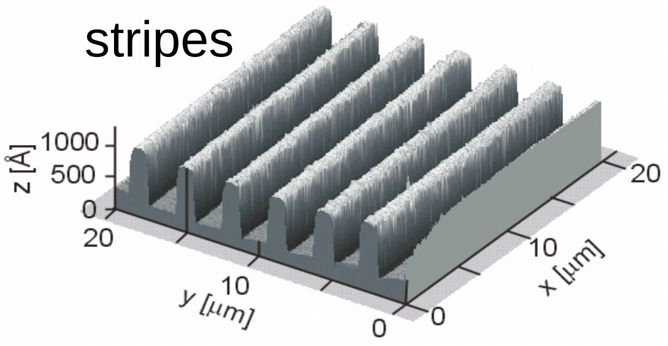
Nanostructured Materials

25. October 2005

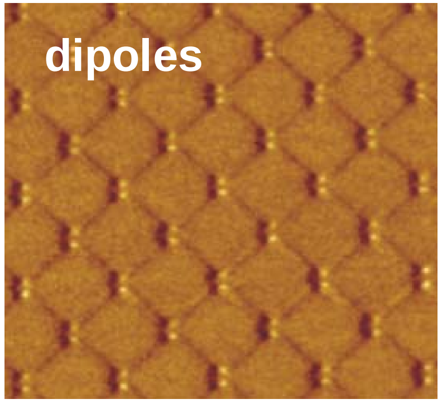
Hartmut Zabel

Ruhr University Bochum, Germany

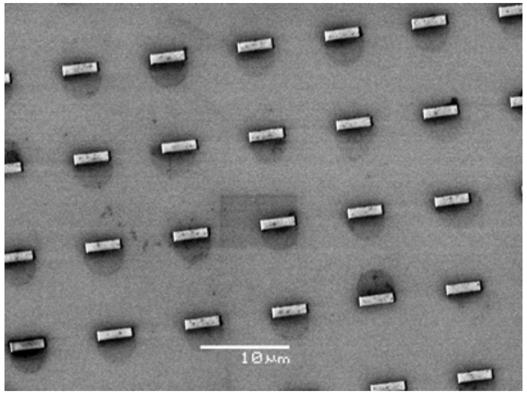
Lateral magnetic structures



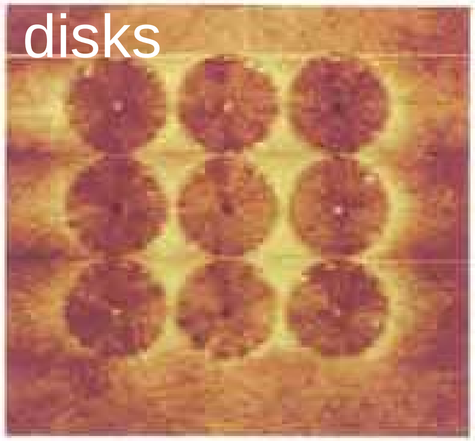
H. Brückl, Bielefeld



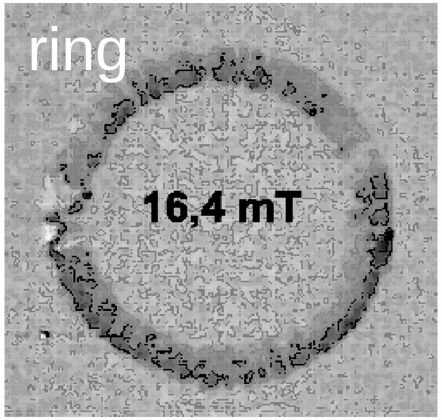
A. Remhof, Bochum



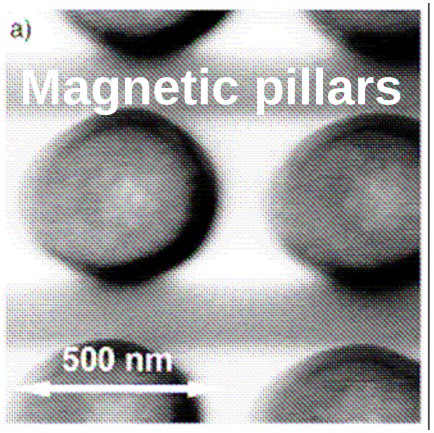
K. Temst, Leuven



Shinjo et al. Kyoto



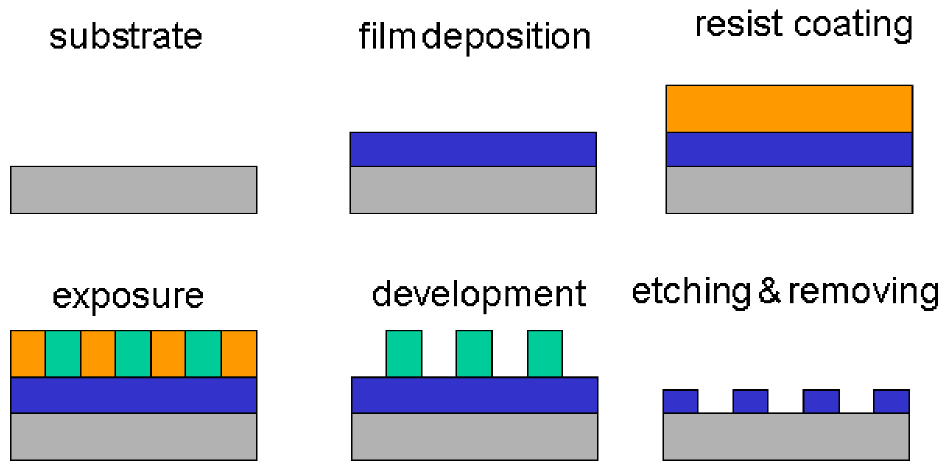
D. Buntix, Leuven



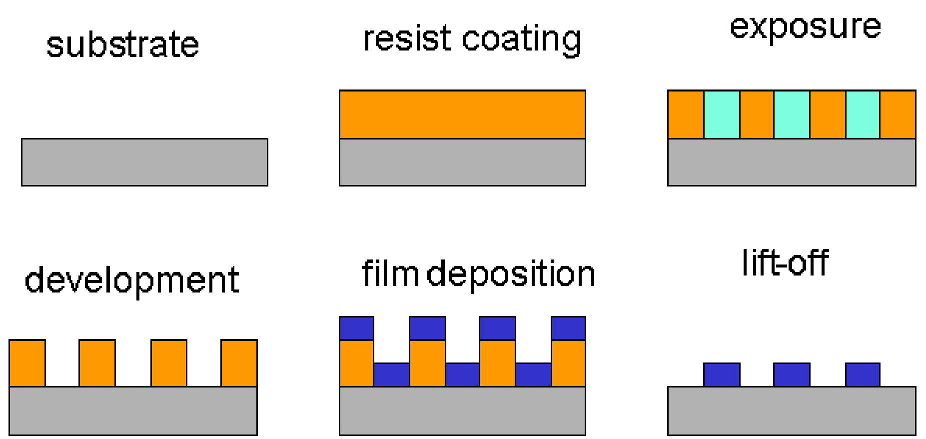
R. Brucas, Uppsala

Lithographic sample preparation

Bottom up



Top down



Lithographic tools

Lithography:
Laser, e-beam, focused ion beam, x-ray, AFM cantilever

Etching:
Wet, dry, ion beam, plasma

Resin, spin coating, annealing, etc.

Nanostructures

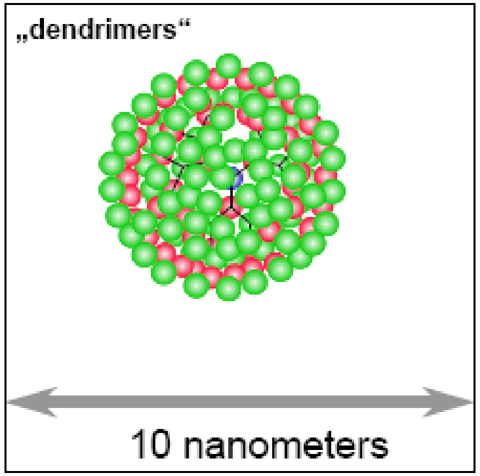
Top-down approaches:

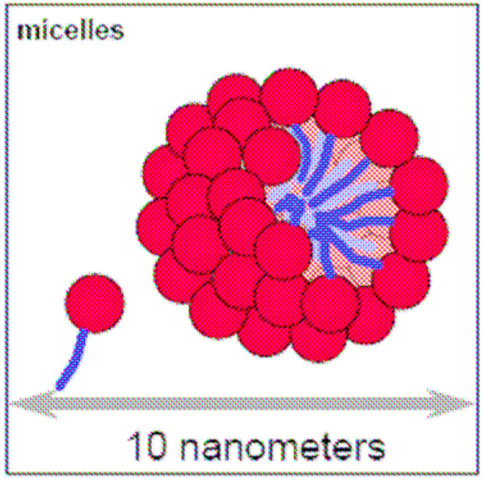
- lithography
- atomic force microscopy

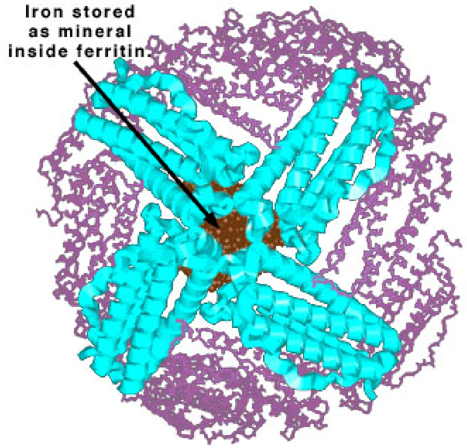
Bottom-up approaches:

- dendrimers
- molecular arrangements (e.g. micelles)
- approaches of molecular biology

Alternative techniques I: molecular self-assembly to defined structures







The advantages of molecular self-assembly:

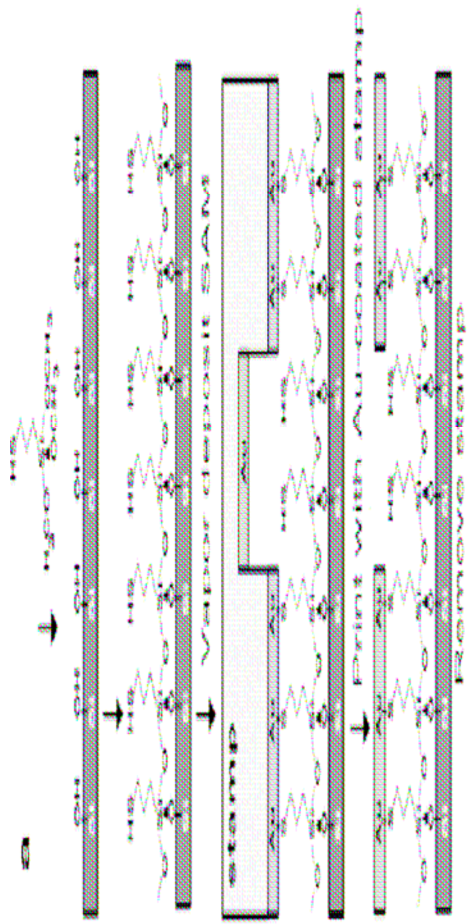
- directly nm-sized technique by assembly of molecules to defined structures
- potential for better versatility
- 3-dimensional structures possible
- imitation of structures of nature

Alternative techniques II:
Nanotransfer printing (nTP)

Schematic representation of the nanotransfer printing (nTP) procedure to create gold patterns on Si substrates.

NOTE: stamp is fabricated by top-down lithography.

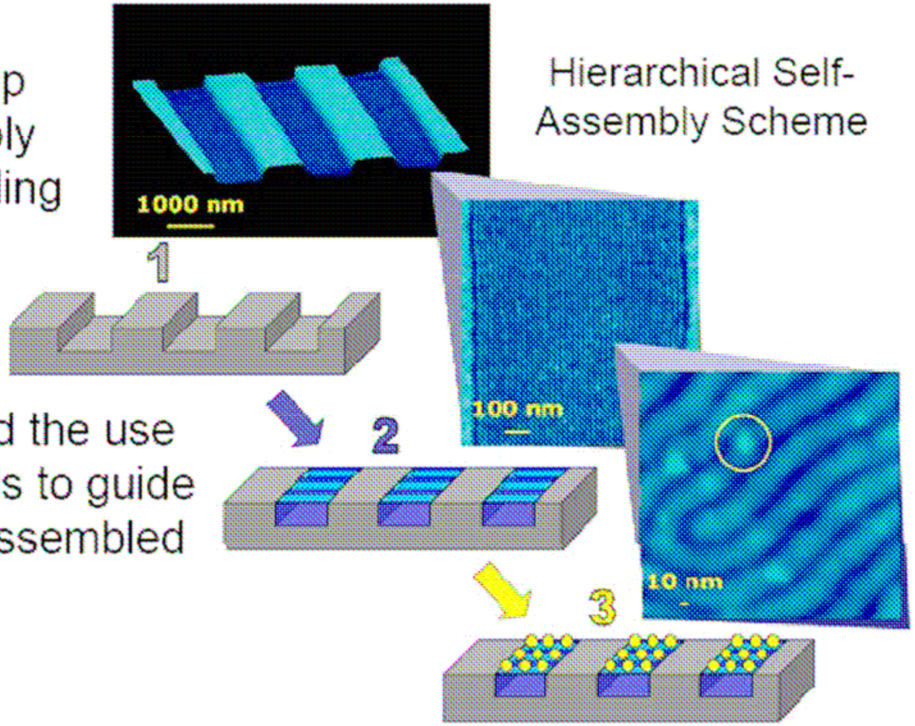
From H. Lipsanen



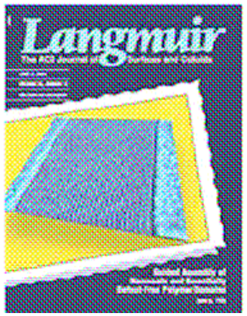
Alternative techniques III:
Polymeric Templating of Magnetic Nanostructures

- A combined top-down/bottom-up hierarchical approach is arguably the most powerful route to building nanostructures

