Investigation of strain-induced magnetization change in ferromagnetic microparticles

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Abstract. This work is devoted to investigation of magnetoelastic strain effect on the ferromagnetic microparticles of permalloy. An original method of sample fabrication with compressed microparticles is proposed. Magnetic force microscopy and magneto-optical Kerr experiments were carried out with unstrained and compressed microparticles. The domain walls transformation in compressed microparticles is in good agreement with numerical calculations. Hard axis of magnetization was observed on the compressed sample.

1. Introduction

Studying of the remagnetization processes caused by the magnetoelastic effect has a big interest because of ability to manage the magnetization by an electric field [1]. It is caused by the demand of increasing data density of magnetic media, speeding up the read-write operations and reliability of the storage. The transition to recording information by electric field is mainly interesting because a very low energy is required for recording a bit of information (about 0.5fJ). This is several orders lower than for other known methods of information recording [2]. This method is called MERAM – magnetoelectric random access memory. For example, if one can deposit a magnetic layer (a continuous film or particles) on the surface of a piezoelectric material, then applying an electric field may cause mechanical deformation and change the magnetic state of the upper layer [3]. Inducing mechanical stresses in the magnetic structures is also possible by depositing it on pre-curved elastic substrates. After substrate straightening mechanical stress occurs and uniaxial anisotropy is induced [4].

In this work the changes of the magnetization structure and coercive properties of permalloy microparticles under elastic mechanical stresses are studied by magnetic force microscopy (MFM) and magneto-optical Kerr-effect (MOKE).

2. Results and Discussion

In this paper a magnetoelastic phenomenon of an aligned ensemble of permalloy ($Ni_{75}Fe_{25}$) microparticles with size 22×22×0.03 mkm^3 detached from each other on 10 mkm is studied. The elastic tension is created by a method described in [4]. Two types of samples were fabricated (figure 1). For the samples of the first type, a metal grid with square holes of 22×22 mkm^2 was placed on the flat (not curved) glass substrate (figure 1c). For the samples of the second type the metal grid was placed on the curved surface of the substrate. The bending was carried out by placing the metal wire with diameter of 80 mkm under the substrate and fixing the edges of the substrate by holders. The permalloy (Py) layer with 30 nm thickness was simultaneously deposited on both samples in ultrahigh vacuum by “Multiprobe P” device (Omicron). After ending of the deposition the samples were extracted from the holders in the atmosphere conditions. It is obvious that the Py microparticles experienced a uniaxial compressive strain after straightening the substrate in the samples of the second type. The image of the part of the structure obtained by an atomic force microscope Solver P47 Pro (NT-MDT) is shown in figure 1d.

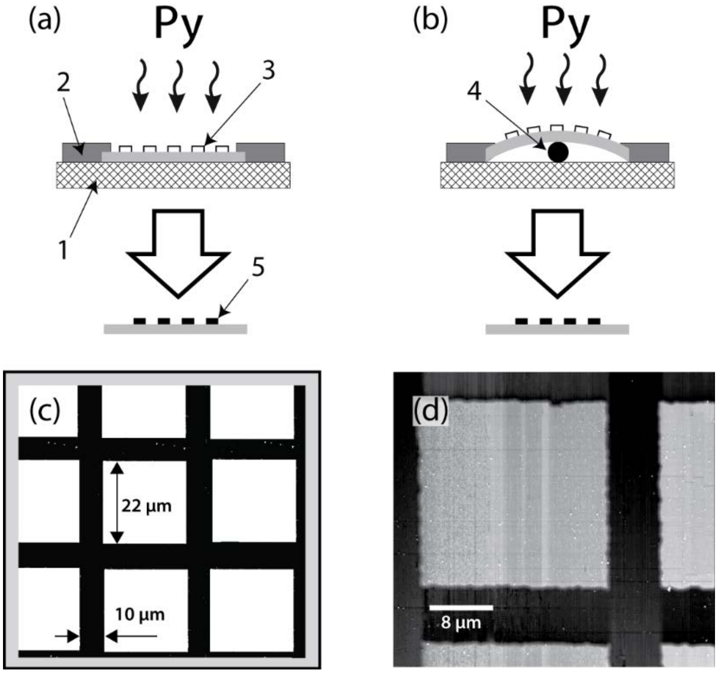

Figure 1. a – scheme of fixing lithographic mask (metal grid) on the original (flat) substrate; b – scheme of fixing lithographic masks on the curved substrate; c – scheme of lithographic mask; d – AFM-image of planar structure of the Py microparticles. 1 – base; 2 – holders; 3 – metal grid; 4 – microwire; 5 – Py microparticles.

The changes of the magnetization structure induced by mechanical stresses have been studied by Solver P47 Pro in MFM mode. The MFM-image of Py microparticles at the initial state has a typical structure for permalloy particles of this size and shape and shows the presence of four domains of the same shape, separated by cross-like domain walls (figure 2a). Under the compression, the domain walls in a particle are deformed and a characteristic bridge at the center of the particle appears (figure 2b). In order to compare the MFM-images with the magnetization distribution in the particle a computer modeling program OOMMF [5] was used. It is based on the numerical solution of the Landau-Lifshitz-Gilbert equation, corresponding to the distribution of local magnetic moments with a minimum total energy. In the simulation, the size of the particle was fixed and the saturation magnetization (M_0), and magnetoelastic anisotropy (H_k) was varied. After that, using the calculated magnetization distribution the MFM-image was simulated (by computer program “Virtual MFM” [6] developed in our laboratory) and compared with the experimental MFM-image (figure 2a,b).

