Current-induced manipulation of domain-walls in $SrRuO_3$

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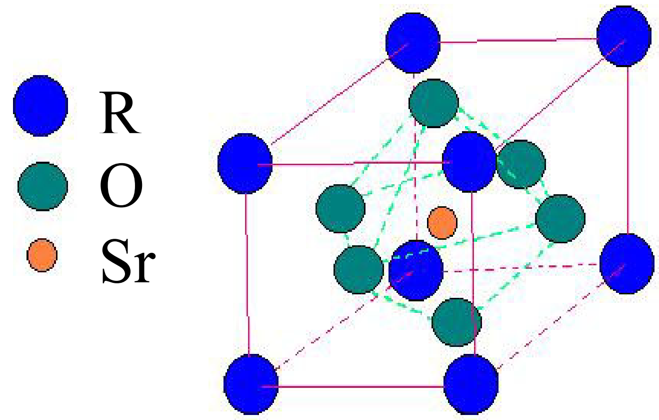
Why $SrRuO_3$?

- Stripe domain wall structure coupled to crystal axes
- Known interface resistance
- Narrow domain walls (~ 3 nm)

$SrRuO_3$ - general properties

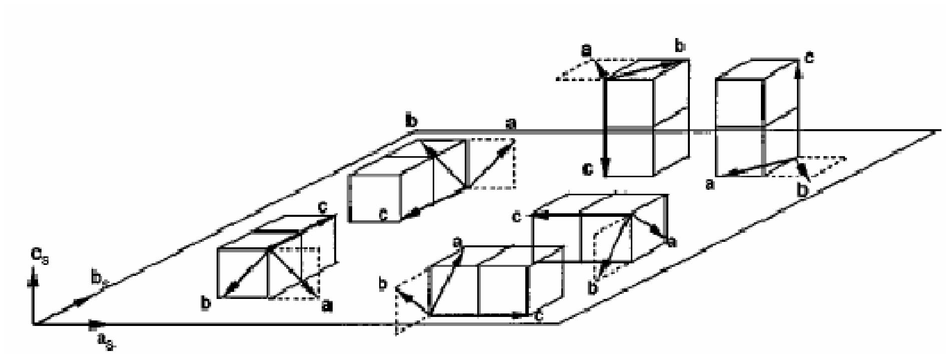
- Pseudo-cubic perovskite

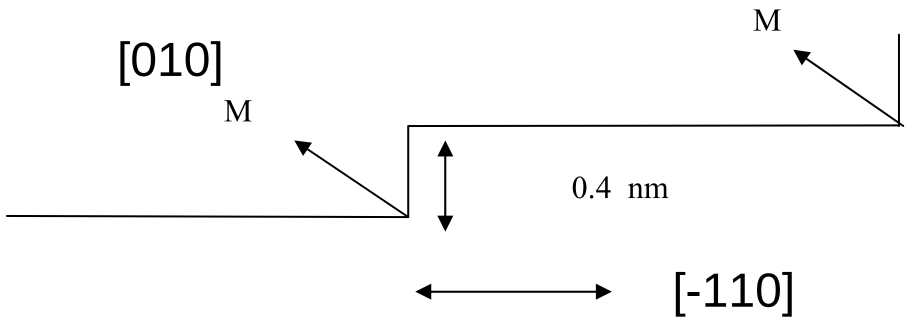
  (a=5.53, b=5.57, c=7.82 Å)
- 4d itinerant ferromagnet
- 1.4 μ_B per Ru
- $T_c \sim 160$ K (150 K)
- Large magnetocrystalline anisotropy



$SrRuO_3$ – epitaxial films

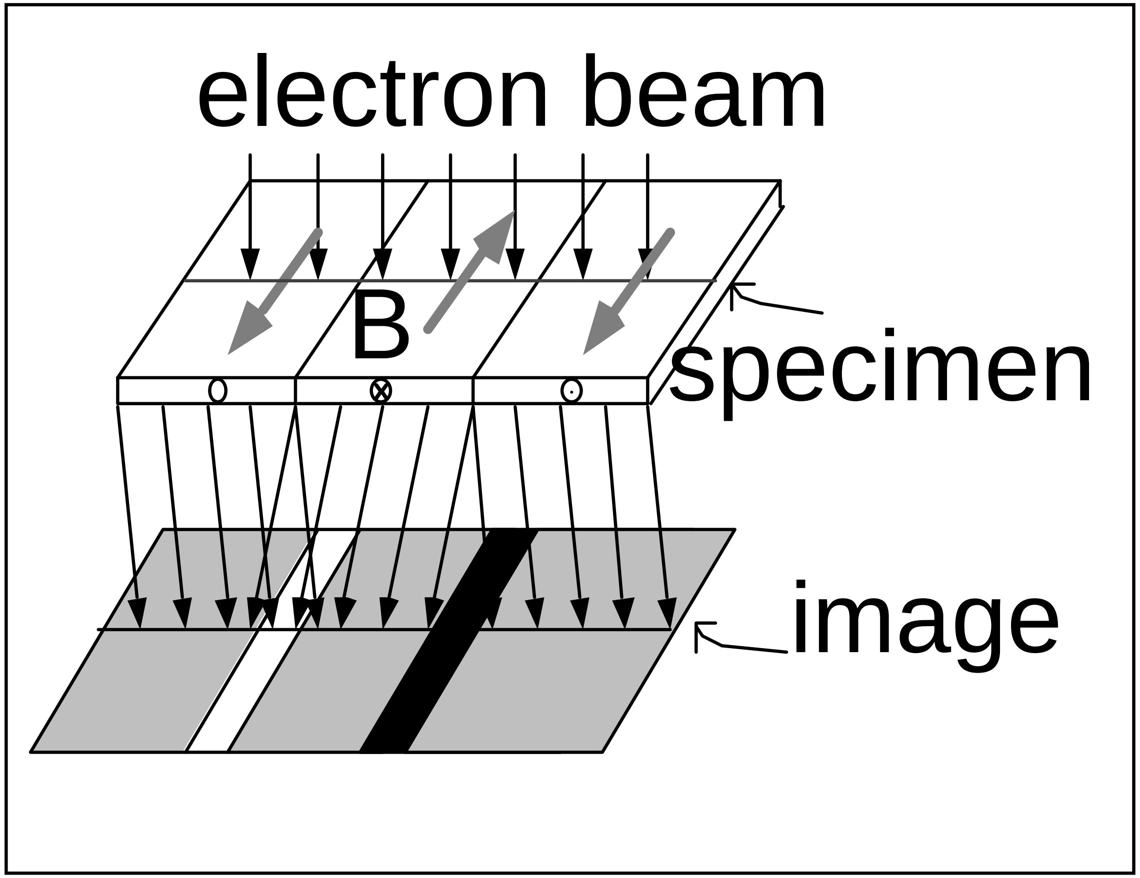
- Untwinned $SrRuO_3$ films grown on miscut $SrTiO_3$
- Large uniaxial magnetocrystalline anisotropy field (~10 T) along (010)
- Tilted easy axis – an advantages for structure and possibility to monitor
- Calculated domain wall width ~ 3 nm





