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CREATION AND OBSERVATION OF DOMAIN STRUCTURES WITH A SPECIAL KERR MICROSCOPE

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A Kerr microscope is presented, which on the one hand allows us to make, in a conventional manner, images of domains in thin films with perpendicular magnetic anisotropy. On the other hand, it is possible to heat the sample locally by a focussed laser beam and make images simultaneously. Therefore, it is possible to write domains thermomagnetically and further to observe temperature dependent magnetic reorientations. For demonstration domains have been created thermomagnetically in TbFe multilayers. Writing with low magnetic field leads to domains with a subdomain structure, as it has been found previously by Lorentz microscopy.

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1. Introduction

TbFe multilayers with $\lambda(= d_{\mathrm{Tb}} + d_{\mathrm{Fe}}) < 3$ nm show a ferrimagnetic behavior and a perpendicular easy axis of magnetization similar to the amorphous TbFe alloy films [1–3]. Hence, these films are candidates for magneto-optical storage media. To prove the capability for this purpose it is necessary to investigate domain structures and to create domains thermomagnetically [4]. It has been observed that the type of domains in TbFe or TbFeCo alloy films depends strongly on the terbium concentration C_{Tb} [5, 6]. Recently there has been also some research on the domain structures of TbFe multilayers, which seem to be similar to the structures in alloy films [7]. In this study we will show both, natural domain structures in TbFe multilayers for different Tb concentrations and domain structures which have been created thermomagnetically.

2. Kerr microscope with writing laser

A Kerr microscope has been built up, which on the one hand allows us to make images of domains in thin films with perpendicular magnetic anisotropy.

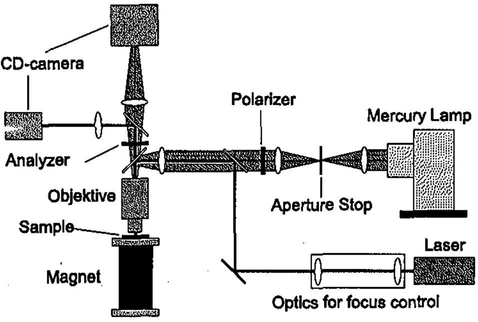

Fig. 1. Kerr microscope with writing laser.

On the other hand, it is possible to heat the sample locally by a focussed laser beam and make images simultaneously. As shown in Fig. 1 the microscope works like a conventional Kerr microscope using the polar magneto-optical Kerr effect as described by Kranz and Hubert [8]. As infinity corrected objectives are used, a tube lens is necessary to create the intermediate image. At this position the ccd-array of a high performance digital ccd-camera is placed, so that images with a resolution of 16 bit are obtained by one exposure. Working with a microscope objective with a numerical aperture of $NA = 0.85$ and taking the wavelength of 546 nm the resolution is limited to 400 nm. The beam of a diode laser with 780 nm, 40 mW and modulation capability up to 1 MHz is coupled into the path of rays. The laser beam is focussed onto the sample by the microscope objective with a minimum diameter of $\doteq 1$ μm. In order to control the position of the laser spot on the sample and not to disturb the image of the domain structure the laser beam which is reflected from the sample is separated from the illuminating light by a wavelength depending beam splitter and can be focussed on a second ccd-camera.

3. Natural and artificial domain structures in TbFe multilayers

3.1. Structural and magnetic properties of the TbFe multilayers

TbFe multilayers have been produced by using a face-to-face dc sputtering equipment as described in Ref. [9]. In between each pair of targets a plasma is started and the glass substrate is alternately moved to the terbium and iron targets. After deposition of the last iron layer a SiN layer ($\doteq$70 nm) is sputtered as a protective layer. The sublayer thicknesses of terbium and iron are about 0.8 and 1 nm and the number of repetitions is 50 resulting in a modulation wavelength λ of 1.8 nm and a total thickness of 90 nm. By means of small-angle X-ray diffraction the multilayer structure could be confirmed and the values of λ could be determined with a high accuracy. The magnetic properties of the multilayers have been investigated by vibrating sample magnetometry at room temperature and perpendicular magnetization was found in all samples. The compensation temperature for a terbium concentration of 23% is near room temperature and therefore the coercivity rises from 400 Oe to 4000 Oe if one approaches the compensation concentration from lower or higher values.

