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Magnetic anisotropy of the ultrathin Fe layers in Fe/NiFe/Fe/Cu multilayers and their effect to the magnetoresistance

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Abstract

The effects of the deposition of ultrathin ^{57}Fe layers on both sides of the NiFe layers in NiFe/Cu multilayers were investigated by focusing on their structural, magnetic and magnetoresistance properties. Conversion electron Mössbauer spectroscopy measurements showed an out-of-plane magnetic anisotropy of the Fe layers. The magnetoresistance curves showed an unusual shape, where up to three peaks were observed. Eight variables computer simulations, based on a phenomenological model that considers bilinear and biquadratic couplings between layers with cubic and in-plane uniaxial anisotropies, were used in order to calculate the best-fitting magnetization curves for the NiFe/Cu and Fe/NiFe/Fe/Cu multilayers. Both model and Mössbauer spectroscopy results showed that it is the rotation of the Fe magnetic moment from out-of-plane to in-plane orientation that provokes the unusual magnetoresistance curve shape. The observed reduction of the magnetoresistance amplitude with the addition of one monolayer of Fe in the NiFe/Cu multilayer was attributed to a less-effective spin-dependent scattering that occurs at Fe/Cu and Fe/NiFe interfaces than at the NiFe/Cu interfaces.

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1. Introduction

Since the discovery of the giant magnetoresistance in antiferromagnetically coupled or in uncoupled multilayers [1–4], a lot of experimental and theoretical work has been carried out on such systems. From the application point of view, the efforts are concentrated to find systems with weak magnetic interlayers coupling in order to obtain high sensitivity to external fields, which has motivated studies of the interlayer coupling in multilayers.

We have recently investigated the magnetic and magnetoresistive properties of Co/NiFe/Co/Cu multilayers prepared by magnetron sputtering [5,6]. The increase of the magnetoresistance (MR) amplitude, provoked by Co deposition at the NiFe/Cu interfaces, has been attributed to the interfacial spin-dependent scattering due to the increase of the magnetic order at the interfaces.

In the present paper, in order to investigate the role of the interfacial Fe layers, we carried out a detailed study on the magnetic, structural, and magnetoresistive properties of NiFe/Cu and Fe/NiFe/Fe/Cu multilayers. Here, contrary to the case of Co deposited at the NiFe/Cu interfaces, the Fe layers showed an out-of-plane magnetic anisotropy, and unusual shape of the magnetoresistance curves was observed. A reentrant magnetoresistance curves shape [7], i.e., MR showing a minimum at zero field, has been found in single crystal NiFe/Cu film, when the magnetic field is applied along the [110] direction in the sample plane. These authors argued that this minimum is caused by the combined effect of the magnetocrystalline anisotropy and bilinear as well as biquadratic exchange couplings. However, a normal-cusped MR shape is found when the field is applied along the easy axis direction for this multilayer. In the present work, a similar

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reentrant behavior is unlikely to occur since the systems studied are textured polycrystallites, and indeed our MR curves do not show minima at zero field. A phenomenological model, that takes into account the magnetocrystalline anisotropies of the magnetic layers as well as their bilinear and biquadratic interactions, was used to simulate the magnetization curves of such multilayer structures. Here, the unusual MR shape will be discussed focusing on the rotation of the Fe magnetic moment from out-of-plane to in-plane when the applied magnetic field is varied.

2. Experimental procedures

Py/Cu and Fe/Py/Fe/Cu multilayers (here Py denotes $Ni_{81}Fe_{19}$) were deposited by magnetron sputtering in 0.27 Pa Ar atmosphere with base pressure before depositing better than 6.7×10^{-6} Pa. The Cu and Fe layers were obtained by direct current (dc) sputtering at a rate of 7.2 nm/min and 12.0 nm/min, respectively, and the Py layer was obtained by radio frequency sputtering at 6.0 nm/min. The substrate was Si(100) covered with a native SiO_2.

The compositions of the films were Py 4.3 nm/Cu 0.9 nm/(Py t_{Py}/Cu 0.9 nm)$_{20}$/Py 1.6 nm for $t_{Py}=1.6$ and 4.3 nm. These samples, in what follows, will be referred as to Py_{16} and Py_{43}, respectively. Also, the sequence Py 4.3 nm/Fe 0.25 nm/Cu 0.9 nm was initially grown, followed by deposition of a (Fe 0.25 nm/Py t_{Py}/Fe 0.25 nm/Cu 0.9 nm)$_{20}$ multilayer ($t_{Py}=1.6$ and 4.3 nm), and finally of a Fe 0.25 nm/Py 1.5 nm layer. Laminae of ^{57}Fe were put around the erosion area of the Fe target to obtain a preferential ^{57}Fe during this deposition. These two samples will be referred as to $FePy_{16}Fe$ and $FePy_{43}Fe$, respectively, and their Fe layers are enriched with ^{57}Fe. A schematic view of these multilayers is shown in Fig. 1.

