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Letter to the Editor

Inverted and crossed hysteresis loops in Ag/Ni multilayers

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Abstract

We report on the observation of inverted magnetic hysteresis loops in Ag/Ni multilayers. The samples were prepared by triode dc sputtering, at 100 K, with nickel layer thickness of about 8 Å and Ag layer thicknesses ranging from about 5 to 40 Å. The phenomenon was observed in all the samples measured at temperatures larger than 90 K.

1. Introduction

Inverted hysteresis loops have been reported for [Co–O]/Cu and [Co–O]/Al multilayers, and attributed to the interface exchange between Co and Co–O phases [1,2]. In the decreasing part of such loops the magnetization becomes negative when the applied field is still positive, while in the increasing part the magnetization becomes positive when the applied field is still negative. The essential feature of the sample is the existence of a relatively soft material (Co) and a hard one (Co–O). Very recently, a theory based on a demagnetizing field was proposed. The surface charge at the end of the films creates a field, which points to the left when the applied field is pointing to the right. The field acting on the soft material is the difference between the applied field and the demagnetizing field, and can be negative in a positive applied field [3].

In this paper we report on the observation of such a phenomenon in Ag/Ni multilayers prepared by dc sputtering.

2. Experimental

Layers of Ag and Ni were alternately deposited on glass substrates, at 100 K, by dc sputtering, as described elsewhere [4]. Samples Ag_xNi_y, in the following referred as (x, y) where x and y are the layer thicknesses, were grown with deposition rates of 0.98 Å/s for Ag and 0.85 Å/s for Ni. Total thicknesses were of the order of 5 mm, with individual layer thicknesses ranging from about 5 to 40 Å for silver and from 2 to 20 Å for nickel. A detailed structural study for more than 40 samples [4] was performed by using X-ray diffraction. Scattering experiments were carried out using the Co Kα radiation ($\lambda = 1.7903$ Å) in both reflection and transmission geometry.

Magnetic measurements were performed, at temperatures between 5 and 300 K, with a superconduct-

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ing quantum interference device (SQUID) magnetometer at the CEN Grenoble. For the present work, hysteresis loops were taken with in-plane applied magnetic field cycled to the saturation field of 10 kOe.

3. Results and discussion

Large-angle X-ray spectra, taken at 300 K for all the samples (x, y), are characteristic of polycrystalline superlattices with (111)Ag and (111)Ni textures. There is no indication of any deterioration of the sample quality even for the smallest layer thicknesses. Good agreement was obtained between simulated and experimental spectra by supposing a rectangular composition profile with (111) interplanar distances slightly larger than the bulk Ag and Ni values. This hypothesis is also suggested by the 'dead layer' thickness estimated from our magnetization measurements, performed at 5 K, to be about 1 to 2 Å on each side of the Ni layer [5].

Magnetization measurements with magnetic field applied either parallel or perpendicular to the plane of the layers suggest that the easy magnetization axis lies in the layer plane for all the samples. In addition, hysteresis loops and magnetoresistance measurements, performed at 5 K, suggest the existence of an oscillatory magnetic coupling between the Ni layers [6].

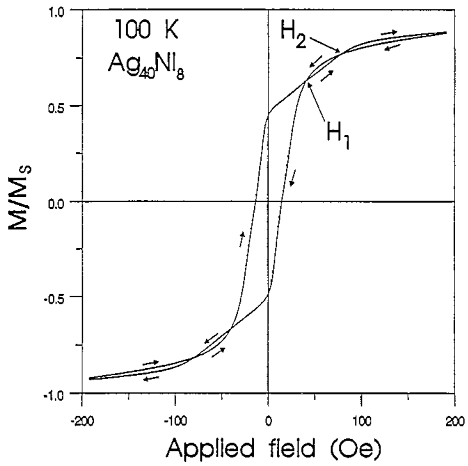

Fig. 1. Typical hysteresis loop taken at 100 K with in-plane applied field. The inversion fields H_1 and H_2 are considered in the text.

