Absence of spin scattering of in-plane spring domain walls

José L. Prieto,[1,*] Bas B. van Aken,[1] José I. Martín,[2] A. Pérez-Junquera,[2] Gavin Burnell,[1] Neil D. Mathur,[1] and Mark G. Blamire[1]

[1]*Department of Materials Science and Metallurgy, University of Cambridge, Pembroke Street, Cambridge CB2 3QZ, United Kingdom*

[2]*Departamento Física, Facultad de Ciencias, Universidad de Oviedo, c/ Calvo Sotelo s/n, 33007 Oviedo, Spain*

(Received 16 February 2005; published 29 June 2005)

We have performed current perpendicular-to-plane measurements in Gd-transition metal multilayers and amorphous $Co_xGd_{1-x}/Co_yGd_{1-y}$ bilayers. Both systems create in-plane exchange spring domain walls (SWs) whose width can be controlled by an external magnetic field. The results can be explained fully by Lorentz magnetoresistance (MR) plus the effect of the interface. They show no intrinsic scattering from the SWs, suggesting that the "mistracking" of the spin to the local magnetization is not the main cause of MR of domain walls but the change of spin populations across a thin barrier as in GMR structures.

DOI: 10.1103/PhysRevB.71.214428 PACS number(s): 75.47.De, 75.60.Ch

I. INTRODUCTION

The magnetoresistance of domain walls (DWs) has been a subject of intensive research over the last decade. Domain walls are boundaries between domains, and therefore, intuitively, one might assume they would produce additional electron scattering if they were thin enough. Nevertheless, unambiguous experimental evidence does not seem to be easy to find. Some authors claim that the DWs contribute to a decrease in the resistance of the material, while a significant number of others, especially recently, claim the opposite (i.e., that they contribute to an increase of the resistance of the material[1–3]).

Although it is possible to find theories that explain both positive and negative contributions,[4,5] perhaps the most generally accepted is that of Levy and Zhang,[6] in which the positive contribution of the DW is related to the degree of spin polarization of the current and on the ability of the spin to track the local magnetization (this being mainly dependent on the width of the DW, the exchange interaction of the material, and the Fermi velocity of the carriers).

The ideal magnetoresistance (MR) measurement of DWs would be one where there are no other sources of MR (anisotropic MR (AMR), Lorentz MR, Hall effect, or orbital motion[7]) and where the width of the domain wall can be controlled by an external source, so that the dependence of the MR on the width of the DW can be established and compared to the theory. Recently we presented configuration to measure MR in DWs with the current perpendicular to plane (CPP) in Permalloy-Gd-Permalloy trilayers, where an in-plane 180° DW was constricted to the Gd layer.[8] In this configuration all the current flows perpendicular to the DW and to the magnetization at any field (so the AMR contribution is kept constant), but also the current only flows through the middle of the mesa containing DW (because of a patterned insulating window on top), avoiding any contribution of the divergent magnetization close to the edges.

Here we report CPP measurements following the same geometry as in Ref. 8 on different multilayers, where we are able to create in-plane exchange spring domain walls (SWs) whose width is controlled by the external magnetic field. The width of the SW can be reduced by the external field,[9] and therefore, potentially, we could arbitrarily increase the scattering produced by the SW. The thickness of the SW has been experimentally compared to thorough simulations[9] using magneto-optical Kerr effect (MOKE) on transparent quartz substrates (so the information of both layers can be obtained)[10] as will be shown later.

This work first reports measurements on Gd-transition metal (TM) multilayers. Gd couples antiferromagnetically (AF) with the TMs Fe, Co, and Ni. Bilayers of Gd/Fe are perhaps the best studied because they form a nearly perfect interface with very little diffusion of one element into the other; Co and Ni are known to form a less perfect interface with Gd.[11,12] This AF coupling means that at low temperatures, when the Gd layer has a larger magnetic moment than the Fe, the application of a magnetic field creates an in-plane SW,[13,14] as sketched in the inset Fig. 1(a). The stronger the applied magnetic field, the narrower the SW, but also the lower the Gd-TM interface angle (reduced from the AF zero field 180°). The effect of this decrease of the angle at the interface with the field has been characterized already[15,16] as a linear decrease of the resistance when the angle is reduced from 180°. Once the effect of the interface is known, it is possible to study the effect of the SW on the MR.

