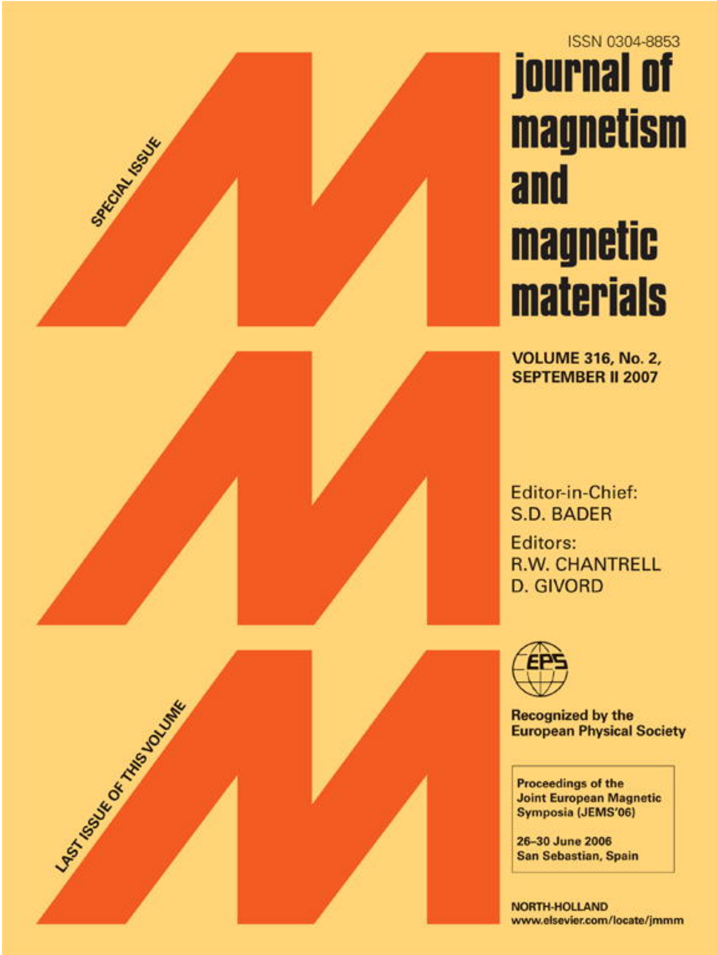
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Enhanced magnetic viscosity at low temperatures in $[Fe/Cr(0\,0\,1)]_{10}$ multilayers

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Abstract

We report on magnetic aftereffect measurements in strongly and weakly antiferromagnetically (AFM)-coupled epitaxial $[Fe/Cr(1\,0\,0)]_{10}$ and in epitaxial Fe(1 0 0), near the orientation transition (OT) between the easy and hard axes, studied at time scales up to 10^3 s and between 300 and 1.8 K. In strongly coupled multilayers, the relaxation is nearly logarithmic in time, has an intrinsic character, and the maximum relaxation rate is almost temperature independent down to 10 K and strongly increases below 10 K. The magnetic relaxation in Fe(0 0 1) films was, however, much faster at $T > 10$ K, but at lower temperatures it is nearly blocked making possible the observation of magnetization jumps of Barkhausen type. The unusual magnetic aftereffect in the Fe/Cr multilayers could be due to opening of relaxation channels through the Cr that separates the Fe layers.

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Keywords: Relaxation effect; Magnetic nanostructure; Fe thin film

1. Introduction

Recent studies of the low-frequency magnetization dynamics, below 10 kHz, in epitaxial strongly antiferromagnetically (AFM)-coupled Fe/Cr(1 0 0) magnetic multilayers (MMLs) revealed a qualitative change in magnetic losses at temperatures below 7 K [1]. Here, we expand the magnetization response frequency range to well below a few Hz and measure magnetic relaxation (magnetic aftereffect) near orientation transitions (OTs). Due to the close relation between magnetization and resistivity, high-resolution time-dependent resistivity measurements has proved to be an excellent technique to study the collective magnetization dynamics of MMLs [2,3], which is a topic of current interest [4]. In the AFM-coupled MML, an OT may be induced by an external applied field in the direction of the hard axis. In this case, the Néel vectors of the Fe layers rotate to the new direction. It may be noted that the coercive field of this reorientation is of order 800 G while the coercive field of full ferromagnetic alignment which gives rise to the giant magnetoresistance (GMR) effect is of order 10 kG in these nanostructures. We have been able to study the relaxation of the magnetization in the neighbourhood of the OT by means of high-resolution resistivity measurements in time scales up to 2000 s.

