Temperature Dependence of the Magnetization Processes in Co/Al Oxide/Permalloy Trilayers

C. Prados, B. J. Hattink, E. Pina, X. Batllé, A. Labarta, J. M. González, and A. Hernando

***Abstract*—The magnetization process of Co/Al oxide/Py trilayers and its evolution with the temperature have been analyzed. The particular behavior of the Co layers, including the shift of the hysteresis loops and a coercivity increase with the decrease of temperature, is related with the apparition of a CoO layer at the Co/Al-oxide interface.**

***Index Terms*—Exchange anisotropy, magnetic layers, magnetization reversal, spin valves.**

I. Introduction

THE MAGNETORESISTANCE of tunnel junctions where two ferromagnetic electrodes are separated by an insulating layer is the subject of intense research activity [1], [7], [8]. Promising applications in reading heads and in magnetic random access memories have been proposed and nowadays a number of this kind of devices has been developed at the prototype level. Although extensive characterizations of the electric properties of the junctions have been performed since the pioneering work by Julliere [2], few works address the understanding of the mechanisms ruling the magnetization reversal in this kind of trilayer systems. The typical insulating materials in tunnel junctions are oxides and more specifically Al oxide. The aim of this work is to clarify the role of the magnetic layer-oxide interface in the hysteretic behavior of the trilayer. Co/Al–O/Permalloy (Py) trilayers have been fabricated by sputtering. During the growth, a Co oxide layer appears at the interface between the Co and the Al–O. The antiferromagnetic behavior of that Co–O layer modifies drastically the magnetization process of the structure, specially at low temperature.

II. Experimental

The studied samples were trilayers deposited by RF magnetron sputtering onto glass substrates held at room temperature. The discharge gas was Ar at 5×10^{-3} mbar. The first layer was Co (30 nm thick). The insulating layer was Al oxide deposited by oxygen reactive sputtering with a thickness ranging between 2 and 10 nm. The discharge gas during the reactive deposition of the Al-O layers was oxygen up to 2×10^{-3} mbar and Ar up to 5×10^{-3} mbar. The second magnetic layer was 30 nm of Permalloy. Finally, a capping Cu layer was deposited in order to prevent further oxidation.

Calibration of the thickness of the individual layers was carried out by low angle X-ray difractometry. High angle X-ray diffraction analysis revealed that the Al–O layers grows with amorphous structure.

Magnetic characterization was performed by measuring the hysteresis loops in the temperature range from 80K up to 300K with a vibrating sample magnetometer, after cooling the samples from RT under an applied magnetic field of 1000 Oe.

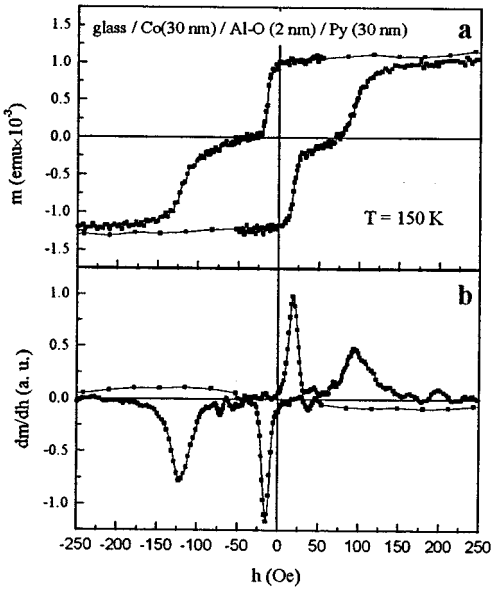

Fig. 1. Hysteresis loop (a) and magnetic moment derivative (b) of the Co (30 nm)/Al–O (2 nm)/Py (30 nm) sample at 150K. The width of the derivative peaks in (b) are related to the dispersion in reversal fields.

III. Results and Discussion

The as-deposited samples exhibited well-developed in-plane easy axes. The origin of this magnetic anisotropy is attributed to the existence of a magnetic field within the deposition chamber during the growth of the samples. All the presented magnetic characterization was performed by applying the magnetic field and measuring the magnetic moment along those easy directions.

