Kerr Microscopy on Magnetic Multilayers (R. Schäfer, IFW- Dresden)

Foil-00-topic.pdf (2k)

Foil-01-couplingtypes.pdf (7k)

Foil-02-Kerrmicroscope.pdf (5k)

Foil-03-microscope.pdf (339k)

Foil-04-contrastenhancement.pdf (938k)

Foil-05-examples1.pdf (3 381k)

Foil-06-examples2.pdf (3 425k)

Foil-07-small-elements.pdf (593k)

Foil-08-big-elements.pdf (4 952k)

Foil-09-exchangespring1.pdf (33k)

Foil-10-exchangespring2.pdf (3 702k)

Foil-11-exchangespring3.pdf (2 969k)

Foil-12-exchangespring4.pdf (3 061k)

Foil-13-exchangespring5.pdf (758k)

Foil-14-NiO1.pdf (186k)

Foil-15-cryostate.pdf (4k)

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Foil-17-NiO3.pdf (3k)

Foil-18-NiO4.pdf (1 599k)

Foil-19-NiO5.pdf (911k)

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Foil-44-F-BQ-AF-Kerr-Voigt.pdf (957k)

Foil-45-FeAluncoupled.pdf (2 703k)

Foil-46-FeCrAgCrFepinhole.pdf (1 931k)

Foil-47-Conclusions.pdf (2k)

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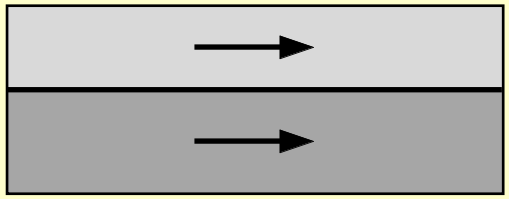
49 object(s) : 57 019k

Kerr Microscopy
on Magnetic Multilayers

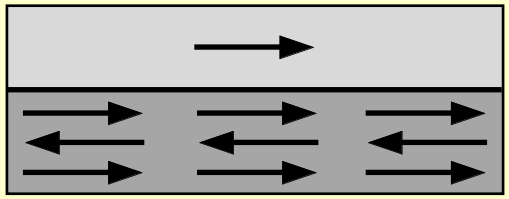
R. Schäfer, IFW-Dresden

Classification of Magnetic Multilayers

Strong coupling



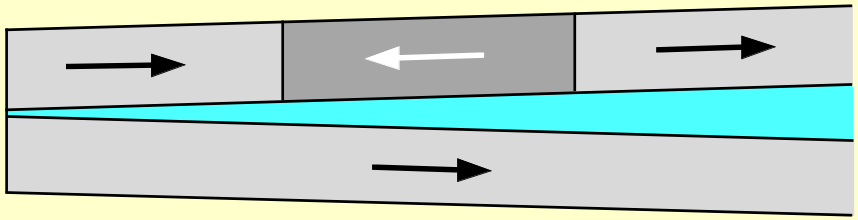
hard/soft ferromagn. layers



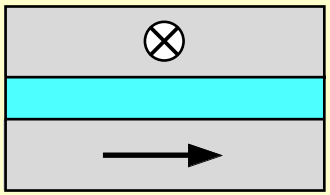
antiferromagn. / ferromagn. layers

Oscillating coupling

ferromagn. antiferromagn. ferromagn.

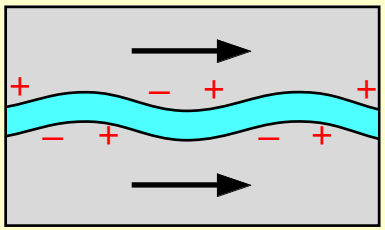


non-collinear (90°)



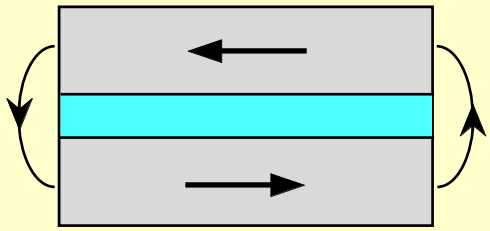
ferromagn. film
non-magn. spacer
ferromagn. film

Weak coupling



orange peel coupling
(Néel coupling)

q.m. exchange
(thin spacers)

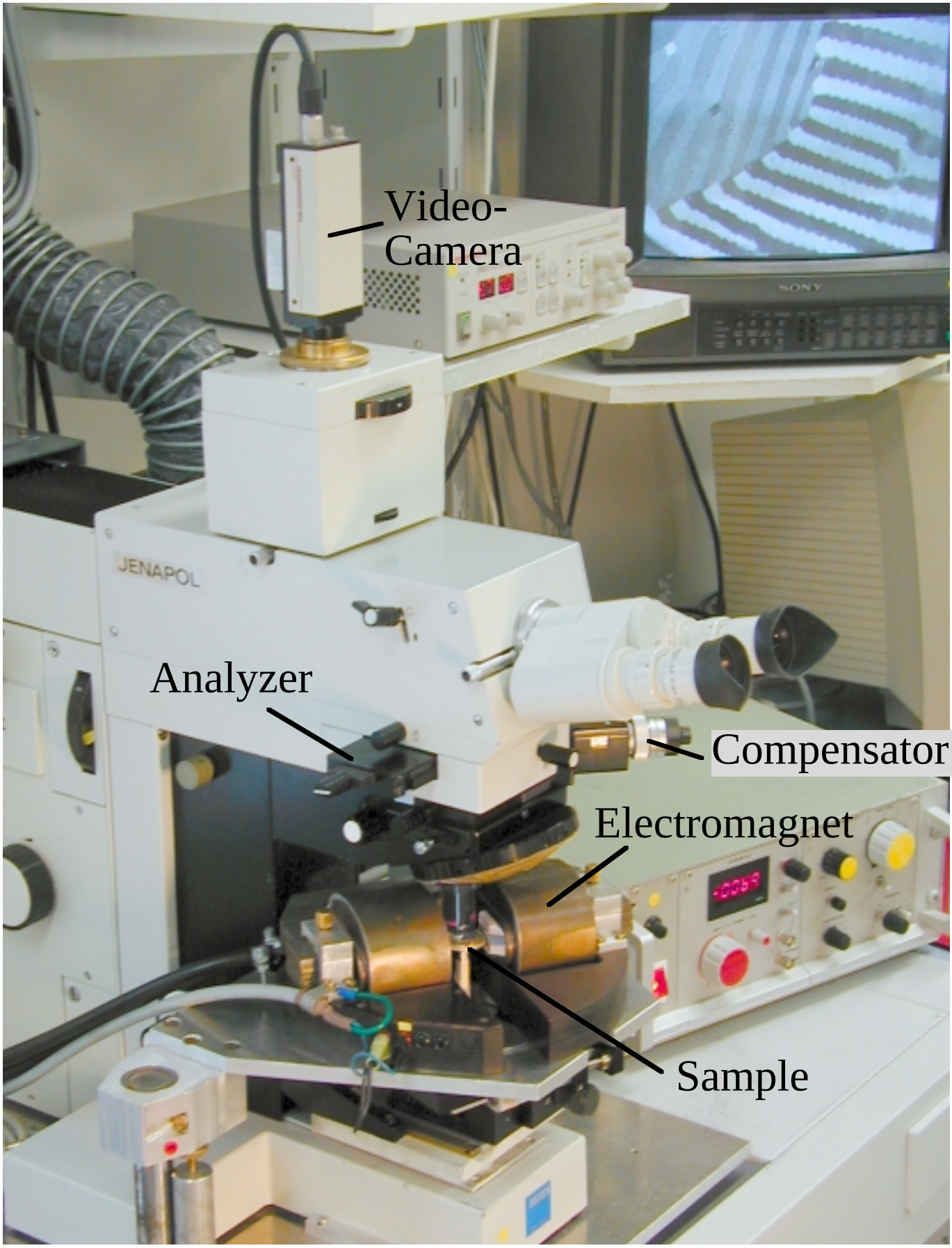


stray field coupling

No coupling

for certain (perfect) spacers

Kerr-Microscope at IFW-Dresden



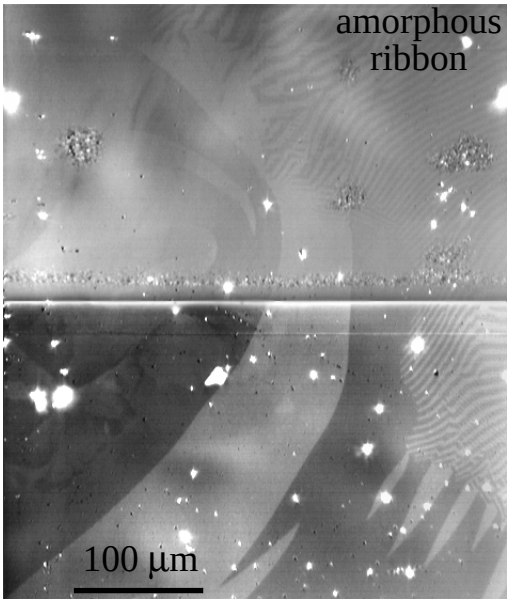
Contrast Enhancement in Kerr Microscopy

Antireflection layer

J. Kranz, A. Hubert **(1963)**

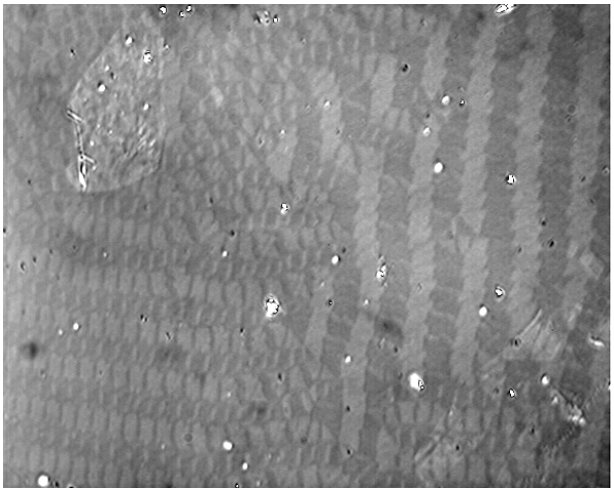
without interference layer

with ZnS interference layer

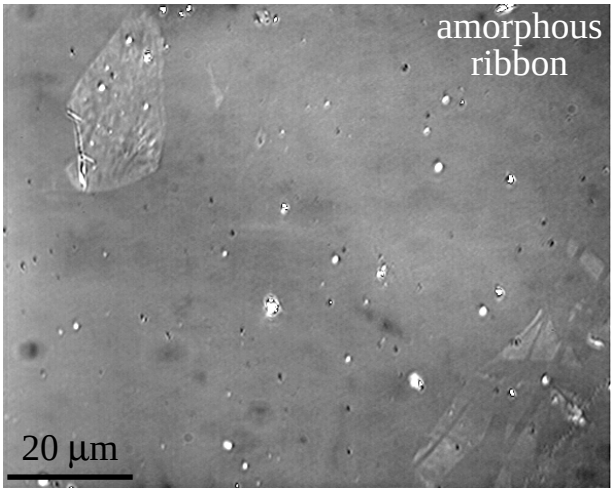


Digitally enhanced Kerr microscopy (difference image technique)

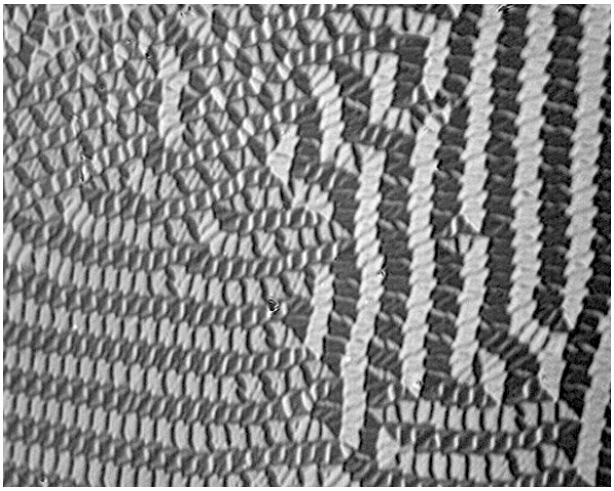
F. Schmidt, W. Rave, A. Hubert **(1985)**



Original image



Reference image



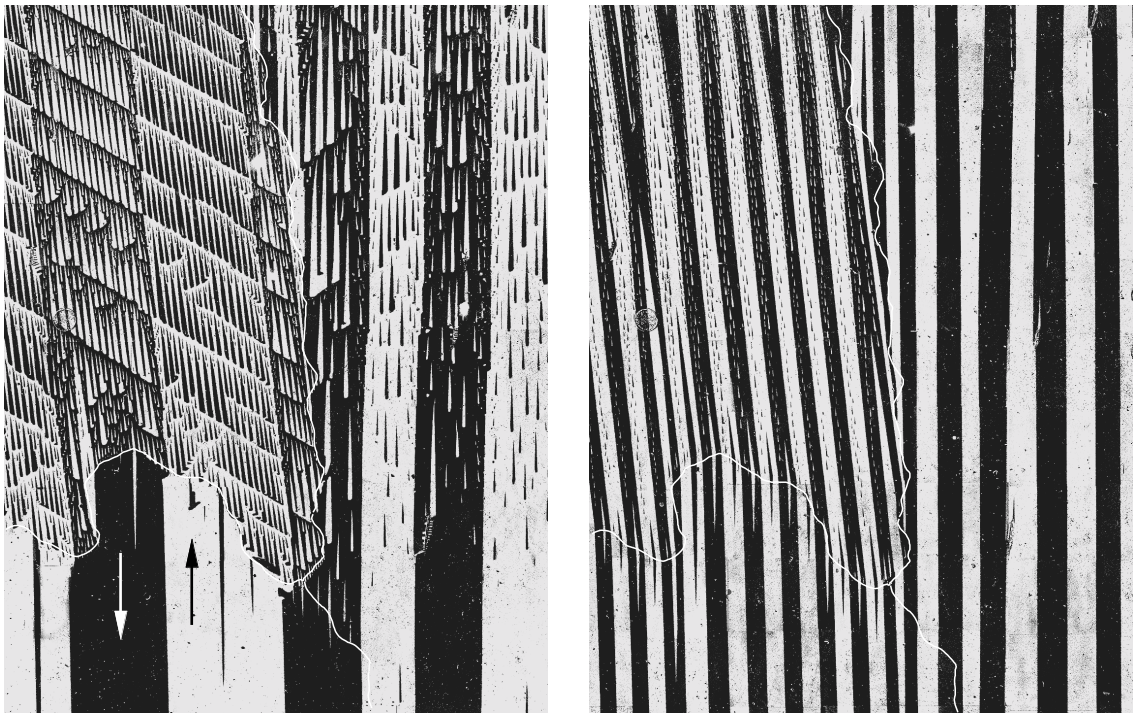
Difference image

Kerr-Microscopy: Examples

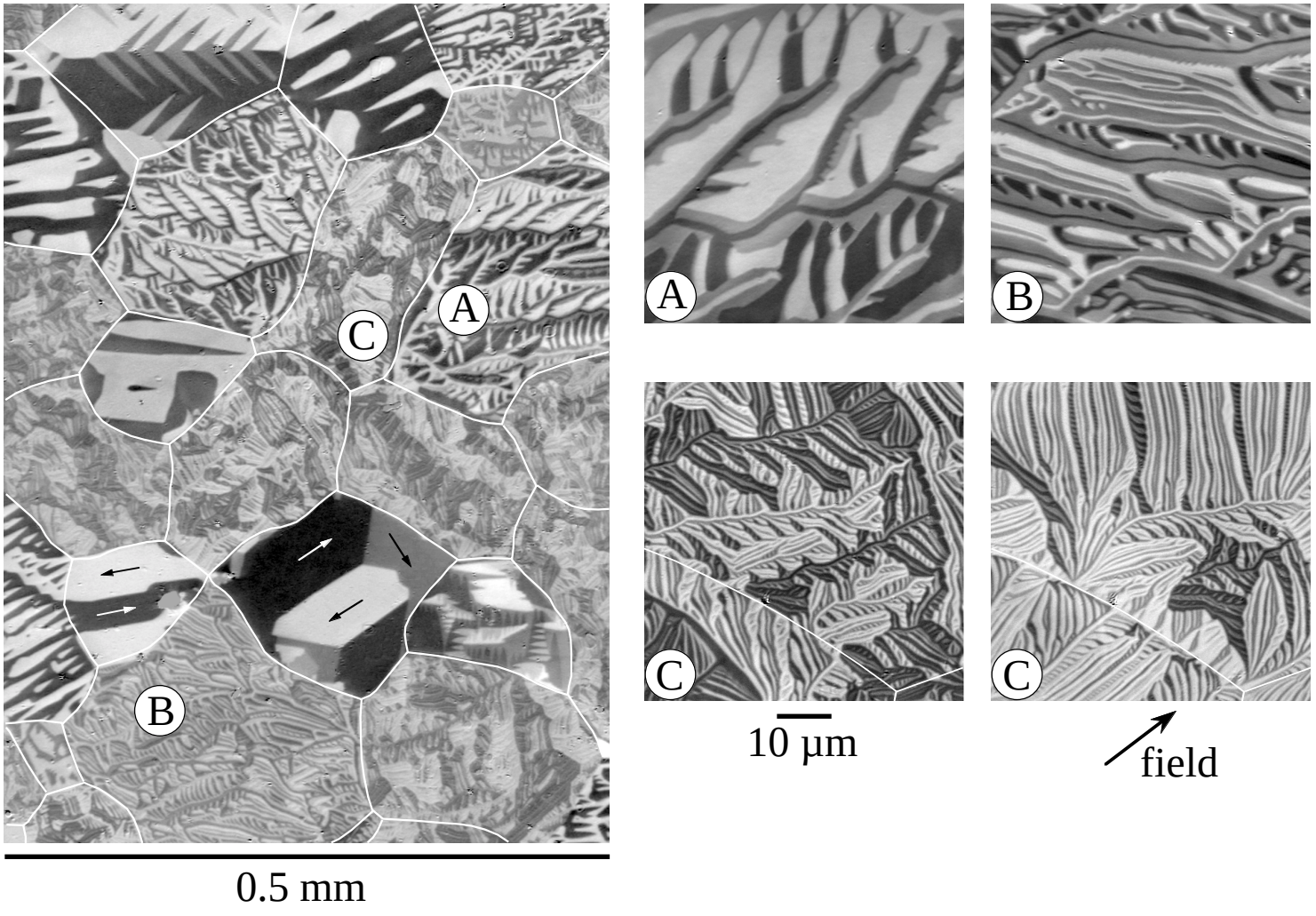
Transformer steel

initial state

under tensile stress

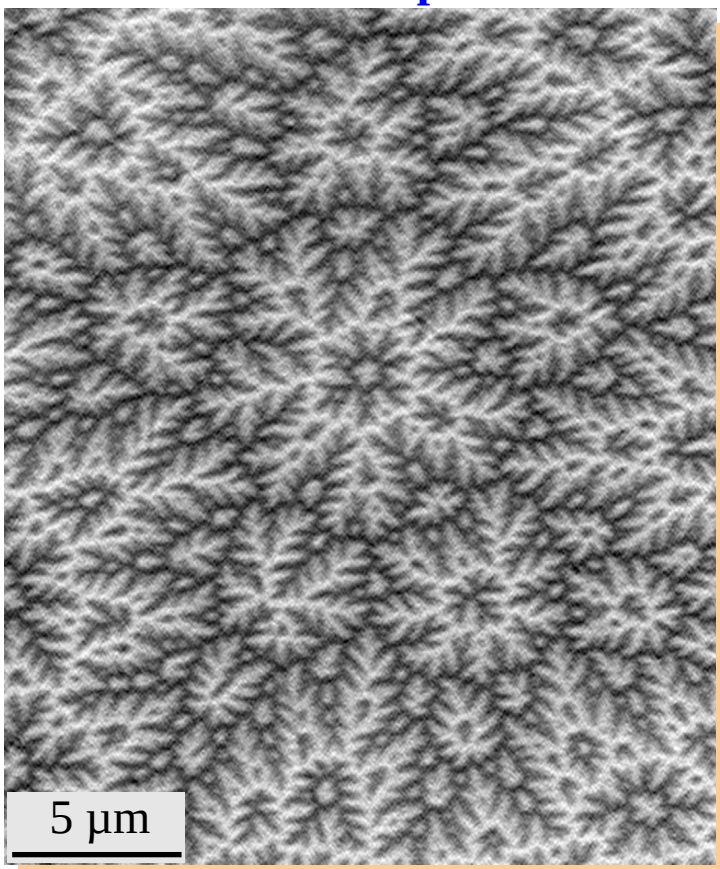


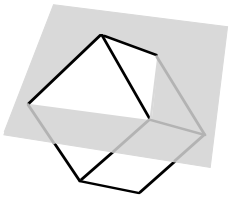
Non-oriented electrical steel



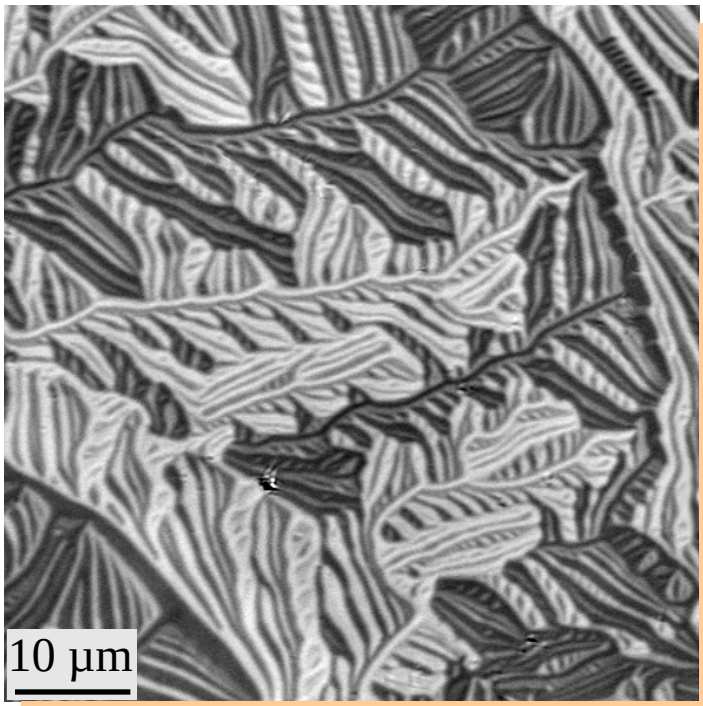
High-resolution Kerr microscopy

Co basal plane



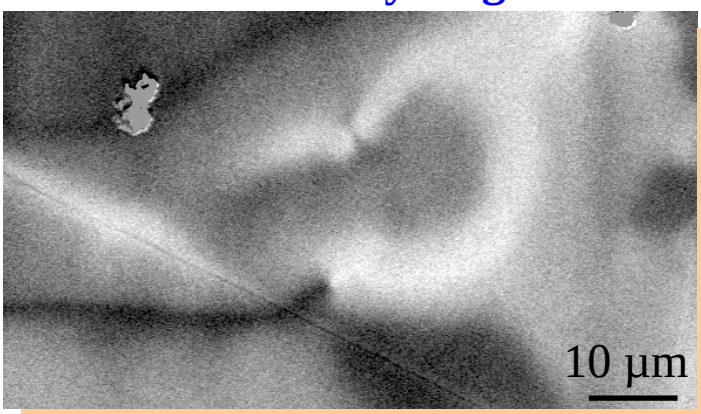


Iron (111) surface

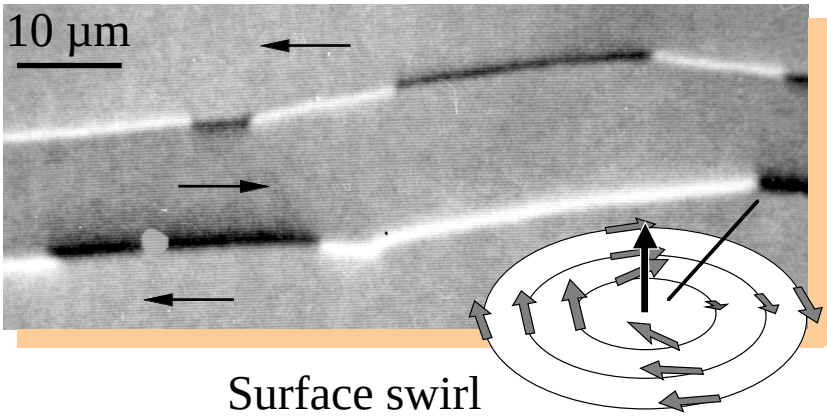


amorphous layer (1 µm thick)

Permalloy ring core

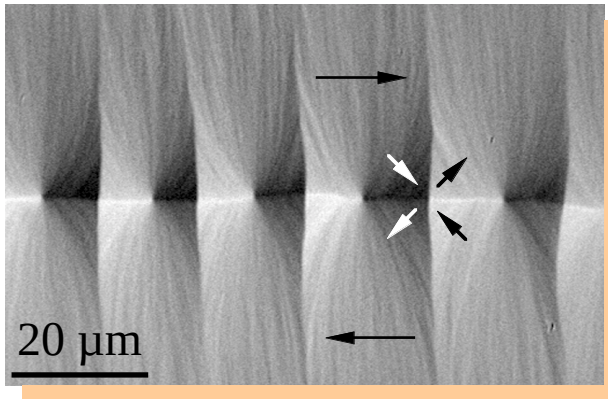


asym. Bloch wall (met. glass)

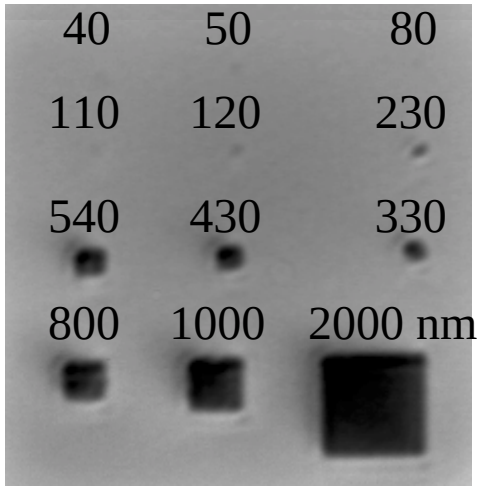


Surface swirl

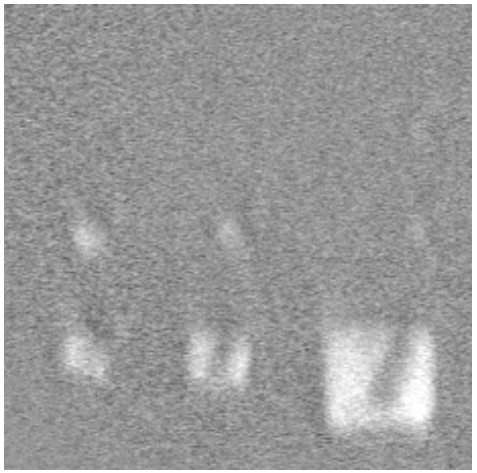
Crosstie wall (Permalloy)



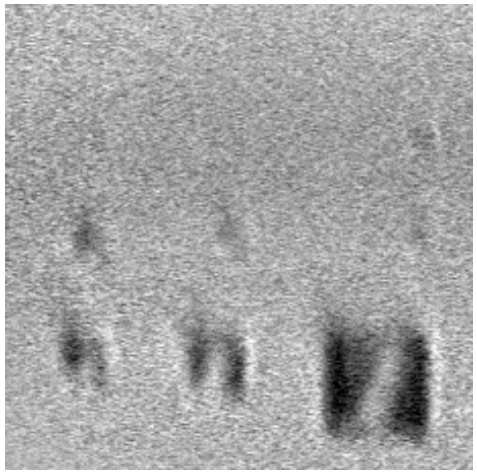
Kerr microscopy on small Co-elements *(sample: A. Carl, Duisburg)*

