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Fabrication of $Bi_2Y_1Fe_5O_{12}$ Films on Glass and Silicon Substrates by Metal Organic Decomposition Method for Photonic Integrated Circuits

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Abstract

We report on fabrication of $Bi_2Y_1Fe_5O_{12}$ (Bi substituted Yttrium Iron Garnet; Bi:YIG) thin films on glass and Si substrates by metal organic decomposition method. By using the YIG buffer layer, polycrystalline $Bi_2Y_1Fe_5O_{12}$ thin films showing large magneto-optic effect were obtained, which is comparable to that of the reported single crystalline Bi:YIG.

1. Introduction

Nonreciprocal devices such as optical isolators and circulators are indispensable devices in photonic integrated circuits (PICs). In order to realize nonreciprocal devices in PICs, it is necessary to fabricate magnetic materials on Si and InP substrates. Bi substituted Yttrium Iron Garnets (Bi:YIG) show high transparency and large Faraday rotation at telecommunication wavelength, and have been applied to free space type optical isolators. However, there are large difference of the thermal expansion coefficient and lattice constant between Bi:YIG and Si/InP substrate, which makes it difficult to prepare Bi:YIG thin films showing large magneto-optic (MO) effect on Si/InP substrate. So far, preparation of Ce substituted YIG thin films on Si substrate have been reported by wafer-bonding [1], pulsed laser deposition (PLD) [2], and magnetron sputtering [3], and application to Si waveguide optical isolator have been reported based on Mach-Zehnder interferometers and ring resonators. In this paper, we report on the preparation of the Bi:YIG thin films showing large MO effect on glass and Si substrates by the metal organic decomposition (MOD) method by using the YIG buffer layer.

2. Sample preparation

We have prepared Bi:YIG thin films on glass and Si substrates by metal organic decomposition (MOD) method. MOD method is a promising one to prepare magnetic garnet film, because it is a simple fabrication method which is composed of spin coating of the MOD solution and annealing. MOD method guarantees high uniformity in chemical composition and purity combined with chemical stability [4]. The MOD solutions to prepare $Y_3Fe_5O_{12}$ (YIG) and $Bi_2Y_1Fe_5O_{12}$ (Bi:YIG) thin films consist of solutions made from Bi_2O_3, Y_2O_3, and Fe_2O_3 carboxylates with chemical composition ratio of $Y_2O_3 : Fe_2O_3 = 3:5$, and $Bi_2O_3 : Y_2O_3 : Fe_2O_3 = 2:1:5$ by Kojundo Chemical Laboratory Ltd. The total concentration of these carboxylates in these MOD solutions was fixed at 3 % in acetic ester. After spin coating in 2 steps process of 500 rpm for 5 s and 2000 rpm for 20 s, followed by drying on a hot plate at 120°C for 10 min. In order to decompose organic materials and obtain amorphous oxide films, the samples were pre-annealed at 550°C for 10 min., and annealed at higher temperature for 2 hours (final annealing) for crystallization. Spin coating, drying and pre-annealing process were repeated for 6 times to obtain an appropriate thickness. The annealing was done with air under atmospheric pressure. Table 1 shows the preparation conditions of the fabricated samples. The thickness of all samples obtained in the present study is approximately 300 nm for the YIG buffer layer Bi:YIG layer. The final annealing temperature for the Bi:YIG thin films were fixed at 620 ^oC. We changed the final annealing temperature for the YIG buffer layer (650 and 750 ^oC) and investigated the influence of the crystalline quality of the YIG buffer layer on the MO property of the Bi:YIG layer (main layer). For comparison, we prepared Bi:YIG thin film without the YIG buffer layer.

Sample	Main layer	Buffer layer (final annealing temperature)	Substrate
A	$Bi_2Y_1Fe_5O_{12}$	-	Glass
B	$Bi_2Y_1Fe_5O_{12}$	$Y_3Fe_5O_{12}$ (650^{o}C)	Glass
C	$Bi_2Y_1Fe_5O_{12}$	$Y_3Fe_5O_{12}$ (750^{o}C)	Glass
D	$Bi_2Y_1Fe_5O_{12}$	-	Si
E	$Bi_2Y_1Fe_5O_{12}$	$Y_3Fe_5O_{12}$ (750^{o}C)	Si

Table 1 Summary of the fabricated Bi:YIG thin films on glass and Si substrates.

3. Characterizations

Fabricated films are characterized by X-ray diffraction (XRD), and Faraday / magneto-optic Kerr effect. Fig. 1 shows the XRD spectra of the Bi:YIG films on (a) glass (Sample A, B, C) and (b) Si substrates (Sample D, E). From Fig. 1(a), it was found that α-Fe_2O_3 phase is dominant for the samples without the YIG buffer layer (Sample A) and with the YIG buffer layer on glass substrates annealed at lower temperature of 650 ^oC (Sample B). On the other hand, Bi:YIG phase is dominant for the samples with the YIG buffer layer annealed at higher annealing temperature of 750 ^oC (Sample C). By increasing the final annealing temperature of the YIG buffer layer, crystalline quality of the YIG buffer layer was improved, and Bi:YIG phase be-

