Magneto-Optical Properties of In-Plane Bi-YIG Films with Oblique-Incident Light

N. Kawai, T. Hirano, E. Komuro, T. Namikawa and Y. Yamazaki

***Abstract*—Because garnet film with an in-plane orientation has no magnetization component parallel to perpendicularly incident light, no magnetooptic effects are observed when such light is incident. We supposed that when a Bi-YIG film is positioned obliquely to incident light, the plane of polarization would be rotated owing to the magnetooptic effect, because of the appearance of a magnetization component in the direction of the incident light. A Bi-YIG film with in-plane orientation was prepared on a Corning #0317 glass substrate by rf sputtering, and was then magnetized in a 2 kOe magnetic field. The apparatus for detecting Faraday rotation consisted of a polarization microscope and a light source. On the stage of the polarization microscope, the plane of the Bi-YIG film was tilted to 45° relative to the stage plane. The apparatus was used to obtain contrast images caused by the remanent magnetization of the in-plane-oriented Bi-YIG film. This result indicates that such in-plane magnetooptic films can be applied in display devices.**

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I. Introduction

Information processing devices such as magnetooptic disks and optical circulators which employ magnetooptic effects have been developed, and some have come into use. Magnetooptic effects capable of controlling the amount of transmitted light may conceivably be employed, together with the memory effect inherent in magnetic materials, in display devices for which storage functions are required. The magnetic thin films which have till now been used in such applications have mainly been so-called perpendicular magnetization films, with their direction of magnetization oriented perpendicular to the plane of the film, whereas applications of in-plane magnetization films have been limited to a few devices for optical communications [1,2]. Bi-YIG system thin films, which are excellent magnetooptic materials, often have an in-plane anisotropy, and despite their superior magnetooptic properties they often cannot be applied in display devices and other fields. In this report, instead of making light incident normally on a film surface as is normally the case in magnetooptic disks and display devices, we caused

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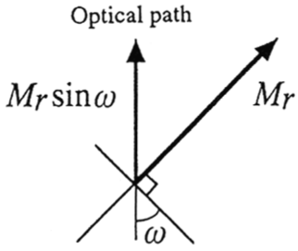

Fig. 1. Component of the magnetization parallel to the optical path in an in-plane magnetized film with light obliquely incident.

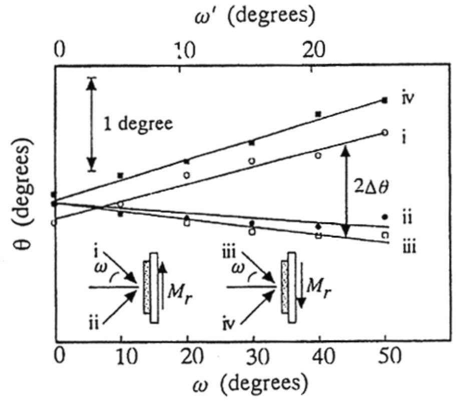

Fig. 2. Rotation of the polarization plane (θ) by an in-plane Bi-YIG film, as a function of ω.

light to be incident at an oblique angle from the film plane, and utilized the component of the in-plane magnetization in the direction of the optical path to rotate the plane of polarization, in an attempt to obtain contrast images generated by differences in the in-plane magnetization.

II. Rotation of the Plane of Polarization Due to Oblique Incidence

When light is transmitted perpendicularly through a thin film with an in-plane magnetization, because the optical path is orthogonal to the direction of magnetization there is no rotation of the plane of polarization due to the magnetooptic Faraday effect. But in thin film with an in-plane magnetization which is oriented at an angle to the optical path, there is a magnetization component parallel to the optical path and so the plane of polarization is rotated. Fig. 1 illustrates the relation between the in-plane magnetization, the optical path and the component of the magnetization in the optical path direction. If the angle made by the incident direction and the plane normal is ω, then the magnitude of the magnetization component in the optical path direction will be sinω times the magnetization, and the magnetooptic effect appears as a result of this component. Fig. 2 shows the relation between the angle of rotation of the polarization plane θ and the angle ω [3]. In the figure are shown the relations for the different possible directions of incident light and sample magnetization directions, labeled i through iv. The points in the figure denote measurement results. As ω increases, the component of the in-plane magnetization in the optical path direction and the optical path length in the sample both increase. The magnetization direction and direction of incidence are the same for i and iv and for ii and iii, and are opposite for i and iii and for ii and iv. The differences between i and iii and between ii and iv are equal to the rotation 2Δθ occurring when the magnetization is reversed. We now consider the optical path in Bi-YIG thin film; Fig. 3 shows the path of light traversing Bi-YIG thin film. If the indices of

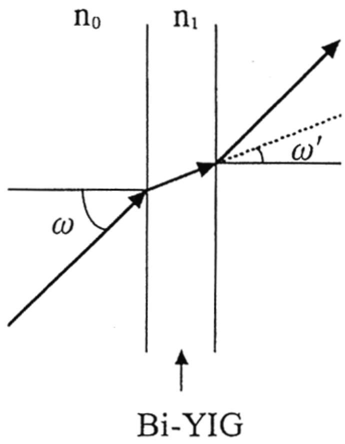

Fig. 3. Optical path in a Bi-YIG film.