Fig. 1(a) shows a typical hysteresis loop, measured at 150K and after cooling the sample from room temperature under an applied field of 1000 Oe, for one of the trilayers (the sample with 2 nm of Al–O). The loop exhibit a stepped shape which

Manuscript received February 10, 2000.

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Publisher Item Identifier S 0018-9464(00)08106-1.

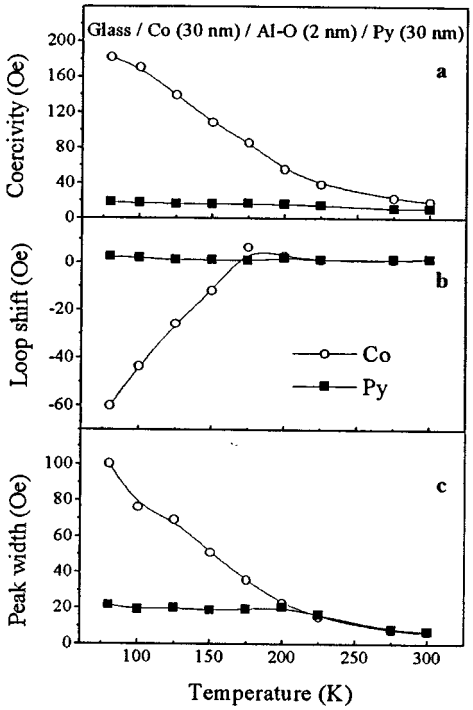

Fig. 2. Evolution with the temperature of the coercivity (a), loop shift (b)-and dispersion of the reversal field (c) for both, Co and Py layers, in the Co (30 nm)/Al–O (2 nm)/Py (30 nm) sample. The derivative peak width for Co displayed in the figure corresponds to negative fields.

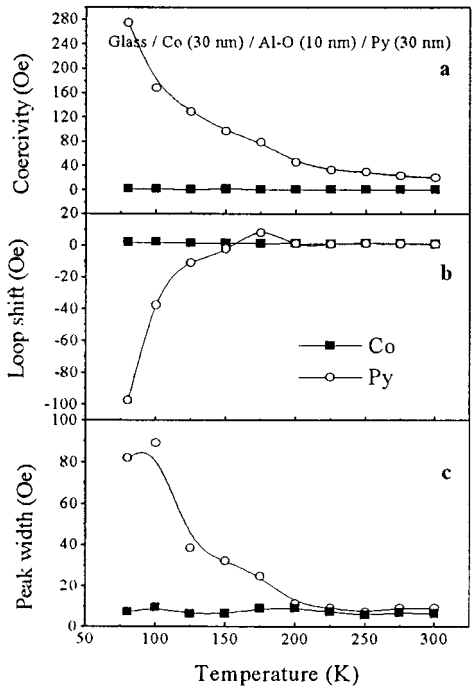

Fig. 3. Evolution with the temperature of the coercivity (a), loop shift (b) and dispersion of the reversal field (c) for both, Co and Py layers, in the Co (30 nm)/Al–O (10 nm)/Py (30 nm) sample. The derivative peak width for Co displayed in the figure corresponds to negative fields.

it is characteristic of two independent magnetization processes. In this case, the Py and the Co layers are demagnetized independently. This behavior has been observed in all the trilayers studied, even with the thinnest Al-oxide insulating layer (2 nm), and at all the temperatures. In order to determine the magnetic properties of the different components of the structure, we have analyzed the magnetic moment derivative [Fig. 1(b)] with respect to the applied field. This allowed us to measure the coercive field and loop shift for each magnetic layer of the structure. The hysteresis loops measured at high temperature exhibit, for both magnetic phases, symmetric demagnetization and remagnetization processes. In those taken at low temperatures [e.g., the results displayed in Fig. 1] the loop corresponding to the harder phase (the Co layer) is shifted toward the opposite direction to that of the cooling field. This result indicates that when the Al-oxide layer is grown by reactive sputtering onto the Co layer, a thin layer of Co-oxide develops. The antiferromagnetic nature of this interlayer would be responsible of the Co loop shift after the field cooling process.

