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Temperature dependence of magnetization reversal in $Ni_{80}Fe_{20}$/Au/Co/Au multilayers

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The results are presented concerning the temperature changes of the magnetic properties of [$Ni_{80}Fe_{20}$ (2 nm)/Au(t_{Au})/Co(t_{Co})/Au(t_{Au})]$_{10}$ multilayers (MLs) with t_{Au} = 1.5, 2.2 nm and t_{Co} = 0.6, 0.8 nm. The hysteresis loops of the investigated MLs were measured using a vibrating sample magnetometer in the temperature range 175–423 K. The saturation field H_S^{Co} of Co layers, determined from loops taken with a field applied in-plane, increases with decreasing temperature. The H_S^{Co} field is directly related to the perpendicular magnetic anisotropy of the Co layer. It was also found that the shape of the central parts of the hysteresis loops, taken with the magnetic field applied perpendicular to the sample plane, is characteristic of samples with large perpendicular anisotropy and a stripe domain structure. The shape of the hysteresis loops is preserved in the whole temperature range of measurements, indicating the presence of stable stripe domains. The magnetization reversal of Co layers can be described by nucleation (H_N), annihilation (H_A), and coercive fields (H_C). The temperature dependences of these parameters are presented.

Key words: *magnetic multilayers; perpendicular magnetic anisotropy*

1. Introduction

There is currently much interest in the investigation of multilayered structures composed of layers with alternating out-of-plane and in-plane magnetic anisotropy, because of their potential applications [1–3]. Examples of such structures are sputter -deposited [NiFe/Au/Co/Au]$_N$ MLs [3]. $Ni_{80}Fe_{20}$ (Permalloy = Py) layers exhibit distinct in-plane anisotropy, while ultrathin Co layers (t_{Co} < 1.4 nm), sandwiched between Au, have strong perpendicular anisotropy [4]. A detailed study of magnetization reversal and GMR effects enabled us to show that an Au spacer with a thickness of $t_{Au} \geq 1.5$ nm assures small interlayer coupling [5]. Therefore, we consider the magnetization reversal of Co and Py layers to be nearly independent. This allows us to

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determine the magnetic properties of Co (separately of Py) layers from *M*(*H*) (as well as *R*(*H*)) curves taken with magnetic fields applied perpendicular ($H_\perp$) and parallel ($H_{||}$) to the layer plane. In this contribution, we have investigated the temperature dependence of the magnetic properties of Py/Au/Co/Au MLs which are important from the point of view of possible applications. Our particular goal was to determine the temperature dependence of the magnetic anisotropy of ultrathin Co layers, sandwiched between Au. Despite the vast literature on the anisotropy of the Co layers, data on its temperature dependence are scarce [6].

2. Experimental

A set of [Py(2 nm)/Au(t_{Au})/Co(t_{Co})/Au(t_{Au})]$_{10}$ MLs with t_{Co} = 0.6, 0.8 nm and t_{Au} = 1.5, 2.2 nm were deposited in an Ar atmosphere using UHV magnetron sputtering [5]. The samples were deposited at room temperature on a Si(100) substrate. A very good periodic structure of the MLs was confirmed by low- and high-angle X-ray diffraction. Magnetization reversal *M*(*H*) was measured in the temperature range 175–423 K, both in the perpendicular and parallel configurations ($H_\perp$, $H_{||} \le 1.5$ T). The *M*(*H*) loops were recorded with a vibrating sample magnetometer.

3. Results and discussion

The measured hysteresis loops are characteristic of a system composed of weakly coupled layers with two mutually perpendicular easy axes (Fig. 1), as mentioned in the Introduction. Apart from the region of small magnetic fields (i.e. |*H*| smaller than the saturation field of layers magnetized along the easy direction), the magnetization of NiFe (Co) layers is always parallel to $H_{||}$ ($H_\perp$), but the magnetization of Co (NiFe) rotates from perpendicular (in-plane) to the field direction.