Hierarchical Self-Assembly Scheme



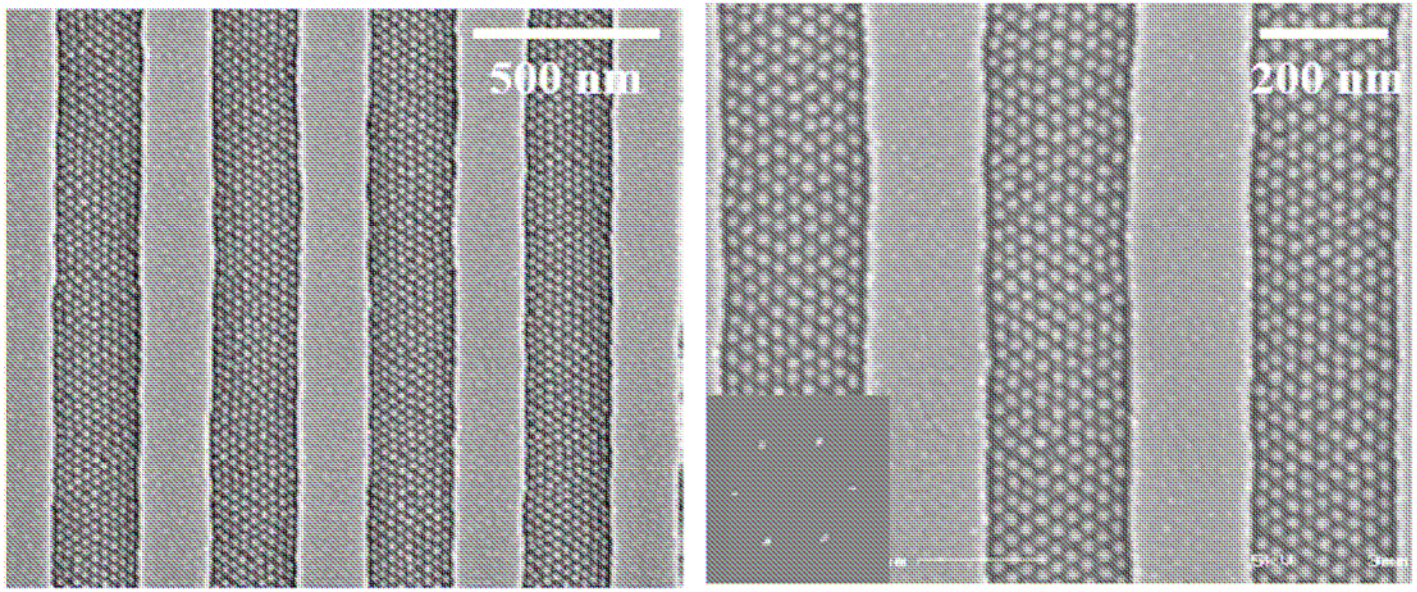
- We have demonstrated the use of lithographic channels to guide the alignment of self-assembled polymer domains



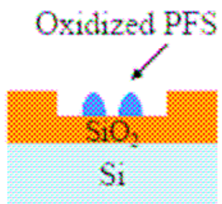
- Next, we aim to use these aligned scaffolds as templates for the organization of functional magnetic nanoparticles

http://www.msd.anl.gov/highlights/docs/darling_polymeric_hl.pdf

Templating with polymer stripes and grooves

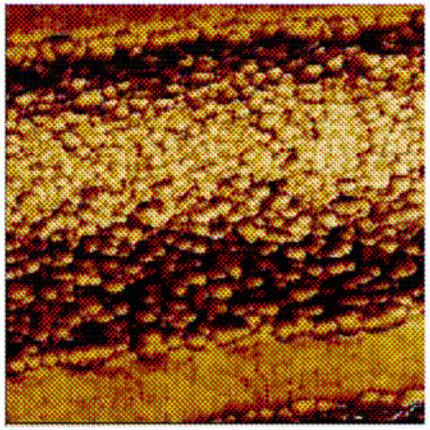


- Long-range ordered block copolymers inside the groove.
- No grain boundaries observed.
- Polymer domains align with the groove edge.
- 9 rows of polymer domains in a 230 nm wide groove.

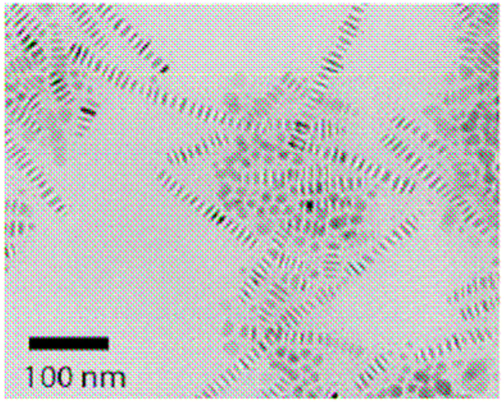


From E.L.Thomas, C.A. Ross, MIT

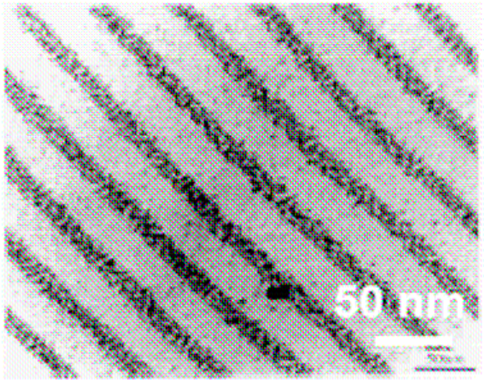
Assemblies of magnetic nanoparticles



8 nm Co nanoparticles in cylindrical Al_2O_3 pores



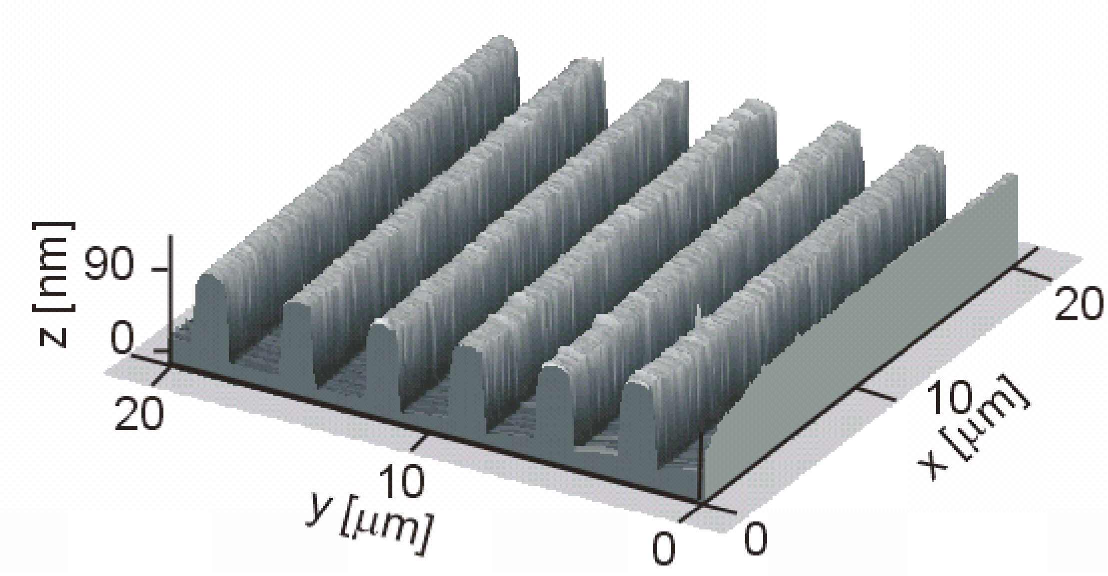
Self-assembly of Co nanodiscs



Polymer-templated assembly of 5 nm Co nanospheres

Meigan Aronson, Sue Inderhees, Omar Yaghi, Jinsang Kim, Nick Kotov, and Glenn Strycker, University of Michigan, Ann Arbor

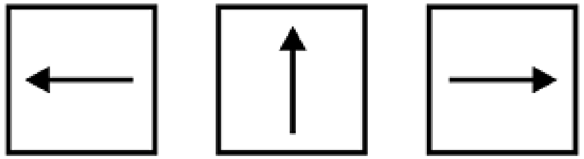
Lateral magnetic stripes



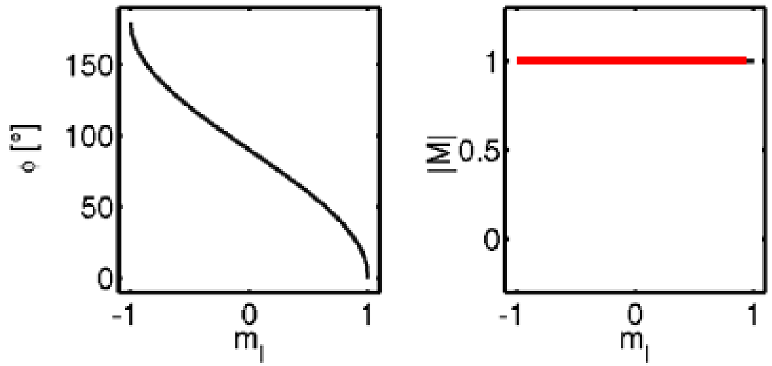
How does the magnetization reversal proceed?

Two limiting cases

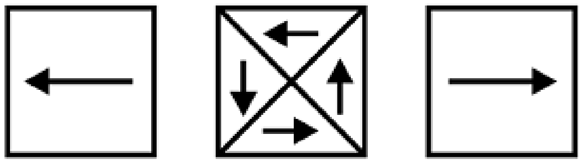
Coherent rotation:



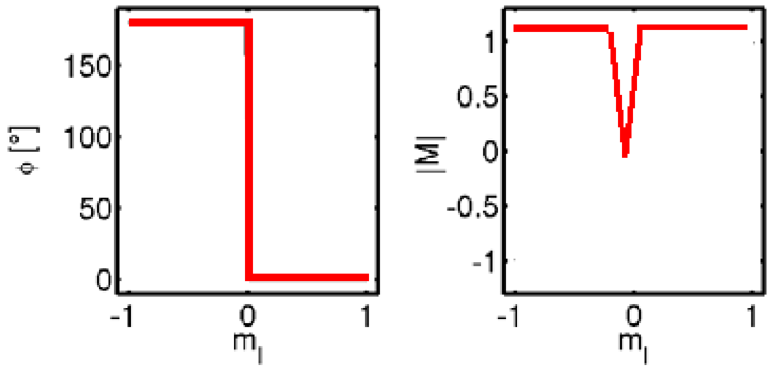
m_l=-1 m_l=0 m_l=1



Domain formation:

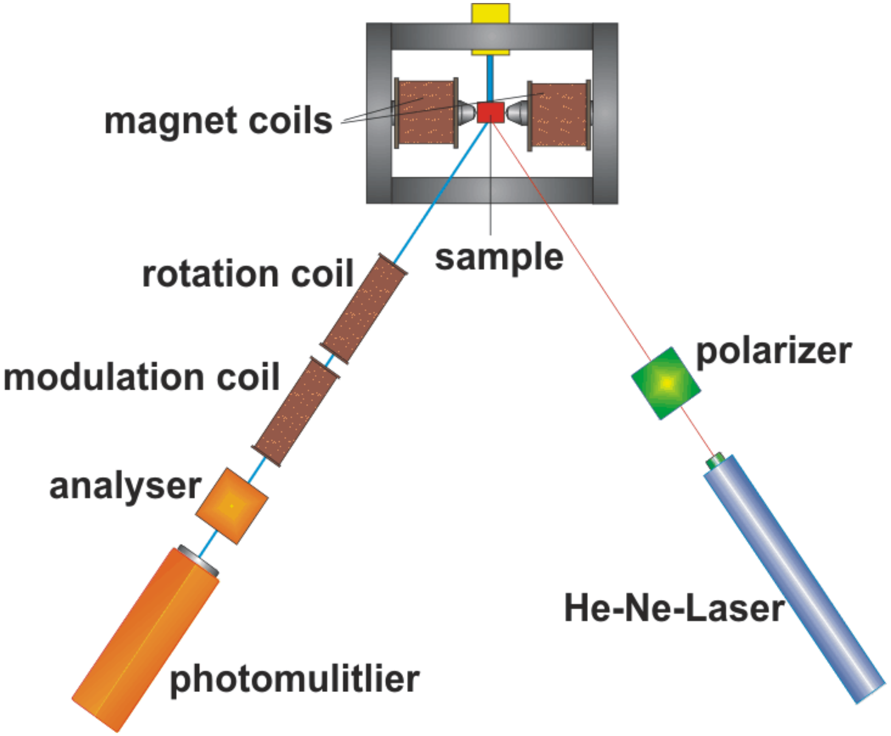


m_l=-1 m_l=0 m_l=1

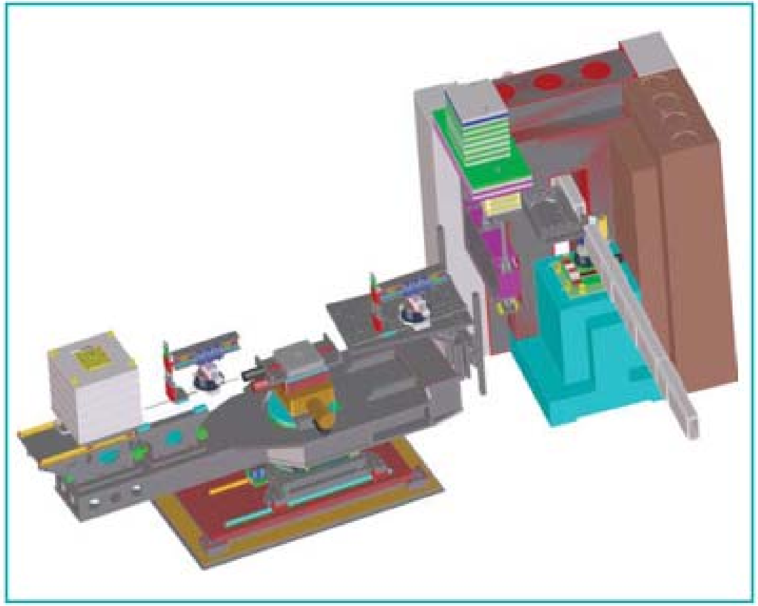


Vector magnetometry

MOKE

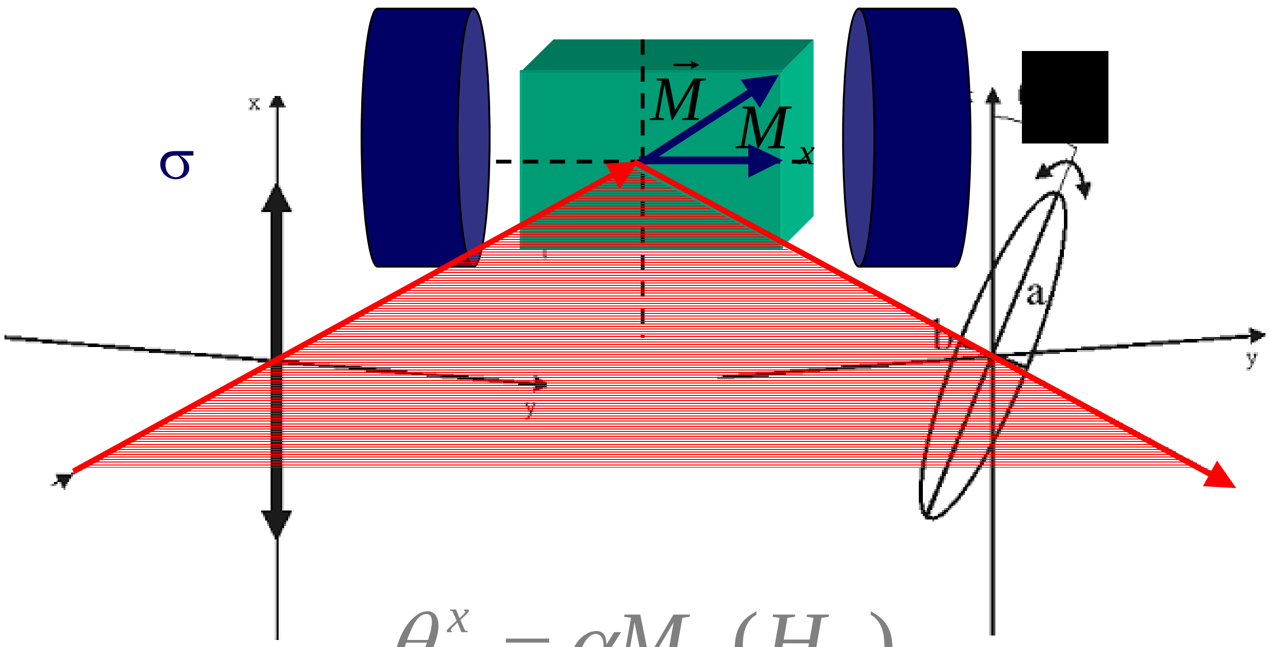


PNR



NND/R, NCNR, NIST

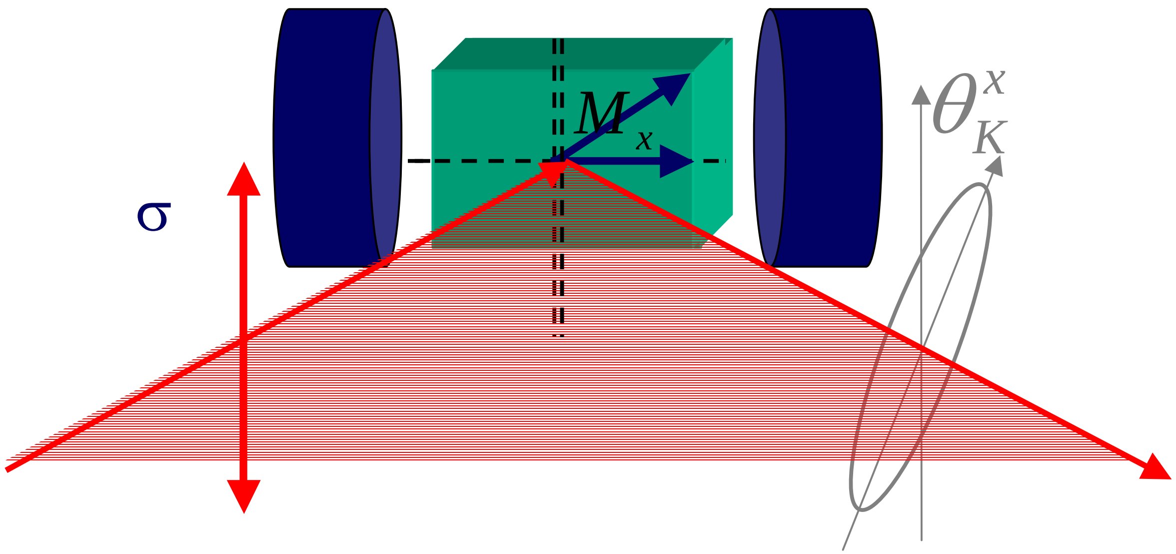
Longitudinal MOKE



$$\theta_K^x = \alpha M_x(H_x)$$

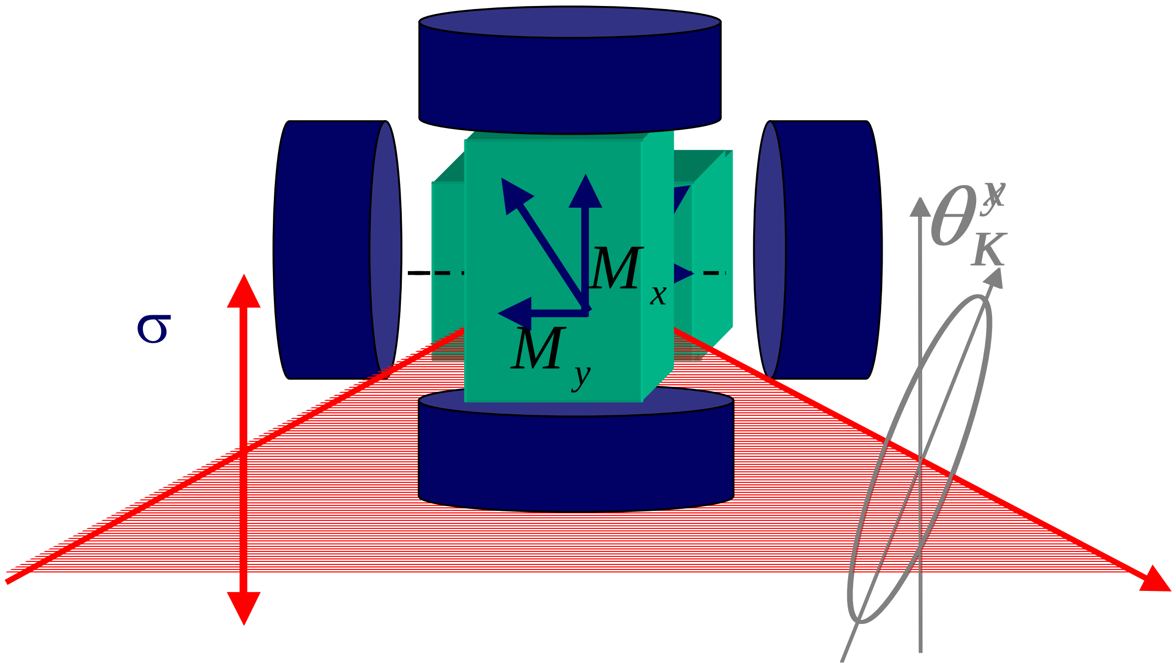
α depends on intraband transition, thickness, wavelength, incident angle, etc.

Vector MOKE



$$\theta_K^x = \alpha M_x(H_x)$$

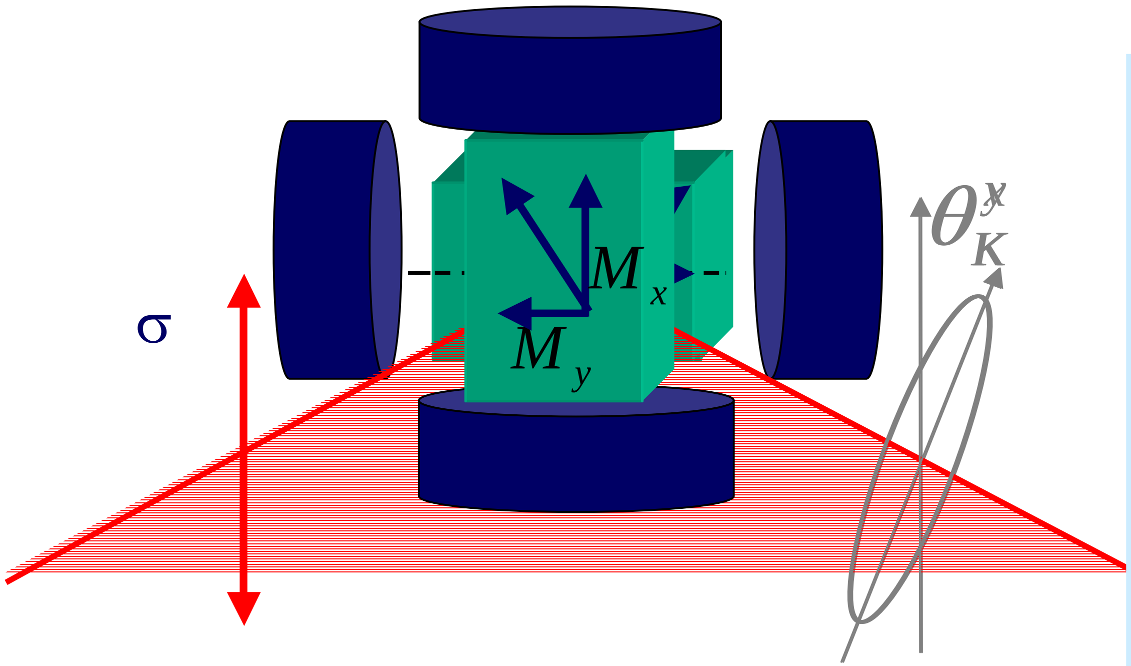
Vector MOKE



$$\theta_K^x = \alpha M_x(H_x)$$

$$\theta_K^y = \alpha M_y(H_y)$$

Vector MOKE



$$\frac{M_x}{M_y} = \frac{\cos\phi}{\sin\phi} = \frac{\theta_K^x}{\theta_K^y}$$

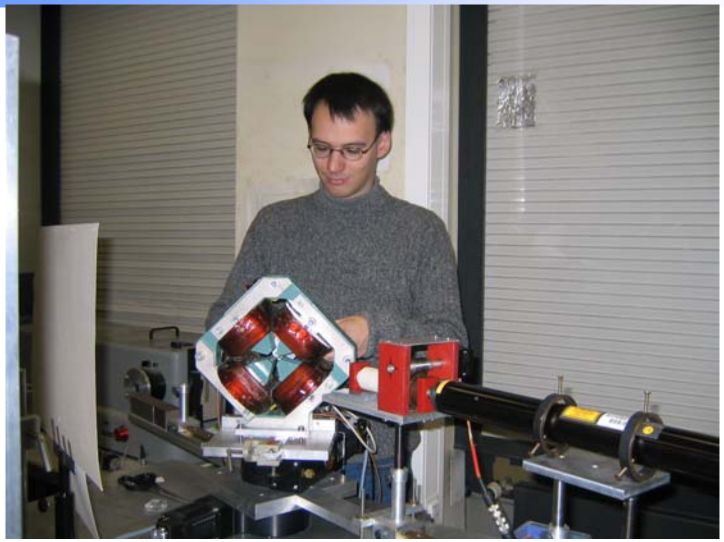
$$\chi = arc\cot\left(\frac{\theta_K^x}{\theta_K^y}\right)$$

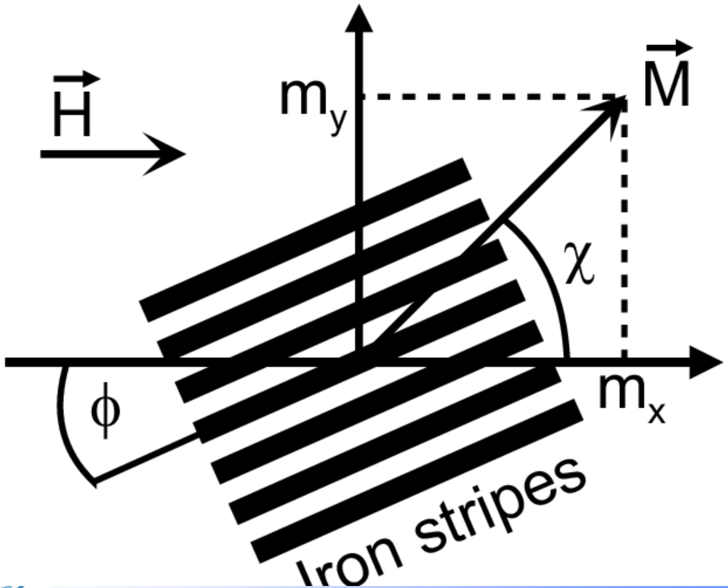
$$\frac{|\vec{M}|}{|\vec{M}|_{x,sat}} = \frac{\theta_K^x}{\theta_K^{x,sat}} \frac{1}{\cos\chi}$$

$$\theta_K^x = \alpha M_x(H_x)$$

$$\theta_K^y = \alpha M_y(H_y)$$

Vector-MOKE





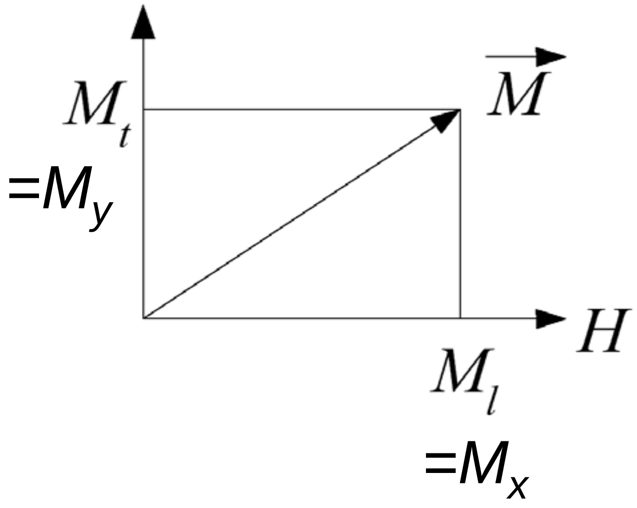
$$\frac{m_x}{m_y} = \frac{\cos\chi}{\sin\chi} = \frac{\theta_K^x}{\theta_K^y}$$

