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HIGH-QUALITY Ni-Fe/Cu MULTILAYER FILMS WITH ANTIFERROMAGNETIC COUPLING

F. STOBIECKI, J. DUBOWIK, T. LUCIŃSKI, B. SZYMAŃSKI,

Institute of Molecular Physics, Polish Academy of Sciences
Smoluchowskiego 17, 60-179 Poznań, Poland

H. ROHRMANN, K. RÖLL

University of Kassel, FB Physik, 34109 Kassel, Germany

AND M. SCHMIDT

Institute of Physics, A. Mickiewicz University, 60-780 Poznań, Poland

We report structural and magnetic properties of $\text{Ni}_{83}\text{Fe}_{17}/\text{Cu}$ multilayer films with various buffer layer and sublayer thicknesses of copper d_{Cu} and Permalloy d_{Py} deposited by face-to-face sputtering. The following features prove a good quality of our films: a well-layered structure, complete antiferromagnetic coupling with a low coupling strength ($2 \times 10^{-5} \text{ J/m}^2$ for $d_{\text{Cu}} = 1 \text{ nm}$ and 10^{-6} J/m^2 for $d_{\text{Cu}} = 2.1 \text{ nm}$) and a low coercive field which make them attractive for possible applications as giant magnetoresistance sensors.

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Recently, there has been a considerable interest in magnetic and magneto-transport properties of Py/Cu and Py/Au (Py = Permalloy) multilayers (Mls) [1-6]. Much of this interest has focused on developing Mls with the highest possible giant magnetoresistance (GMR), a low antiferromagnetic coupling strength (J_{AF}) with a high fraction of antiferromagnetically (AF) coupled regions $F_{\text{AF}} = (1 - M_{\text{R}}/M_{\text{S}})$ (M_{R} , M_{S} are the remanence and saturation magnetization) and a low coercive field H_{C} . Since the results obtained by several authors with the use of different deposition techniques vary [1-5], the magnetic properties of Py/Cu Mls seem to be very sensitive to the deposition and growth conditions. In the present paper we report on magnetic and structural properties of $\text{Si}(100)/\text{B}/(\text{Py}/\text{Cu})_N$ Mls (B — buffer layer with a thickness d_{B} , Py = $\text{Ni}_{83}\text{Fe}_{17}$, N — number of periods) with various sublayers thicknesses of Cu d_{Cu} and Permalloy (d_{Py}) obtained by the face-to-face sputtering technique [7]. The magnetic properties of the samples were determined from the hysteresis loops measured with a vibrating sample magnetometer (VSM) and magneto-optical Kerr effect (MOKE). The well-defined

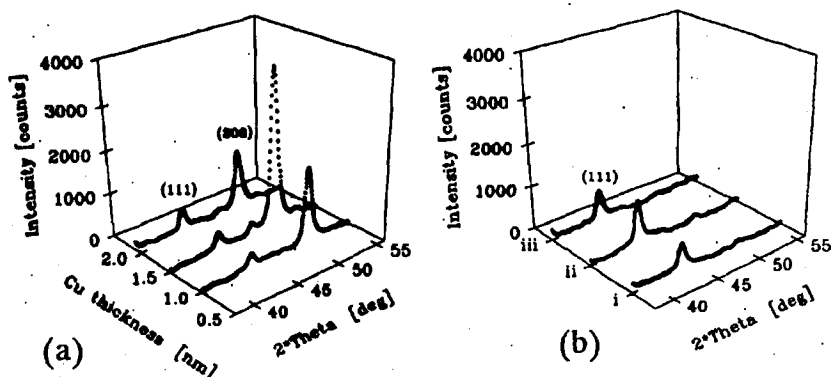


Fig. 1. X-ray diffraction patterns for: (a) Si(100)/Cu - 20 nm/(Py - 2.0 nm/Cu - d_{Cu})₁₀₀, (b) (i) Si(100)/(Py - 2.0 nm/Cu - 2.1 nm)₁₀₀, (ii) Si(100)/SiO₂/Cu - 20 nm/(Py - 2.0 nm/Cu - 2.1 nm)₁₀₀, (iii) Si(100)/Py - 5 nm/(Py - 2.0 nm/Cu - 2.1 nm)₁₀₀.

