High-throughput characterization of $Bi_x Y_{3-x} Fe_5 O_{12}$ combinatorial thin films by magneto-optical imaging technique

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Kouichi Akahane
National Institute of Information and Communications Technology

Takayuki Ishibashi
Nagaoka University of Technology

Katsuaki Sato
Tokyo University of Agriculture and Technology

Yoshinari Matsumoto
Kishiwada City Hospital

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Magneto-optical imaging for high-throughput characterization of combinatorial magnetic thin films

X.R. Zhao[a,*], N. Okazaki[a], Y. Konishi[b], K. Akahane[b], Z. Kuang[c], T. Ishibashi[c], K. Sato[c], H. Koinuma[a,d], T. Hasegawa[a,e]

[a]National Institute for Materials Science, 1-1 Namiki Tsukuba, Ibaraki 305-0044, Japan
[b]Neoark Corporation, 2-8-33 Wakamatsu-cho, Fuchu, Tokyo 183-0005, Japan
[c]Department of Applied Physics, Faculty of Technology, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588, Japan
[d]Materials and Structures Laboratory, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama 226-8503, Japan
[e]Frontier Collaborative Research Center, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama 226-8503, Japan

Abstract

A new magneto-optical (MO) imaging system for high-throughput characterization of combinatorial magnetic thin films has been developed. The instrument allows us to measure both Faraday rotation and ellipticity maps at various wavelengths, and at different magnetic fields for wide variety of materials. We confirmed that the system possesses enough spatial resolution and sensitivity for detecting MO signals of individual pixels contained in a combinatorial library with a dimension of $<7\ \text{mm} \times 9\ \text{mm}$.

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Keywords: Magneto-optical imaging; Faraday rotation; Ellipticity; Magnetic circular dichroism (MCD); Combinatorial library; High-throughput characterization

1. Introduction

Information about magneto-optical (MO) properties is very important in many applications, such as biasing of ring lasers [1] and magneto-optical storage [2]. Moreover, recent dramatic improvements of MO characterization tools [3–7] have been stimulating new basic research, including studies of giant MO response of bismuth-substituted ferrite garnet films [8], domain formation in magnetic materials [9], flux penetration into superconductors [10], magnetic alloys [11], diluted magnetic semiconductors [12], and artificial superlattices [13,14]. However, high-throughput characterization of the MO properties of combinatorial libraries has scarcely been attempted so far [11] because it is needed not only to resolve μm scales in combinatorial libraries but also to evaluate them quantitatively.

In this paper, we present a new magneto-optical imaging system, suitable for fast measurements and

* Corresponding author. Tel.: +81-45-924-5876;
fax: +91-45-924-5876.
E-mail address: xrzhao@nano.fcrc.titech.ac.jp (X.R. Zhao).

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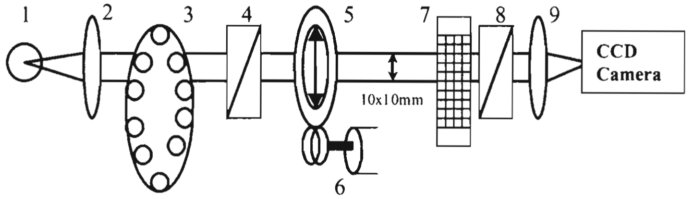

Fig. 1. Schematic drawing of the system. (1) Halogen lamp; (2) collimation lens; (3) color filters; (4) linear polarizer; (5) wave-plate; (6) digital motor; (7) combinatorial library and magnet; (8) analyzer; (9) focusing lens. The size of CCD chip is 6.72 mm × 8.96 mm, and the size of pixel on CCD chip is 14 μm × 14 μm.

quantitative data analyses of combinatorial libraries in thin film forms.

2. Experimental setup

The configurations of MO characterization systems reported so far can be classified into two categories, according to the condition of polarized light. One is based on a conventional optical microscope, which uses linearly polarized light in the transmission or reflection geometry to obtain a Faraday rotation angle or Kerr information, respectively. The other measures magnetic circular dichroism (MCD), using left and right circularly polarized light [15]. In principle, both types can provide identical information about MO properties. But the former is easer to map out the magnetic domain structure and Faraday and Kerr angles. The latter is suitable for studying electronic structures of magnetic materials, such as the field-induced modification of band structure, the Zeeman splitting and the critical points of the Brillouin zone. By carefully comparing the two configurations, we adopted the MCD type system, because it is relatively free from background signals arising from substrates. In addition, the system allows us to analyze the Faraday rotational angle very precisely by inserting an additional analyzer.