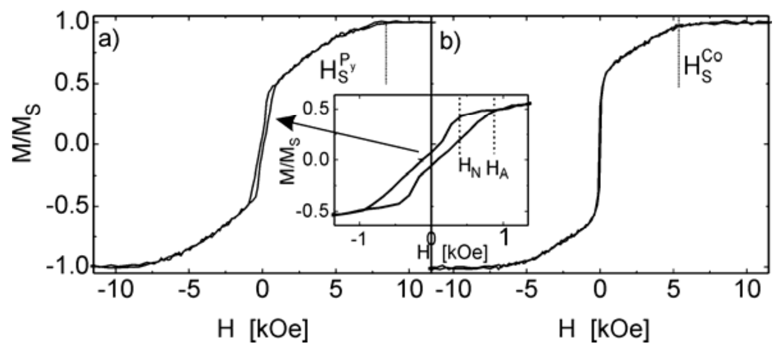

Fig. 1. Exemplary hysteresis loops of MLs with t_{Co} = 0.8 nm and t_{Au} = 2.2 nm, at room temperature in perpendicular (a) and parallel (b) configurations of the applied field

The shape of the central parts of loops, taken with $H_\perp$ (Fig. 1a), which is related to the magnetization reversal of Co layers, strongly suggests the existence of a stripe domain structure. The latter was confirmed by magnetic force microscopy [7]. We characterize the $M(H_\perp)$ loops by the nucleation (H_N), annihilation (H_A), and coercive (H_C) fields (Fig.1a and its inset), which are related to the stripe domain structure in the Co layer and saturation field H_S^{Py} of the Permalloy layers. The most important parameter of the loop shown in Fig.1b is H_S^{Co}, which is directly related to the effective perpendicular anisotropy of Co layers, $H_S = 2K_{eff}/M_S$. In further discussion, we will concentrate on the temperature changes of Co layer magnetic properties because they are crucial for applications.

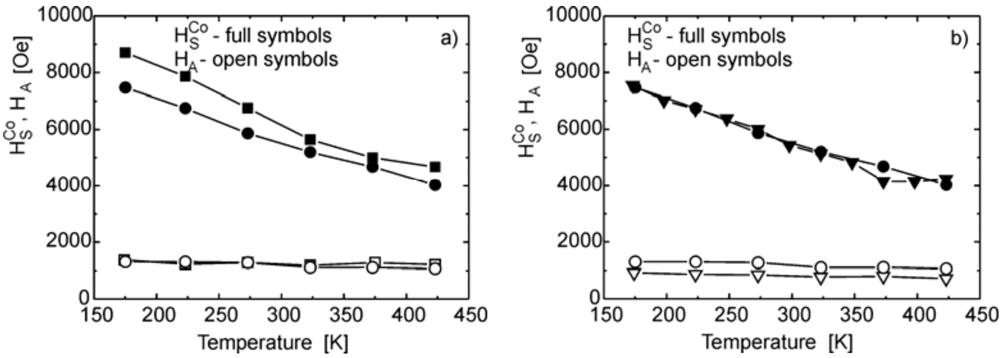

Fig. 2. Temperature dependence of the H_S^{Co} and H_A fields in the MLs:
a) with constant t_{Au} = 1.5 nm and various Co thicknesses: 0.6 nm (squares) and 0.8 nm (circles),
b) with constant t_{Co} = 0.8 nm and various Au thicknesses: 1.5 nm (circles) and 2.2 nm (triangles)

Figure 2 presents the temperature dependences of the saturation and annihilation fields of Co layers, measured in both configurations. H_S^{Co} values clearly diminish when the temperature increases. The values determined for the thinner Co layer, with t_{Co} = 0.6 nm, are systematically higher than for t_{Co} = 0.8 nm, which reflects the enhanced role of surface anisotropy in the former Co layer (Fig. 2a). Moreover, H_S^{Co} has exactly the same value and temperature dependence for samples with different values of t_{Au} and the same t_{Co} (Fig. 2b). This confirms our assumption of weak coupling between ferromagnetic layers, and additionally indicates a very good reproducibility of the parameters of our sputtered MLs. A slight decrease in H_A with temperature is negligible in comparison to H_S^{Co} changes. It should be stressed that, despite perpendicular anisotropy diminishing with T, the difference between H_S^{Co} and H_A is large enough to preserve the Co easy axis perpendicular to the sample plane over the whole T range.