Inoue *et al.*[17] recently predicted a change in the scattering because of the kind of SWs described in this paper. When the external field is increased, initially the resistance should decrease because of the reduction of the angle at the interface but, for stronger fields, when the SW is thinner, the resistance would increase because of the increased scattering of the SW. This effect was not observed in AF boundaries in Fe_3O_4,[15] but it was thought to have been observed in some Gd/Fe multilayers.[16]

All the samples in this paper have been prepared for transport measurements in the same way, explained in detail in Ref. 16 (see Fig. 1 of that paper) and outlined here for clarity. The samples were deposited by sputtering with a base pressure below 10^{-8} mbar, in an Ar atmosphere of 10^{-2} mbar. For all the Gd/TM samples we deposited six bilayers plus an extra layer of TM on top, capped with Cu. The quality of the interfaces was tested by low angle x-ray reflectivity and the magnetic characterization was done mainly by VSM and MOKE for different temperatures. Magnetic evi-

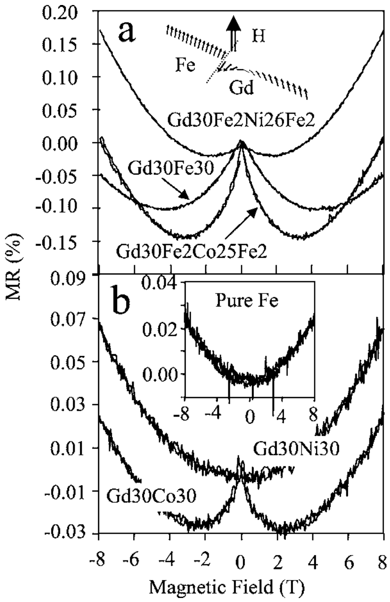

FIG. 1. Transport measurements for the samples with Gd and different transition metals. (a) Measurements in which the interface is Ge/Fe. Inset in (a) shows a schematic drawing of the formation of DWs in both Gd and Fe layers when a magnetic field is applied. (b) Samples without a Fe interlayer and therefore a slightly poorer interface. Inset in (b) shows the measurement in pure Fe in order to emphasize the similarity with the samples Gd30Ni30 and Gd30Co30.

dence that the samples grown in these conditions develop SWs at high fields can also be found elsewhere.[16] We will refer to the samples according to the thicknesses of the layers, for example, Gd30Fe30 refers to the sample (Fe 30 nm–Gd 30 nm) $\times 6+$Fe 30 nm. We have also grown samples of Gd30Co30 and Gd30Ni30, and plain Fe samples to compare to the Gd/Fe results, as well as samples with a thin Fe interlayer at every interface in order to improve the interface: Gd30Fe2Co26Fe2 and Gd30Fe2Ni26Fe2.

II. Gd: Co, Fe, or Ni MULTILAYERS

The CPP transport measurements of these samples are shown in Fig. 1. The transport properties clearly show the stabilizing function of the Fe at the interface. The samples Gd30Ni30 and Gd30Co30 show only a small parabolic MR, which one would attribute to Lorentz MR. In fact, the behavior of a pure film of Fe [inset to Fig. 1(b)] shows the same parabolic shape. Obviously, in the Fe sample there are no in-plane SWs. In the samples with Gd/Fe interfaces, the MR curves are linear for low fields and have a parabolic upturn for larger fields. This upturn is larger than for the samples Gd30Ni30, Gd30Co30, and pure Fe.

The linear decrease of the resistance at low fields of the samples with Gd/Fe interfaces is caused by the decrease of the angle at the interface from 180° (Ref. 16) when the field increases. The parabolic upturn at high fields could be initially interpreted as the positive scattering of the SWs when their width decreases at high fields, as predicted by Inoue *et al.*[17] Nevertheless, the parabolic shape also suggests that it could be caused by Lorentz MR. If we measure the high-field part of the curves of Fig. 2 for different temperatures, all follow Kholer's rule[18] as shown in the inset, suggesting that the effect is simply Lorentz MR.