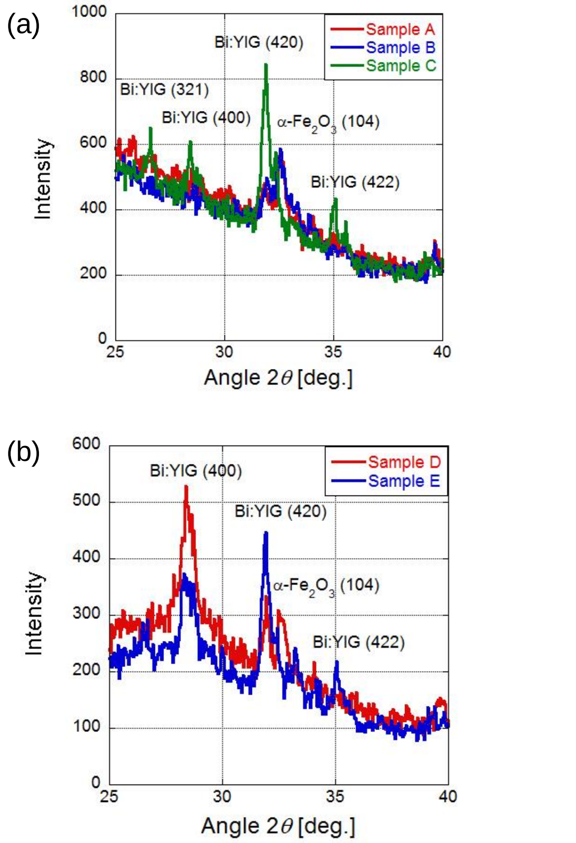

Fig. 1 X-ray diffraction spectra of Bi:YIG samples on (a) glass and (b) Si substrates.

came more dominant than the α-Fe_2O_3 phase. From Fig. 1(b), it also was found that the α-Fe_2O_3 phase is dominant for the samples without the YIG buffer layer on Si substrate. By using the YIG buffer layer annealed at 750 ^oC, Bi:YIG phase are more dominant than α-Fe_2O_3 phase became smaller, which is the same situation as the crystal growth process of the Bi:YIG layer on glass substrates.

Fig. 2 shows the magnetic field dependences of (a) the Faraday rotation of the Bi:YIG films on glass (Sample A, B, C) substrates and (b) Kerr rotation of the Bi:YIG films on Si substrates (Sample D, E). The measurement wavelength was 600 nm. Faraday rotation of as high as 60000 deg./cm was obtained for Sample C. The obtained Faraday rotation is comparable as that of the Bi:YIG prepared by liquid phase epitaxy [5]. Faraday rotation of Sample A and B is much smaller (2000 deg./cm) than that of Sample C. The appearance of the (420) Bi:YIG phase and supression of the α-Fe_2O_3 phase are important in order to obtain Bi:YIG thin films showing large MO effect on glass substrates. Kerr rotation of as high as 0.97deg. was obtained for the Bi:YIG films on Si substrate (Sample E). Please note that obtained Kerr rotation includes the multiple interference of the incident light inside the Bi:YIG films, leading to enhanced Kerr rotation which is analyzed by the wavelength dependence. There is strong correlation between the appearance of the (420) Bi:YIG phase with disappearance of the α-Fe_2O_3 phase by using the YIG buffer layer annealed at higher temperature of 750 ^oC, and large MO effect on Si

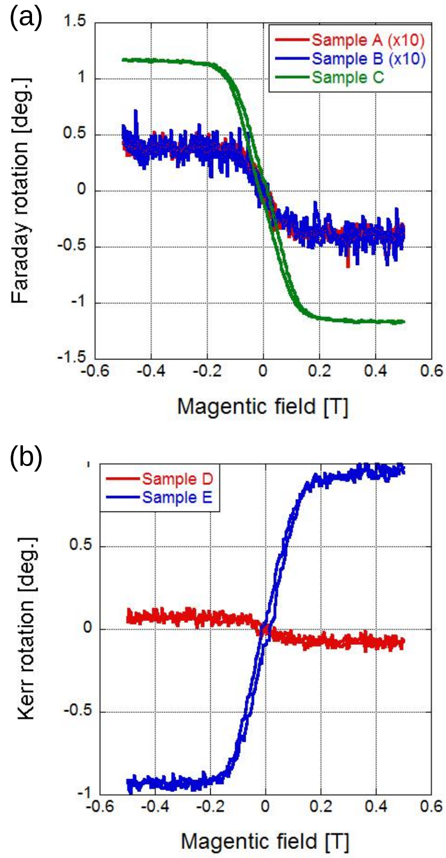

Fig. 2 Magnetic field dependence of the Faraday rotation of the Bi:YIG samples on (a) glass and (b) Si substrates. The measurement wavelength is 600 nm

substrates, which is the same situation as in glass substrates. Therefore, obtaining the YIG buffer layer having high crystalline quality and appearance of the Bi:YIG phase are important to realize Bi:YIG films showing large MO effect on both glass and Si substrates.

3. Conclusions

We have successfully fabricated Bi:YIG films on glass and Si substrates by the MOD method. Insertion of the YIG buffer layer without Bi is a key to realize the Bi:YIG films showing large magneto-optic effect. These results are promising for magneto-optical devices in photonic integrated circuits.

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