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Magneto-Optical Switching Devices Based on Si Photonic Resonators

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Abstract

The magneto-optical switching devices based on Si ring resonators and Si photonic crystal resonators have been fabricated using $Bi_3Fe_5O_{12}$ (BIG) film deposited by the metal organic decomposition (MOD). And the light modulation of ≦20% was demonstrated.

1. Introduction

Recently, due to an increase in power consumption and transmission delay of the metal wiring in CPU, processor performance is being limited. In order to overcome this problem, studies of optical interconnection in LSI using silicon photonics are actively carried out [1]. Especially for the low-operation voltage and compactness, we have studied optical switches using Si ring or photonic crystal resonators with magneto-optical material, $Bi_3Fe_5O_{12}$ (BIG). A structure of the device is shown in Fig. 1. In table 1, the performance is compared with the other related optical switches [2-4]. The proposed device operates at very low voltage less than 100 mV (using a coil) and relatively small power dissipation especially for the photonic crystal device because only the small volume is exposed to magnetic field. Although the combination of magneto-optical material and Si ring resonator has been reported for non-reciprocal devices [5], this is the first report for the combination with Si photonic crystal resonator.

2. Evaluation of Magneto-Optic Material BIG

We have evaluated a quality of magneto-optical material $Bi_3Fe_5O_{12}$ (BIG) film fabricated by the metal organic decomposition (MOD) method [6]. First the buffer layer of $BiY_2Fe_5O_{12}$ (~ 50 nm) was first spin-coated on SiO_2/Si substrate, followed by decomposition and crystallization processes according to the recipe in Ref. 5. Then the MOD process of BIG film was repeated 18 times to produce 300 nm thick film and finally annealed at 490°C for 3 h. XRD spectra of the BIG film with and without the $BiY_2Fe_5O_{12}$ buffer layer is shown in Fig. 2. Only for the film with the buffer layer the specific diffraction peaks of BIG crystal are observed. From the diffraction peak at 2θ=32° (orientation of (420)) The lattice constant was calculated to be 12.61Å, which is equal to the other reported value of 12.62Å[6]. Next the magnetic Kerr effect was measured using the system shown in Fig. 3. The result is shown Fig. 4 where a Kerr effect of 8.8% was observed. This value is relatively large compared to other works (e.g. 1.8%) [7]. From these results, it is concluded that the film quality is relatively good when the buffer layer is employed.

3. Si ring photonic crystal magneto-optical switches

Fabrication process of the device is shown in Fig. 5, where the electron beam lithography and Si dry etching using Cl_2 plasma are used to pattern the Si layer of the silicon insulator (SOI) wafer. Then the BIG film is covered with the buffer layer and annealed. The optical micrograph of the fabricated Si ring magneto-optical switch is shown in Fig. 6 and the scanning electron microscope (SEM) picture of the fabricated Si photonic crystal magneto-optical switch is shown in Fig. 7.

The measurement system for resonance spectra and optical modulation is shown in Fig. 8. The movable neodymium magnet (0.38T) was used to apply magnetic field perpendicular to the substrate. Figure 9 shows the change of the resonance spectra of Si ring magneto-optical switch due to the magnetic field. By applying the magnetic field the resonance wavelength was shifted toward the longer wavelength irrespective of the direction (up or down) of the magnetic field. This result is consistent with the Cotton-Mouton effect [8], where the light speed is reduced in this arrangement between magnetic field, incident light and the magneto-optical material. The observed shift of the resonance wavelength caused by the magnetic field is 0.1nm. And when the wavelength of the input light is fixed at 1535 nm, the light intensity modulation of 12~19% was observed as shown in Fig. 10.

The results for the Si photonic crystal resonator magneto-optical switch are shown in Fig. 11 to 13. We have examined two kinds of resonators, defect type (no holes in the resonator) and cavity type (bigger hole in the resonator) which are shown in Fig. 12. The results of Fig. 13 are for the defect type. We have also observed a light modulation of 12~20% for the photonic crystal type modulator. In Fig. 12 the resonance wavelength shift is compared between the defect type and cavity type. It is found that the cavity type has larger resonance wavelength shift because the hole in the resonator is filled with the magneto-optical material. While for the defect type the slightly leaked light from the resonator feels the magneto-optic effect. In the photonic crystal device the direction of the magnetic field also did not affect direction of the shift of the resonance wavelength.

