# Bi-YIG Magneto-Optical Coated Films for Visual Applications

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***Abstract* - Garnet fine particles of $Bi_{1.8}Y_{1.2}Fe_5O_{12}$ were prepared by coprecipitation and annealing processes, and were coated on glass or plastic substrates. The annealing was carried out at 650 °C for 4 h. The obtained particles were identified as garnet by X-ray diffraction. The coated films showed a Faraday rotation of 1 degree in the visible wavelength region. A magnetic field pattern was observed by using a MO film coated on a plastic substrate. The demonstration was made with reflected light. It is expected that Bi-YIG coated films are suitable for a large-size visual MO devices.**

## I. Introduction

Thin films of bismuth substituted yttrium iron garnet (Bi-YIG) have a potential for developing magneto-optical (MO) devices working in the visible wavelength region as well as in the inflared region. Until now Bi-YIG films have normally been prepared by sputtering with a substrate temperature of more than 500 °C. Therefore, the inexpensive plastic sheets which are prepared in a large size can not be used as substrates. However we can solve this thermal problem by employing a coating technique in film preparation processes. Bi-YIG particles have been prepared by coprecipitation, sol-gel, and pyrolysis methods[1][2]. Some coated films were prepared for the use of MO recording media[3][4].

In this report we study the possibility that Bi-YIG coated films can be applied to the devices working in the visible wavelength region to display recorded magnetic images. The test of the coated film is performed using reflected light since that configuration seems to be more suitable for the device applications.

## II. Experimental

### A. Preparation of Bi-YIG particles

The preparation process of Bi-YIG particles used as the active material in the MO films is shown in Figure 1. The particles were prepared by coprecipitation and annealing processes[5][6]. First aqueous solutions of the nitrates of Bi, Y and Fe were mixed where the ratio of the cations corresponded to the composition of $Bi_{1.8}Y_{1.2}Fe_5O_{12}$. Then the solution was mixed with a solution of $NH_4OH$ with stirring at room temperature to coprecipitate the cations. The concentration of the alkaline solution was adjusted so that the pH of the mixed solution was 10.0 after the coprecipitation reaction. The obtained slurry was washed, filtered and dried at 100 °C for 8 h. Then the coprecipitate was heated in air at 650 °C for 4 h to form fine garnet particles. The composition of the cations in the coprecipitate was analyzed by inductively coupled plasma spectroscopy. The crystal phases of the particles were examined by X-ray diffraction analysis with a Cu-K$\alpha$ source.

### B. Particle coating procedure

The prepared Bi-YIG particles were mixed with an organic binder (polyurethane) and cyclohexanon and milled with a Pulverisette P7 milling machine (Fritsch) for 10 h, then it was coated on a Corning #7059 glass substrate with a thickness of 1.7 μm using a spin coater (Toppan Printing Co., Ltd.). The thickness of the film was adjusted by the speed of disk rotation. The magnetic properties of the coated film was measured with a vibrating sample magnetometer at room temperature. The Faraday rotation of the coated film was measured by the polarization modulation method. These optical measurements were carried out in the visible wavelength region.

### C. Preparation of flexible MO films

The magnetic ink described in the previous section was

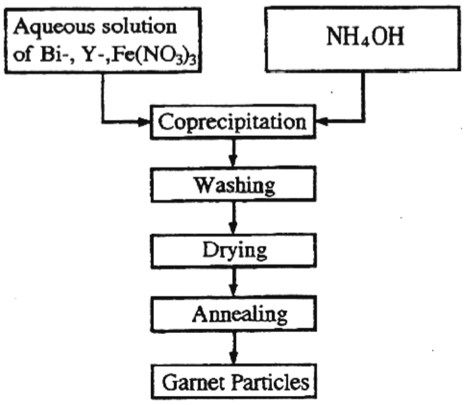


Fig.1 Preparation process of Bi-YIG particles by coprecipitation and thermal treatment.

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coated on a polyethyleneterephthalate (PET) film by a roll coater (Toppan Printing Co., Ltd.). An aluminum mirror was evaporated on the plastic film prior to the coating. The prepared film was flexible.