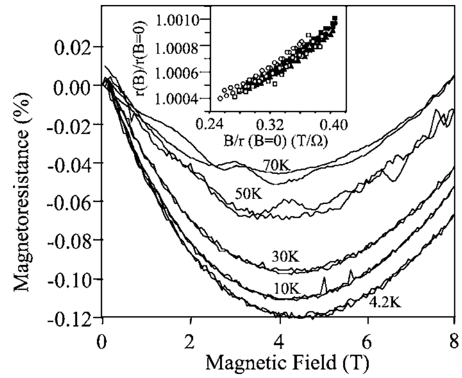

FIG. 2. The transport measurements of the sample Gd30F30 for different temperatures. Inset: resistance vs field normalized to the resistance at zero fields (extrapolated from the parabolic part of the curves) for different temperatures: (●) 10 K, (■) 20 K, (▲) 30 K, (□) 50 K (○) 70 K.

III. MICROMAGNETIC SIMULATIONS

In our experimental system the current is flowing perpendicular to plane through the center of every mesa, thanks to the SiO_2 window. This allows us to ignore the effect of the edges of the mesas, where the magnetization could be misaligned by magnetostatic energy. This simplifies the simulations because we can assume periodic boundaries in the plane of the sample. The simulations were done with the commercially available LLG simulator. The simulation volume was $10\times 10\times t_{tot}$ nm^3 with t_{tot} the total thickness of the multilayer. The cell size of the simulation is $1\times 1\times 0.25$ nm^3. The parameters used for the different materials were: $M_S^{Fe}=17000$ G, $M_S^{Co}=14000$ G, $M_S^{Ni}=5000$ G, and $M_S^{Gd}=15000$ G (reduced magnetization in Gd for thin films[19,20]), $A^{Fe}=20.5$ pJ/m, $A^{Co}=30.5$ pJ/m, $A^{Ni}=9.7$ pJ/m, $A^{Gd}=7.5$ pJ/m, $K^{Fe}=4.7\times 10^4$ Jm^{-3}, $K^{Co}=5.3\times 10^5$ Jm^{-3}, and $K^{Ni}=5.1\times 10^3$ Jm^{-3}. The interlayer coupling between Fe and Gd was chosen as $A_{int}=1.0$ μerg/cm.

Figure 3 shows a summary of the results from the simulations for the three samples Gd30Fe30, Gd30Fe2Ni26Fe2, and Gd30Fe2Co26Fe2. As the field increases, the width of the SWs decreases in all samples (therefore, a potential increase in the scattering), but so does the total rotation (therefore, a potential decrease in the scattering). The SW width is extracted from a linear fit to the magnetization angle versus vertical distance curves in the multilayers. Figures 3(a) and 3(b) show the behavior of the Gd layer in all the samples. As can be seen, the SW in this layer fully develops for relatively low fields and after ~1 T the SW does not get much narrower, although its rotation continues to decrease significantly up to 8 T. In principle, this means that the scattering from the SW in Gd should be maximum around 1 T. The situation for the SWs in the transition metal is shown in Figs. 3(c) and 3(d) and is quite similar to that in the Gd layer: the

