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Magnetic properties of epitaxial bismuth ferrite-garnet mono- and bilayers

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ABSTRACT

Magnetic properties of $Bi_{1.5}Gd_{1.5}Fe_{4.5}Al_{0.5}O_{12}$ (84 nm) and $Bi_{2.8}Y_{0.2}Fe_5O_{12}$ (180 nm) films epitaxially grown on gallium-gadolinium garnet (GGG) single crystal (111) substrate as well as $Bi_{1.5}Gd_{1.5}Fe_{4.5}Al_{0.5}O_{12}/Bi_{2.8}Y_{0.2}Fe_5O_{12}$ bilayer were investigated using ferromagnetic resonance technique. The mismatch of the lattice parameters of substrate and magnetic layers leads to formation of adaptive layers which affect on the high order anisotropy constant of the films but practically do not affect on uniaxial perpendicular magnetic anisotropy The magnetic properties of the bilayer film were explained in supposition of strong exchange coupling between magnetic layers taking into account film-film and film-substrate elastic interaction.

1. Introduction

Bismuth-substituted iron garnet films are of great interest now due their potential applications as magneto-optical layers in one-dimensional magneto-photonic crystals, which are supposed to be used in a new generation of magneto-optical devices such as modulators, optical valves, and high sensitivity magnetic field sensors [1]. But a preparation of high quality films with high bismuth content (to provide strong Faraday rotation) on traditional substrates is quite problematic. It has been shown earlier [2–4] that iron garnet films with high bismuth concentration for magneto-photonic crystals can be grown on buffer sublayer with lower bismuth content. However due to numerous requirements to magnetooptic layers such as desired values of specific Faraday rotation, coercive force, compensation temperature, transmittance coefficient, hysteresis loop squareness, etc., it is practically impossible to get a perfect match between the lattice parameters of the films and substrates. This should strongly affect on the magnetic parameters of obtained structures. The exchange interaction between magnetic layers should be also taken into account during the development of such systems.

Here we report the investigation of magnetic properties of lower and higher Bi content films as well as their double layer structure deposited on gallium-gadolinium garnet single crystal substrates. The parameters of the films are presented in Table 1. The composition of the films and their thickness are chosen to be close to that for the magneto-photonic crystals [4].

2. Experimental

Bi-substituted ferrite garnet films were deposited on (111) single crystal gadolinium-gallium garnet with lattice parameter $a = 1.2383$ nm by ion-beam sputtering in argon–oxygen atmosphere. The targets were prepared using conventional ceramic technique. To provide the crystallization the films were annealed at 680 °C in the air. The films preparation details are presented elsewhere [2].

The chemical composition of the targets and films was determined using scanning electron microscope with energy dispersive X-ray analyzer. The film thickness t was measured by polarization interference microscope using the double immersion method. X-ray diffraction was used to control crystal structure of the targets and films. The thickness of the S1 film is chosen to be $\lambda/4$ and of the S2 film $3\lambda/4$ as in for magnetophotonic crystals operating in visible spectrum range [4]. It has been shown previously [5] from the investigation of such films of different thicknesses that the diffusion layer for these films does not exceed 10 nm and the magnetic and magnetooptical properties of the films with chosen thicknesses are close to those for the bulk materials.

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Table 1
Composition and parameters of the investigated films.

Sample	Composition	t, nm	a, nm	Δa, %	$4\pi M$, emu/cm^3
S1	$Bi_{1.5}Gd_{1.5}Fe_{4.5}Al_{0.5}O_{12}$	84	1.255	1.34	360
S2	$Bi_{2.8}Y_{0.2}Fe_5O_{12}$	180	1.26	1.75	1600
S3	$Bi_{1.5}Gd_{1.5}Fe_{4.5}Al_{0.5}O_{12}/Bi_{2.8}Y_{0.2}Fe_5O_{12}$	84/180		1.34/0.39	1150

Here t is the thickness of the film, a is the lattice parameter, Δa lattice mismatch between the film and substrate or bottom layer, M is the saturation magnetization.

The saturation magnetization of the films was extracted from room temperature hysteresis loops measurements carried out using Quantum Design SQUID magnetometer. The results of the measurements are presented in Table 1. The error in the determination of saturation magnetization did not exceed 5%. The saturation magnetization values of single layer films are close for ones previously reported for the films of a similar composition (see for instance [6,7] and references therein). Note that the value of the saturation magnetization for the bilayer structure (S3) presented in the Table 1 is the magnetic moment of the film per total volume of both magnetic layers. The value of the magnetization of S3 obtained from the measurements (1150 emu/cm^3) within the experimental error coincides with the weighted mean value (1200 emu/cm^3) if the measured values of the separate layers are taken for the calculation.

Bruker Elexis E500 EPR spectrometer operating at 9.87 GHz was used for ferromagnetic resonance studies. In-plane and out-of-plane angular dependences of the resonance field were measured at room temperature to extract magnetic parameters of the films.