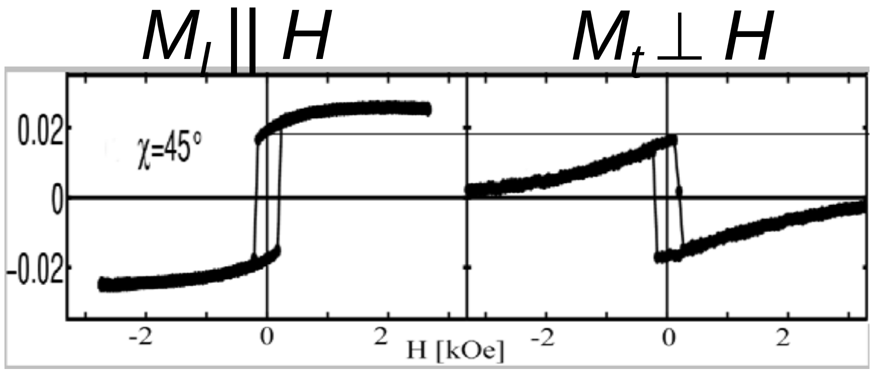
$$\chi = arc\cot\left(\frac{\theta_K^x}{\theta_K^y}\right)$$

$$\frac{\left|\vec{M}\right|}{\left|\vec{m}\right|_{x,sat}} = \frac{\theta_K^x}{\theta_K^{x,sat}} \frac{1}{\cos\chi}$$

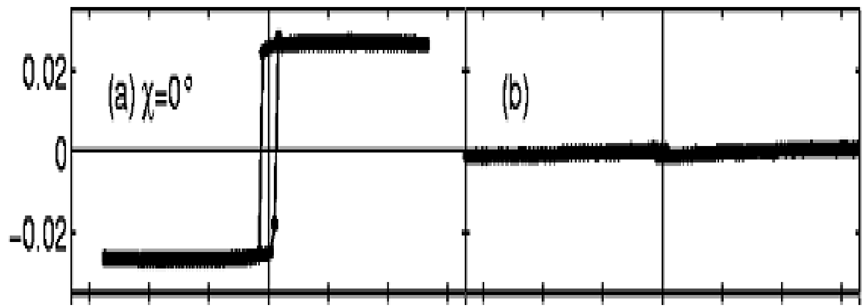
Vector-MOKE for....

Coherent rotation:

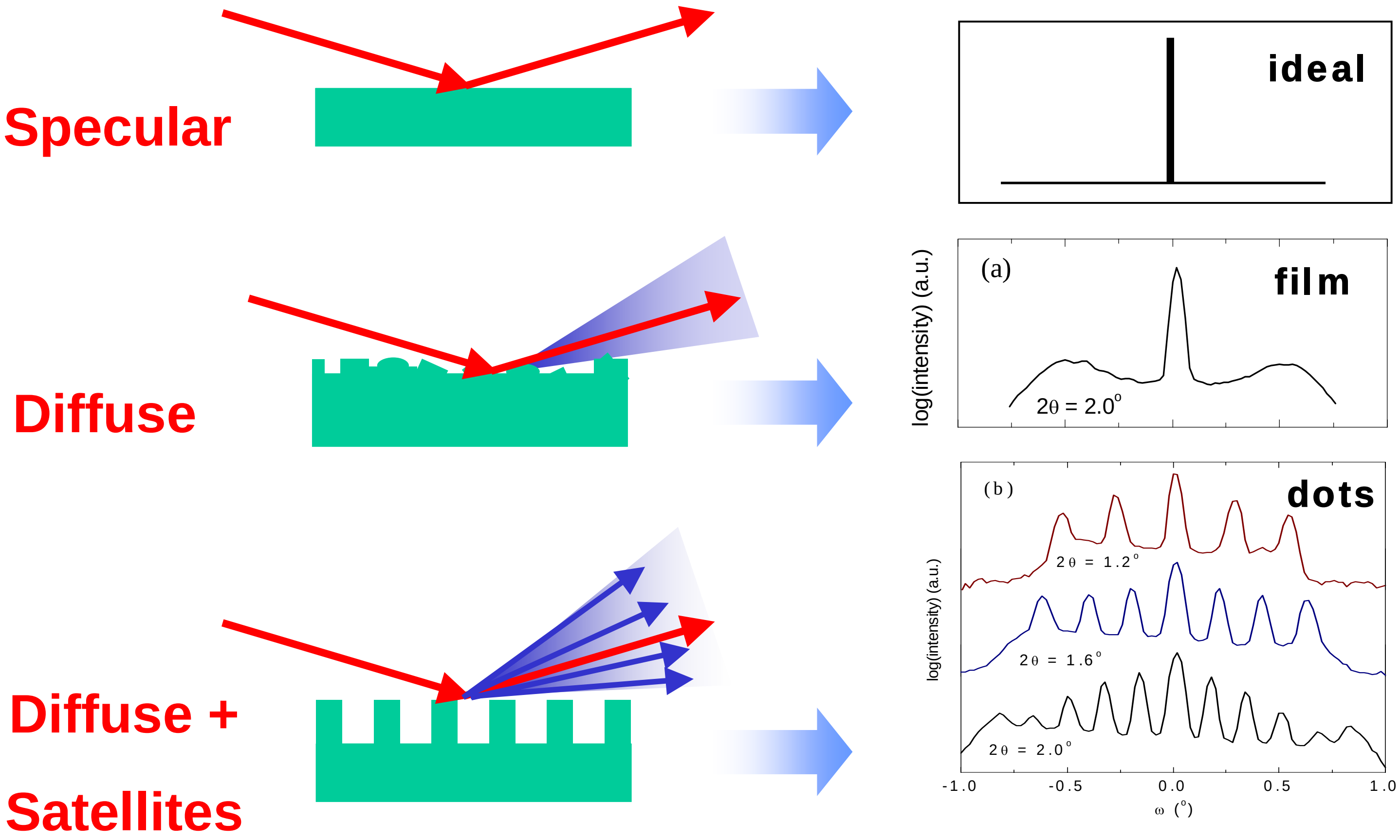




Domain formation:



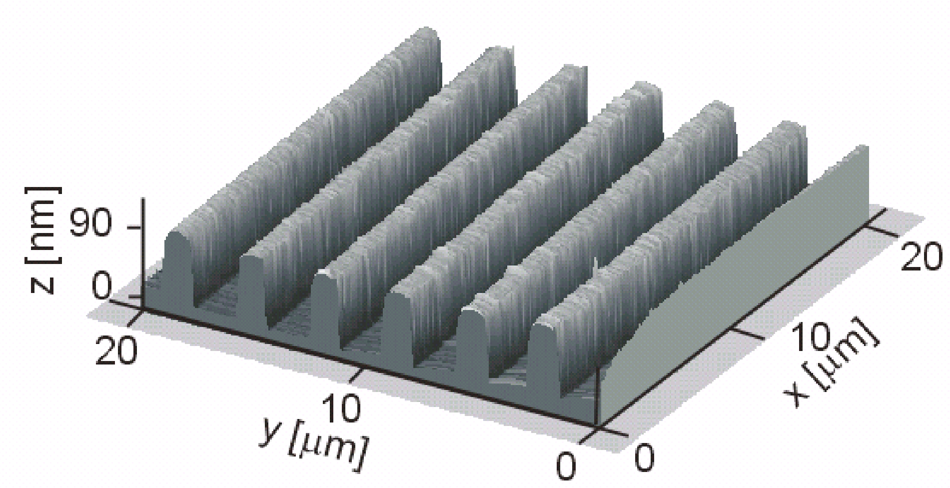
Off-specular reflectivity of a film surface



Courtesy K. Temst, Leuven

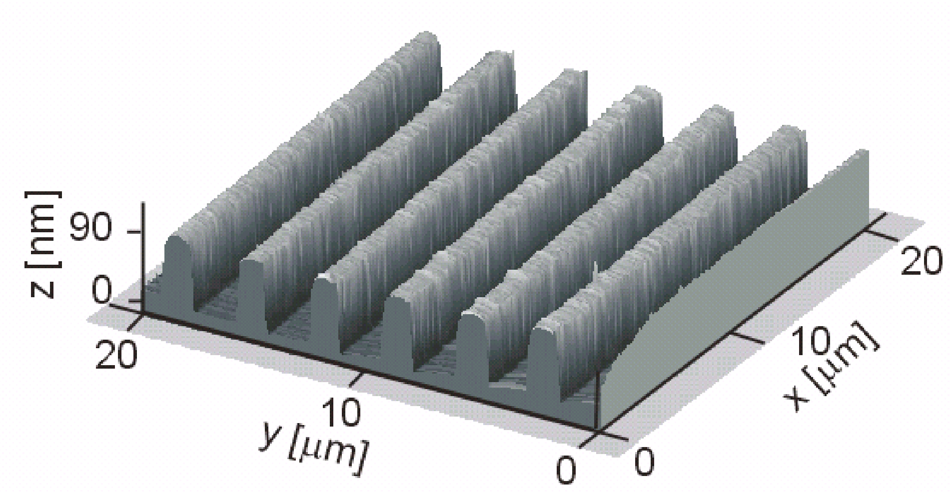
1. Example: thin stripes

Sample: $Co_{0.7}Fe_{0.3}$ stripes,
w=1.2 μm, D=3 μm, thickness 90 nm



1. *Example: thin stripes*

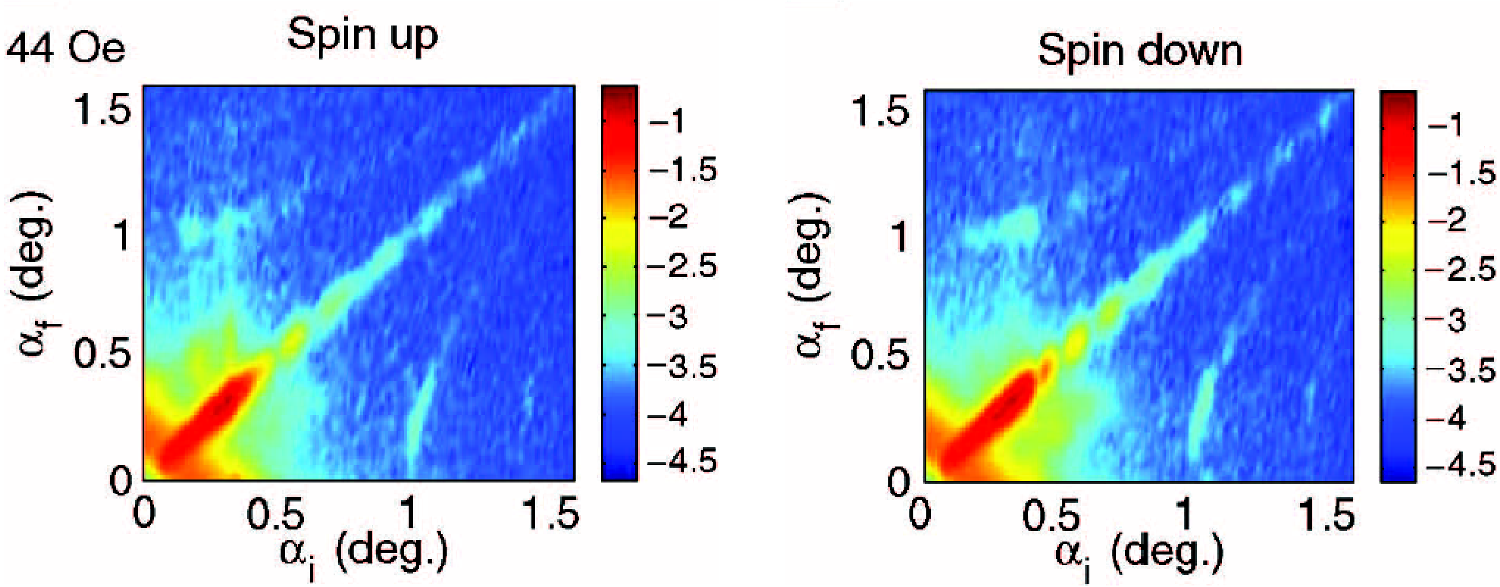
Sample: $Co_{0.7}Fe_{0.3}$ stripes,
w=1.2 μm, D=3 μm, thickness 90 nm



Two-fold shape anisotropy:

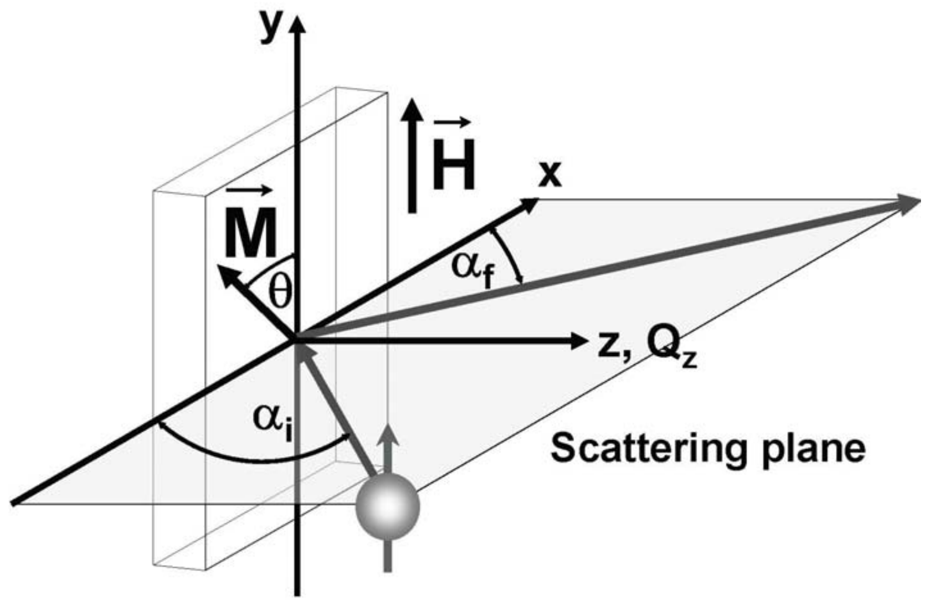
- easy axis: along the stripes
- hard axis: perpendicular to the stripes

