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He^+ Ion Bombardment Induced Effects on Magnetic Properties of Ni–Fe/Au/Co/Au Films

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The influence of He^+ (10 keV) ion bombardment on magnetic properties of sputter deposited $Ni_{80}Fe_{20}$/Au/Co/Au layered films was studied. The variable parameters were the thickness of the Co layer or Au spacer and the ion dose. The magnetooptical Kerr measurements were performed on samples with wedge shaped Co or Au layers. With increasing dose of helium ions the following changes in magnetic properties were observed: (i) a decrease in the Co thickness range corresponding to the perpendicular anisotropy, (ii) a decrease in the coercive field (H_C), (iii) an increase in the ferromagnetic coupling between ferromagnetic layers.

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1. Introduction

It is well established that patterned magnetic media are promising candidates for a new generation of magnetic recording characterized by storage densities distinctly higher than in conventional discs. There are different methods for the fabrication of such structures, however, for all of them the magnetic anisotropy of the bits perpendicular to the plane is strongly desired [1]. This is because the same relative orientation of the recording head to the magnetization direction in

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all bits enables an efficient read-out. Additionally, the typical layered film for perpendicular recording system is composed of a recording layer (with perpendicular anisotropy), exchange break layer (non magnetic), and soft under layer (with in-plane anisotropy) [2]. The above-mentioned requirements are fulfilled for the substrate/buffer/$Ni_{80}Fe_{20}$/Au/Co/Au system characterized by alternating in-plane and perpendicular anisotropies of Ni–Fe and Co layers, respectively [3]. Among the various techniques enabling patterning, a local modification of the magnetic properties by an ion bombardment (induced magnetic patterning) seems to be a promising one [1, 4]. In this paper we present a study concerning the magnetic properties of Si(100)/buffer/$Ni_{80}Fe_{20}$/Au/Co/Au layered films with different thicknesses of Co layer and Au spacer in an as-deposited state and after bombardment with He^+ ions with different doses (D).

2. Experimental

The $Ni_{80}Fe_{20}$/Au/Co/Au layered films were deposited by UHV magnetron sputtering onto naturally oxidized Si(100) substrates (20×15 mm^2) covered by a ($Ni_{80}Fe_{20}$–2 nm/Au–3 nm)$_{10}$ buffer layer. The base pressure in the preparation chamber was 10^{-9} mbar and the Ar pressure during the deposition was 10^{-4} mbar. To investigate the influence of the ion bombardment on the perpendicular anisotropy of the Co layer and, independently, on interlayer coupling between Co and NiFe layer, two different samples were prepared: (A) $Ni_{80}Fe_{20}$ 2 nm/Au 3 nm/Co wedge/Au 3 nm and (B) $Ni_{80}Fe_{20}$ 2 nm/Au wedge/Co 1 nm/Au 3 nm. The thickness gradient was along the longer edge of the sample. The ion bombardment was performed using 10 keV He^+ ions with doses D varying in the range $10^{13} \leq D \leq 10^{15}$ He^+/cm^2. Under these conditions all He^+ ions stop deeply in the substrate [4]. The areas bombarded with constant doses were limited to stripes (1 mm in width) located along the thickness gradient.

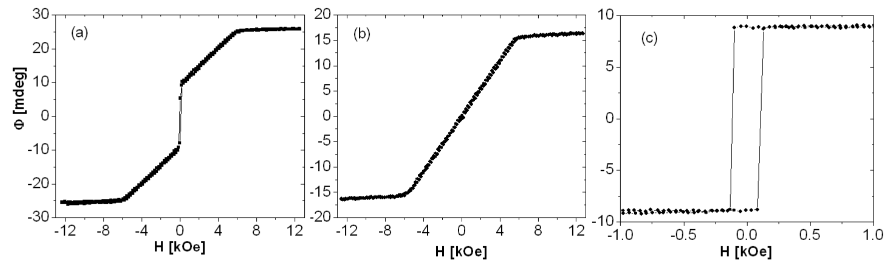

Fig. 1. Exemplary polar magnetooptical Kerr-effect hysteresis loop (Φ — Kerr rotation) of Si/($Ni_{80}Fe_{20}$/Au)$_{10}$/$Ni_{80}Fe_{20}$/Au/Co/Au layered film measured in a magnetic field applied perpendicularly to the sample plane (a). Constituent magnetization curves related to $Ni_{80}Fe_{20}$ and Co layers, respectively (b) and (c).

