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MFM Investigations of [NiFe/Au/Co/Au]$_N$ Multilayers

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Magnetic force microscopy measurements combined with computer simulations were applied to investigate the strengths of magnetic field over the [NiFe/Au/Co/Au]$_N$ multilayers with in-plane and out-of-plane anisotropy observed for NiFe and Co layers, respectively. All measurements were performed in air atmosphere at room temperature. Dimensions and density of magnetic domains were estimated. The distribution of magnetization directions was deduced from comparison of magnetic force microscopy with the simulation results. Some sort of modulation in stray magnetic field was observed, but till now it is of unknown origin.

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1. Introduction

The interaction between Co and permalloy (Py — $Ni_{80}Fe_{20}O$) layers in [NiFe/Au/Co/Au]$_N$ multilayers (MLs) is well known [1–3]. The remnant magnetic configuration of NiFe layers is strongly influenced by stripe domains in Co layers. Modification of the MLs by adding additional Co layers next to NiFe layers increases this effect. Those layers behave like a single magnetic layer due to strong exchange coupling between them. This coupling depends on order of Co and NiFe layers rather than on Co thickness [2] as a result of sequence-dependent growth.

The Mössbauer measurements as well as results obtained from the magnetic field dependence of resistance show that in MLs with Co-0.6 nm/NiFe-2.6 nm bilayers magnetic moments of permalloy are deflected out of the easy-plane by magnetostatic fields of stripe domains of Co layers by approximately 36°, while in MLs with NiFe-2.6 nm/Co-0.6 nm bilayers, by approximately 15° [1].

In this paper we used the magnetic force microscopy (MFM) method combined with computer simulations to present differences in remnant magnetic field over the samples.

2. Experimental details

The samples were prepared by deposition of multilayers on Si(100) wafers by magnetron sputtering in UHV [4]. Py-3.2 nm/Au-2.2 nm/Co-0.8 nm/Au-2.2 nm/[Py-2.6 nm/Co-0.6 nm/Au-2 nm/Co-0.8 nm/Au-2 nm]$_{10}$ (further called A) and Py-3.2 nm/Au-2.2 nm/Co-0.8 nm/Au-2.2 nm/[Co-0.6 nm/Py-2.6 nm/Au-2 nm/Co-0.8 nm/Au-2 nm]$_{10}$ (further referred as B) were prepared. Samples were magnetized in the magnetic field perpendicular to the surface (and easy-plane). The MFM measurements were performed in air atmosphere at room temperature (RT) using Co coated cantilevers. The modified Wadas model of magnetic stray field over the sample [5, 6] combined with the mathematic model of magnetic interactions between tip and the sample presented in [7] was used to compute magnetic force acting on the cantilever. The profiles of magnetic force acting on the cantilever moving over the sample on dedicated height were simulated. For purpose of simulations two approaches to MLs were applied. First model treated all layers (excluding interface) as one with contribution to overall magnetization according to thickness of layers and deflection angle of magnetic moments in NiFe layers (further called single layer model). This way magnetic force acting on the cantilever over 84 nm thick single layer was simulated. Second model assumed that final magnetic force acting on the cantilever is a linear combination of magnetic force contributions from each magnetic layer (multilayer model).

3. Results and discussion

Figure 1 presents a 10×10 μm^2 MFM picture of magnetic field over the A sample in lift mode. The tip–sample distance was 100 nm to exclude potential tip–topography interactions. Stripe-like domain structure was observed. Mean distance between two maxima equals 300 nm which is visible in Fig. 2b. The measurement shown in Fig. 2a was done with the tip–sample distance of 40 nm.

The MFM picture of 10×10 μm^2 size of B sample is presented in Fig. 3a. The period of the stripe-like domain structure is approximately 200 nm (see Figs. 4a and b), but there is another modulation in the magnetic image with period of about 3 μm. Figures 3c and d present magnetic image after FFT filter to show mentioned modulation. The explanation of this supra structure is given further in this text.

From MFM measurements we can conclude that sample A has 50% wider domains than sample B. Their length cannot be estimated for neither of samples because most of the domains are longer than the maximum scan area (10×10 μm^2). The density of magnetic domains is therefore 50% smaller for MLs with bigger deflection

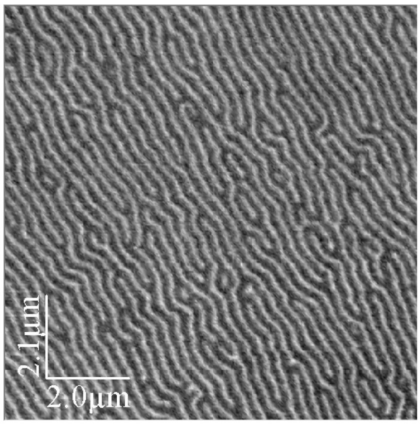

Fig. 1. MFM image of Py-3.2 nm/ Au-2.2 nm/ Co-0.8 nm/Au-2.2 nm/[Py-2.6 nm/Co-0.6 nm/Au-2 nm/ Co-0.8 nm/Au-2 nm]$_{10}$; scan size 10×10 μm^2; tips–sample distance 100 nm.

