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Non equilibrium magnetization in antiferromagnetically coupled $[Fe/Cr]_{10}$ multilayers on large time scales

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Abstract

Ultra slow nonequilibrium magnetization dynamics in epitaxial antiferromagnetically coupled $[Fe/Cr(0\,0\,1)]_{10}$ has been studied at temperatures down to 50 mK by using giant magnetoresistance. Measurements, carried out in magnetic fields up to 90 kG show, depending on the magnetic field, temperature and magnetic history, a coupled domain rotation or slow logarithmic relaxation followed by avalanches or transition to chaotic noise regime.

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Keywords: Fe/Cr multilayers; Magnetic after-effect; Magnetic noise

Recently, time dependent properties of magnetoelectronic structures have attracted much attention [1]. Little is known, however, about evolution of the resistance and magnetization of antiferromagnetically coupled multilayers after change of the magnetic field (magnetic after-effect). Indeed, most of the time dependent experiments are carried out on uniaxial ferromagnets (thin films and nanoparticles), i.e., in systems where the external magnetic field allows tuning the energy barrier between two different magnetic moment directions. Giant magnetoresistance (GMR) in uncoupled magnetic trilayers was recently shown to be a powerful tool to determine the magnetization dynamics with high precision [2]. Specific of GMR response in antiferromagnetically coupled multilayers (MMLs) is that it may reflect collective magnetization dynamics of the whole system. Recent analyses, which considered MMLs as a discrete non linear system, found spin density waves, spin vortex states and chaotic magnetic structures which may arise in magnetic multilayers [3].

We report on the time dependence of the resistivity of epitaxial antiferromagnetically coupled $[Fe/Cr(1\,0\,0)]_{10}$ multilayers at the scales ranging from a few seconds to a few days at temperatures of 4 K and 50 mK, and near the field induced orientation phase transition (OPT) from easy (1 0 0) to hard (1 1 0) axes. Details of sample preparation and characterization have been published before [4].

Here we present three different sets of experimental data obtained on the same sample patterned along the hard (1 1 0) axis. The magnetic field was directed parallel to the electric current. After the system was cooled directly to 50 mK without application of the magnetic field, we observed that the resistance is rather stable on the time scale to at least 10^5 s. Variation of the resistance with time for $500 < H < 1000$ G and when the magnetic field is changed at 4 K, was found to be rather unusual (see Fig. 1). At $H = 500$ G the resistance gradually increases from the initially stable state (S1) and then drops into a new state (S2) with reduced resistance. The new state S2 is apparently not stable and the system returns back to S1 through the same path S2–S1 but "inverted in time". For the field around 1000 G we observed similar back and forth transitions, but with S2 more stable than S1. The characteristic time for the transition between the two states is of the order of $1-2$ h

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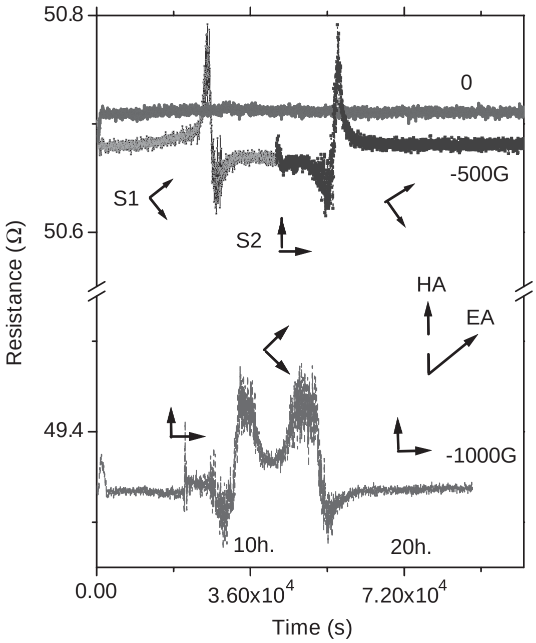

Fig. 1. Time dependent resistance of $[FeCr]_{10}$ for different applied magnetic fields measured at $T = 50$ mK after magnetic field was changed at 4 K. Arrows show proposed magnetisation of the BC coupled domains changing between easy (EA) and hard (HA) axes.

with evident noise increasing during the transition. These kinds of transitions were not observed for fields above 1000 G. Magnetic force (MFM) domain images taken before application of the magnetic field show the presence of different domains in Fe/Cr MMLs with typical dimension from above 10 μm to below 1 μm. Primary the domains with finite magnetic moment (biquadratically coupled, BC) will be affected by the external magnetic field. We believe that the transitions S1–S2 (S2–S1) reflect the instability of a coupled two-level system created by two BC domains. The observed behaviour can be described by a simple model with two oscillators located in minima and connected by a spring.

