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Low frequency magnetic noise in epitaxial antiferromagnetically coupled Fe/Cr multilayers

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Abstract

For antiferromagnetically coupled epitaxial $[\mathrm{Fe/Cr}(0\,0\,1)]_{10}$ multilayers we detected a strong enhancement of the magnetism-related electrical noise in the vicinity of the orientation transition between the easy and hard axes. Our measurements are performed at different temperatures and we also identified the noise caused by depinning of domain walls (DWs). We are able to detect and follow in real time the motion of rather extended (of the order of 100 μm) DWs by comparing the magnetic noise in the presence and absence of a DC transport current, respectively. The presence of large and small (<1 μm) DWs is confirmed by magnetic force microscopy images obtained at room temperature. © 2001 Published by Elsevier Science B.V.

Keywords: Multilayers; Domain wall; Stray field; Magnetic imaging

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Knowledge of the magnetism-related electrical noise in *antiferromagnetically* (AF) coupled magnetic multilayers (MML) is important both from an applied and a fundamental point of view. However, until now only one study has been reported concerning the low-frequency noise in Co/Cu MML at room temperature [1]. Here, we present the time dependence and the noise power spectrum of the electrical transport in Fe/Cr multilayers for a wide temperature interval ranging between 300 and 10 K. The epitaxial $[\mathrm{Fe/Cr}(1\,0\,0)]_{10}$ multilayers are prepared in a molecular beam epitaxy (MBE) system on MgO(1 0 0) substrates held at 50°C. The Fe layers have a thickness of 30 Å, while the thickness of the Cr layers, 13.5 Å corresponds to the first AF peak in the interlayer exchange coupling, producing a maximum giant magnetoresistance (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 time (up to 400 s) dependence and the noise power spectrum (0.01–2 Hz) have been measured for an in-plane magnetic field varying between −600 and +600 Oe in steps of 4–10 Oe. Fig. 1 shows the variation of the magnetoresistance (part a) as well as of the slope A (part b) of the low-frequency part of the noise power spectrum ($S = A/f$, with f being the frequency) when the magnetic field is applied along the hard (1 1 0) axis. In Fig. 1(b), we observe a strong enhancement of the magnetic noise around 300 Oe, i.e., within the field region corresponding to the orientation transition (OT) between the easy axis and the hard axis. A strong enhancement of the magnetic noise also occurs for fields below 150 Oe. We link this low-field noise to the depinning of domain walls (DWs). Both the depinning of DWs and the OT are clearly visible in the magnetoresistance (see Fig. 1(a)). A reproducible observation of these effects can be made at low temperatures after the inversion of the magnetic field. The OT is absent when the magnetic field is oriented along the easy axis (Fig. 2) and in that case the electrical transport noise appears to be dominated by depinning and motion of DWs. When the temperature is increased above

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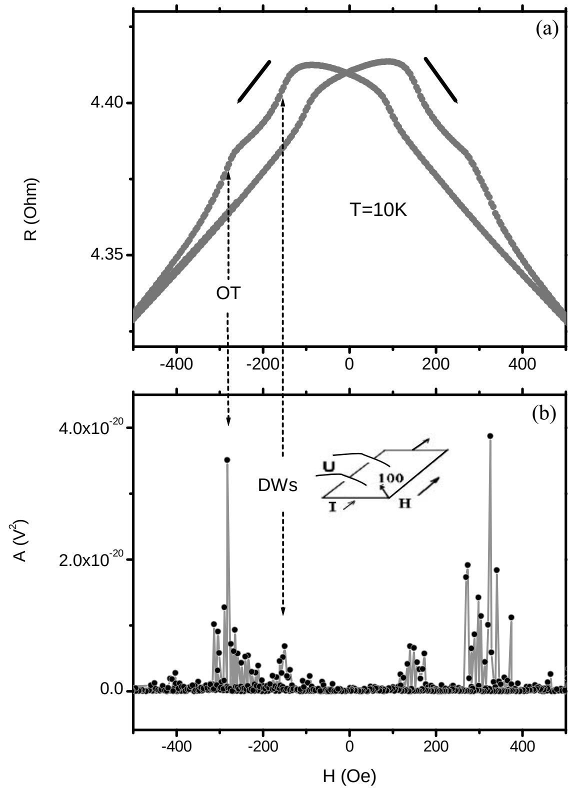

Fig. 1. (a) Resistance and (b) slope A of the noise power spectra (see text) for the $[\mathrm{Fe}(30\,\mathrm{Å})/\mathrm{Cr}(13.5\,\mathrm{Å})]_{10}$ magnetic multilayer as a function of a magnetic field which is applied along the hard (1 1 0) axis. The measurements are taken at $T = 10\,\mathrm{K}$.

