In situ MFM Investigation of Magnetization Reversal in Co Patterned Microstructures

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Cobalt patterns were formed on the HOPG surface by vacuum evaporation method with mask system utilization. Their geometric and magnetic properties were investigated by the scanning probe microscopy method. Samples with the pattern thickness ranging between 40 and 200 nm were obtained. The patterns had planar shape about 25 μm in length. The observed length-to-width ratio for the patterns was from 1.5 up to 12. Coercivity of the patterns in the surface direction was found to depend on the pattern height and lateral sizes. In zero magnetic field the stripe magnetic domain structure of magnetization was observed in wire-like patterns with length-to-width ratio of about 10 and more.

1. Introduction

Magnetic structures of submicron sizes such as magnetic nanoparticles or ultrathin magnetic films have unique properties: the specific magnetization distributions such as vortex and monodomain structures of the magnetization, the magnetization reversal behavior and some others effects are typical of them. A special attention is devoted to surface magnetic nanostructures based on metals of iron chemical group (Ni, Co, Fe) because they usually demonstrate extraordinary ferromagnetic features. Thus they can be viewed as potential candidates for the basis of novel materials for high density magnetic storage media [1] or for new memory chips [2]. Besides, the study of such objects may help to solve some difficult problems in the micromagnetism theory and make an essential contribution to physics of magnetic phenomena. That is why the magnetic micro- and nanostructures attract a great interest of different researchers and investigators.

The methods of scanning probe microscopy have often been used to study the surface structures with small sizes for several last years because of their potential ability to get different information about the investigated surface with high resolution and sensitivity [3]. The magnetic force microscopy (MFM) has a

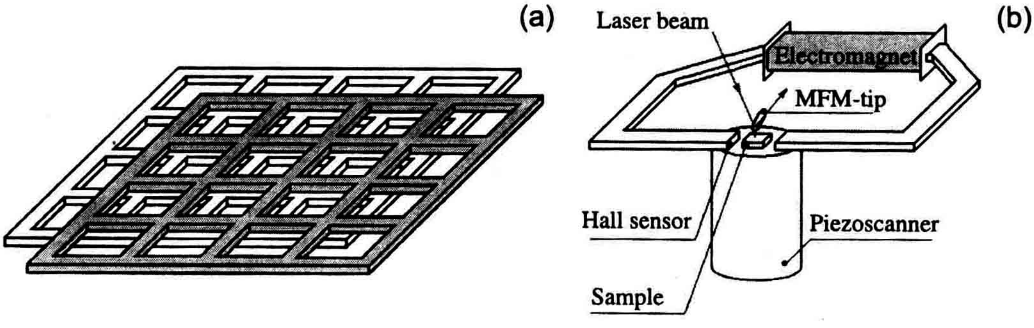

Figure 1. (a) System of two intersecting masks used to pattern the evaporated film. (b) Scheme of the electromagnet mounted into the microscope.

great potential for investigation of magnetic properties of solid-surface structures with rather high resolution and sensitivity. Application of external field in the MFM experiments (*in situ* experiments) can give qualitatively more interesting information about the magnetic reversal properties of the single surface structure of the investigated sample [4].

This paper presents the results of MFM investigation of magnetic properties of cobalt micron planar patterns formed on HOPG surface by the vacuum evaporation method with mask system utilization.

2. Experimental

The vacuum evaporation method was used to obtain the sample with Co planar patterns. The cobalt films were formed on the HOPG surface in a vacuum chamber by heating and vaporizing the cobalt powder. A film was patterned by a system of intersected masks placed over the HOPG surface during evaporation (Fig. 1(a)). The mask hole element size was about of 25×25 μm^2. The planar size and the shape of the patterns were set by the ratio of the mask intersection and were determined by atomic force microscopy (AFM) experiments. The variation of the mass of the evaporated cobalt powder allowed us to obtain the samples with different pattern heights.

