

Magnetotransport as a tool to probe magnetic domains in thin films

A. Husmann, S.N. Holmes, Toshiba Research Europe Ltd, UK

M. Pepper, Toshiba Research Europe Ltd and Cavendish Laboratory, University of Cambridge, UK

R. Dunin-Borkowski, Department of Materials Science, University of Cambridge, UK

Wednesday Poster Session

1

Introduction

- Understanding magnetotransport in small magnetic structures is important for spintronic applications.
- Magnetotransport is determined by direction and magnitude of local magnetic moment, domain structure, and scattering rate of domain wall
- And by domain wall motion and spin wave excitations.

2

Magnetotransport

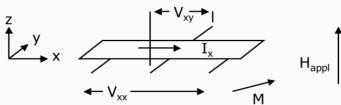
Three experimental signatures:

- Anisotropic magnetoresistance (AMR)
- Planar Hall effect (PHE)
- Anomalous Hall effect (AHE)

3

Experimental Set-up for Magnetotransport

- Thermally evaporated polycrystalline Co films with thickness 10nm to 75 nm
- Hall bar of various widths (10 μm to 75 μm) up to 1mm long on GaAs and Si substrates
- Applied magnetic field in plane (AMR and PHE) and out of plane (AMR and AHE)



4

Anomalous Hall effect (AHE)

H_{appl} perpendicular to film plane: $H_{\text{appl}} = (0,0,H_z)$

To first order in M and B

with $B = H_{\text{appl}} + 4\pi M(1-N)$, N: demagnetisation factor:

$$I = \sigma_0 E + \sigma_H' E \times M + \sigma_H E \times B$$

Spin interactions such as skew scattering and side jump leading to anomalous Hall effect

Ordinary Hall effect

Note: $\sigma_0 > \sigma_H' > \sigma_H$

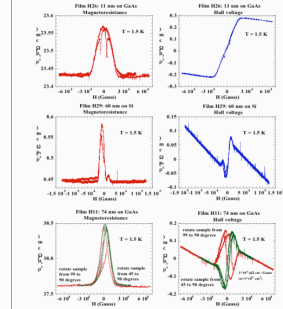
Converting to resistivity (assuming $I = [I_x, 0, 0]$):

$$\rho_{xx} = E_x/I_x = \sigma_0^{-1} [\sigma_0^2 + (\sigma_H B_x + \sigma_H' M_x)^2] \quad \text{AMR}$$

$$\rho_{xy} = E_y/I_x = \sigma_0^{-1} [\sigma_0 (\sigma_H B_z + \sigma_H' M_z) + (\sigma_H B_x + \sigma_H' M_x) (\sigma_H B_y + \sigma_H' M_y)]$$

↑
ordinary Hall effect AHE additional contributions when M_x or $M_y = 0$

5



AHE Cont'

AHE with little contributions from additional terms

AHE with contributions from moments in plane

AHE with contributions from moments in plane, direction depending on history

6

Planar Hall effect (PHE)

H_{appl} in film plane: $H_{\text{appl}} = (H_x, H_y, 0)$

Useful geometry for spintronics applications

To first order in $\cos^2\alpha$:

(α : angle between current and direction of magnetic moment)

AMR $\rho_{xx} = \rho_{\perp} + \Delta\rho \cos^2\alpha$ ($\Delta\rho = \rho_{\parallel} - \rho_{\perp}$)

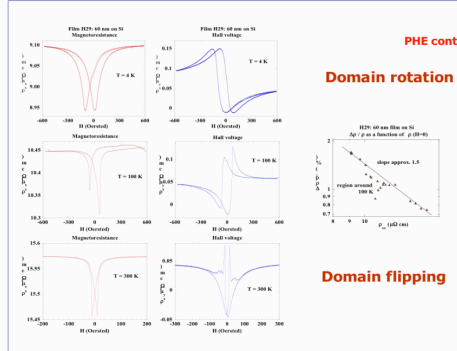
and

PHE $\rho_{xy} \approx \Delta\rho \sin 2\alpha$

as $\rho_{\parallel} \neq \rho_{\perp}$, E is not parallel to I.



7



PHE cont'

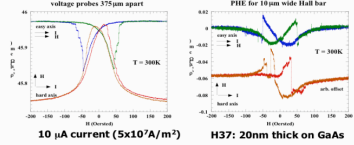
Domain rotation

Domain flipping

8

Barkhausen Noise

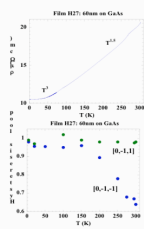
- Signal in MR and PHE from single domains flipping under reversal of field at 300 K
- PHE along easy axis shows flipping of one main domain
- Estimation of domain size: 7 $\mu\text{m} \times 50 \mu\text{m}$
- Contributions to MR and PHE from domain walls?
- Energy barrier for domain flip: about 20 K for 20nm thick film, about 100 K for 60 nm thick film (see page 8)



9

Additional measurements

- $\rho(T)$ and MOKE(T) for H27



$\rho(T)$ shows a crossover from T^3 to $T^{1.5}$ at around 60K.

There is a crystallographic anisotropy in MOKE loops on unprocessed wafers along $[0, -1, 1]$ and $[0, -1, -1]$ which is T dependent.

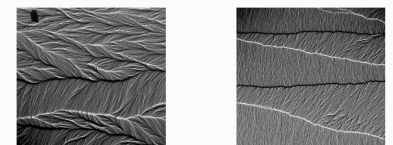
10

TEM

- Fresnel Mode of Lorentz microscopy
- Co films on electron transparent SiN membranes
- Film thickness: 15 and 40 nm
- Snapshots during field reversal
- coercive fields around 20-30 Gauss

11

TEM Cont'



Magnetization reversal cycle - direction 2. Field of view 200 μm for 40 nm thick film. Snapshot at 5. 22 eV towards bottom right.

Magnetization reversal cycle - direction 2. Field of view 200 μm for 15 nm thick film. Snapshot at 5. 24 eV towards left.

Internal domain structure in 40 nm more complicated than in 15 nm.

12

Conclusions

- Competition of various energy scales such as demagnetisation, geometric confinement and surface contributions lead to complex magnetotransport behaviour under magnetic field reversal.
- Magnetotransport is a powerful tool to probe magnetic domains.
- Pronounced Barkhausen noise in electrical transport for 10 μm wires.

Future Work

- Correlate magnetotransport with TEM in more detail.
- Model domain switching.