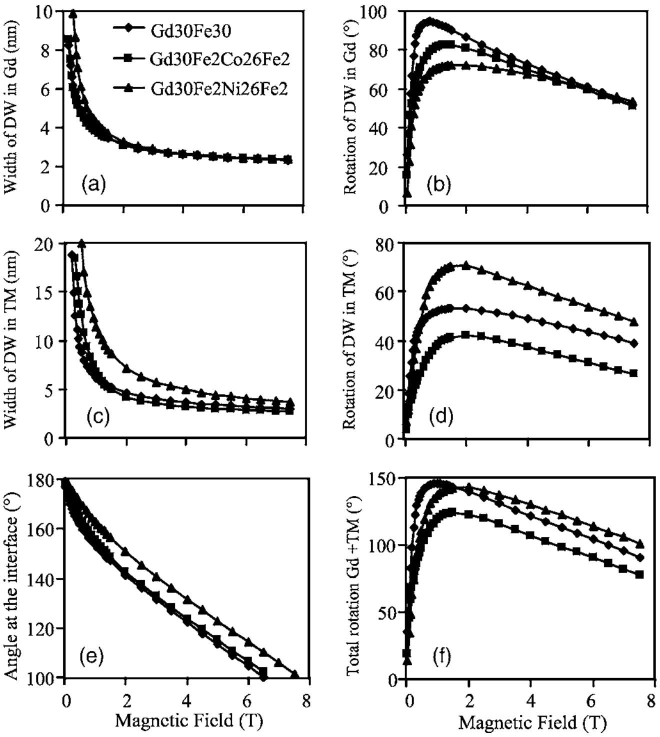

FIG. 3. Behavior of the magnetization around the interface for the samples Gd30Fe30 (♦), Gd30Fe2Ni26Fe2 (▲), and Gd30Fe2Co26Fe2 (■). The total rotation of the spring wall is the difference between the angle at the interface (in either Gd of TM depending on the case) and the angle at the center of that layer.

spring wall is mostly formed for fields below 2 T and for higher fields only a small decrease in the SW width and a more significant decrease of the rotation within the SW is observed. The rotation in the TM depends strongly on the exchange energy, and therefore the SW in Co develops only a rotation of 40°, while Ni almost reaches 90°. According to this, intuitively one can think that the scattering caused by the SW in the transition metal should be higher in the sample with Ni than in the sample with Fe or Co.

Nevertheless, as mentioned above, on top of the positive effect of scattering of the SWs at the interface, we have to subtract the effect of the reduction of the interface angle. The interface angle versus applied field is plotted in Fig. 3(e). As expected, the angle at the interface decreases almost linearly with field, from the antiparallel 180° toward 0° (aligned with the field), in the limit of very high fields.

The results from the simulation can be used as input for models that describe the behavior of the interface[16] and the scattering created by the SWs.[6] As a first approximation, we have considered the SWs and the interface as independent scattering systems: the SWs will increase the scattering as their widths decrease and their total rotation increases, whereas the interface will contribute to a decrease of the scattering when the angle at the interface reduces toward zero. We can calculate both contributions separately and add them to check if there is any similarity with the transport measurements plotted in Fig. 1. This analysis could help us understand whether the SW scattering contributes to the MR.

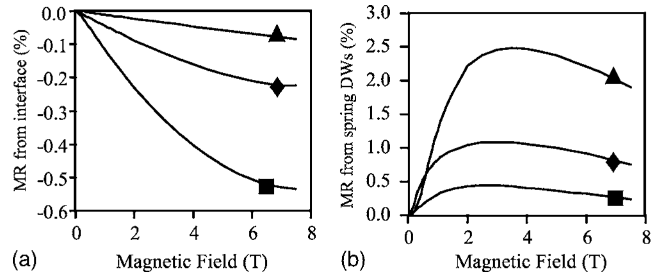

FIG. 4. Estimated MR obtained with the available theories and the magnetic configuration obtained from the micromagnetic simulation. (a) represents the estimated MR exclusively from the behavior of the interface with field [see Fig. 6(e)]. (b) represents the estimated MR exclusively from the spring DWs in the Gd and the TM layers. Gd30Fe30 (♦), Gd30Fe2Ni26Fe2 (▲), and Gd30Fe2Co26Fe2 (■).

Treating SW scattering and interface scattering as independent systems might not necessarily be a good approximation, especially at high fields where the width of the spring DWs in both Gd and TM are of the order of the mean-free path of the electrons. We will discuss this point in further detail in the Conclusions.

The angles in Fig. 3 have been taken as an input in the model of sharp antiferromagnetic interfaces described in Ref. 16. The values used are resistivity ($\rho^{Fe}=10\ \mu\Omega.\text{cm}, \rho^{Co}=6\ \mu\Omega.\text{cm}, \rho^{Ni}=7\ \mu\Omega.\text{cm}, \rho^{Gd}=130\ \mu\Omega.\text{cm}$), polarization ($\beta^{Fe}=0.5, \beta^{Co}=0.4, \beta^{Ni}=0.5, \beta^{Gd}=0.35$), and the spin diffusion length,[21] which does not seem to be very critical to the final result, has been chosen in all materials $\sim 0.1\ \mu$m. The spin scattering at the interface is modeled through the parameters γ (asymmetry of the spin flip at the interface) and r_b (surface resistance of the interface). The values of these two parameters have been chosen to be the same in all the samples because the interface is always Gd-Fe: $\gamma=0.2$ and $r_b=0.3\times 10^{-15}\ \Omega\text{m}^2$. The results of the model for the interface using the magnetization angles obtained from the simulations are displayed in Fig. 4(a). The result closely reproduces the initial drop of the MR curves shown in Fig. 1(a). It is important to note that the multilayers do not show a significant twisting in the SWs for small fields, thus the interface will play the most significant role at such fields. The good agreement between experimental results and theory for lower fields confirms this point.

