Preparation of Polycrystalline $\text{Bi}_3\text{Fe}_5\text{O}_{12}$ Films by Annealing Process

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1 INTRODUCTION

Since the first synthesis of bismuth iron garnet (BIG: $\text{Bi}_3\text{Fe}_5\text{O}_{12}$) film in 1987¹⁾, the preparation process has been studied intensively because it shows an extremely large magneto-optical effect. BIG films were prepared up to now by the direct epitaxial growth on single crystals which have garnet structure^{2,4)} or on polycrystalline garnet thin layers formed on glass substrates^{5, 6)}. In both cases, the BIG films must be deposited at temperature about 500°C, and it is difficult to control the conditions at sputtering when the epitaxial growth is carried out. In this paper, we prepare transparent polycrystalline BIG films on polycrystalline garnet underlayers. The BIG films are grown by annealing after the sputtering at the substrate temperature (T_s) of 400°C. The structure, magnetic and magneto-optical properties of the films are investigated.

2 EXPERIMENTAL

The garnet underlayers were prepared by annealing as-deposited amorphous films in air at 650°C for 4h. The composition of the underlayers was $\text{Bi}_{1.7}\text{Y}_{1.2}\text{Fe}_{5.1}\text{O}_{12}$. The amorphous films for the underlayers and BIG films were deposited on vitreous SiO_2 substrates by rf-sputtering under the conditions given in Table 1. BIG films were deposited at a substrate temperature of 400–500°C. Then the films were annealed at 500°C for 4h in air. The thickness of underlayers was 280nm. The thickness of BIG layers ranged from 660nm to 830nm. The film structure was examined by X-ray diffraction. The saturation magnetization of the films was measured by using a vibrating sample magnetometer. Faraday rotations were measured by polarization modulation method. These measurements were carried out before and after annealing the films.

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Table 1 Sputtering conditions.

	Underlayers	BIG layers
Target composition	$\text{Bi}_2\text{YFe}_4\text{O}_{10.5}$	$\text{Bi}_{4.2}\text{Fe}_5\text{O}_{13.8}$
Film composition	$\text{Bi}_{1.7}\text{Y}_{1.2}\text{Fe}_{5.1}\text{O}_{12}$	$\text{Bi}_{3.2}\text{Fe}_{4.8}\text{O}_{12}$
Sputter gas	Ar	Ar:O ₂ = 6:4
	6.7Pa	6.7Pa
Substrate temperature	400°C	400, 450, 500°C
rf power density	2.5W•cm ⁻²	2.5W•cm ⁻²
Deposition rate (ave.)	4.7nm•min ⁻¹	6.2nm•min ⁻¹

3 RESULTS AND DISCUSSION

The X-ray diffraction patterns of the prepared films for various substrate temperatures at sputtering are shown in Fig. 1 (a), (b) and (c) for $T_s=400^\circ\text{C}$, $T_s=450^\circ\text{C}$ and $T_s=500^\circ\text{C}$, respectively. All peaks measured, before annealing, for the film prepared at $T_s=400^\circ\text{C}$ are assigned to the garnet phase of the underlayer. Thus, the deposited film on the underlayer seems to be amorphous. When the deposited film was annealed, the peaks of BIG appeared. The lattice constant of the annealed film is 1.261nm which is slightly smaller than the reported value of 1.2622nm¹⁾. The differences in X-ray diffraction peaks before and after annealing shown in Figs. 1 (b) and (c) are fairly small. Garnet peaks are scarcely observed and nonmagnetic phases are observed in Fig. 1 (b), and almost all peaks are assigned to BIG in Fig. 1 (c) which suggests the epitaxial growth.

Figure 2 shows the saturation magnetizations (M_s) of BIG layers prepared on underlayers with various substrate temperatures before and after annealing the films. The magnetization of the underlayer is not included in the M_s values in Fig. 2. Before annealing the films, M_s is fairly small for $T_s=400^\circ\text{C}$ and 450°C . However, after annealing, the M_s of the sample for $T_s=400^\circ\text{C}$ increases to 63 emu•cm⁻³. The values of M_s did not change while the films for $T_s=450^\circ\text{C}$ and 500°C were annealed. From the result of X-ray diffraction

Fig. 1 X-ray diffraction patterns of BIG films on $\text{Bi}_{1.7}\text{Y}_{1.2}\text{Fe}_{5.1}\text{O}_{12}$ underlayers before and after annealing the films at 500°C for 4h; the BIG layers were deposited at (a) 400°C , (b) 450°C and (c) 500°C . (T_s : substrate temperature)

Fig. 2 Saturation magnetization of the BIG layers prepared on underlayers before and after annealing, as a function of the substrate temperature at sputtering.

Fig. 3 Faraday rotation of the BIG layers prepared on underlayers before and after annealing, as a function of the substrate temperature at sputtering.

measurements for $T_s=500^\circ\text{C}$, it is concluded that a BIG phase is formed by a direct epitaxial growth.

Figure 3 shows the Faraday rotation (θ_F), measured before and after annealing, of BIG layers prepared on the underlayers at various substrate temperatures. The θ_F was measured at the wavelength range from 400nm to 750nm and the maximum value for each sample in the wavelength range is plotted in the figure. The Faraday rotation of the underlayer is not included in the θ_F values in Fig. 3. Two lines of θ_F are very similar to those of the M_s shown in Fig. 2. The value of θ_F for $T_s=400^\circ\text{C}$ increases after annealing, however, the values of M_s and θ_F are smaller than those for $T_s=500^\circ\text{C}$. The most suitable annealing temperature should be searched to obtain higher crystallinities on the BIG films.

The preparation of BIG films by the annealing process is advantageous because the deposition can be made in

more stable conditions than that of the epitaxial growth method.

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