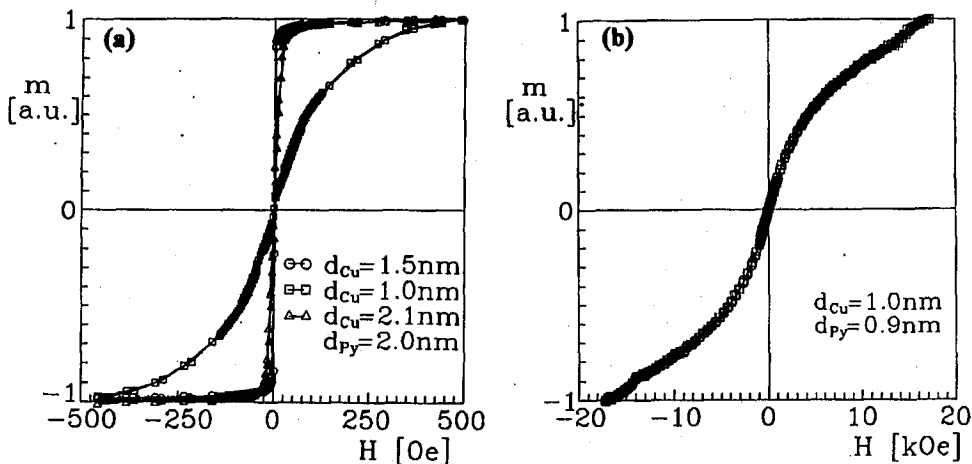


Fig. 2. (a) The fraction $1 - M_R/M_S$ of antiferromagnetically coupled part of the multilayer as a function of Cu sublayer thickness d_{Cu} for MLs: (i) Si(100)/Cu - 20 nm/(Py - d_{Py} /Cu - d_{Cu})₁₀₀, (ii) Si(100)/SiO₂/Py - 5 nm/(Py - d_{Py} /Cu - d_{Cu})₄₀, (iii) Si(100)/(Py - d_{Py} /Cu - d_{Cu})₁₀₀, (iv) Si(100)/SiO₂/Cu - 20 nm/(Py - d_{Py} /Cu - d_{Cu})₁₀₀, (v) Si(100)/Cu - 20 nm/(Py - d_{Py} /Cu - d_{Cu})₃₀, (vi) Si(100)/Py - 5 nm/(Py - d_{Py} /Cu - d_{Cu})₁₀₀, $1 \leq d_{Py} \leq 5$ nm. (b) Saturation magnetic moment m_S per surface area S and number of periods N as a function of d_{Py} for (Ni₈₃Fe₁₇/Cu) _{N} multilayers.

layered structure of our MLs was confirmed by the low- and the high-angle X-ray diffraction (LAXRD and HAXRD). Figure 1 shows the Cu K_α HAXRD patterns for selected Si(100)/B/(Py/Cu)₁₀₀ MLs. The samples with Cu buffer layer ($d_B = 20$ nm) deposited onto Si(100) substrate cleaned by HF-dip exhibit the

