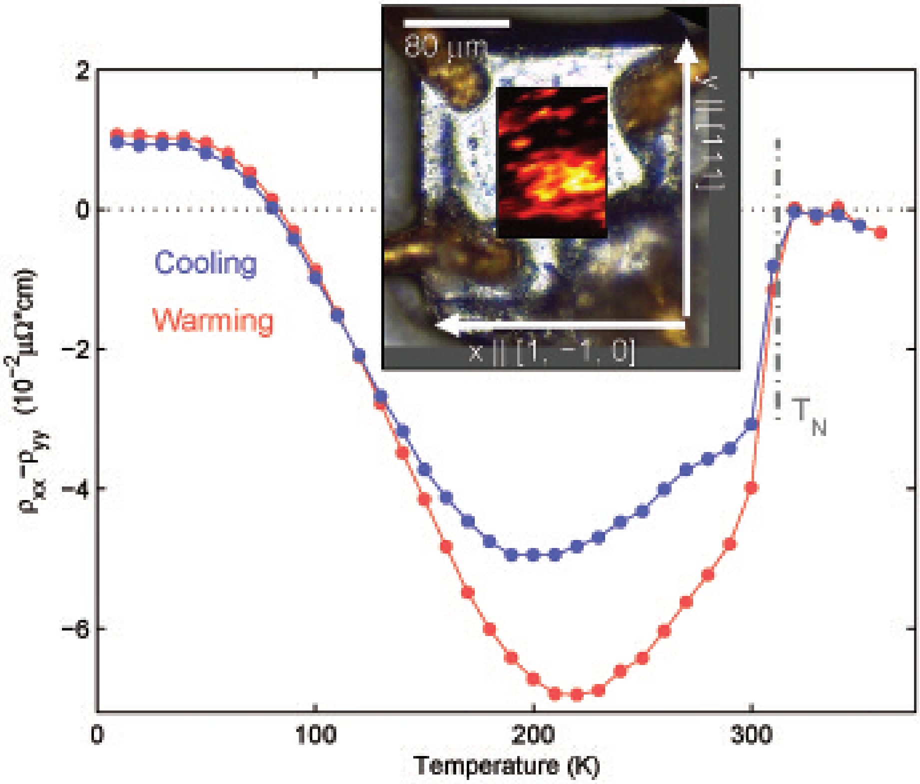
TRANSPORT ACROSS DOMAIN WALLS IN ANTI-FERROMAGNETIC MATERIALS

The number of studies that focus on antiferromagnetic domain imaging has been growing in recent years, in large part due to the increased importance of hybrid magnetic structures for advanced electronics. Notable examples include magnetic bilayers, in which an antiferromagnetic thin film causes a shift in the soft magnetization curve of a ferromagnetic film. This is known as the exchange-bias effect, and it is of great importance in magnetic recording. However, as more hybrid applications of this type are developed, detailed knowledge of the effects on transport of antiferromagnetic domain structure, both at the micro and macro scales, becomes increasingly important. Recently an international group of researchers have performed a combined electrical transport and x-ray imaging study of single chromium (Cr) crystals to address this issue. By comparing the thermal hysteresis observed in the longitudinal and Hall resistivities with that observed with real-space domain imagery, the researchers were able to isolate the transport signatures of the antiferromagnetic domain walls themselves. In particular, they were able to deduce the electrical resistance of a single antiferromagnetic domain wall. This work is an important contribution to the nascent science of antiferromagnetic domain walls and suggests new directions of inquiry into their potential applications in electronic devices.



Magnetic domains are volumes where the magnetic fields of a large number of atoms are grouped together and aligned, giving rise in a ferromagnet to a net local magnetization. These domains are separated by domain walls, whose thickness depends on the type of magnetic material used; across these walls, the orientation of the magnetization changes from one domain to its neighbor. In a ferromagnet, each domain is characterized by a single magnetization vector. The formation, motion, and electron scattering properties of these domain structures are exploited in the design of devices ranging from transformers to magnetic memory storage. On the other hand, antiferromagnetic materials are described by a pair of vectors that specify the orientation of the local magnetic moments as well as how those moments are modulated in space within a given domain. While this richness of structure is tantalizing, the lack of a net magnetic moment has complicated the study of antiferromagnetic domains, which in turn has held back the development of possible applications.

The electronic properties of the domain walls are governed by how readily electrons can scatter between the different Fermi surfaces of neighboring domains. The ease with which electrons perform this trick depends strongly on the ratio of the domain wall width R to the electron mean-free path l. For conventional ferromagnetic materials this ratio is large. The transport across domain walls is therefore diffusive, and the resistivity of an individual wall is very small. By contrast, for antiferromagnetic Cr the ratio R/l is of order unity. In this case quantum scattering effects are expected to dominate the transport of spin and charge across the domain wall, and the resistance of a single wall should be large. In order to isolate the transport signatures of this interesting domain structure the researchers in this study—from The University of Chicago, Argonne, the University of Wisconsin-Madison, and University College London—prepared crystals that were small enough to allow only a finite number of domains, yet large enough to be fully in the bulk regime. These crystals exhibited a pronounced thermal hysteresis in their electrical transport properties that was attributed to evolution of the antiferromagnetic domains with temperature.

The actual behavior of the domains themselves was then elucidated via the x-ray microprobe at XOR beamline 2-ID-D, where direct images of the domain structure at various points around the thermal hysteresis loop could be obtained (Fig. 1). Combining macroscopic and mesoscopic experimental probes in this way made it possible to pinpoint the effect of the antiferromagnetic domain walls on electron transport, as well as to begin to understand their thermodynamics. By contrasting transport results taken on samples with different domain orientations, the group was able to deduce that a single antiferromagnetic domain wall has an interface resistance of about 5×10^{-5} $\mu\Omega$ cm^2. This large value indeed corresponds to the $R/l \sim 1$ limit and confirms the notion of transport across domain walls in Cr as the scattering of electrons between volumes with mismatched gaps on their Fermi surfaces. In addition to making an important contribution to the nascent science of antiferromagnetic domain walls, this work points toward new directions of inquiry into their potential applications in electronic devices. What remains is to obtain a first-principles theoretical calculation for electron scattering from antiferromagnetic domain walls, exploring their full potential to modulate charge and spin transport. — *Luis Nasser*

< Fig. 1. Anisotropic resistivity $\rho_{xx} - \rho_{yy}$ measured on the imaged sample around a thermal hysteresis loop, showing clear evidence for magnetic domain reconfiguration and hysteresis with thermal cycling. The inset color map shows the population of one domain type as measured at the x-ray microprobe beamline 2-ID-D. The sample micrograph and x-ray image are to scale (but do not represent the same sample), allowing comparison of the current path lengths to the typical domain dimensions.

See: R. Jaramillo[1], T.F. Rosenbaum[1]*, E.D. Isaacs[2], O.G. Shpyrko[2], P.G. Evans[3], G. Aeppli[4], and Z. Cai[5], “Microscopic and Macroscopic Signatures of Antiferromagnetic Domain Walls,” Phys. Rev. Lett. **98**, 117206 (16 March 2007).
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2-ID-D • XOR • Life science, materials science, environmental science • Microfluorescence (hard x-ray), microdiffraction, micro-x-ray absorption fine structure • 3.3-cm Undulator A • Accepting general users