Marshall et al, JAP, 85, 4131 (1999)

TEM images of domain-wall structure



Marshall et al, JAP, 85, 4131 (1999)

In Situ Lorentz TEM Studies of $SrRu0_3$

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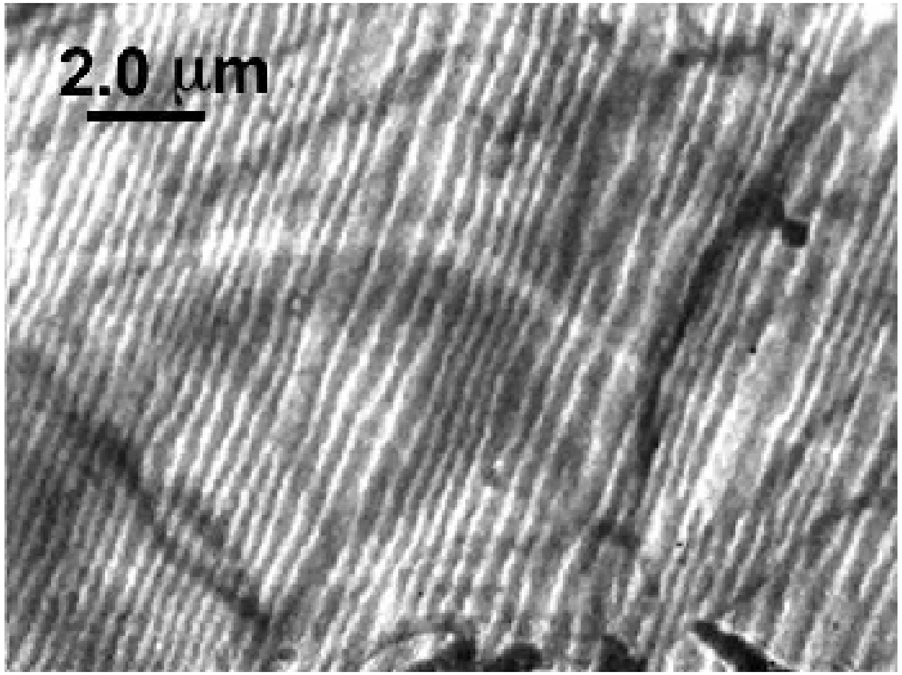
Center for Materials Research
Stanford University

$SrRuO_3$ – domain structure



$SrRuO_3$ – domain structure

$Q=K/2\pi M_s^2$

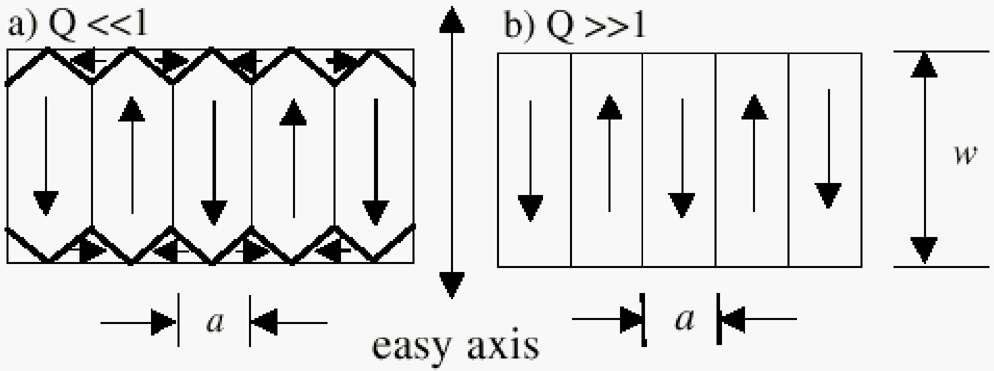


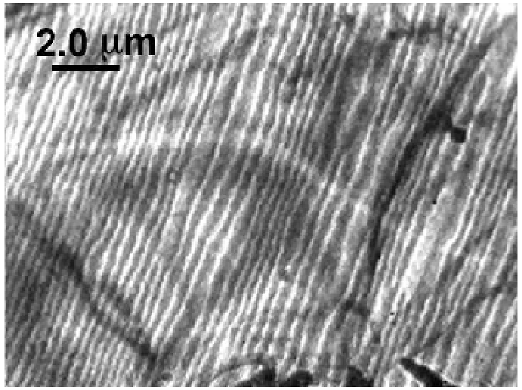
Figure 1. Illustration of stripe domain configurations in (a) low anisotropy ($Q \ll 1$) and (b) high anisotropy materials ($Q \gg 1$).