Before starting the second set of the experiments (not shown) the sample was heated to 300 K and cooled in zero magnetic field down to 50 mK and magnetic field was changed only at $T < 100$ mK. We observed that the reaction of the system in the variation of the magnetic field to the vicinity of the OPT was different. We found that GMR relaxes via multiple step transitions. For the magnetic field range well outside the OPT, the relaxation of the system is purely logarithmic. The magnetic after-effect studied in similar conditions but at 4.2 K was also logarithmic in time and did not reveal any specific anomalies near OPT.

The evolution of the magnetization from the metastable state created by a quench to the vicinity of the OPT from a magnetic field of 100 kG (Fig. 2) proceeds again via multiple steps. Heating of the system to above 4 K makes relaxation nearly logarithmic. However, contrary to the purely logarithmic relaxation without quench, some "modulation" in the log(t) slope was observed on the initial stage of the relaxation (below 10^4 s) when response was measured far from OPT (see data for $H = -1$ kG). This effect becomes specially pronounced once we subtract the logarithmic background in the relaxing GMR between 10^4 s and 10^5 s (see Fig. 2b). A non monotonous variation of the log (t) slope appears to be enhanced as the temperature decreases from 4 K to 50 mK. We note that oscillating relaxation with decaying amplitude was recently predicted for aging in quantum spin systems [5].

Occasionally, the logarithmic relaxation from the quenched state, after 10−15 h, was followed by a transition to a chaotic variation of the resistance with time (not shown), which continued at time scales at least up to 2×10^5 s. By changing the magnetic field in about 20% we could suppress this noise. Chaotic noise re-appeared in about 30 min once the initial field was restored. Details of these phenomena will be published elsewhere.

In conclusion, time dependences of the GMR in Fe/Cr multilayers on large time scales reveal a variety of novel

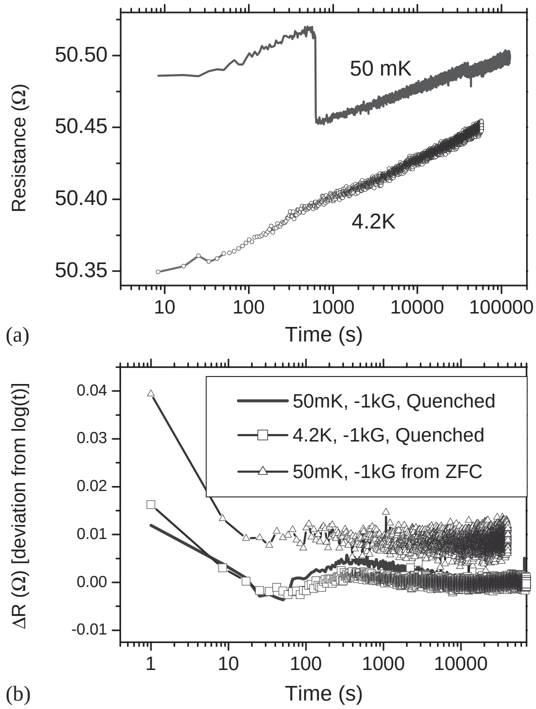

Fig. 2. (a) Time dependent GMR for magnetic field quenched from +100 kG to −450 G at 50 mK and 4.2 K. (b) Deviation from the log (t) relaxation determined at different temperatures at $H = -1$ kG in the presence (line,) and absence (Δ) of the quenching procedure.

dynamical phenomena related to coupled domain rotation and unusual relaxation of the magnetization. The possible influence of quantum or thermal fluctuations on the observed effects remains to be investigated.

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