4. Conclusions

The magneto-optical switching devices based on Si ring resonator and Si photonic crystal resonator have been fabricated and the light modulation was demonstrated. Although the modulation is still small (12~20%) at this stage, it would be improved by using the better magneto-optical material with smaller loss (ex. YIG) and employing, for example, slot waveguide ring resonator.

References

[1] Q. Xu, B. Schmidt, *et al.*: Nature **435** (2005) 325-327.
[2] H. Taura *et al.* : Jpn. J. Appl. Phys. **47** (2008) 2915.
[3] K. Nozaki *et al.*: Nature Photonics **4** (2010) 477.
[4] K. Tokuhashi *et al.*: IEICE Transactions on Communications J**93-B** (2010) 1087.
[5] L. Bi *et al.*: Nature Photonics **5** (2011) 758.
[6] S. Ikehara *et al.*, J. Magn. Soc. Jpn. **36** (2012) 169.
[7] T. Okuda *et al.*, J. Appl. Phys. **69** (1991) 4580.
[8] A. Cotton and H. Mouton, Compt. rend **141** (1905) 317.

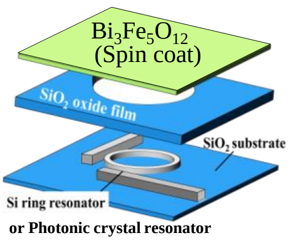

Fig. 1. Structure of optical switches based on Si photonic resonators, which are covered with magneto-optical material: $Bi_3Fe_5O_{12}$.

Table 1. Comparison with other related studies concerning optical switches.

	Device	Driving Force	Voltage	Switching Energy	Switching Speed
This Work & Ref. 2	Si Ring Resonator & Magneto-Optic Material	Magnetic Field	~100 mV	~ 10 fJ	~ 1 ns
This Work	Si PhC Resonator & Magneto-Optic Material	Magnetic Field	~100 mV	~ 20 nJ	~ 1 ns
Ref. 3	InGaAsP PhC Resonator	Photocarrier Injection	---	420 aJ	20 ps
Ref. 4	Si MZI & PLZT	Electric Field	10 V	10 mJ	10 ns

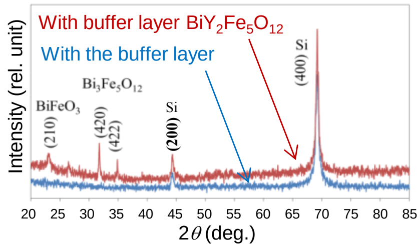

Fig. 2. XRD spectra of the magneto-optical material: $Bi_3Fe_5O_{12}$ fabricated by the metal organic decomposition (MOD) method with and without buffer layer: $BiY_2Fe_5O_{12}$. Forbidden Si (200) is observed due to the strain.

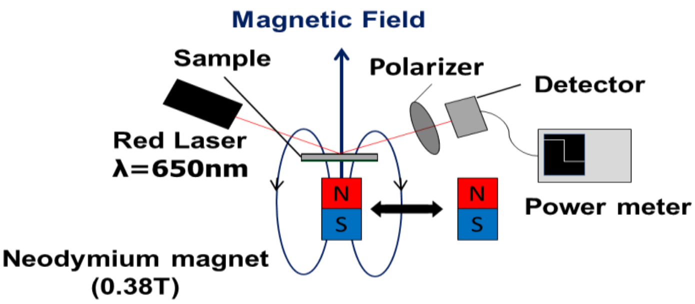

Fig. 3. Measurement system for magnetic Kerr effect of $Bi_3Fe_5O_{12}$ film.

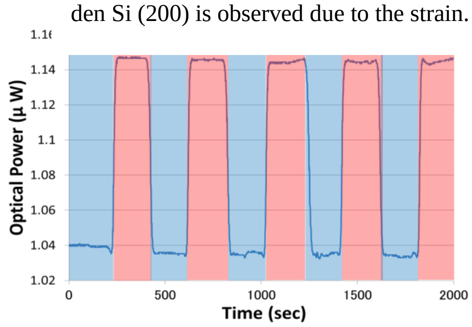

Fig. 4. Measured magnetic Kerr effect of $Bi_3Fe_5O_{12}$ film deposited by MOD method with buffer layer: $BiY_2Fe_5O_{12}$.

