# Magnetostatic Interactions in $[NiFe/Au/Co/Au]_N$ Multilayers Studied by SXRMS & XMCD-PEEM


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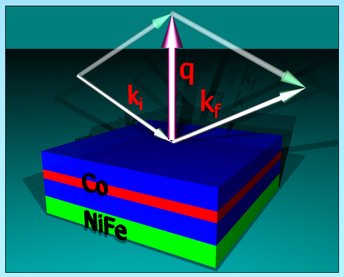
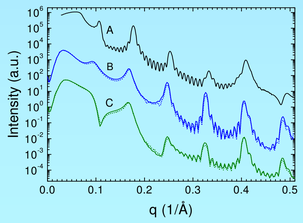
## Element specific hysteresis loops SXRMS - Bessy

Geometry of experiment

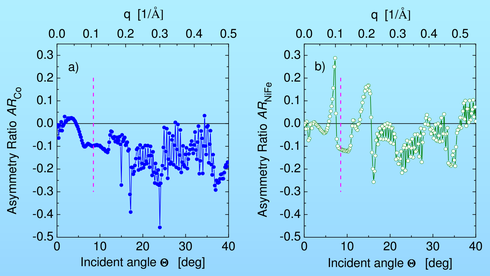



Comparision of reflectivity profiles taken at different energies of incident radiation
(A – 8040 eV, B – 778 eV, C – 853 eV)



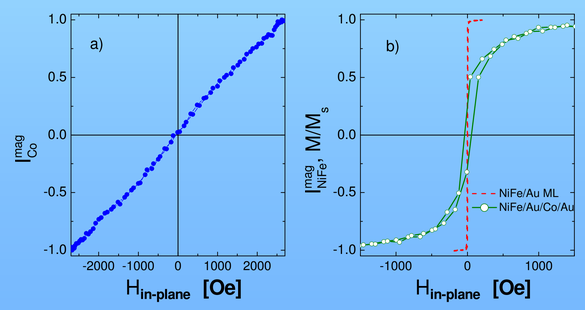

Soft x-ray resonant magnetic scattering (BESSY II, Berlin) – **ALICE diffractometer** - reflectivity curves with circularly polarized x-rays tuned to L3 Co (778 eV) and L3 Ni (853 eV) absorption edges.

The asymmetry ratios versus Θ calculated from profiles $I^+$ and $I^-$ taken at $L_3$ Co and $L_3$ Ni



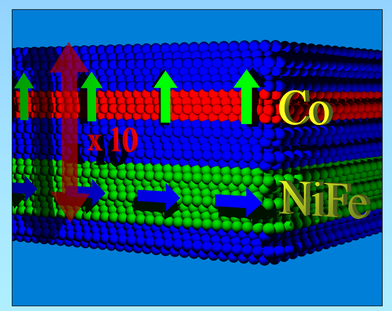

**Asymmetry ratio**

$$AR = \frac{I^+ - I^-}{I^+ + I^-}$$



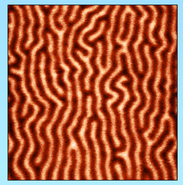

Normalized magnetic signals versus H determined from curves measured at L3 Co and L3 Ni and incident angle of 8.5°

## Magnetoresistance vs. magnetization



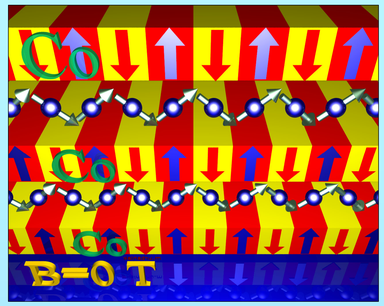

Co layers - perpendicular magnetic anisotropy and stripe domains:

MFM image of the domain structure



$[NiFe(2nm)/Au(t_{Au})/Co(t_{Co})/Au(t_{Au})]_{10}$, $t_{Au}$=1-4nm, $t_{Co}$=.4-1.6nm

Magnetic stray fields of the stripe domains of Co layers deflect the magnetic moments of NiFe out of plane

