Fabrication of asymmetric MZI silicon nanowire waveguides loaded with a crystallized Ce:YIG cladding using contact epitaxy method

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***Abstract*— We fabricated an asymmetric MZI waveguide for an optical isolator. A magneto-optical material Ce:YIG deposited on an asymmetric MZI composed of silicon wire waveguides was crystallized in multiple steps.**

Keywords—Optical Isolators, MZI, Ce:YIG, Mach-Zehnder Interferometer

I. Introduction

With the development of communications such as 5G, the amount of data is steadily increasing. Therefore, there is a demand for even higher speeds and larger transmission capacities for optical communications. In recent years, optical integrated circuits using silicon photonics have been researched, and as a result, higher density integration and higher speed are being promoted [1].

Using optical isolators, which are an element that prevents the return of reflected light, enable stable operation of silicon photonics devices. For this purpose, it is necessary to crystallize and integrate magneto-optical garnets. Waveguide isolators fabricated with magneto-optical garnets formed on Si platforms by direct bonding [2, 3], adhesive bonding [4], and pulse laser deposition [5] have been demonstrated. We have been trying to realize optical isolators using a contact epitaxy method, in which amorphous Ce:YIG deposited on Si is crystallized by contacting seed crystals and heat-treating them. In this study, we fabricated an asymmetric Mach-Zehnder interferometer (MZI) composed of silicon thin-wire waveguides and performed the crystallization process on Ce:YIG films deposited by sputtering on both sides.

II. Device structure

We fabricated an asymmetric MZI type silicon wire waveguide for demonstration nonreciprocal phase effect. Figure 1 shows an optical isolator composed of a nonreciprocal phase shifter and reciprocal phase shifters. The input lightwave is divided by a 3dB multimode interferometer (MMI) coupler. The divided lightwaves propagate through two arm waveguides in the MZI and are combined by an output 3dB MMI coupler. 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. Therefore, the proposed structure provides a non-reciprocal phase shift in the transverse magnetic (TM) mode. Si waveguides with magneto-optic garnet as the upper cladding layer provides strong nonreciprocal phase shift for TM polarization mode due to the large refractive index difference between Si (3.48) and magneto-optical garnet (2.2) at 1550 nm [7]. For forward light propagation, the nonreciprocal phase shifter gives a phase difference of $-\pi/2$ and the reciprocal phase shifters give a phase difference of $\pi/2$ between the upper and lower arms. The phase difference between two arms becomes zero, and the lightwave is output from cross port. For backward propagation, the lightwave launched into the output port experiences the nonreciprocal phase difference of $\pi/2$. The total phase difference between the two arms amounts to π since the reciprocal phase shifters continue to yield $\pi/2$ phase difference. Therefore, the backward traveling waves coming from the output port interfere destructively and are not coupled to the input port..

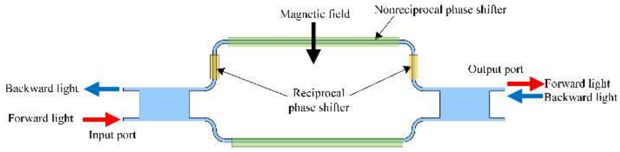


Fig. 1. Schematic of asymmetric MZI silicon nanowire waveguides having a crystallized Ce:YIG cladding

III. Crystallization of magneto-optic material Ce:YIG

Crystallization of magneto-optical materials is necessary to make them function as non-phase retarders. Therefore, we use the contact epitaxy method. The contact epitaxy method is characterized by the formation of amorphous magneto-optical garnet on a dissimilar material, followed by crystallization by seed final and heat treatment. The seed crystals can then be peeled off. The fabrication of asymmetric MZI-shaped waveguides requires highly crystalline Ce:YIG. Conventionally, magneto-optical materials were crystallized in a single layer, but to increase the effect on the waveguide, they were crystallized in two separate layers. The two layers increase the crystallinity inside the film and increase the magneto-optic effect. To further improve crystallinity, an etch-back process was used to refresh the surface conditions of the first layer. Fig. 2 shows the etch-back process. RF sputtering method was used to deposit Ce:YIG films. This time, after 200 (nm) deposition and crystallization, the film was etch-backed, and then deposited and crystallized again. Each was heat treated at 750(°C) for 1 hour in the crystallization process. Fig. 3 shows XRD measurement results. We obtained diffraction peaks of about 29,000 for both the first and second layers. Crystallization using the etch-back process yielded a diffraction peak of about 120000.

