ELSEVIER

Journal of Magnetism and Magnetic Materials 226–230 (2001) 745–746

Journal of magnetism and magnetic materials

www.elsevier.com/locate/jmmm

Electron interaction with domain walls in Fe/Cr multilayers at low temperatures

F.G. Aliev[a,*], R. Schad[b], A. Volodin[c], C. van Haesendonck[c], Y. Bruynseraede[c], R. Villar[a]

[a]*Dpto. de Fisica de la Materia Condensada, Instituto Ciencia de Materiales "Nicolas Cabrera", C -III, Universidad Autonoma de Madrid, 28049 Madrid, Spain*

[b]*Center for Materials for Information Technology, University of Alabama, Tuscaloosa, AL 35487, USA*

[c]*Laboratorium voor Vaste-Stoffysica en Magnetisme, Katholieke Universiteit Leuven, B3001 Leuven, Belgium*

Abstract

For antiferromagnetically coupled $[\mathrm{Fe/Cr}]_{10}$ multilayers with Fe(Cr) thickness 30(13.5) Å and 12(12) Å, we found that at low fields the contribution of the domain walls to the resistivity, ρ_{DW}, is small at room temperature and strongly enhanced at low temperatures. Magnetic force microscopy images clearly reveal the presence of domain walls. In a wide interval above 1.9 K ρ_{DW} varies as $\rho_{\mathrm{DW}}(T) = \rho_{\mathrm{DW}}(0) - AT^{\alpha}$ with the exponent $\alpha \simeq 0.7$–1, indicating the possible presence of quantum interference effects in the quasiballistic electron transport through domain walls. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Domain wall; Magnetoresistance—multilayers; Magnetic imaging

In this paper, we report the results of a detailed study of low-field electrical resistivity in *antiferromagnetically* (AF) coupled magnetic multilayers (MML). The well-known giant magnetoresistance (GMR) in this system is mainly attributed to a realignment of the magnetization direction of adjacent magnetic layers [1]. However, the presence of domain walls (DWs) in MML may result in a small additional "in-plane" DW-MR. While the GMR is known to saturate at low temperatures, the temperature dependence of DW-MR could be different.

The epitaxial $[\mathrm{Fe/Cr}]_{10}$ multilayers were prepared in a MBE system on MgO (1 0 0) substrates held at 50°C and covered with an approximately 10 Å thick Cr layer. The Cr thickness corresponds to the first AF peak in the interlayer exchange coupling in this system and produces a maximum GMR which is about 20% at 300 K and 100% at 4.2 K. A detailed description of sample preparation and structural characterization has been reported elsewhere [2].

The inset to Fig. 1 shows magnetic force microscopy images of $[\mathrm{Fe(30Å)/Cr(13.5Å)}]_{10}$ MML taken with a Park Scientific Instruments M5 microscope at room temperature (RT) over the same $(16 \times 16)\,\mu\mathrm{m}^2$ area. The first image has been obtained before application of a magnetic field. The magnetic contrast disappeared after a magnetic field of 70 Oe had been applied. One sees different irregular shape domain walls with different dimensions down to micrometer scale. Presence of the DWs has almost no effect on the room temperature magnetoresistance, while the low temperature and low-field MR is strongly enhanced. Fig. 1 shows the temperature dependence of the electrical resistivity ρ of the $[\mathrm{Fe(12\,Å)/Cr(12\,Å)}]_{10}$ MML measured in various magnetic fields parallel to the plane and with the current flowing along (1 1 0) direction. For magnetic fields $|H| > 100$ Oe, $\rho(T)$ has metallic temperature dependence, while for $|H| \leqslant 100$ Oe, there is a clear minimum in $\rho(T)$ which cannot be due to usual GMR effects. We attribute this behavior to electron interaction with domain walls because characteristic fields which remove DWs and those which affect the anomalous low temperature electron transport are of the same order of the magnitude.

* Corresponding author. Tel.: + 34-91-3974756; fax: + 34-91-3973961.

E-mail address: Farkhad.Aliev@uam.es (F.G. Aliev).

