveguids and a top view of a disk resonator. It consists of two bus lines and a disk. A part of the light from input port is circurated in a disk and resonates with light of a bus line. The structural parameters of the fabricated device are as follows. Si core layer thickness (h_{core}) is 220[nm], rib height (h_{rib}) is 180.1[nm], waveguide width (w) is 500[nm], The gap (d) is 100[nm], and the radius (r) of the disk resonator is 2.5[μm], 5[μm], and 10[μm].

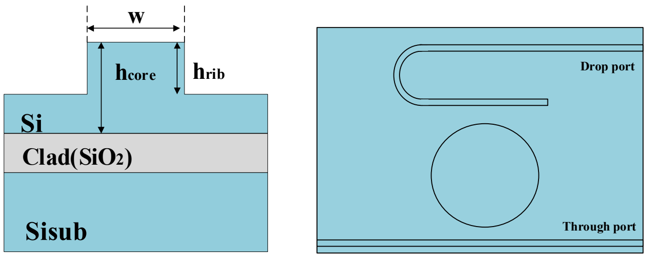


Fig.2.(a) Cross sectional view (b) Structure of disk resonator

The resonance characteristics with different disk radius are calculated using the finite-difference time-domain (FDTD) method. The theoretical analysis was performed with TE mode light and disk radius of 2.5[μm], 5[μm] and 10[μm].

Figure 3(a) shows the theoretical analysis results a 2.5[μm] disk radius. The input light circulates widely inside the disk with high intensity, but light was leaked. Also, the calculated the free spectral range (FSR) was 39.4[nm].

Figure 3(b) shows the theoretical analysis results a 5 [μm] disk radius. Leaked light was small and circulated around the outside of the disk with high intensity. Also, the FSR was 20.9 [nm].

Figure 3(c) shows the theoretical analysis results a disk radius of 10 [μm]. There was almost no leaked light, and the input light circulated around the inside of the disc with a weak intensity. Also, the FSR was 10.1 [nm].

From the result of the optical analysis, following tendency was cleared.As the disk radius was increased, the FSR and light intensity in disk decreased. Also, periodic resonance characteristics were obtain at any disk radius.

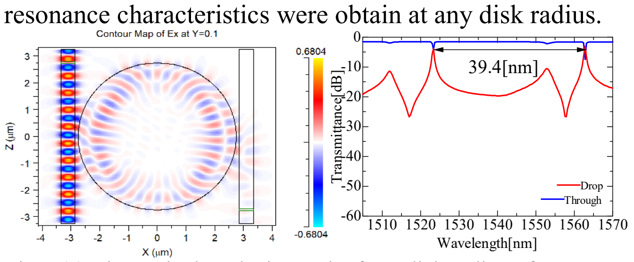


Fig.3.(a) Theoretical analysis results for a disk radius of 2.5[μm]

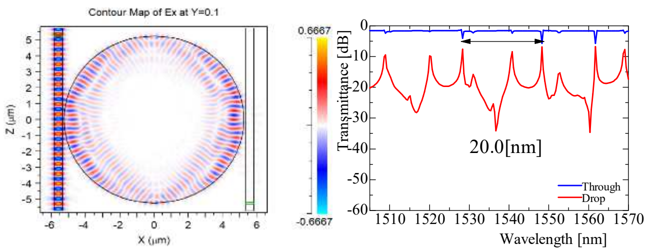


Fig.3.(b) Theoretical analysis results for a disk radius of 5 [μm]

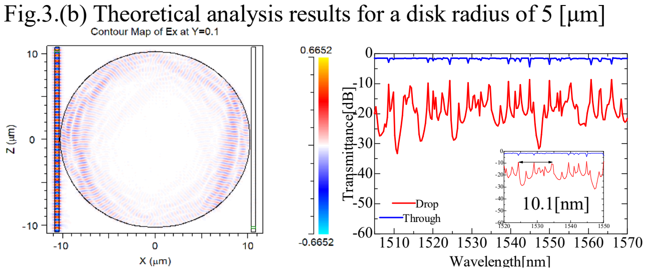


Fig.3.(c) Theoretical analysis results for a disk radius of 10 [μm]