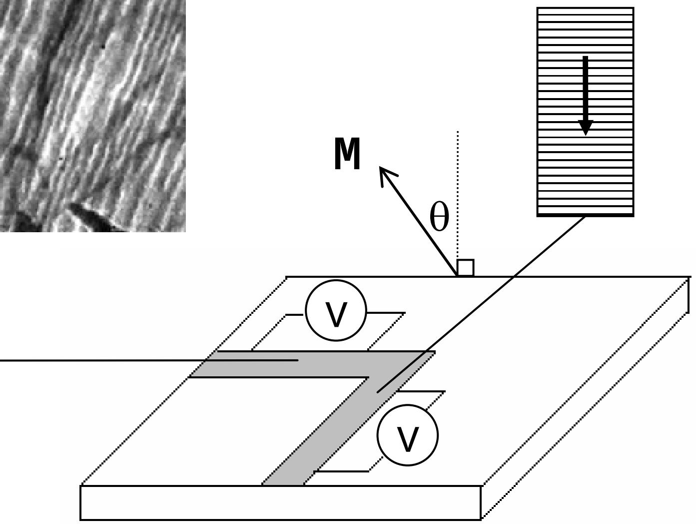
Q ($_{SrRuO3}$)= 10

Q (Co) = 0.35

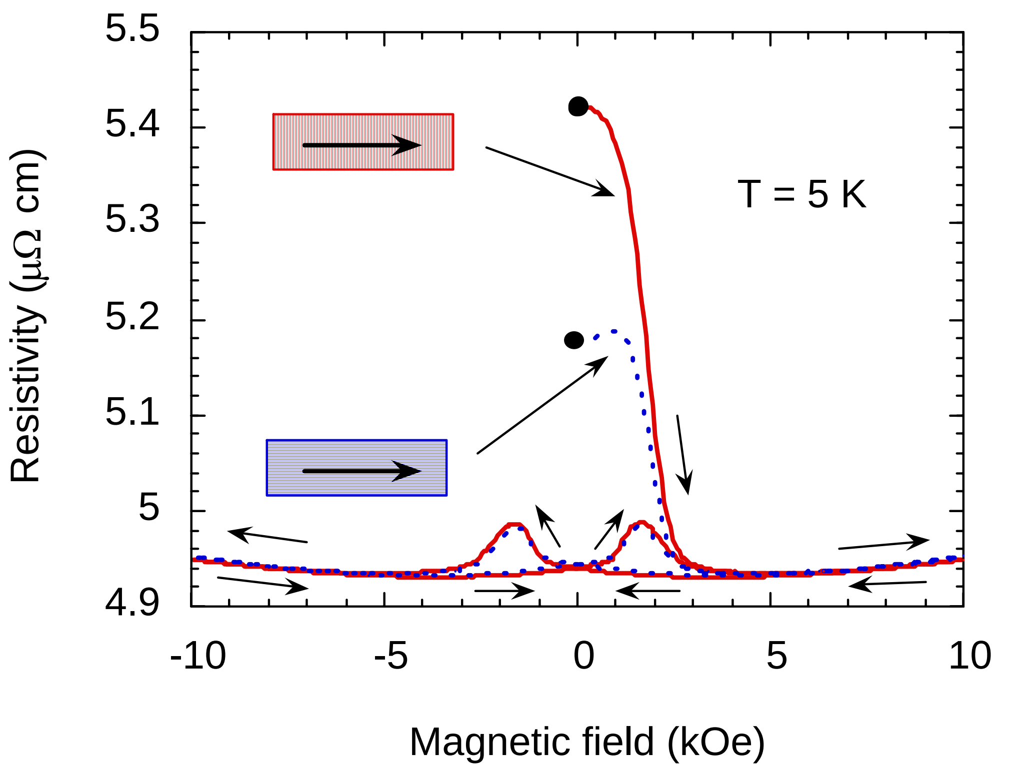
Q(FePd) = 1.5

Measurements of domain wall resistivity





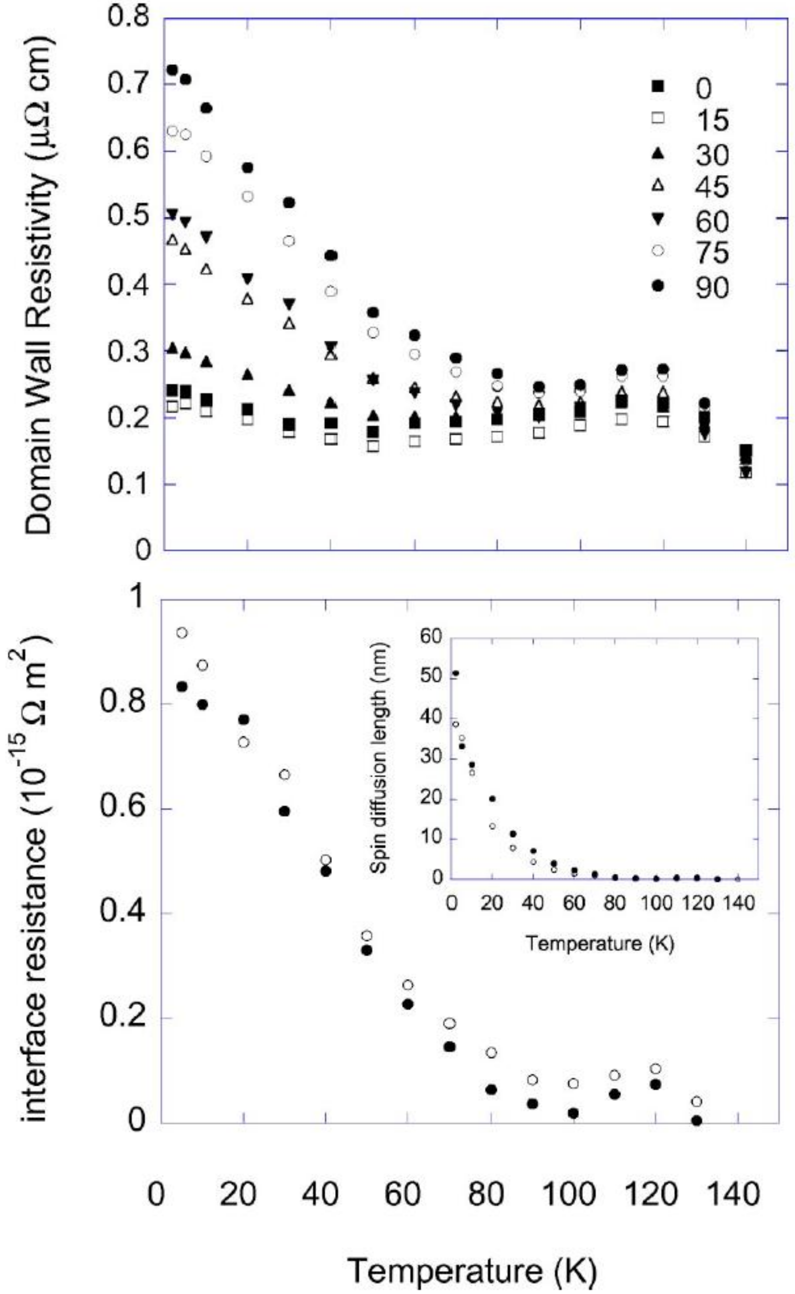
Extraction of domain wall resistivity from hysteresis loops



Interface resistance ~ $10^{-15}\ \Omega m^2$

LK et al, PRL 84, 6090 (2000)

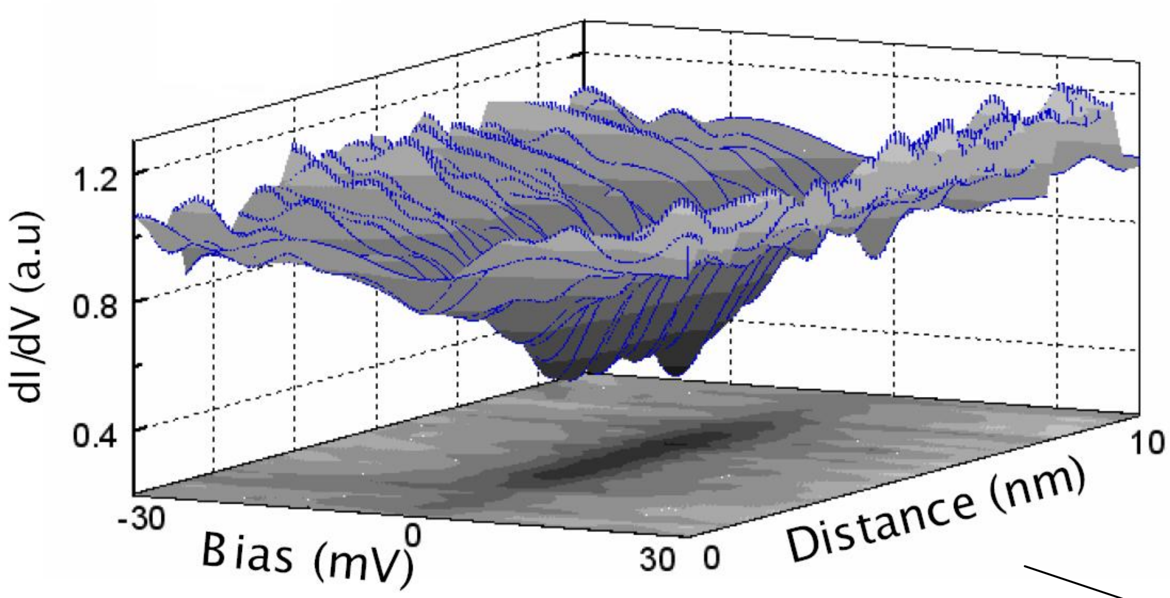
Angular dependence domain wall resistivity

