In-plane Magnetic Anisotropy of (111) and (100) Garnet Film prepared for Magneto-optical Indicator

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Abstract

The in-plane magnetic anisotropy of (100) garnet film was compared with that of (111) film from the point of view of magneto-optical indicator. The $(BiLu)_3(FeGa)_5O_{12}$ films were grown on $Gd_3Ga_5O_{12}$ substrates by LPE technique. With substituting Fe ions with Ga ions, the perpendicular magnetic domain structure appeared at 0.8/ f.u. of Ga content for the case of (111) film, however, the (100) film kept in-plane anisotropy up to at 1.0/ f.u. of Ga content. The roll of crystalline magnetic anisotropy was important roll for the in-plane magnetic film.

Keywords: magneo-optical indicator, magnetic garnet, LPE, in-plane magnetic film
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Visualization of magnetic flux using magneto-optical (MO) effect is attractive technique since it was practically applied for the characterization of superconductors [1-3]. Recently, the dynamic behavior of the quantized magnetic vortices in superconductors has reported by the MO imaging using magnetic garnet film [4]. The MO imaging is powerful technique for the real time observation when applied magnetic fileds and temperatures are continuously changed. Magnetic garnets have an advantage for the observation of magnetic flux in high T_c superconductor because the Curie temperature is more than 500 K. We recently reported the synthesis of Bi-Lu-substituted iron garnet film with in-plane magnetic anisotropy [5]. Because of no appearance of perpendicular magnetic domain, an in-plane magnetic film is considered to realize high spatial resolution less than 1 micron and the response time to the field change is expected to be several nanoseconds.

In the film, the growth induced-magnetic anisotropy, the stress-induced anisotropy, the shape magnetic anisotropy and the crystalline magnetic anisotropy are competed from each other. For the growth of in-plane magnetic film, it is important that those anisotropy energies are totally treated. In this report, we focused on the difference of in-plane magnetic anisotropy of (111) and (100) $(BiLu)_3(FeGa)_5O_{12}$ [BLIG] film. Bi enhances the MO effect in visible light region. Dilution of Fe ions have a role of increment of Verdet constant, which increase the sensitivity to magnetic fields.

The BLIG films were grown on both <100> and <111> oriented GGG [a_s=12.383 Å] substrates in the same growth condition by the horizontal dipping mode. $PbO-B_2O_3-Bi_2O_3$ flux were used. The lattice mismatch (Δa_s) was determined by X-ray diffraction analysis. The compositions of the films were analyzed using an Energy Dispersive X-ray spectrometer (EDX). The magnetization was measured by VSM and SQUID. Magnetic domains were observed by polarized microscope.

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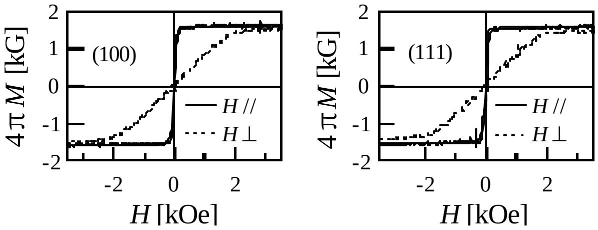

Fig. 1. Magnetization curves of (100) and (111) BLIG films without Ga substitution in the magnetic field parallel and perpendicular to the plane measured at room temperature.

The growth temperature was kept at approximately 750 ℃. Ga content in the film was varied from 0 to 1.0 /f.u.

Without Ga substitution, both (100) and (111) BLIG films showed in-plane magnetic anisotropy and no perpendicular domain structures. The lattice mismatch between the film and the substrate are 0.01 Å and 0.00 Å, respectively. Figure 1 shows the magnetization curve of (100) and (111) films in the magnetic field parallel and perpendicular to the film plane measured at the room temperature. It is clear that the magnetization curve in the magnetic field parallel to the plane is quickly saturated in the applied magnetic field. The magnetic field in order to saturate the magnetization magnetic field perpendicular to the film plane (we call "saturation field" in the following) is approximately 2 kOe for both films.

With substitution of Fe ions with non-magnetic Ga ions, the saturation magnetization and the saturation filed of the films decreased. The dilution of Fe ions resulted in the decrease of absolute energy of magnetic anisotropy. With increment of Ga content, the (111) film changed into perpendicular magnetic film at 0.8 /f.u. substitution of Fe ions with Ga ions. Figure 2 shows the magnetization curve of the film with 1.0 /f.u. of Ga content . The magnetization is easily saturated in the magnetic field perpendicular to the plane. On the contrary to the (111) film, the (100) film kept in-plane magnetic anisotropy at the same Ga content.

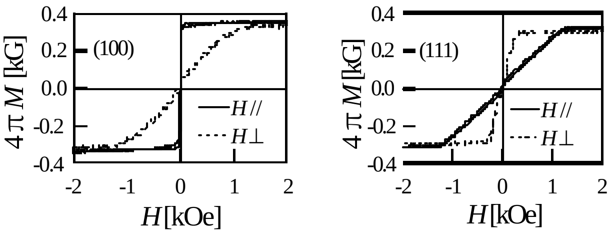

Fig. 2. Magnetization curves of (100) and (111) BLIG films with approximately 1 /f.u.of Ga content in the magnetic field parallel and perpendicular to the plane measured at room temperature.

With dilution of Fe, the crystalline magnetic anisotropy is considered to have a sensitive influence for the in-plane magnetic anisotropy. Cubic crystalline anisotropy is expressed the following;

$$E_a = K_1(a_1^2 a_2^2 + a_2^2 a_3^2 + a_3^2 a_1^2) + K_2\, a_1^2 a_2^2 a_3^2 + \cdots$$

where, K_1 and K_2 are anisotropy constants. When $K_1<0$ and $K_2< 0$, the magnetic easy axis lies <111> direction [6]. The sign of K_1 and K depends on materials. In this case, the easy axis is considered to be <111> direction. This is the possible reason that the (111) film change from in-plane to perpendicular magnetic film easier than the (100) film.

In summary, the in-plane magnetic anisotropy of (100) and (111) BLIG films were compared each other under the same growth condition. With substitution of Fe ions with Ga ions, the effect of crystalline magnetic anisotropy increased. Thus, the growth on (100) substrates is concluded to be easier for the in-plane magnetic film than the growth on (111) substrates.

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