Magnetic-force microscopy of thin Bi:IG films for thermomagnetic recording

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Abstract. Thermomagnetic recording on thin films is currently one of the most promising methods for copying records with high density and weak magnetization. These films can be characterized by a couple of parameters very suitable for recording reconfigurable magnetic atomic traps whose geometry is visible. Different types of materials are investigated to be the most effective for thermomagnetic recording propose. In this paper authors showed possibility and features of thermomagnetic recording on Bi:IG thin films. High coercivity thin films with low Curie temperature and different film-lattice mismatch parameters were synthesized. Thermomagnetic recording of magnetic disc was performed. Features of magnetic records were investigated and influence of film-lattice mismatch parameters on meta-stable domain structure that defines the thermomagnetic recording resolution was showed. Magnetic-force microscopy was used for topography and magnetic structure characterization of thin films with different film-lattice mismatch parameters. Some features of films morphology were investigated using atomic-force microscopy with sharp AFM probe.

1. Introduction
Thermomagnetic recording on thin films is currently one of the most promising methods for copying records with high density and weak magnetization [1-3]. In addition, Heat Assisted Magnetic Recording is one of the most perspective technology for high density storage devices [4]. These facts drive to high interest of different type materials investigation in order to possibilities and features of thermomagnetic recording on these objects. Iron garnet thin films is one the most perspective materials for thermomagnetic recording in order to possibility creation high coercivity and low Curie temperature thin films which is important for thermomagnetic recording [5]. Development high coercivity thin films with low Curie temperature and its morphology and domain structure investigation by magnetic force microscopy [6] is important for understanding possibility and features of using this material for thermomagnetic recording.

2. Experimental
One of the most effective method for increasing the coercivity in an YIG thin films is the creation of misfit stresses between the film-substrate crystal lattices. In this case, both elastic stresses and plastic deformation are realized. Stress relaxation mechanism caused by misfit dislocations. The morphology
of the samples after epitaxy and the type of domain structure determined by so called “facet” surface’s structure [6]. Thin films with composition of (Sm,Lu,Bi)₃(Fe,Ga,Al,Sc)₅O₁₂ were synthesized by liquid phase epitaxy technique [7], [8]. Substrates of gadolinium gallium garnet with lattice parameter of 12.383 Å were used. Film-substrate lattice mismatch parameter Δa of different films was in the range of 0.070 – 0.113 Å. Curie temperature and the thickness of films varied in the range of 55 – 90°C and 3 – 7 μm, respectively. Topography of thin film (Δa=0,087 Å) with its original magnetic structure are showed in figure 1. Topography of polished thin film and its magnetic domain structure from same area are shown. Opposite domains have bright and dark color correspondently (figure 1b).

**Figure 1 (a, b).** Topography of polished thin film (a) and its original magnetic structure from same area (b). Scan size is 50x50 μm.

Thermomagnetic recording of magnetic disc was performed by heating the films in contact with disc up to 100°C and then cooling down to ambient temperature. Original domain structure of thin films as well as recorded domain structure was obtained by magnetic-force microscopy and compared to domain structure of the disc (figure 2).

**Figure 2 (a, b, c).** MFM image of original magnetic structure of the disc (a) and recorded magnetic structure to the thin film (b, c).

It was shown that the recorded magnetic structure has smooth borders compare to original one. The reason of this shiftiness is that the thin film has mismatch dislocation substructure which is appeared during the epitaxy growth (figure 3, a). Domains border goes strictly on the corresponding dislocation line. The shiftiness of recorded magnetic structure is ± 0.4 μm. Authors performed investigation of influence of film-lattice mismatch parameter on the metastable domain’s size (figure 3, b and c).
Figure 3 (a, b, c). (a) Morphology of film with $\Delta a = 0.096$ Å after polishing and selective etching HNO$_3$ during 10 min; metastable domain structure of films with $\Delta a = 0.089$ Å (b) and 0.099 Å (c).

Figure 4 (a, b). Dependence of domain structure period (a) and coercive force $H_C$ (b) on film-lattice mismatch parameter.

It was shown in figure 4 that domain structure period on film-lattice mismatch parameter dependence has the minimum in the range of 0.085 – 0.105 Å. The period of domain structure of similar coercive samples was measured using optical microscopy with frames of about 125 x 125 μm [9]. The data of magnetic force microscopy taking into account the measurement errors for synthesized samples repeat the original dependence in the studied range. Period of domain structure showed good correlations with dependence of average defects’ heights defined as average roughness on mismatch parameters showed in figure 5 (a). Simultaneously, we observe a change in the distribution of defects’ density (triangular elements) on the surface (figure 5, b). The most density packing of surface triangular elements is observed for the films with film-lattice mismatch parameter in the range of 0.084 – 0.099 Å. Average roughness and number of defects were determined for each film as medium value in the area of 15 x 15 μm by magnetic-force microscopy or atomic-force microscopy data. The films with the smallest elements of surface and domain period are characterized by the highest $H_C$ among all the studied samples (figure 4, b) [10], which makes this range of film-lattice mismatch parameter the most suitable for thermomagnetic recording.
3. Conclusion
Spatial resolution of thermomagnetic recording is limited by dislocation substructure which is corresponded to film-lattice mismatch parameter. It was shown that microscale epitaxial high-coercive \( \text{Bi:IG} \) films with \( \Delta a \) in the range from 0.084 to 0.099 Å have the smallest period of metastable domain structure and highest Hc that makes them optimal for thermomagnetic recording.

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