IV. Fabrication Process

Figure4 shows the Fabrication process of the disk resonator-type optical isolators. A resist is applied on the SOI substrate for the disk resonator pattern. An electron beam (EB) lithography system (CRESTEC CABL-9200TFTN) was used to draw the pattern. The pattern of the disk resonator was formed by the lift-off process. Next, waveguides are formed by reactive ion etching (RIE). Then the Cr metal mask was removed. SiO2 materials such as covered were deposited using a sputtering system (CFS-4EP-LL). After that, a pattern of Ce:YIG regions were drawn using an EB lithography system. The resist and SiO2 were removed by wet etching. Finally, Ce:YIG was deposited and crystallized to cover the disk resonator.

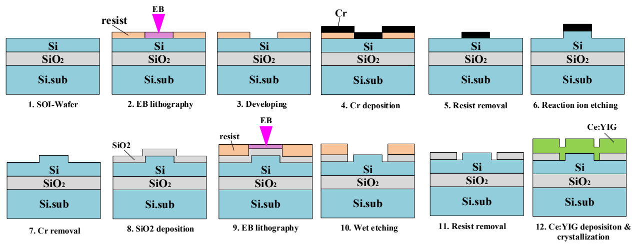


Fig.4. Fabrication process

V. Measurement Result (Air Cladding)

We measured the wavelength transmittance of the disk resonator type waveguide after step 7 in Fig. 4.

A scanning electron microscope (SEM) image of the fabricated disk resonator is shown in Fig. 5, and a schematic diagram of the disk resonator type waveguide is shown in Fig.6.

Wavelength transmittance measurement was measured in air cladding.

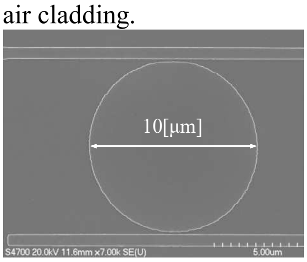


Fig.5. SEM image of disk resonator

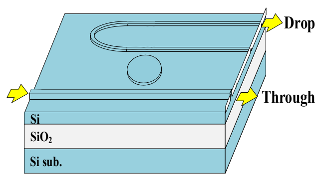


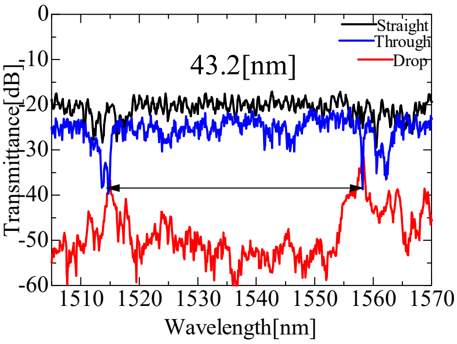
Fig.6. Schematic diagram of disk resonator type waveguide

Fig 7.(a) shows the measurement results a 2.5 [μm] disk radius. Propagating light was obtained at each of Through port and Drop port. Similar to the theoretical analysis in Fig. 3(a), periodic resonance characteristics were obtained. Also, the FSR of the fabricated device was 3.8 [nm]. This value is larger than the result of theoretical analysis.

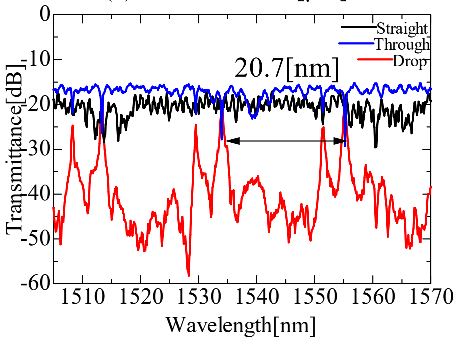
Fig 7.(b) shows the measurement results a 5 [μm] disk radius. Propagating light was obtained at each of Through port and Drop port. Similar to the theoretical analysis in Fig. 3(b), periodic resonance characteristics were obtained. Also, the FSR of the fabricated device was 0.7[nm]. This value is larger than that of the result theoretical analysis.