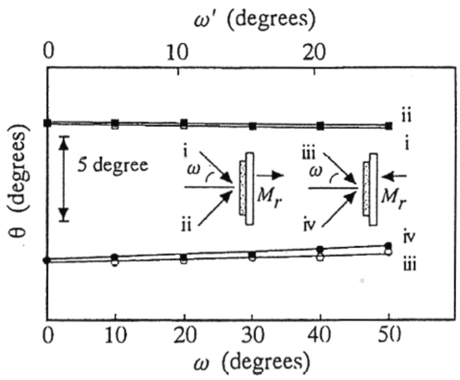

Fig. 4. Rotation of the polarization plane (θ) by a perpendicular-oriented Bi-YIG film as a function of ω.

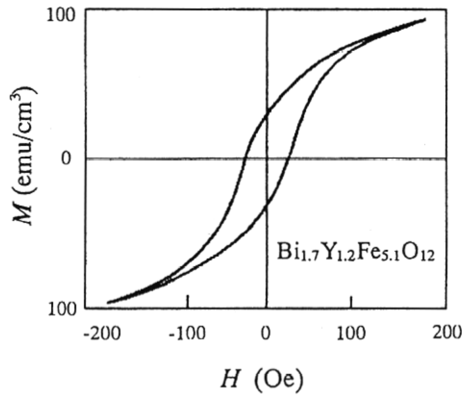

Fig. 5. Hysteresis loop of an in-plane Bi-YIG film used in experiments.

refraction of air and of the Bi-YIG thin film are respectively n_0 and n_1, then the angle ω' of the optical path and the angle of incidence ω are related as follows:

$$\omega' = \sin^{-1}\{(n_0/n_1)\sin\omega\}$$

Fig. 2 shows the values of ω' calculated with 1.8 substituted for the index of refraction of the Bi-YIG film, an effective value determined from optical transmission spectra measured after multiple reflections. 2Δθ is proportional to the optical path length (L) in the Bi-YIG thin film and to the component of the remanent magnetization (M_r) in the optical path direction, $M_r\sin\omega'$. If the film thickness is L_0, then L is equal to $L_0(1/\cos\omega')$, so that

$$2\Delta\theta = M_r L_0 \sin\omega'(1/\cos\omega') = M_r L_0 \tan\omega'$$

and 2Δθ is proportional to tanω', and increases with increasing ω', that is, with increasing ω.

Fig. 4 shows the relation of θ to ω and ω' for perpendicular magnetization film [3]. The measurement results differ from those of Fig. 2, and 2Δθ retains a nearly constant magnitude regardless of ω'. This may be understood as follows. When the remanent magnetization (M_r) is in the perpendicular direction, the component parallel to the optical path is $M_r\cos\omega'$. Hence from the relation

$$2\Delta\theta = M_r\cos\omega' L_0(1/\cos\omega') = M_r L_0$$

the quantity 2Δθ is constant.

From the above-described measurement results for in-plane and perpendicular magnetization films, it is inferred that by causing light to be incident obliquely on Bi-YIG thin film with an in-plane magnetization, the magnetization pattern can be read out.

III. Samples

The Bi-YIG thin films used in experiments were prepared by rf sputtering. An oxide powder in which the cation composition was Bi:Y:Fe=2:1:4 was sintered for four hours at 800°C, then crushed for four hours in a ball mill and mixed; following this it was pressed into disks 10 cm in diameter to form targets. Argon gas at a pressure of 6.7 Pa was used, the rf power density was 2.5 W/cm², and the substrate temperature during sputtering was 400°C. The amorphous thin films deposited in this way were annealed in air for four hours at 650°C to obtain garnet polycrystalline films. The film thickness was 1.7 μm. X-ray diffraction was used to confirm that samples consisted of a single garnet

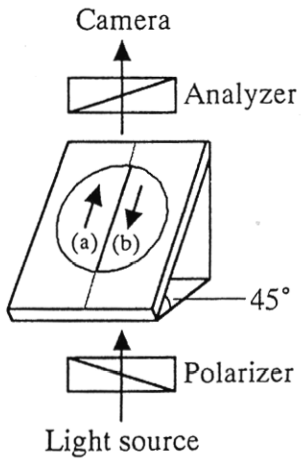

Fig. 6. Schematic diagram of an in-plane Bi-YIG film mounted in a polarization microscope to produce magnetooptic contrast.

