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Domain-wall resistivity in $SrRuO_3$: the influence of domain walls spacing

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Abstract

$SrRuO_3$ is an itinerant ferromagnet with a stripe domain structure. Here, we report how the resistivity due to the domain walls is affected when the density of the domain walls is decreased. We find that while the perpendicular resistivity is uniformly scaled down, the effect on the parallel resistivity seems to be temperature dependent. We discuss possible implications of these results.

Keywords: Domain wall—resistivity; Domain wall—structure; Magnetoresistance—giant; Spin-dependent scattering

The effect of domain walls (DWs) on the resistivity of itinerant ferromagnets has focused intensive experimental [1–4] and theoretical [5–12] efforts, as part of an increasing interest in spin-polarized transport across and along magnetic interfaces. Ideally, one would measure domain wall resistivity (DWR) by comparing the resistivity of a sample with DWs to its resistivity after eliminating the DWs by applying a magnetic field. If the latter state remains stable after removing the field and if the only change relative to the initial state is the absence of DWs, then the difference between the initial and final resistivity can be reliably attributed to DWR. Unfortunately, in most cases this ideal scenario is inapplicable. In most materials DWs renucleate when the field is set back to zero; hence, the zero-field resistivity without DWs can be only estimated by extrapolation from higher fields. Another more difficult problem is that in the process of DW annihilation, in some bulk regions the magnetization changes its orientation. This commonly induces large effects on the resistivity (e.g. anisotropic magnetoresistance or change in the Lorentz magnetoresistance) which should be distinguished from the intrinsic DWR. Furthermore, in many cases the domain structure is such that it is difficult to distinguish between the DWR for currents flowing perpendicular and parallel to the DWs.

These difficulties do not exist in $SrRuO_3$. We have explored the statics and dynamics of the DWs there by combining transmission electron microscopy (TEM) [13] with transport and magnetization measurements and found the following: (a) The domains form a structure of parallel stripes with the magnetization pointing alternately in two opposite directions along a single easy axis (hence, it is simple to measure separately the influence of the DWs on the resistivity for the perpendicular and parallel currents). (b) Due to the high uniaxial anisotropy of $SrRuO_3$ (~ 10 T) combined with its small self field (~ 0.2 T), no closure domains are created; therefore, no reorientation of bulk regions is involved when the DWs are annihilated. (c) For the same reasons as in (b), DWs do not renucleate when the magnetic field is reduced to zero (the magnetization reversal starts only at some negative field); hence, a direct measurement of zero-field resistivity without DWs is possible. The TEM study also showed that the DWs become static a few degrees below T_c (and their separation is 2000 Å) which assures that the temperature dependence of DWR is not related to changes in the number of DWs. All this allowed us to present

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detailed temperature dependence of DWR in $SrRuO_3$ for both current directions [4].

Here we continue our effort to study the DWR and its underlying mechanism by exploring the effect of reducing the density of DWs on the DWR for perpendicular and parallel currents. Our samples are thin films of $SrRuO_3$, which is an itinerant ferromagnet ($T_c \sim 150$ K) with a saturation moment of 1.4 μ_B/ Ru. The films were grown on slightly-miscut ($\sim 2°$) substrates of $SrTiO_3$ by reactive electron beam evaporation. They are single crystal, in an orthorhombic phase ($a \simeq 5.53$ Å, $b \simeq 5.57$ Å, $c \simeq 7.85$ Å), with the [0 0 1] direction in the plane of the film, and the [0 1 0] direction at 45° out of the plane of the film. The easy axis lies in the (0 0 1) plane. The films were patterned for measurements of resistivity in the [0 0 1] and [$\bar{1}$ 1 0] directions. The first direction is perpendicular to the easy axis, therefore the current there flows perpendicularly to the DWs. In the second direction, the current flows in parallel to the DWs. The thickness of the sample used in this work is 2000 Å. Its resistivity varies from 4.6 $\mu\Omega$ cm at 1.8 K up to 130 $\mu\Omega$ cm near T_c.

In order to dilute (but not eliminate) the DWs we have cooled the sample in fields smaller than the field required to avoid the DW nucleation. Such small magnetic fields do not avoid the formation of magnetic domains, but the domains are wider than in the zero-field-cooled case (i.e., the distances between the DWs are larger).

The DWR as a function of temperature, for different cooling fields from 0 to 250 Oe, is presented in Fig. 1 for the currents perpendicular (Fig. 1a) and parallel (Fig. 1b) to the DWs. The upper curve in each figure is the zero-field-cooling result.

It is clearly seen that the perpendicular DWR maintains the same form, only the magnitude of the DWR changes. This may have been expected assuming that the dominant scattering mechanisms are potential step scattering and spin accumulation [14,15]. The results only suggest that for perpendicular current the scattering at neighboring DWs is uncorrelated, and that relevant length scales (e.g., the spin diffusion length) are smaller than the spacing between the DWs at the zero-field-cooled state (2000 Å). Previously, we extracted a single interface resistance ($10^{-15}\,\Omega\,m^2$ at 5 K [4]) by measuring the global effect of numerous DWs and dividing it by the number of DWs in the measured region. This value should be identical to the interface resistance of an isolated DW only if scattering at neighboring DWs is uncorrelated. The present results provide evidence that this is the case.

The underlying mechanism of the parallel DWR is still in question. The present results show that contrary to the perpendicular case, the effect of increasing the spacing between DWs *is* temperature dependent. We hope that these results will provide useful hints for elucidating the underlying mechanism of the parallel DWR.

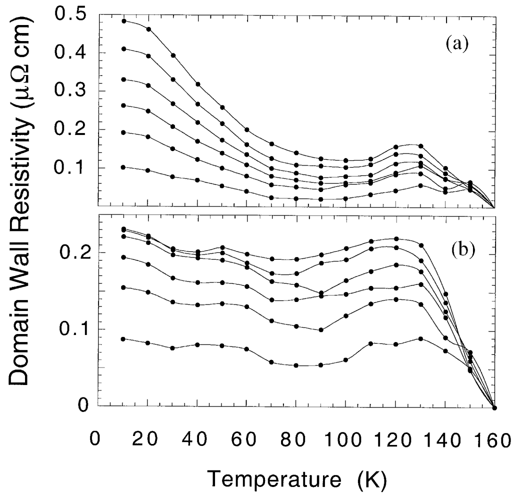

Fig. 1. DWR for different cooling fields from 0 (the top line) to 250 Oe (the bottom line) for currents (a) perpendicular and (b) parallel to the DWs. (The lines are guides for the eye.)

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