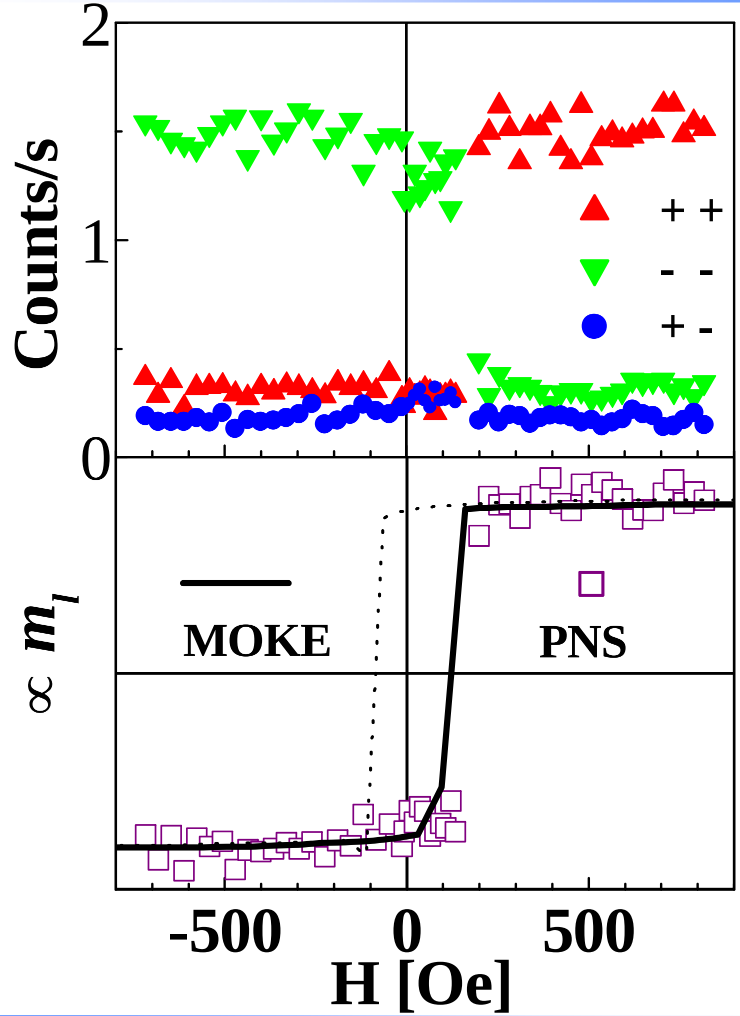
Reciprocal space map from a stripe array



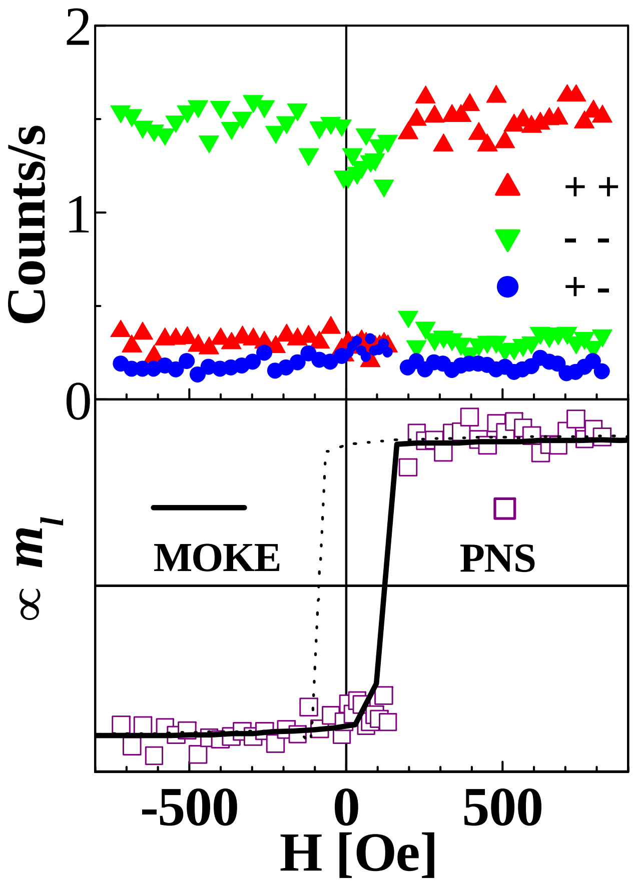
Specular reflectivity ridge can be recognized and off-specular Bragg peaks from the lateral stripe array.

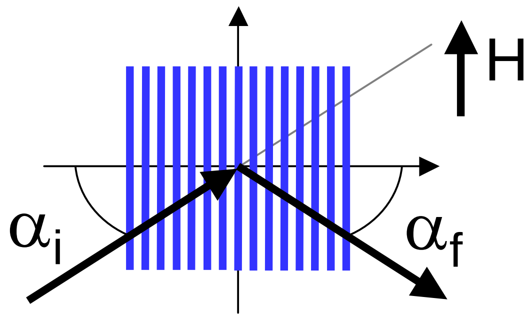
PNR: easy axis, χ=0°





PNR: easy axis, χ=0°

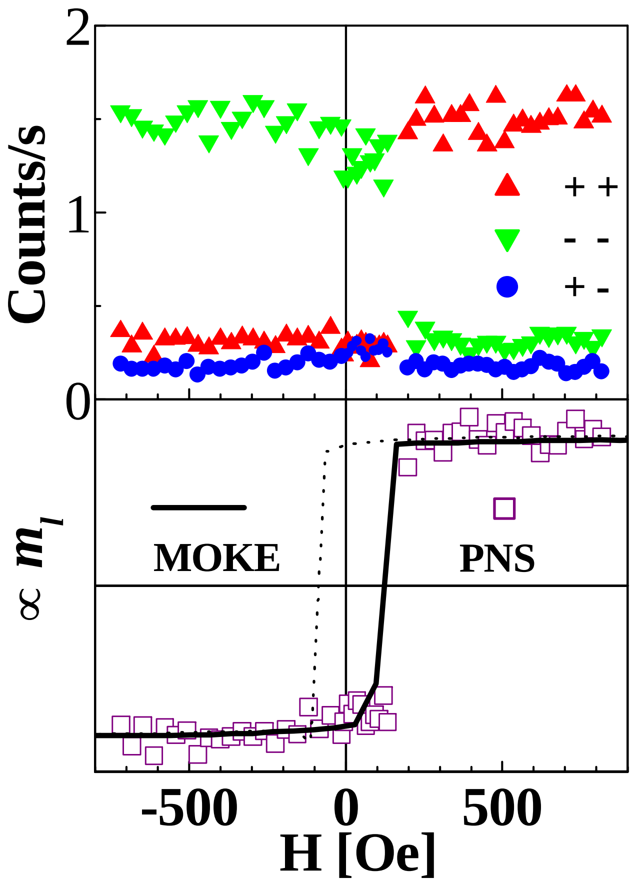


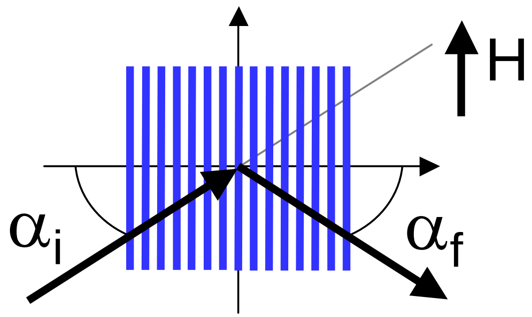


Kerr Microscopy

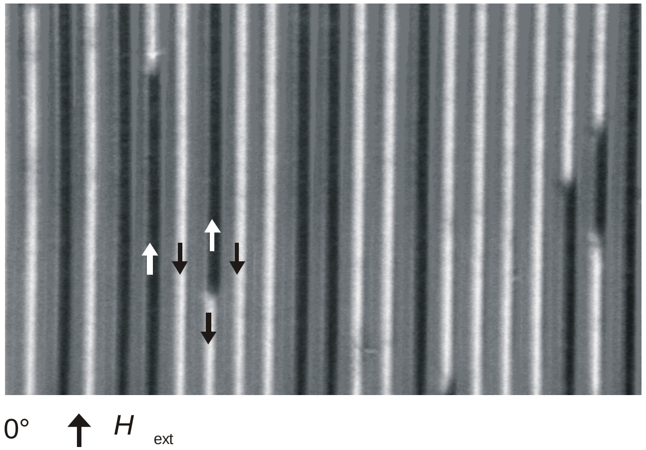
K. Theis-Bröhl et al. Phys. Rev B **68**, 184415 (2003).