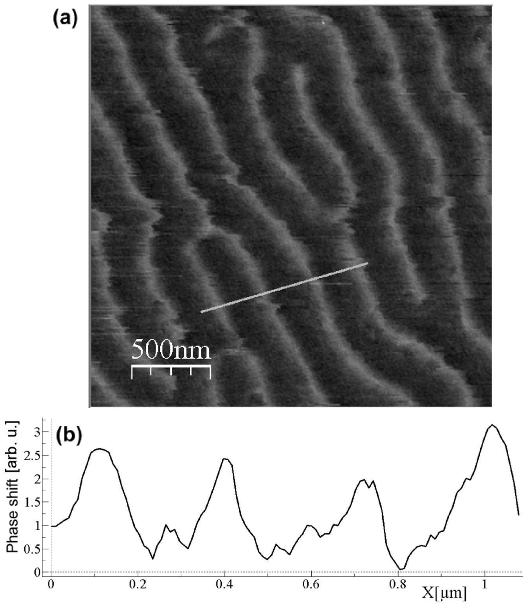

Fig. 2. (a) MFM image of Py-3.2 nm/ Au-2.2 nm/ Co-0.8 nm/Au-2.2 nm/[Py-2.6 nm/Co-0.6 nm/Au-2 nm/ Co-0.8 nm/Au-2 nm]$_{10}$; scan size 2.5×2.5 μm^2; tips–sample distance 40 nm; (b) profile taken out of image (a); phase shift presented in arbitrary units.

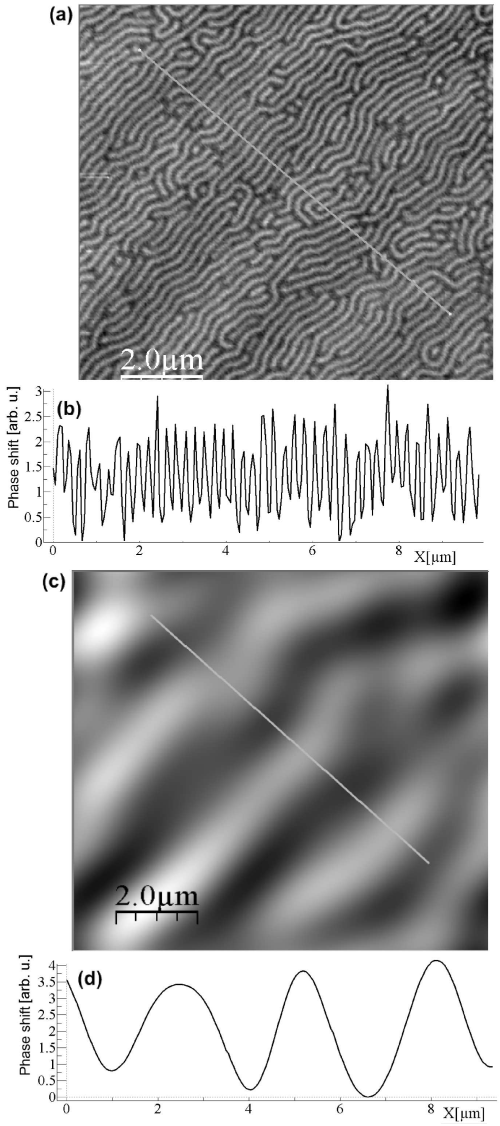

Fig. 3. (a) MFM image of Py-3.2 nm/ Au-2.2 nm/ Co-0.8 nm/Au-2.2 nm/[Co-0.6 nm/Py-2.6 nm/Au-2 nm/ Co-0.8 nm/ Au-2 nm]$_{10}$; scan size 10×10 μm^2; tips–sample distance 100 nm; (b) profile taken out of image (a); (c) image after applying FFT low pas filter to image (a); (d) profile taken out of image (c); phase shift presented in arbitrary units.

angle of magnetic moments in permalloy layers. The surface defects can induce ordering of magnetic domains in the MLs nevertheless, no connection between topography and magnetic image could be found.

