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Crystal structure and magnetic characteristics of $Y_2Bi_1Fe_{5-x}Ga_xO_{12}$ films fabricated by metal organic decomposition method

*Hina Saito[1], Yoshito Ashizawa[2], and Katsuji Nakagawa[2]

$Y_2Bi_1Fe_{5-x}Ga_xO_{12}$ films (x = 0 and 1) were fabricated on $Gd_3Ga_5O_{12}$ (GGG) (111) and glass substrates by metal organic decomposition (MOD) method. The garnet films on GGG (111) were single-phase and (111) orientated, and those effective perpendicular magnetic anisotropy K^{eff} showed the same tendency of K^{eff} of the films on glass substrates depending on x. The each saturation magnetization M_s of the $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films on glass substrates is 30.3, 65.0 emu/cc, respectively. The measured M_s of the $Y_2Bi_1Fe_4Ga_1O_{12}$ film is as same as the estimated M_s, although the measured M_s of the $Y_2Bi_1Fe_5O_{12}$ film is almost a half of the estimated M_s.

1. Introduction

Garnets are one of the interesting magnetic materials for spin wave devices because of their small damping constant of precession and controllability of the magnetic characteristics by substitution [1]. In our previous research, we fabricated $Y_1Bi_{1.5}R_{0.5}Fe_4Ga_1O_{12}$ (R = Dy, Eu, Gd) films on glass and $Gd_3Ga_5O_{12}$ (GGG) (111) substrates by metal organic decomposition (MOD) method. Then we have confirmed that the uniaxial magnetic anisotropy of the garnet films was changed by substitution of rare earth elements for c-site [2]. The $Y_1Bi_{1.5}R_{0.5}Fe_4Ga_1O_{12}$ (R = Dy, Eu, Gd) films on GGG (111) substrates, however, included not only the garnet phase but also unknown phases [2], even though single-phase garnet films are essential to long-range spin wave propagation. In this report, we fabricated simple composition: $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ on GGG (111) substrates. Then crystal structure and magnetic characteristics of the garnet films were investigated.

2. Experimental procedure

The MOD solutions for garnet films were spin-coated on glass and GGG (111) substrates, then dried at 100 °C for 10 minutes, and then decomposed and volatilized at 450 °C for 10 minutes. The thickness of a single-coated garnet film is expected to be 40 nm [3]. This process was repeated 4 times. After the process, the film was crystalized at various temperatures higher than 750 °C. The thickness of a garnet film is expected to be 160 nm. The crystal structures were analyzed by X-ray diffraction (XRD) with Cu-$K\alpha$ line. Magnetic characteristics were evaluated by M-H loops measured by vibrating sample magnetometer (VSM) and Faraday loops with light wavelength of 500 nm.

3. Results and discussion

First, the $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films were fabricated on glass substrates that it is easy to evaluate magnetic parameters by M-H loops. XRD patterns of $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films on glass substrates are shown in Fig. 1. Each observed diffraction line of all the films was identified as only a garnet phase, without unknown phase.

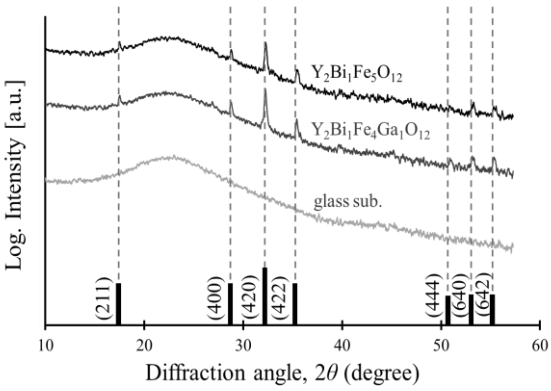

Fig. 1 XRD patterns of $Y_2Bi_1Fe_4Ga_1O_{12}$ garnet film and $Y_2Bi_1Fe_5O_{12}$ garnet film on glass substrates.

M-H loops of $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films on glass substrates are shown in Fig. 2. The saturation magnetization M_s of the $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films is 30.3, 65.0 emu/cc, respectively. To estimate the M_s, M_s of $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ garnet films was calculated from the volume and net magnetic moments at room temperature per unit cell. M_s of the $Y_2Bi_1Fe_5O_{12}$ garnet phase was estimated from net magnetic moments of 8 times Fe^{3+} per unit cell at 300 K [4]. On the other hand, M_s of the $Y_2Bi_1Fe_4$-

1: Department of Electronic Engineering, GST., Nihon-U.　2: Department of Electronic Engineering, CST., Nihon-U.