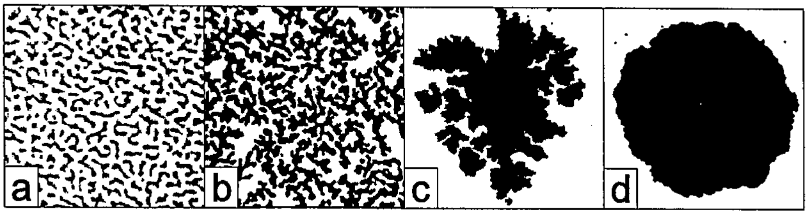

Fig. 2. Domain structures in TbFe multilayers: (a) $C_{\mathrm{Tb}} = 24.4\%$, $H_c = 490$ Oe, (b) $C_{\mathrm{Tb}} = 24.2\%$, $H_c = 850$ Oe, (c) $C_{\mathrm{Tb}} = 23.8\%$, $H_c = 1140$ Oe, (d) $C_{\mathrm{Tb}} = 23.6\%$, $H_c = 1780$ Oe. The field of view is 25 μm × 25 μm in (a) and 50 μm × 50 μm in cases (b)–(d).

Kerr microscopy studies show that films with a Tb concentration $C_{\mathrm{Tb}} = 21$ or 24.4% have domains of stripe type as shown in Fig. 2a. Near to the compensation concentration $C_{\mathrm{Tb,comp}}$ the domain structure becomes broader (Fig. 2b, c). Close to $C_{\mathrm{Tb,comp}}$ the domains grow nearly circular (Fig. 2d). These results are in good agreement with the investigations of Lanchava and Hoffmann [7]. Qualitatively these domain structures result from the competition between magnetostatic energy, which depends strongly on M_s and therefore from C_{Tb}, and domain wall energy σ_{w} during magnetization reversal. However, it has to be noticed that due to the high coercivity no equilibrium structures are present in zero field and different types of domains can be created and frozen. One example will be given in the next section.

3.2. Artificial domain structures

A TbFe multilayer with $C_{\mathrm{Tb}} = 23.6\%$ and a coercivity of 1780 Oe has been chosen for the writing of domains because this sample shows nearly circular domain structures during magnetization reversal (Fig. 2d). Domains have been written thermomagnetically with a maximum laser power of 0.74 mW (measured with a photodiode at the position of the sample), 10 μsec pulse duration and different bias fields. If small bias fields are used ($\ll H_c$) the growth process is finished in 1 μsec and the size of domains is defined by the temperature distribution in the film [10]. The resulting domain images are shown in Fig. 3a–d. It can be

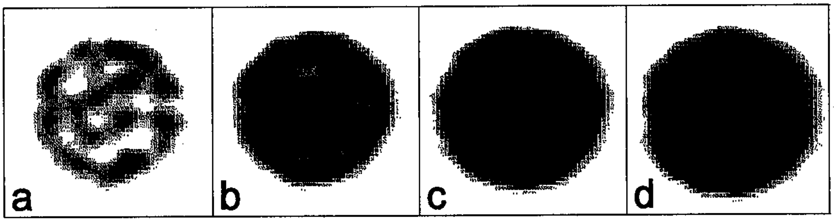

Fig. 3. Thermomagnetic written domains with different bias fields: (a) $H = 0$ Oe, (b) $H = 100$ Oe, (c) $H = 170$ Oe, (d) $H = 250$ Oe. The field of view is 6 μm×6 μm in all cases.

seen that domain structures with subdomains have been created for fields smaller than 250 Oe like those which have been found by Lorentz microscopy in TbFe alloy films in a smaller scale [11]. The reason for the subdomain structure is that the magnetic properties M_s, K_u, H_c, and σ_w change with rising temperature. Near to the Curie temperature the magnetostatic energy overcomes the domain wall energy and favors a "demagnetized state". During cooling this structure is frozen and at room temperature it is stabilized by the high coercive field. Hence, the subdomain structure displays a high temperature equilibrium state, which is completely different from the domain structure during magnetization reversal.

4. Domain observations in GdFeCo/TbFeCo double layers

Recently we have studied GdFeCo/TbFeCo double layers, where the GdFeCo layer shows a temperature dependent magnetization reorientation from in-plane to perpendicular. These layers can be useful for magneto-optical storage with magnetically induced superresolution [12]. Although the optical resolution of the microscope is limited to 400 nm, the physical principle of temperature dependent apertures in double layers can be investigated. The detailed results of these experiments will be published elsewhere.

5. Conclusions and outlook

We have demonstrated that a laser beam assisted Kerr microscopy is very useful for the investigation of new film systems for magneto-optical recording, e.g. TbFe multilayers. It is possible to write domains thermomagnetically and to find appropriate conditions for stable and saturated domains. Further, temperature dependent magnetic reorientations in double layer structures can be investigated.

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