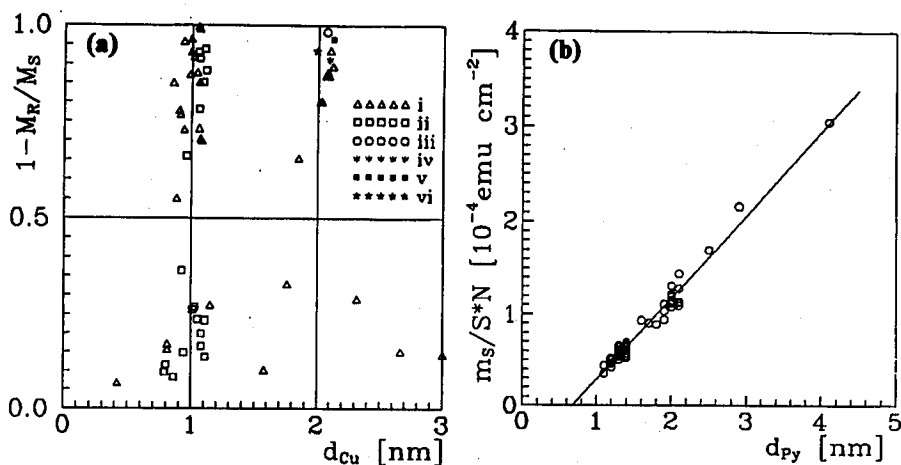


Fig. 3. Magnetization versus in-plane magnetic field H for Si(100)/Cu – 20 nm/(Py – d_{Py} /Cu – d_{Cu})₁₀₀ Mls (magnetic moment m at 1800 Oe for the sample with $d_{Py} = 0.9$ nm is 10 times smaller than the saturation moment for the samples with $d_{Py} = 2$ nm).

pronounced (200) diffraction from both Py and Cu sublayers (Fig. 1a). In contrast to Nakatani results [2], the domination of the (100) over the (111) texture for our films is independent of the Py and Cu sublayer thicknesses. For the Mls grown in other conditions, i.e., either without any HF-dip or with Py buffer, or without any buffer, the (200) reflection vanishes almost completely (Fig. 1b). It can be seen from Fig. 2a that the high values of the antiferromagnetic coupled fraction exceeding 0.95 were achieved both for the films with distinct (100) preferred orientation and for the films with the weak (111) texture. For all the samples, maxima in F_{AF} have been observed for $d_{Cu} = 1$ and 2.1 nm. The AF exchange coupling strength $J_{AF} = M_S H_S d_{Py} / 4 (H_S - \text{saturation field})$ was determined from the hysteresis loops. For the films with $d_{Py} \geq 1$ nm, $J_{AF} = 2 \times 10^{-5} \text{ J/m}^2$ at $d_{Cu} = 1$ nm, and $J_{AF} = 10^{-6} \text{ J/m}^2$ at $d_{Cu} = 2.1$ nm independently of d_{Py} and the actual texture. For the films with $d_{Py} \geq 1$ nm, the hysteresis loops are typical of Mls with ferro- or antiferromagnetic coupling depending on d_{Cu} and exhibit very small $H_C \leq 1$ Oe (Fig. 3a). The hysteresis loops for the samples with $d_{Py} < 1$ nm show a Langevin-like behaviour characteristic of superparamagnetic films (Fig. 3b). It may result from an interface roughness and/or from the composition gradient across the interface. To elucidate the magnetic behaviour of the Py/Cu interfaces, the saturation magnetic moment per surface area as a function of d_{Py} was plotted in Fig. 2b. The magnetization determined from the curve slope is $M_S = 880 \text{ G}$, a typical value for the bulk Py. The offset from the origin (0.6 nm) can be interpreted as a thickness of two nonferromagnetic interfaces (with zero moment at room temperature) located at each side of the Py sublayers. Superparamagnetic behaviour of Py/Cu Mls with $0.6 < d_{Py} < 1$ nm at room temperature may be tentatively explained as resulting from both magnetically inactive interfaces and a possible interface roughness of about 0.4 nm. For lower temperatures, such

films show ferromagnetic behaviour which was confirmed by FMR measurements. In conclusion, the Py/Cu MIs deposited by the face-to-face sputtering technique show the structural and magnetic properties interesting for possible applications: (i) a well-defined layered structure and oscillatory behaviour in interlayer exchange coupling, (ii) complete AF coupling ($M_R/M_S \approx 0$) of a small value ($2 \times 10^{-5} \text{ J/m}^2$ for $d_{\text{Cu}} = 1 \text{ nm}$ and 10^{-6} J/m^2 for $d_{\text{Cu}} = 2.1 \text{ nm}$) for the MIs regardless of a preferred structural orientation.

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