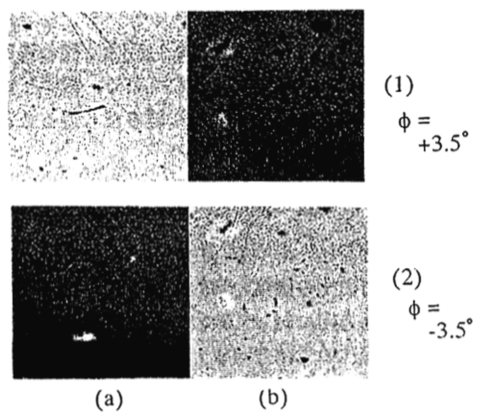

Fig. 7. Images obtained with in-plane Bi-YIG films with opposite remanent magnetization vectors.

phase. Fig. 5 shows a sample magnetization curve measured using a VSM. This is an in-plane magnetization film with a coercivity of approximately 25 Oe. The sample composition as determined by ICP emission spectroscopy is also shown in the figure.

IV. Results and Discussion

Fig. 6 shows the optical system used in the experiments. A uniform 2 kOe magnetic field was applied in an in-plane direction to two Bi-

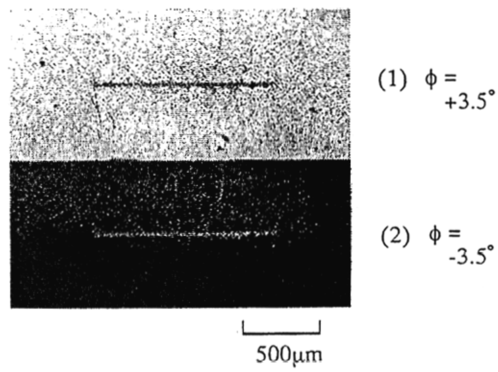

Fig. 8. Readout from an in-plane magnetization image written with a ring head.

YIG thin films, each with an in-plane magnetic anisotropy, and the films were positioned with their magnetic anisotropy axes antiparallel. Let these magnetized films be (a) and (b). The thin film samples were placed on the stage of a polarization microscope, and the sample holder was used to set them at 45° relative to the optical path direction. Changes in the contrast when the analyzer was rotated were then observed and photographed. Here the sample holder was adjusted such that the plane of polarization of the linearly-polarized incident light and the plane of the Bi-YIG films were perpendicular. If this angle deviated even slightly from 90°, a clear contrast could not be obtained, probably because at the point of incidence the incident light deviated from linear polarization to become elliptically polarized.

Fig. 7 presents photographs of the differences in transmitted light intensity due to the remanent magnetization, that is, the contrast resulting from the magnetooptic effect. Photo (1) was taken with the detector rotated for maximum brightness in region (a); (2) was similarly taken such that region (b) was as bright as possible. With the polarizer and the analyzer positioned orthogonally, the amount of light transmitted was equal. With this state as reference, the angle ϕ by which the analyzer was shifted in (1) and (2) is shown in the figure.

In order to study the recording of arbitrary dot patterns in such films, a ring head was used in attempts at magnetic recording of uniformly magnetized Bi-YIG thin film. Fig. 8 is a photo of a recorded sample film, observed using the magnetooptic effect. The analyzer was rotated to confirm contrast reversal.

When the sample was laid flat on the polarization microscope stage, so that the angle made by the thin film and the stage was 0° and light was incident normally on the sample surface, the contrast vanished. This is attributed to the fact that the direction of magnetization in the in-plane magnetization film and the optical path are orthogonal, and the magnetization component in the optical path direction vanishes.

The contrast reversals observed in this work are due to differences in the direction of the remanent magnetization within the film plane, indicating that the in-plane magnetization produced by magnetic recording can be read out magnetooptically.

V. Conclusion

Bi-substituted YIG thin film with an in-plane easy axis of magnetization was used in attempts to read out magnetooptically the in-plane remanent magnetization. By positioning the sample film at an angle from the optical path, the component of the remanent magnetization parallel to the optical path was utilized to observe contrast. By making use of the method for producing contrast corresponding to the remanent state described in this paper, it should be possible to employ in-plane magnetization Bi-substituted YIG thin films in display devices.

References

[1] R. Wolf, J. Hegarty, J.F. Dillon, Jr., L.C. Luther, G.K. Celler and L.E. Trimble, IEEE Trans. Magn., MAG-21, 1647, 1985.
[2] K. Tsushima and N. Koshizuka, IEEE Trans. Magn., MAG-23, 3473, 1987.
[3] T. Hirano, T. Namikawa and Y. Yamazaki, J. IEICE, J76-c-II, 484, 1993.