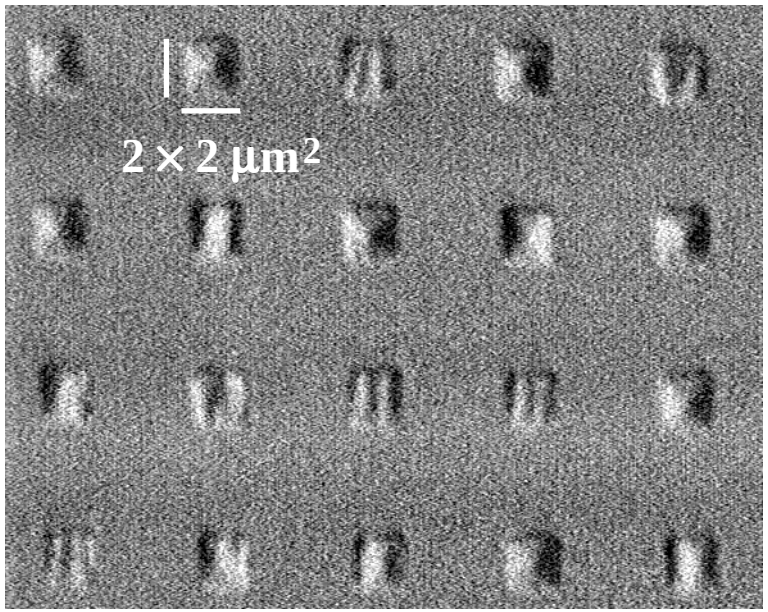


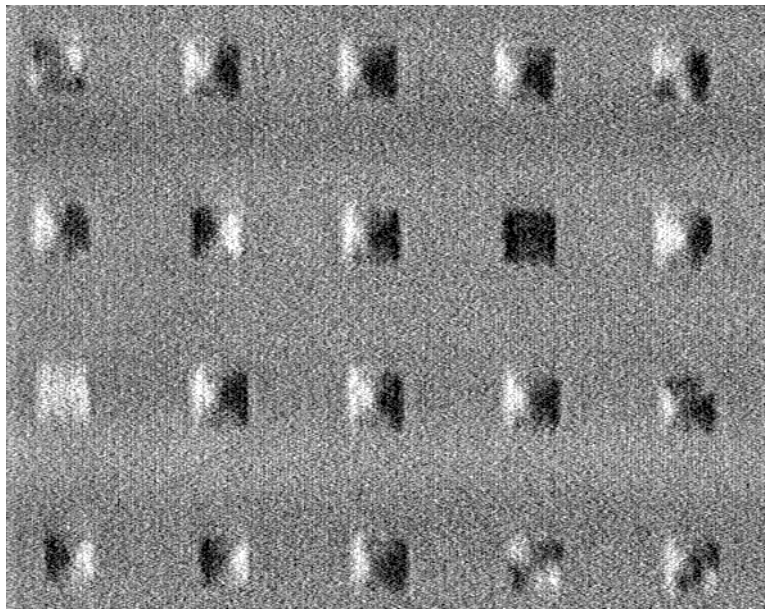
$M_r^+ - M_r^-$



$M_r^- - M_r^+$

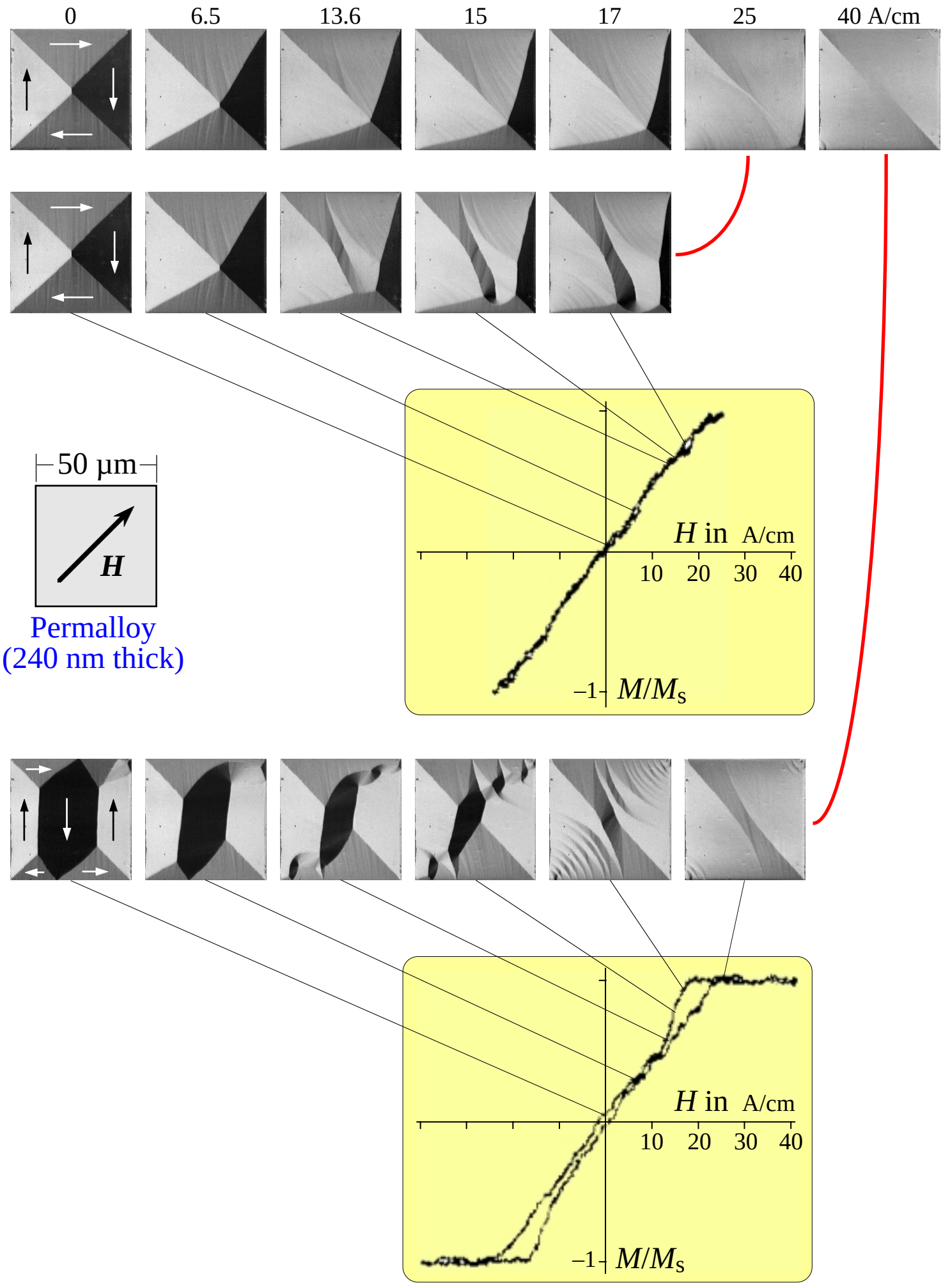


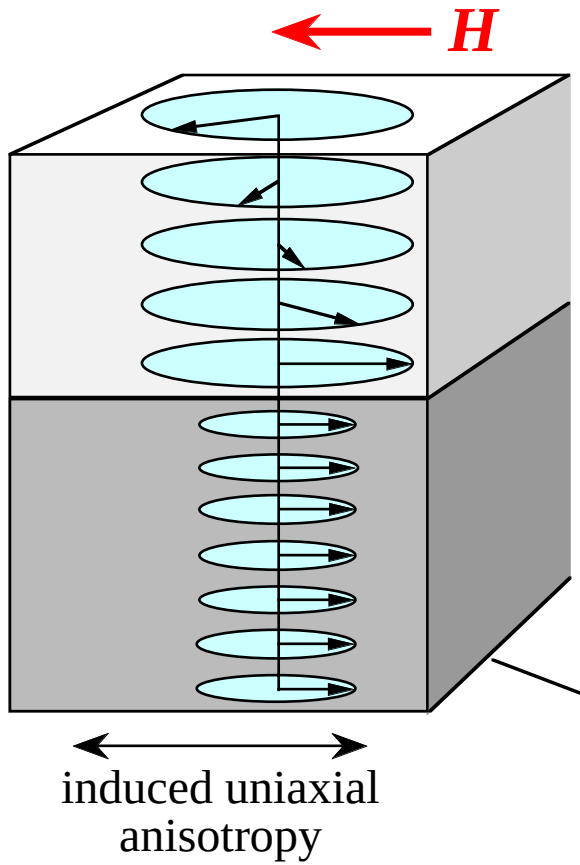


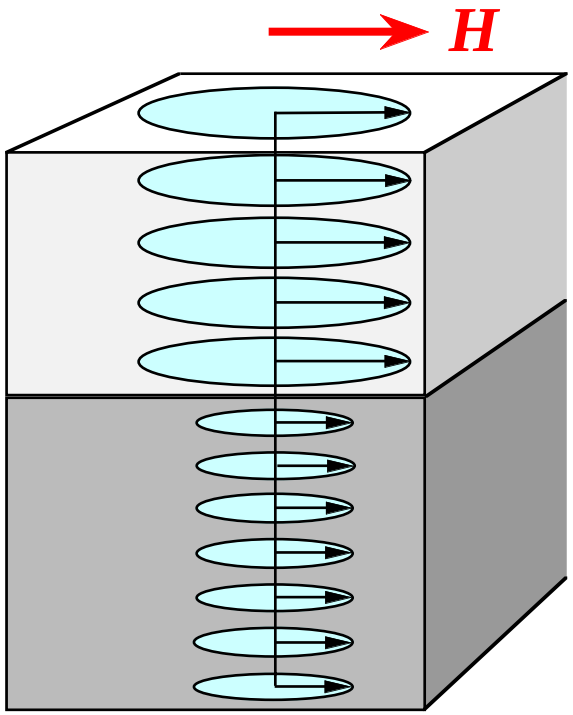


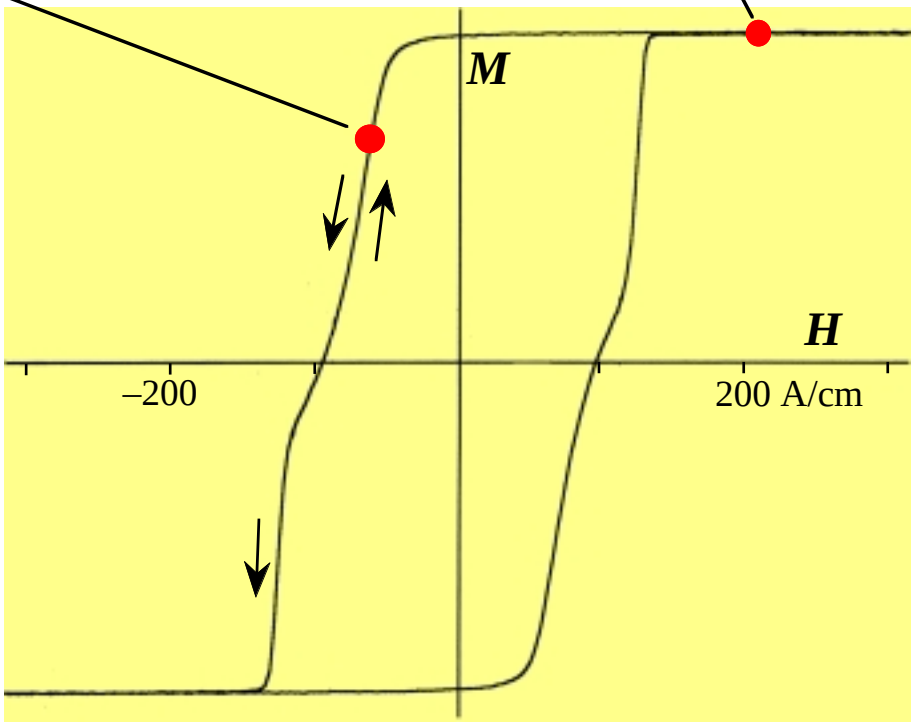
$H_{demag.}$

$H_{demag.}$


0
6.5
13.6
15
17
25
40 A/cm
50 µm
H
Permalloy
(240 nm thick)
H in A/cm
10 20 30 40
–1
M/M_S
H in A/cm
10 20 30 40
–1
M/M_S





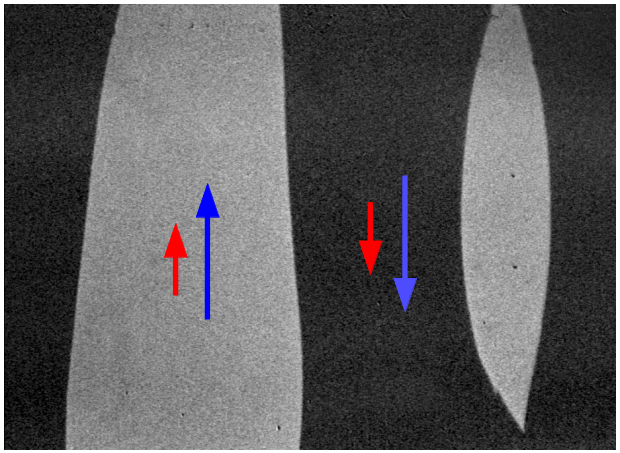


Hard-/soft magnetic films in contact: Exchange-spring films

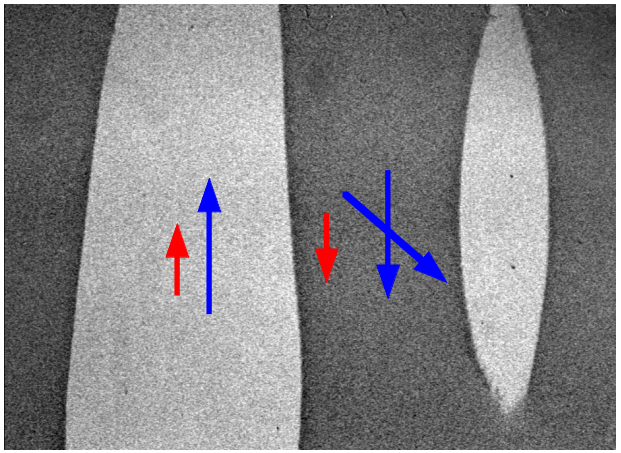
together with
D. Chumakov (IFW-Dresden)
and S. Yan (Tallahassee)

easy axis

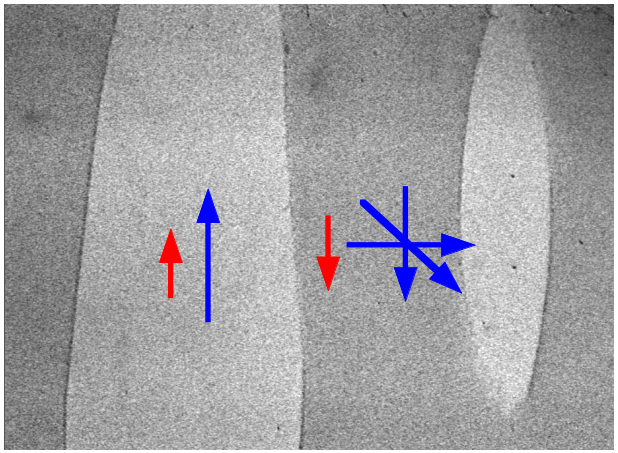
NiFe/SmFe exchange spring system seen from *Permalloy side*



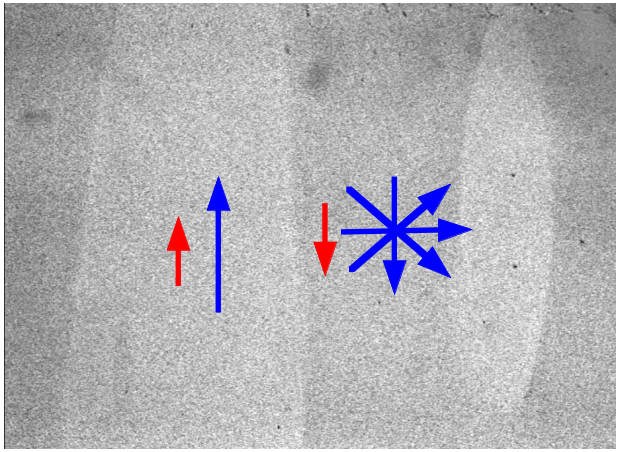
0 A/cm



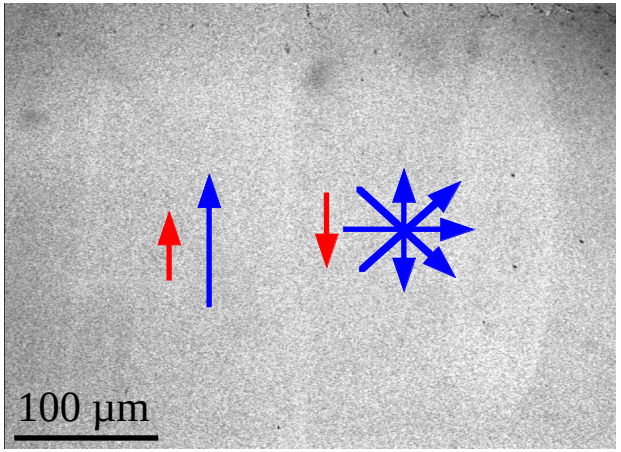
45 A/cm ***H***



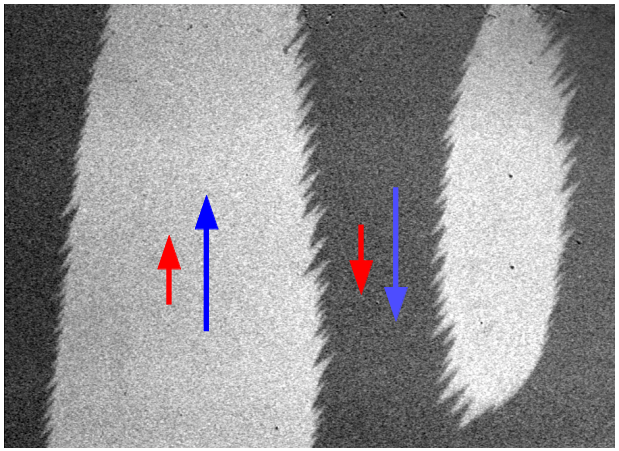
65 A/cm



75 A/cm

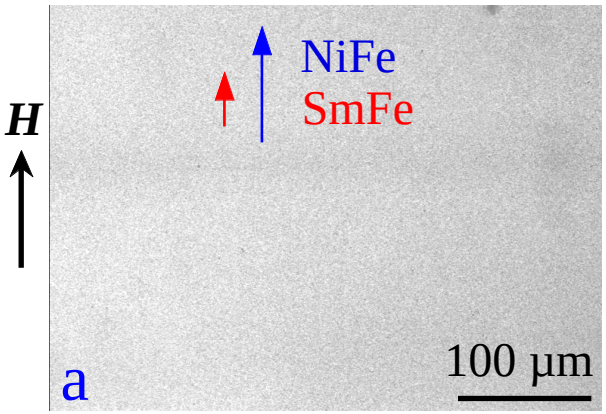


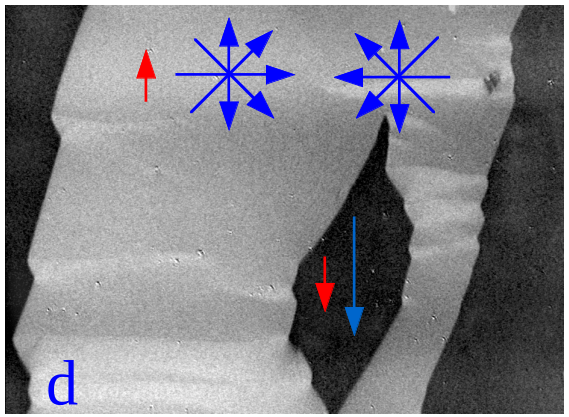
83 A/cm

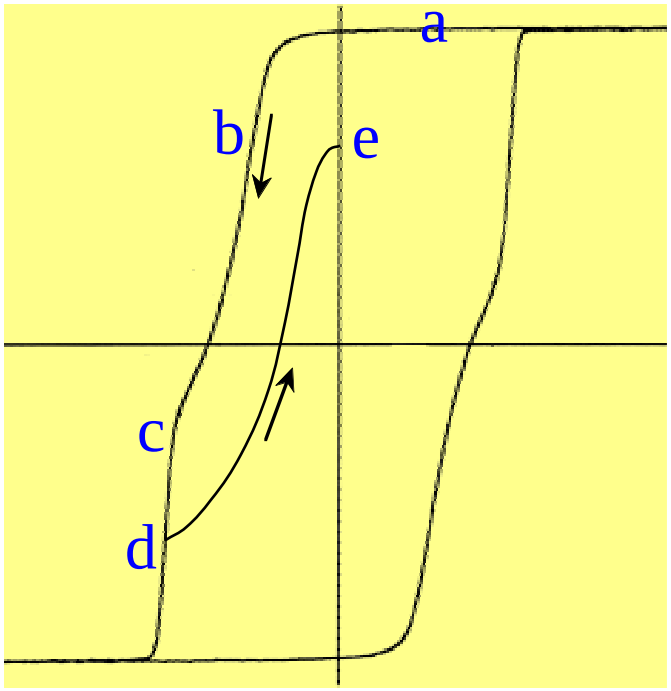


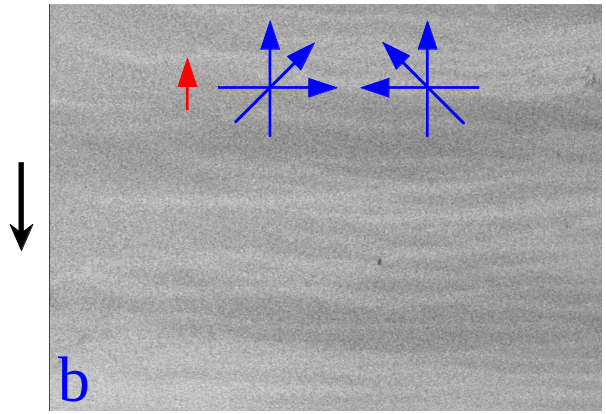
0 A/cm (after 90 A/cm)

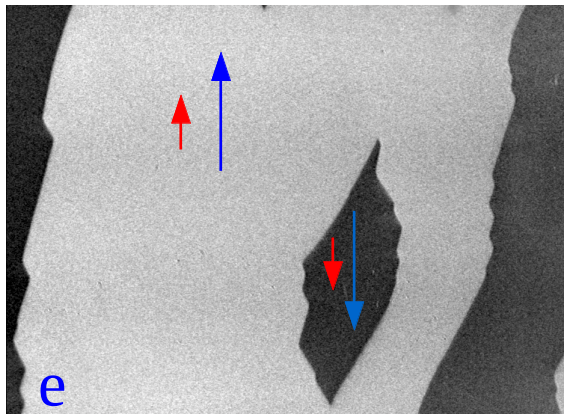
Magnetization process in NiFe/SmFe exchange spring system seen from *Permalloy side*

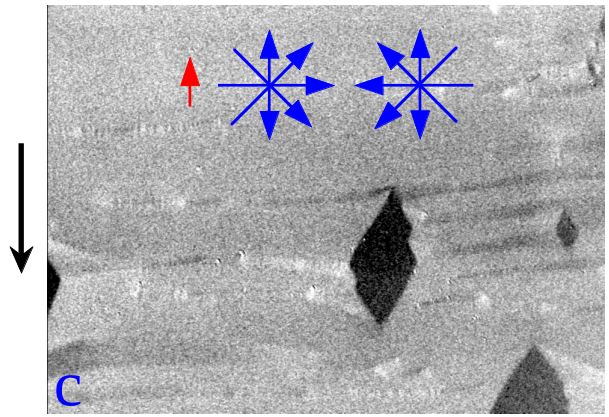


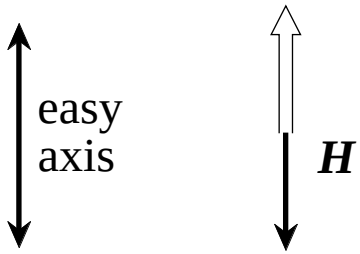




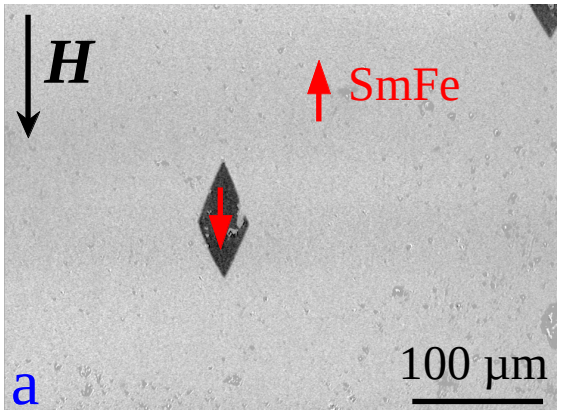


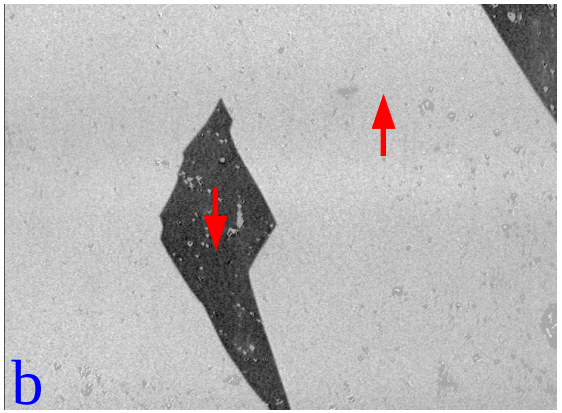


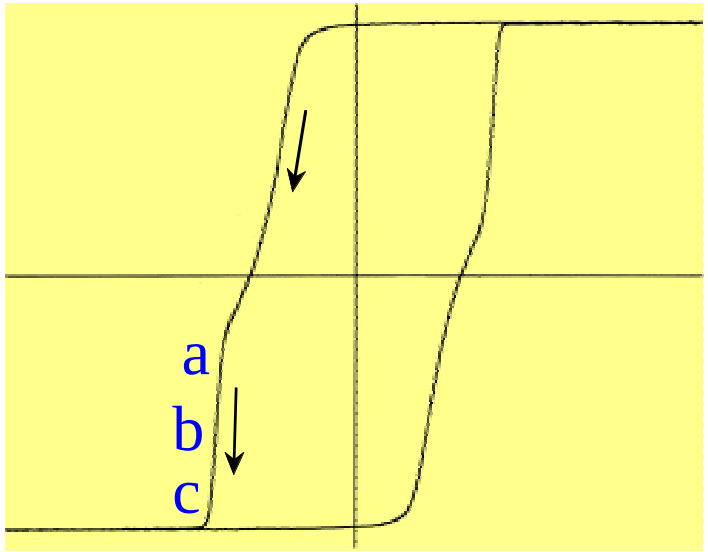


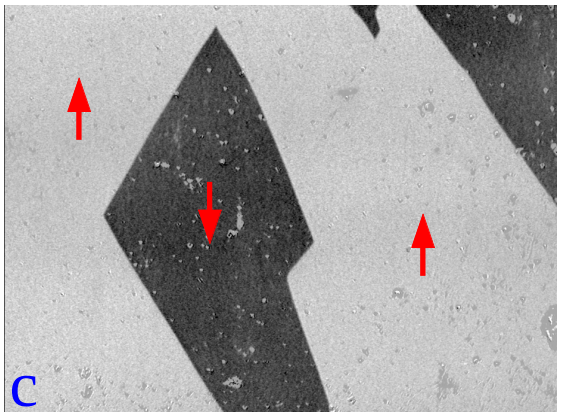


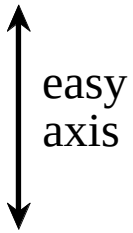
Magnetization process in NiFe/SmFe exchange spring system, seen from *SmFe side*