For higher fields we have to include the SWs in our analysis. Over ~ 2 T, the spring DWs are thinner than ~ 5 nm and the total twist of the magnetization across this width ranges from 40° to 90°, depending on the material. According to previous results on MR of DWs and to Levy and Zhang's theory,[6] we could expect a positive scattering coming from the SWs. Figure 4(b) shows the results of Levy and Zhang's theory applied to the data obtained from our simulation for this set of samples. We have used $k_F=1.7\times 10^{10}\ \text{m}^{-1}$ for all TM and $k_F=8\times 10^{9}\ \text{m}^{-1}$ for Gd, $m^*=1$ for TM and $m^*=3$ for Gd, and the ratio of resistivities for majority and minority spin $\rho^+/\rho^-=5$ for TM and $\rho^+/\rho^-=3$ for Gd. The rest of the material constants required for the calculations can be found in the text above.

Figure 4(b) shows that the predicted behavior at high fields, according to our model, is quite different from that observed in the transport measurements [Fig. 1(a)]. Indeed for higher fields, when the rotation of the magnetization within the SWs is reduced under the influence of the external magnetic field, one would expect the positive contribution to the scattering (and therefore the resistance) to go down, as the calculations show. It seems again that the parabolic behavior of the transport measurements might not be due to the scattering in the SWs but instead is because of Lorentz MR. This point is reinforced by the fact that the measurements at different temperatures for the samples Gd30Fe2Ni26Fe2 and Gd30Fe2Co26Fe2 fit Kohler's rule, as in the case of Fe30Gd30 (Fig. 2).

This raises the question of why the SWs are not having any effect on the resistance of the material. The parabolic shape of the transport measurements for high fields does not deviate from parabolic at all; therefore, we can assume that there is no extra source of MR besides the AFM interface scattering and the Lorentz force.

Before we enter the discussion we show in Sec. IV further measurements in a completely different system in order to confirm that this type of SW does not show any appreciable scattering.

IV. BILAYERS OF $Gd_xCo_{1-x}/Gd_yCo_{1-y}$

In order to confirm this lack of scattering caused by the SWs, we also studied a set of $Gd_xCo_{1-x}/Gd_yCo_{1-y}$ bilayer samples. For the appropriate composition range, Gd_xCo_{1-x} is an amorphous ferrimagnet with a well-defined uniaxial anisotropy;[22,23] the Gd and Co are AF coupled and the net magnetization (M_S) of Gd_xCo_{1-x} is dominated by either the Gd or Co, depending on the composition and temperature. For $T<T_{\text{comp}}$ (the compensation temperature at which $M_S=0$), the Gd moments are larger than the Co moments and vice versa for $T>T_{\text{comp}}$. We, therefore, fabricated bilayers with compositions such that M_S is parallel to Gd in one layer and parallel to Co in the other [see Fig. 5(a)]. The antiparallel configuration of M_S between adjacent layers is controlled by the interaction of the elements at the interface, mainly the strong Co-Co exchange interaction; when a large magnetic field is applied, a SW is created in order to keep the ferromagnetic Co-Co exchange at the interface but minimize the Zeeman energy.[23–25]

Our $Gd_xCo_{1-x}/Gd_yCo_{1-y}$ bilayers have been prepared by cosputtering from independent Co and Gd targets[25,26] onto a Cu buffer layer; a Cu capping layer protects the underlying bilayer from oxidation. The thickness of each Gd_xCo_{1-x} layer is 50 nm. The presence of the DW at the bilayer interface has been characterized by transverse magneto-optical Kerr effect (MOKE). For visible wavelengths, MOKE measurements are only sensitive to the Co moments, which allows us to follow the switching or rotation of M_S when the field is varied.[25] Since the optical penetration depth is smaller than the thickness of the layers, MOKE in combination with bulk magnetization data can determine the reversal of each individual layer and demonstrate the presence of the SW.