PNR: easy axis, χ=0°



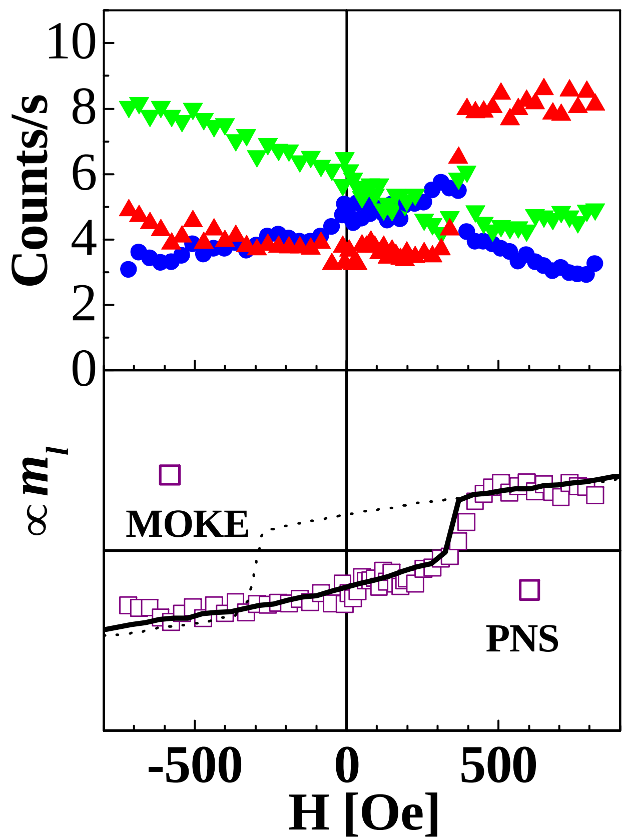


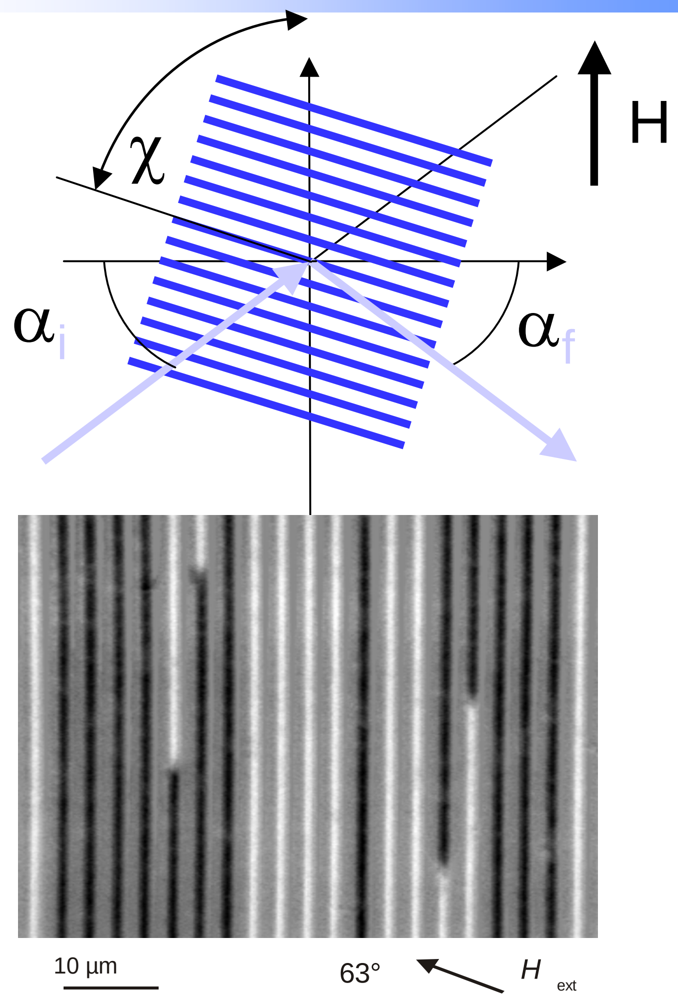
Kerr Microscopy



K. Theis-Bröhl et al. Phys. Rev B **68**, 184415 (2003).

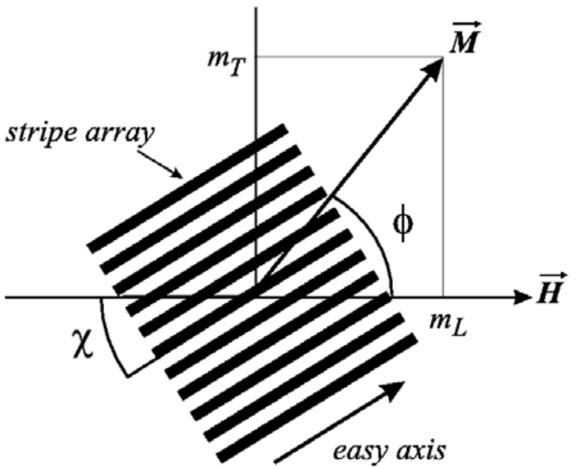
PNR: hard axis, χ=63°



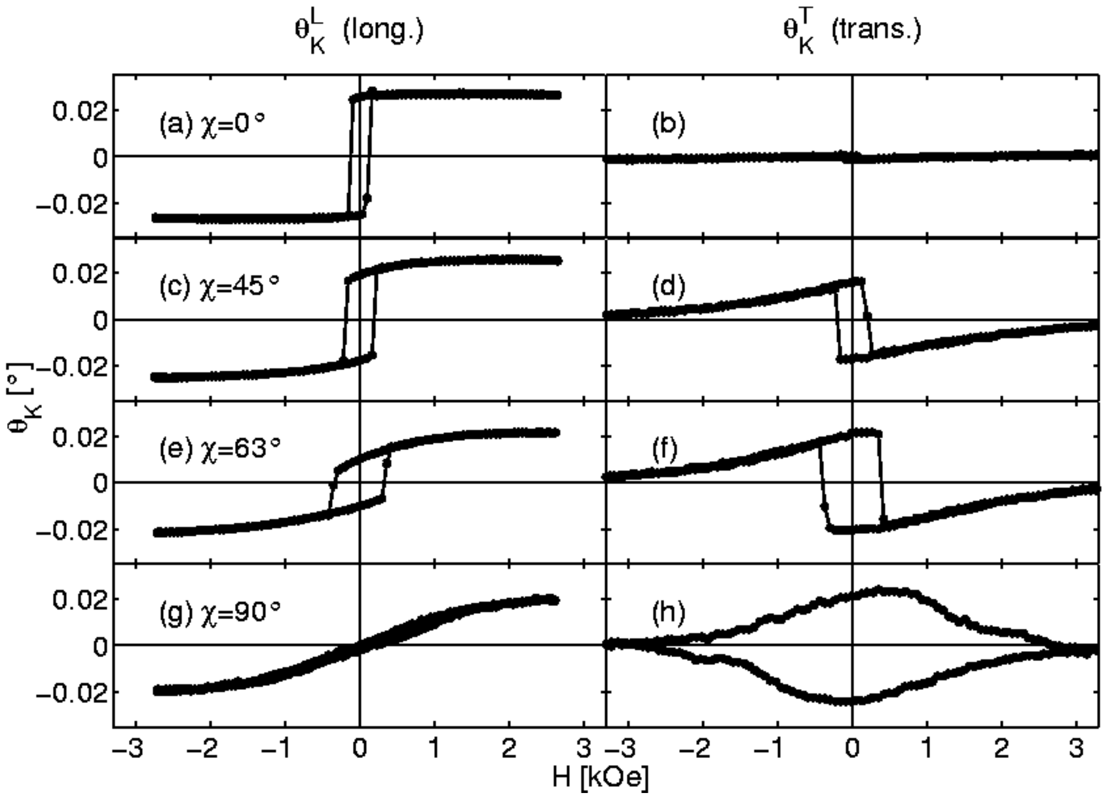


K. Theis-Bröhl et al. Phys. Rev B B **68**, 184415 (2003).

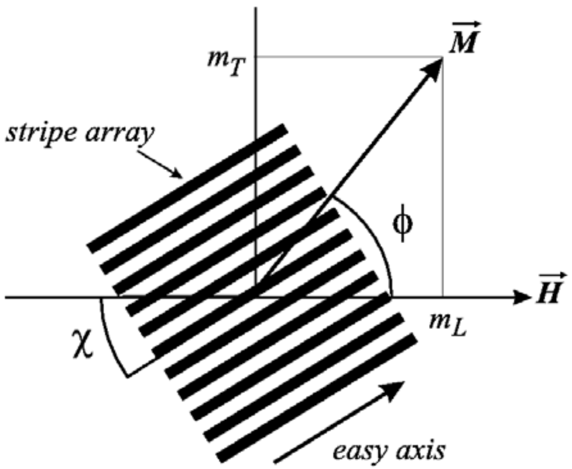
Vector-MOKE -thin stripes



longitudinal transverse

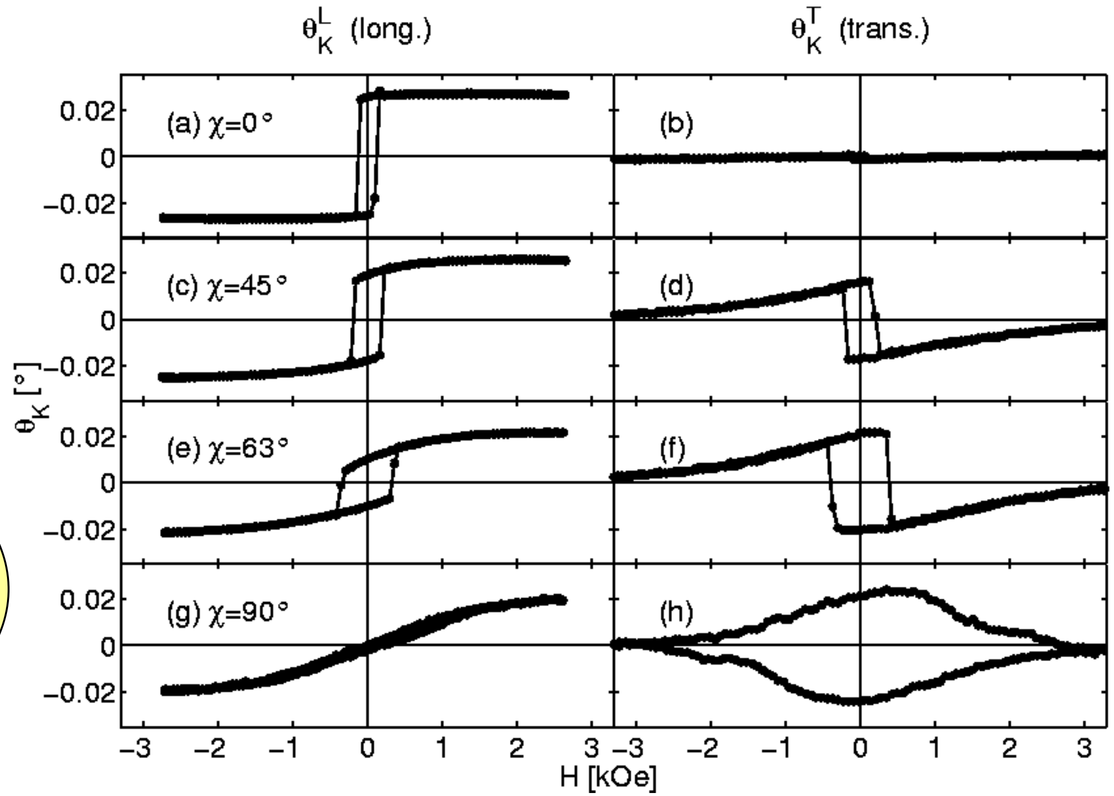


Vector-MOKE -thin stripes



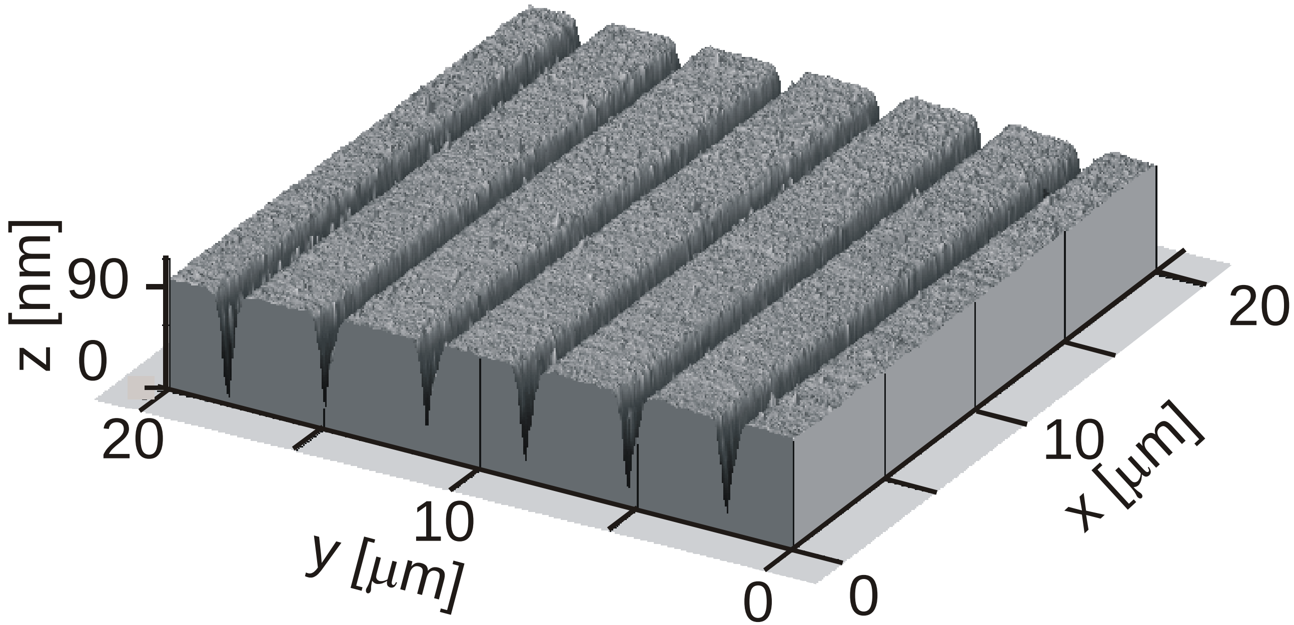
Coherent rotation over most of the field range!

longitudinal transverse

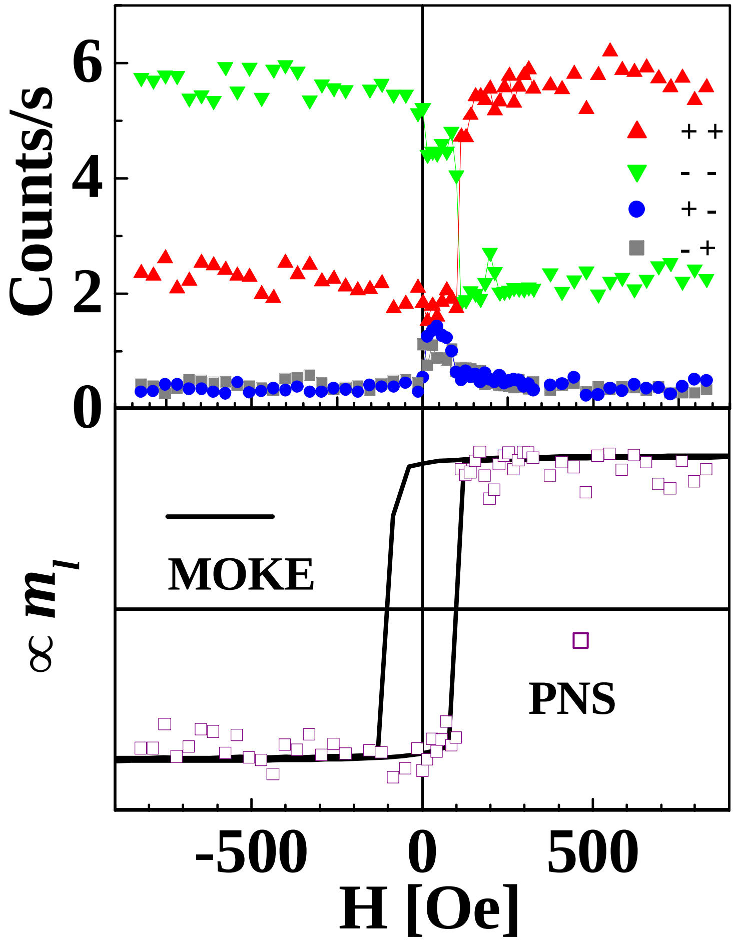


2. Example: thick stripes

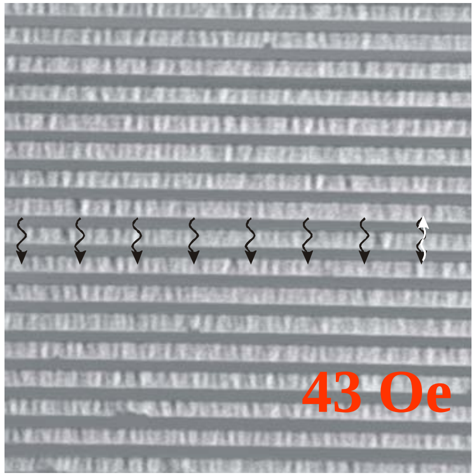
Sample: $Co_{0.7}Fe_{0.3}$ stripes,
w=2.4 μm, D=3 μm, thickness 80 nm