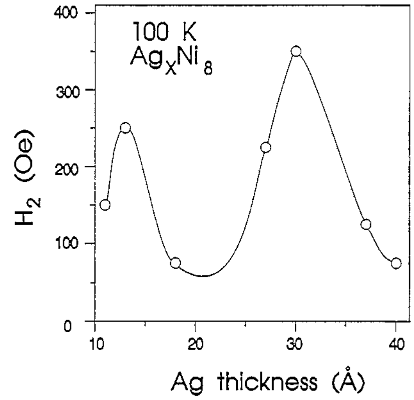

Fig. 2. Inversion field H_2 vs. Ag layer thickness for samples Ag_xNi_8. The solid line is a guide to the eyes.

Magnetization measurements at 100 K, with in-plane applied field, have shown for all the samples with $y = 8$ Å, unusual inverted and crossed hysteresis loops. A typical curve is shown in Fig. 1. As can be seen, there are two pairs of symmetrical crossing points; one at fields near ± 50 G, named H_1, and the other one at fields near ± 75 G, named H_2. The crossing field H_1 is almost the same for all the samples, but the other crossing field, H_2, oscillates as the silver layer thickness changes (Fig. 2). For

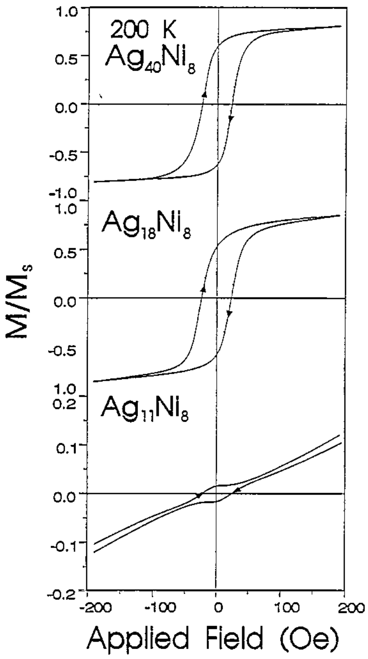

Fig. 3. Hysteresis loops taken at 200 K with in-plane applied field, for the indicated samples.

similar measurements performed at 200 K, the inversion fields are very high (> 2000 Oe), and for low fields, the hysteresis loops are completely inverted (Fig. 3).

The Aharoni's hysteresis loop with small demagnetizing field [3] approach that computed by Gao and O'Shea with no demagnetization [1]. That is to say, the crossing of the increasing and decreasing part of the hysteresis loop is observed for fields that increase with the increasing of the demagnetizing field. In this sense, Fig. 1 and Fig. 3 suggest a temperature dependence for the demagnetizing field in our samples; it increases with the temperature. Yet, the second inversion field, H_2 (Fig. 1), is not considered by the previous works. From the results displayed in Fig. 2, we could speculate about some kind of dependence of this inversion field on the exchange-coupling character of the sample. It is remarkable that the value of H_2 oscillates in phase with that of the saturation field, H_{sat}, measured at 5 K in the same samples, but with the second maximum, at about 30 Å, much more evident as compared to the previous ones [6]. Following this reasoning, we could correlate high H_2 value to antiferromagnetic coupling between the Ni layers, and low H_2 value to ferromagnetic coupling.

4. Conclusion

Magnetization measurements performed on Ag/Ni multilayers show inverted and crossed hysteresis loops taken at temperatures higher than 90 K. An inversion magnetic field was observed, which correlates to the Ag thickness, in a fashion very similar to one observed for the saturation magnetic field. This behavior is, apparently, associated to the magnetic coupling character between the Ni layers. We have no clear explanation for this correlation, but the phenomenon is apparently mediated by the interface. So, it is reasonable to suppose that a start point for an explanation could be the adaptation of the Gao and O'Shear's model, considering each Ag/Ni/Ag sandwich containing three different materials: (i) one magnetically soft, at the central region, named the bulk-like Ni; (ii) on each side of this region there are the interfaces, a mixed Ag–Ni material; (iii) at the external surface of the sandwich there is the non-magnetic Ag. The mixed Ag–Ni material presumably plays a similar role as that played by the CoO in the previously published works [1,2]. In such extended model, the oscillatory magnetic coupling between the Ni layers could play a significant role on the variation of the inversion field H_2.

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