Different bilayers were grown to create the in-plane SW at different temperatures in each sample. Sample A, $Gd_{0.12}Co_{0.88}/Gd_{0.29}Co_{0.71}$ shows an in-plane SW from 0 to 300 K; sample B, $Gd_{0.16}Co_{0.84}/Gd_{0.29}Co_{0.71}$ shows a SW only $\gtrsim 100$ K, and sample C, $Gd_{0.16}Co_{0.84}/Gd_{0.12}Co_{0.88}$ shows an in-plane SW only for temperatures $\lesssim 100$ K.

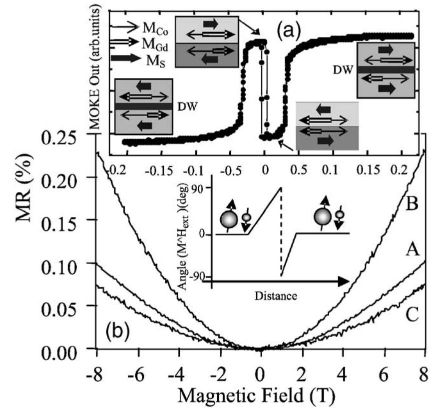

FIG. 5. (a) MOKE hysteresis loop of $Gd_{0.12}Co_{0.88}/Gd_{0.29}Co_{0.71}$ bilayer (sample A) at 20 K; the magnetic configurations for each step in the magnetization reversal process are sketched, indicating the presence of the DW at the interface at higher fields. (b) Transport measurements for the samples $Gd_xCo_{1-x}/Gd_yCo_{1-y}$ measured at 20 K; the total resistances at zero field are 37.4, 22.7, and 42.5 Ω for samples A, B, and C respectively. Inset: a visualization of the angular barrier created by the spring domain wall, separating two parallel domains with the same magnetization direction.

Figure 5(a) shows the MOKE hysteresis loop obtained from $Gd_{0.12}Co_{0.88}/Gd_{0.29}Co_{0.71}$ bilayer at 20 K with the field applied along the easy axis of the sample. When the M_s in the top layer is aligned with the field, it will also be aligned in the bottom layer, and therefore a SW must have been created at the interface. Figure 5(a) shows that for fields >100 mT, the top layer is almost saturated and the presence of the in-plane SW is demonstrated. When the field is reduced to zero, the MOKE signal is completely reversed, indicating that because of the exchange interaction the SW has been annihilated and the Co moments in the reversed top layer (and the unchanged bottom layer) are antiparallel to the external field. When the applied field is further reduced below zero, the MOKE signal reverses, which corresponds to the complete switching of the magnetic configuration. Applying a larger negative field will switch the top layer again and create a SW. When the SW is present, the Co and Gd moments are arranged in a 180° Bloch wall, but the magnetization is arranged in a springlike DW [see insets to Fig. 5(a)].

Figure 5(b) shows the magnetoresistance curves obtained for the three $Gd_xCo_{1-x}/Gd_yCo_{1-y}$ samples at 20 K. The results do not show any difference, whether there is an in-plane SW or not (even when measuring the same sample at different temperatures). The measurements obtained at different temperatures (not shown here) do not show any change other than Kohler's decrease of the slope as seen in other samples (Fig. 2), suggesting again Lorentz MR as the primary cause of the positive scattering.

In the case of $Gd_xCo_{1-x}/Gd_yCo_{1-y}$ bilayers it is also possible to experimentally estimate the width of the SW using MOKE on transparent quartz substrates.[10] The results shown