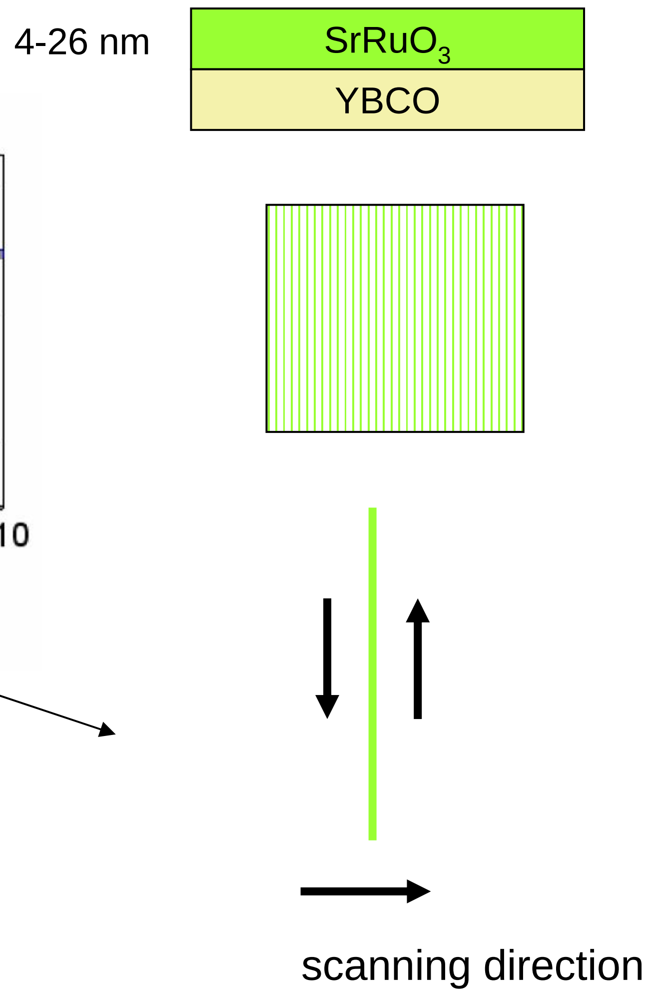


Feigenson et al, PRB 67, 134436 (2003)

Experimental verification of the narrow-wall limit in $SrRuO_3$ (Asulin et al.)

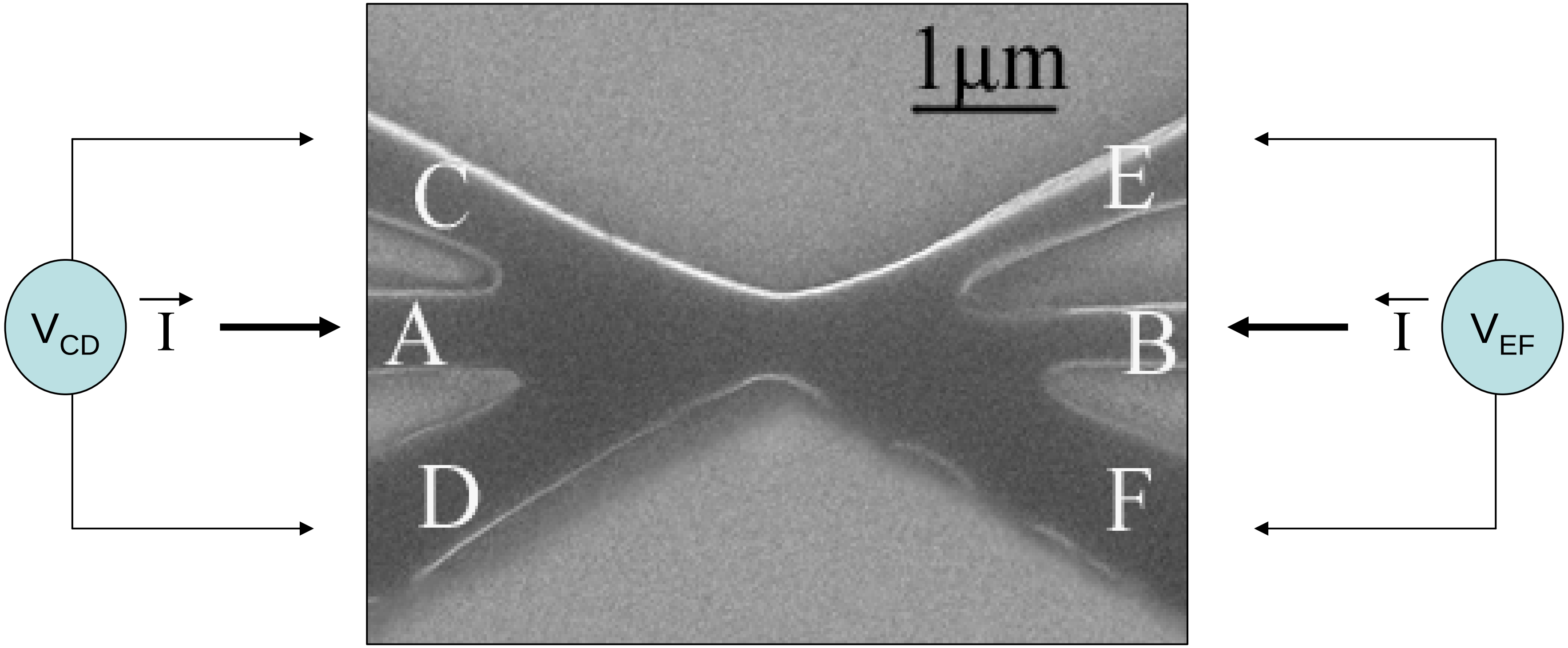
Tunneling spectra across a domain wall





Asulin, Yuli, Koren, Millo, PRB 74, 092501 (2006)