2. Experimental

We have studied a strongly AFM-coupled sample (N1) with a GMR ratio of 100% at 4.2 K, a weakly AFM-coupled sample (N2) with 16% GMR ratio at 4.2 K, and, for comparison, an epitaxial Fe thin film on MgO substrate [5]. Composition of the multilayers was $[Fe(30\,Å)/Cr(13\,Å)]_{10}$ on a MgO(1 0 0) substrate [6]. In each measurement, the external field was cycled from −2000 to 2000 G, then fixed

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to the new point value and the relaxation was recorded. In all cases, the external field was applied parallel to the sample plane.

3. Results and discussion

We discuss first the results for the strongly coupled MML. The change in magnetoresistance due to the OT with an external field applied along the hard axis (1 1 0) is shown in Fig. 1.

It may be seen that the coercive field corresponding to this reorientation has an unusual behaviour practically constant in the wide temperature range from 150 to 10 K increasing sharply with decreasing temperature below 10 K. Some examples of relaxation curves near the OT at different temperatures from 250 to 2 K are shown in Fig. 2.

The relaxation was mainly logarithmic with time, though in some cases small sudden adjustments of the global magnetization were detected as jumps in the resistivity.

Normalized magnetic viscosity is represented in Fig. 3. At each temperature, there is a clear minimum (maximum magnitude relaxation rate) near the OT field.

These minima are represented versus temperature in the inset and it may be appreciated that the viscosity is very small and weakly temperature dependent from 250 to 10 K and its magnitude increases very steeply below this temperature. For thermally driven magnetization dynamics, the magnetic viscosity S on ferromagnetic metals is proven to be proportional to temperature ($S \propto T$) [7]. The experimentally observed temperature-independent magnetic viscosity indicates the non-trivial possibility of Cr-layer mediated, and non-thermally driven, magnetic relaxation in AFM-coupled Fe/Cr multilayers. The strong increase of the magnetic viscosity below 10 K could be

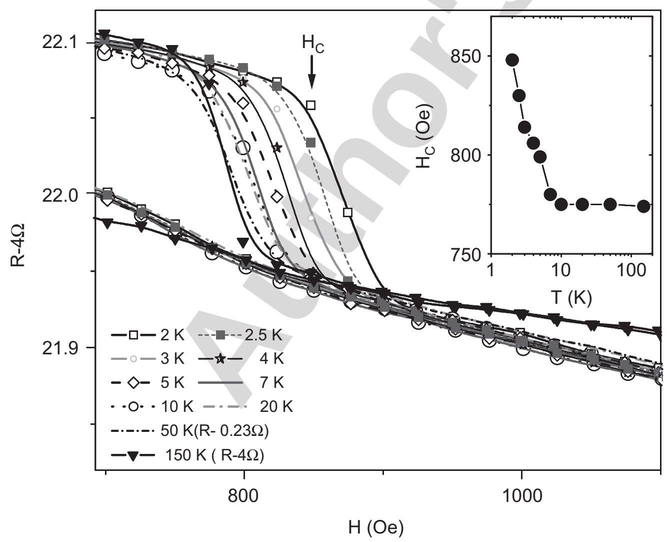

Fig. 1. Change of magnetoresistance of the strongly coupled multilayer in the OT. The relatively sharp transition allows to plot the corresponding coercive field H_C as a function of temperature (inset).

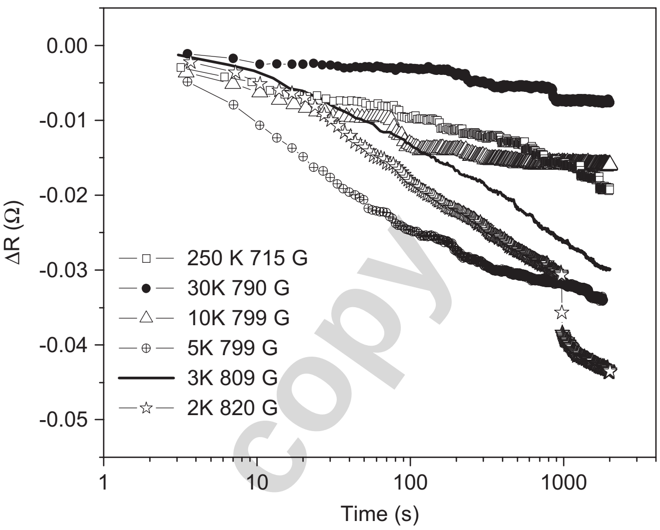

Fig. 2. Some selected relaxation curves of the change in magnetoresistance as a function of the logarithm of time, near the OT of the strongly coupled MML.