Fig 7.(c) shows the measurement results a 10 [μm]disk radius. Propagating light was obtained at each of Through port and Drop port. Similar to the theoretical analysis in Fig. 3(c), periodic resonance characteristics were obtained. Also, the FSR of the fabricated device was 0.4 [nm]. This value is larger than that of the result theoretical analysis.

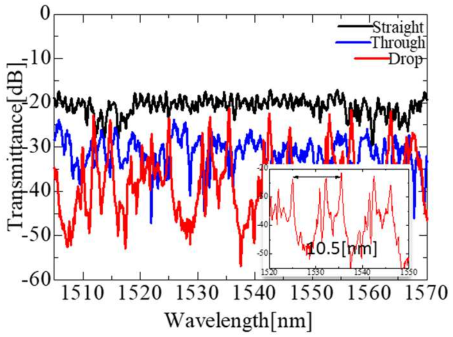
Thus, the resonance characteristics of the disk resonator were obtained in the state of air cladding. Similar to the theoretical analysis. The shorter FSR was obtained by using larger disk radius. The larger FSR was obtained compared with theoretical analysis result. The propagation loss was the smallest in the devis with a disk radius of 5 [μm].



(a) disk radius 2.5[μm]



(b) disk radius 5 [μm]

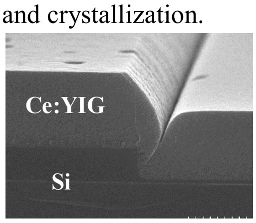


(b) disk radius 10 [μm]

Fig.7.(a).(b).(c). Measurement results

VI. MEASUREMENT RESULTS (AFTER CE:YIG FILM DEPOSITION AND CRYSTALLIZATION)

We tried to fabricate a disk resonator loaded with Ce:YIG cladding as a preliminary experiment. Fig. 8 shows a cross-sectional view of the waveguide in a scanning electron microscope (SEM) image. Fig. 9 shows a schematic diagram of a disk resonator type waveguide after Ce:YIG deposition and crystallization.



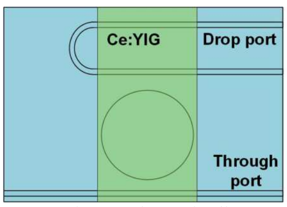


Fig.8. Waveguide cross section

Fig.9. Schematic diagram of disk

Fig. 10 shows the measurement results. Periodic resonance characteristics were obtained even when Ce:YIG was deposited and crystallized on the side surface of the disk resonator.The FSR was 22.3 [nm], which was 1.6 [nm] larger than that of the air cladding.

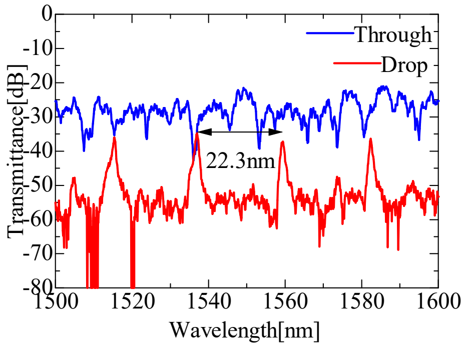


Fig.10. Measurement results after Ce:YIG deposition and crystallization

VII. CONCLUSION

A disk resonator type waveguide was fabricated for an optical isolator operating in TE mode light. We fabricated waveguides with disk radius of 2.5[μm], 5[μm] and 10[μm] and obtained their resonance characteristics. The resonance characteristics were maintained even after Ce:YIG was deposited and crystallized on the sidewall of the disk resonator.

Currently, we are improving the crystallinity of Ce:YIG for demonstoration.

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number JP23K03977.

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