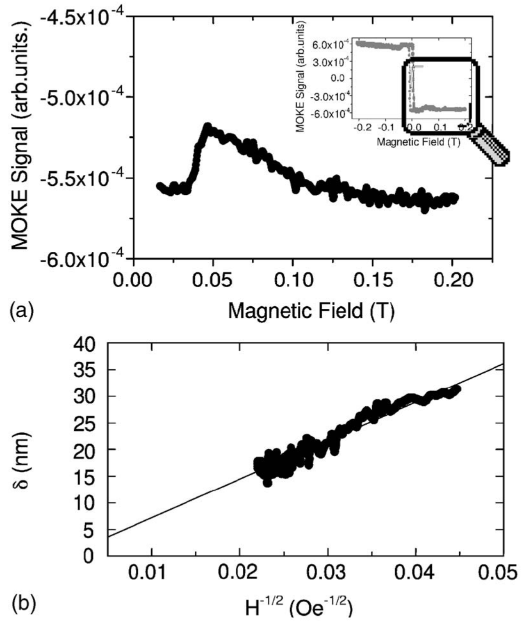

FIG. 6. (a) Inset shows the MOKE signal of the bottom layer of one of the GdCo samples. The samples are grown in parallel with the ones used for the transport measurements. The hysteresis loop is complementary to the one shown in Fig. 5(a) because MOKE is only sensitive to Co moments. The main panel is a magnification (indicated in the inset) of the saturation part where the formation of the spring wall is shown. (b) Field dependence of the width (d) of the SW deduced from the curve in (a) using the model developed in Ref. [28] for the MOKE signal, that presents a $H^{-1/2}$ behavior in agreement with Ref. [10]. An approximate value of 4 nm for 4 T can be extrapolated.

in Fig. 6 extrapolate a SW width <4 nm for fields >4 T. This is valid only if this extrapolation holds until nanometer scale, something that we cannot demonstrate, although our simulations give similar results.

The transport measurements in the bilayers of $Gd_xCo_{1-x}/Gd_yCo_{1-y}$ confirm that the conduction electrons does not seem to be sensitive to the fast rotation of the local moments in the SWs. Whether the carriers are sensitive only to the Co moments (180° DW) or to the total magnetization (two consecutive 90° SWs with opposite chiralities), it does not seem to make any difference to the transport within the metal.

V. DISCUSSION AND CONCLUSIONS

Taken together these measurements, in two different types of multilayer, both with in-plane SW structures, lead us to conclude that this type of SW does not contribute to enhanced electron scattering. This is a surprising result because the width of the SW can be reduced to very small values (on the order of a nanometer) when the external field is large enough. Previous experimental results,[2,7] including a 180° in-plane DW,[8] showed clear evidence of DW magnetoresistance.

However, the particularity of these SWs is that they separate regions with parallel magnetization [see inset in Fig. 1(a)]. This is in marked contrast to previous work in which DWs separate regions with antiparallel moments, the key qualitative difference being that the spin polarized carriers do not have to change sign when passing from one layer to another across the SW. It is important to note that in Ref. 8 scattering was found in a thin 180° DW (separating antiparallel domains). In this work, though, the SW separate parallel domains and no sign of scattering are found. This striking and unexpected result suggests that a fast rotation of the local magnetization is not on its own sufficient to enhance scattering and electrical resistivity.

It is important to briefly discuss how comparable our results are to previously published work. The measurements are taken at 20 K (versus 77 K, for instance, in Ref. 8). The results are qualitatively comparable because at lower temperatures we should expect higher scattering of the walls. Nevertheless, the results in this work show no sign of MR at all. On the other hand, according to the model of MR in multilayers using CPP geometry,[21,16] the MR is not very sensitive to the thicknesses of the layers but more so to the polarization and the bulk and surface spin-flip scattering. Therefore (as happens in standard GMR multilayers) a layer of few tens of nanometers should be enough to make the polarized carriers sensitive to every magnetic layer.

Although a theoretical study in structures similar to those studied in this work,[17] predict a measurable contribution of the DW to the total resistance of the material, it seems that in order to get scattering from a DW, it is essential that the DW separates two domains where the magnetizations are misaligned at a large angle with respect to one another, so the spins have to rotate (or flip) from one domain to the other. For a relatively wide domain wall this rotation can be accomplished adiabatically.

Therefore, a finite DW resistivity contribution requires both a change of the orientation of the majority carriers and a "mistracking" of the spin to the local magnetization.[27] Instead, a more general model is required that also includes, for example, the possibility of spin tunneling through the DW, which could avoid the mistracking effect. Taking into account that the transport measurement is sensitive to the angle of the interface, we believe any tunneling effect should be also detectable as a decrease in the resistance when the field is increased, but this could require greater sensitivity than our measurement achieved.

ACKNOWLEDGMENT

The authors acknowledge Spanish CICYT (Grant No. MAT2002-04543) for partial funding of this work.