A commercial scanning probe microscope Solver-P47 (Nanotechnology-MDT, Russia) and commercial magnetic cantilevers (Silicon-MDT, Russia) with 50 nm cobalt coating were used in the experiments. The "lifting" mode was used to obtain both the topography and the magnetic images from the same area of a sample. MFM-images included the information about cantilever oscillation phase shift (φ) due to magnetic interactions with the magnetic stray field from

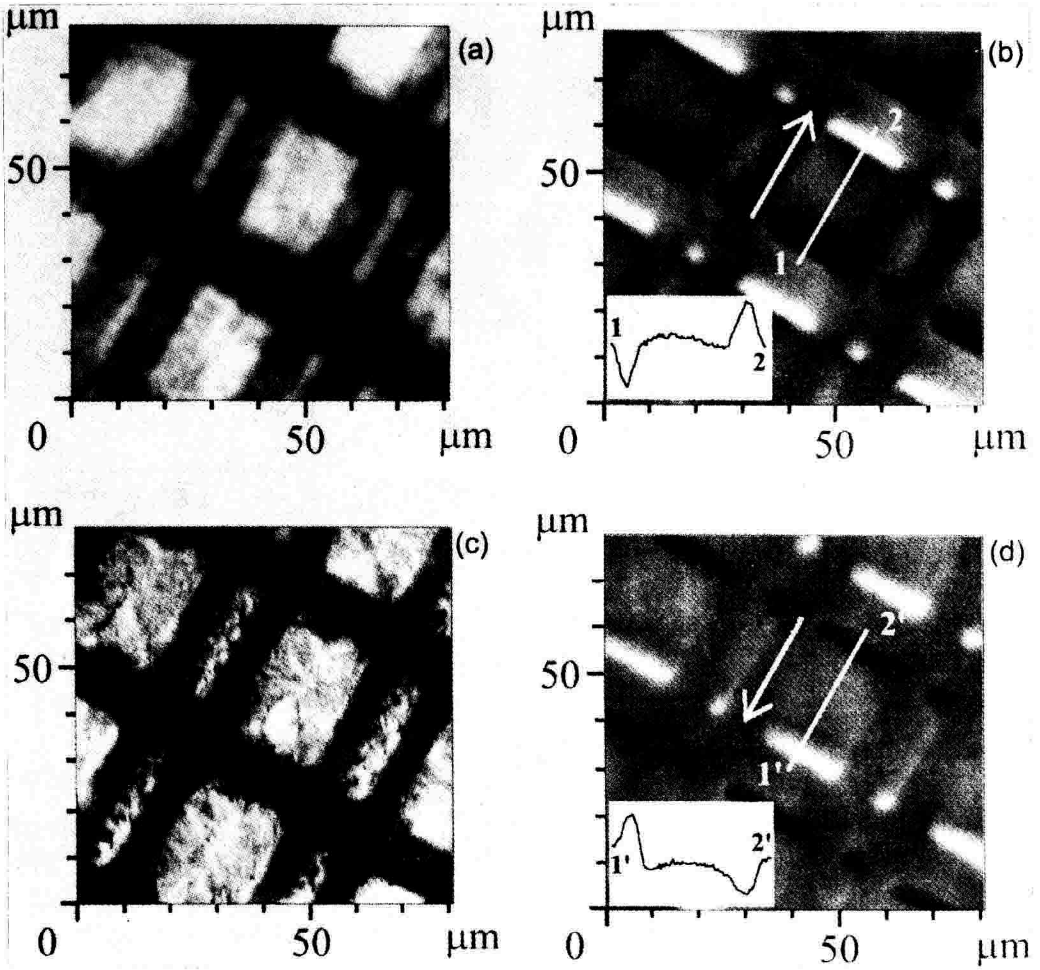

Figure 2. MFM investigation of magnetization reversal of the Co planar patterns in the external magnetic field with different magnitudes and directions. (a) Topography of the surface area of the sample with Co planar patterns 50 nm in height; (b), (c), (d) MFM-images of the same sample area in the external magnetic field of 300 Oe, 0 Oe, and −300 Oe, respectively; arrows show the field direction. The profiles of the MFM-image across the lines 1–2 and 1′–2' are presented in the insets in panels (b) and (d).