Ga_1O_{12} garnet phase was estimated from magnetic moments of 1.6 times Fe^{3+} per unit cell at 300 K under the case that substitution ratio of Ga^{3+} in *d*-site to *a*-site is 0.9 : 0.1 [4]. The estimated M_s of $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ garnet phases is 28.8, 144.2 emu/cc, respectively. Measured M_s of the $Y_2Bi_1Fe_4Ga_1O_{12}$ film is as same as the estimated M_s, although measured M_s of the $Y_2Bi_1Fe_5O_{12}$ film is almost a half of the estimated M_s.

Next, the films were fabricated on GGG substrates for epitaxial growth. XRD patterns of $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films on GGG substrates are shown in Fig. 3. It was confirmed that both $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films are (111) oriented, because each diffraction line of the films indicated only the (444) garnet phase at 50.8° without any other diffractions. This means that the films were single-phase garnets.

Faraday loops of $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films on GGG substrates are shown in Fig. 4. Effective perpendicular magnetic anisotropy K^{eff} of the $Y_2Bi_1Fe_4Ga_1O_{12}$ film on GGG substrate was larger than K^{eff} of the $Y_2Bi_1Fe_5O_{12}$ film on GGG substrate. The tendency of K^{eff} between $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films on GGG substrates depending substitution of Ga is as same as that of the garnet films on glass substrates.

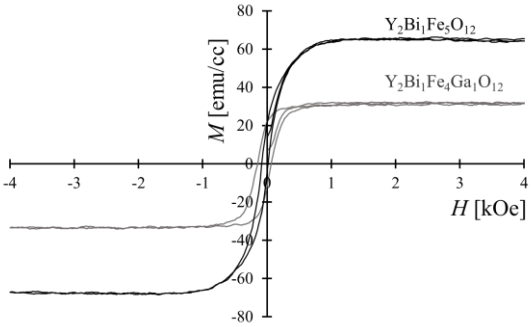

Fig. 2 *M-H* loops of $Y_2Bi_1Fe_4Ga_1O_{12}$ garnet film and $Y_2Bi_1Fe_5O_{12}$ garnet film on glass substrates.

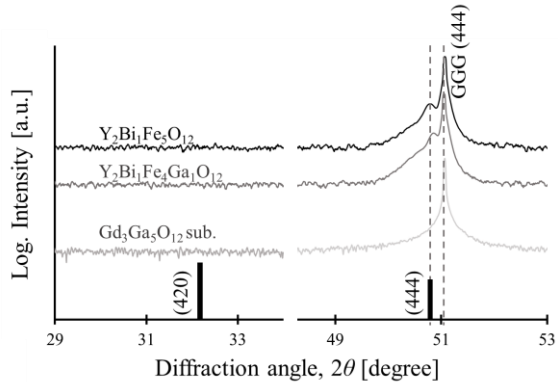

Fig. 3 XRD patterns of $Y_2Bi_1Fe_4Ga_1O_{12}$ garnet film and $Y_2Bi_1Fe_5O_{12}$ garnet film on GGG substrates.

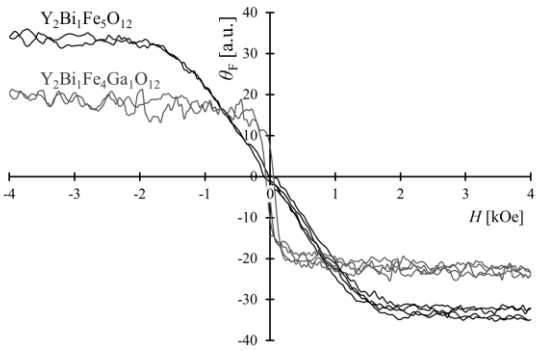

Fig. 4 Faraday loops of $Y_2Bi_1Fe_4Ga_1O_{12}$ garnet film and $Y_2Bi_1Fe_5O_{12}$ garnet film on GGG substrates.

4. Summary

$Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ on GGG (111) and glass substrates by the MOD method. The $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films on GGG substrates were single-phase and (111) orientation. In the films on both GGG (111) and glass substrates, K^{eff} of the $Y_2Bi_1Fe_4Ga_1O_{12}$ film was larger than that of the $Y_2Bi_1Fe_5O_{12}$ film. M_s of the $Y_2Bi_1Fe_4Ga_1O_{12}$ and $Y_2Bi_1Fe_5O_{12}$ films on glass substrates is 30.3, 65.0 emu/cc, respectively. The measured M_s of the $Y_2Bi_1Fe_4Ga_1O_{12}$ film is as same as the estimated M_s, although the measured M_s of the $Y_2Bi_1Fe_5O_{12}$ film is almost a half of the estimated M_s.

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