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The Influence of He^+ Ion Bombardment on Magnetic Properties of NiFe/Au/Co/Au Multilayers

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The influence of He^+ ion bombardment on magnetoresistance, magnetization reversal and domain structure of sputtered $(Ni_{80}Fe_{20}$(2 nm)/Au(2 nm)/Co(0.6 nm)/Au(2 nm)$)_{10}$ multilayers was investigated. The samples were bombarded using He^+(30 keV) ions with fluences D varied from 10^{13} to 3×10^{16} He^+/cm^2. With increasing D the following changes in magnetic properties were observed: (i) exponential decay of the saturation field of Co layers, (ii) progressive decrease in magnetoresistance as a result of degradation of Co layers perpendicular anisotropy, (iii) linear decrease in stripe domain period with $\log(D)$.

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1. Introduction

Patterned media are promising candidates for ultrahigh density magnetic recording [1]. There are many different ways to realize patterned structures. Practical consideration requires that the magnetic anisotropy of the reversed area (bits) in patterned material should be perpendicular to the sample plane [2, 3]. Therefore, NiFe/Au/Co/Au multilayers composed of ferromagnetic layers with alternating out-of--plane (Co) and in-plane (NiFe) magnetic anisotropy are interesting for such application. The tailoring of magnetic properties can be realized by changes in anisotropy and/or coupling between ferromagnetic layers, caused by ion irradiation. In this contribution we present a study concerning the magnetic properties of $(Ni_{80}Fe_{20}$(2 nm)/Au(2 nm)/Co(0.6 nm)/Au(2 nm)$)_{10}$ multilayers after He^+ ions bombardment with different D. The investigation was focused on the modification of the perpendicular anisotropy of the Co layers.

2. Experimental

The $(Ni_{80}Fe_{20}$(2nm)/Au(2nm)/Co(0.6nm)/Au(2nm)$)_{10}$ multilayer was deposited onto naturally oxidized Si(100) substrate in Ar atmosphere using UHV magnetron sputtering. To investigate the influence of the ion bombardment on the perpendicular anisotropy of the Co layers the sample was cut into ten parts of the same size (5×10 mm^2) characterized by the equal magnetic properties. Each of them was irradiated using 30 keV He^+ ions with different fluences. The D were varied from 10^{13} to 3×10^{16} He^+/cm^2. The magnetization reversal processes $M(H)$ were recorded with vibrating sample magnetometer (VSM). The magnetoresistance MR and resistance R were measured in current-in-plane geometry using four point technique. The $M(H)$ and $R(H)$ curves were studied at room temperature (RT) in magnetic field applied perpendicular ($H_\perp$) and parallel ($H_\parallel$) to the sample plane. The MR were calculated according to $\Delta R/R = [R(H) - R(20\text{ kOe})]/R(20\text{ kOe})$, i.e. relatively to the resistance at 20 kOe, and the maximum value determined from $\Delta R/R$ is called MR amplitude throughout the text. The domain structures before and after ion bombardment were visualized by magnetic force microscopy (MFM).

3. Results and discussion

The recorded $M(H)$ and MR curves are characteristic of multilayers consisting of two weakly coupled ferromagnetic layers with mutually perpendicular easy axes (Fig. 1).