The magnetization process, as a function of magnetic field H applied perpendicularly to the sample plane was investigated using magnetooptical polar Kerr effect [5]. A typical hysteresis loop with distinct contribution from cobalt and permalloy layers is shown in Fig. 1a. Due to a well-defined magnetization reversal of the $Ni_{80}Fe_{20}$ layers, characterized by a coherent rotation of the magnetization with saturation at 6.5 kOe (Fig. 1b), the contribution corresponding to the cobalt layer can easily be separated (Fig. 1c). The magnetization curve determined for Co was used for evaluation of the coercive field (H_C) and remanent Kerr rotation Φ_{REM} ($\Phi_{REM} = \Phi(H = 0)$). These parameters were determined as a function of the Co and Au layer thicknesses (t_{Co} and t_{Au}, respectively) and ion dose D.

3. Results and discussion

The dependence of the Kerr rotation angle at remanence Φ_{REM} on t_{Co} and t_{Au} (Fig. 2), measured for samples A and B in the as- deposited state, indicates that the perpendicular anisotropy ($\Phi_{REM} > 0$) is observed for $t_{Au} \geq 0.7$ nm and $0.4 \leq t_{Co} \leq 1.7$ nm (see also Fig. 4 in [3]). On decreasing t_{Au} below 0.7 nm the ferromagnetic coupling between Ni–Fe and Co layers strongly increases for

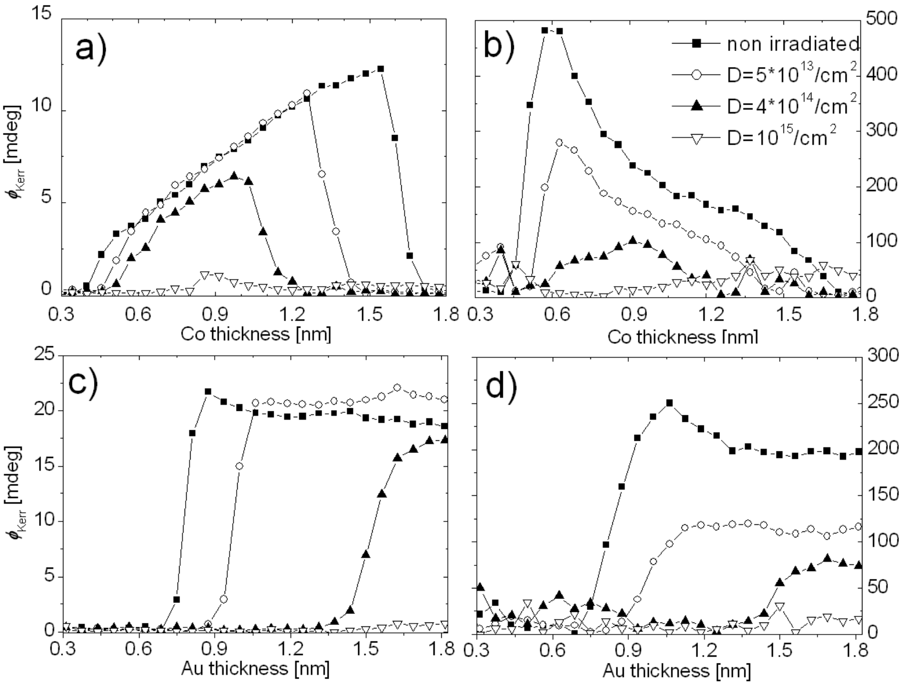

Fig. 2. The remanent Kerr rotation Φ_{REM} (a, c) and coercive field H_C (b, d) of cobalt layer determined for sample A and B, respectively, in the as-deposited state and after ion bombardment with different He$^+$ ion dose, as a function of Co (a, b) and Au thickness (c, d), respectively.

$t_{Au} < 0.7$ nm, most probably due to the creation of pinholes. As a consequence, the ferromagnetic layers reverse simultaneously in a manner characteristic of a single layer with in-plane anisotropy. For samples with weak coupling (sample A, $t_{Au} = 3$ nm) the value of $\Phi_{REM} = 0$ is related to superparamagnetic behavior of the Co layer with $t_{Co} < 0.4$ nm and to a transition from perpendicular to in-plane effective anisotropy for $t_{Co} > 1.7$ nm (this transition is caused by a competition between volume and surface anisotropy). It should be noted that both the range of t_{Co} corresponding to the perpendicular anisotropy as well as the maximal value of the coercive field ($H_C \approx 500$ Oe for $t_{Co} = 0.6$ nm) are similar to those observed for epitaxial Au/Co/Au films deposited using MBE technique on sapphire substrates covered by a Mo buffer layer [5].

