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Preparation of Ce:YIG thin films on Si and application to integrated optical isolator on Si substrate

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Abstract

Monolithically integrated optical isolator has been studied to protect the laser diode from a scattered or a reflected light at a material surface/boundary. To realize compact integrated optical isolators, magnetooptical materials are suitable because of its non-reciprocity. This fact is well-known, but this has been challenging because of a large mismatch of the lattice constants between a usual magnetooptical material and silicon. In order to prepare high quality magnetooptical materials on non-garnet substrates, the double-step epitaxial deposition method and the vacuum annealing method have been developed. Their details of the growth mechanism have not been shown so far. In this paper, we revealed them with various film structures and showed its functionality with the demonstration of optical isolator device. Especially, a cerium substituted yttrium iron garnet (CeYIG) was used as a magnetooptical material because of its large Faraday rotation angle at near IR range. And also, CeYIG on silicon substrate were prepared and then annealed. Transmission electron microscopy was used to know the function of YIG layer. Monolithically integrated optical isolator was demonstrated with silicon on insulator substrate/CeYIG/YIG. An 18.4 pm shift of the transmission peak was demonstrated at around the wavelength of 1566 nm.

1. Introduction

Integrated photonics and its fruitful applications attract many interests from researchers and engineers. This is based on the lower loss and higher operation frequencies of the light. Recently, several integrated photonic device chips [1] were demonstrated. Unlike an electrical wire, an optical waveguide has relatively large absorption, scattering, and reflection. In particular, the reflection/scattering at interfaces/surfaces of the different materials makes the laser diode source unstable. To protect such a degradation of integrated photonic device, the optical isolators are essential. Actually, solid state laser systems use optical isolators, but there are no reports of the demonstration of integrated photonic circuits including optical isolators.

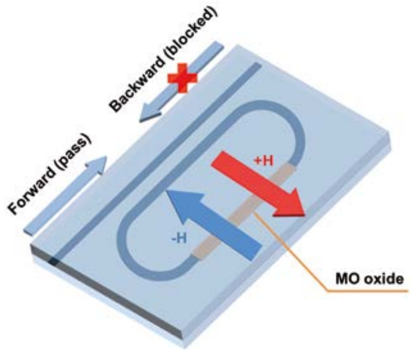

Fig. 1. Sketches of the race-track-shaped on-chip optical isolator using CeYIG contacting to the part of the silicon waveguide. The part of the waveguide has the window mask composed of silica.

On the other side, the film/multilayer typed optical isolators have been studied widely. Most studies are based on magnetooptical effects because of its large non-reciprocity. In special, yttrium iron garnet ($Fe_3Y_5O_{12}$) based materials are widely used because of its low absorption and large Faraday rotation angle. To increase the Faraday rotation angle, the substitution of a rare earth into the yttrium site is effective. In the visible wavelength region, a bismuth is widely used as a rare earth, but its magnetooptical effect is not so large in near IR region, then the device size was not so small. In contrast, a cerium substituted yttrium iron garnet (CeYIG) is good because of its large Faraday rotation angle. Shintaku [2] and Gomi [3] showed single crystalline CeYIGs on gadolinium gallium garnet (GGG) substrates. However, the fabrication of CeYIGs on non-garnet substrates has been challenging because of large mismatch of the lattice constants between the film and substrates. Hence, we developed the two deposition method and the vacuum annealing technique to obtain polycrystalline CeYIG on Si, SOI, and silica substrates. However their quality has not been studied as device structure. In this paper, we fabricated the racetrack shaped magnetooptical isolator using CeYIG, like shown in Fig. 1.

2. Experimental method

The racetrack shaped optical isolator was fabricated with lithography techniques. HSQ resist was used to fabricate the waveguide. The racetrack part had the radius of 45 μm. The length of the straight line portion of the racetrack was 200 μm. The silicon was etched with the RIE in 10 mTorr HBr gas pressure. As shown in Fig. 2, the waveguide had sharp edge and transmission showed good agreement with other reports.

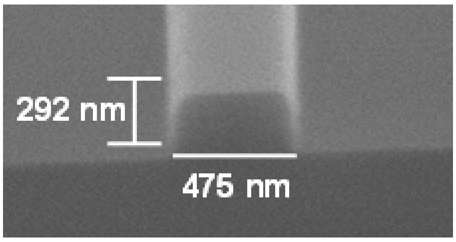

Fig. 2. The bird's view image of the fabricated silicon waveguide. The height was 292 nm. The width was 475 nm.

CeYIG was deposited on a part of racetrack using magnetron sputtering. To deposit CeYIG limited area, a window in the SiO_2 cladding layer was etched using a positive resist. The sample was annealed in vacuum chamber. The pressure was 5 Pa. The crystallinity, magnetooptical response (Faraday rotation angle), transmissivity, magnetic properties, and shift of the resonant peak driven by external magnetic field were characterized.

3. Results and discussion

The fiber coupled system [4, 5] was used for evaluating the resonant mode of the fabricated racetrack resonator. The magnetic field was applied perpendicularly to the waveguide and parallel to the substrates. As Fig. 3 shows, the transmission peak was shifted as a function of the applied magnetic field. This shift value was close to that the previous report [5] using the two step deposition method for obtaining CeYIG. Therefore, the simpler process (single step deposition) provided same amount of magnetooptical response.

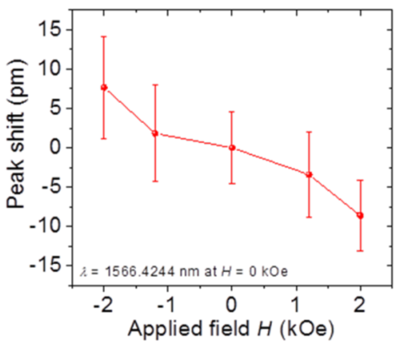

Fig. 3. The transmission peak shift of the TM mode as a function of the applied magnetic field.

4. Conclusions

A nonreciprocal peak shift using the racetrack magnetooptical isolator was demonstrated. The CeYIG was deposited by magnetron sputtering method and annealed in vacuum chamber. The evaluated Faraday rotation angle was comparable with the single crystalline CeYIG's value. This report provides a further step toward realizing integrated magnetooptical devices on silicon substrates.

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