Effect of Au thickness on magnetoresistance and Kerr spectra in Co/Au multilayers

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Abstract

Magnetotransport and magneto-optical (MO) results on sputtered Co/Au multilayers at 300 K are reported. The thickness of Co layer was fixed at \( t_{Co} = 1 \) nm while that of Au, \( t_{Au} \), varied between 2.2 and 4 nm. Two giant-magnetoresistance (GMR) maxima were observed for \( t_{Au} \approx 2.4 \) and 3.9 nm. For \( t_{Au} \approx 2.4 \) nm the coercive field and switching fields are 7 and \( \pm 30 \) Oe, respectively. MO Kerr hysteresis loops and spectra were measured in polar and longitudinal configurations. The loops provide evidence for the exchange coupling at the first GMR maximum and interface magnetic anisotropy for \( t_{Au} < 3 \) nm. © 1999 Elsevier Science B.V. All rights reserved.

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The only system of sputtered TM/Au multilayers (TM = magnetic material) that exhibits oscillatory magnetoresistance (GMR) with a period of Au layer thickness \( t_{Au} \approx 1.2 \) nm, was reported in untextured NiFe/Au films [1] while the most recent results for Co/Au sputtered MLs [2] are related with interesting magneto-optical (MO) properties. In the present study, Co/Au MLs grown by magnetron sputtering, were found to show a GMR oscillation with \( t_{Au} \) and a sensible change in GMR ratio per unit field for the [Co(1 nm)/Au(2.4 nm)]\(_{30}\) composition. A series of magnetron sputtered [Co(1 nm)/Au(\( t_{Au} \))\(_{30}\) MLs, nominal \( t_{Au} = 2.2, 2.4, 2.5, 3, 3.6, 3.9 \) and 4 nm, has been deposited on Si(001) covered with 100 nm thick SiN\(_x\) buffer. The samples were characterized by X-ray diffraction and cross-section TEM. Sharp interfaces and an (111) preferred orientation are evident along the growth direction [3]. All the samples were studied by polar and longitudinal Kerr spectroscopy. The present paper reports on magnetotransport (MR) and selected magneto-optical (MO) investigations.

The GMR measurements were performed at 300 K with the four-point-probe method, using a DC current of 1 mA for two directions of the applied field \( H \): first with \( H \) lying in the film plane parallel to current (\( H \parallel I \)) and then with \( H \) applied perpendicular to film (\( H \perp I \)). All MR measurements were performed by first applying the maximum positive field \( H \) of 4 kOe and then completing the loop.

In Fig. 1 are shown the GMR curves for the [Co(1 nm)/Au(2.4 nm)]\(_{30}\) sample. In the (\( H \parallel I \)) configuration the coercive field \( H_c \), that is the field where the GMR maximum is observed, and the switching field \( H_s \), that is the field where the GMR ratio approaches its lower value from both sides around \( H_c \), are 7 and \( \pm 30 \) Oe, respectively. For comparison the observed values in the trilayers [4,5] are \( H_c \approx 500 \) Oe and \( H_s \approx \pm 50 \) Oe. This order of magnitude improvement of \( H_c \) brings the Co/Au MLs in the area of applications for GMR sensors.

In Fig. 2 are shown the MR ratio, \( [R_{max} - R(H_s)]/R(H_s) \), \( H_s \) and \( H_c \) as a function of \( t_{Au} \) with \( H \parallel I \). For \( t_{Au} > 2 \) nm, two MR maxima were observed for \( t_{Au} \approx 2.4 \) and 3.9 nm ( ~ 10 and 16 Au atomic planes),
Fig. 1. GMR measurements in [Co(1 nm)/Au(2.4 nm)]_{30} MLs. On the left is plotted the GMR loop with \( H \) lying in the "lm plane parallel to current flow (\( H \parallel I \)). On the right is plotted the transverse field (\( H \perp I \)) GMR loop with \( H \) perpendicular to film.

Fig. 2. Variation of the GMR ratio (squares), \( H_\parallel \) (triangles) and \( H_\perp \) (circles) with \( t_{Au} \) for \( H \) applied parallel to current flow direction.

respectively, attributed to the GMR effect. The existence of a residual GMR ratio about 0.4\% in \( t_{Au} \) regions where the interlayer coupling is expected to be ferromagnetic is attributed to intralayer ("bulk") spin-dependent scattering [6]. These oscillations differ from those observed in epitaxial Co/Au(1 1 1)/Co trilayers [4] where GMR maxima occur for \( t_{Au} \approx 5, 9 \) and 14 atomic planes (1.2, 2.1 and 3.3 nm). In the epitaxial trilayers the mean oscillation period is 4.5 atomic planes in agreement with the theoretical prediction [6]. A comparison \( t_{Au} \) values at the GMR maxima indicate that our first GMR peak, at \( \sim 10 \) atomic planes of Au, is near the second GMR maximum of the trilayer in Ref. [4]. For \( t_{Au} \approx 2.4 \) nm the GMR effect is mainly due to interfacial spin-dependent scattering while for thicker Au layers the increase of magnetic decoupling between adjacent Co layers enhances the contribution of intralayer spin-dependent scattering. The variation of \( H_\parallel \) and \( H_\perp \) fields with \( t_{Au} \) (Fig. 2), obtained from the GMR curves with \( H \parallel I \), are in agreement with the last argument.

In Figs. 3 and 4 are shown the longitudinal Kerr-effect hysteresis loops. At the GMR minima (\( t_{Au} = 2.2 \) and 3.6 nm) they reveal a significant magnetic anisotropy, that may be induced in the Co layers from a high concentration of step edges [7] located at the Co/Au interfaces due to surface reconstruction of the Au (1 1 1) planes. For \( t_{Au} = 2.4 \) nm there is a manifold loop with insignificant residual magnetization, inferring coexistence of the so-called [8,6] "bilinear" and "biquadratic" interlayer coupling terms at the first GMR maximum. However, at the second GMR maximum there is a ferromagnetic loop, characteristic for a random distribution of Co magnetic moments (uncoupled layers) that contributes into "bulk-like" spin scattering [6,7].

The polar loops confirmed the presence of the interface-induced anisotropy which reduces the saturation field below 3 kOe, while the coercive field varies between 10 and 65 Oe. The Kerr spectra show a distinct Au plasma edge peak centered near 2.5 eV. A narrowing and reduction in the amplitude of the peak is observed by increasing \( t_{Au} \). These trends were reproduced by computer simulations [9] with the experimental amplitudes about 50\% smaller. This difference can be attributed to extended intralayer and/or interface disorder, located mainly at the ferromagnetic Co layers, and to changes in Au electronic states induced by adjacent Co layers.

In summary, it is shown that magnetron sputtered Co/Au MLs with (1 1 1) texturing display GMR effects, for \( t_{Au} > 2 \) nm, with small saturation and switching...
Fig. 4. Saturated polar Kerr rotation spectra of [Co(1 nm)/
Au(tAu nm)]30 multilayers with a fixed Co thickness, tCo = 1 nm and tAu between 2.2 and 4.0 nm.

fields. Static deposition of the constituents with low rates,
on SiNx buffer layer, seems to enable the development of a considerable fraction of faults in the atomic packing of Co layers along the growth direction. Thus, the observed differences in magnetotransport properties, between the examined here Co/Au MLs and those reported by now, can be attributed to the development of a specific microstructure in the magnetic layers. The practical advantage of the prepared Co/Au MLs is the achievement of a low $H_c$, obtained under deposition conditions requiring less demand on the growth process, that makes possible their use in GMR sensors.

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