Figure 3 shows the temperature dependence of H_N and H_C for MLs, (i) with different t_{Co} (Fig. 3a) and constant t_{Au} = 1.5 nm, and (ii) with different t_{Au} (Fig. 3b) and constant t_{Co} = 0.8nm. In all cases, H_N slightly increases with T. Thus, considering the weak decrease of $H_A(T)$ (Fig. 2), the difference ΔH between these fields, at which the nucleation (H_N) and annihilation (H_A) of stripe domains in Co layers takes place ($\Delta H = H_A - H_N$), diminishes with increasing temperature.

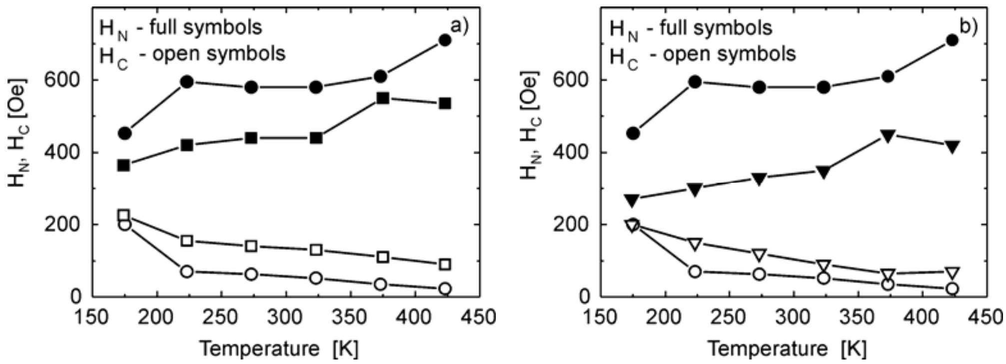

Fig. 3. Temperature dependences of the H_N and H_C fields in the same MLs as in Fig. 2

For instance, ΔH decreases from 1000 to 700 Oe when T increases from 175 to 425 K for MLs with t_{Co} = 0.6 nm and t_{Au} = 1.5 nm. This tendency (as well as the decrease of $H_C(T)$) is related mainly to the temperature dependence of Co perpendicular anisotropy. The influence of other effects, however, such as the diminishing role of domain wall pinning centres at higher T, can also be substantial. It should also be noted that both the decrease of Co thickness (compare results for MLs with t_{Au} = 1.5 nm and t_{Co} = 0.8, 0.6 nm) and increase of Au spacer thickness (compare MLs with t_{Co} = 0.8 nm and different values of t_{Au}: 1.5 and 2.2 nm) leads to diminishing H_N values in the entire T range. This effect, in our opinion, is related mainly to magnetostatic (dipolar) coupling originating from the dense domain structure [8]. For the studied MLs, the values of H_N and H_A indicate the presence of stable stripe domains up to 425 K, which is important from the application point of view.

4. Conclusions

The temperature dependences of magnetic properties in sputtered $[Ni_{80}Fe_{20}(2nm)/Au(t_{Au})/Co(t_{Co})/Au(t_{Au})]_{10}$ MLs with t_{Au} = 1.5, 2.2 nm and t_{Co} = 0.6 and 0.8 nm was investigated in the range 175–425 K. It was shown that the effective perpendicular anisotropy of Co layers, which is the most important parameter for applications, diminishes almost linearly with increasing T. It remains sufficiently high in the investigated T range, however, to ensure that the easy axis of Co is perpendicular to the sample plane. This implies a good stability of stripe domain structure. Thus the studied MLs are promising candidates for applications such as magnetic storage media with perpendicular arrangements of bit cells.

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