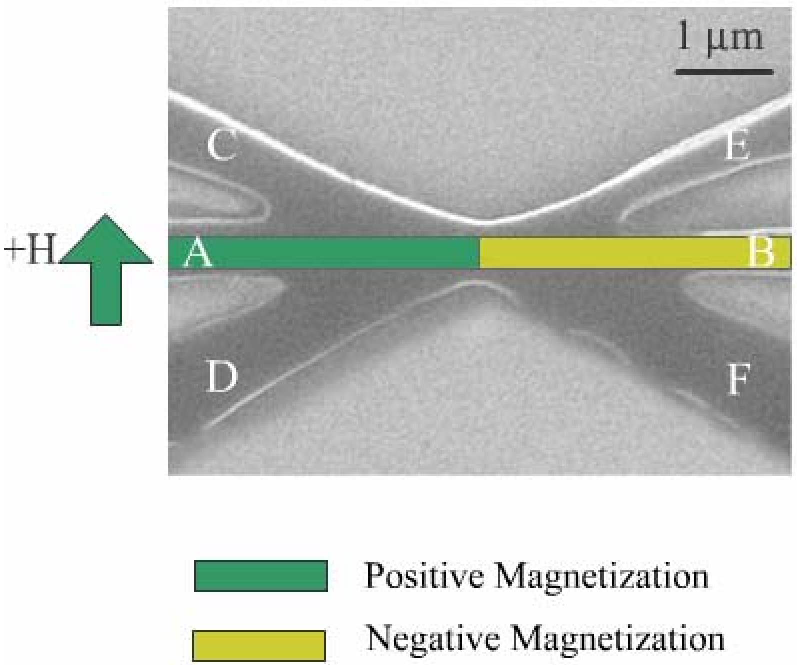
Sample fabrication

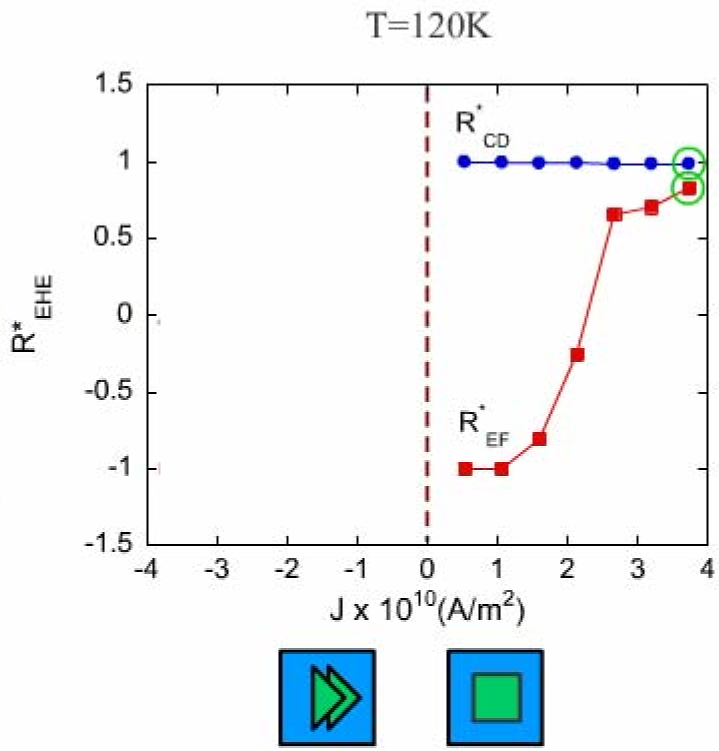


Extraordinary Hall effect measurements are used to monitor magnetization in the entire region

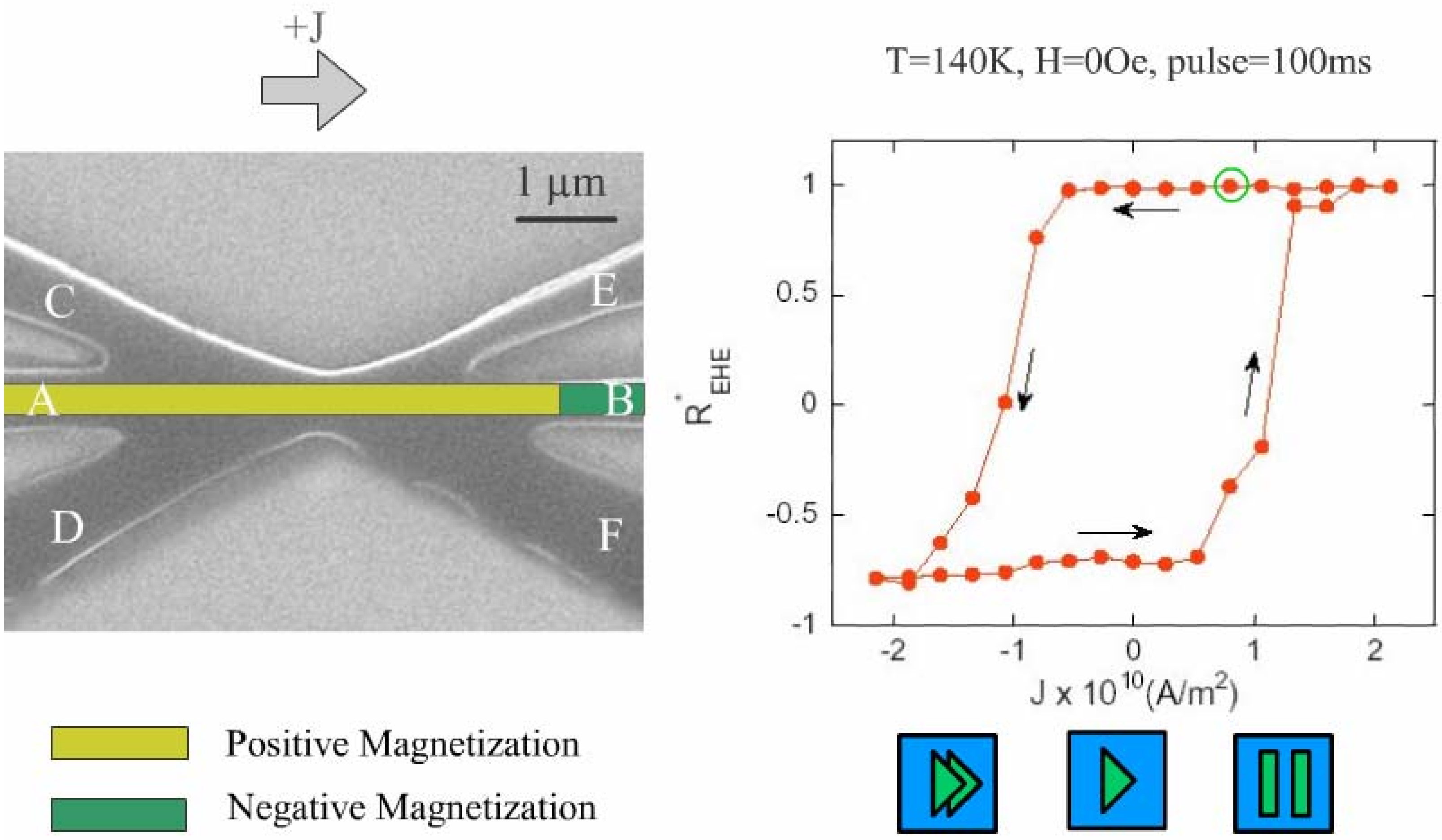
Feigenson, Reiner, LK, PRL 98, 247204 (2007)

