Domain-wall Resistance at Low Temperature

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The electrical resistance of a domain wall and the resistance of entire domain structures have attracted much interest in recent times. For a review see Ref. [1]. It had been shown that spin-dependent transport phenomena analogous to the GMR effect in multilayers are a source of a domain-wall resistance (DWR). In magnetic microstructures the effect can be of the order of the usual magnetoresistance (MR) caused by anisotropic MR (AMR) and Lorentz MR (LMR). At room temperature, many experiments on magnetic thin films can be interpreted in terms of spin-dependent scattering analogous to the GMR effect in magnetic multilayers. At low temperature the experimental picture is more complex: Measurements performed on epitaxial iron stripes with an alternating in-plane magnetization result in a DWR decreasing with decreasing temperature, even to negative values. This means that in the presence of a domain structure conductivity is larger than in the state of uniform magnetization. In contrast, for Co stripes with alternating perpendicular magnetization and in-plane closure domains an increase of the DWR with decreasing temperature is observed. The transition between high- and low-temperature regime takes place near the compenzation temperature, which is typically 50-100 K. At the latter value the anisotropies of the AMR and Lorentz contributions to the MR compensate. Since the Lorentz MR dominates at lower temperature, it has been suggested to link the DWR at low temperature to some effect resulting from the Lorentz force [1,2].

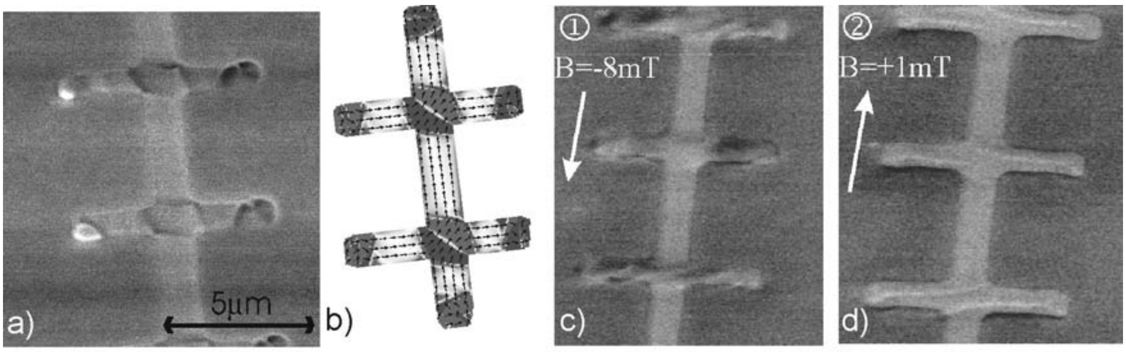

Fig. 1 a),b): MFM image and micromagnetic simulation of permalloy crossed stripe with remanent domain structure obtained from a saturation field oriented at 45° to the stripe's axis. c),d): Domain structures obtained from a saturation field parallel to the stripe's axis.

In order to check this hypothesis, the low-temperature DWR of permalloy ($Ni_{81}Fe_{19}$) was measured [3]. Since the mean free path of permalloy is roughly independent of temperature, Lorentz-force effects can be ruled out at any temperature. Consequently, the DWR is expected to remain unchanged. In addition, spin-dependent transport effects are strong in permalloy and the domain structure is determined by shape anisotropy. 1 µm wide crossed stripes of permalloy with contact pads for four-probe measurements were prepared from a 30 nm thick film by electron beam lithography. Magnetic force microscopy images of remanent states show that there are two fundamental states [Figs. 1 c),d)]. For the initial magnetization tilted by more (less) than about 20° relative to the symmetry axis the structure in Fig. 1a is obtained. Micromagnetic calculations [Fig. 1b)] confirm the existence of a square area at the crosses with the magnetization under 45° to the long axis. These configurations with their well-defined domain structures have been used originally to measure the DWR at room temperature [4]. MR measurements at T=4.6 K have been performed in the present work.

LMR of thin films in the presence of surface scattering and domain structures

A modeling of electronic transport in thin films with diffuse surface scattering in the presence of a magnetic domain structure has been performed as well [5]. The conductance is obtained from the mean square displacement of electrons. The results indicate that in alternatingly oriented stripe domains, with film thicknesses and domain periodicities comparable to the mean free path, the conductance is increased in comparison to a homogenous magnetization and the MR anisotropy tends to vanish. In Fig. 2 simulated conductance of iron films with alternating domain structure is shown. The conductance in presence of a domain structure is higher than in the homogenously magnetized film, in agreement with the experiment. Respective calculations provide a qualitative explanation for the pronounced temperature dependence of the DWR in cobalt films.

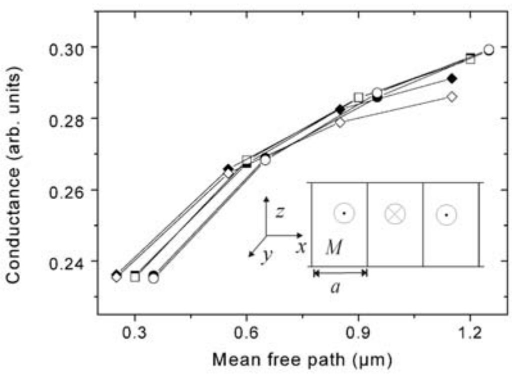

Fig. 2: Conductance in *x* direction (filled symbols) and *y* direction (empty symbols) versus mean free path in a thin film with alternating in-plane magnetization [see inset] for *a* = 100 nm (squares) and *a* = 400nm (circles), and with homogenous magnetization in *y* direction (diamonds). A Larmor radius for iron of R_B = 5 µm and a film thickness of *d* = 40 nm have been assumed. The curves have been shifted horizontally for convenience.

[1] A. D. Kent et al.; J. Phys. Cond. Mat. **13** (2001) R461.
[2] I. Knittel, U. Hartmann; to appear in Appl. Phys. A
[3] I. Knittel, S. Faas, M. A. Gothe, M. R. Koblischka and U. Hartmann; to appear in J. Magn. Magn. Mat.; (ICM 2003 Rome)
[4] Y.B. Xu et al.; Phys. Rev. B **61**, R14901 (2000)
[5] I. Knittel, U. Hartmann; submitted to J. Magn. Magn. Mat.