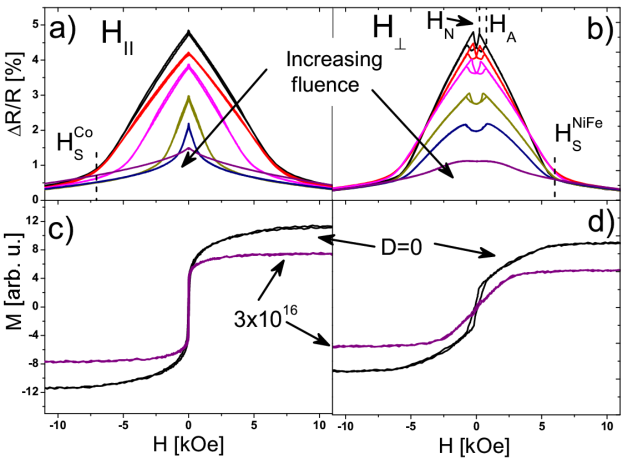

Fig. 1. Magnetoresistance (a, b) and magnetization (c, d) hysteresis curves of $(Ni_{80}Fe_{20}(2\ nm)/Au(2\ nm)/Co(0.6\ nm)/Au(2\ nm))_{10}$ multilayer with magnetic field applied parallel (left part) and perpendicular (right part) to the sample plane with $D = 0$, 3×10^{13}, 10^{15}, 4×10^{15}, 10^{16}, 3×10^{16} He$^+$/cm^2 (for $M(H)$ only data for $D = 0$ and $D = 3 \times 10^{16}$ He$^+$/cm^2 are shown). Characteristic parameters H_N, H_A, H_S^{Co}, H_S^{NiFe} are shown on the MR curves of as-deposition sample.

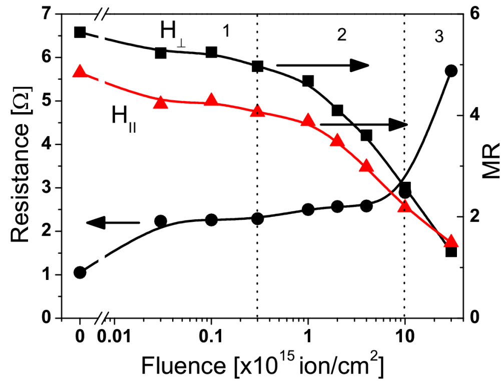

Fig. 2. The magnetoresistance amplitude of $(Ni_{80}Fe_{20}(2\ nm)/Au(2\ nm)/Co(0.6\ nm)/Au(2\ nm))_{10}$ multilayer measured in magnetic field perpendicular (■) and parallel (▲) to the sample plane and resistance $R(H = 0)$ (●) versus ion fluence.

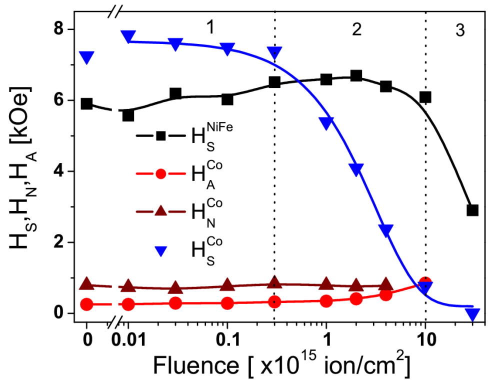

Fig. 3. The changes of saturation, annihilation, and nucleation field of Co layers and saturation field of NiFe versus fluence of 30 keV He$^+$ ions. The line for H_S^{Co} is an exponential decay fit.

The magnetization reversal of such system can be described as follows: for $|H|$ higher than the saturation field of layers magnetized along the easy direction, the magnetization of NiFe (Co) layers is always parallel to $H_{\parallel}$ ($H_{\perp}$) while the magnetization of Co (NiFe) rotates from perpendicular (in-plane) to the field direction. From hysteresis loops and MR curves recorded for $H_{\perp}$ the following parameters can be determined: saturation field of NiFe layers (H_S^{NiFe}), nucleation (H_N) and annihilation (H_A) fields, which are related to appearance of stripe domain structure in the Co layer and for $H_{\parallel}$ the anisotropy field of Co layers (H_S^{Co}).

The discussion of the results will be divided into three parts corresponding to different fluences of He$^+$ ions. This partition is shown in Figs. 2 and 3. In the first range, where $D \leq 3 \times 10^{14}$ He$^+$/cm^2, only a slight decrease in MR amplitude and R at $H = 0$ with D is observed (Fig. 2). After ion bombardment the number of defects in the multilayer structure increases, which results in shortening of the mean free path of electrons [4, 5]. The MR amplitude decreases as a consequence of the resistance increase. It should be noticed that in this range of D the effective anisotropy of Co layer does not change distinctly (Fig. 3).