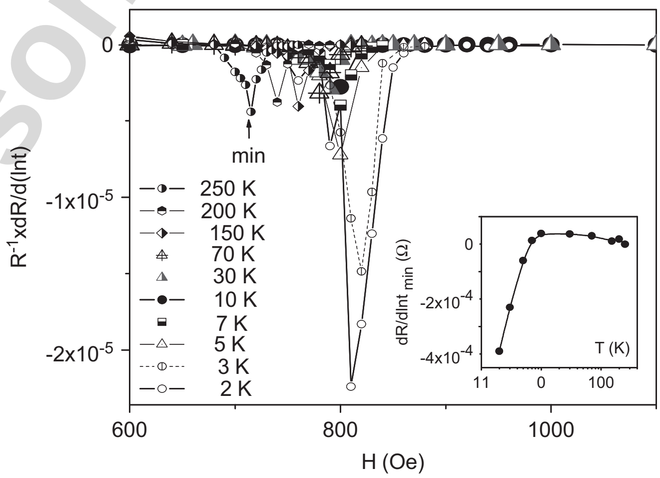

Fig. 3. Plot of the slope of the normalized relaxation curves (magnetic viscosity) at several temperatures as a function of the applied field for the strongly coupled multilayer. The inset shows the minimum value of the relaxation as a function of temperature.

linked with the qualitative transformation in the low-field magnetic losses at low temperatures ($T<7$ K) reported previously in similar MMLs [1]. It was then speculated that the observed qualitative changes might indicate the importance of quantum effects in the magnetization dynamics of strongly coupled Fe/Cr MMLs. The present experiments seem to confirm this possibility. The observed qualitative change in the magnetization dynamics could be related to a field induced classic-quantum transition in the escape rate of antiferromagnetic nanoclusters forming Fe/Cr MMLs [8].

The unique character of the low-frequency magnetization dynamics in AF coupled MMLs at $T\rightarrow 0$ has been further confirmed by the study of weakly coupled multilayer Fe/Cr MMLs and epitaxially grown Fe films. For the first system, probably due to reduced epitaxy and enhanced interface disorder, suppressing GMR, we fail to observe any indication of an OT. However, a noticeable resistance change of order 1% at a small field near 20 Oe applied along the hard axis, caused by anisotropic magnetoresistance (AMR), allowed us to follow the magnetization relaxation rate near this transition.

The magnetization relaxation rate was found to be only weakly temperature dependent between 1.8 and 25 K with a tendency to gradually reduce the magnitude of the logarithmic relaxation with decreasing temperature, as shown in Fig. 4, as is expected for thermally activated processes. The coercive field of the AMR transition along the supposed easy axis versus temperature (not shown) follows a trend that is not far from the $\sqrt{T}$ temperature dependence expected for nanoparticle arrays [9].

Finally, we discuss the results on the Fe film. In Fig. 5a, we present the magnetoresistance with the external field along the current (hard axis) and perpendicular to the current, showing some reorientation at fields near 300 Oe and saturation around 800 Oe, as detected previously by initial susceptibility measurements [5]. At temperatures above 10 K, most probably after a much faster relaxation than in the multilayers, we only record a constant resistivity vs. time after magnetic field cycling ended with a fixed field close to the OT. However, below 10 K and near the OT, the magnetization seems to be blocked and we are able to record back and forth jumps of Barkhausen type (Fig. 5b).

In conclusion, high-resolution measurements of the low-frequency magnetization dynamics close to the field-induced OT between easy and hard axes, have revealed some unusual features: (i) maximum values of the magnetic relaxation rate near the OT practically independent of temperature down to 10 K, (ii) strong enhancement of the relaxation rate taking place below 10 K, (iii) however, the weakly coupled MML shows a decrease in magnetic viscosity with decreasing temperature, even extending below 10 K, and varying nearly linearly with temperature above the magnetic blocking temperature. In Fe film of comparable thickness, the dynamics is also very different from the one observed for AFM-coupled Fe/Cr MMLs, showing a very fast relaxation (in few seconds) above 10 K and a long time blocking of the magnetization (typically for some minutes) before suddenly jumping to the new state below this temperature. These observations indicate the opening of non-thermally induced relaxation channels in AFM-coupled Fe layers. The role of the Cr layer not only in interlayer exchange coupling but also in the unusual magnetization dynamics has to be further investigated.