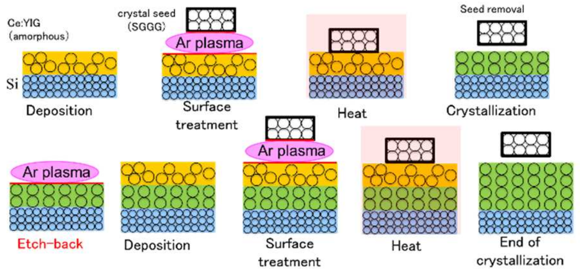


Fig. 2. Crystallization process of Ce:YIG layer

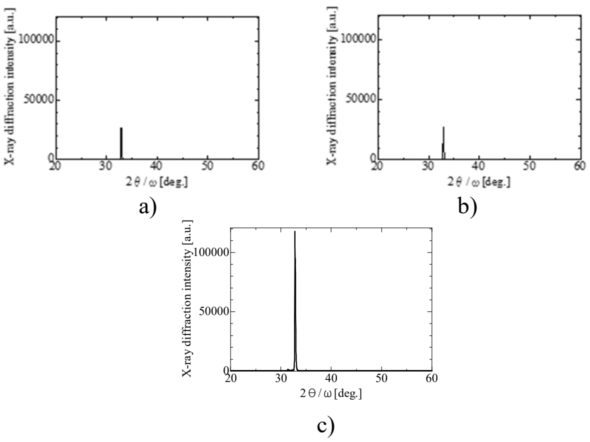


Fig. 3. Measured XRD results : (a) Single-step crystallized, (b) Two-step crystallization, (c) Two-step crystallization with etch back

IV. FABRICATION OF ASYMMETRIC SI-WIRE MZI WAVEGUIDES

An asymmetric MZI waveguide was fabricated to compare light loss before and after loading Ce:YIG. Fig.4 shows The fabrication process of an asymmetric MZI-shaped waveguide. Waveguide patterns were drawn on SOI wafers with a core layer of 220 (nm) and a BOX layer of 3 (µm) using an EB lithography system. The rib height was designed to be 220 (nm), the waveguide width 500 (nm), and the total Ce:YIG loading area 1600 (µm). The width of the MMI coupler is 3.5µm and the length is 37.5 (µm). A metal mask was then deposited and reactive ion etching was performed to form the waveguide. CF_4 was used as etching gas. The areas other than the Ce:YIG deposition area were deposited with 1µm of SiO_2 as the upper cladding. The magneto-optic material Ce:YIG was deposited on both arm waveguides of the MZI and crystallized twice in the same manner as described above. Crystallization was done using SGGG as seed crystals, contacted at 750 (°C) for 1 hour.

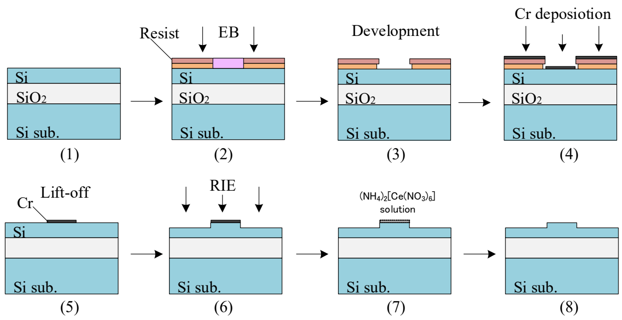


Fig. 4. Fabrication process for asymmetric Si-MZI waveguides

V. WAVELENGTH CHARACTERISTICS AFTER MAGNETO-OPTICAL MATERIAL LOADING

The waveguide characteristics of the fabricated asymmetric MZI silicon thin-wire waveguide before and after loading Ce:YIG were measured in TM-mode. The element structure and measurement results are shown in Fig. 5. We were able to confirm that light passes through the Ce:YIG loading. The phase shift due to the difference in transmission refractive index between SiO2 and Ce:YIG can also be confirmed. Comparing the optical loss of Ce:YIG before and after loading, it can be seen that the average loss is about 16 (dB) after loading. The cause of the loss due to Ce:YIG loading needs to be investigated in the future.

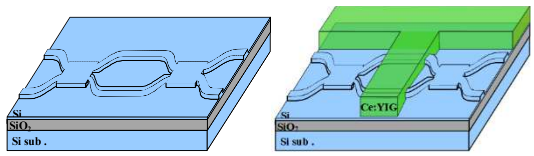
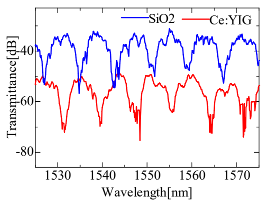


Fig. 5. Schematics of the fabricatde devices: (a) Asymmetric Si-MZI waveguide, (b) Asymmetric Si-MZI waveguide loaded with Ce:YIG.



c) Wavelength Characterization

Fig. 6. Measured wavelength characteristics of the fabricated device.

VI. CONCLUSION

Multi-step crystallization of magneto-optical materials using etch-back yielded a diffraction peak of 120000. The process was also used to crystallize magneto-optical materials on asymmetric MZI and fabricate waveguides.

The waveguide characteristics of the fabricated asymmetric MZI-shaped silicon thin-wire waveguide were measured, and it was confirmed that light could pass through even when loaded with Ce:YIG, a magneto-optic material. Losses after loading will be a matter for future study.

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