Simulated MFM-images closest to experiment were obtained at H_k = 7 Oe, M_0 = 889 Oe for the sample of the first type (uncompressed) and H_k = 42 Oe, M_0 = 895 Oe for the sample of second type (compressed). The same parameters were experimentally obtained for the same samples from an analysis of the angular dependence of the spectra of ferromagnetic resonance (FMR) [7]. In our

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opinion, a nonzero value of H_k for the sample of the first type is caused of minor residual stresses arising during the deposition. Figure 2 shows good agreement between the experimental and modeling MFM-images.

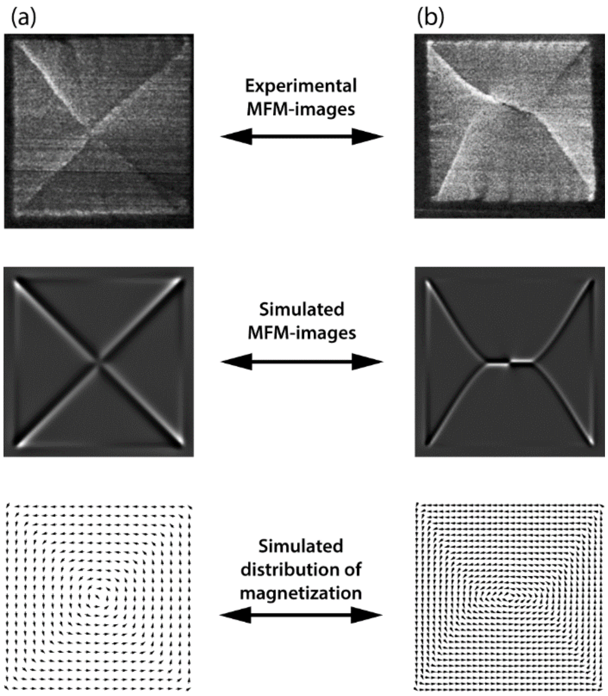

Figure 2. The experimental and simulated MFM-images and distribution of magnetization of Py microparticle in the unstrained (a) and compressed (b) states.

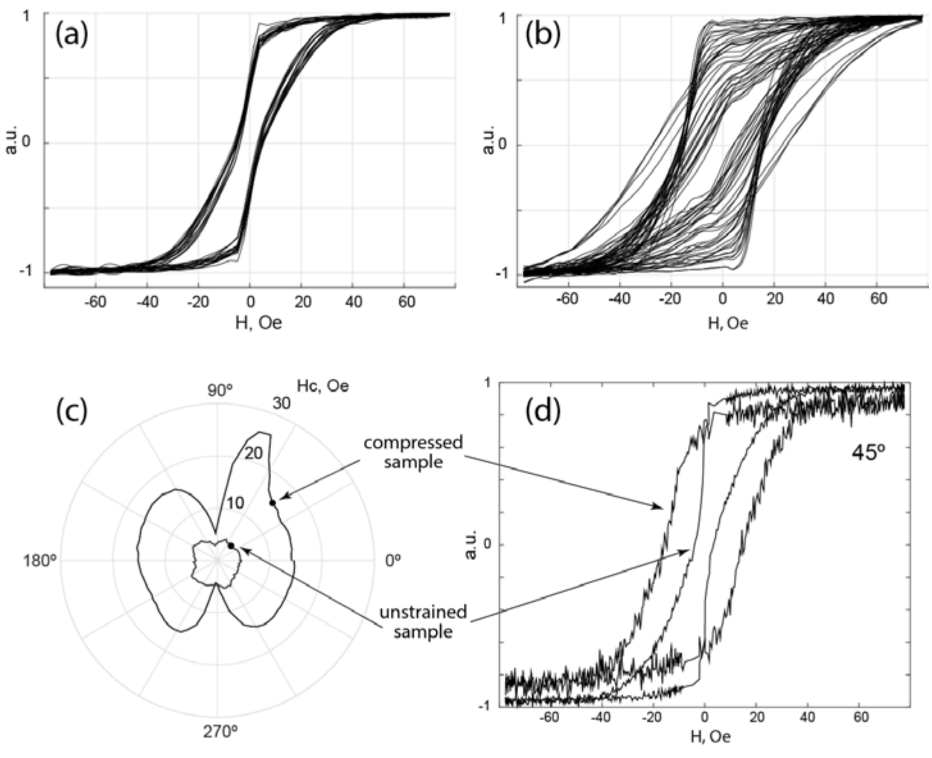

Figure 3. MOKE experiments. The hysteresis loops of Py microparticles obtained at different azimuthal angles for the relaxed (a) and compressed (b) samples. c – the angular dependence for coercivity force of unstrained and

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compressed microparticles; d – the selected hysteresis loops for angle 45 deg.

The influence of uniaxial compression on the magnetic structure of microparticles was investigated by scanning polarimetry device, based on the ellipsometer. The device is based on magneto-optical Kerr effect (MOKE) and allows to register hysteresis loops (from -100 Oe to +100 Oe) at different azimuthal angles between magnetic field and sample. In figure 3 the hysteresis loops of the samples of the first and second types under different azimuthal angles (i.e rotation takes place in the plane of the substrate) and the angular dependences of coercivity force (H_c) are shown. From these dependencies, one can see that due to the magnetoelastic effect the sample with microparticles under compression has a preferred direction (figure 3c) and H_c varies from 7 to 25 Oe. The sample has a hard axis of magnetization because magnetization saturation exceeds 70 Oe along the selected direction (figure 3b).

3. Conclusion

By the analysis of experimental data, one can see that significant changes the magnetic properties of Py microparticles under mechanical stress appeared due to magnetoelastic effect. The changes of four-domain magnetic structure registered by MFM and MOKE data demonstrate the strong angular dependence of coercivity force and magnetization saturation.

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