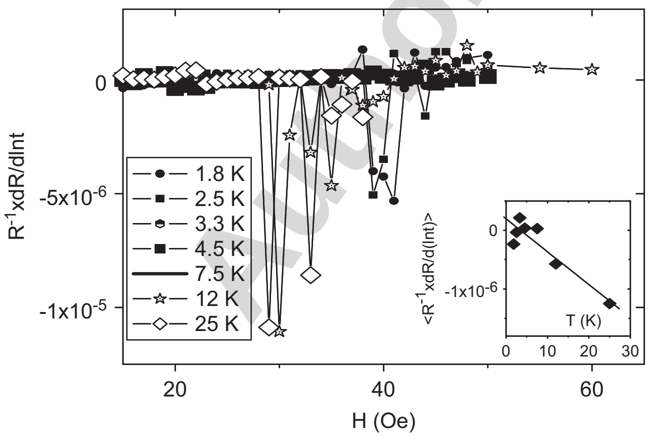

Fig. 4. Plot of the slope of the normalized relaxation curves (magnetic viscosity) at several temperatures as a function of the applied field for the weakly coupled multilayer. The inset shows the integrated relaxations as a function of temperature.

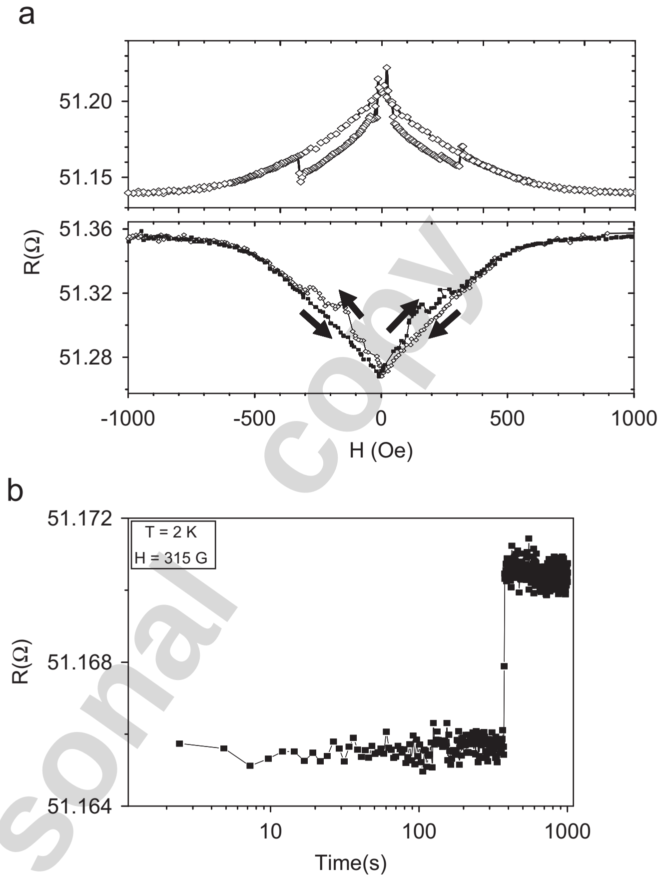

Fig. 5. (a) Magnetoresistance of the Fe film as a function of the applied field H: upper graph: H perpendicular to the current I and parallel to the hard axis; lower graph: H along the current. (b) Typical relaxation of the Fe film below 10 K near the orientation transition, with Barkhausen-type jump.

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References

[1] F.G. Aliev, J.L. Martínez, V.V. Moshchalkov, Bruynserade, A.P. Levanyuk, R. Villar, Phys. Rev. Lett. 88 (2002) 187201.
[2] F.G. Aliev, C. Van Haesendonck, R. Villar, J. Magn. Magn. Mater. 272–276 (2004) 299.
[3] F.G. Aliev, R. Guerrero, V.V. Pryadun, J.L. Martinez, R. Villar, J. Appl. Phys. 97 (2005) 1.
[4] A. Moser, D.T. Margulies, E.E. Fullerton, Phys. Rev. B 66 (2002) 92410.
[5] C. Contreras, J.L. Menéndez, A. Cebollada, J.F. Calleja, Jpn. J. Appl. Phys. 38 (1999) 6699.
[6] R. Schad, C.D. Potter, P. Beliën, G. Verbank, V.V. Moshchalkov, Y. Bruynserade, Appl. Phys. Lett. 64 (1994) 3500.
[7] P. Gaunt, J. Appl. Phys. 59 (1986) 4129.
[8] B. Zhou, J. Ling, F. Pu, Phys. Rev. B 64 (2001) 132407.
[9] W.C. Nunes, W.S.D. Folly, J.P. Sinnecker, M.A. Novak, Phys. Rev. B 70 (2004) 014419.