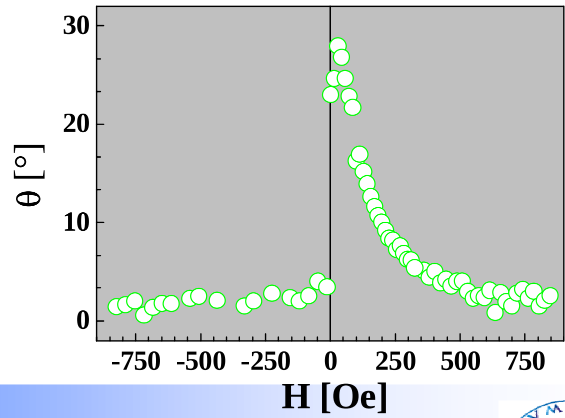
PNR: easy axis, χ=0°



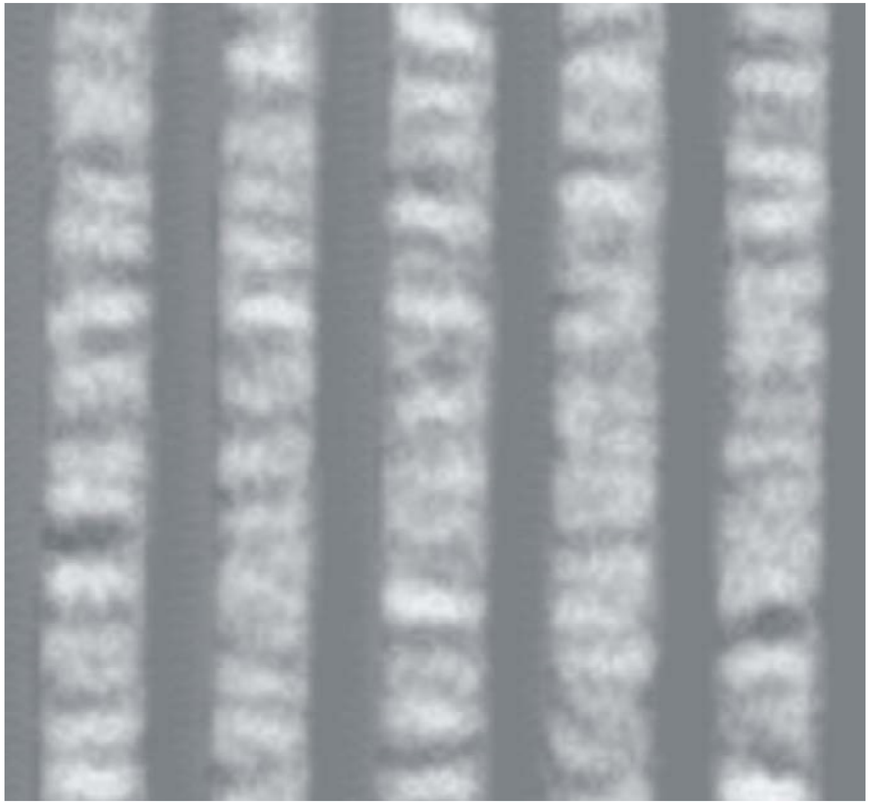
Kerr Microscopy

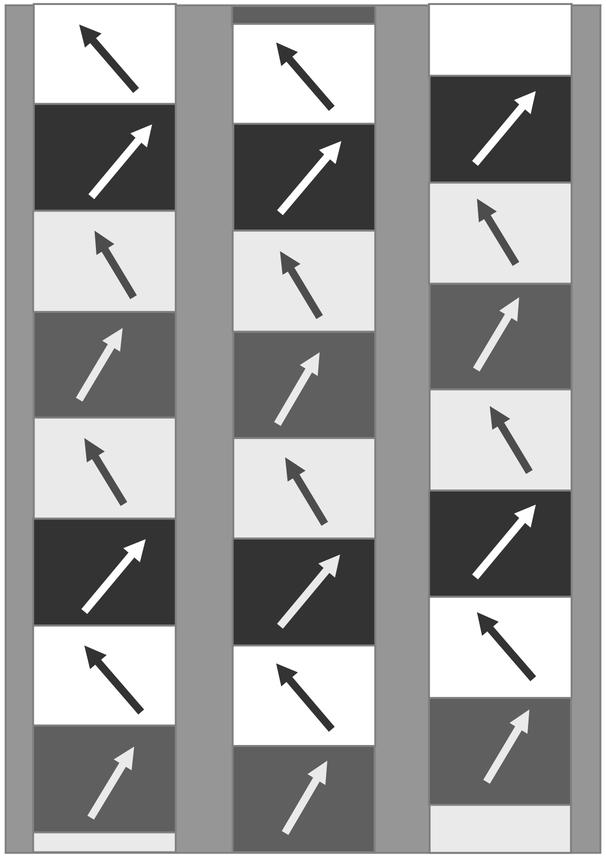


Spin flip scattering

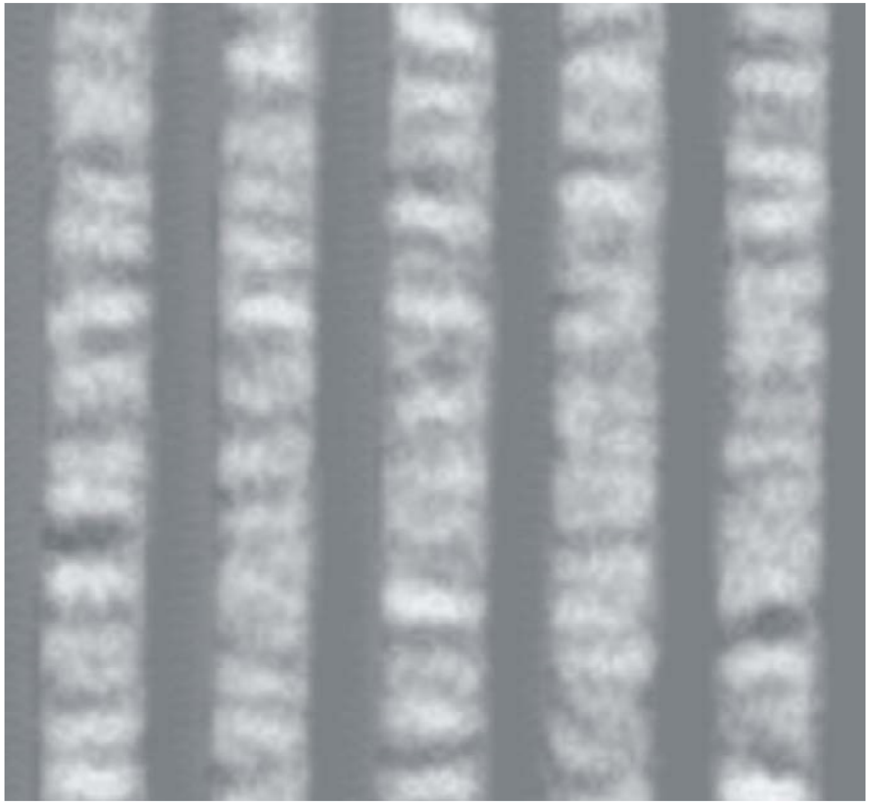


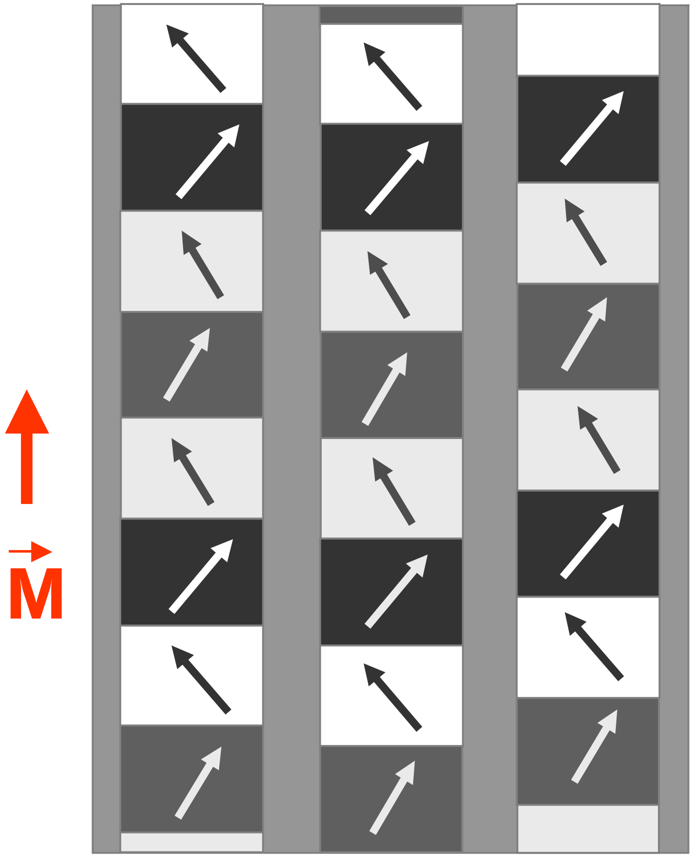
Small angle domains in remanence





Small angle domains in remanence





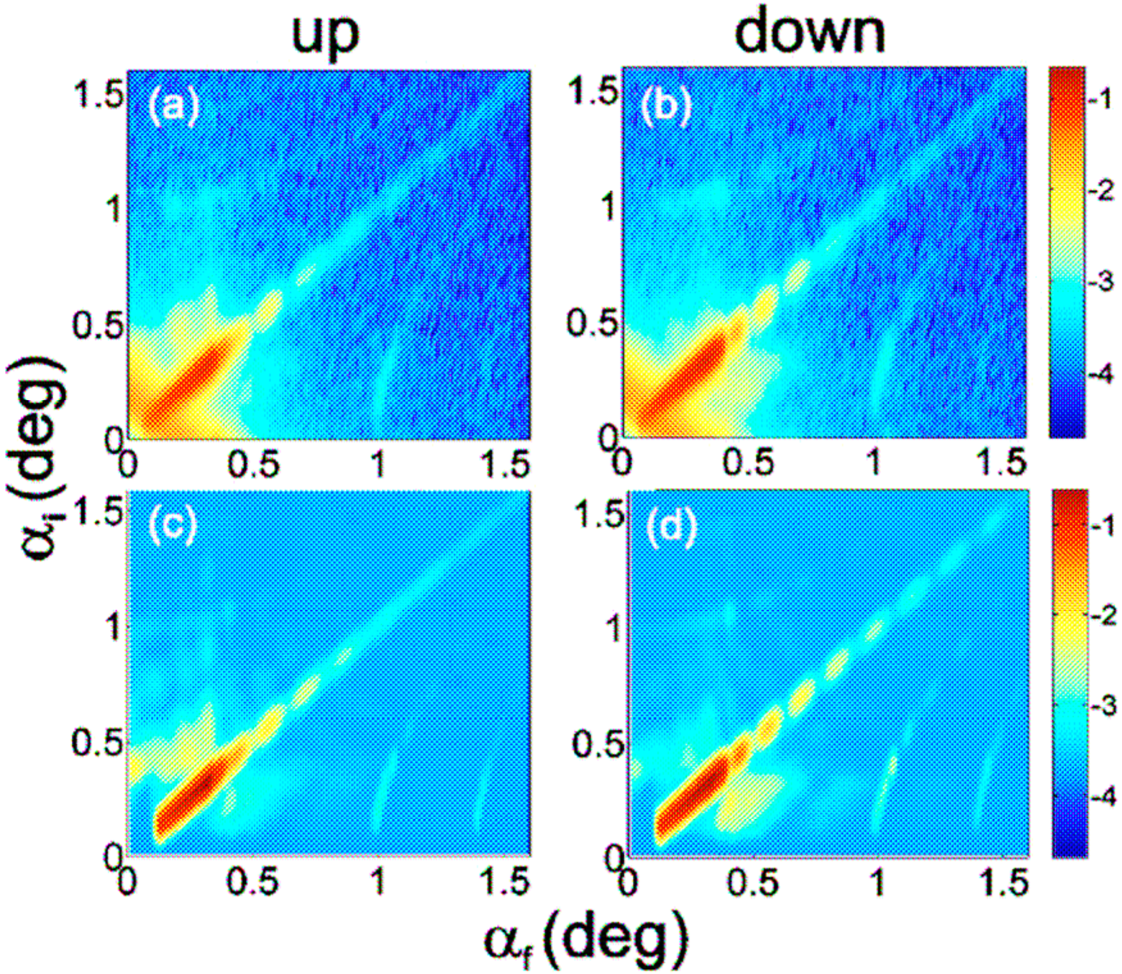
Diffuse scattering from domains

Experimental:

44 Oe

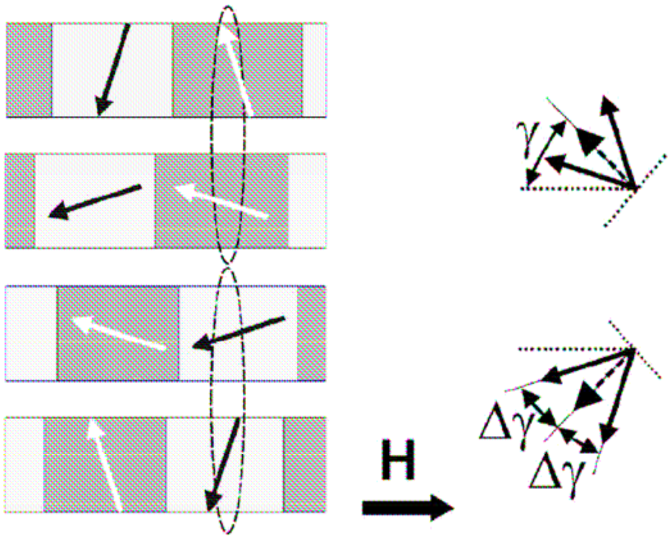
(at maximum of spin-flip)

Simulation:

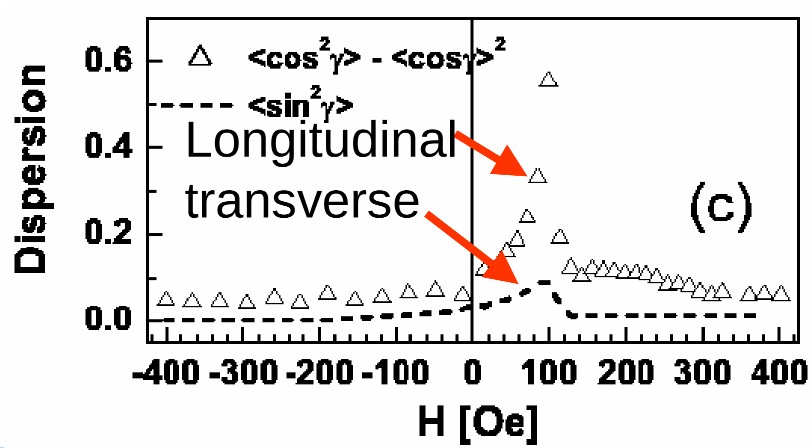


K. Theis-Bröhl et al. Phys. Rev B **71**, 020403 (2005)

Domains and Fluctuations

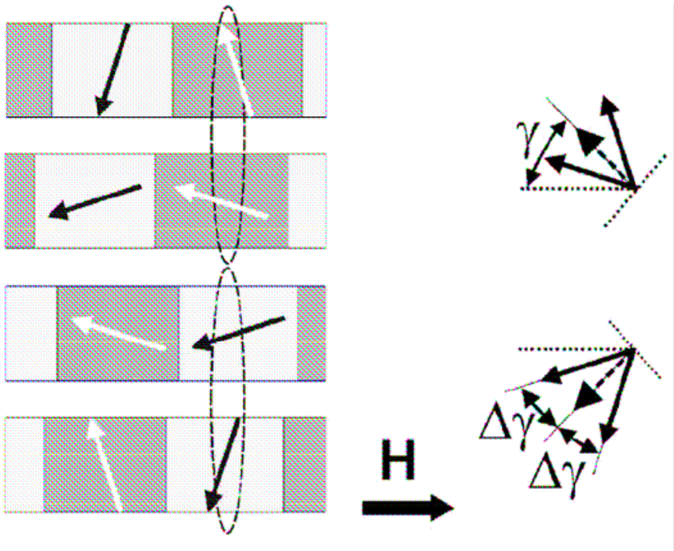


Fluctuations:

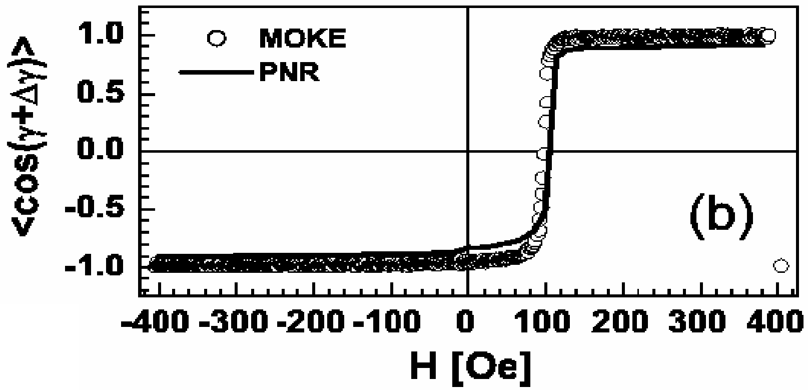


K. Theis-Bröhl et al. Phys. Rev. B 71 (2005) 020403

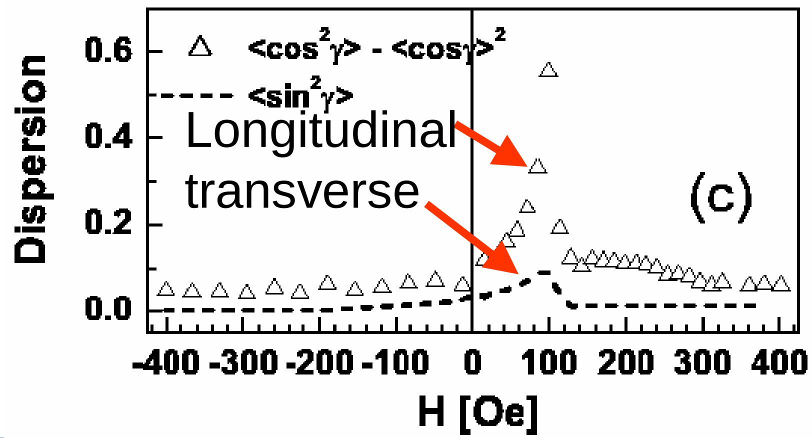
Domains and Fluctuations



Normal component || H:

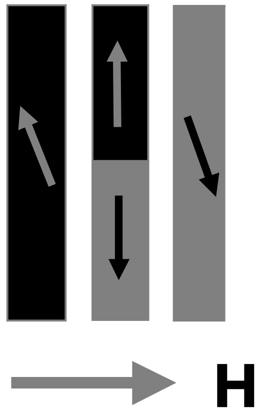


Fluctuations:



K. Theis-Bröhl et al. Phys. Rev. B 71 (2005) 020403

Summary stripes

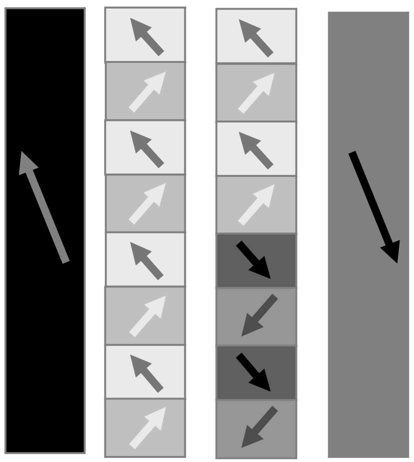


Thin stripes

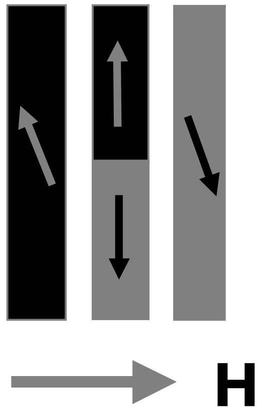
•Mostly single domain

•Simple reversal process

PNR and MOKE agree



Summary stripes

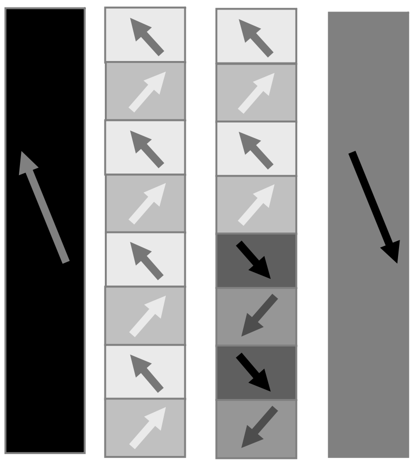


Thin stripes

•Mostly single domain

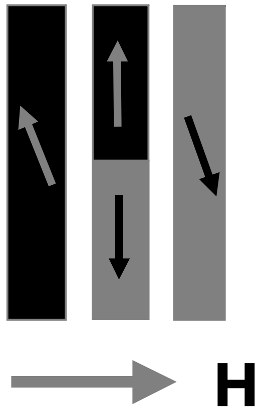
•Simple reversal process

PNR and MOKE agree



Thick stripes

Summary stripes

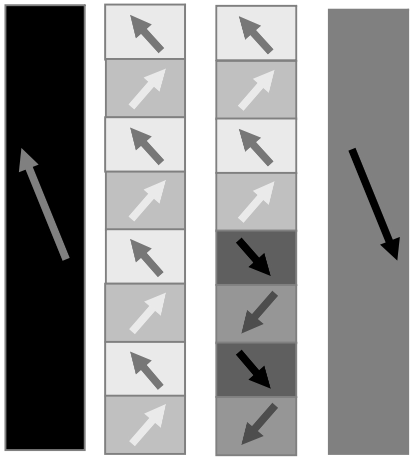


Thin stripes

•Mostly single domain

•Simple reversal process

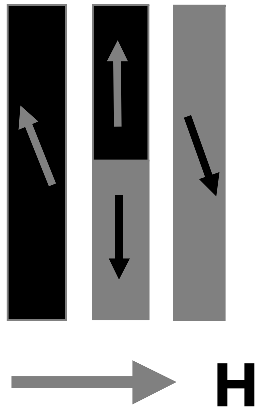
PNR and MOKE agree



Thick stripes

•Complex domain structure

Summary stripes

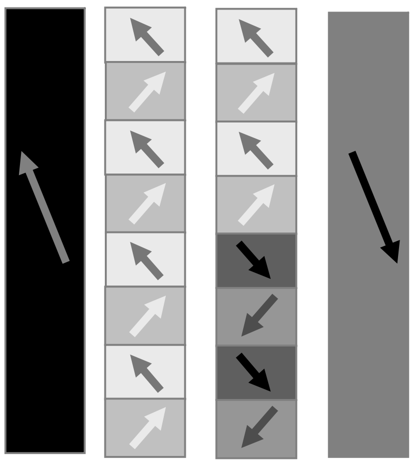


Thin stripes

•Mostly single domain

•Simple reversal process

PNR and MOKE agree

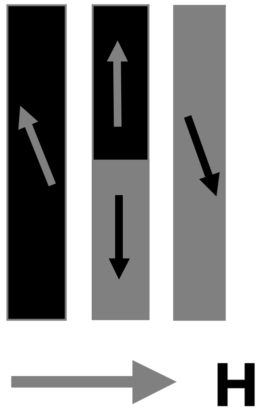


Thick stripes

•Complex domain structure

•Dipol - interaction

Summary stripes

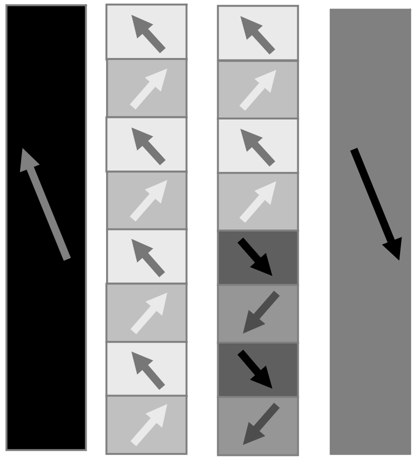


Thin stripes

•Mostly single domain

•Simple reversal process

PNR and MOKE agree



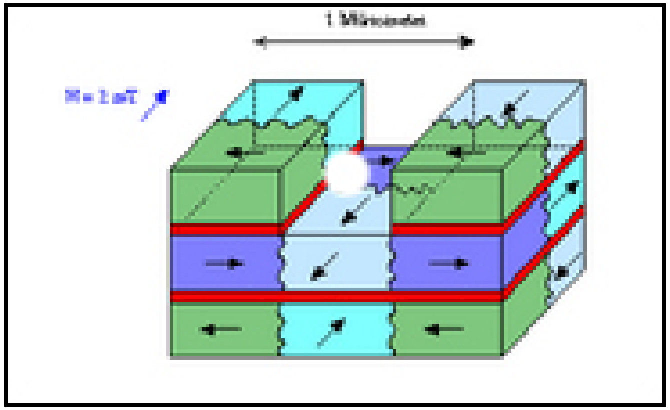
Thick stripes

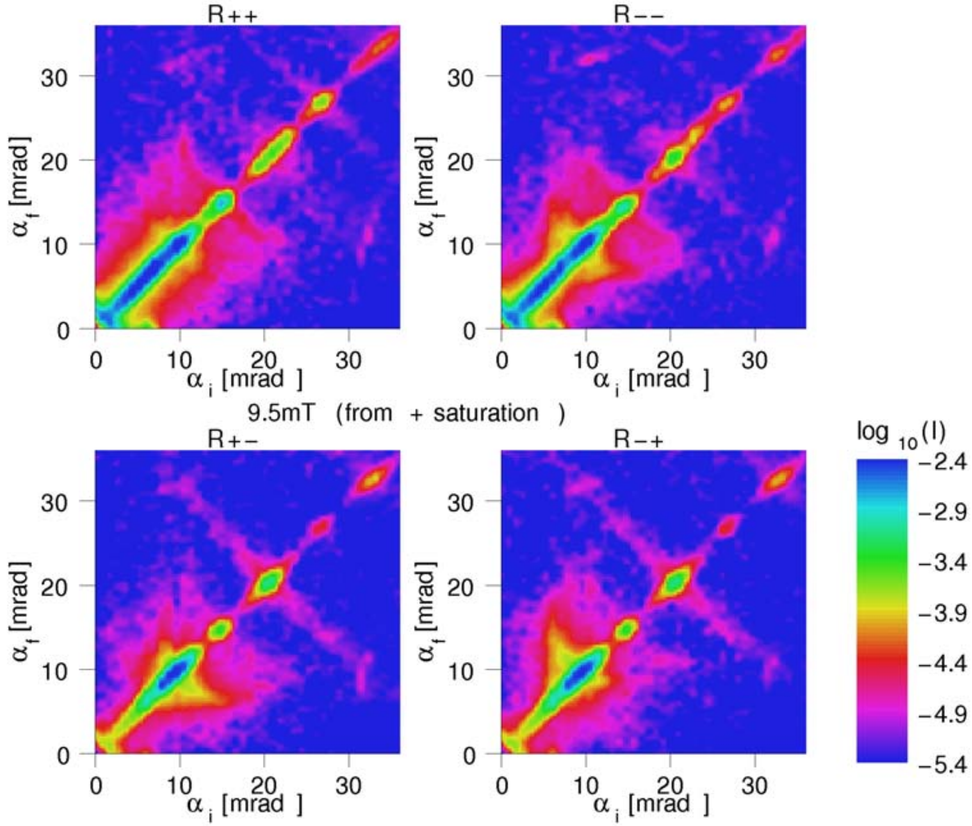
•Complex domain structure

•Dipol - interaction

PNR yields additional information on the magnetization direction

PNR at lateral Fe/Cr multilayer





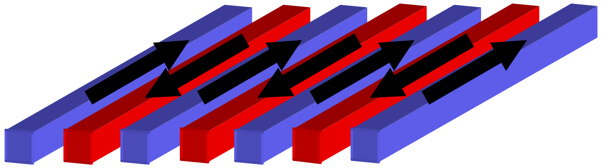
HADAS,
Jülich

Competing interactions between crystal anisotropy, exchange field, and dipolar field

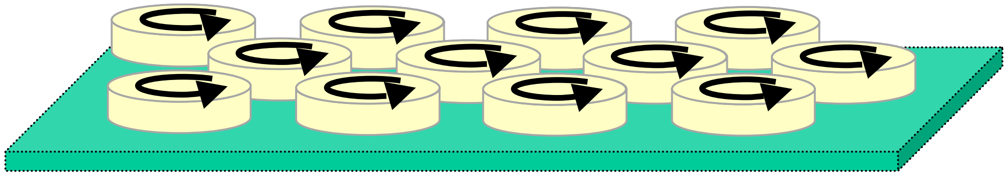
N. Ziegenhagen et al., Physica B 335, 50 (2003)

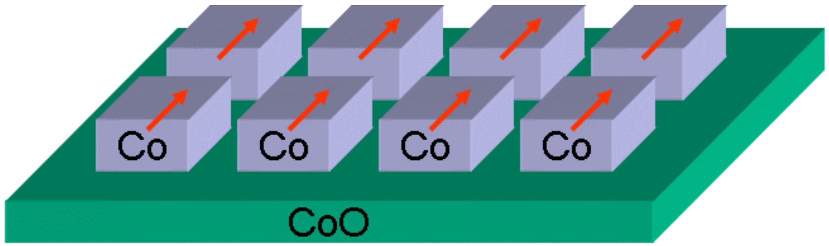
Future prospects for lateral magnetic structures

Stripes with dipole character



Islands with vortex structure





Acknowledgements

RUB	**Katharina Theis-Bröhl** **Max Wolff** **Florin Radu** **Boris Toperverg**
Uni Bielefeld	**J. Schmalhorst, V. Höink, H. Brückl**
FZ-Jülich	**U. Rücker, Th. Brückel**
IFW Dresden	**J. McCord**
Funding	SFB 491 bmb+f Großgeräte der physikalischen Grundlagenforschung