the sample surface structures [5]. The MFM tip was preliminary magnetized along its symmetry axis in a strong magnetic field higher than 2000 Oe. The samples were grounded during experiments in order to to avoid electrostatic effects. A home-made electromagnet mounted into the microscope was used to

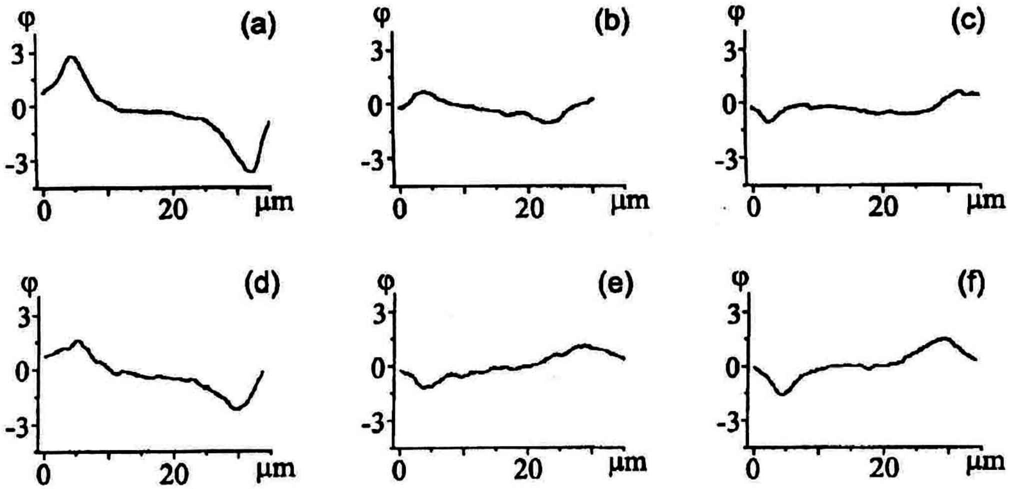

Figure 3. MFM-contrast profiles of two patterns with the thickness of about 150 nm. The pattern length-to-width ratio was about 2 for (a), (b), (c), and about 10 for (d), (e), (f). The magnitude of the external field was +40 Oe ((a), (d)); −40 Oe ((b), (e)); −50 Oe ((c),(f)).

produce the additional external magnetic field with the magnitude that could be controlled by the Hall detector and managed by a special system of the electromagnet delivery (Fig. 1(b)). This field was oriented along the sample surface and its strength could be changed from +500 Oe to −500 Oe. The MFM experiments with magnetic hard materials (similar to those performed in [4]) demonstrated that the applied magnetic cantilevers had rather small coercivity. So only a narrow enough range of the field magnitudes from +300 Oe to −300 Oe could be used in order to neglect the MFM-tip effect on the sample magnetization structure.

3. Results and Discussion

A series of the samples with cobalt planar patterns with different geometric parameters were formed. The samples with different pattern heights from 40 to 200 nm were obtained. The patterns were found to be 25 μm in length and ranged from 2 μm to 20 μm in width. Fig. 2(a) presents the topography of an area composed of the cobalt patterns with different aspect ratios of the sample and the pattern thickness determined to be of about 50 nm.

