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***In Situ* Growth of Polycrystalline Bismuth-iron-Garnet Films on Quartz Glass Substrate**

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Abstract. Polycrystalline $(\text{Bi,Gd})_3(\text{Fe,Ga})_5\text{O}_{12}$ garnet layer was prepared on a quartz glass substrate at 500°C by alternating reactive ion beam sputtering using two ceramic targets, $\text{Gd}_3\text{Ga}_5\text{O}_{12}$ and $3\text{Bi}_2\text{O}_3\cdot 5\text{Fe}_2\text{O}_3$. The lattice constant was $12.548\text{\AA}$. The layer was almost magnetically compensated and paramagnetic. On that layer, polycrystalline $\text{Bi}_3\text{Fe}_5\text{O}_{12}$ garnet layer was epitaxially grown by reactive ion beam sputtering. Those two layers were successively deposited in the same apparatus.

1. INTRODUCTION

Pure Bismuth Iron Garnet (BIG) is a magnetically soft material which shows giant Faraday effect[1,2]. Polycrystalline BIG (*p*-BIG) is an attractive material from the viewpoints of magneto-optical recording or microwave applications. BIG is a metastable phase which is only obtainable in a film state by direct epitaxial growth from the vapor phase onto a substrate with the garnet structure. It decomposes at about 600°C . The *p*-BIG can be epitaxially grown at 500°C on the layer of polycrystalline garnet such as YIG or GGG prepared on a quartz glass (*a*- SiO_2) substrate[3]. Those layers act as the substrate for *p*-BIG are usually prepared by crystallization of the amorphous layer deposited at room temperature or by direct deposition of polycrystalline film at high temperatures in oxidizing atmosphere. The crystallization temperatures (T_{cr}) of YIG and GGG layers are 800 and 1000°C , respectively. Gomi et al. found that crystallization during sputter-deposition of highly Bi-substituted iron garnet took place as low as 500°C [4]. For the purpose of *in situ* growth of *p*-BIG on an *a*- SiO_2 substrate, we examined low temperature synthesis of polycrystalline garnet substrate layer of highly Bi-substituted GGG (*p*-BGGG).

2. EXPERIMENTAL

For the preparation of *p*-BGGG layer, we employed an alternating reactive ion beam sputtering technique. Two ceramic targets, T_A (GGG) and T_B ($\text{BIG}=3\text{Bi}_2\text{O}_3\cdot 5\text{Fe}_2\text{O}_3$) were sputtered alternately using Ar ion beam. An *a*- SiO_2 substrate was kept in O_2 gas flow which act as the reactive atmosphere. Sputtering time in one period for respective targets, t_A and t_B , and substrate temperature were taken as the parameters. Deposition rate was $10\text{\AA}/\text{min}$ in average. Sputtering conditions are summarized in Table 1. The films were examined using X-ray diffractometer (XRD), atomic force microscope (AFM) and vibrating sample magnetometer (VSM).

Table 1 Sputtering conditions

sample no.	1	2	2*	3	4
substrate material	<i>a</i> - SiO_2	<i>a</i> - SiO_2	<i>a</i> - SiO_2	<i>a</i> - SiO_2	sample 2*
sputtering time: t_A (GGG)/ t_B (BIG)	20s/20s	20s/20s	20s/20s	10s/20s	0/6h
number of repetition of alternating sputtering (times)	450	450	100	450	continuous
substrate temperature($^\circ\text{C}$)	480	500	500	500	500
material phase of deposited layer	amorphous	garnet	garnet	non-garnet	garnet

Fig.1 XRD pattern (a) and AFM image (b) of the sample 2.

Fig.2 XRD pattern (a) and AFM image (b) of the sample 4.

3.RESULTS AND DISCUSSION

In all the samples, periodical layered structure was not observed. The samples excepting sample 1 crystallized during deposition, which suggests T_{cryst} of 500°C is very critical. *In situ* growth of single phased garnet was only observed for $t_A=t_B=20$ s or 40s, which suggests that homogeneous mixing process of garnet constituent cations at atomic level is requisite for *in situ* crystallization. In Fig.1(a), XRD pattern of the sample 2 is shown. The layer was assigned as almost single phased garnet. The lattice parameter was 12.548Å which is slightly larger than the maximum value of 12.540Å available for thermodynamical iron garnet[5]. The composition analyzed by ICP method was as follows: Bi:Gd:Fe:Ga=1.87:1.24:3.38:1.50. The layer was magnetically compensated and paramagnetic. In Fig.1(b), AFM image of the sample 2 is shown. Both of the primary particles of about 0.04 μm in diameter and the secondary particles of about 0.4 μm in diameter have rather narrow size distribution. Substitution of Ga^{3+} for Fe^{3+} decreases optical absorption. These properties of the sample 2 satisfy the material requisite for the substrate.

The sample 4 was prepared by *in situ* growth of BIG in succession to growth of the sample 2* which was deposited under the same condition for the sample 2. In Fig.2(a), XRD pattern of the sample 2* is presented. In the layer, garnet phase and $\text{Bi}_2\text{Fe}_4\text{O}_9$ coexist. The garnet phase was assigned as BIG, because the lattice parameter was 12.62Å. In Fig.2(b), AFM image of the sample 4 is shown. Growth of grain and facet of BIG is remarkable.

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