Computer simulation results of two models for each of the sample are presented in Fig. 5. Simulations were made assuming the tip–sample distance of 40 nm. Magnetic force comes from 4 magnetic domains of preset dimensions 300 nm and 200 nm, respectively, for given samples. The only difference in the final result between two models is the amplitude of periods. However we observed that few first Co layers gave characteristic pattern in multilayer model, but in the end the contribution to overall force was too small to change the character of profile curves. In the case of larger domains found in B sample (300 nm) characteristic pattern was better developed and lasted longer (was found in profiles calculated for Co layers placed deeper in the sample).

Assuming that interface NiFe layer is not under the influence of Co stripe-like domains above it we can conclude that this layer should have its own magnetic structure. We took it under consideration and we simulated the magnetic force acting on the cantilever

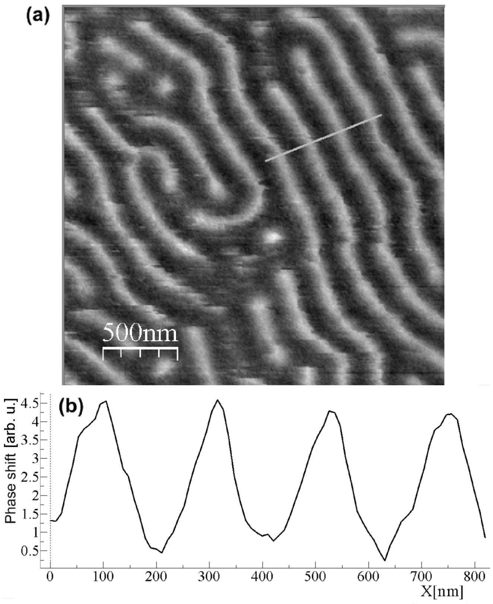

Fig. 4. (a) MFM image of Py-3.2 nm/ Au-2.2 nm/ Co-0.8 nm/Au-2.2 nm/[Co-0.6 nm/Py-2.6 nm/Au-2 nm/ Co-0.8 nm/Au-2 nm]$_{10}$; scan size 2.5×2.5 μm^2; tips–sample distance 40 nm; (b) profile taken out of image (a); phase shift presented in arbitrary units.

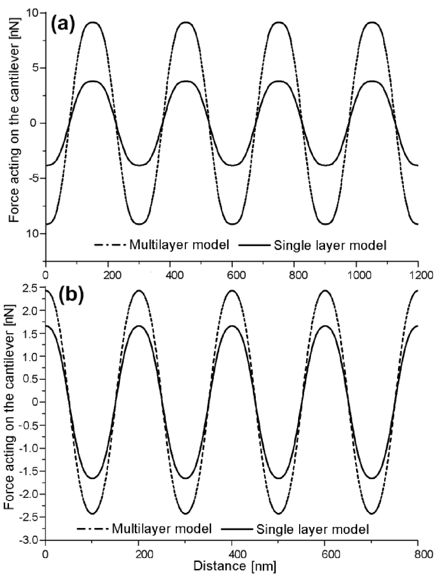

Fig. 5. The computed force acting on the cantilever over the sample A (b) and B (a); results for single layer and multilayer models are presented; tip–sample distance 40 nm.

for a bilayer consisting of 84 nm thick single layer taken from single layer model and interface NiFe layer with different periodicities. Results for this simple model are surprisingly good. Figure 6 shows the calculated force acting on the cantilever over a wide area on the sample. Both modulations are clearly visible.

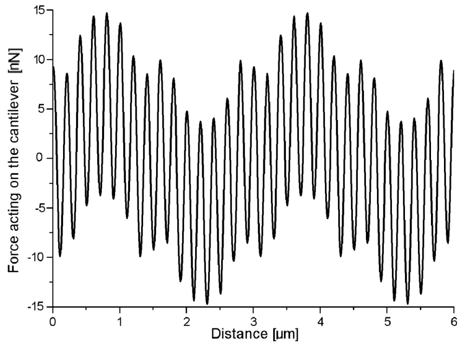

Fig. 6. The computed force acting on the cantilever over the wide area of the sample B; stripe like structure with aditional modulation is obtained; tip–sample distance 100 nm.

Taking under consideration that these profiles were calculated for infinitely long, straight stripe domains we can say that they are consistent with MFM measurements.

4. Conclusions

The MFM measurements confirmed expected stripe-like magnetic structure of the [X/Au/Co/Au]$_N$ where X is a Co/NiFe or NiFe/Co bilayer. The MLs with NiFe/Co bilayer stripe domains were approximately 50% wider than with Co/NiFe. None characteristic patterns could be observed which is consistent with computer simulation. The supra structure in B can be explained by different magnetic structure of interface permalloy layer.

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