Fig. 1 is the schematic diagram of the present MO characterization system. Different wavelengths from 400 to 1000 nm can be used by selecting band-pass filters. Linearly polarized light passing through a polarizer is converted to circularly polarized one by a quarter wave-plate. In a ferromagnet, circularly polarized light waves with left and right rotation

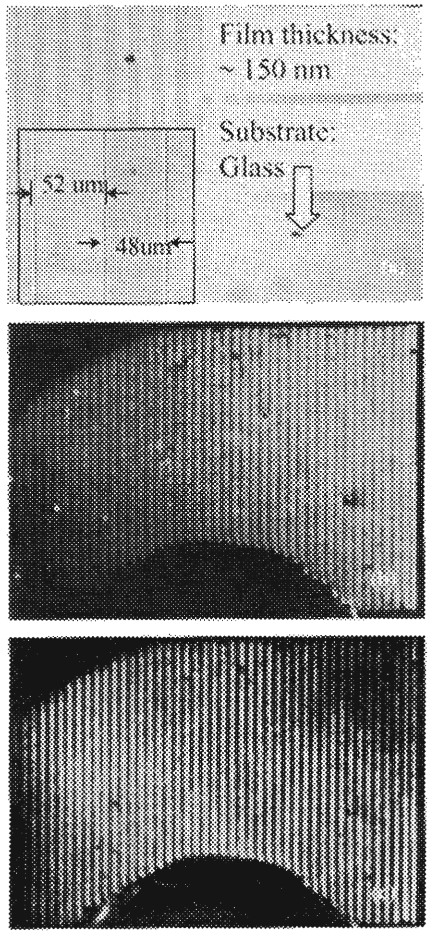

Fig. 2. MO images for a $Y_2BiFe_4GdO_{12}$ garnet thin film with perpendicular magnetization. (a) An optical microscopy image including sample information. The width and interval of the garnet stripe is 48 and 52 μm, respectively; (b) Faraday rotation map and (c) ellipticity map.

propagate, in general, with different velocities. As a consequence, the intensities of two transmitted light waves, I_L and I_R, differ with each other, which can be recorded by a CCD camera, shown in Fig. 1, separately. According to the Jones Matrix analysis [16], an ellipticity map is obtained as $(I_L - I_R)/(-8)$, while a map of the Faraday rotational angle can be calculated as $[I_P - (I_L + I_R)/2]/4$, by carefully adjusting the wave-plate to generate a linearly polarized light I_P.

3. Results and discussion

In order to evaluate the spatial resolution and sensitivity of this system, we prepared garnet thin films as standards by the spin coating method. Stripe patterns were fabricated on them by photoengraving. Typical MO images obtained for a $Y_2BiFe_4GdO_{12}$ garnet film with perpendicular magnetization is shown in Fig. 2, where a field of 30 G, close to the saturation field, was applied. A stripe with a width of 48 μm