The second range, $3 \times 10^{14} < D \leq 10^{16}$ He$^+$/cm^2, is characterized by significant changes of H_S^{Co}. The H_S^{Co} exponentially decays with increasing D (Fig. 3), while the resistance weakly increases. A strong decrease in H_S^{Co} and slight increase in H_A with ion fluences, indicate on the gradual weakening of perpendicular anisotropy followed by transition from the out-of-plane to the in-plane anisotropy of Co layers. Similar results were previously reported [6, 7]. It should be stressed that for $H_{\perp}$ the NiFe layers saturate at about 6.2 kOe, which corresponds to their shape anisotropy field $H_S^{NiFe} \approx 4\pi M_S^{NiFe}$ (M_S^{NiFe} — saturation magnetization of $Ni_{80}Fe_{20}$) [8]. Anisotropy of NiFe layers does not change after ion bombardment up to 10^{16} He$^+$/cm^2.

Finally, in the third part, where $D > 10^{16}$ He$^+$/cm^2, the H_S^{NiFe} diminishes. It suggests that the magnetization of the NiFe layers is reduced by mixing on the NiFe/Au interfaces [9]. There is also a possibility that the ion irradiation can destroy the continuous structure of very thin (0.6 nm) Co layers. As a consequence, for a large D paramagnetic alloys (Co–Au) and/or superparamagnetic Co clusters embedded in Au can be formed [10]. The described changes in magnetic properties of NiFe and Co layers lead to decrease in total magnetic moment of layered films. This was indeed observed (Fig. 1c, d). Moreover, as a consequence of the intense mixing strong rise of resistance is also observed (Fig. 2).

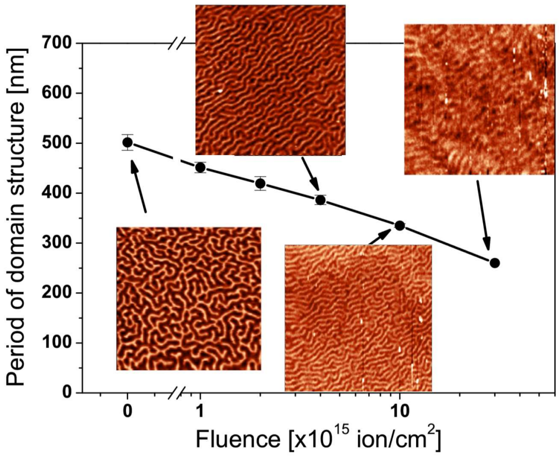

Fig. 4. The period of the domain structure versus fluence. The magnetic force microscopy images corresponding to 10×10 μm^2 for $D = 0$, 4×10^{15}, 10^{16} He^+/cm^2 and to 5×5 μm^2 for 3×10^{16} He^+/cm^2 are shown as insets.

The influence of ion bombardment on the domain structure was also investigated. The period of domain structure was calculated from MFM images using the Fourier transform. The linear decrease in period with $\log(D)$ was observed (Fig. 4). This effect is in qualitative agreement with changes in anisotropy of Co layers described above [11]. Moreover, the magnetic contrast in MFM image (Fig. 4, inset) diminishes with increasing fluence, and domain structure is hardly visible for $D = 3 \times 10^{16}$ He^+/cm^2. This indicates that for the highest fluence the perpendicular anisotropy or ferromagnetic behavior of Co layers are partially destroyed.

4. Conclusion

Influence of the ion bombardment on magnetic and magnetoresistive properties of sputter deposited $(Ni_{80}Fe_{20}/Au/Co/Au)_{10}$ multilayer was systematically investigated. It is shown that variation of magnetoresistance with ion bombardment is mainly caused by anisotropy changes of Co layers. The demonstrated ability of tailoring the perpendicular anisotropy may result in a better control of magnetic patterning via ion bombardment.

Acknowledgments

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