## III. RESULTS AND DISCUSSION

### *A. Magnetic properties*

Figure 2 shows the X-ray diffraction pattern of the Bi-YIG powder. All the peaks were assigned to the garnet structure. The saturation magnetization of the powder sample was 16 emu/g at room temperature. The perpendicular M-H curve of the coated film was shown in Figure 3. The value of Ms for perpendicular was 1.6 emu/cm$^3$.

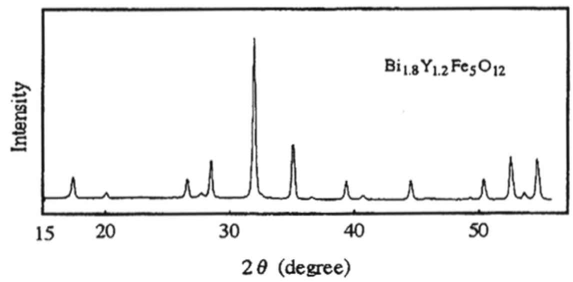


Fig.2 X-ray diffraction pattern of Bi-YIG particles.

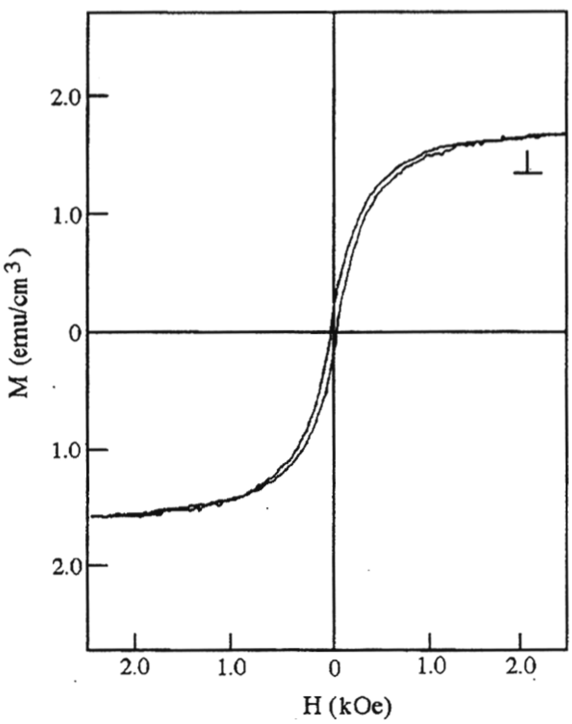


Fig.3 Perpendiculer M-H curve of Bi-YIG coated film.

### *B. Magneto-optical properties of coated film*

Figure 4 shows the Faraday rotation, $\theta_F$, spectrum and the absorption, $\alpha$, spectrum of the Bi-YIG coated film. The maximum of Faraday rotation is about 1 degree at 520 nm. The figure of merit ($2\theta_F/\alpha$) at 520 nm is about 4.0 degrees which is comparable to Bi-YIG sputtered films[7]. Figure 5 shows the $2\theta_F/\alpha$ of the Bi-YIG coated film as a function of wavelength. The maximum of $2\theta_F/\alpha$ is about 5.8 degrees at 580 nm.

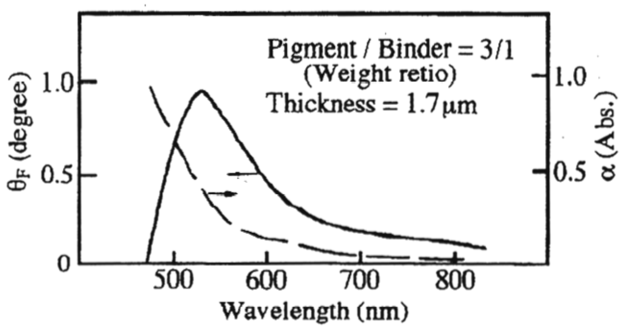


Fig.4 Faraday spectrum and absorption of Bi-YIG coated film.

