MFM study of soft magnetic samples.

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The purpose of this report is to compare two techniques for magnetic domain imaging. The first is a standard two-pass technique (TPT) [1]. TPT implies that the topographic line scan is first taken, and then this information is used to make the second pass at a constant user-defined flying height *h*. The shift in the cantilever phase, recorded at the second pass, is caused by the sensitivity of the cantilever coated with a ferromagnetic material to the sample's stray field. The second technique (let us call it single pass technique (SPT)) involves only one scan at constant *z*-position of the tip. Phase shift is measured during this scan. There are two obvious disadvantages in the SPT: one cannot keep the constant tip-sample distance and the plane of the sample should be carefully adjusted. Nevertheless, our results show that the SPT is that best suited to the study of soft magnetic samples. The reason is that the tip fields may influence the micromagnetic structure of sample (see, for example, [2] and references there). This may cause random, partial remagnetization of the low-coercitivity sample during the first pass in TPT. Thus one cannot avoid these effects by increasing a tip lift at the second pass. The SPT seems to be a more delicate way of MFM imaging.

All experiments were performed using scanning probe microscope Solver P47H produced by NT-MDT (Russia). Tips coated with Co were used. In what follows, some examples of images taken with different techniques are given.

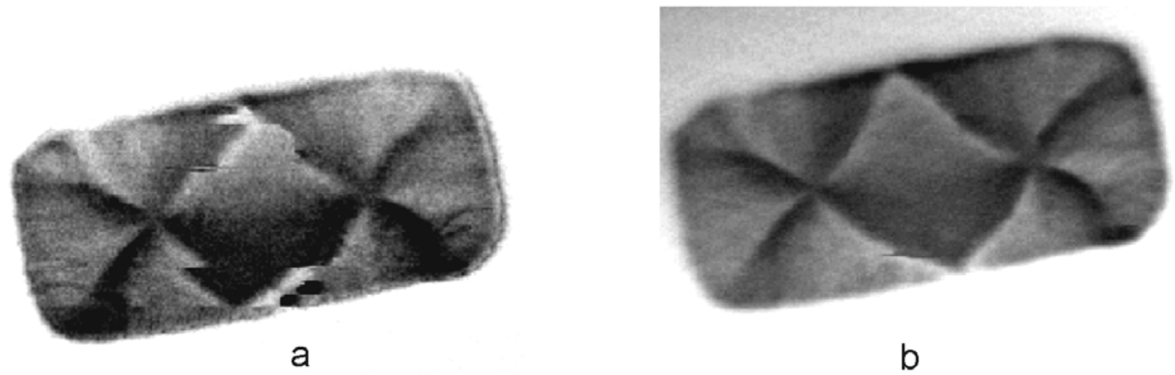

Fig. 1. MFM images of $10\times5\times0.07\ \mu m^3$ permalloy element; (a) –TPT, h = 150 nm; (b) –SPT.

It is clearly seen in Fig 1a that the influence of the tip leads to the appearance of the ragged domain boundaries. This effect is significantly reduced if the MFM scan is taken with the SPT (Fig 1b). In order to obtain the SPT scan the following steps were made: 1) the plane of the sample was adjusted to be approximately parallel to the tip movement; 2) the tip was loaded on the surface and its *z* position was noted; 3) the feedback was turned off and the *z* position was set at 50-200 nm higher than the surface; 4) phase shift is measured during the scanning.

Note that the MFM scans shown in Fig.1 were made when the direction of fast scanning was set to *x* (It means that the tip firstly goes along the *x* direction and then changes the *y* position). By switching the direction of the fast scanning, one can check how the tip affects the domain structure. Fig. 2 shows that this influence can completely change the domain pattern. Three sequential scans of the same magnetic strip are given. The first two differ in the direction of the fast scanning. Fig. 2c shows the SPT scan.