The changes in magnetic properties of sample A and B caused by 10 keV He^+ ions and $D < 10^{13}$ He^+/cm^2 are small. However, for higher doses the changes are significant for both samples due to stronger mixing at interfaces. The $\Phi_{REM}(t_{Co})$ dependencies determined for sample A after bombardment with different ion doses indicate that the range of t_{Co} corresponding to the ferromagnetic behavior of the Co layers and their perpendicular anisotropy decreases with D and for $D = 10^{15}$ He^+/cm^2 it becomes very narrow. In our opinion the reduction of the thickness range is related to two processes caused by short-range ion-induced atomic displacements. The first, important for $t_{Co} \geq 0.8$ nm, corresponds to the degradation of the surface anisotropy caused by the mixing (increased interface roughness) at Au/Co and Co/Au interfaces. In consequence, with increasing D the reorientation transition is observed for smaller t_{Co}. The values of coercive fields are reduced accordingly (Fig. 2a and b). The second process, observed for small Co thickness ($t_{Co} < 0.6$ nm) is related to the destruction of the continuous Co layer and the formation of paramagnetic alloys and/or superparamagnetic clusters embedded in Au.

The influence of the ion bombardment on the interlayer coupling between Ni–Fe and Co layers was studied on sample B with the Au wedge (Fig. 2c and d). Similarly to the effect observed in Fe/Cr multilayers the increase in ferromagnetic coupling caused by ion bombardment is stronger the higher the ion dose and the thinner the spacer layer is [6]. For example the critical value of Au spacer thickness $t_{Au} = 0.7$ nm assuring quasi-independent magnetization reversal of Ni–Fe and Co layers (weak coupling regime) increases to 1 nm and 1.5 nm for $D = 5 \times 10^{13}$ He^+/cm^2 and $D = 4 \times 10^{14}$ He^+/cm^2, respectively. The abrupt increase in the ferromagnetic coupling strength for films with a small Au thickness strongly suggests that this effect is caused by the creation of pinholes [6]. It is worth noting that the changes of H_C for sample B in the thick spacer range ($t_{Au} \geq 1.6$ nm) are the same as for sample A with $t_{Co} = 1$ nm. This indicates a good reproducibility of the deposition process and ion induced magnetic patterning.

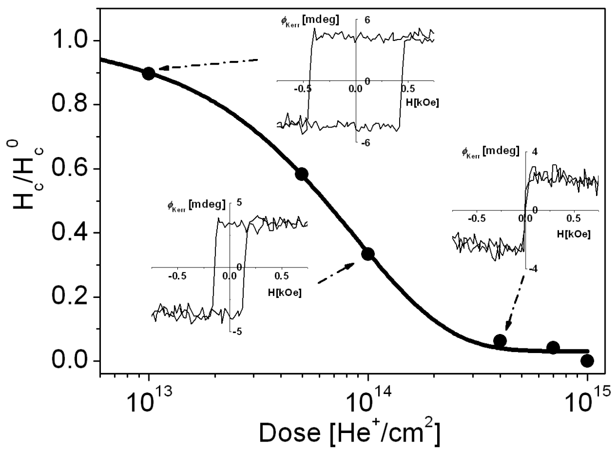

Fig. 3. The relative changes of the cobalt layer coercivity $H_{\mathrm{C}}/H_{\mathrm{C}}^0$ (H_{C}^0 and H_{C} denote coercive field in as-deposited state and after ion bombardment) versus dose of 10 keV He^+ ions determined for sample A with $t_{\mathrm{Co}} = 0.6$ nm. The exemplary hysteresis loops are shown as insets.

The evolution of hysteresis loops of the Co layer with increasing ion dose and the changes in the $H_{\mathrm{C}}(D)$ dependence are demonstrated in Fig. 3 for sample A and $t_{\mathrm{Co}} = 0.6$ nm, i.e., for the thickness corresponding to the maximal value of H_{C} in the as-deposited state. In our thin film system, similarly to Pt/Co/Pt layered films [7] or multilayers [8], the coercive force can also be reduced in a controlled way (from $H_{\mathrm{C}} \approx 500$ Oe to $H_{\mathrm{C}} < 50$ Oe in our films with $t_{\mathrm{Au}} = 3$ nm and $t_{\mathrm{Co}} = 0.6$ nm) by bombardment with 10 keV He^+ ions and $10^{13} \le D \le 4 \times 10^{14}$ He^+/cm^2. From the application point of view it is very important that in this range of D the square shape of the loops is conserved and that for $t_{\mathrm{Au}} \ge 1.5$ nm the Ni–Fe and Co layers are decoupled.

4. Conclusion

The magnetooptical studies of sputter deposited $Ni_{80}Fe_{20}$/Au/Co/Au layered films confirm that the films are characterized by in-plane and perpendicular anisotropy of Ni–Fe and Co layers, respectively. The coercive field of the Co layer ($H_{\mathrm{C}} \le 500$ Oe) can be reduced in a controlled way by 10 keV He^+ ion bombardment with doses ranging from 10^{13} to 4×10^{14} He^+/cm^2. To assure an exchange break between permalloy and cobalt layers after ion irradiation the Au spacer should be thicker as 1.5 nm.

Acknowledgments

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