Morphology of garnet films for thermo-magnetic recording

V Berzhansky¹, Y Danishevskaya¹,², A Nedviga¹, M Bektemirova¹
¹Institute of Physics and Technology, V. I. Vernadsky Crimean Federal University, Simferopol 295007, Russia
²Crimean University of Culture, Art and Tourism, Simferopol 295017, Russia

Abstract. The work deals with the investigation of sensitivity of epitaxial garnet films for thermo-magnetic recording. The spatial resolution of replicas of inhomogeneous fields was associated with the morphological features of the films. Surface morphology of the intense epitaxial films was studied by optical methods and atomic force microscopy. It was shown that the changes in the block structure with an increase in the mismatch between the film-substrate constants occur.

1. Introduction

Uniaxial anisotropy high-coercive garnet films (GF) are an optimal media for thermo-magnetic recording by laser beams or contact printing [1]. For example, contact printing magneto-optic (MO) films were used [2] for criminalistics examinations of magnetic recordings. For these purposes the films had a low Curie temperature (T_C < 100°C). The effective technological way to increase coercivity H_c is to make strains by increasing mismatch Δa = (a_f – a_s) between crystalline lattices of film a_f and substrate a_s. Stresses are proportional to the mismatch and networks of misfit dislocations are formed usually to relieve them [3].

2. High-Coercive Garnet Films Synthesis

The films of composition (Bi,Lu,Sm,Ca)(Fe,Ga,Al,Sc,Zr)₃O₁₂ were investigated. The films were synthesized by liquid-phase epitaxy on substrates Gd₃Ga₅O₁₂ with crystallographic orientation (111) and thickness 0.6 mm. The crystal lattice parameter of all applied substrates was standard (a_s = 12.383 Å). The thickness of the initial epitaxial layer was h = 4-7 μm. According to the results of the X-ray diffraction analysis, the absolute mismatch of the crystal constants was within the limits of Δa = a_f–a_s = 0.040 – 0.113 Å corresponded to the relative mismatch of f = 0.3-0.9%. Samples after epitaxy were polished by an Al₂O₃ abrasive of fraction 1/0. Some of them were polished to get a wedge.

3. Magnetic and Morphology Properties of the Films

All samples have a block structure that forms a kind of mosaic with an element of the order of 1-5 μm in size (Fig. 1). The stress distribution is obtained in images of a polarization-optical microscope with a phase-contrast objective. Stresses are seen on the cross section of the film in reflected light (differential interference-contrast microscopy).
Figure 1 (a, b). Domain structure and stress in the film. Phase contrast microscopy (a). The cross section of the film. Differential interference-contrast microscopy (b).

The dimensions of the blocks have a dependence on the value $\Delta a$ (Fig. 2, Fig. 3). We assume that such a block structure affects the sensitivity and spatial resolution of the magneto-optical converter.

Figure 2 (a, b, c, d). Surfaces of samples with $\Delta a : 0.074 \, \text{Å} \, (a)$, $0.089 \, \text{Å} \, (b)$, $0.099 \, \text{Å} \, (c)$ and $0.102 \, \text{Å} \, (d)$. Optical Microscopy.

Figure 3 (a, b, c, d). Surfaces of samples with $\Delta a : 0.074 \, \text{Å} \, (a)$, $0.089 \, \text{Å} \, (b)$, $0.099 \, \text{Å} \, (c)$ and $0.102 \, \text{Å} \, (d)$. Atomic Force Microscopy.

The existing of two types of domain structure (DS) (i.e. hysteresis) is a standard property of strained GF [4,5]. Magneto-optical images of two types DS are obtained after demagnetizing of the same film’s area by variable magnetic field (stable DS) and heating up to $T > T_c$ (meta-stable one).
Figure 4 (a, b). Magnetooptical images of two types DS. Stable DS (a), meta-stable DS (b).

Images of the films were registered (Fig. 5) with the help of polarization microscopy in crossed polarizers. These images are showed the distribution of internal stresses in films with different $\Delta a$ and the domain boundaries in the form of black curve. It is seen that the contrast of stresses image in the films is increased with increasing $\Delta a$. Domain boundaries are torn at places of strong stress contrast.

Figure 5 (a, b, c, d). Domain walls and stress in the films after demagnetization by heating up to $T > T_C$ (samples with $\Delta a : 0.074 \text{ Å} \ (a), 0.089 \text{ Å} \ (b), 0.099 \text{ Å} \ (c)$ and $0.102 \text{ Å} \ (d)$). Polarization microscope (polarizers crossed).

It is possible to use these films for contact printing due to the existence of a metastable domain structure. The film and magnetic recording media are pressed and heated to the Curie point of the film. Then the system cools down. As a result, we have a copy of the signal on the ferrite-garnet film.

To investigate the sensitivity of epitaxial garnet films for thermo-magnetic recording, records of signals with spatial periods from 150 to 1.9 $\mu$m were used. The amplitude of the residual magnetization is varied within more than 60 dB. Thus, a sequence was formed on the carrier consisting of at least 11 differently magnetized sections – wave packets with free (demagnetized) gaps.

Figure 6 (a, b). Thermomagnetic replicas (a) and intensity profiles for recording period of 15 $\mu$m (b). Amplitude of the field increases from right to left.
Copies of both "complete" and "incomplete" replicas are actually observed. It is advisable to analyze the ratio of the number of the first to the number of the second (or vice versa). If this ratio is the lower, then the sensitivity of the sample to the field at a given spatial frequency is lower.

The sensitivity of the film was calculated by counting the number of $N_r$ packets reproduced by the film in the form of complete replicas, as well as the total number of observed $N_v$ packets. As a result, the signal with a period of 5.95 $\mu$m is best copied. Signals with periods of 1.98 $\mu$m, 2.06 $\mu$m, 3.6 $\mu$m are copied well with films with $\Delta a = 0.098$ Å.

The spatial resolution of thermal replicas of magnetic records is limited by the dimensions of the segments of the block structure of the films. As a result, the sensitivity of the magneto-optical converter is lost in replicas of signals with periods 1-2 $\mu$m. Areas of concentration of dislocations are nonmagnetic regions. Replica of the magnetic field of the information carrier takes the form of a curved or discontinuous line.

4. Conclusions
It has been established that all samples have a block structure that forms a kind of mosaic with an element of the order of 1-5 $\mu$m in size. The dimensions of the blocks have a dependence on the value $\Delta a$. We assume that such a block structure affects the sensitivity and spatial resolution of the magneto-optical converter. Therefore, samples with $\Delta a > 0.099$ Å with large segments are not appropriate for replication purposes.

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