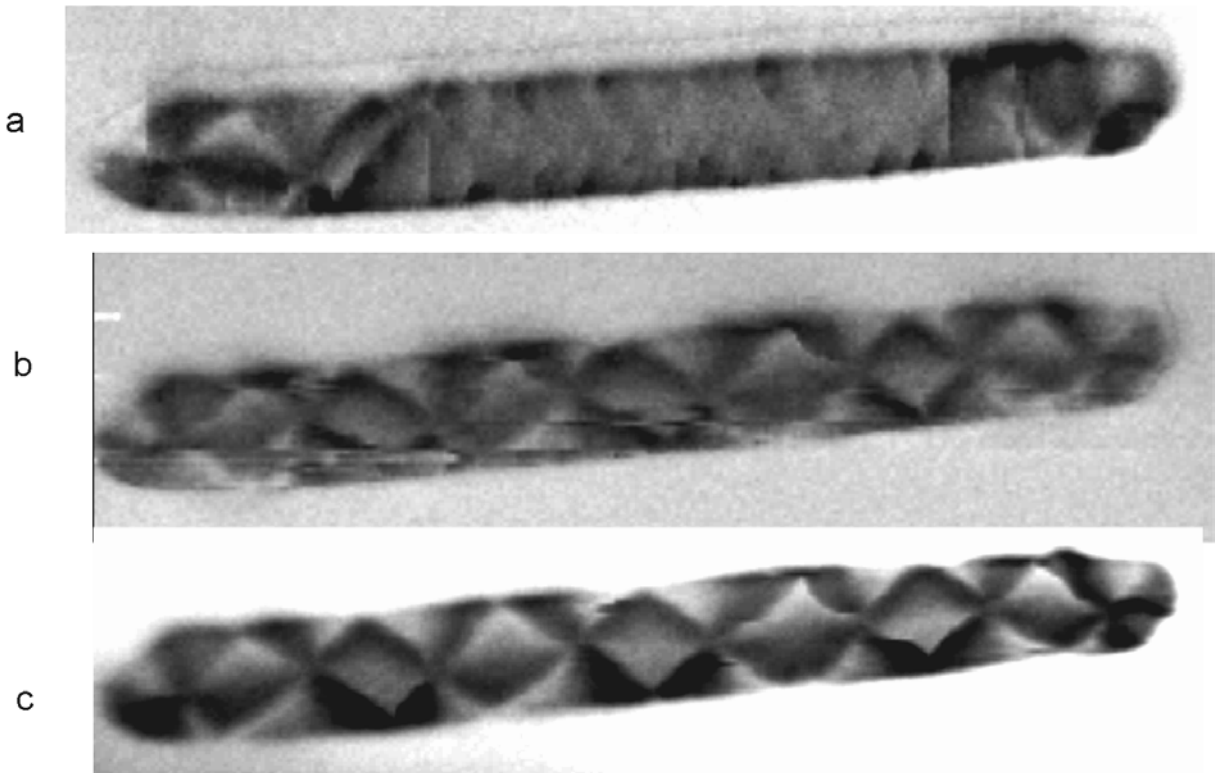

Fig. 2. MFM images of 16×2×0.07 μm^3 permalloy element;
(a) TPT, h = 100 nm, y-direction of the fast scanning;
(b) TPT, h = 100 nm, x-direction of the fast scanning;
(c) SPT, x-direction of the fast scanning.

