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MAGNETORESISTANCE AND MAGNETIZATION STUDIES OF ULTRATHIN Co-Au SANDWICHES AND BILAYERS

P. Beauvillain, P. Bruno, C. Chappert, C. Dupas, F. Trigui, E. Vélú and D. Renard ¹

Institut d'Electronique Fondamentale, CNRS UA 022, Bât. 220, Université Paris Sud, F-91405 Orsay Cedex, France

Abstract. — We compare the hysteresis loops of ultrathin Co films sandwiched in gold obtained by SQUID magnetometry and by magnetoresistance (MR) measurements. The agreement is very good for most of the samples. The MR appears as a very simple method for the determination of coercive fields of these magnetic films.

We have shown previously that magnetoresistance (MR) measurements allow a direct determination of the easy magnetization direction and coercive fields in hcp cobalt films sandwiched in gold down to the monolayer [1, 2]. In the present paper, we check the comparison between the values of magnetization of Co mono- and bilayers directly measured by SQUID magnetometry and deduced from MR.

The samples were prepared by UHV evaporation (10^{-10} Torr) onto a glass substrate. A detailed description of sample preparation and structure determination can be found elsewhere [3, 4]. The Au substrate (thickness 250 Å) is polycrystalline with an atomically flat (111) surface. The Co film grows with an hcp structure, the hexagonal *c* axis being perpendicular to the film. The upper Co/Au interface spreads on about 2 to 3 atomic layers.

In such ferromagnetic films, the total anisotropy arises mainly from a competition between the dipolar shape anisotropy and the crystalline anisotropy [5]. At low thickness ($t < 11.5$ Å) the crystalline anisotropy prevails and the *c* axis perpendicular to the film becomes the easy axis. For $t > 11.5$ Å the easy axis is in the film plane. In real films this picture may be taken as approximately true as long as the interface roughness σ remains small compared to the average thickness t . In ultrathin films where $t \simeq \sigma$ we should on the contrary observe superimposed contributions of areas with different anisotropies.

The MR measurements are described in reference [1]. They are made at room temperature with field up to 0.8 T and in the helium range 1.3-4.2 K with fields up to 5.5 T. Despite the fact that the resistance R is essentially due to the two gold layers, the cobalt hysteresis is clearly seen in the MR $R(H)$ at room and at low temperature. For fields $H > 3$ T a parabolic contribution to $R(H)$ is due to the MR $R_{Au}(H)$ of gold. The difference $\delta R(H) = R(H) - R_{Au}(H)$ exhibits a maximum δR_c for the field H_c . The reduced magneti-

zation M/M_s can be obtained from MR by assuming that the Co contribution is proportional to the number of walls in the magnetic film and thus to M^2 as predicted by a simple model valid only at low M values and for perpendicular magnetizations. We deduce M/M_s from R by the simple empirical formula.

$$M/M_s = \sqrt{(1 - \delta R / \delta R_c)}. \quad (1)$$

If this relation holds, H_c is the coercive field. We thus compare here M/M_s deduced from MR with M/M_s measured by SQUID magnetometry.

Hysteresis curves $M(H)$ have been recorded at 5 K with a commercial SQUID magnetometer at Regensburg University in collaboration with Bayreuther and Lugert. On our laboratory made SQUID magnetometer [6] we have measured dc-demagnetization remanence curves $M_d(H)$ obtained by first applying a positive saturation field to the sample, then an inverse field H and finally measuring the remanent magnetization in zero field. $M_d(H)$ can be also deduced from MR measured in the same conditions. We note H_r the field for which $M_d = 0$.

The agreement is satisfactory for most of the samples, as can be seen in figure 1 for a 15.2 Å Co sandwich, although the easy-axis is in plane in that case. The bilayers exhibit a hysteresis loop much more squared than the sandwiches. These results, and the values of M_r/M_s (Tab. I) show that MR measurements allow to determine easily H_c and M_r/M_s in ultrathin films with an accuracy better than 10 %, in spite of the crudeness of the theoretical treatment. A study of H_c in sandwiches and bilayers as a function of Co thickness t evidences systematic decrease of H_c when increasing t (Fig. 2). For $t = 2$ Å, H_c goes up to 9 300 Oe. Preliminary calculations of the energy of a domain wall *versus* the local thickness of the film have been done with the hypothesis that changes in M are due to domain wall displacements. They show that H_c varies as t^{-n} , with $n > 1$ and give the right order of

¹IOTA, CNRS UA 014, Bât. 503, Université Paris Sud, F-91405, Orsay Cedex, France.

Fig. 1. - Hysteresis loop of a 15.2 Å Co sandwich measured by SQUID and MR at low temperature. The field is parallel to the film.

Fig. 2. - Log-Log plot of the characteristic coercive fields versus the Co thickness t for all the studied samples at low temperature.

Table I. - Reduced remanent magnetization and remanent coercivity H_r parallel to the easy axis for some samples at low temperatures.

MR			SQUID	
t_{Co} (Å)	M_r / M_s	H_r (Oe)	M_r / M_s	H_r (Oe)
4.1		6 000		5 650
5.4	0.90		0.65	3 000
9.5	0.74		0.76	640
15.2	0.56	230 ± 20	0.58	260
bilayer	0.99	1 650	1	1 500
7.5/30/7.5				

magnitude for H_c . Our results are consistent with a t^{-2} variation for H_r and H_c perpendicular to the film and t^{-1} for H_r and H_c parallel. Concerning the maximum relative MR $\delta R_c / R$, we observe an enhancement of this quantity when decreasing t ; the maximum value we obtained was 3 percent for a bilayer. The interface

quality is crucial in that phenomenon and we could not observe any MR in films with important interface roughness.

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