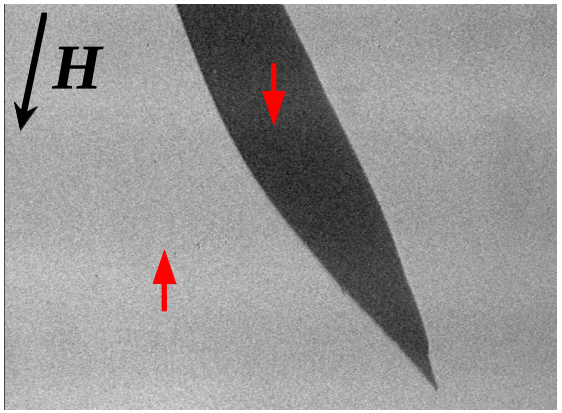


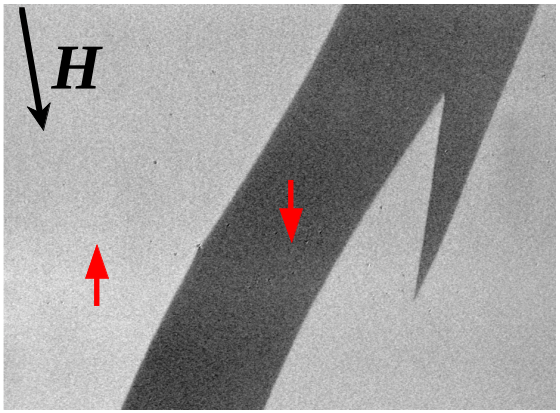


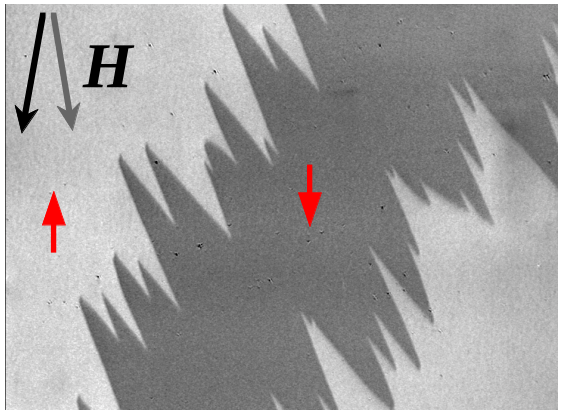


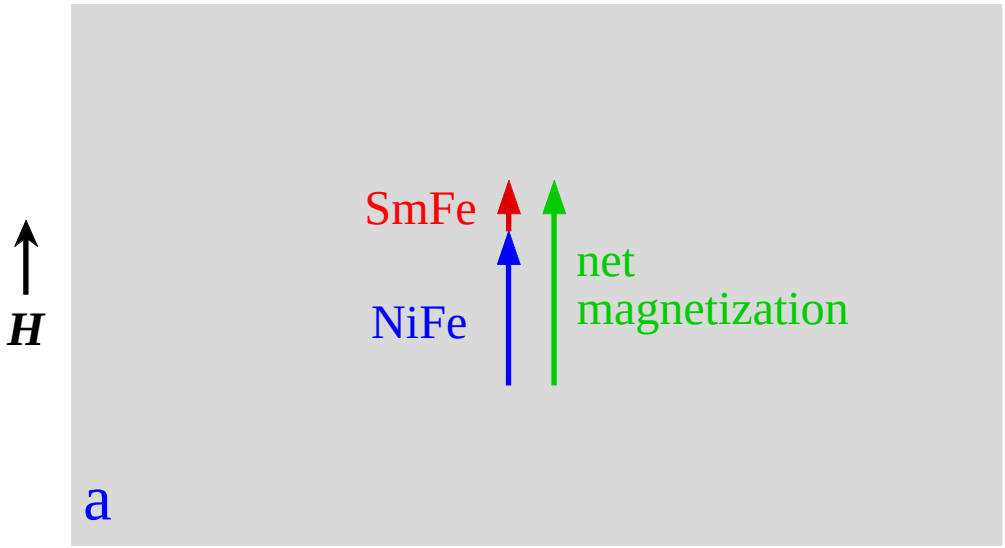


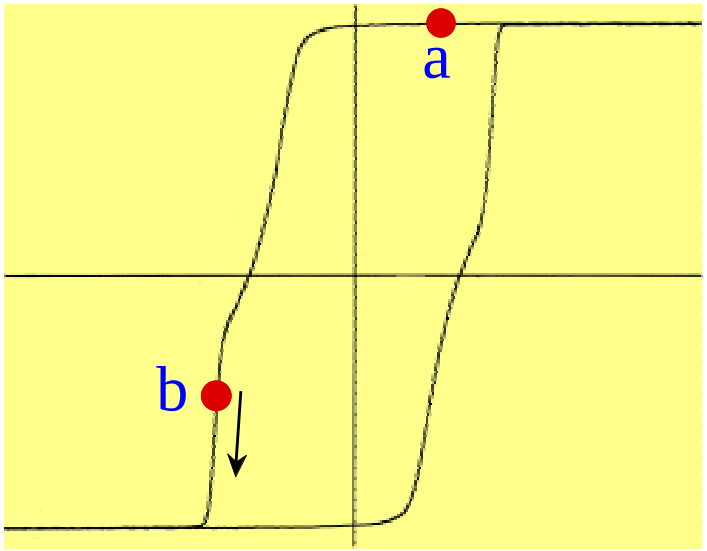


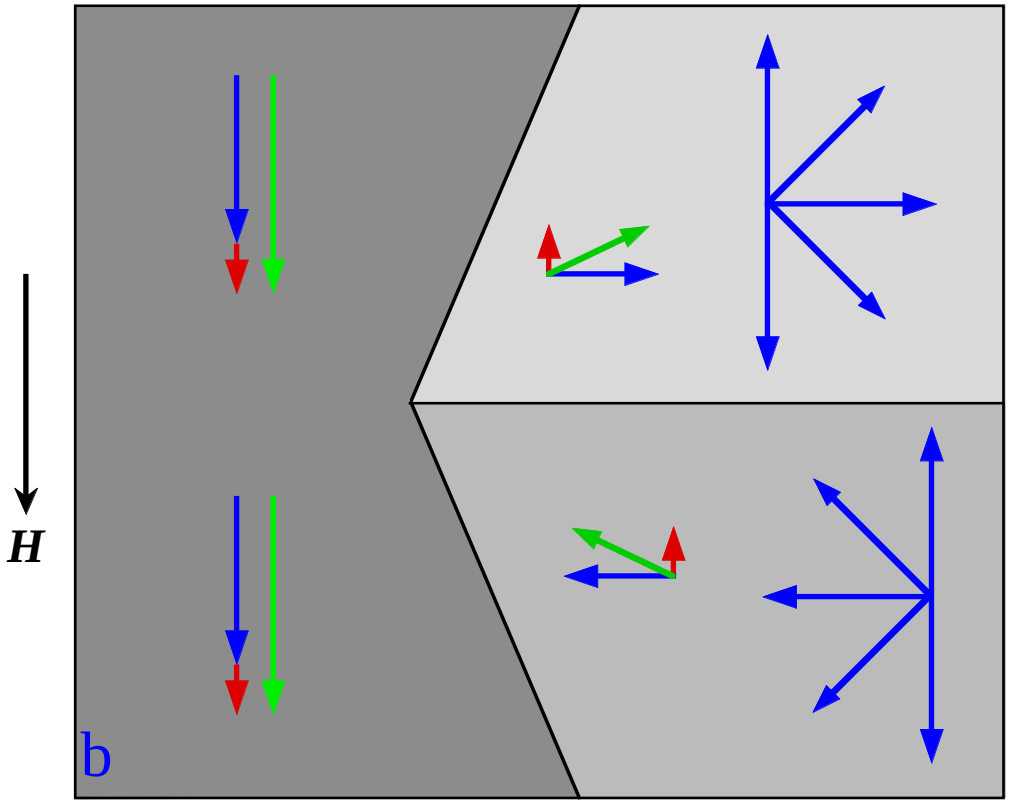


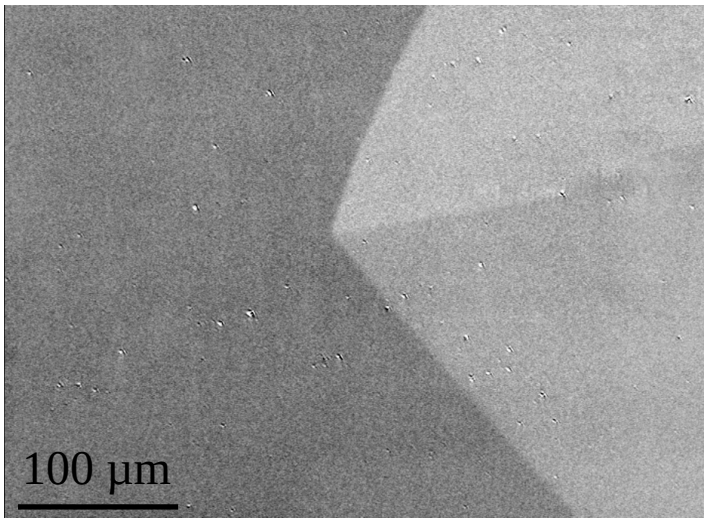




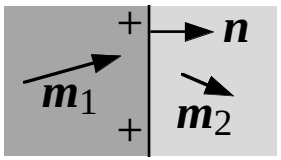




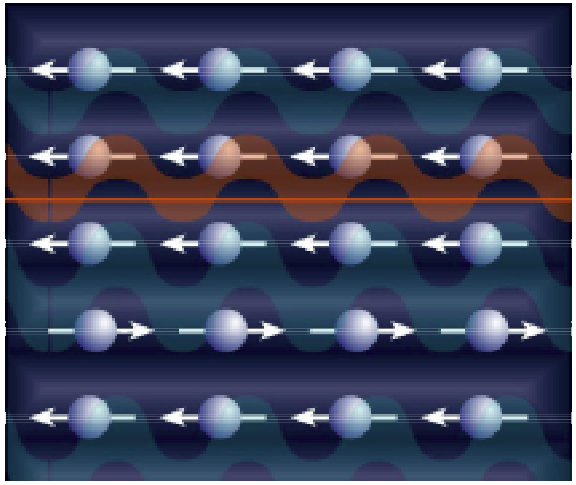




$\sigma_s = (\boldsymbol{m}_1 - \boldsymbol{m}_2) \cdot \boldsymbol{n}$

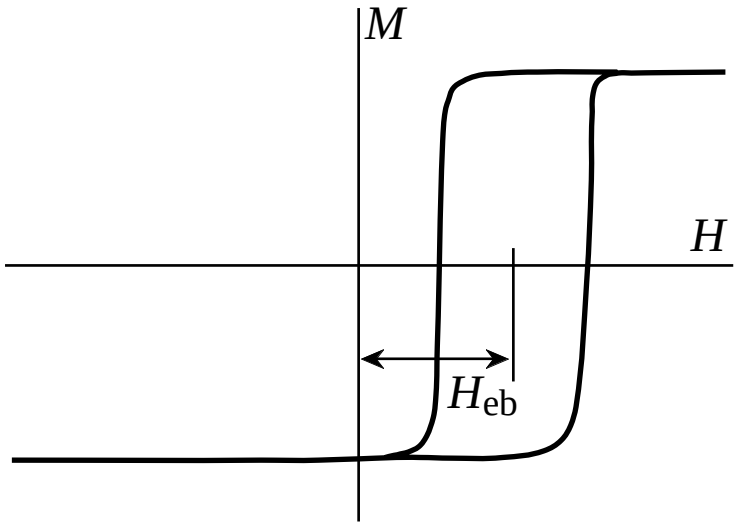


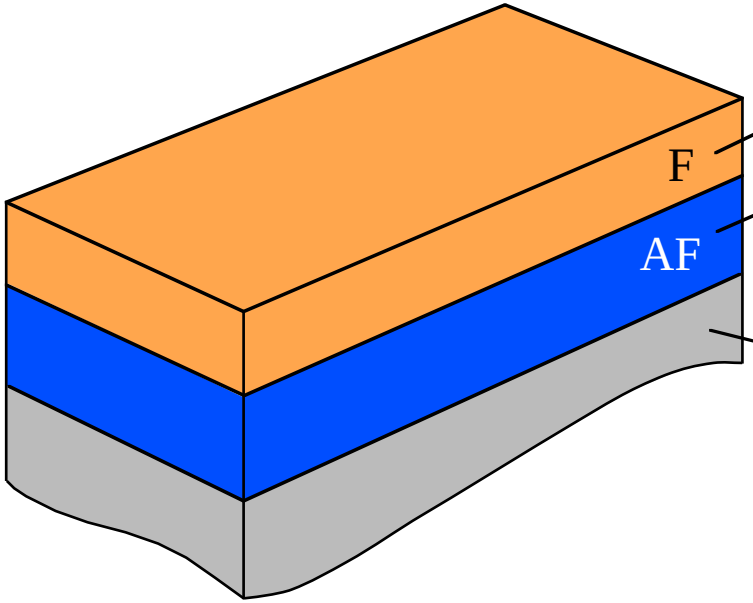
Magnetization processes in exchange biased FM-AFM systems



ferromagnetic film

antiferromagnetic film





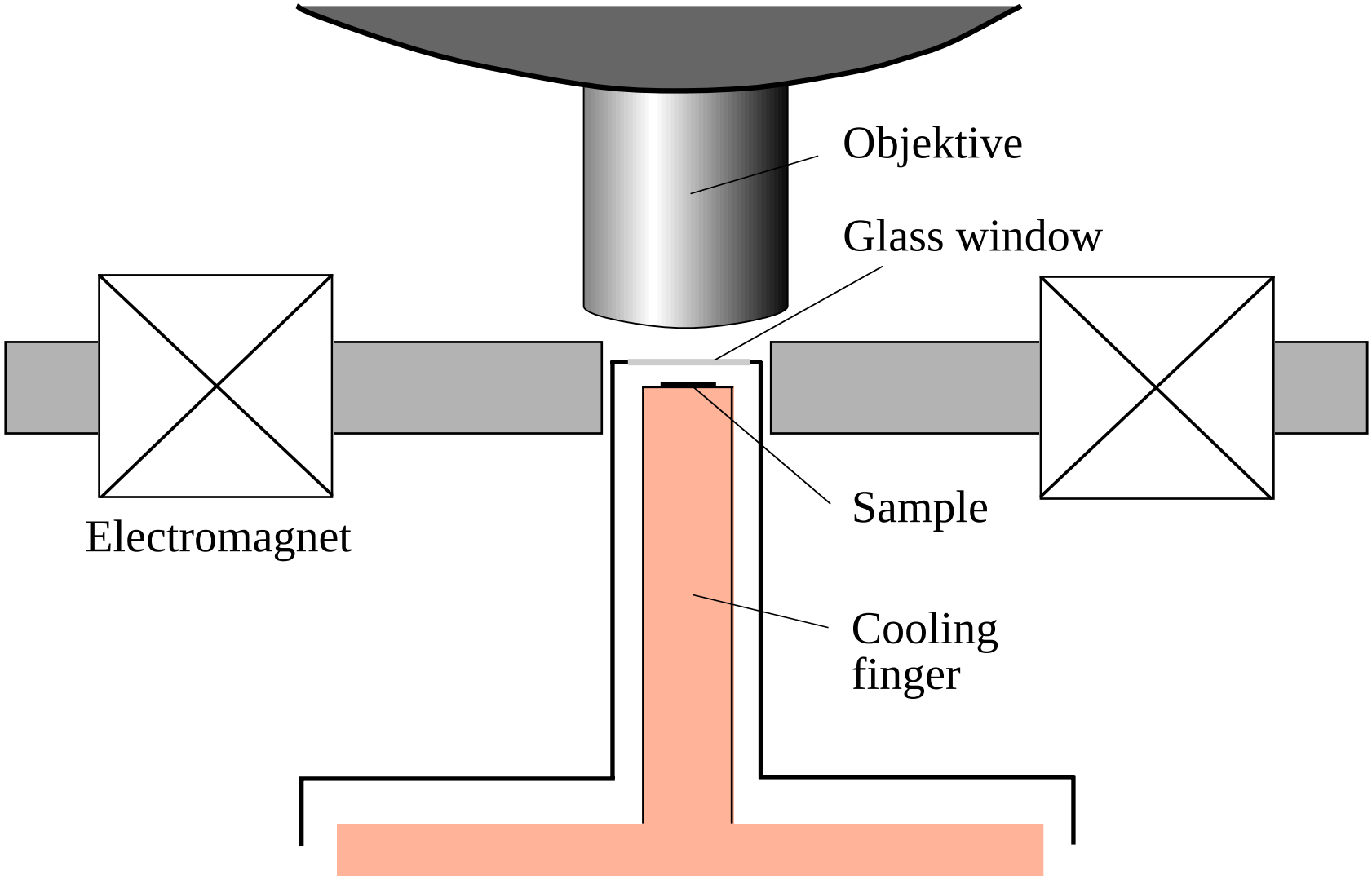
NiFe (Permalloy, 10 nm thick)

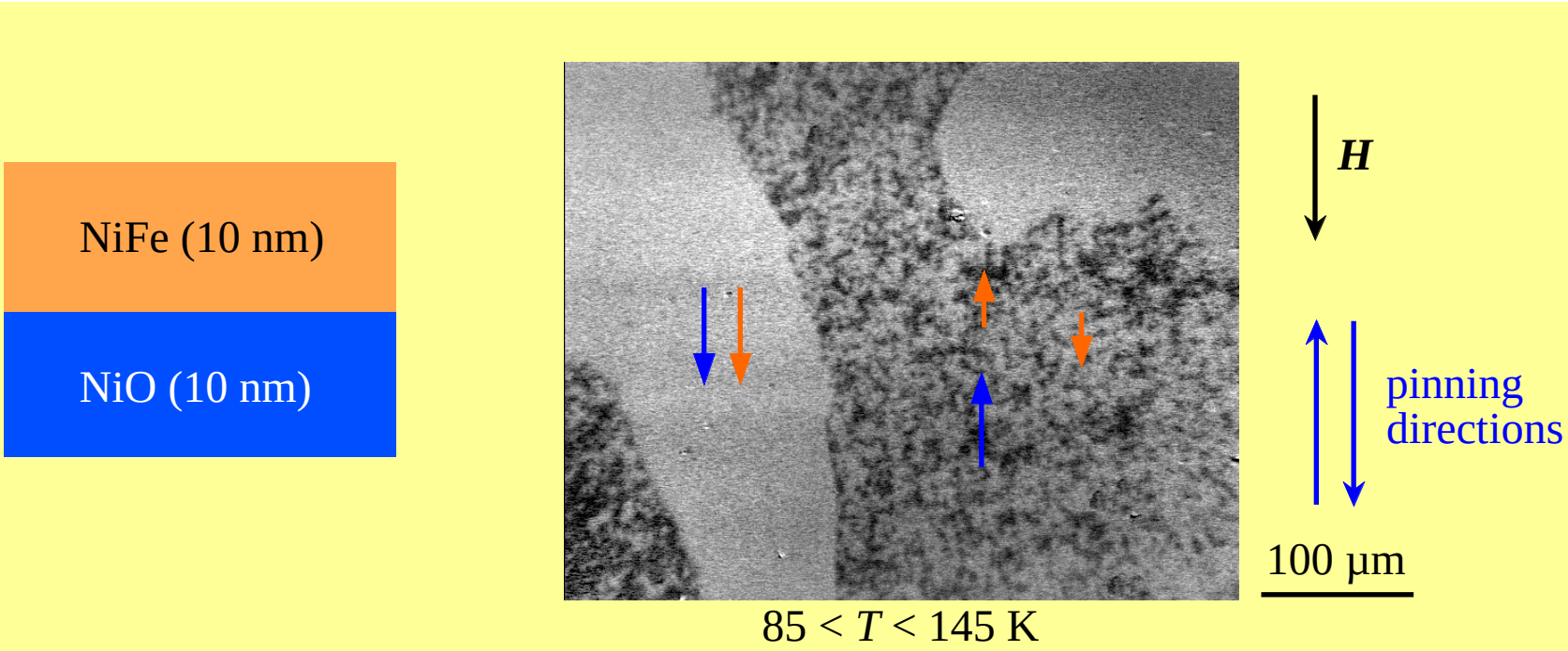
NiO (10 nm thick)
for $t \leq 10$ nm: reduced coupling temp. of 200K

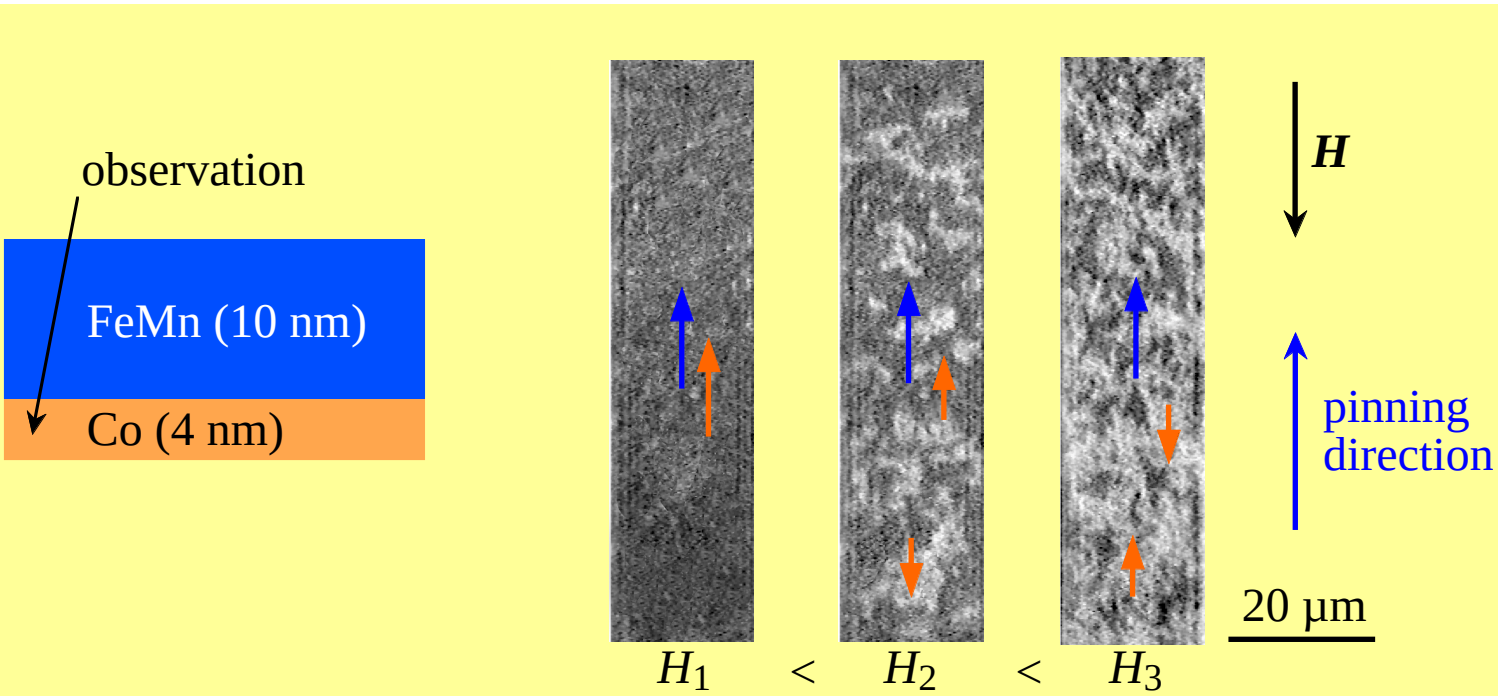
Substrate

together with
O. de Haas and C. M. Schneider (IFW-Dresden)

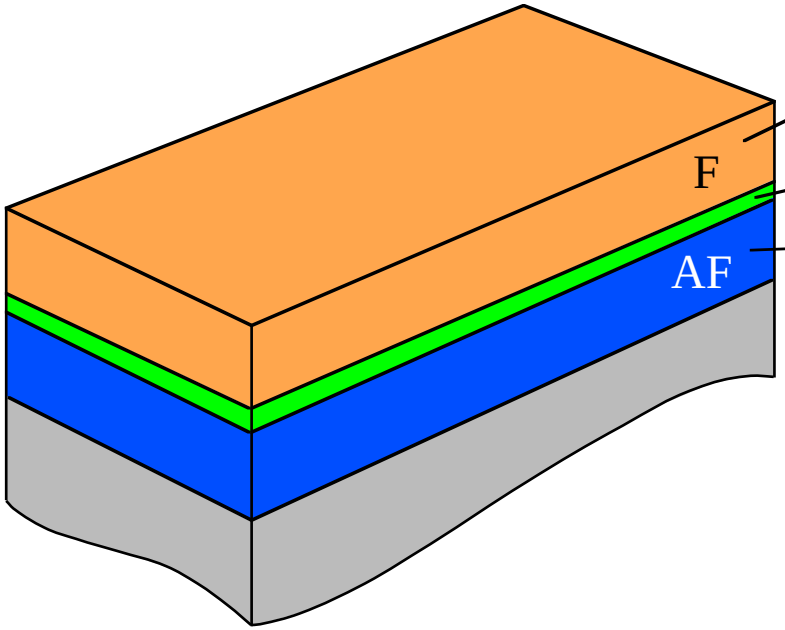
Domain Observation in Optical Cryostat




NiFe (10 nm)
NiO (10 nm)
H
pinning directions
100 µm
85 < T < 145 K


observation
FeMn (10 nm)
Co (4 nm)
H
pinning direction
20 µm
H1 < H2 < H3

Processes in NiFe/NiO with reduced exchange biasing

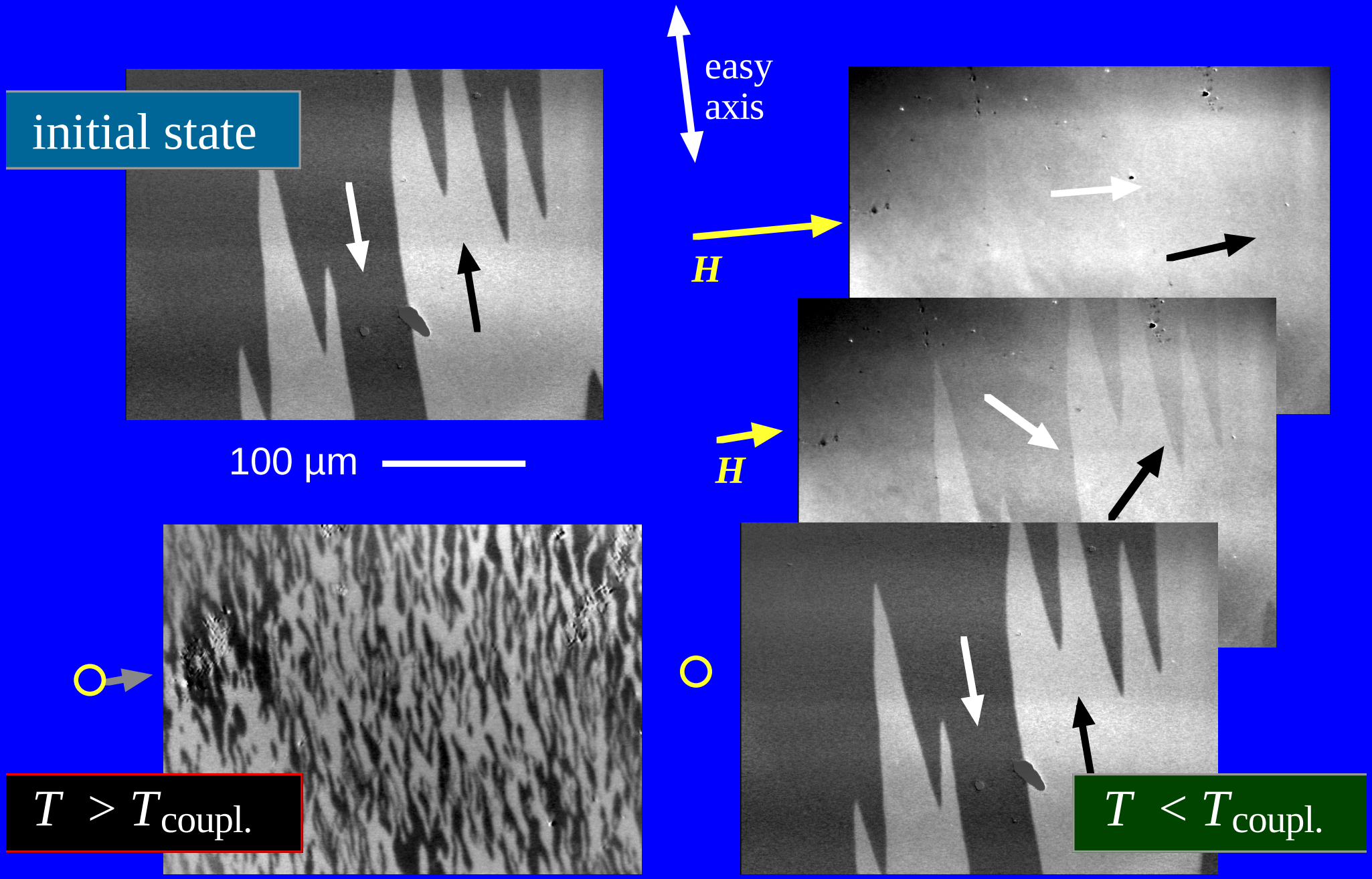


NiFe (Permalloy, 10 nm thick)