Introducing a single domain wall

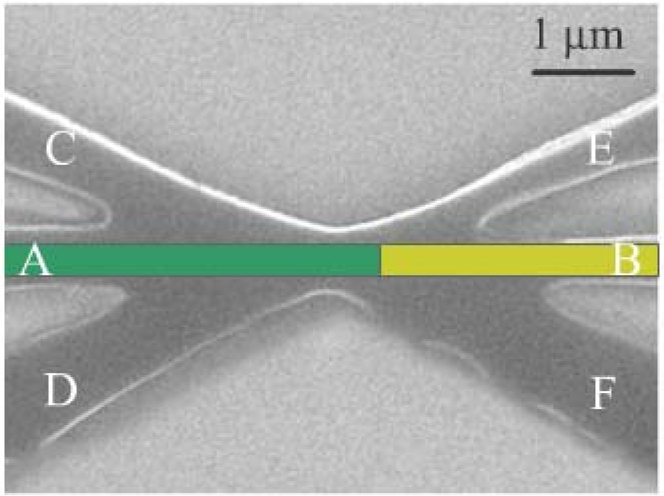




Single domain wall displacement

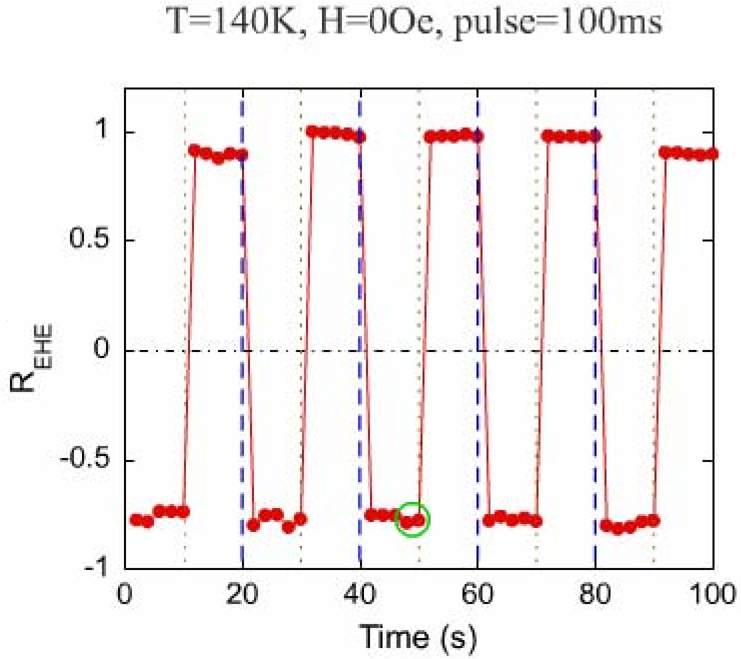


Single domain wall switching

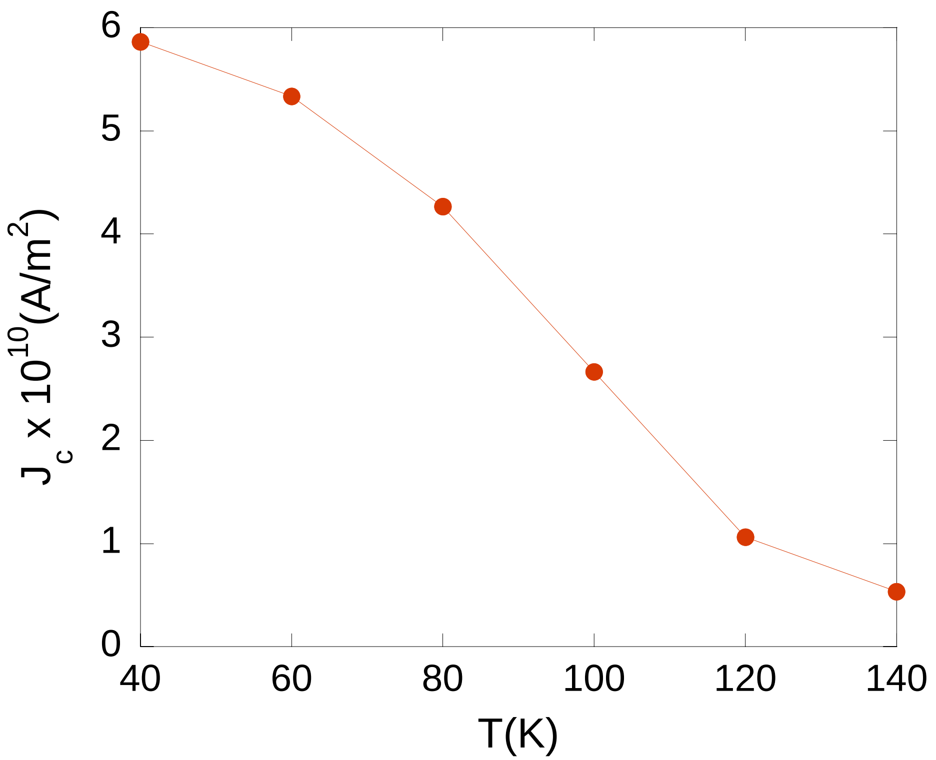


Positive Magnetization

Negative Magnetization



Critical current vs temperature



In comparison:

