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Changes of Structure and Magnetic Properties of $(\mathrm{Ni}_{80}\mathrm{Fe}_{20}/\mathrm{Au}/\mathrm{Co}/\mathrm{Au})_N$ Multilayers as a Function of Repetition Number N

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The influence of repetition number N on magnetoresistance, magnetic reversal and structure of sputtered $(\mathrm{Ni}_{80}\mathrm{Fe}_{20}/\mathrm{Au}/\mathrm{Co}/\mathrm{Au})_N$ multilayers was investigated. The multilayers are characterized by in-plane ($\mathrm{Ni}_{80}\mathrm{Fe}_{20}$) and out-of-plane (Co) magnetic anisotropy of ferromagnetic layers and show considerable magnetoresistance effect ($\Delta R/R$) of the giant magnetoresistance type. Increased N results in an enhancement of $\Delta R/R$ from about 0.5% for $N = 1$ up to above 5% for $N = 15$. This enhancement is caused by: diminishing the role of electron scattering at the surfaces, decreasing the effect of structural imperfection and the lack of the perpendicular anisotropy of Co layer in the first period. The interpretation is corroborated by low $\Delta R/R$ value observed for $N = 1$ and an evolution of the $\Delta R(H)/R$ dependence with increasing N. The anisotropy field of Co layers also increases with N.

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1. Introduction

Multilayered structures consisting of layers with alternating out-of-plane (perpendicular) and in-plane anisotropy could find application as magnetic field sensors [1, 2] and spin-transfer oscillators [3]. We have shown previously that sputtered $[\mathrm{NiFe}/\mathrm{Au}/\mathrm{Co}/\mathrm{Au}]_N$ multilayers (MLs) are an example of these systems and show a significant giant magnetoresistance (GMR) effect with a linear $R(H)$ dependence [2].

The aim of this study is to determine and explain the changes of magnetic properties and structure of $(\mathrm{Ni}_{80}\mathrm{Fe}_{20}/\mathrm{Au}/\mathrm{Co}/\mathrm{Au})_N$ MLs with different N.

2. Experimental

A set of [NiFe-2 nm/Au-3 nm/Co-0.8 nm/Au-3.0 nm]$_N$ MLs with different repetition number $N = 1 \div 15$ was deposited onto Si(100) wafers using UHV magnetron sputtering [2]. The structure of MLs was determined using high angle X-ray diffraction (XRD) and X-ray reflectometry (XRR). The magneto-resistance and magnetization reversal processes were studied for the magnetic field applied both perpendicularly and parallel to the sample plane, $H \leq 18$ kOe. The $\Delta R/R(H)$ dependence was calculated using the formula: $\Delta R/R(H) = [R(H) - R(18 \text{ kOe})]/R(18 \text{ kOe}) \times 100\%$, whereas $\Delta R/R$ denotes the maximum value determined from the $\Delta R/R(H)$ dependence and is called the MR amplitude.

3. Results and discussion

Figure 1a presents exemplary MR curves for the MLs with different N. The values of $\Delta R/R$ determined from these curves are shown in Fig. 1b. It is easy to observe that both the character of $R(H)$ dependence and its amplitude $\Delta R/R$ change clearly as a function of N. There are many possible explanations. Firstly, the changes can result from increasing contribution of elastic scattering of electrons on the growing number of interfaces and accompanied diminishing role of non-elastic scattering of electrons on outer interfaces. This allows us to explain the effect of $\Delta R/R$ saturation with N which arises when a total thickness of MLs is larger than the mean free path of electrons. Secondly, the changes of $R(H)$ could be due to variations of interface microstructure with N. Particularly important is that the first period of ML can have disturbed microstructure as compared to the others and thus have different magnetic properties. The character of $\Delta R/R(H)$ dependence and small value of $\Delta R/R$ suggest that in MLs with $N = 1$ cobalt layer does not have effective perpendicular anisotropy in contrast to the other Co layers

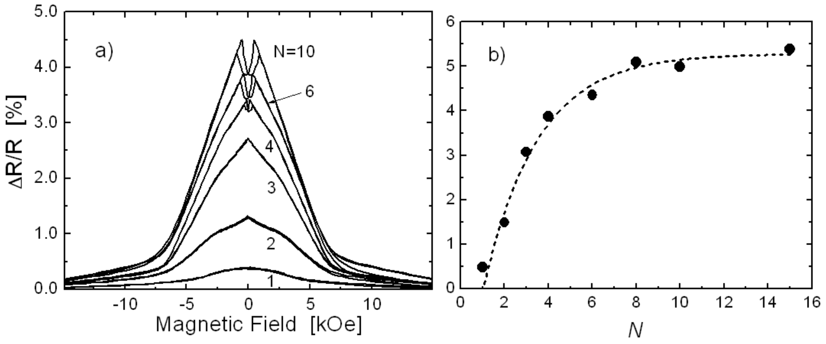

Fig. 1. (a) MR curves for MLs with different N measured with magnetic field applied perpendicularly to the sample plane, (b) MR amplitude versus N. Curves for $N = 8$ and 15 are omitted as they are very similar to the curve for $N = 10$.