Cu (0.5 nm thick) – reduction of exchange bias

NiO (10 nm thick) – reduced coupling temp. 200K

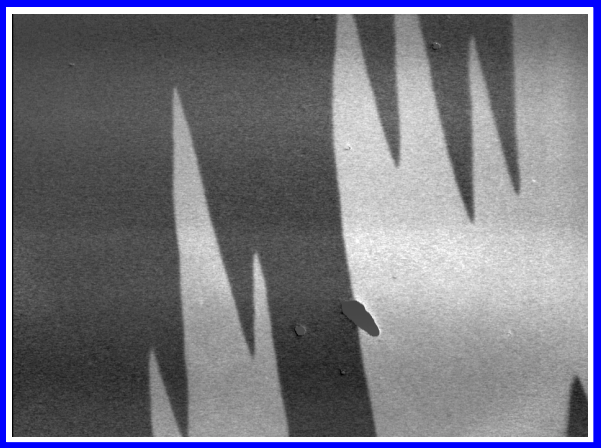
Hard axis magnetization process

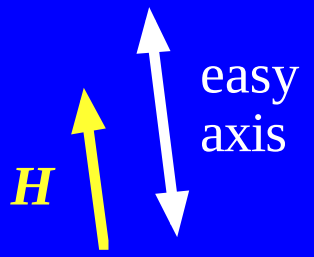


Easy axis magnetization process

initial state

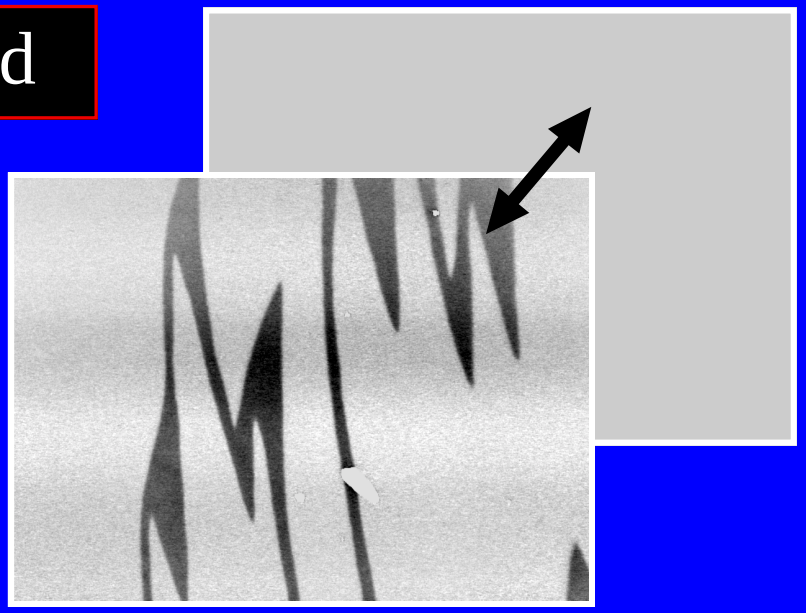
zero field



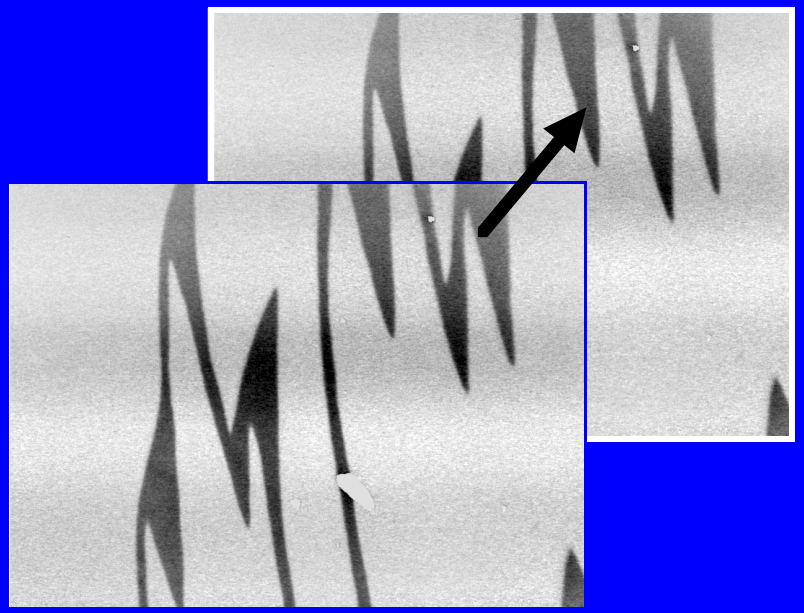


magnetized

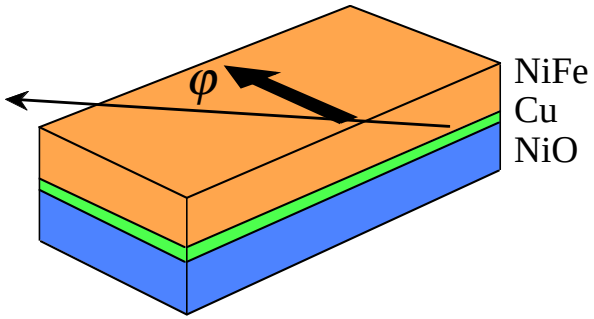
T < 220 K - reversible

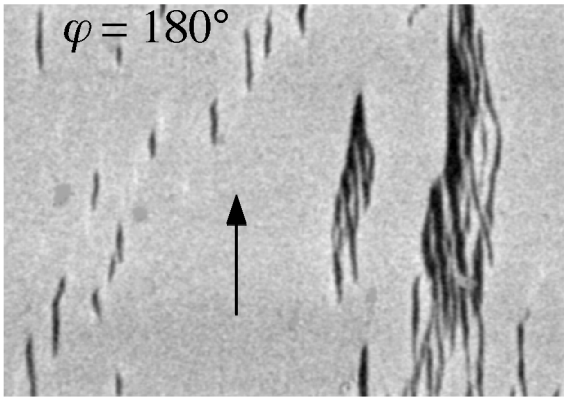


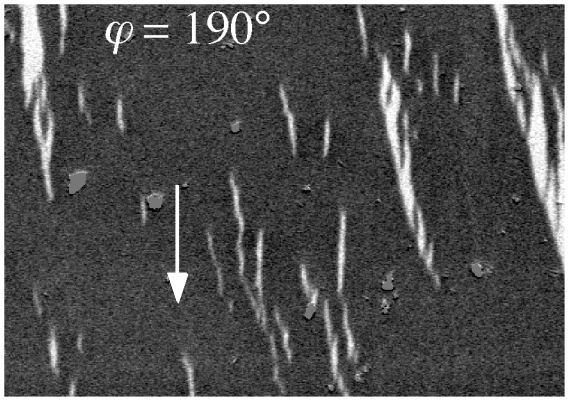
T > 220 K - irreversible

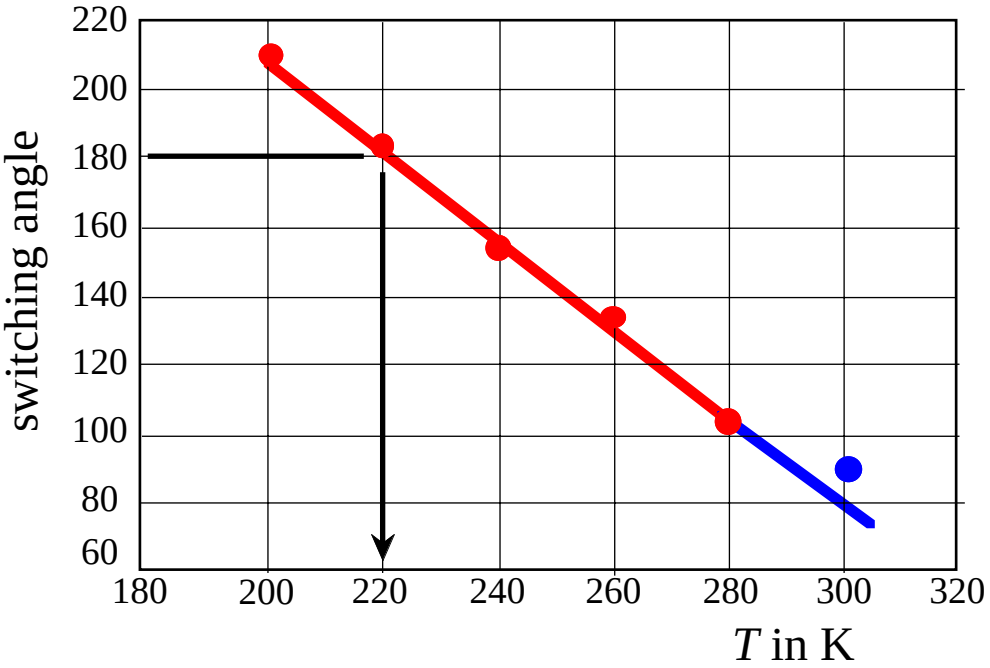


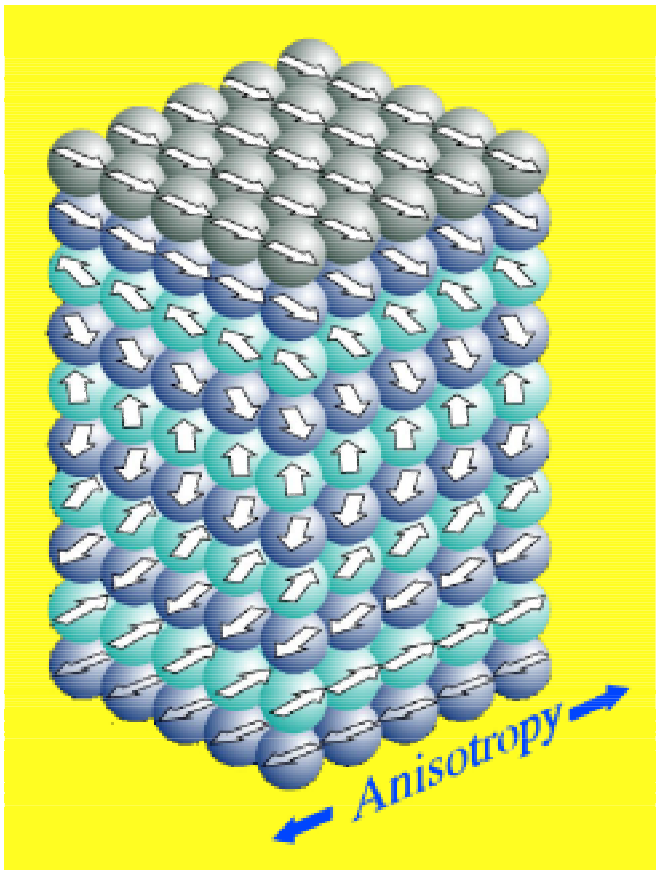
Switching in rotating field











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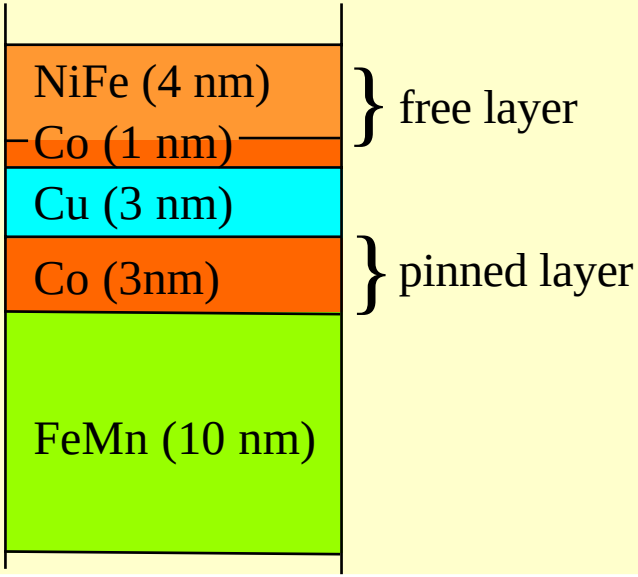
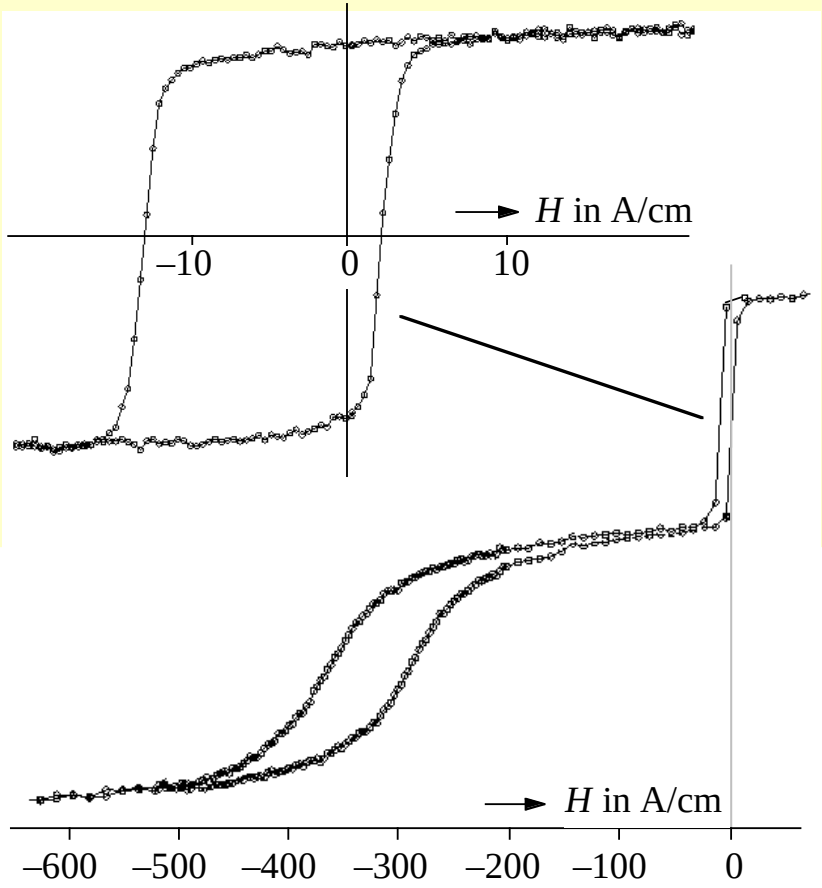
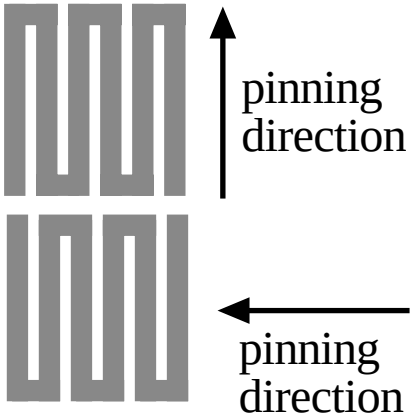
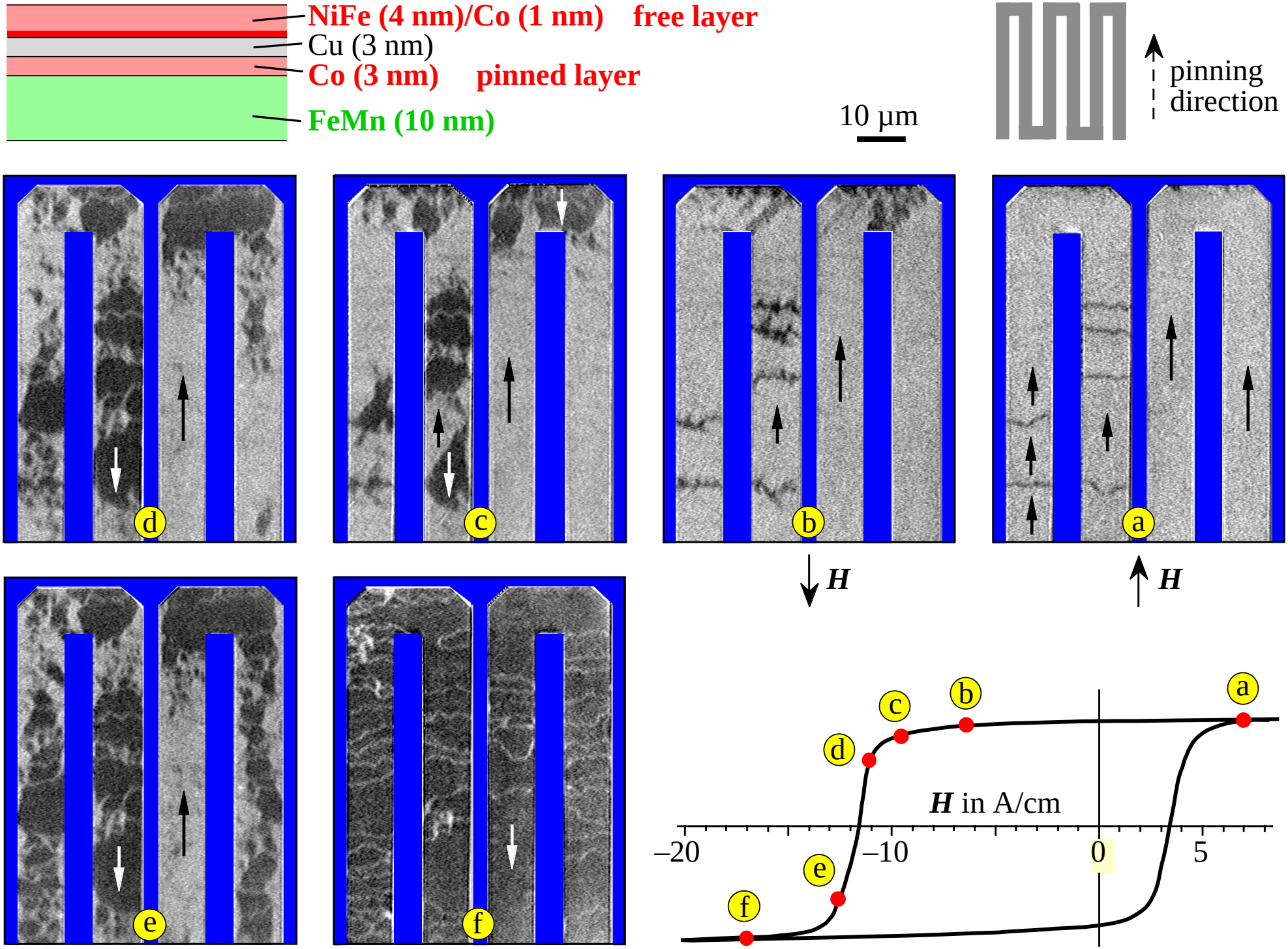
Magnetization processes in spin-valve meanders



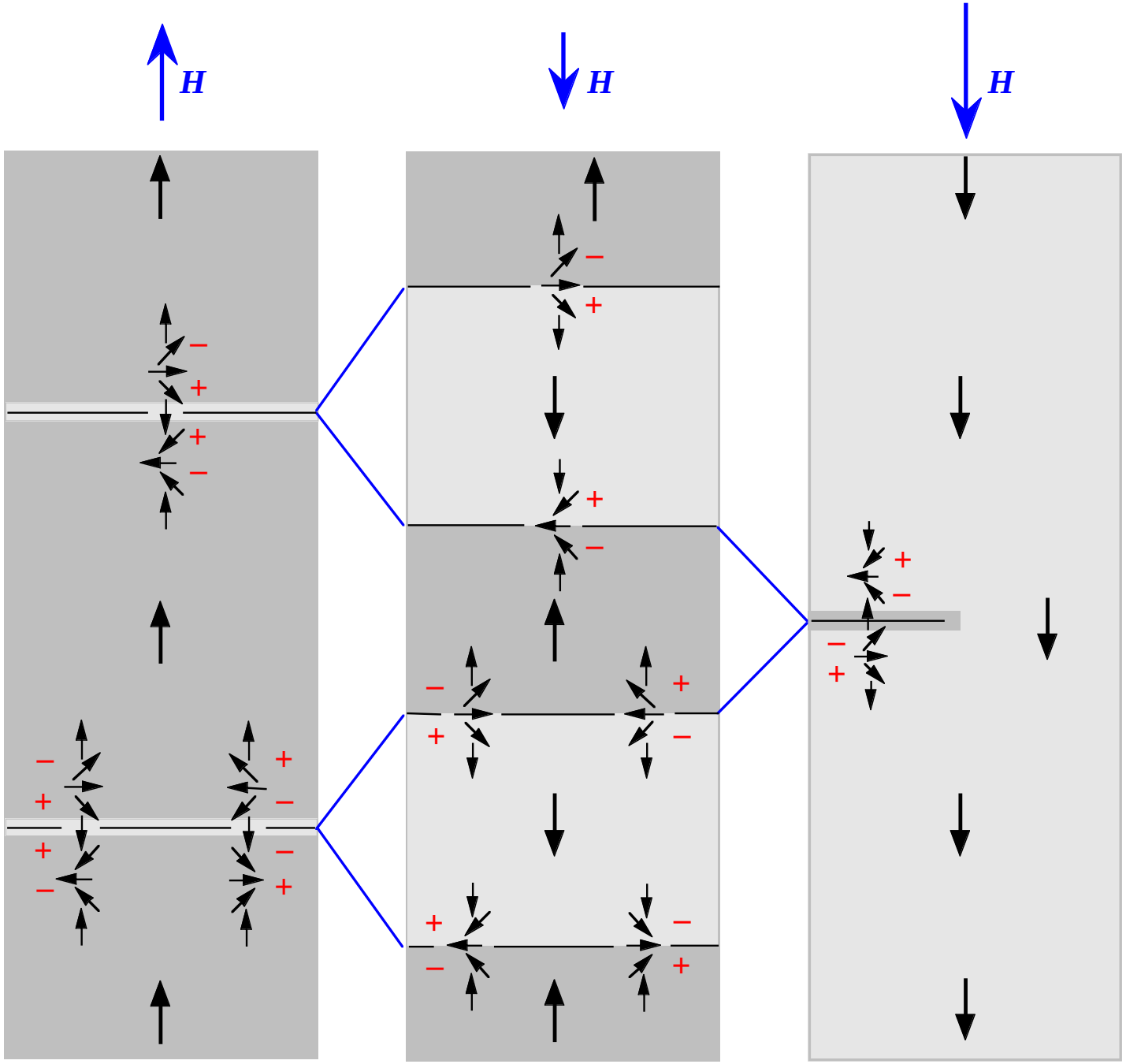


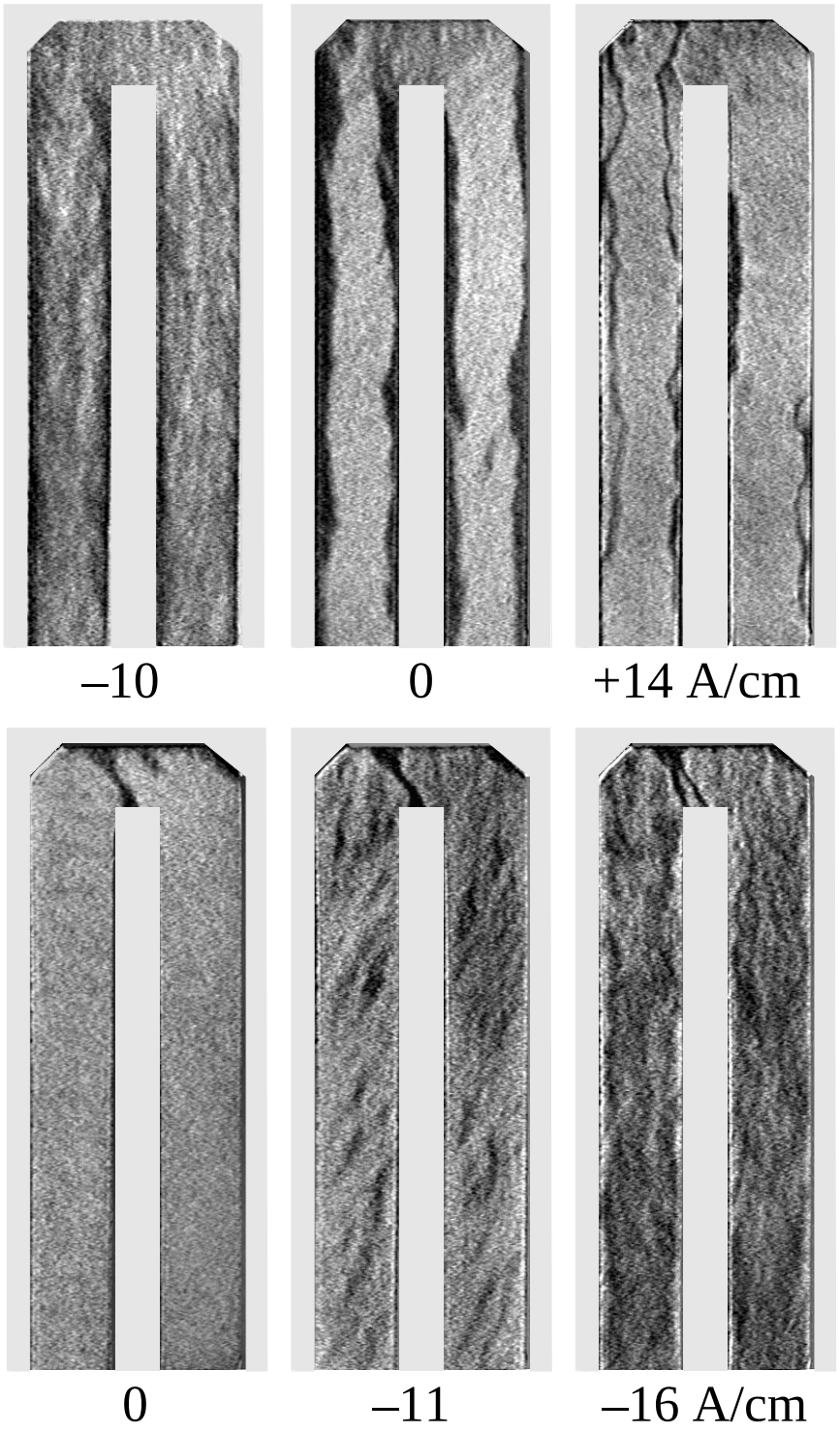


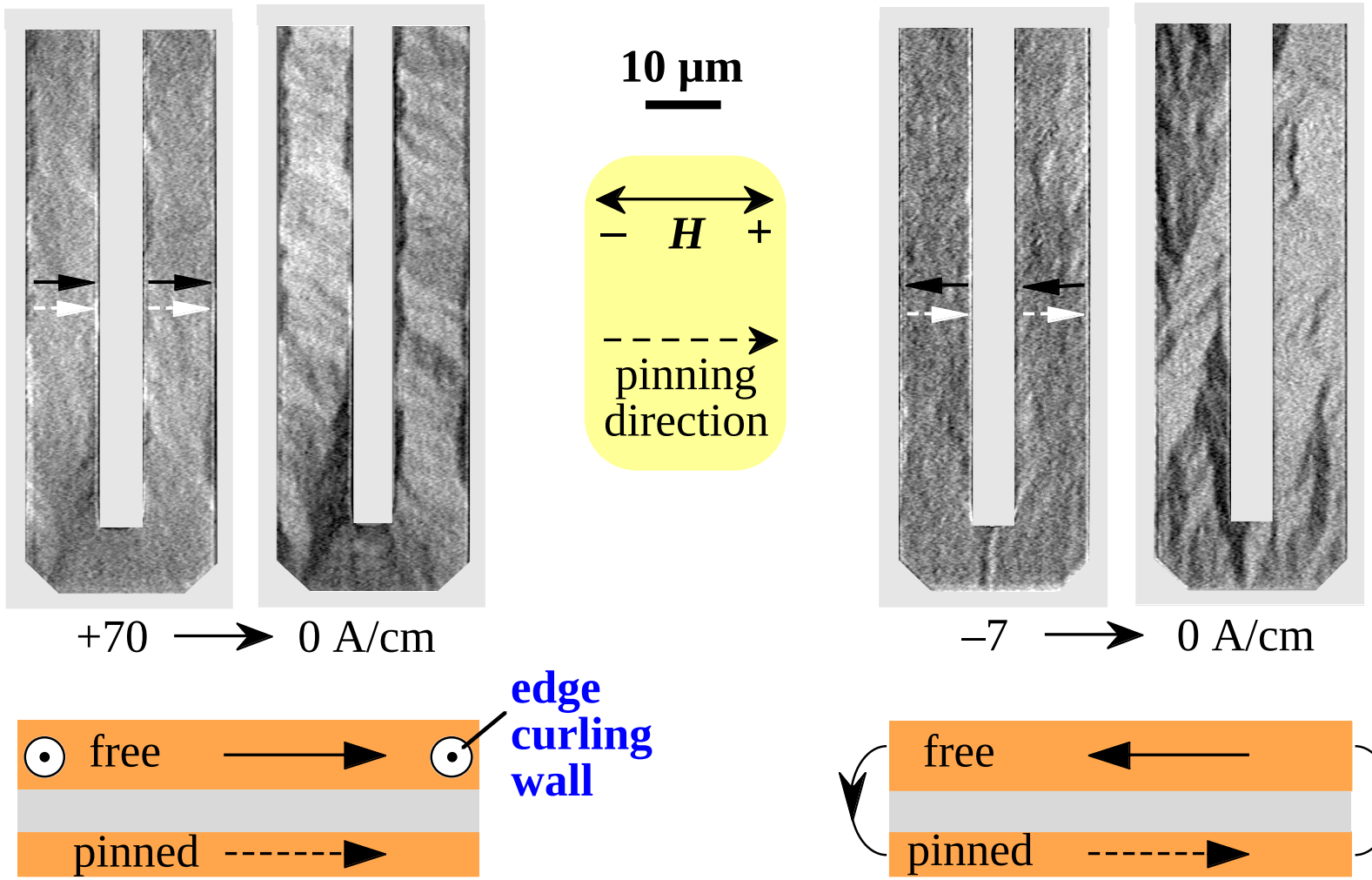
together with D. Chumakov (IFW-Dresden), K. U. Barholz and R. Mattheis (IPHT-Jena)


