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Low-frequency response in antiferromagnetically coupled Fe/Cr multilayers

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Abstract

We have studied the magnetic field dependences of the real (χ) and imaginary (χ') contributions to the low-frequency magnetic susceptibility in epitaxial antiferromagnetically coupled $[Fe(Cr(1\,0\,0)]_n$ ($n = 10$–50) multilayers. For the magnetic field directed along (1 1 0), the magnetic susceptibility shows on orientation phase transition. For the magnetic field either along the easy or the hard axes we observe a strong enhancement of the $\chi'(H)$ (i.e. magnetic losses) at low magnetic fields ($H < 50$ Oe), which we relate to AC field-induced domain wall movement. This response is strongly dependent on frequency and temperature.

Keywords: Susceptibility—low field; Domain wall; Magnetic loss

Knowledge of dynamical properties of antiferromagnetically (AF) coupled metallic multilayers (MML) [1] is important both from applied and fundamental points of view. This paper reports on the low-frequency response of MML, which may contain important information on the typical domain wall (DW) pinning energy, characteristic time response and some other parameters. Surprisingly, not much is known about the subject [2]. This work reports on the first, to our best knowledge, study of the real and imaginary parts of AC magnetic susceptibility of epitaxial $[Fe/Cr(1\,0\,0)]_n$ multilayers. Here, we shall present mainly the data corresponding to $n = 10$, the drive frequency of 987 Hz, peak-to-peak excitation (*pp*) of 4 and 8 Oe, and temperatures down to 5 K. Details on the AC susceptibility for the various AF coupled multilayers $n = 10$–50, for the frequency range from 3 to 10^4 Hz and temperatures down to 2 K will be reported elsewhere.

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The epitaxial $[Fe/Cr]_{10}$ multilayers were prepared in a MBE system on MgO (1 0 0) substrates held at 50°C and covered by 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 magnetoresistance 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 [3]. The dynamic magnetic properties of multilayers which included real (χ) and imaginary (χ') susceptibilities were measured with PPMS and MPMS (Quantum Design) systems by using a conventional AC method with both the external magnetic field H and the drive field parallel to each other and to the film surface.

Fig. 1 shows the magnetic field dependence of the real (part a) and imaginary (part b) contributions to the magnetic susceptibility of $[Fe(30\,Å/Cr(13.5\,Å)]_{10}$ measured at ambient (300 K) and low (20 K) temperatures, obtained by applying $pp = 4$ Oe and in a magnetic field directed along the (1 1 0) axis. Both $\chi(H)$ and $\chi'(H)$ clearly demonstrate hysteretic behavior as a function of the magnetic field at high temperatures. The situation

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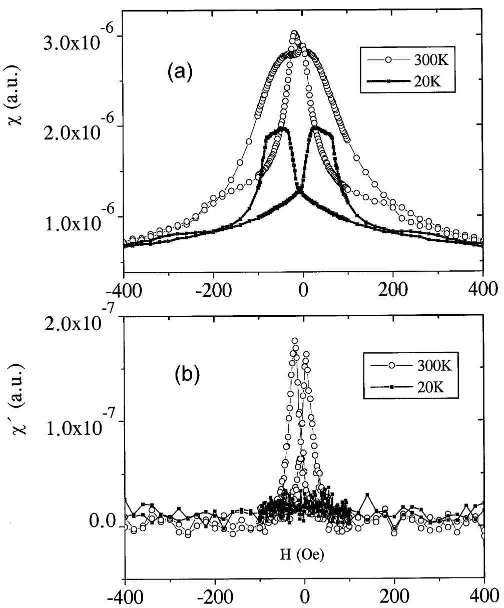

Fig. 1. Real (part a) and imaginary (part b) contributions to the magnetic susceptibility of $[Fe(30\,Å)/Cr(13.5\,Å)]_{10}$ measured at 300 and 20 K by applying the AC drive amplitude of $pp = 4$ Oe.

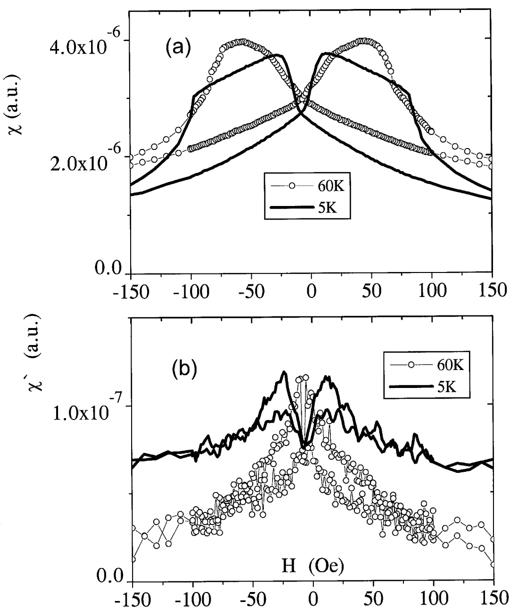

Fig. 2. Magnetic field dependence of the real (a) and imaginary (b) contributions to the magnetic susceptibility of $[Fe(30\,Å)/Cr(13.5\,Å)]_{10}$ at 60 and 5 K measured with $pp = 8$ Oe.

changes at low temperatures (part b, $T = 20$ K), where the magnetic susceptibility keeps hysteretic while we find almost no evidence for the maxima in magnetic losses. We attribute this change to a transition from weakly pinned (at high temperatures) to strongly pinned (at low temperatures) antiferromagnetic. The characteristic temperature of this transition is below 100 K and its value depends on the sample preparation conditions and the applied *pp* drive.

The presence of a well-defined change of the slope in $\chi(H)$ around $H = 0$ (see Fig. 1a) indicates that the magnetization direction of the coupled Fe layers is changed via nucleation and propagation of the DWs even at low temperatures. In order to study the evolution of the low-frequency spin dynamics in Fe/Cr multilayers at low temperatures, we increased the *pp* amplitude. Fig. 2a and b compares $\chi(H)$ and $\chi'(H)$ for the same sample shown in Fig. 1 for temperatures 5 and 60 K, magnetic field directed along (1 1 0) and $pp = 8$ Oe. The enhanced AC drive amplitude let us observe the qualitative change in the field dependences of the magnetic losses at low temperatures, where a clear minimum in $\chi'(H)$ around $H = O$ develops below 5–7 K. We have found that this low field anomaly is strongly dependent on the frequency and is independent on the drive amplitude below $pp = 4$ Oe.

Besides the anomalies in $\chi'(H)$ at small fields ($H < 50$ Oe) almost independent on the magnetic field direction, which we relate to formation and propagation of 180° and 90° DWs, for some Fe/Cr multilayers we observed a second strong hysteretic change in the magnetic losses for magnetic fields of about 300 Oe. The amplitude of this anomaly depends on the orientation of the magnetic field and shows maxima when $H \| 1\,1\,0$. This strong anisotropy indicates that the possible explanation for the enhancement in $\chi'(H)$ at $H \approx 300$ Oe is a magnetic field-induced transition from the Fe layers magnetization oriented along the easy ($H < 300$ Oe) to the hard ($H > 300$ Oe) axes.

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