Fig. 2 displays the evolution of the coercivity and the loop shift with the temperature for both magnetic components of the trilayer with 2 nm of Al oxide. Data for Py exhibit a weak temperature dependence of the coercive force and a negligible loop shift. In the case of the Co layer, the coercivity increases with the decrease of the temperature, with a weak thermal dependence in the high temperature range. However, a discontinuity is apparent in the rate of increase of the coercivity at a temperature close to 200K. Also around that critical temperature, the shift in the loop corresponding to the Co layers start to be observed. The magnitude of that shift increases with the decrease of the temperature. Similar behavior is observed in the rest of the analyzed samples (see Fig. 3, which correspond to the trilayer with 10 nm thick Al–O layer). As it has been pointed out before, these results are interpreted in terms of the development of an antiferromagnetic interfacial Co oxide phase at the Co/Al oxide interface. This critical temperature (around 200K) is well below the N,el temperature of the common Co-oxides, but it is close to the typical blocking temperature in CoO, measured in a number of polycrystalline systems [3].

Figs. 2(c) and 3(c) show the evolution with the temperature of the peak width observed in the field derivatives of the magnetic moments of the two different samples. That width can be understood as related to the distribution of local reversal fields. While the value of that parameter is similar at high temperatures for Co and Py, its behavior shows clear differences between both phases below the critical temperature.

The above described magnetic results seem to indicate that the exchange anisotropy related to the antiferro-ferromagnetism at the Co–Al oxide interface would be the mechanism responsible not only for the shift in the loop, but also for the coercivity increase below the critical temperature. The classical interpretation of the exchange anisotropy, as related to the exchange interaction between the biased uncompensated moments at the interface of the antiferromagnetic phase (Co-oxide) and the ferromagnetic phase (Co), would account for the apparition of an unidirectional anisotropy (loop shift) but it would not explain the increase of coercivity. Recently, the increase of coercivity in magnetic systems exhibiting unidirectional anisotropy has been related to a change in the magnetization mechanism in the

biased layer [4]. Also, at least in the case of a polycrystalline antiferromagnetic layer, the increase of coercivity could be caused by antiferromagnetic grains switching together with the ferromagnetic layer [5]. The trilayered system examined in this paper allows us to analyze simultaneously the magnetization process of a biased and an unbiased layer. Above the critical temperature, both layers show similar dispersion of the reversal field, which is indicating that a similar mechanism is driving the magnetization reversal process: probably nucleation of an inverse domain wall and propagation. However, below the critical temperature, while the Py layer follows on a quite similar behavior, the biased Co layer exhibit a larger dispersion of the reversal field. A change in the dominant magnetization mechanism, for instance magnetization rotation, could account for this increase in the width of the peaks of the magnetic moment derivative. It is also interesting to remark the differences [see Fig. 1(b)] between the profiles of the Co peaks measured below the critical temperature and corresponding to the demagnetization and remagnetization processes: the peak measured at negative fields is higher and narrower than the peak observed at positive fields. This could be related to the occurrence of different processes depending on the direction of the applied field during the magnetization. Thus, the magnetization process toward negative fields could exhibit a more collective character [6]. As in the case of the loop shift, this particularity could be related to the presence of different sites in the Co oxide layer playing roles relevant, on the one side, for the magnetization reversal process (for instance, nucleation sites of domain walls sweeping the whole Co layer) and, on the other, for the remagnetization process (for instance, easily polarizable sites weakly coupled to the Co layer).

IV. Conclusion

Co/Al oxide/Py trilayers have been fabricated by sputtering. The apparition of a Co-oxide layer at the Co/Al-oxide interface modifies drastically the magnetic behavior of the system at low temperature, due to the antiferromagnetic properties of such a Co-oxide layer. Below a critical temperature (similar to those reported in the literature for the blocking temperature of the Co oxides), and after a field cooling process, a shift of the Co hysteresis loops appears, and related to this, an increase of the coercivity and a broadening of the dispersion of reversal fields in the biased layer are observed. These features have been assigned to a change in the magnetization mechanism of the biased layer. Since this kind of structures, Ferro/Insulating oxide/Ferro, are the base of the tunnel magnetoresistance devices, the analysis of the magnetization process in the magnetic components and the evaluation of the interaction between the different elements constituting the structure, are important in order to control the final behavior and performance of the device.

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