0304-8853/01/$ - see front matter © 2001 Elsevier Science B.V. All rights reserved.
PII: S0304-8853(00)00771-X

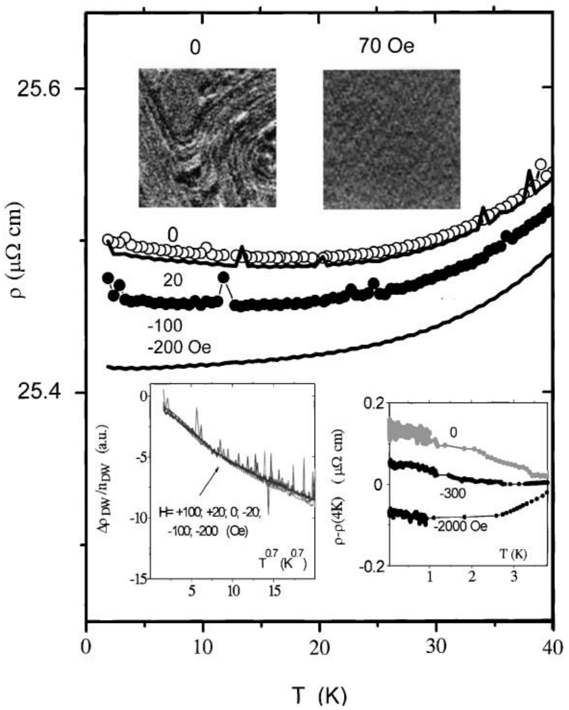

Fig. 1. Upper inset shows magnetic force microscopy images of $[Fe(30\,\mathring{A})/Cr(13.5\,\mathring{A})]_{10}$ MML taken over the $(16 \times 16)\,\mu m^2$ area before and after applying an external magnetic field. The main part of the figure shows the temperature dependence of the resistivity in different magnetic fields. In the left lower inset we have plotted $\Delta\rho_{DW}/n_{DW}(H)$ as a function of $T^{0.7}$ for various magnetic fields (here $n_{DW}(H)$ is a parameter which roughly reflects the DW concentration). In the right lower inset we have plotted variation of resistivity $\rho(T,H) - \rho(T, 4\,K)$ down to 50 mK.

The sharp peaks observed in the $\rho(T)$ curves can be related to Barkhausen noise.

The most obvious way to determine the DW-MR is to subtract the temperature dependences of the resistivity measured in the presence and in the absence of DWs. In order to separate the GMR (ρ_S) from the DW-MR (ρ_{DW}), we define $\rho_{DW} = \rho(T,H) - \rho(T,H_S)$ with $H_S < 300$ Oe. Although this method may underestimate the DW-MR because not all domains (in particular those which are most strongly pinned) will be removed by the applied field H_S, it provides the possibility to reconstruct the variation of the DW-MR with temperature. Our analysis shows that the function $\Delta\rho_{DW} = An_{DW}(H)T^{\alpha}$ (where A is a constant and $\alpha = 0.7$–1) fits the experimental data for different samples reasonably well (see left lower inset to Fig. 1. The power-like temperatures dependence of $\Delta\rho_{DW}(T)$ and relatively small magnetic fields needed to remove minimum in $\rho(T)$ indicate that the observed anomalous low-temperature electron transport is not due electron interaction with local magnetic moments or with structural disorder.

Interestingly, the resistivity of Fe/Cr multilayers is strongly temperature dependent down to ultralow temperatures (see the lower inset to Fig. 1). The relatively high noise/signal ratio for $T < 1$ K, which results from applying a rather low measuring current, does not allow to identify the exact temperature dependence. We also note that for the measurements performed at very low temperatures with the magnetic field applied below 50 K, the observed anomalous temperature dependence becomes more stable with respect to applied field due to stronger pinned DWs.

The ballistic approach to electron transport through DWs [3] requires that the mean free path along our epitaxial layers l exceeds the DW width (estimated of the order 10–100 nm [4]) or characteristic scale which characterizes the non-uniform field ($l \geqslant D$), a condition which may be fulfilled only at low enough temperatures. We believe that the ballistic approach alone cannot explain the strong variation in $\rho_{DW}(T)$ down to 1.9 K because the mean free path is expected to saturate at low temperatures. In order to explain the strong variation of the DW-MR at low temperatures, one should go beyond the classic approach [3] and consider the possibility of quantum interference (QI) phenomena among electrons. The QI approach [5] explains the observed temperature dependences because the quantum correction to the conductivity varies as $T^{-p/2}$ with $p = \frac{3}{2}$ or 2 in the dirty and clean limits, respectively, giving rise to $\Delta\rho_{DW} \sim T^{\alpha}$ with $\alpha = 0.75$ or 1.

The work was supported in parts by Spanish CICYT and by the Belgian FWO, IUAP and GOA research programs.

References

[1] A. Fert et al., J. Magn. Magn. Mater. 140–144 (1995) 1.
[2] R. Schad et al., Appl. Phys. Lett. 64 (1994) 3500.
[3] J.B.A.N. van Hoff et al., Phys. Rev. B 59 (1999) 138.
[4] C.M. Schmidt et al., Phys. Rev. B 60 (1999) 4158.
[5] Y. Lyanda-Geller et al., Phys. Rev. Lett. 81 (1998) 3215.