NiFe (4 nm)/Co (1 nm) free layer
Cu (3 nm)
Co (3 nm) pinned layer
FeMn (10 nm)
10 µm
pinning direction
d
c
b
a
H
H
e
f
H in A/cm
–20
–10
0
5

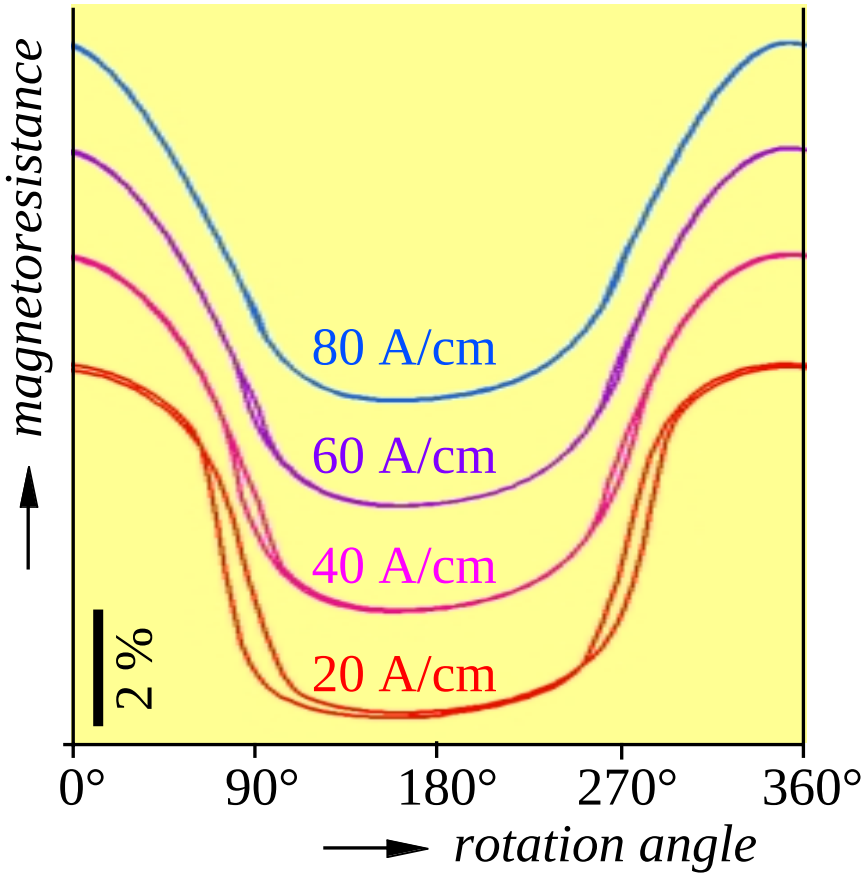
Domain nucleation at 360° walls

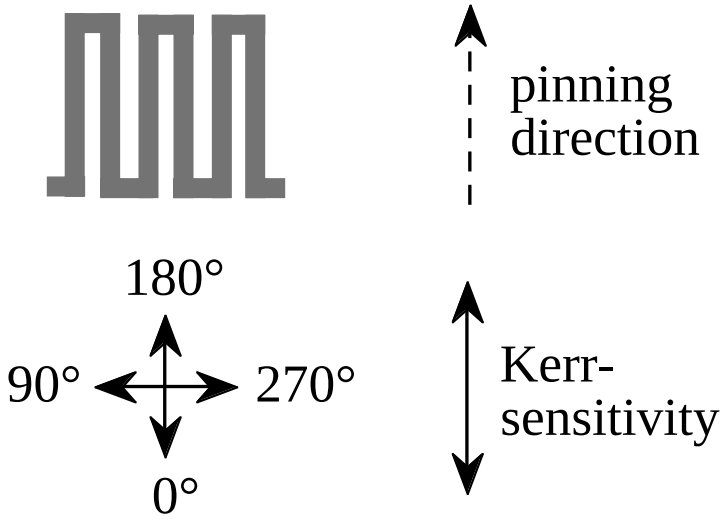


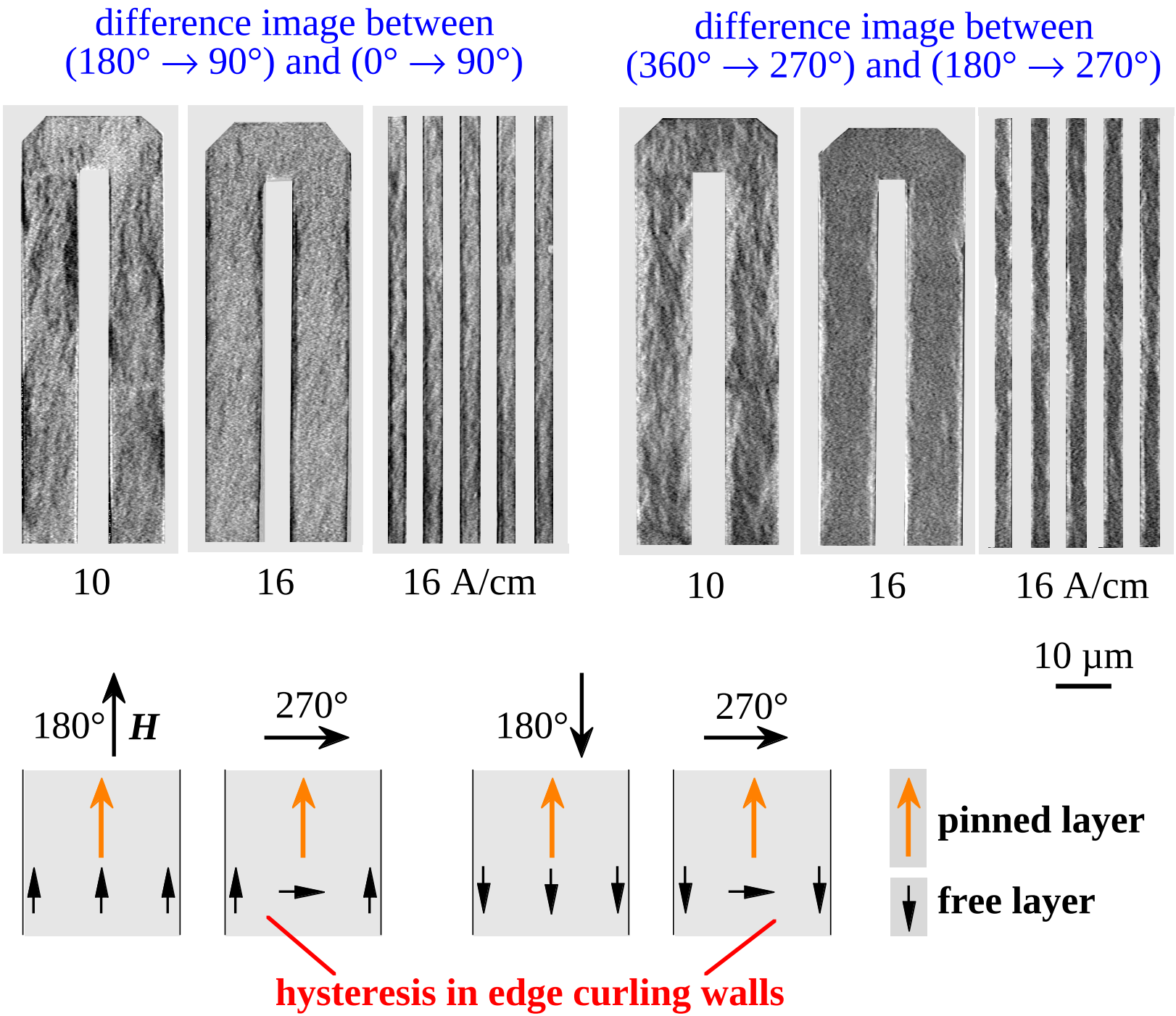

–10
0
+14 A/cm
0
–11
–16 A/cm
edge curling walls
edge domains
360° walls
H
10 µm
pinning direction
H
+
–
edge curling walls
homog. magn.
edge curling walls
H


10 µm
– H +
pinning direction
+70 → 0 A/cm
–7 → 0 A/cm
free
pinned
edge curling wall
free
pinned

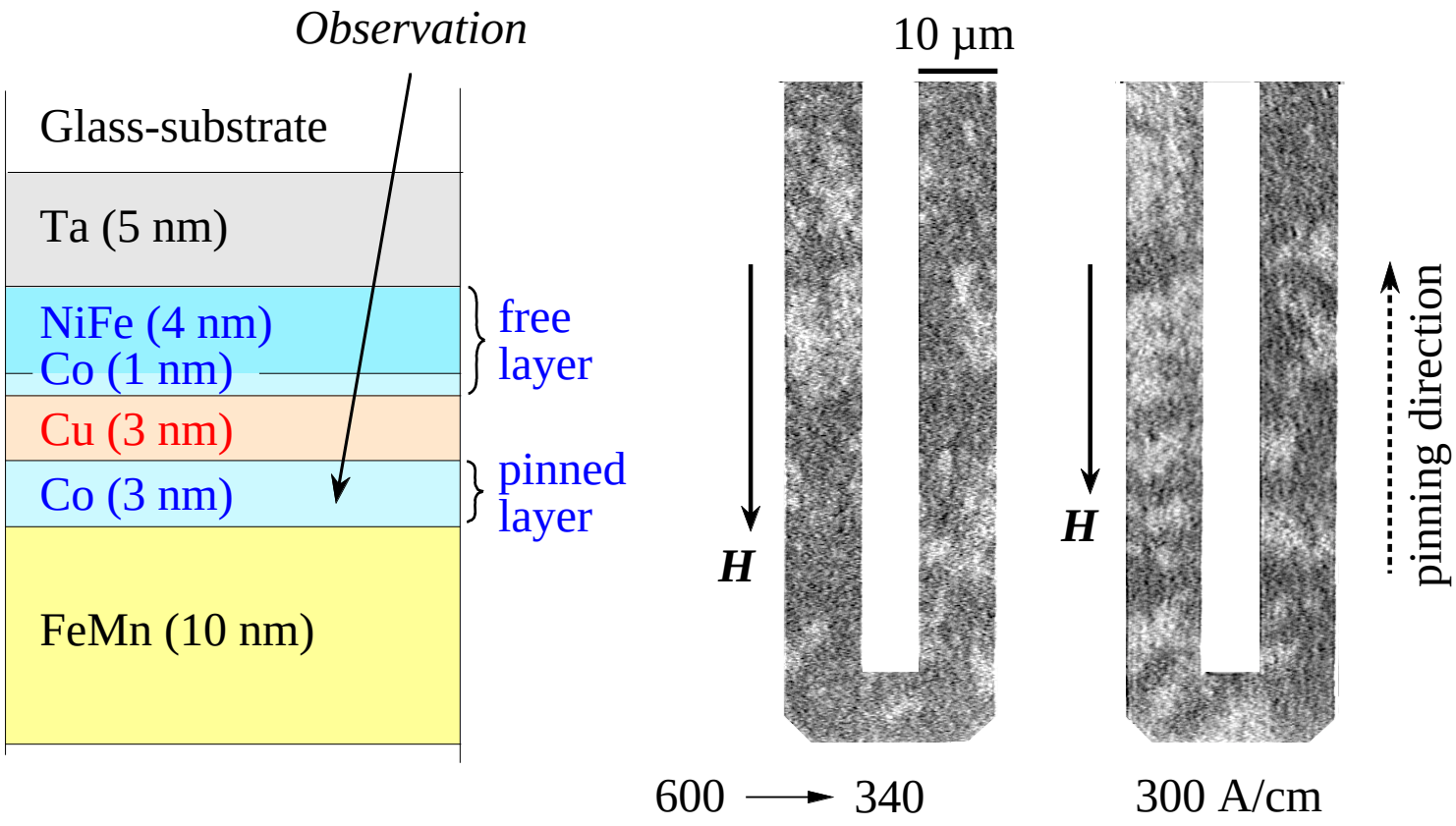
Rotational Hysteresis

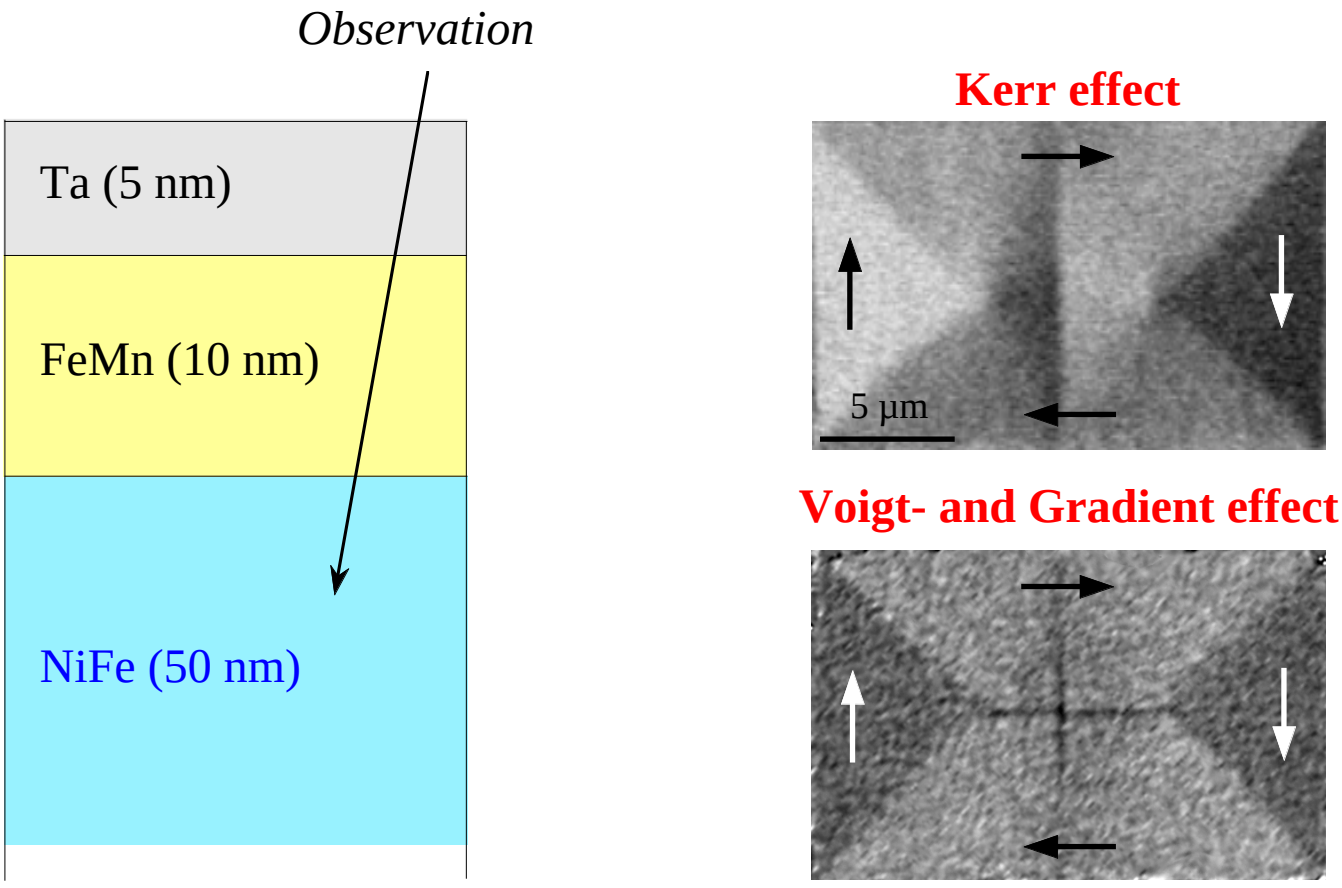




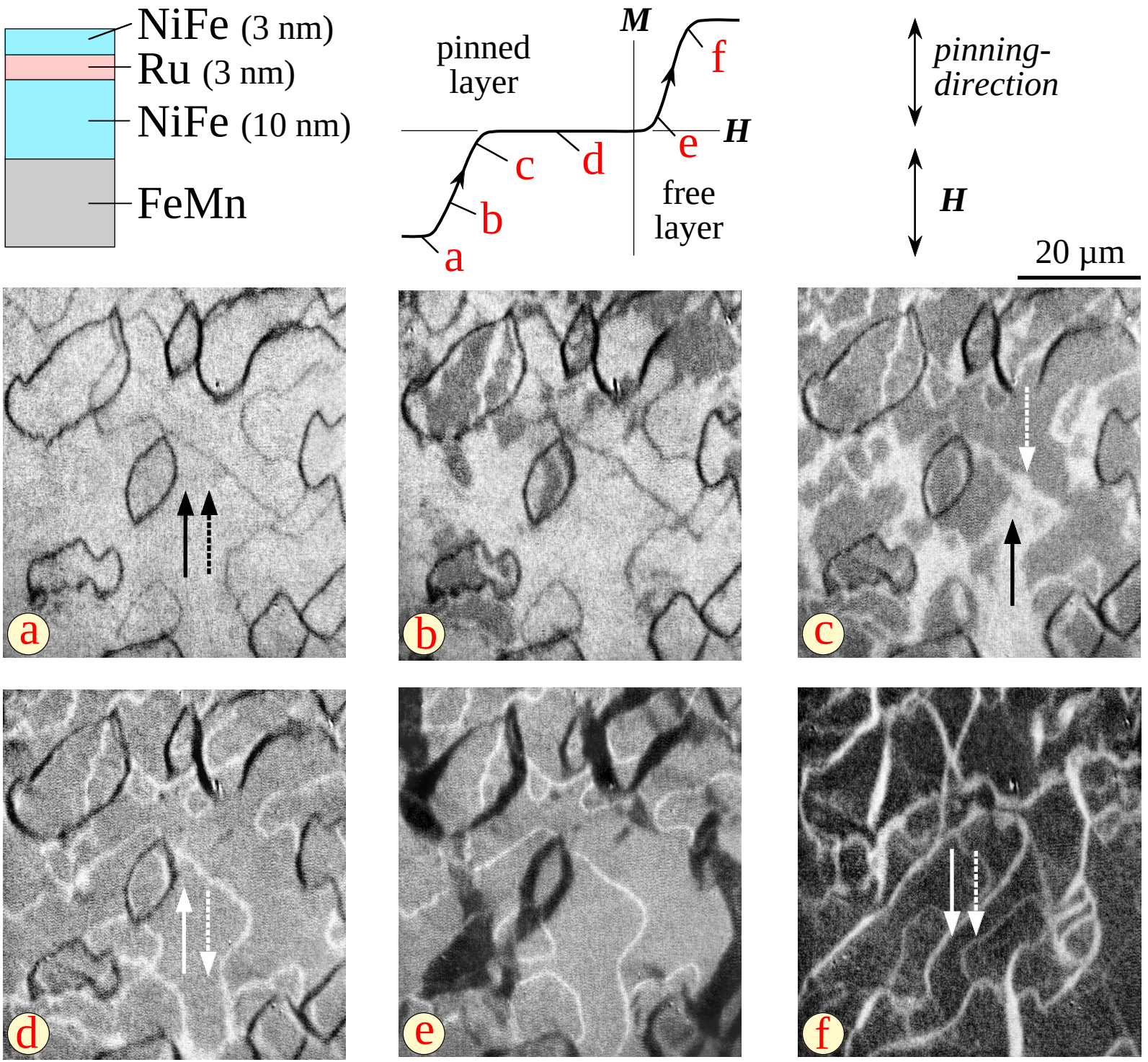

difference image between
(180° → 90°) and (0° → 90°)
difference image between
(360° → 270°) and (180° → 270°)
10
16
16 A/cm
10
16
16 A/cm
10 µm
180°
H
270°
180°
270°
pinned layer
free layer
hysteresis in edge curling walls

On depth-sensitivity of m.o. microscopy



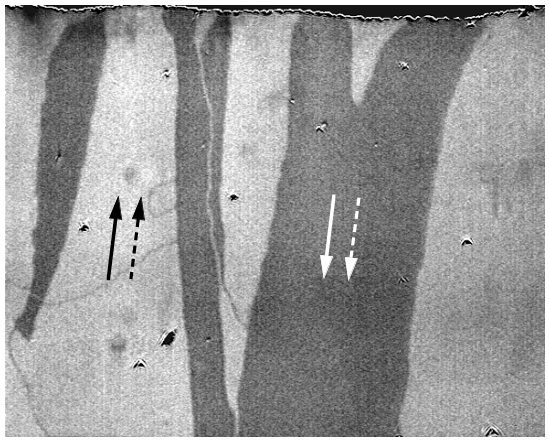


Samples: R. Mattheis, IPHT-Jena

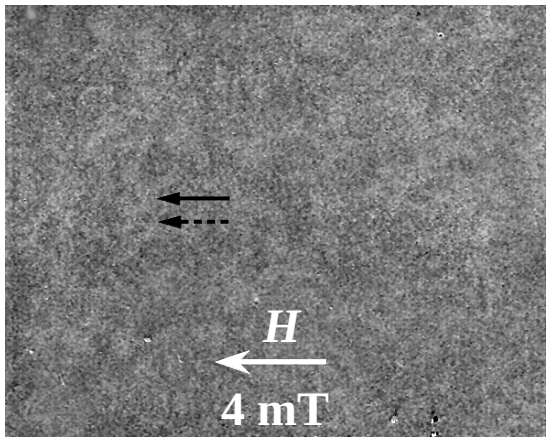


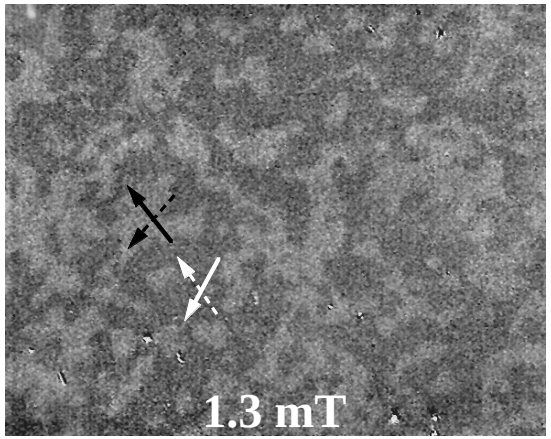
Sample:
S. Parkin,
IBM

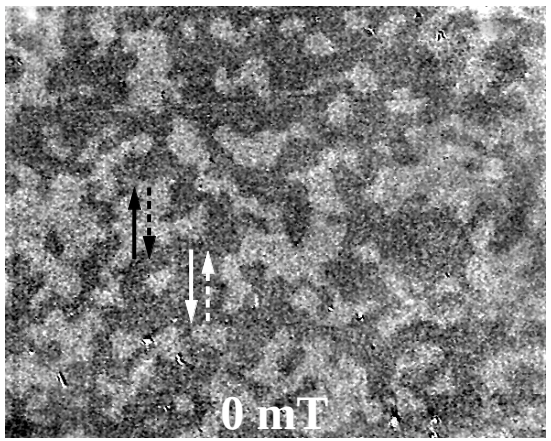
Ferromagnetic coupling



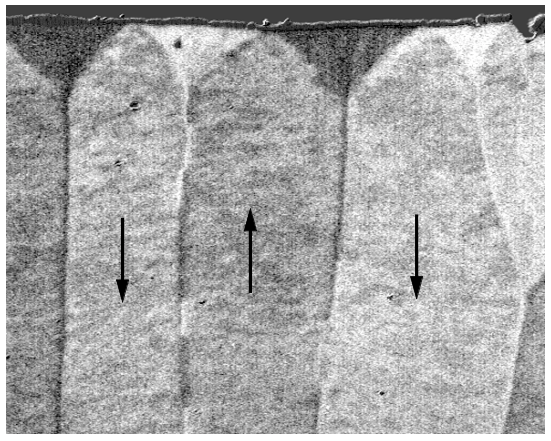
Antiferromagnetic coupling

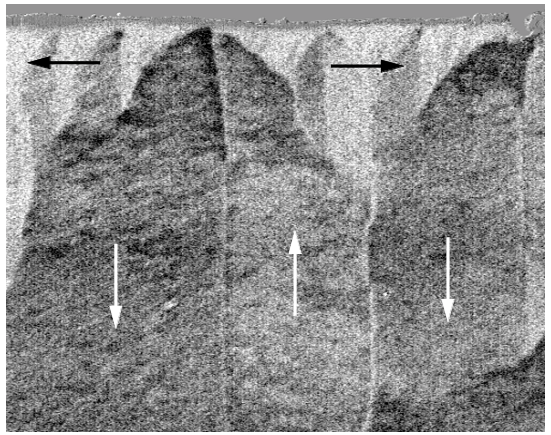






Destroyed antiferromagn. coupling (after annealing)

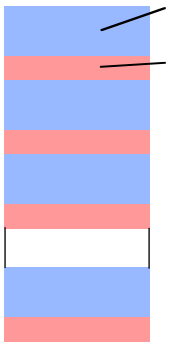




20 µm

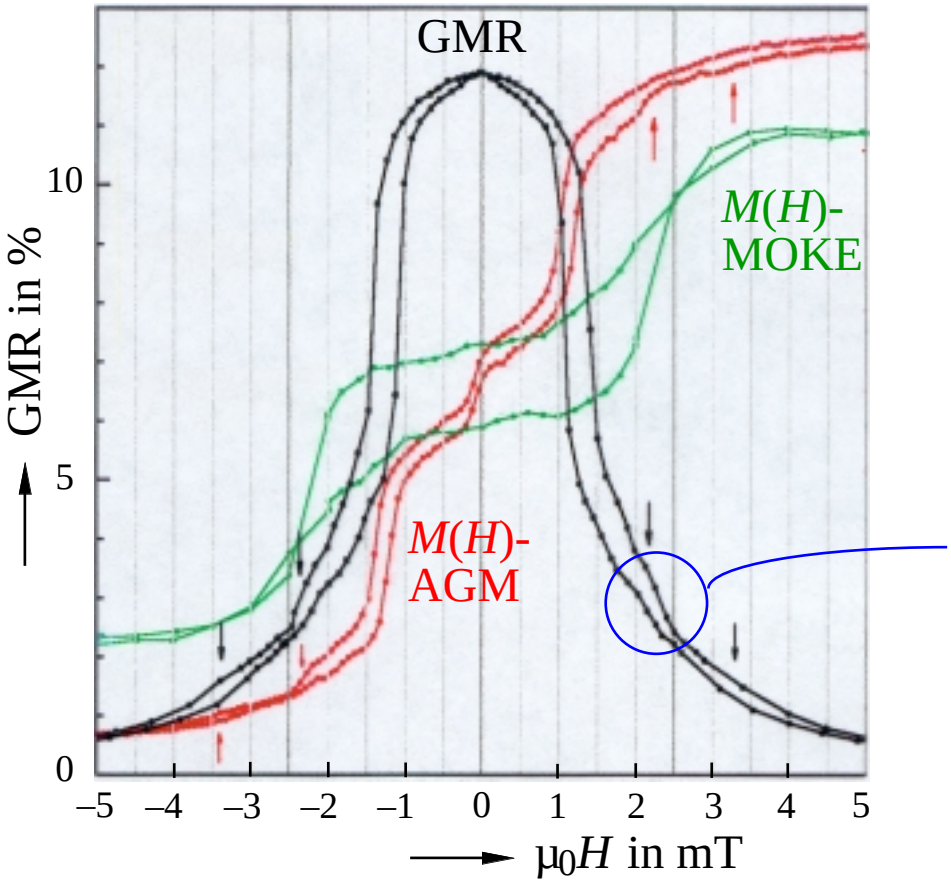
easy axis

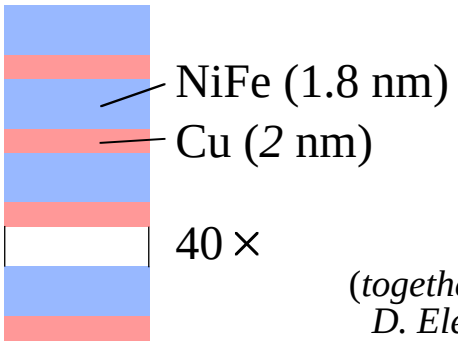
Sputtered multilayers



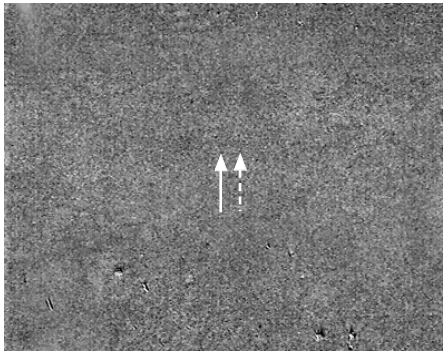
samples:
D. Elefant, IFW-Dresden

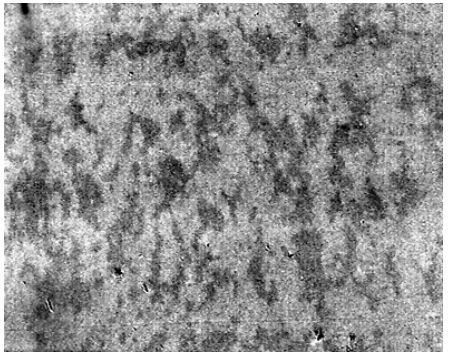
Magnetization processes in AF-coupled multilayers