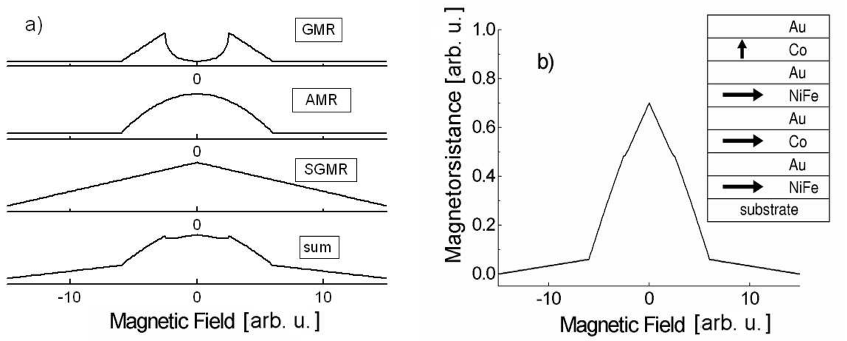

Fig. 2. Schematic simulations of MR curves for MLs with: (a) $N = 1$ (Co and NiFe layers have in-plane anisotropy) and (b) $N = 2$.

in MLs with $N \geq 2$. If the first Co layer had perpendicular anisotropy then the $\Delta R/R(H)$ dependence would be quite different [2]. However, the observed $R(H)$ dependence for MLs with $N = 1$ can be qualitatively explained if the following contributions to MR are considered: (i) the GMR type related to magnetization reversal of the Co and NiFe layers having in-plane anisotropy (then quasi- simultaneous reversals of layers result in small GMR effect), (ii) the anisotropic MR (AMR), (iii) MR caused by superparamagnetic precipitations (SGMR) (Fig. 2a). The two latter contributions, usually negligible, become important when the GMR is small ($< 1\%$). If this assumption is correct then it should be reflected in the MR curves for small N. This indeed takes place and is schematically shown in Fig. 2b for MLs with $N = 2$. During simulation of MR curves we have assumed that the second Co layer (in second period) shows effective perpendicular anisotropy and the first Co layer have in-plane anisotropy as shown in the inset. Adding up contributions to GMR from first and second periods of MLs, we obtain a characteristic kink on the MR curve. The kink is clearly observed experimentally not only for MLs with $N = 2$ but also for $N = 3$, 4. Since the GMR amplitude increases with growing N we observe a gradual reduction of the influence of the first period on the MR curves. For MLs with $N \geq 8$ the shape of the $R(H)$ dependence does not appreciably change and is similar to that of earlier studied MLs with $N = 10$, 15 [2]. The saturation field of Co layers which is a measure of perpendicular anisotropy increases with growing N (Fig. 3). This increase indirectly confirms an evolution of microstructure of MLs. It seems that the changes influence mainly interfaces between Co and Au. Most probably it leads to an increase in surface anisotropy with growing N. Saturation field of NiFe layers does not depend on N (Fig. 3).

XRD studies show that our MLs have good periodic structure, are polycrystalline and show (111) texture. Normalized profiles of XRD are shown in Fig. 4. It is worth noting that the profile for MLs with $N = 3$ shows all features typical of profiles for large N. Even the profile for $N = 2$ is similar to the typical one. Thus, it seems that only a crystalline structure of the first period is significantly dis-

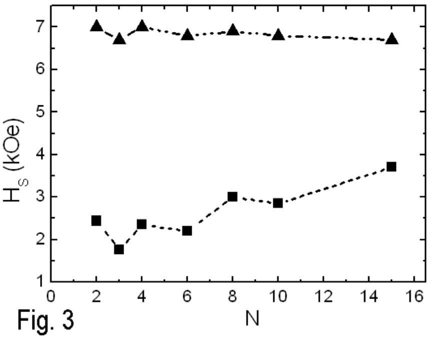

Fig. 3

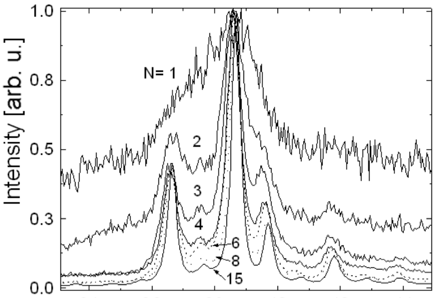

Fig. 4

Fig. 3. Saturation fields H_S^{Co} (■), H_S^{NiFe} (▲) of Co and NiFe layers measured in a magnetic field applied parallel and perpendicularly, respectively.

Fig. 4. Normalized high-angle XRD profiles measured for the MLs with different N.

turbed. As a gradual increase in peaks intensity relative to background is clearly visible, this conclusion is not decisive. XRR profiles confirm very good chemical modulation of MLs also for small $N \geq 1$. Preliminary simulations of the XRR profiles indicate that structural quality of the first period is similar to the others. Summarizing, the change of magnetic properties of MLs with N, well documented by the MR studies, can be hardly correlated with results of standard XRD and XRR analyses.

Acknowledgments

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