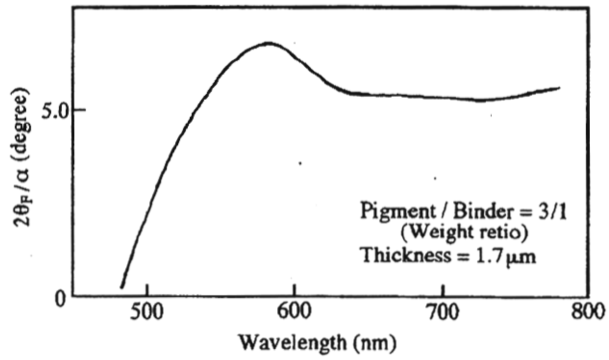


Fig.5 The figure of merit ($2\theta_F/\alpha$) of Bi-YIG coated film as a function of wavelength.

### *C. Display of a magnetic pattern by using coated film*

The prepared flexible MO film was tested by visual readout of a magnetic pattern formed by an array of magnets. Figure 6 shows the optical arrangement for the readout test. The flexible MO film was placed on the magnets. The magnets were arranged in a checkerboard pattern as shown in the figure. The magnetic field near the flexible MO film was about 1000 Oe. MO contrasts were observed with analyzer angles of ± 2 degrees from the cross Nicol condition. A tungsten halogen lamp was used for the light source.

Figure 7 shows the readout patterns observed with the reflected light. The images shown in the figure were recorded by an ordinary photo film. This confirms that the coated flexible MO film converts a magnetic field pattern to a visible image. It is also noted that the readout was carried out with the optical arrangement of reflection configuration which is more suitable

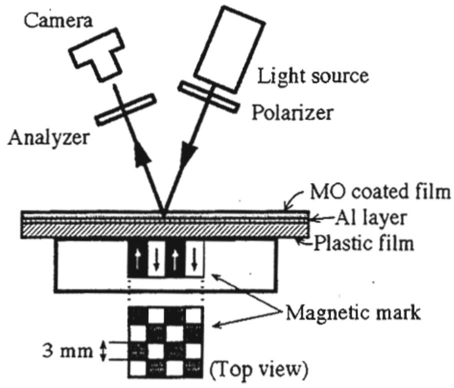


Fig.6 Schematic diagram showing the optical read out of a magnetic pattern by reflected light.

for the display applications than that of transmission configurations.

## IV. Conclusions

In order to prepare coated MO films working at the visible wavelength region, Bi substituted YIG particles are prepared by coprecipitation and annealing processes. Optimizations were made on the pH values in the coprecipitation process and on the annealing temperature and time. The coated films showed a considerable Faraday rotation of ± 1 degree at a wavelength of 520 nm. Because a clear Faraday contrast was observed, we expect that the flexible MO film can be applied to display media.

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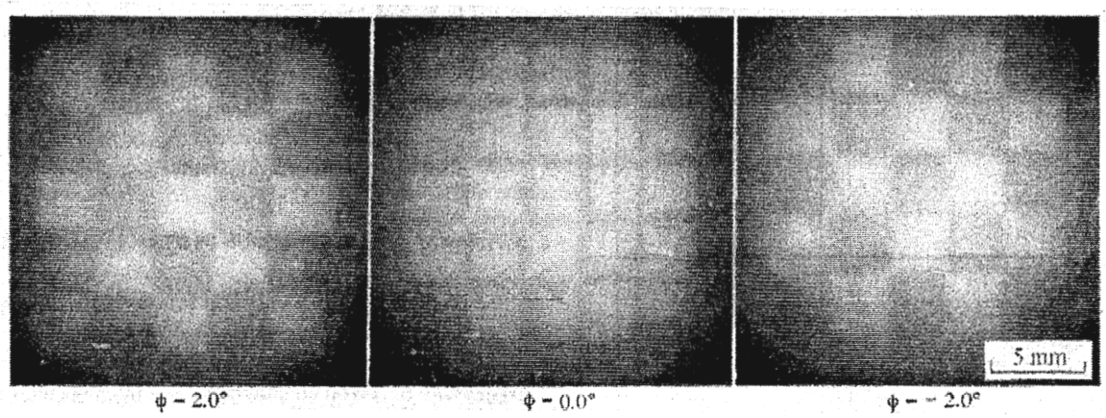


Fig.7 Readout patterns of the magnetic field which is shown in Fig.6 ; φ : offset angle of analizer.