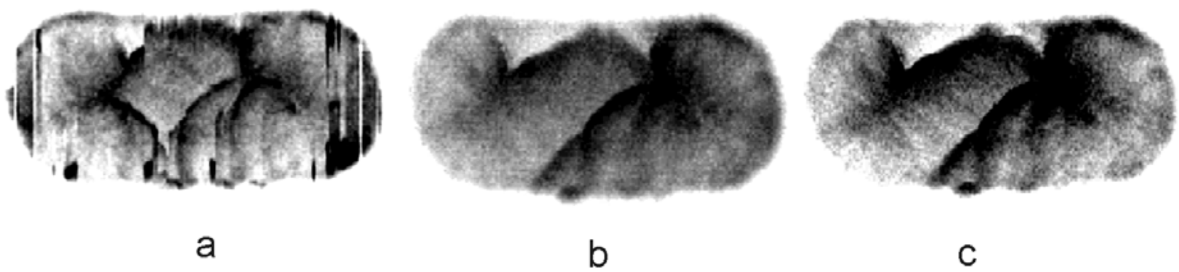

Fig. 3. MFM images of 10×5×0.03 μm^3 permalloy element;
(d) TPT, h = 100 nm, y-direction of the fast scanning;
(e) SPT, y-direction of the fast scanning;
(f) SPT, x-direction of the fast scanning.

Fig. 3 shows MFM images of the thinner sample as compared with Fig. 1. The tip-induced image perturbation is clearly manifested under TPT. When SPT is used, the scanning direction change does not produce any radical modification of the image.

All images given in Fig. 4 were made using SPT when external magnetic field was applied. One can estimate from this figure the scale of the fields that cause the domain wall movement. Notice that SPT is convenient to use for the imaging in the field. It takes less time to make SPT image because just one pass is conducted and the speed can be increased since the feedback is turned off. This may be important when one has to scan repeatedly the same area, as it is take place when the domain wall motion is studied.

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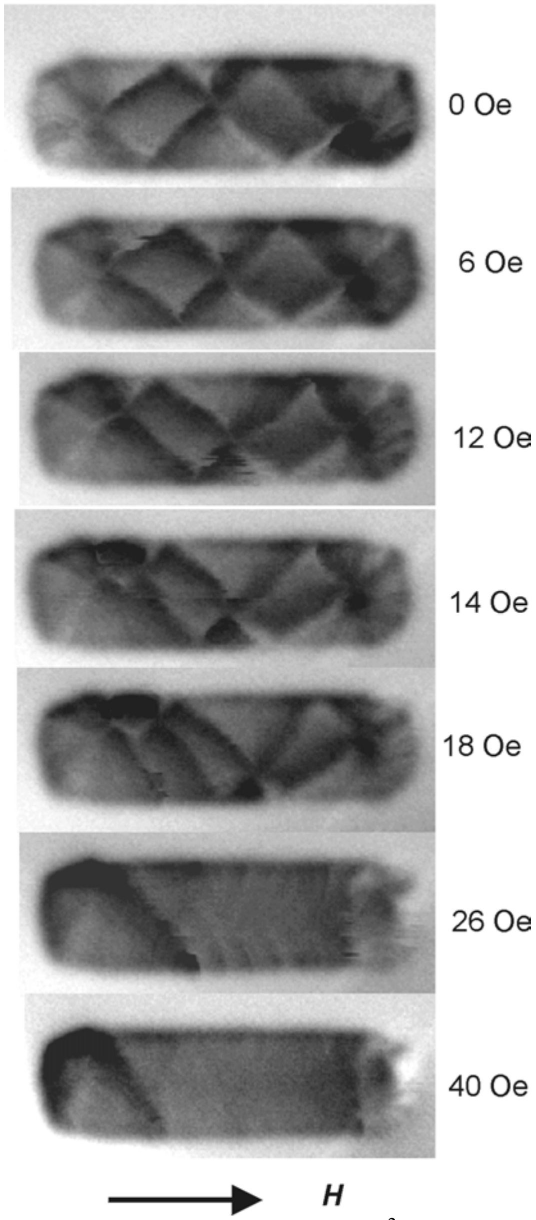

Fig. 3. MFM images of $15\times5\times0.07$ μm^3 permalloy element in the external magnetic field; SPT.

[1]. Y.E. Martin and H.K. Wickramasinghe, Appl. Phys. Lett. **50**, 1455 (1987).
[2]. R. Proksch, K. Babcock, and J. Cleveland, Appl. Phys. Lett. **74**, 419 (1999).