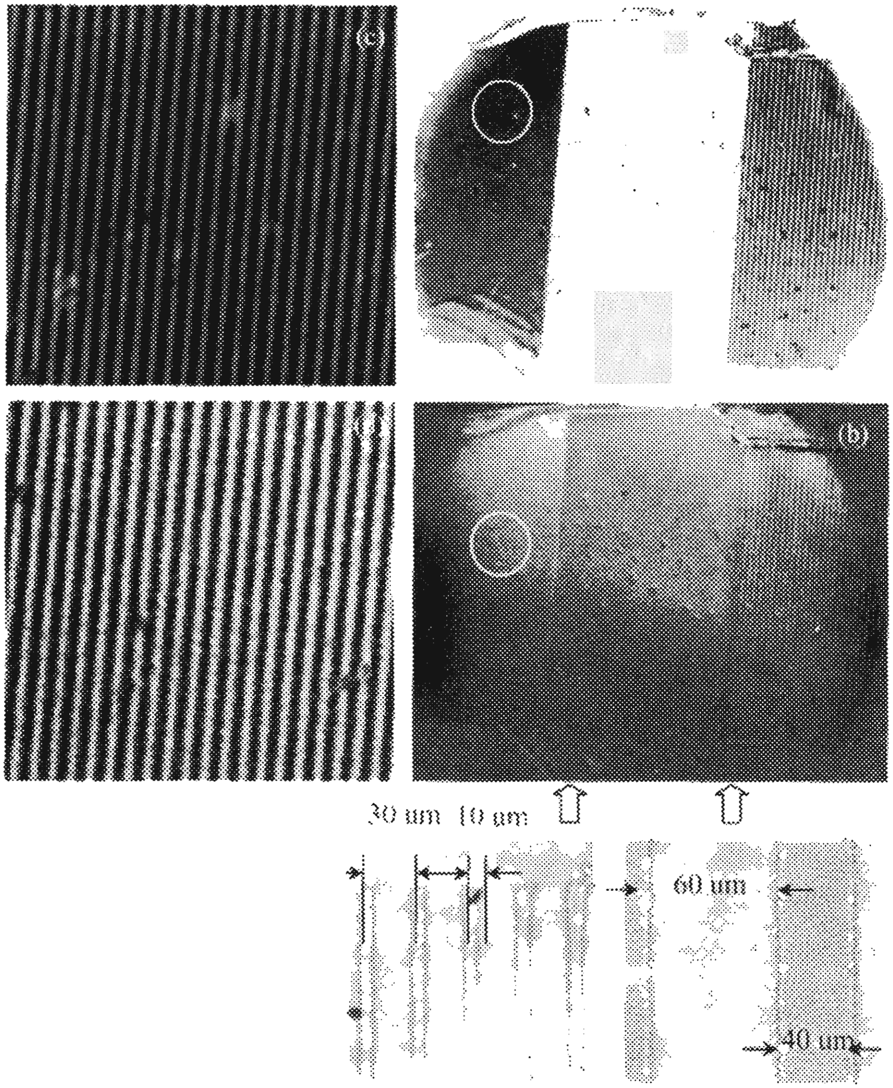

Fig. 3. MO images for a $Y_2BiFe_5O_{12}$ garnet thin film with in-plane magnetization. (a) Faraday rotation map; (b) ellipticity map; (c) and (d) are magnified images of circle regions marked in (a) and (b), respectively.

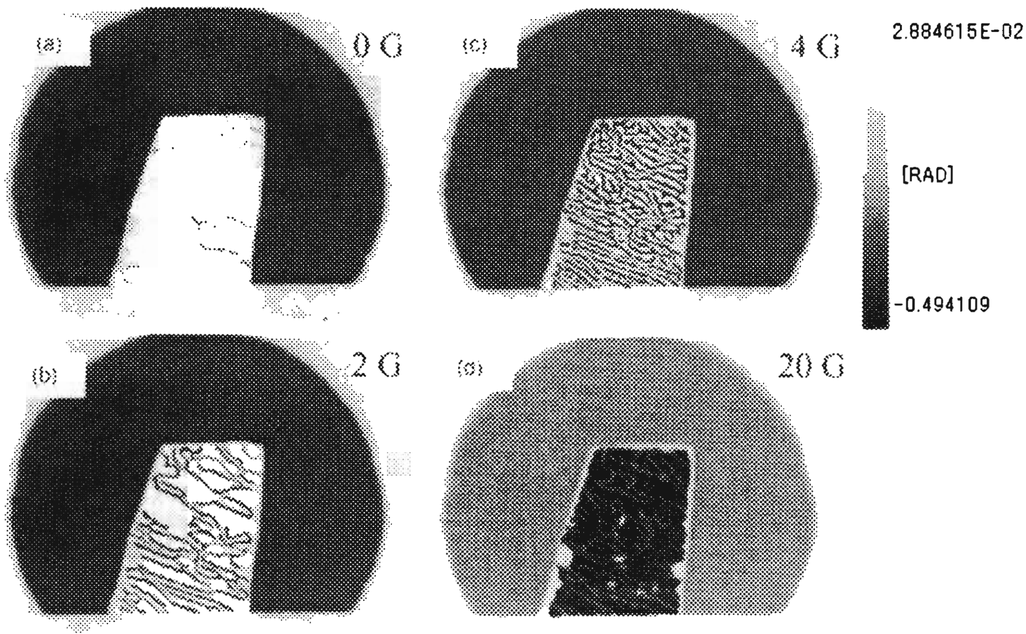

Fig. 4. Observation of domain structure in a Bi-doped garnet film under different magnetic fields.

and an interval of 52 μm are clearly discernible from both the Faraday rotation and ellipticity maps shown in Fig. 2b and c, respectively.

We performed similar experiments for a $Y_2BiFe_5O_{12}$ garnet thin film with in-plane magnetization, as shown in Fig. 3. Two kinds of patterns with different widths and intervals were photoengraved on one glass substrate. The sample information is indicated in the microscopy image at the bottom of Fig. 3. From the MO images in Fig. 3, a finer stripe with a width of 10 μm, located in the left parts of Fig. 3a and b, can not be resolved, because of the limited pixel size of our CCD camera, which is 14 μm × 14 μm. To improve the spatial resolution, we can set a zoom lens in front of the CCD camera. The resulting obtained MO images are shown in Fig. 3c and d, which clearly resolve the stripe pattern of 10 μm. From a series of experiments, we confirmed that the spatial resolution can be as high as 2–5 μm in the visible light range, which is generally enough for the characterization of combinatorial materials. Another important parameter of MO imaging is sensitivity. The sensitivities for the Faraday rotation angle and ellipticity are estimated to be 0.03–0.06°, which is sufficiently high for characterizing garnet-based materials.

Fig. 4 shows Faraday rotation images for a $Y_2BiFe_4GdO_{12}$ garnet film taken under various external fields. Evidently, the domain structure is varied by sweeping the magnetic field between ±30 G. We have succeeded in detecting a small change in the rotation angle, associated with slight increase/decrease of applied field by 0.1 G.

4. Summary

In summary, we have developed a new magneto-optical imaging instrument using the MCD modification technique, which is suitable for characterization of combinatorial magnetic films. This system allows us to measure both Faraday rotation and ellipticity maps at various wavelengths, and different magnetic fields. We also confirmed that the system possesses enough spatial resolution and sensitivity for detecting MO signals of individual pixels in garnet-based combinatorial libraries with a dimension up to 6.72 mm × 8.96 mm.

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