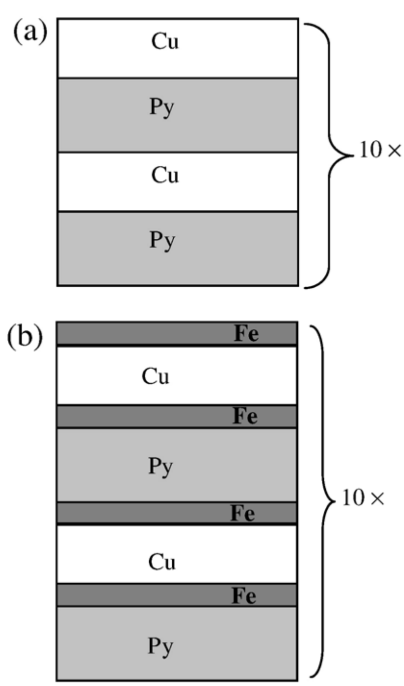

Fig. 1. Schematic view of the multilayers referred as to: (a) Py_{16} ($t_{Py}=1.6$ nm), Py_{43} ($t_{Py}=4.3$ nm); (b) $FePy_{16}Fe$ ($t_{Py}=1.6$ nm), $FePy_{43}Fe$ ($t_{Py}=4.3$ nm).

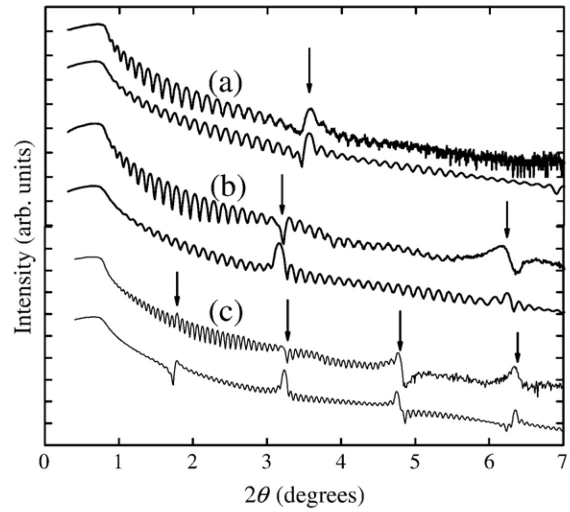

Fig. 2. Small angle reflectivity spectra for Py_{16} (a), $FePy_{16}Fe$ (b), and $FePy_{43}Fe$ (c), where the upper spectrum of each pair represents the measured data, and the other the simulation results. The curves have been displayed vertically for clarity.

The samples' magnetization was measured with an alternating gradient force magnetometer. The in-plane magnetoresistance data were extracted using a dc four-point-probe method (dc current amplitude ~ 1 mA). Conversion electron Mössbauer spectroscopy (CEMS) was performed using a constant acceleration electromechanical drive system, a multichannel analyzer, and a He–CH_4 proportional counter. ^{57}Co in rhodium was used as a Mössbauer source. This system was calibrated with Fe metal. A Philips X'Pert θ–2θ difractometer employing Cu Kα radiations was used to obtain the reflectivity scans. For their quantitative analysis, a commercial software package, WINGIXA by Philips, was used. All measurements were performed at room temperature.

3. Results and Discussion

Some of the reflectivity data for the multilayers are shown in Fig. 2. One notes a presence of Kiessig fringes and peaks associated to the superlattice Bragg peak (indicated by arrows). The WINGIXA reflectivity data fittings are shown in this figure as well. Since the atomic scattering factors of Py, Cu and Fe are very close, these fittings are not so good. The values of the root-mean-square roughness for the interfaces in the Py_{16} multilayer are shown in Table 1 and for the ones in $FePy_{16}Fe$ and $FePy_{43}Fe$ multilayers are shown in Table 2. One can note higher roughness values at Py/Cu and Cu/Py interfaces than at the others ones. Using this technique, the roughness and interdiffusion are

Table 1
Values of the root-mean-square roughness at the interfaces for Py_{16} multilayer

Sample	σ (nm) Py/Cu	σ (nm) Cu/Py
Py_{16}	0.50 ± 0.05	0.45 ± 0.05