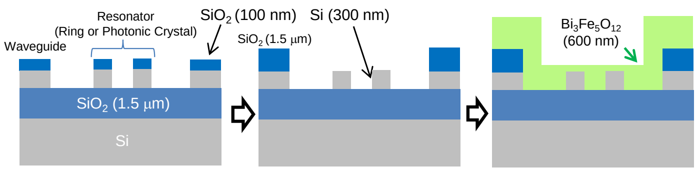

Fig. 5. Fabrication process of the optical switches. op-

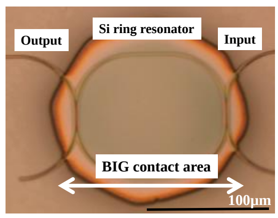

Fig. 6. Optical micrograph of fabricated Si ring resonator covered with $Bi_3Fe_5O_{12}$. .

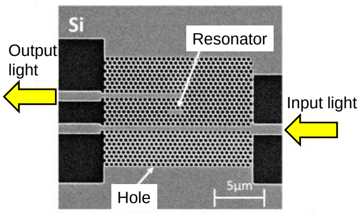

Fig. 7. Scanning electron micrograph of fabricated Si photonic crystal resonator.

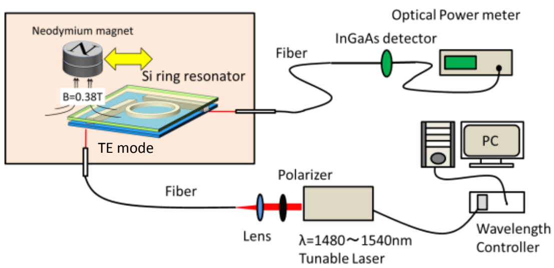

Fig. 8. Measurement system for resonance spectra of the fabricated devices.

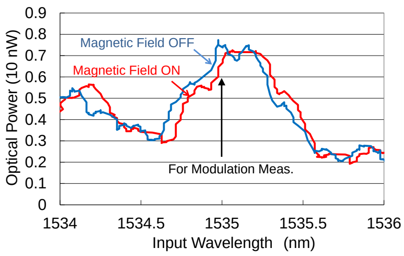

Fig. 9. Resonance curves of fabricated ring resonator magneto-optical switch with and without magnetic field.

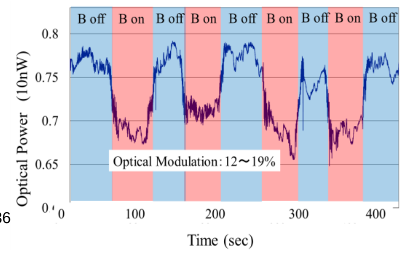

Fig. 10. Optical modulation characteristics of fabricated ring resonator magneto-optical switch.

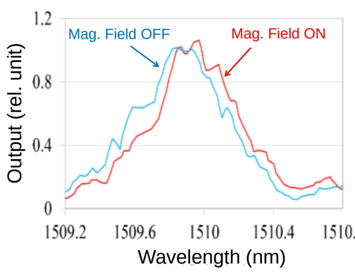

Fig. 11. Resonance curves of fabricated photonic crystal resonator (cavity type) magneto-optical switch with and without magnetic field.

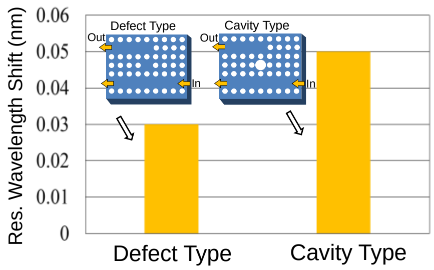

Fig. 12. Resonance wavelength shifts of defect type and cavity type photonic crystal resonator magneto optical switches.

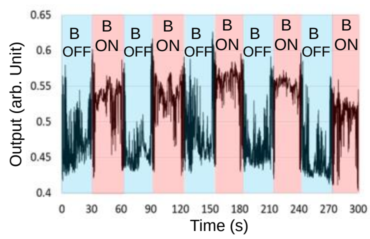

Fig. 13. Optical modulation characteristics of fabricated photonic crystal resonator (defect type) magneto-optical switch.