$10^{11} - 10^{12}$ A/m^2 in NiFe

10^9 A/m^2 in MnGaAs

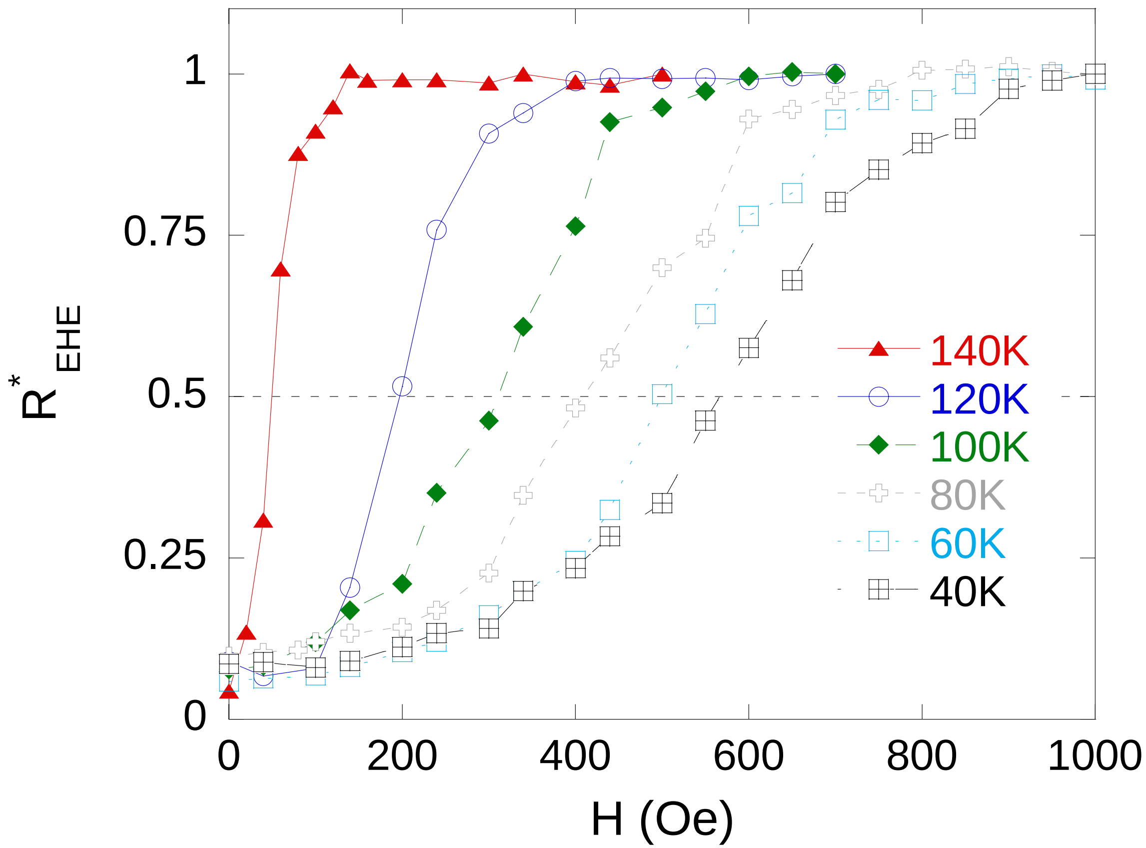
Suggested efficiency criterion

$$efficiency = \frac{H_c}{J_c}$$

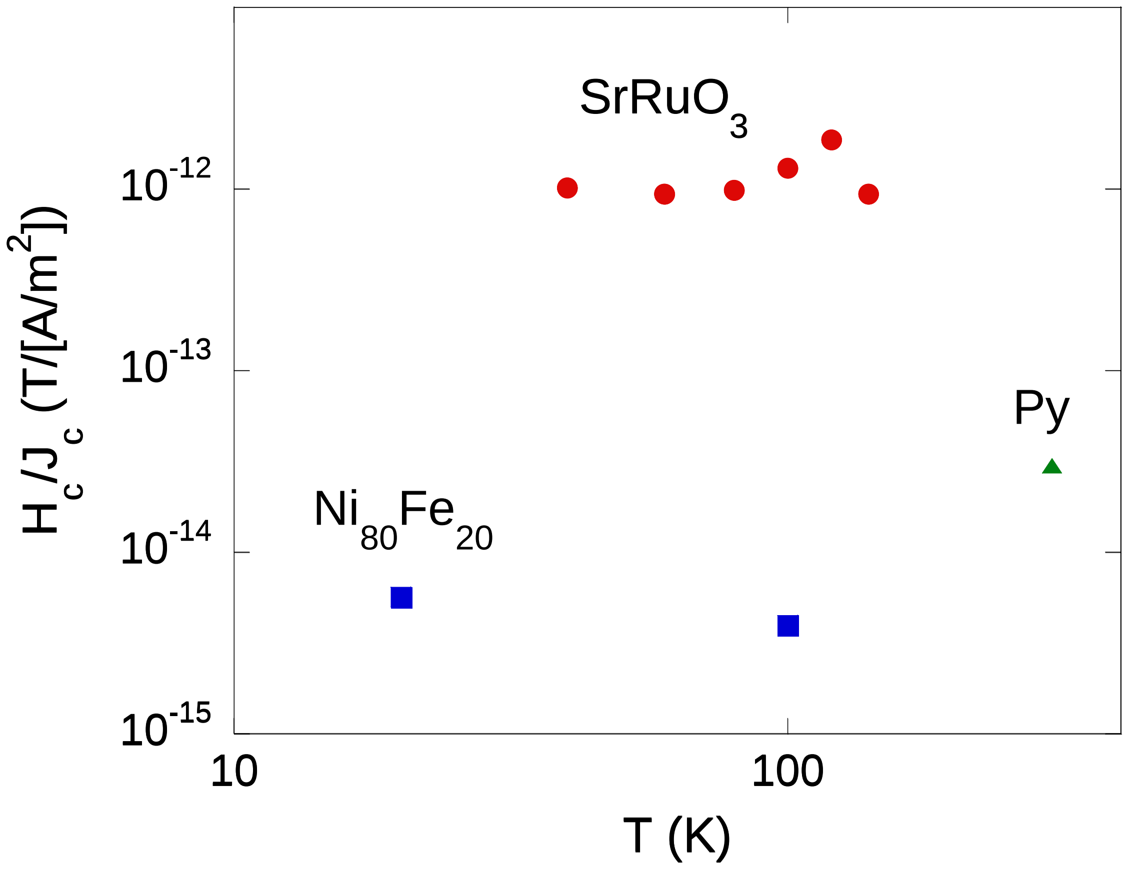
To determine current efficiency in displacing a domain wall one needs to consider not only the value of the critical current but also the pinning potential in which the domain-wall is trapped

Determining the relevant H_c

Field-induced magnetization after zero field cooling



Efficiency



Experiment and theory

Narrow limit prediction $$J_c = \frac{2H_c\mu_B}{ena^3R_wA}$$

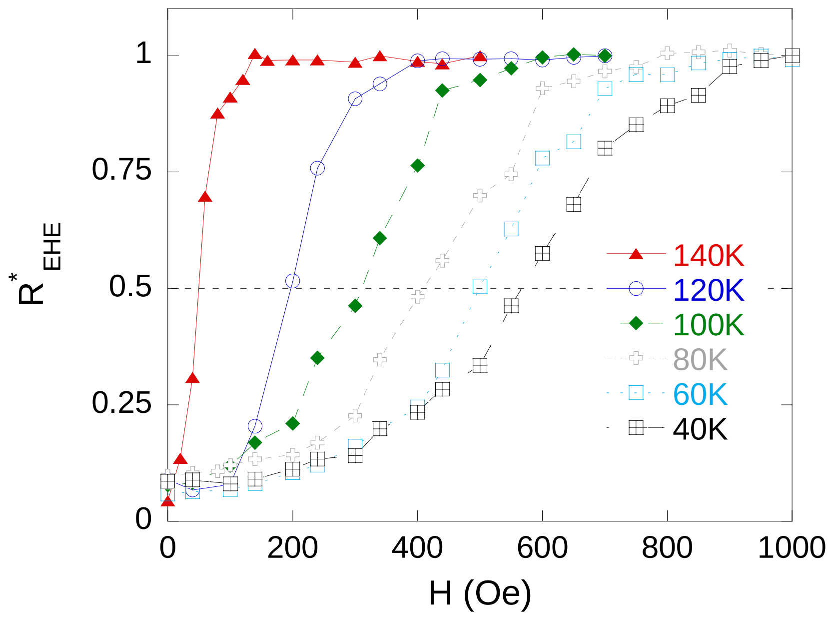
- R_w – wall resistance
- A – cross section area
- n - electron density
- a – lattice constant