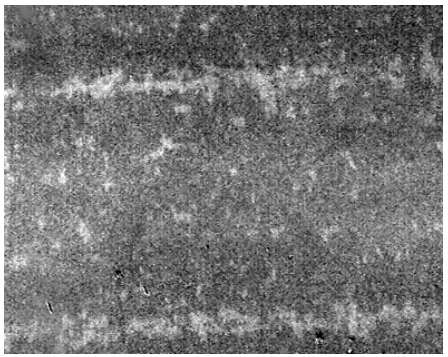


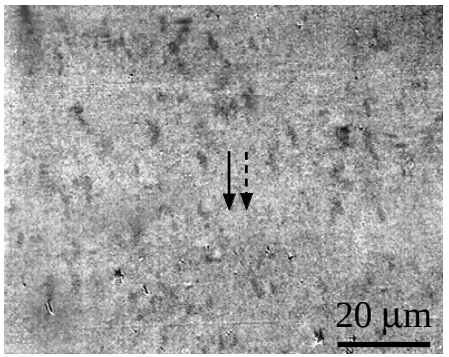


(*together with D. Tietjen and D. Elefant, IFW-Dresden*)

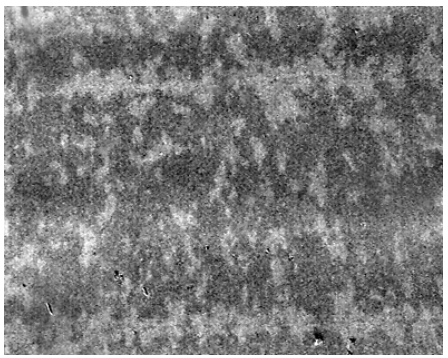

0 mT

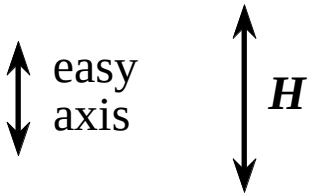

2.29 mT


2.2 mT

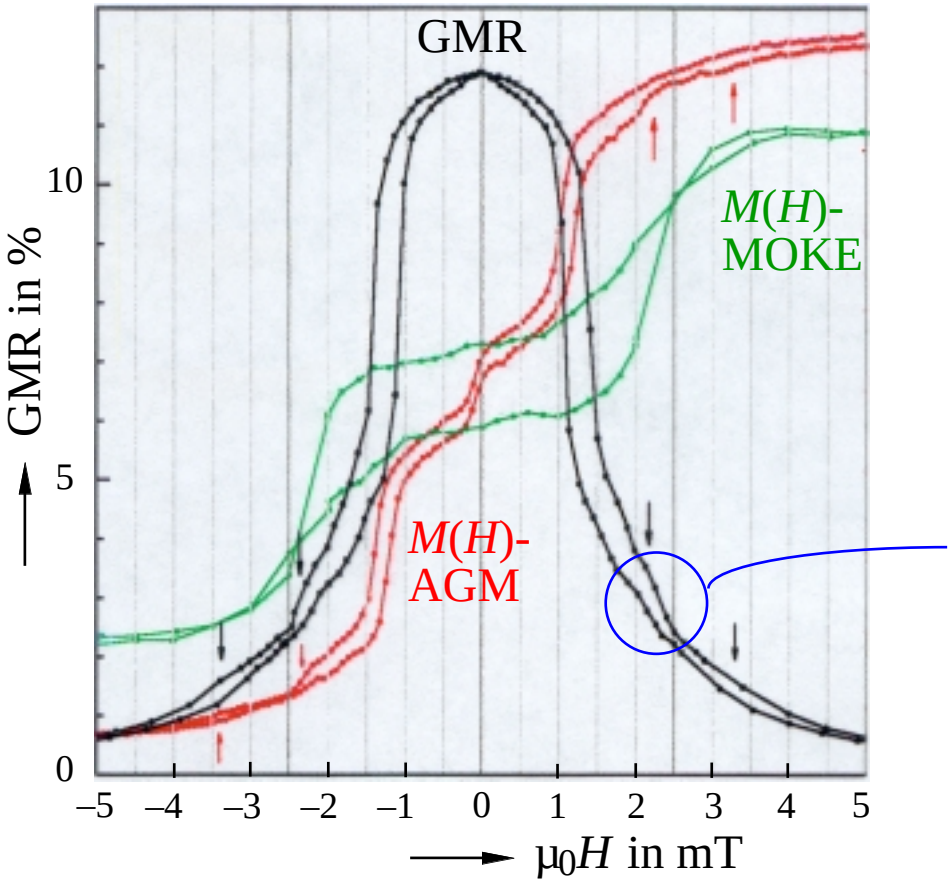


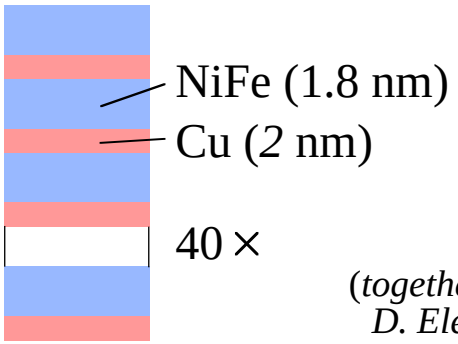
2.38 mT


2.26 mT

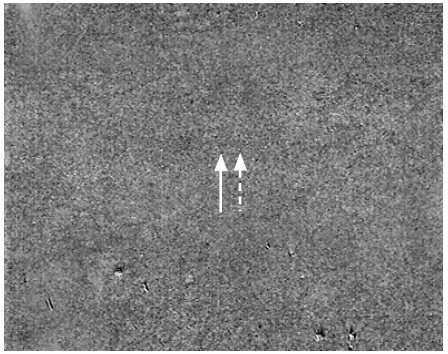


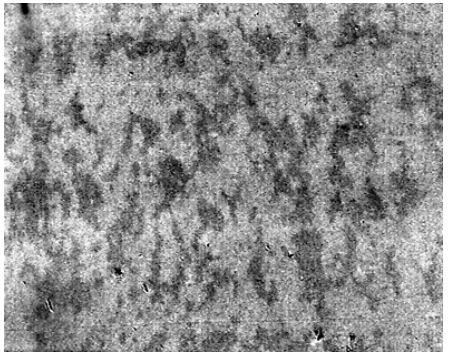
Magnetization processes in AF-coupled multilayers

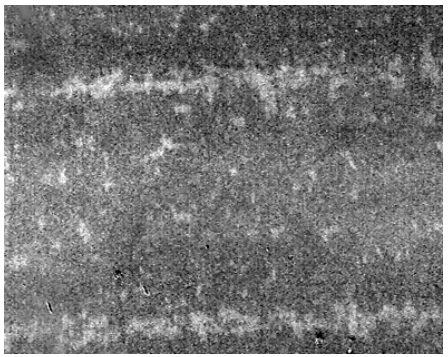


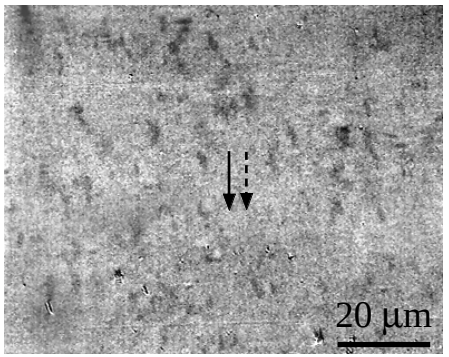


(*together with D. Tietjen and D. Elefant, IFW-Dresden*)

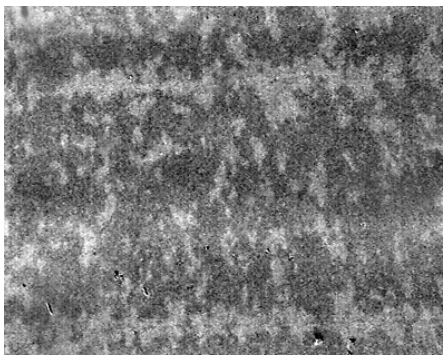

0 mT

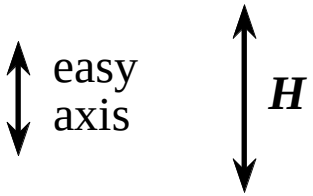

2.29 mT


2.2 mT

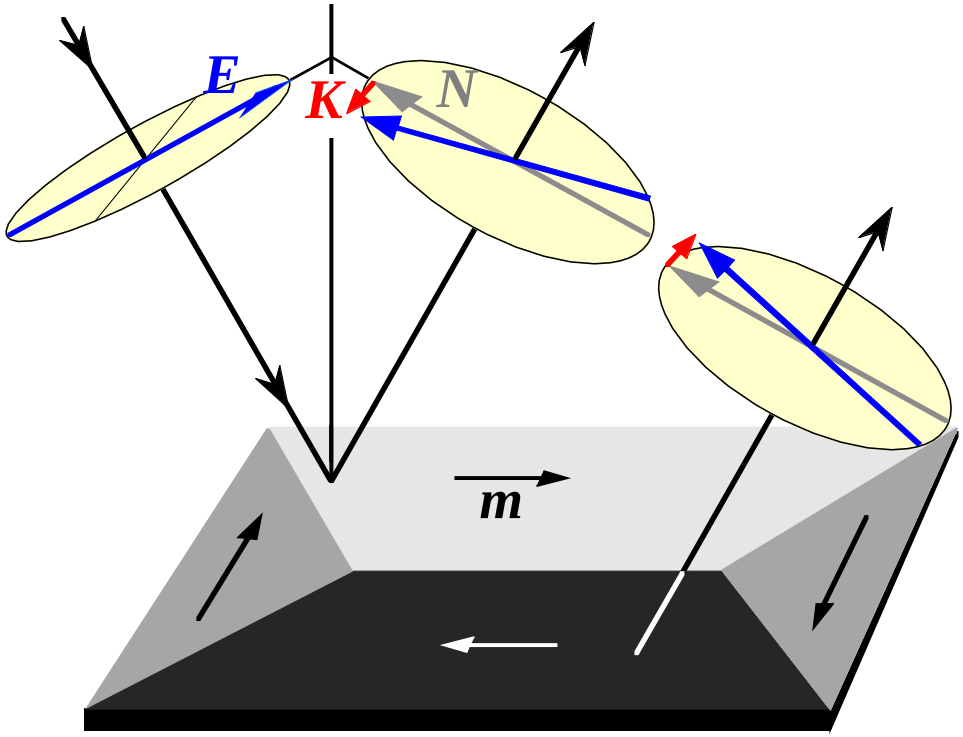


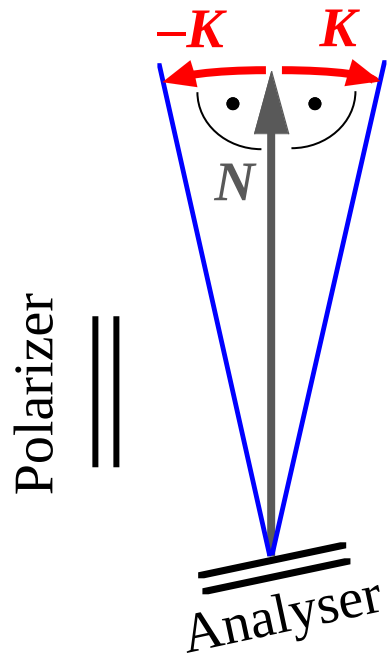
2.38 mT


2.26 mT

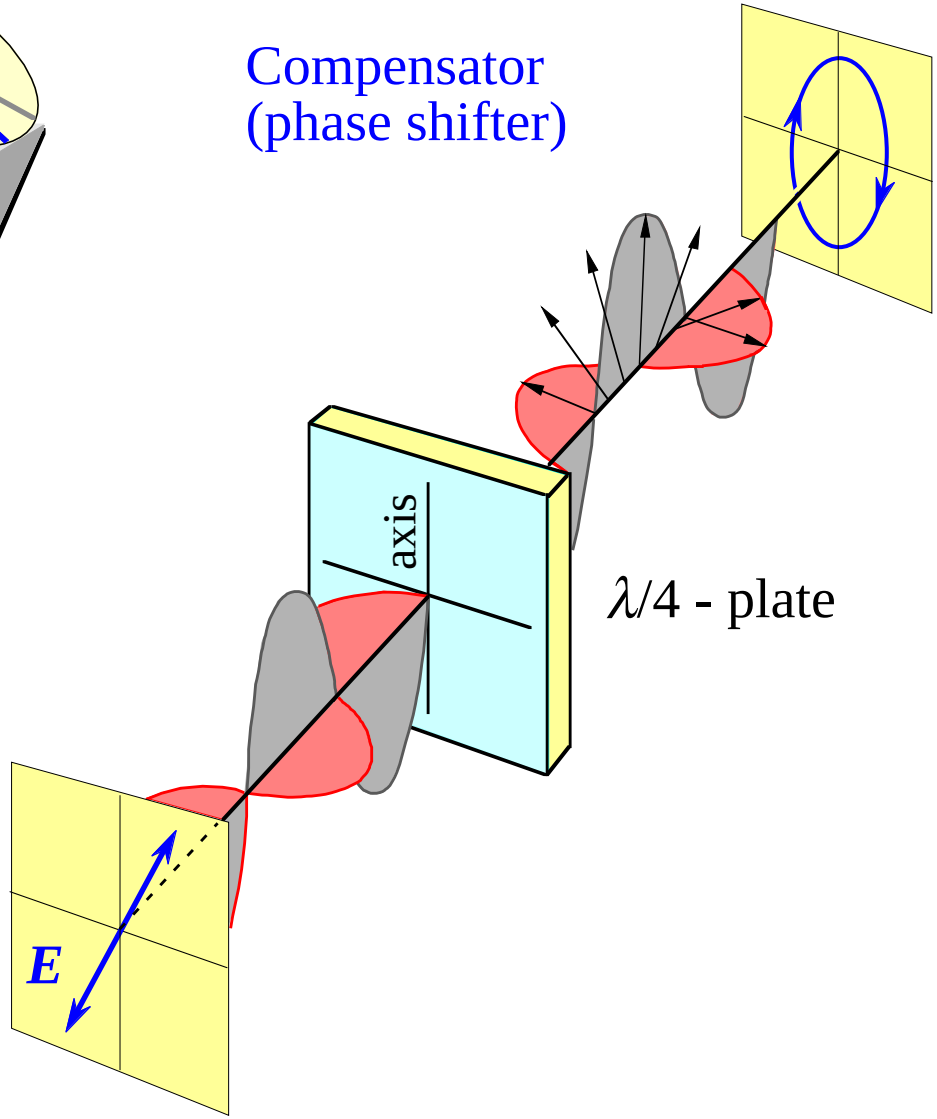


Kerr Effect





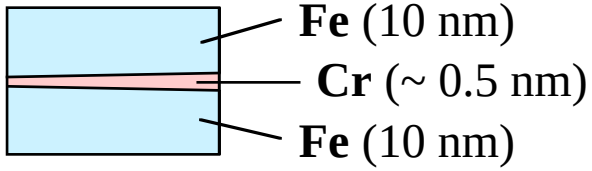
Compensator
(phase shifter)

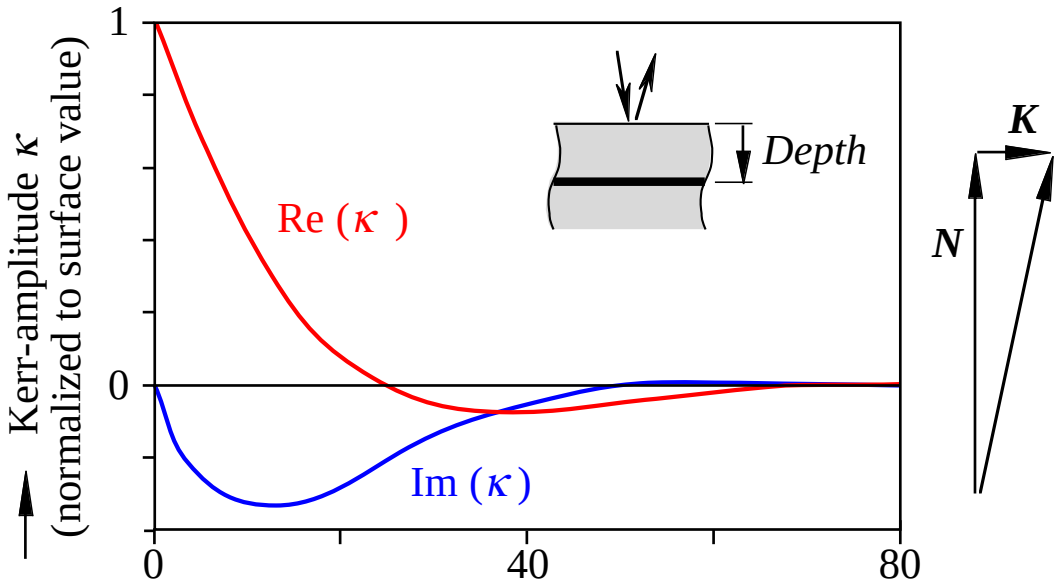


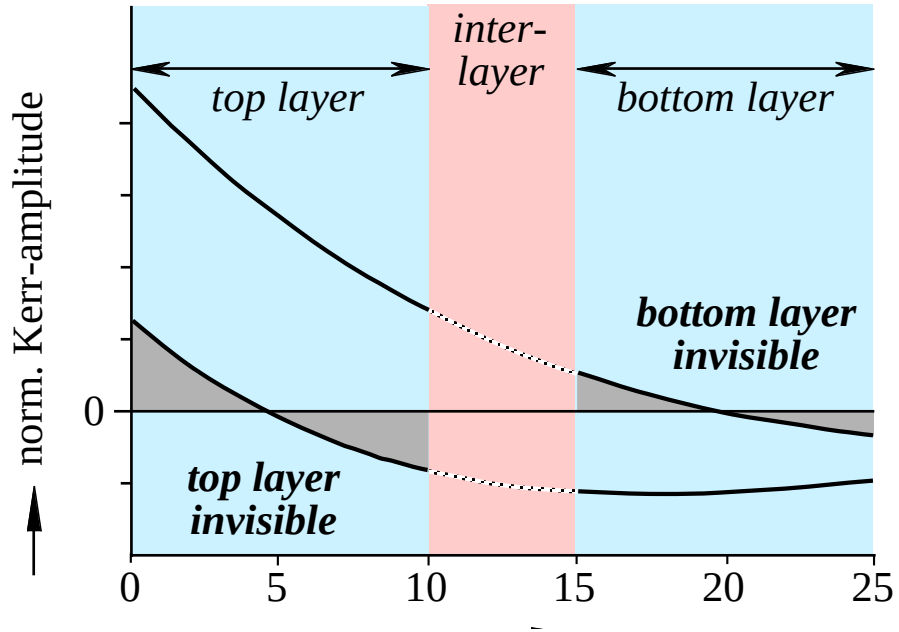
λ/4 - plate

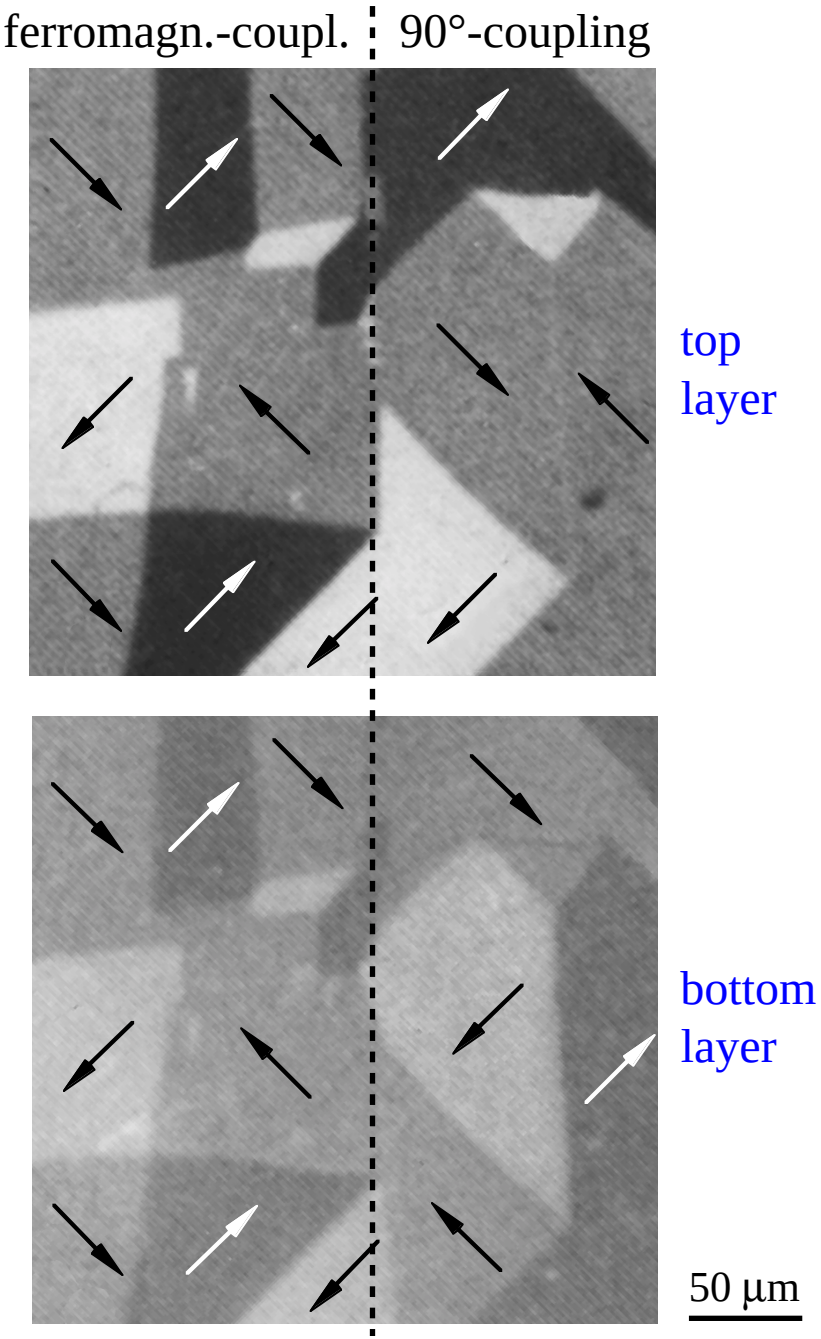
Depth-selective Kerr microscopy in epitaxial Fe/Cr/Fe-layers

(Sample: P. Grünberg, Jülich)

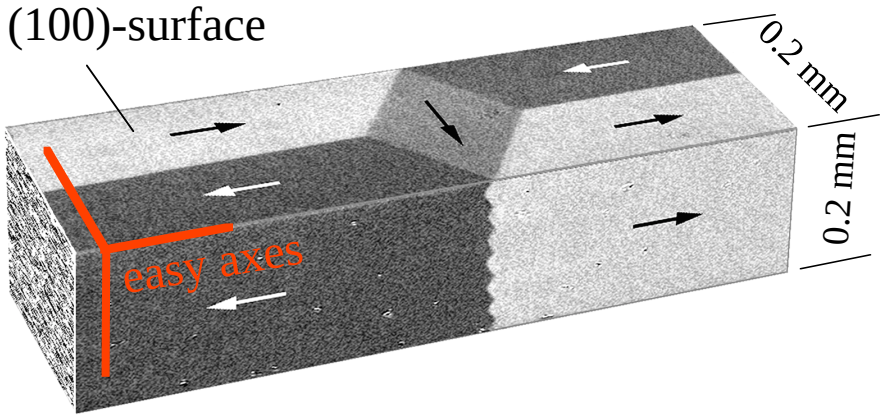


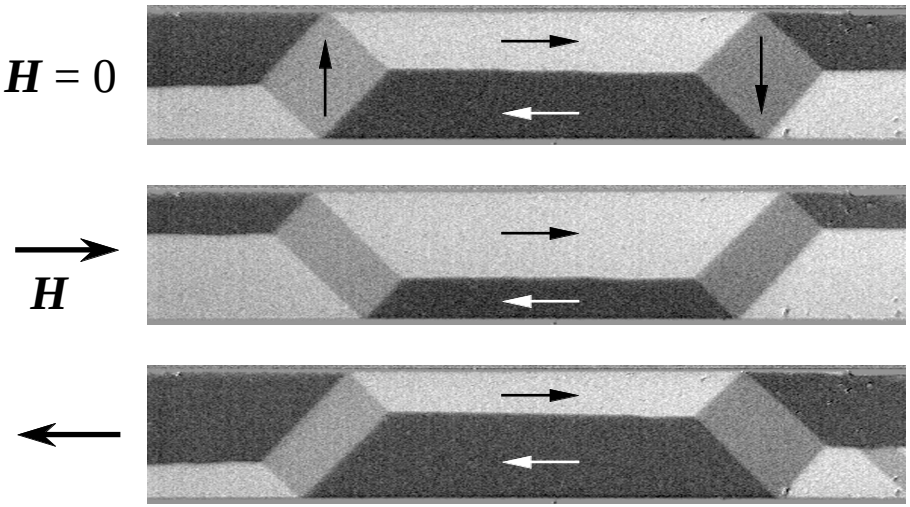




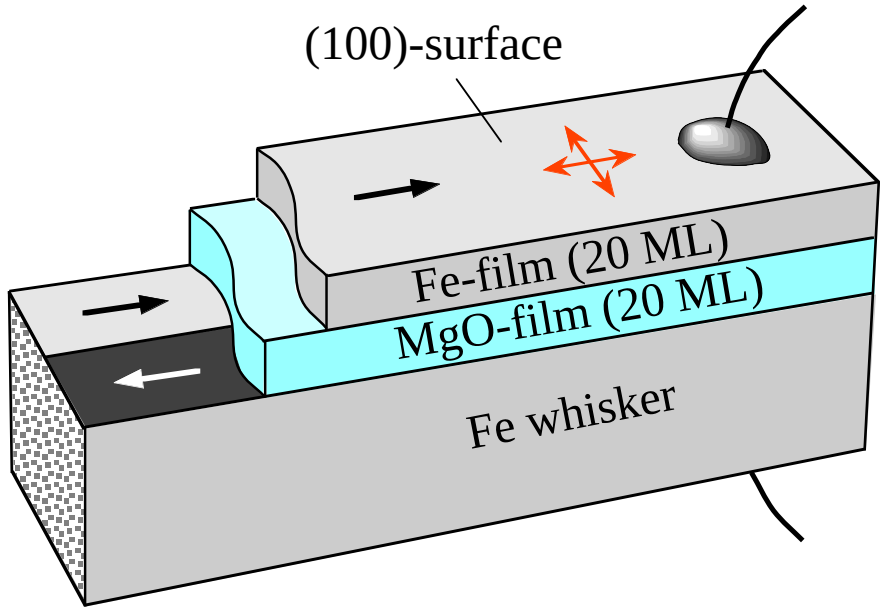


Iron whisker





Iron whisker with tunneling films



Epitaxial growth of films on whisker

together with:

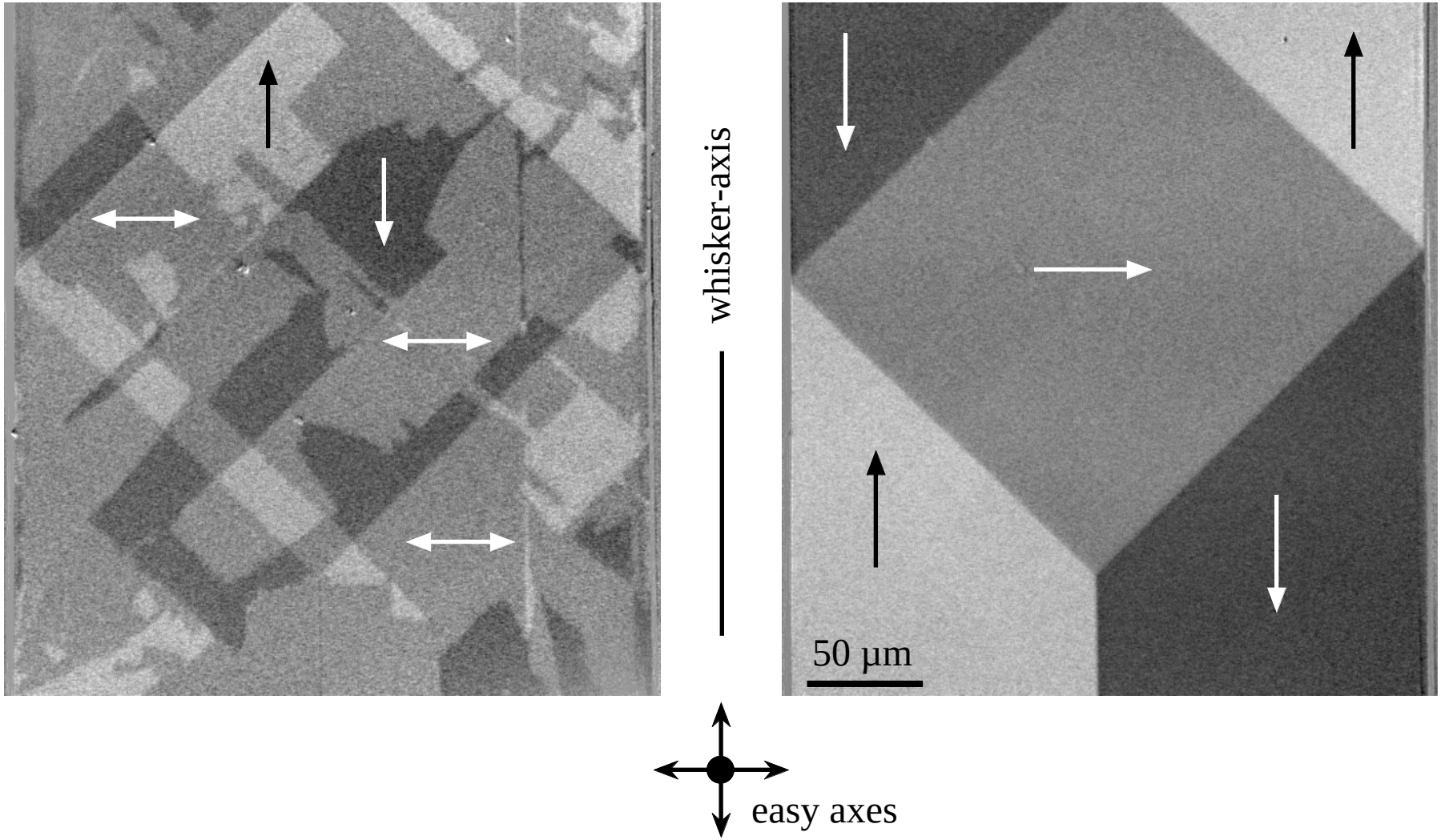
R. Urban, B. Heinrich Simon Fraser University, Burnaby, Canada
D. Ullmann, H. Meyerheim, J. Kirschner MPI für Mikrostrukturphysik, Halle, Germany

Selective imaging of whisker- and film domains

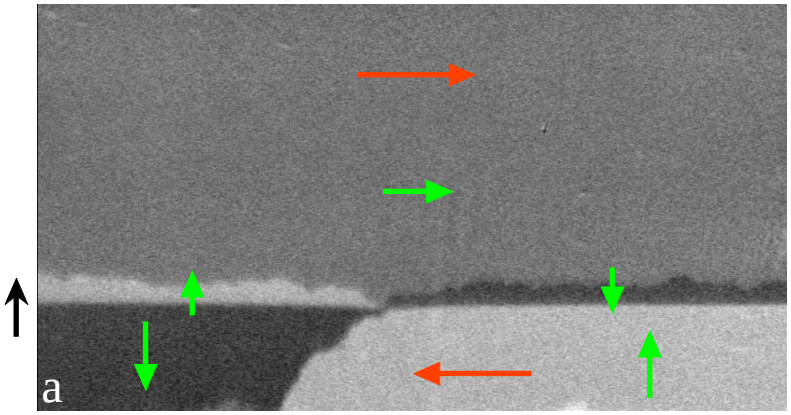
[by proper phase selection in the Kerr microscope, using a phase-shifter (compensator) between polarizer and analyzer]

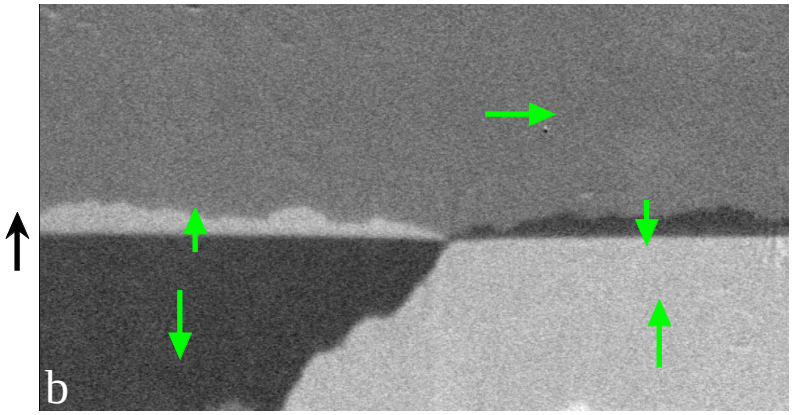
Domains in Fe-film

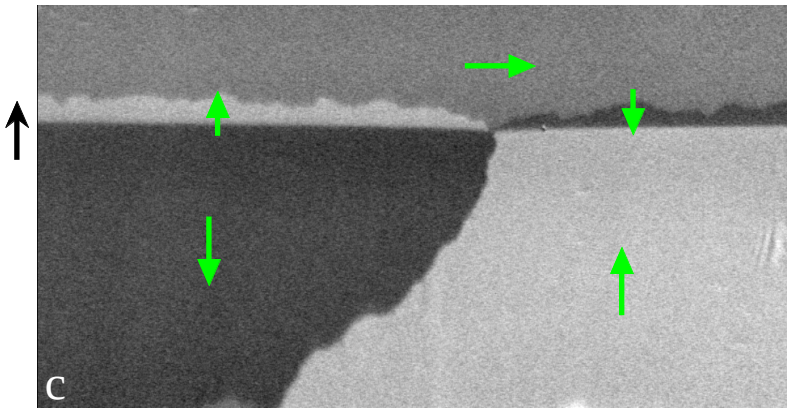
Whisker domains

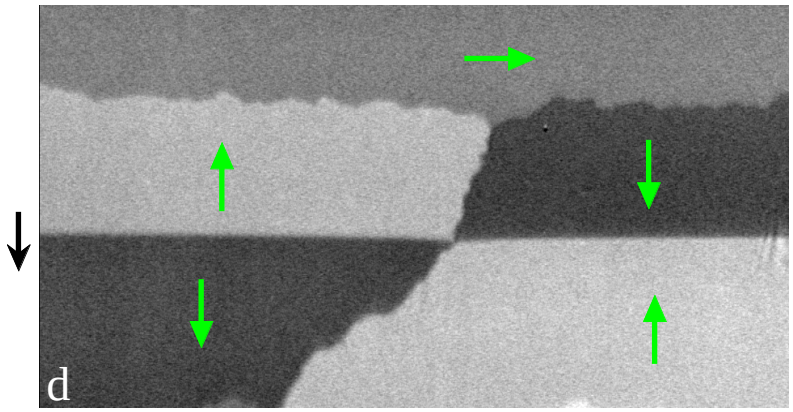


Remagnetization of Fe-film by 180°-wall in whisker





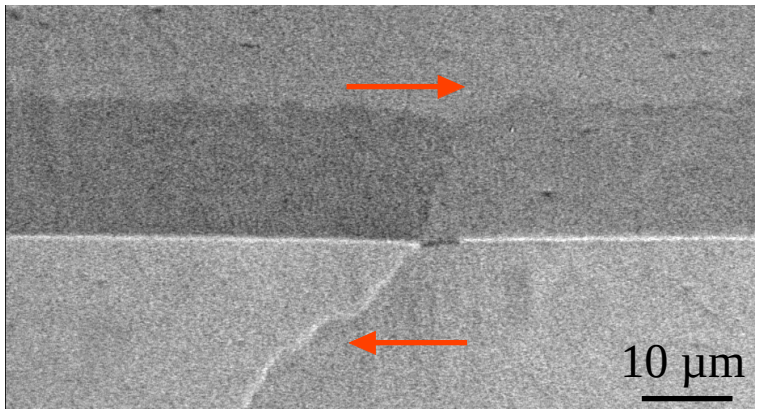




domains in Fe-film

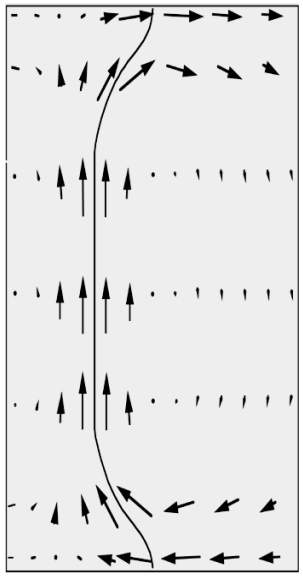
whisker axis

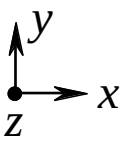
easy axes



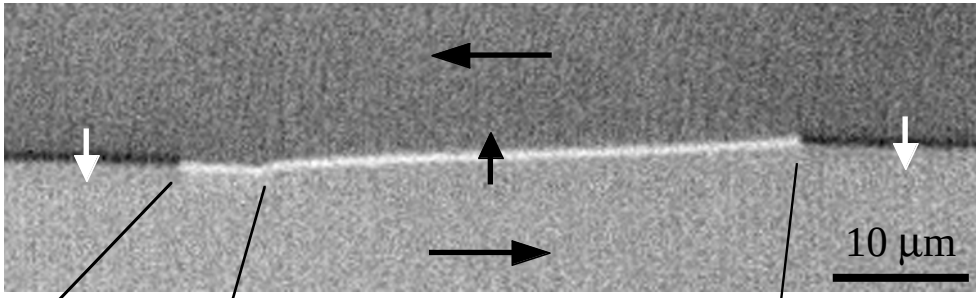
domains in whisker

Structure of 180-vortex wall





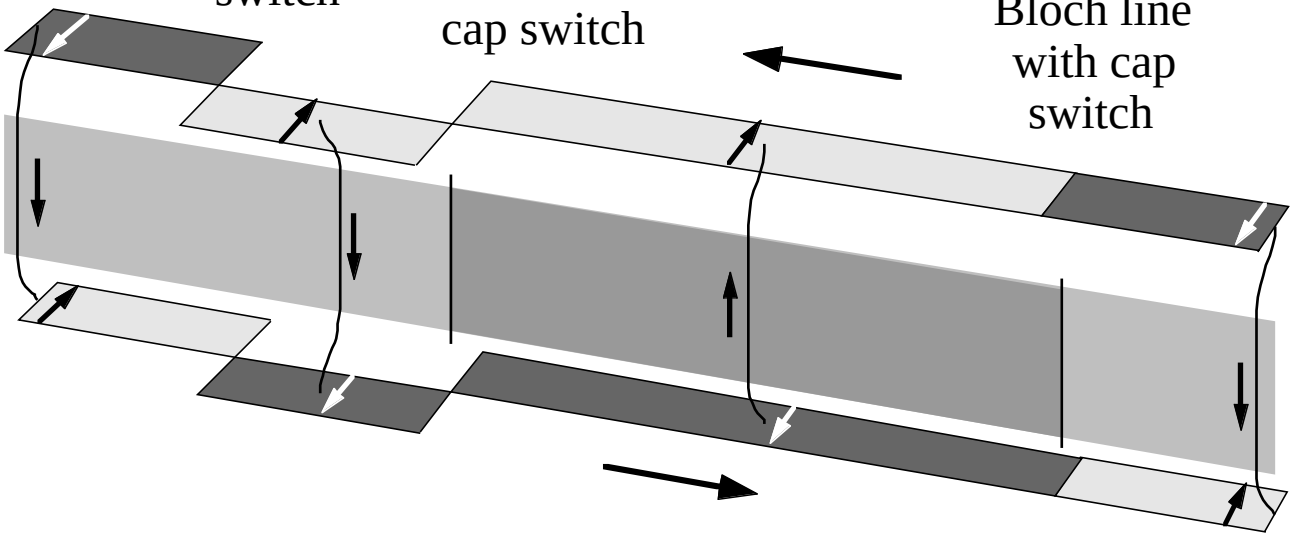
Kerr observation on Fe whisker



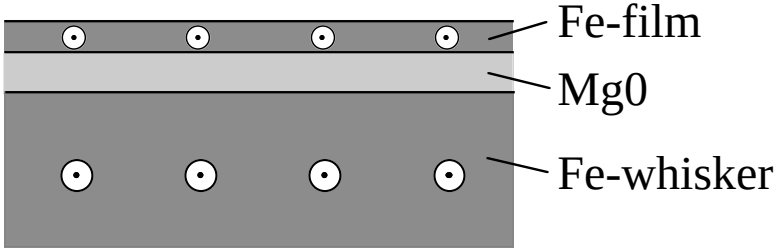
cap switch

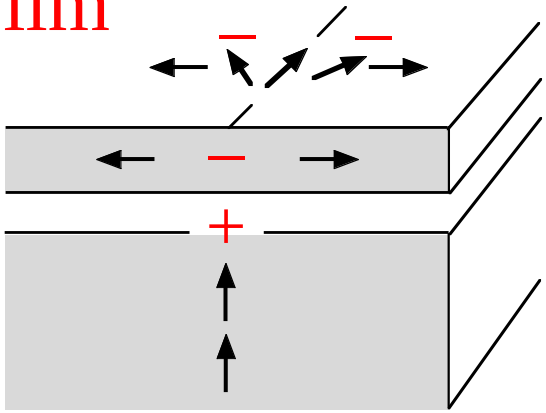
Bloch line without cap switch

Bloch line with cap switch



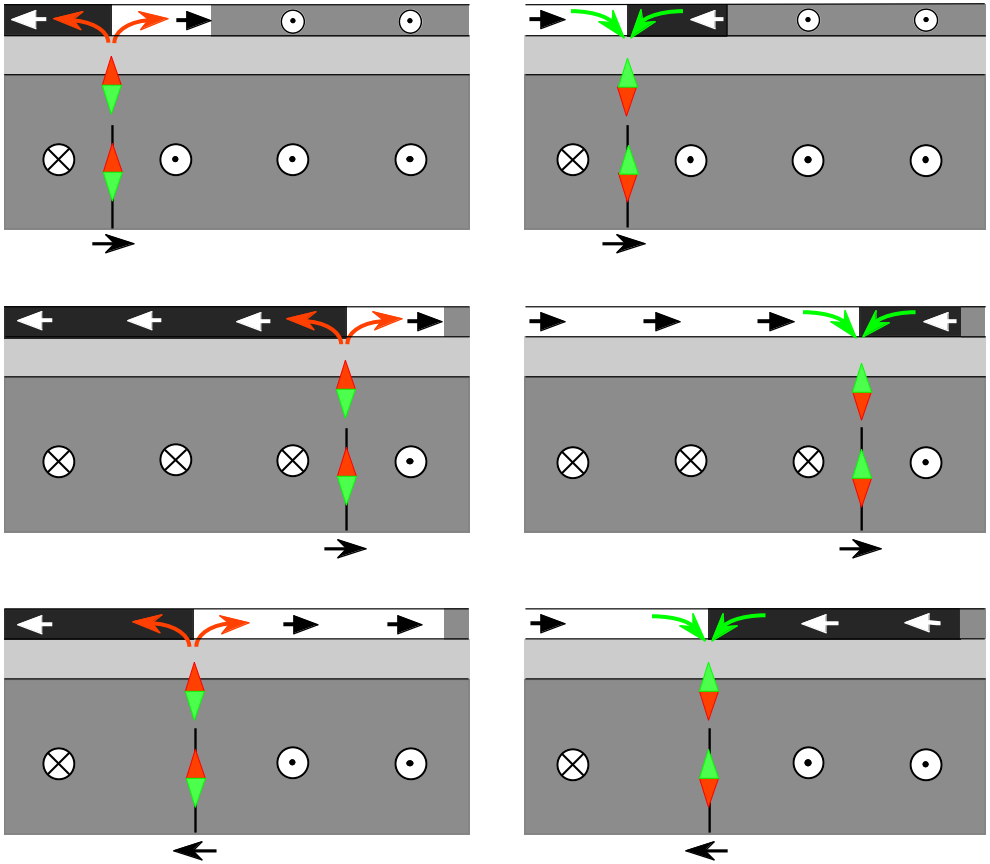
Mechanism of whisker wall writing in Fe-film



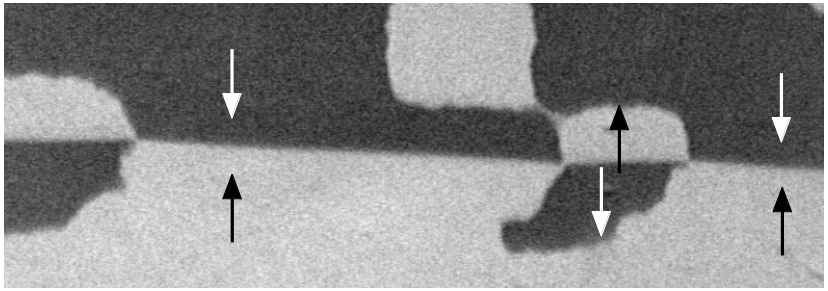


Bloch component upwards

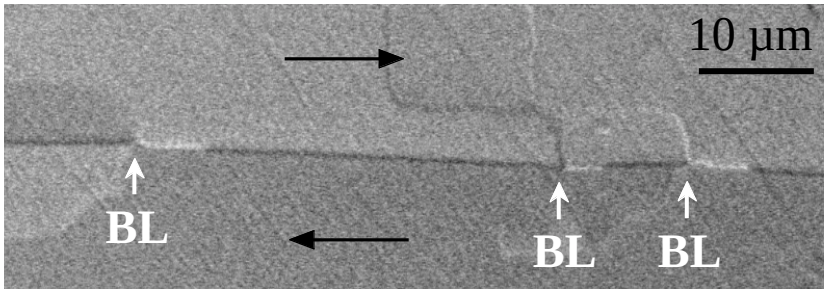
Bloch component downwards

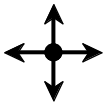


Domains in iron film



Whisker wall

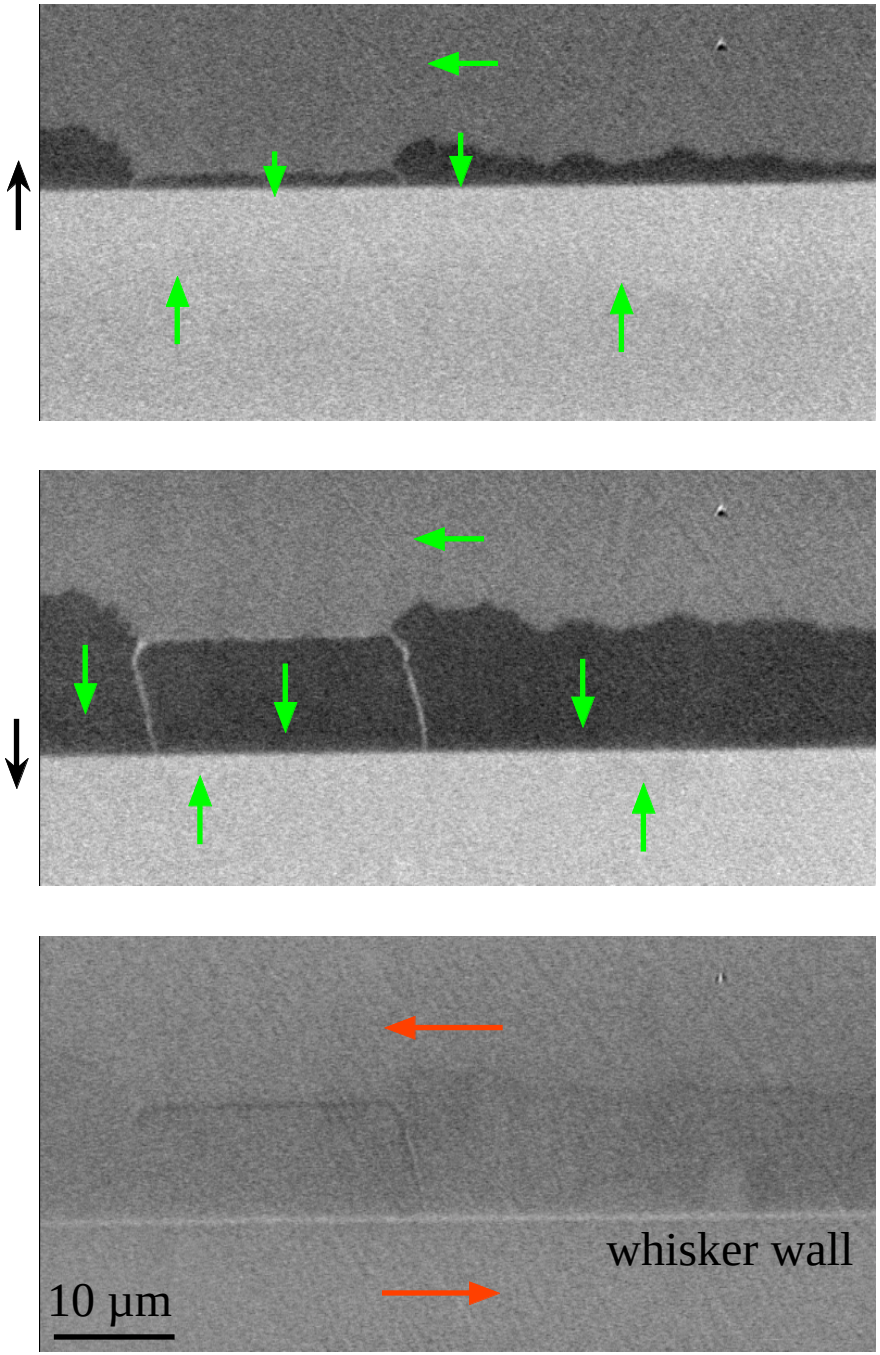




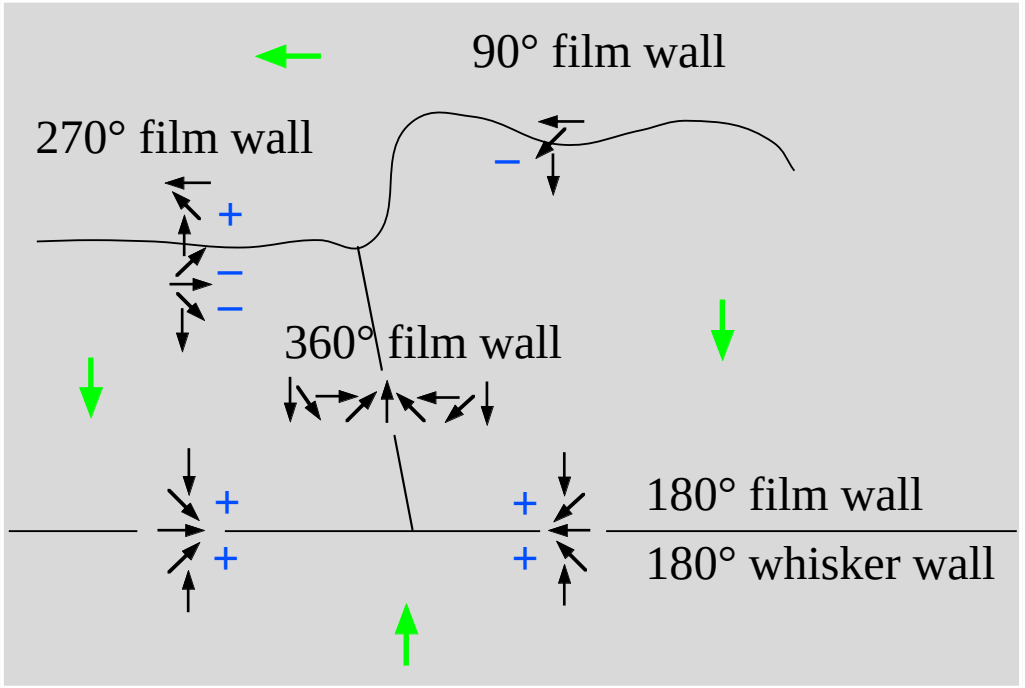
easy axes

whisker-axis

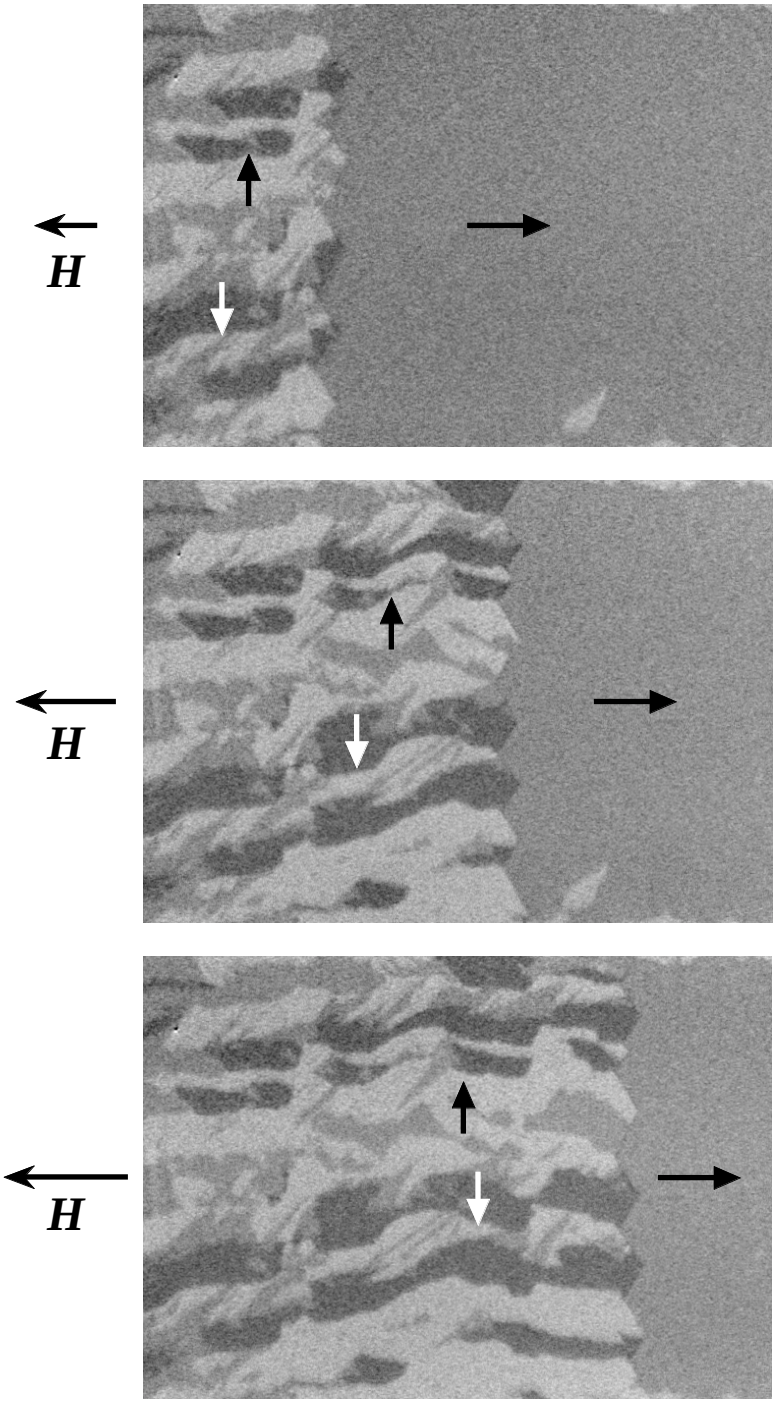
Topological formation of 360°-walls in Fe-film