The MFM-images of the same area were obtained in the presence of the external magnetic field of variable magnitude. The magnitude of the field was changed step-by-step from +300 Oe to −300 Oe, so that the hysteresis properties

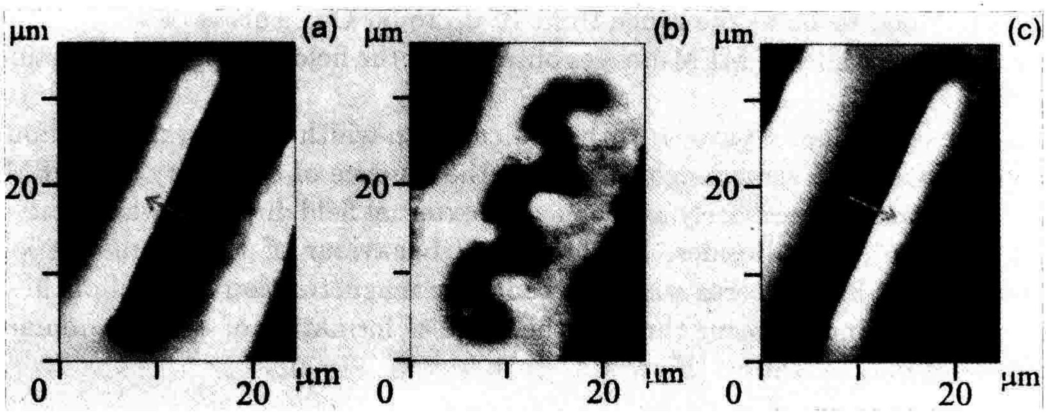

Figure 4. MFM-images of a wire-like Co pattern with the thickness of about 70 nm in external magnetic field directed along the short edge with the strength of +100 Oe (a); 0 Oe (*b*); −100 Oe (c). Arrows show the field direction.

of the patterns could be followed.

First, when the magnitude of the field was +300 Oe and its direction was along the long edge of the patterns the MFM-image of the patterns was obtained. This image was similar to uniformly magnetized particle [5], so it was concluded that the patterns were in monodomain state with the total magnetic moment directed along the field (Fig. 2(b)). This type of MFM-contrast was preserved until the field was switched off. In the absence of the field a rather complex MFM-image was obtained (Fig. 2(c)). This image could be explained by the formation of multidomain structure of magnetization of the patterns. The patterns became uniformly magnetized once again but in the opposite direction after the appearance of even rather small field of 10 Oe in this direction. So it could be concluded that the patterns 50 nm in height had very small coercivity (less than 10 Oe). The same behaviour was exhibited by the patterns with the height less than 100 nm.

A different result was obtained for the patterns with the height more than 100 nm and rather small length-to-width ratio. The MFM-contrast for such patterns was preserved as the external field magnitude was reduced down to zero. Fig. 3(a) presents a profile of the MFM-image of such a pattern with the height of about 150 nm in the +40 Oe field directed along the long edge of the pattern. This contrast changed only when a rather strong magnetic field of the opposite direction was switched on (Figs. 3(b),(c)). In this way the coercivity of the pattern could be estimated. For example, the coercivity of this pattern was determined to be in the range from 40 up to 50 Oe. This is clear from the comparison of profiles of MFM-images obtained in the fields of opposite direction (Fig.3(b) and (c)).

At the same time a pattern with the length-to-width aspect ratio of about 10 or more with the same height displayed the absence of coercivity. Its MFM-contrast reversed immediately as soon as the external field direction was changed (Figs. 3(d),(e),(f)). Besides, an interesting behaviour of the magnetization reversal of wire-like patterns was observed. The magnetization reversal of these patterns was found to occur through the stage of formation of a stripe domain structure of magnetization (Figs. 4(a)–(c)).

4. Conclusions

The Co planar patterns with different planar size and height were formed on the HOPG surface with vacuum evaporation and utilization of the intersected mask system. The shapes and sizes of the patterns were determined by the AFM measurements. Their magnetization reversal behavior was examined by the MFM method with the external magnetic field of variable magnitude and direction. The coercivity of the pattern was found to depend on its height and width. The stripe domain structure was observed in zero external magnetic field for the wire-like patterns which had the length-to-width aspect ratio of about 10 or more.

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