*Electronic address: joseluis.prieto@upm.es

[1] C. H. Marrows and B. C. Dalton, Phys. Rev. Lett. **92**, 097206 (2004).
[2] S. Lepadatu and Y. B. Xu, Phys. Rev. Lett. **92**, 127201 (2004).
[3] R. Danneau, P. Warin, J. P. Attané, I. Petej, C. Beigné, C. Fermon, O. Klein, A. Marty, F. Ott, Y. Samson, and M. Viret. Phys. Rev. Lett. **88**, 157201 (2002).
[4] G. Tatara and H. Fukuyama, Phys. Rev. Lett. **78**, 3773 (1997).
[5] R. P. van Gorkom, A. Brataas, and G. E. W. Bauer, Phys. Rev. Lett. **83**, 4401 (1999).
[6] P. M. Levy and S. Zhang, Phys. Rev. Lett. **79**, 5110 (1997).
[7] A. D. Kent, J. Yu, U. Rüdinger, and S. S. P. Parkin, J. Phys.: Condens. Matter **13**, R461 (2001).
[8] J. L. Prieto, M. G. Blamire, and J. E. Evetts. Phys. Rev. Lett. **90**, 027201 (2003).
[9] B. B. van Aken, J. L. Prieto, and N. D. Mathur, J. Appl. Phys. **97**, 063904 (2005)
[10] B. Dieny, D. Givord, and J. M. B. Ndjaka, J. Magn. Magn. Mater. **93**, 503 (1991).
[11] J. P. Andrés, L. Chico, J. Colino, and J. M. Riveiro, Phys. Rev. B **66**, 094424 (2002).
[12] V. L. B. de Jesús, I. S. Oliveira, P. C. Riedi, and A. P. Guimarães. J. Magn. Magn. Mater. **212**, 125 (2000).
[13] D. Haskel, G. Srajer, J. C. Lang, J. Pollmann, C. S. Nelson, J. S. Jiang, and S. D. Bader. Phys. Rev. Lett. **87**, 207201 (2001).
[14] J. Landes, Ch. Sauer, B. Kabius, and W. Zinn, Phys. Rev. B **44**, 8342 (1991).
[15] W. Eerenstein, T. T. M. Palstra, S. S. Saxena, and T. Hibma. Phys. Rev. Lett. **88**, 247204 (2002).
[16] J. L. Prieto, B. B. van Aken, G. Burnell, C. Bell, J. E. Evetts, N. Mathur, and M. G. Blamire, Phys. Rev. B **69**, 054436 (2004).
[17] J. I. Inoue, H. Itoh, S. Mitani, and K. Takanashi, Phys. Rev. B **68**, 094418 (2003).
[18] F. C. Schwerer and J. Silcox, Phys. Rev. Lett. **20**, 101 (1968).
[19] N. Ishimatsu, H. Hashizume, S. Hamada, N. Hosoito, C. S. Nelson, C. T. Venkataraman, G. Srajer, and J. C. Lang, Phys. Rev. B **60**, 9596 (1999).
[20] W. Hahn, M. Loewenhaupt, Y. Y. Huang, G. P. Felcher, and S. S. P. Parkin, Phys. Rev. B **52**, 16041 (1995).
[21] T. Valet and A. Fert, Phys. Rev. B **48**, 7099 (1993).
[22] H. Fu, M. Mansuripur, and P. Meystre, Phys. Rev. Lett. **66**, 1086 (1991).
[23] T. Yonamine, A. P. B. Tufaile, A. D. Santos, and Y. Souche, J. Appl. Phys. **81**, 5722 (1997).
[24] D. Mergel, J. Appl. Phys. **74**, 4072 (1993).
[25] R. Morales and J. M. Alameda, IEEE Trans. Magn. **37**, 2305 (2001).
[26] R. Morales, J. I. Martín, and J. M. Alameda, J. Magn. Magn. Mater. **272–276**, 855 (2004).
[27] J. F. Gregg, W. Allen, K. Ounadjela, M. Viret, M. Hehn, S. M. Thompson, and J. M. D. Coey. Phys. Rev. Lett. **77**, 1580 (1996).
[28] C. Dehesa-Martínez, L. Blanco-Gutiérrez, M. Vélez, J. Díaz, L. M. Álvarez-Prado, and J. M. Alameda, Phys. Rev. B **64**, 024417 (2001).