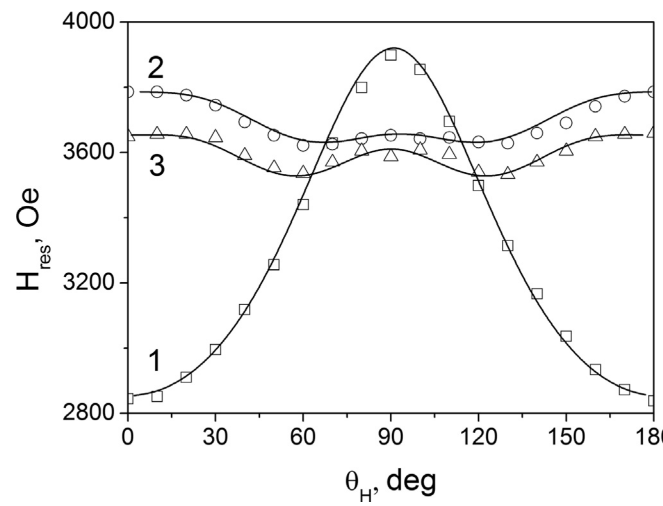

Fig. 2. The out-of-plane angular dependences of the resonance field $H_r(\theta_H)$ for samples S1, S2 and S3 (curves 1, 2 and 3 respectively). The lines drown trough the data are theoretical fits using the parameters presented in Table 2.

3. Results and discussion

The angular dependences of the resonance fields for the investigated samples are shown in Figs. 1 and 2. The in-plane angular dependence of the resonance field $H_r(\varphi_H)$ (Fig. 1) for all films demonstrates a formation of six-fold in-plane anisotropy. Here φ_H is azimuthal angle between the direction of the external magnetic field and $[1\bar{1}0]$ direction (see Fig. 3). However for sample S1 the direction $[1\bar{1}0]$ is an easy magnetization direction while for S2 and S3 it is a hard one. Six-fold anisotropy for cubic crystal in (111) plane is quite usual situation and can be easily explained from symmetry reason. The fact that only six-fold anisotropy is observed and there is no sign of four-fold anisotropy present clearly demonstrates that films perfectly inherit the crystalline orientation of the substrate.

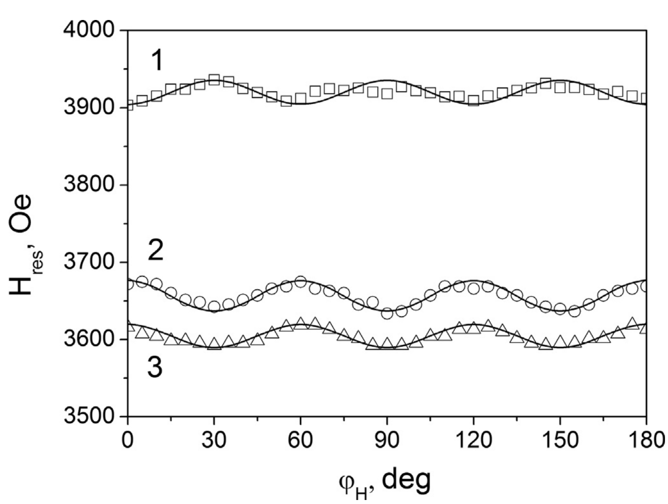

Fig. 1. The in-plane angular dependences of the resonance field $H_r(\varphi_H)$ for samples S1, S2 and S3 (curves 1, 2 and 3 respectively). The lines drown trough the data are theoretical fits using the parameters presented in Table 2.

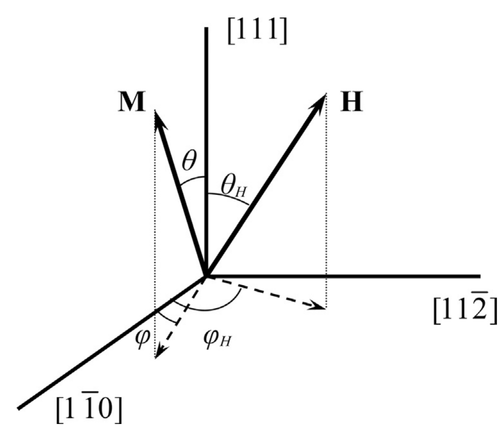

Fig. 3. To the calculation of ferromagnetic resonance fields.

The out-of-plane angular dependences of the resonance field $H_r(\theta_H)$ (Fig. 2) were measured in $(1\bar{1}0)$ plane. The analysis of these dependences showed a formation of pretty strong uniaxial anisotropy perpendicular to the film plane, which is usually ascribed to magnetoelastic contribution [8].

The fact that for sample S1 the perpendicular resonance field ($\theta_H = 0$) is lower than the in-plane resonance field ($\theta_H = \pi/2$) is supposed that the second order anisotropy constant $K_{2\perp} > 2\pi M^2$. For S2 sample this anisotropy constant should be of about $2\pi M^2$. The character of the angular dependence clearly demonstrates that high order anisotropy terms should be taken into account for correct description of the experimental data. A good fit to the data was obtained when forth order anisotropy terms for sample S1 and forth and sixth ones for S2 were introduced into analysis.