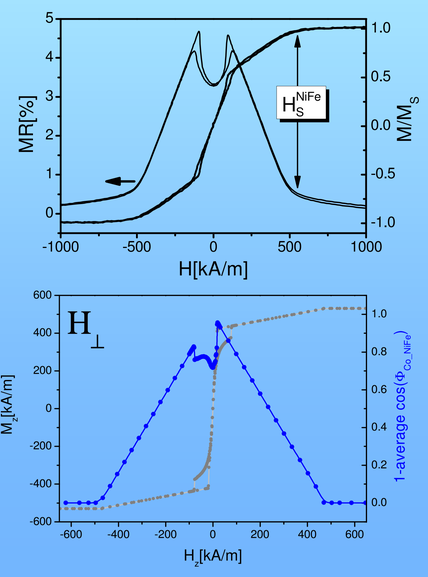



This MLs display the giant magnetoresistance (GMR):

Resistance depends on the angle between neighboring magnetic moments

$$R = R_0 - \Delta R_{GMR}\cos(\theta_{NiFe-Co})$$

The deflection of NiFe moments decreases the $\theta_{NiFe-Co}$ and leads to the local minimum of resistance.



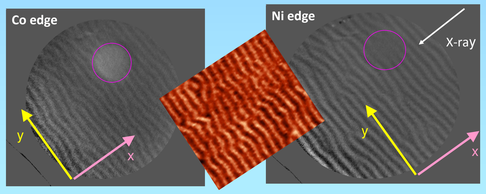

Characteristic fields of Co layers hysteresis (nucleation of stripe domains, their annihilation) are visible on resistance on field dependence[1,2].

The R(H) dependence can be qualitatively explained with micromagnetic simulations[5].*

*we have used a free **OOMMF** package[3]

## Domain replications-XMCD-PEEM - Elettra

PEEM images registered for MLS with dCo=1.2nm

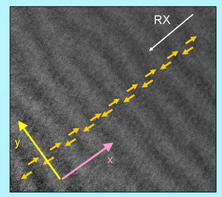


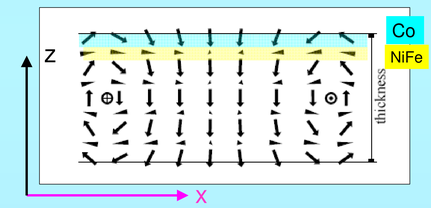

**Sample was initially saturated in –plane by magnetic field applied along y axis. Stripe domains oriented along „y" axis were produced. Images size 5x5μm.**

X-ray in xz plane with the incidence angle of 16 deg in respect to the surface.

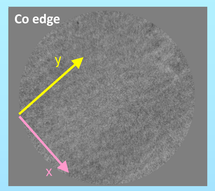
PEEM images for Co and Ni are similar (replication of Co domain structure in NiFe).

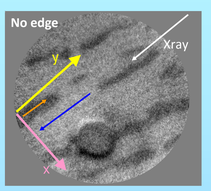
An attempt to analyze PEEM image based on micromagnetic simulations




**After 90 degrees sample rotation. (X-ray in y-z plane)**




There is weak contrast related to stripe domains (in both Co and NiFe).

Additionally macrodomains, with large contrast, are visible in NiFe layers (this contrast could be related to y magnetization component).

## Conclusions

- Analysis of soft x-ray reflectivity allowed us to determine magnetization reversal of Co and NiFe layers separately.
- Magnetic fields of stripe domains of Co layers lead to a domain replication in NiFe layers and lower resistance
- Stripe domains replication and macrodomains in NiFe sublayers were observed with PEEM

## References


[1] F. Stobiecki, M. Urbaniak , B. Szymański, J. Dubowik, P. Kuświk, T. Weis, D. Engel, D. Lengemann, A. Ehresmann, I. Sveklo, A. Maziewski, Appl. Phys. Let. **92**, 012511 (2008)

[2] F. Stobiecki, B. Szymański, T. Luciński, J. Dubowik, M. Urbaniak, K. Röll, J. Magn. Magn. Mater. **282**, 32 (2004)

[3] M. J. Donahue and D. G. Porter, "OOMMF User's Guide, Version 1.0," National Institute of Standards and Technology Interagency Report No. NISTIR 6376, 1999.

[5] M. Urbaniak, J. Appl. Phys. **104**, 094909 (2008)