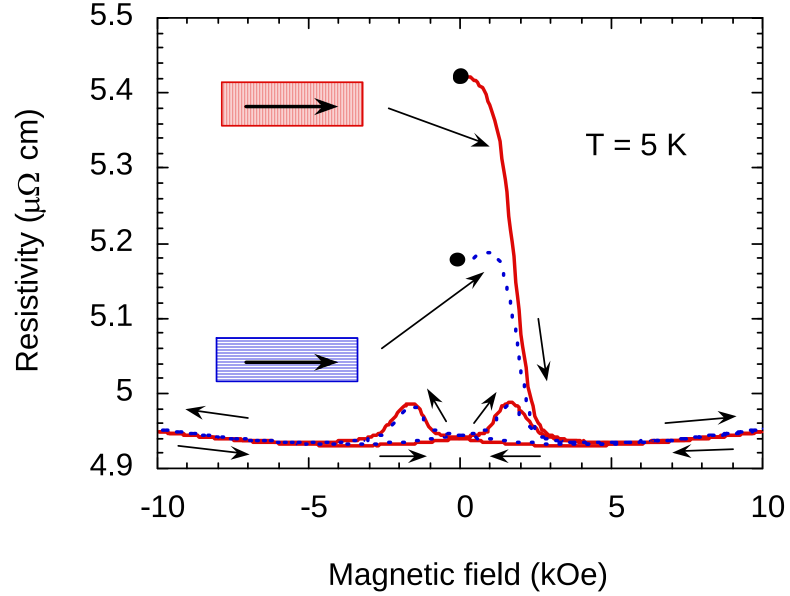
G. Tatara and H. Kohno PRL 92, 086601 (2004)

Interface resistance in $SrRuO_3$ – 10^{-15} Ωm^2 as expected in the narrow limit

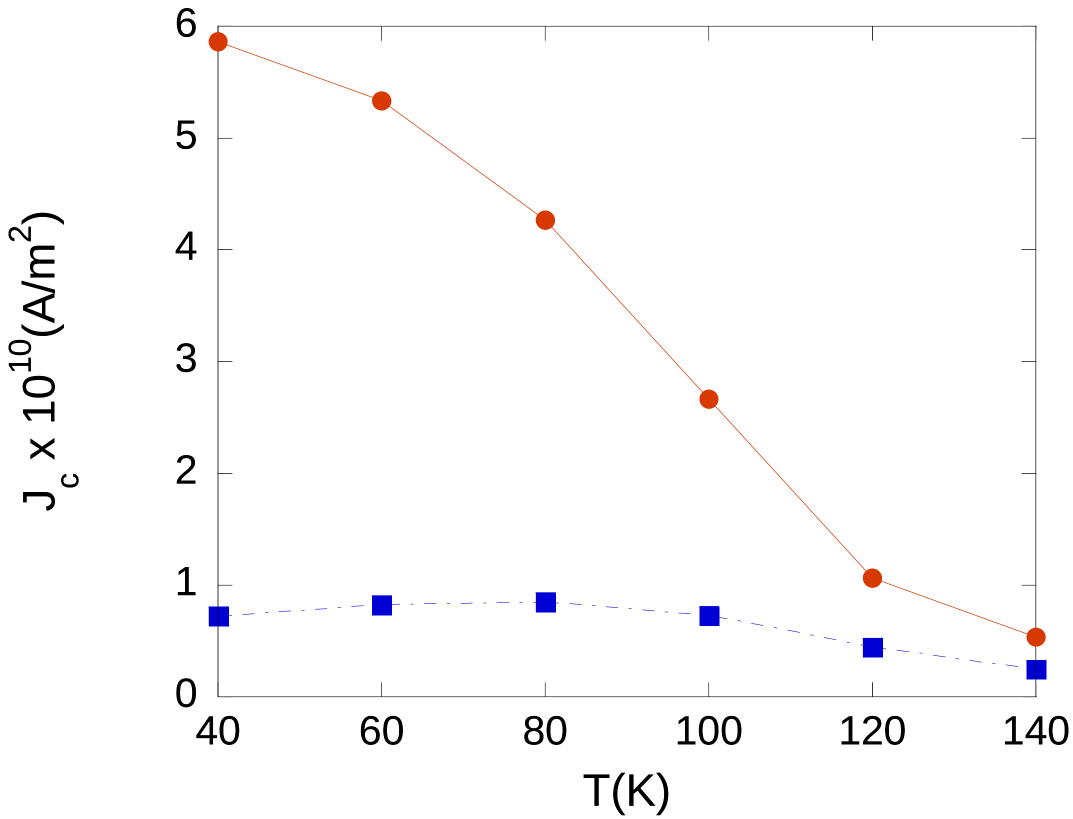
This value is more than 3 orders of magnitude higher than in cobalt

LK et el, PRL 84, 6090 (2000)





Experiment and theory

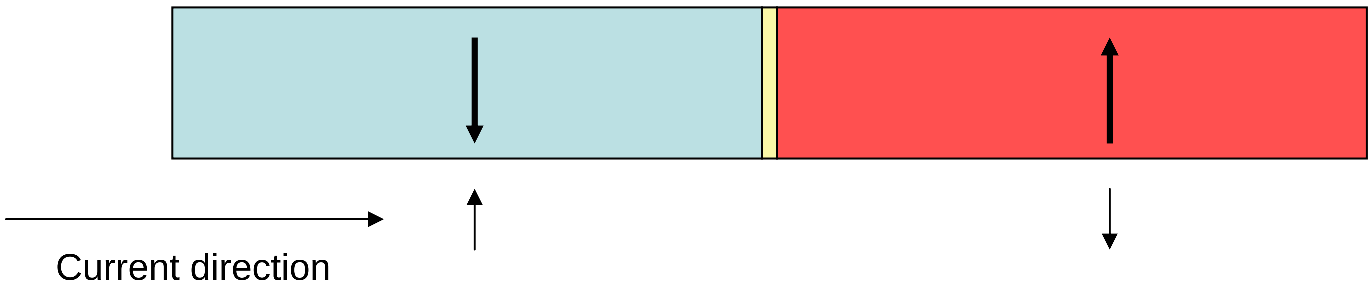


$$J_c = \frac{2H_c \mu_B}{ena^3 R_w A}$$

R_w – wall resistance
A – cross section area
n - electron density
a – lattice constant

Disagreement between theory and experiment: magnitude, temperature dependence and displacement direction

Displacement direction



The spin polarization in $SrRuO_3$ is negative

The electron current flowing from left to right gains
negative magnetic moment

The magnetic domains gain
positive magnetic moment

The wall moves to the left contrary to the flow of the electrons and with the current direction as observed

Summary

- Current-induced domain-wall motion is studied for the first time in the narrow wall limit
- Relatively low $J_c \sim 10^9 – 10^{10}$ A/m^2,
- Very high efficiency - two orders of magnitude higher
- Existing theory is inconsistent with results

Co-authors

- Michael Feigenson

Ph.D. student in my group

- James W. Reiner –

grew the samples at Stanford (Beasley’s Lab)