Crystal structure and magnetic characteristics of $\text{Y}_2\text{Bi}_x\text{Fe}_{5-x}\text{Ga}_4\text{O}_{12}$ films 
fabricated by metal organic decomposition method

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$\text{Y}_2\text{Bi}_1\text{Fe}_{5-y}\text{Ga}_y\text{O}_{12}$ films ($x = 0$ and $1$) were fabricated on Gd$_3$Ga$_5$O$_{12}$ (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 $K^\text{eff}$ showed the same tendency of $K^\text{eff}$ of the films on glass substrates depending on $x$. The each saturation magnetization $M_s$ of the $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ and $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ films on glass substrates is $30.3$, $65.0$ emu/cc, respectively. The measured $M_s$ of the $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ film is as same as the estimated $M_s$, although the measured $M_s$ of the $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ 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 $\text{Y}_2\text{Bi}_{1-x}\text{R}_{x}\text{Fe}_5\text{Ga}_4\text{O}_{12}$ $(R = \text{Dy, Eu, Gd})$ films on glass and Gd$_3$Ga$_5$O$_{12}$ (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 $\text{Y}_2\text{Bi}_{1-x}\text{R}_{x}\text{Fe}_5\text{Ga}_4\text{O}_{12}$ $(R = \text{Dy, Eu, Gd})$ 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: $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ and $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ 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 $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ and $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ films were fabricated on glass substrates that it is easy to evaluate magnetic parameters by $M$-$H$ loops. XRD patterns of $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ and $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ 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.

$M$-$H$ loops of $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ and $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ films on glass substrates are shown in Fig. 2. The saturation magnetization $M_s$ of the $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ and $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ films is $30.3$, $65.0$ emu/cc, respectively. To estimate the $M_s$, $M$, of $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ and $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ garnet films was calculated from the volume and net magnetic moments at room temperature per unit cell. $M_s$ of the $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{O}_{12}$ garnet phase was estimated from net magnetic moments of $8$ times $\text{Fe}^{3+}$ per unit cell at $300$ K [4]. On the other hand, $M_s$ of the $\text{Y}_2\text{Bi}_1\text{Fe}_5\text{Ga}_4\text{O}_{12}$ garnet film on glass substrates.

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Ga$_3$O$_{12}$ 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$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ and Y$_2$Bi$_2$Fe$_5$O$_{12}$ garnet phases is 28.8, 144.2 emu/cc, respectively. Measured $M_s$ of the Y$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ film is as same as the estimated $M_s$, although measured $M_s$ of the Y$_2$Bi$_2$Fe$_5$O$_{12}$ 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$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ and Y$_2$Bi$_2$Fe$_5$O$_{12}$ films on GGG substrates are shown in Fig. 3. It was confirmed that both Y$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ and Y$_2$Bi$_2$Fe$_5$O$_{12}$ 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$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ and Y$_2$Bi$_2$Fe$_5$O$_{12}$ films on GGG substrates are shown in Fig. 4. Effective perpendicular magnetic anisotropy $K_{eff}$ of the Y$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ film on GGG substrate was larger than $K_{eff}$ of the Y$_2$Bi$_2$Fe$_5$O$_{12}$ film on GGG substrate. The tendency of $K_{eff}$ between Y$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ and Y$_2$Bi$_2$Fe$_5$O$_{12}$ films on GGG substrates depending substitution of Ga is as same as that of the garnet films on glass substrates.

4. Summary

Y$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ and Y$_2$Bi$_2$Fe$_5$O$_{12}$ on GGG (111) and glass substrates by the MOD method. The Y$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ and Y$_2$Bi$_2$Fe$_5$O$_{12}$ 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$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ film was larger than that of the Y$_2$Bi$_2$Fe$_5$O$_{12}$ film. $M_s$ of the Y$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ and Y$_2$Bi$_2$Fe$_5$O$_{12}$ films on glass substrates is 30.3, 65.0 emu/cc, respectively. The measured $M_s$ of the Y$_2$Bi$_2$Fe$_5$Ga$_{12}$O$_{34}$ film is as same as the estimated $M_s$, although the measured $M_s$ of the Y$_2$Bi$_2$Fe$_5$O$_{12}$ film is almost a half of the estimated $M_s$.

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References