Magnetoresistance in Ferromagnet Breakjunctons

Abstract:
We fabricate ferromagnetic nanowires with constrictions such that the cross-section at the constriction can be controllably reduced from 100 nm to the atomic scale by means of electromigration. This allows measurements of the resistance of a domain wall trapped at the constriction as a function of the cross-section’s size. We observe magnetoresistance (MR) of around 0.3% for a (100 x 30) nm² wide constriction and around 10% for an atomic-sized constriction. No MR higher than 15% is observed. These results are consistent with a geometrically-constrained domain wall trapped at the constriction [4].

Summary:
The micromagnetic structure of materials on a nanometer scale differs from that in the bulk. One example is the width of a domain wall located at a constriction separating two regions of wider cross-section. In bulk the domain wall’s structure is determined by a competition between exchange and anisotropy energies and does not depend on the geometry of the system. However, the situation changes once the cross-section of the constriction is just tens of square nanometers. The width of such a “constrained” domain wall is determined by the size of the constriction and can be of atomic dimension in the limit of a point contact [1]. Experimentally, formation of such domain walls can be monitored through resistance measurements. When the size of the magnetic wall gets smaller than the Fermi length, electrons cannot propagate adiabatically from one side of the wall to the other, resulting in a higher resistance [2]. Recently, several groups reported MR in excess of 100% in such atomic-sized constrictions [5], while others failed to reproduce these findings [6].

We developed a technique based on controlled electromigration [3] to tune the size of the constriction between two single-domain magnets from 3000 nm² down to nanometer dimensions, and to measure its MR as a function of the constriction size. The cross-section of the constriction determines its resistance which varies from 100 Ω into the kΩ range for atomic point contacts.

We fabricate two permalloy magnets separated by a narrow bridge using electron-beam lithography. The shapes of the magnets are chosen to promote shape anisotropy and favor formation of the domain wall in the area of the constriction at intermediate magnetic fields. The magnets are electrically contacted with gold leads using a separate step of e-beam lithography. DC conductance measurements are performed in a cryostat at 4.2 K.

The voltage across the constriction is slowly ramped up while monitoring the current. At roughly 3 mA, electromigration sets in (as indicated by a slower increase in current) and the bias voltage is quickly lowered by acquisition software. Repeating this procedure allows us to lower the resistance of the junction to any value between 100 Ω and 10 kΩ with 10% accuracy.

The MR of such a device strongly depends on its resistance. For resistances below 100 Ω the magnetoresistance typically is around 0.3-0.6%. The value of MR increases when the size of the constrictions gets smaller. In addition, the sign of MR changes in some devices. Finally, we observe MR as high as 10% when the resistance of the device is comparable to the quantum of resistance. This observation is consistent with electrons scattering off a constrained domain wall trapped in the region of the constriction [4]. At this point, however, we cannot exclude other sources of MR, such as tunneling contributions in the high-resistance regime.

References:
Magnetoresistance in Ferromagnet Breakjunctions

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Figure 1, top right:
Two permalloy magnets separated by a narrow constriction.

Figure 2, below left:
The cross-section of a constriction is reduced in stages (insets) by ramping the bias voltage until electromigration begins, and then quickly decreasing the bias.

Figure 3, below right:
Magnetoresistance for 3 different samples as a function of resistance (A and B) and magnetic field (C).