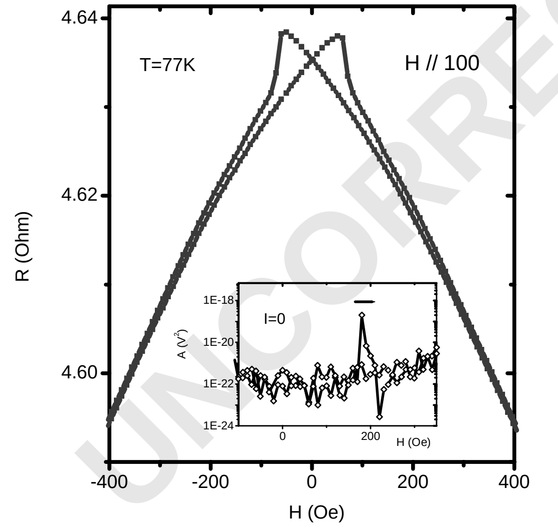

Fig. 2. Resistance of a function of magnetic field directed along (1 0 0) at $T = 77\,\mathrm{K}$. The inset shows slope A at $T = 77\,\mathrm{K}$ as a function of magnetic field without applied current.

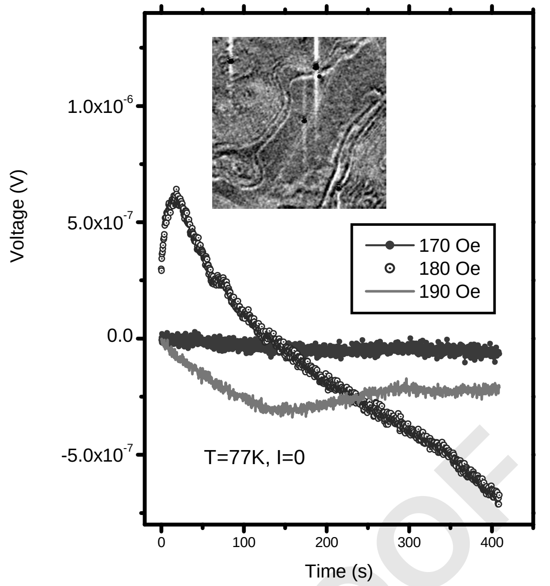

Fig. 3. Time dependence of the voltage noise caused by electromagnetic induction at 77 K. The magnetic field is oriented along the easy axis. The inset shows an MFM image obtained at zero magnetic field at room temperature for an area of $60 \times 60\,\mu\mathrm{m}^2$.

100 K, the magnetic field interval where the OT and DWs affect the noise diminishes, and instead a non-reproducible noise signal appears.

We have compared the magnetism-related noise signal in the presence and absence of a DC transport current. We find that there exist two qualitatively different contributions to the noise induced by the DWs. When performing the measurements with the field applied along the easy axis and at temperatures around 100 K (see inset to Fig. 2 which shows slope A at $T = 77\,\mathrm{K}$ as a function of the magnetic field without applied current), it is possible to discriminate between the noise produced by DWs occurring on different length scales. The DWs created on relatively small length scales (of the order of 1 μm) when compared to the distance between the sample voltage probes, move incoherently and therefore only contribute to the current-induced noise. The corresponding noise power spectrum is consistent with the spectrum in Fig. 1(b) and scales with the square of the electrical current. On the other hand, we are also able to detect and follow the real time movement of rather extended (of the order of 100 μm) DWs. When the noise measurements are done in the absence of a DC current, the motion of the extended DWs causes the appearance of an additional noise voltage due to the electromagnetic induction originating from the stray field of the DWs. Fig. 3 shows the relative change of the induced voltage $V \propto -\mathrm{d}\Phi/\mathrm{d}t$ (Φ is the flux created by the stray field of one or a few extended DWs through the loop formed by the probes and the sample surface) as a function of time after the magnetic field is changed in steps of 10 Oe. At $T = 77$ K, the induction-related noise voltage is consistently observed for the narrow magnetic field range above the characteristic magnetic field which removes the smaller scale DWs. At low temperatures ($T = 10$ K), the strong pinning potential slows down the DWs dynamics and the induced voltage becomes hard to detect. At high temperatures ($T = 300$ K), the DWs become much more mobile and the appearance of the induction-related noise voltage can no longer be linked to a characteristic magnetic field.

The presence of large and small domain walls in our $[\mathrm{Fe/Cr}(1\,0\,0)]_{10}$ multilayers is confirmed by the magnetic force microscopy (MFM) images obtained at room temperature. The inset in Fig. 2 shows a typical MFM image taken with a commercial MFM system (Park Scientific Instruments, M5) for an area of $60 \times 60\,\mu m^2$. We observe the irregularly shaped domain walls with different dimensions down to the micrometer scale. As expected, the domains in the MFM images disappear when applying a magnetic field. The results of our electrical noise measurements indicate that extended 180° or 360° DWs (looking like "rivers" in the MFM images) can be held responsible for the induction-related noise voltage (no DC current), while the smaller scale DWs can account for the DW magnetoresistance as well as for the current-induced electrical noise.

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