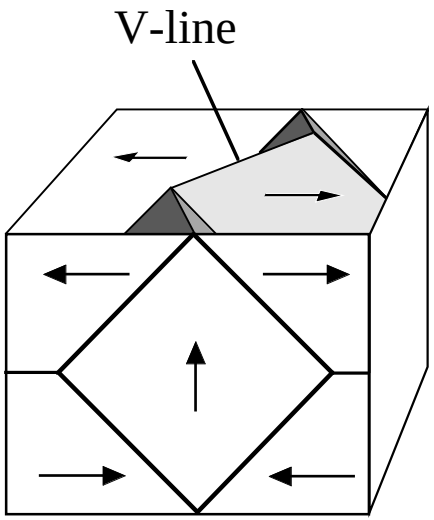
Magnetization of Fe-film



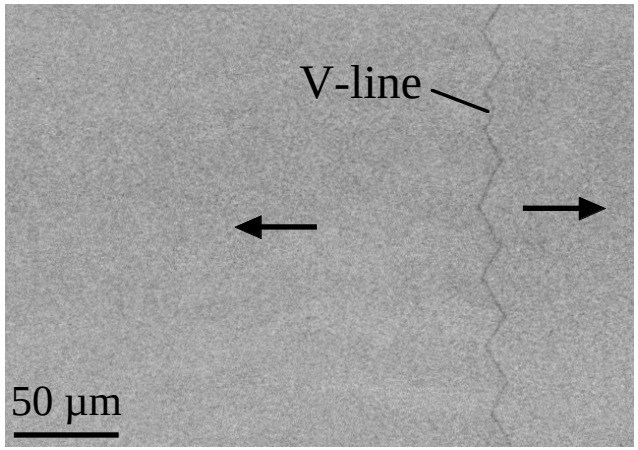
Domains in Fe-film



Remagnetization of Fe-film by V-line in whisker



Whisker domains

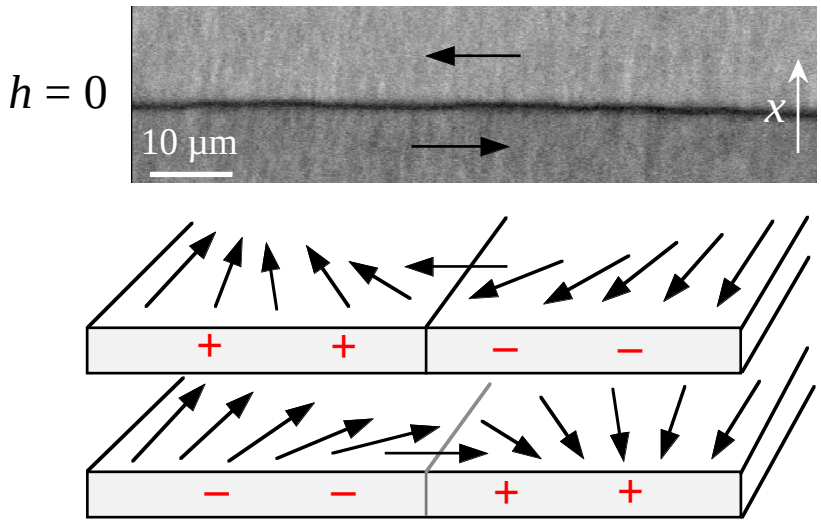


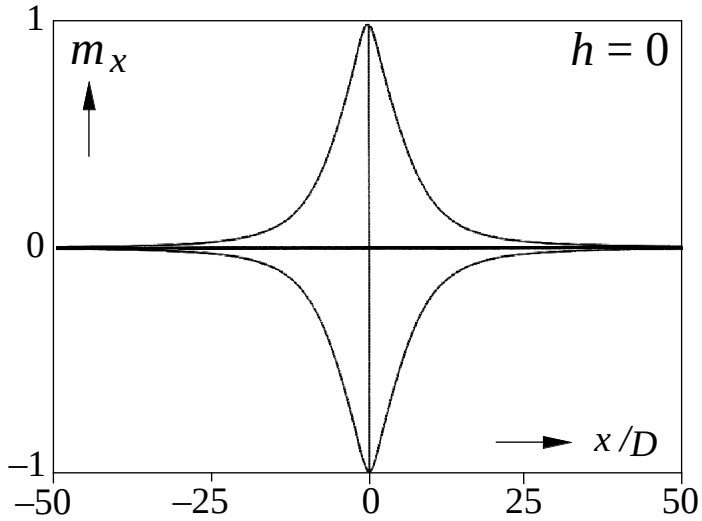
whisker axis

Weak coupling: charge compensation by superimposed walls

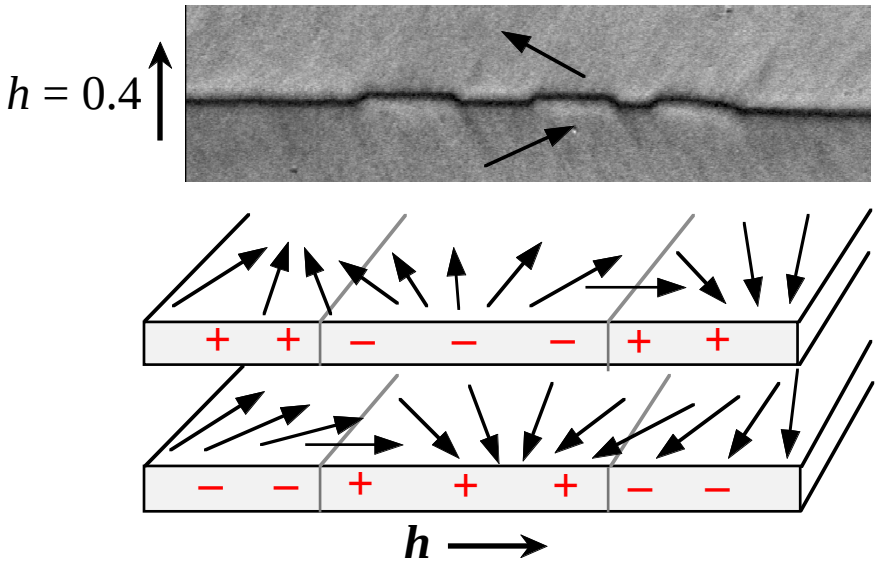
[50 nm NiFe / 5 nm SiO_2] x5

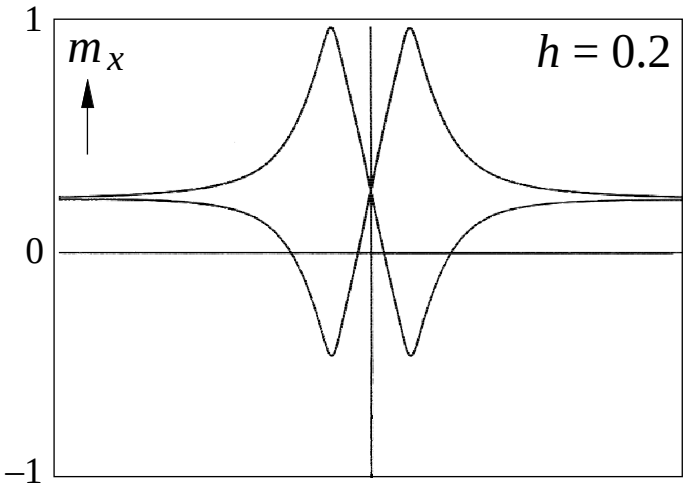
Superimposed Néel wall





Twin wall

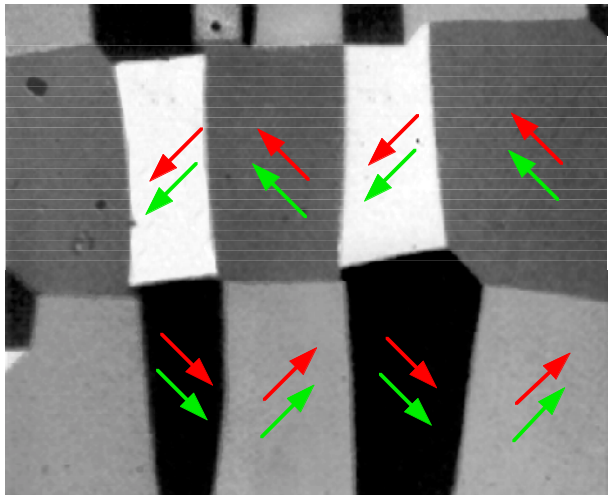


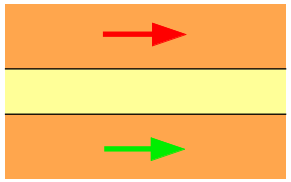


$h = H J_s / 2K_u = 0.2$

Oscillating coupling

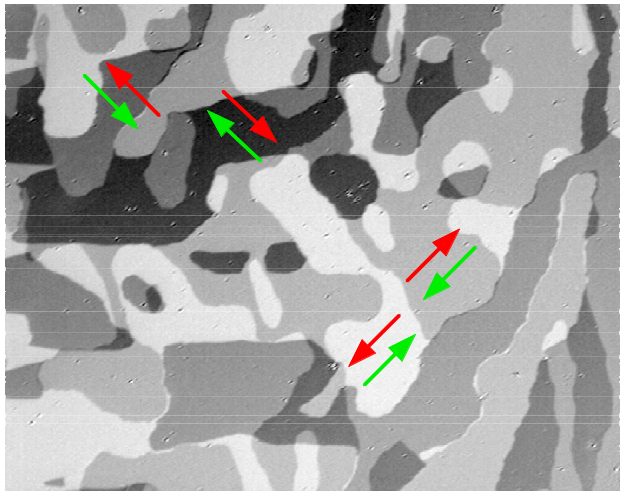
Ferromagnetic

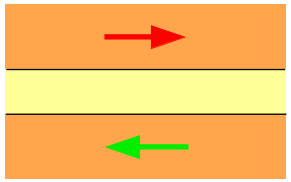




Fe (10 nm)
Cr (0.3 nm)
Fe (10 nm)

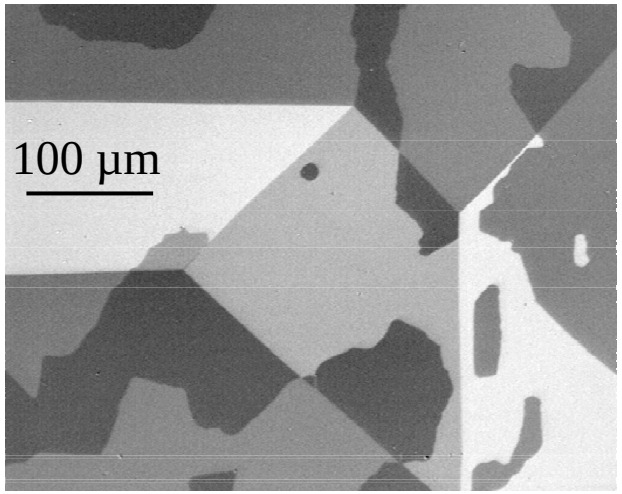
Antiferromagnetic

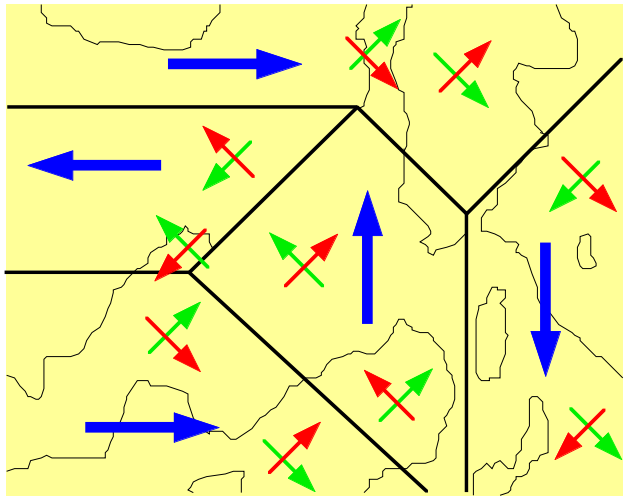




Fe (30 nm)
Cr (1.6 nm)
Fe (30 nm)

Biquadratic (90°)





upper layer

bottom layer

net magnetization

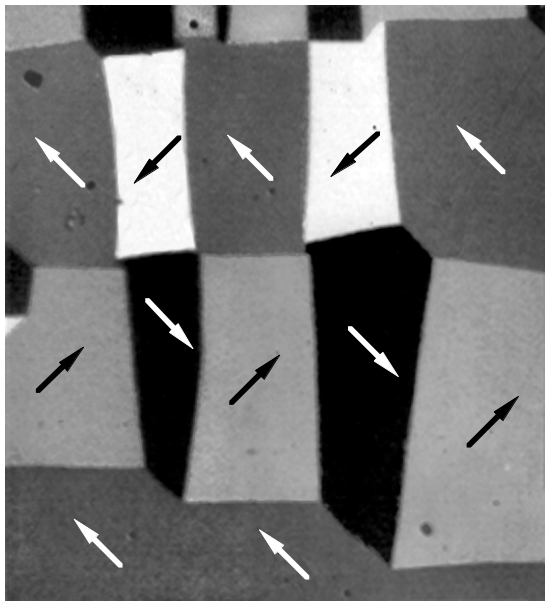
samples:
P. Grünberg, Jülich

Phenomenological description of Kerr-, Voigt-, and Gradient effect

Kerr effect

$$D = -\mathrm{i}\varepsilon Q\, \boldsymbol{m} \times \boldsymbol{E}$$

linear in magnetization

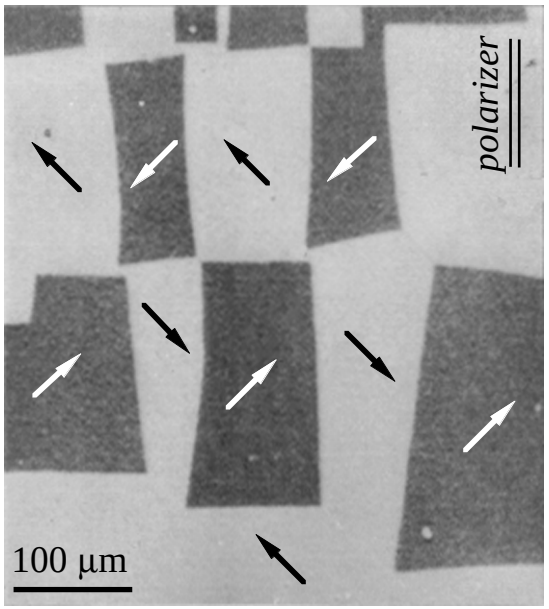


- ***oblique incidence of light***
- ***analyser***

Voigt effect

$$D = B\, \boldsymbol{m}\,(\boldsymbol{m} \cdot \boldsymbol{E})$$

quadratic in magnetization

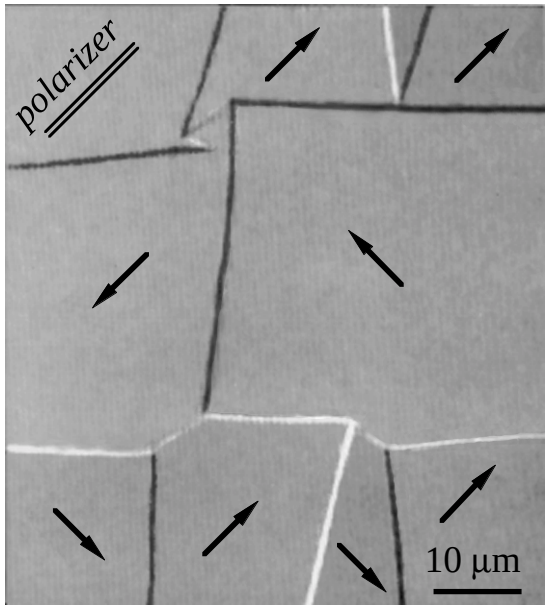


- ***perpendicular incidence***
- ***compensator***

Gradient effect

$$D_y = P\left(\frac{\partial m_x}{\partial x} - \frac{\partial m_y}{\partial y}\right) E_x$$

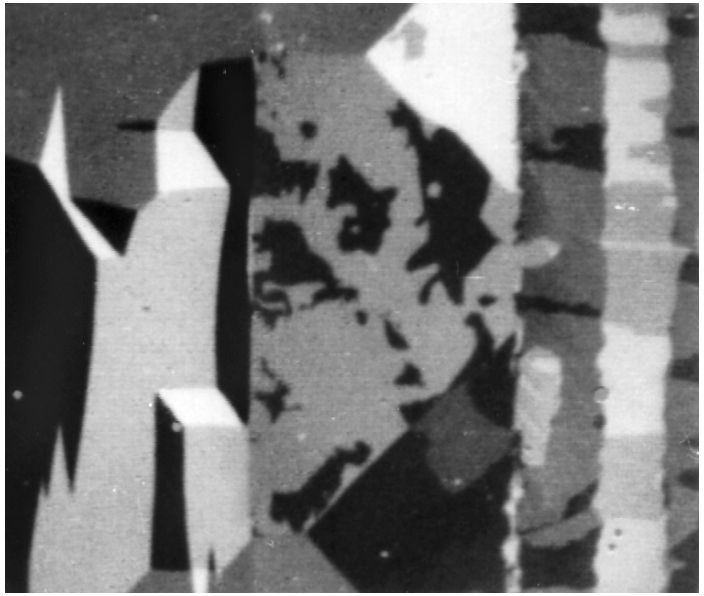
linear in certain gradients



- ***perpendicular incidence***
- ***compensator***

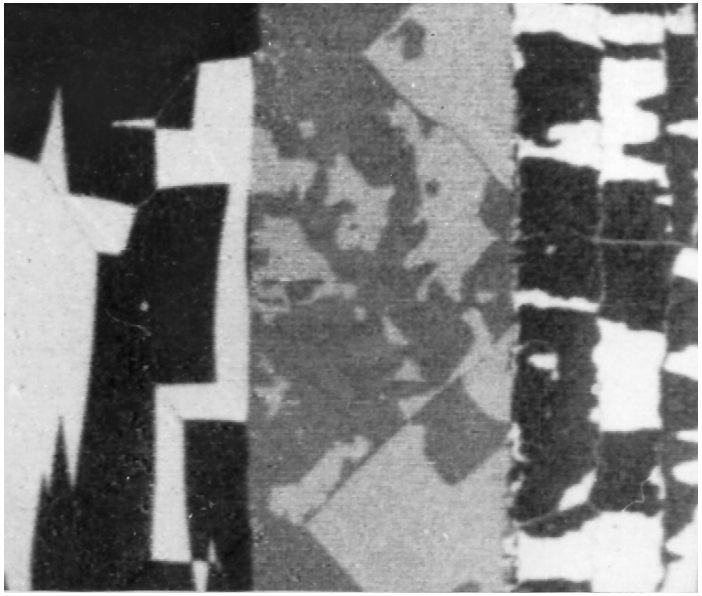
Fe / Cr / Fe
10 0.3 10 nm

Kerr effect



F 90° AF

Voigt effect



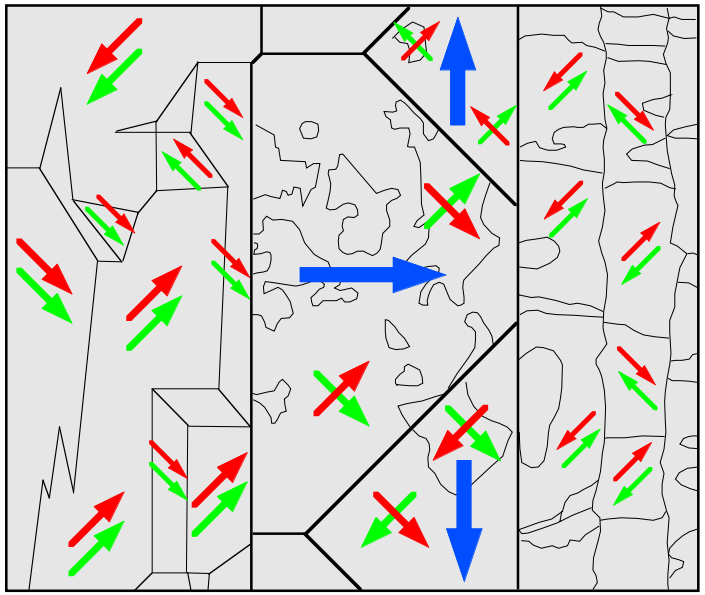
F 90° AF

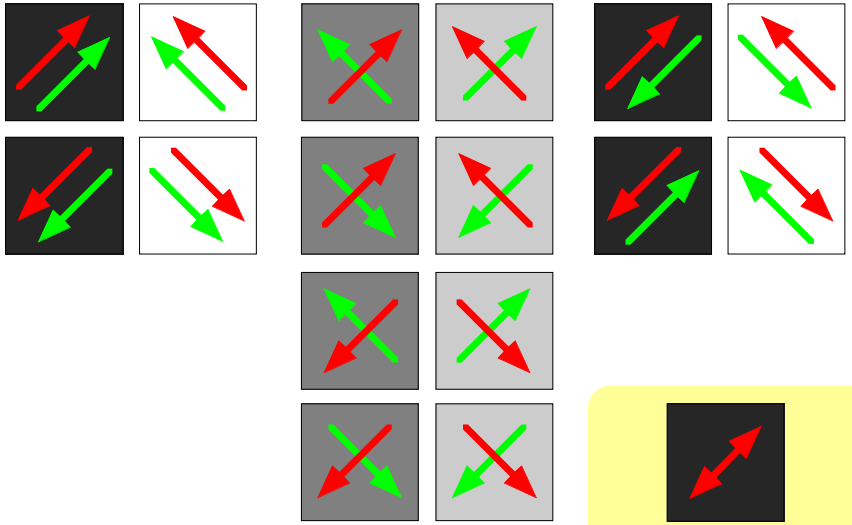
easy axes

top layer

bottom layer

net magn.

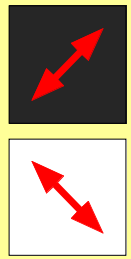




Fe (10 nm)

Cr (0.44 - 0.57 nm)

Fe (10 nm)



Voigt contrast

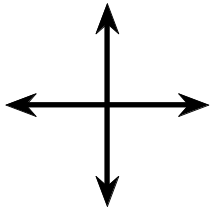
Kerr effect

Voigt effect

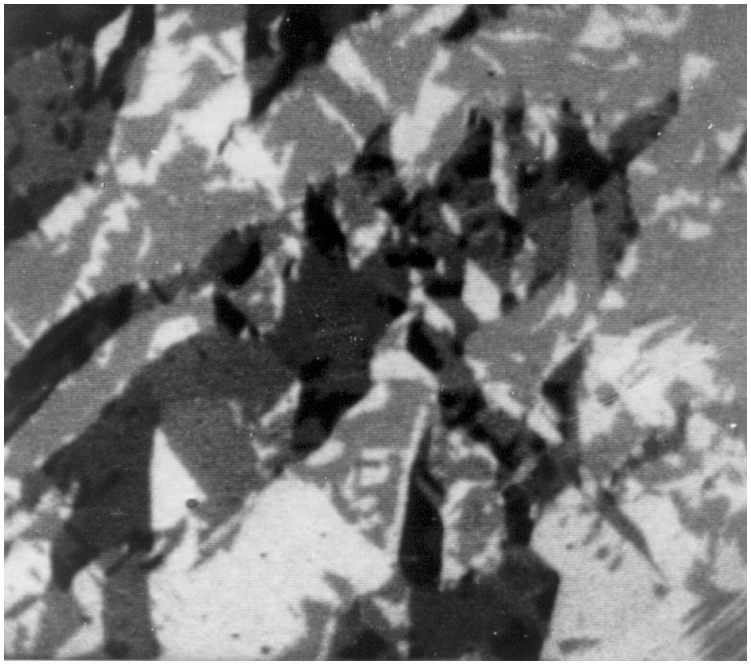
Fe (10 nm)

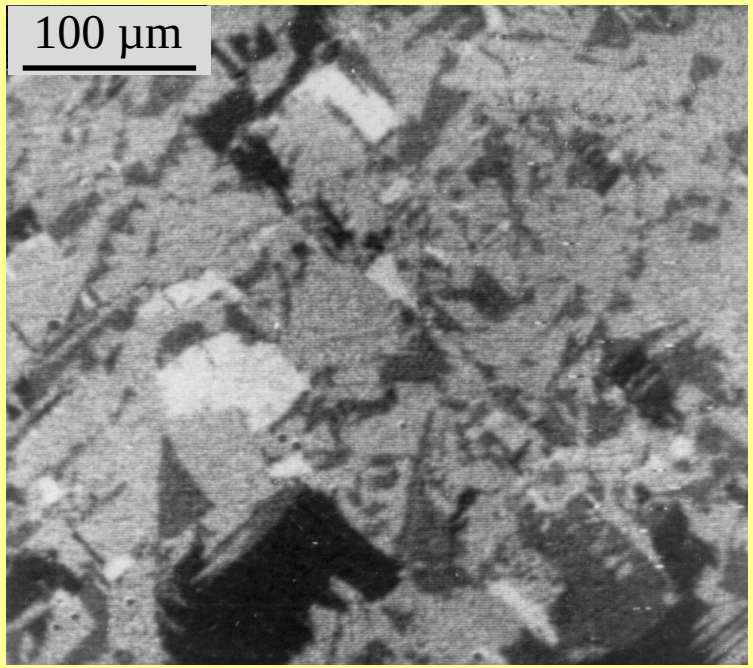
Al (2.2 nm)

Fe (10 nm)



easy axes

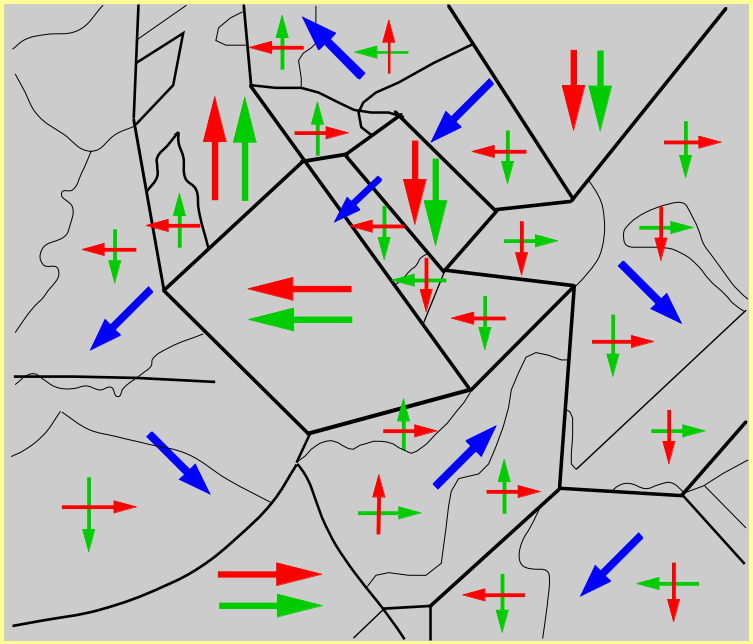


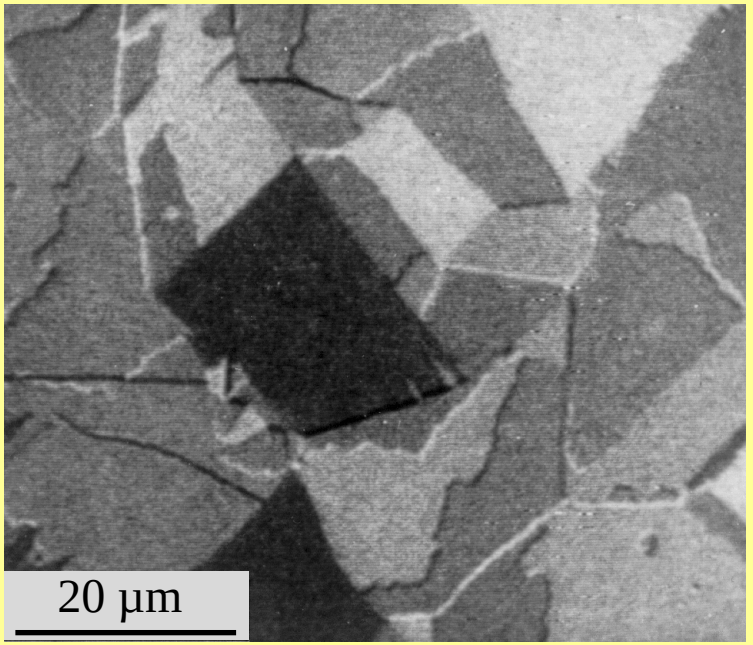


top layer

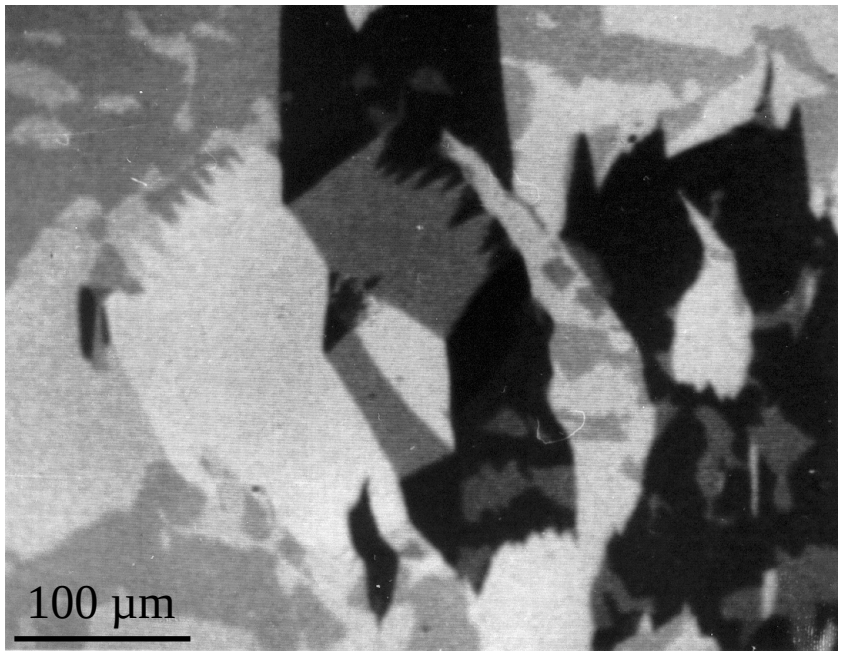
bottom layer

net magn.

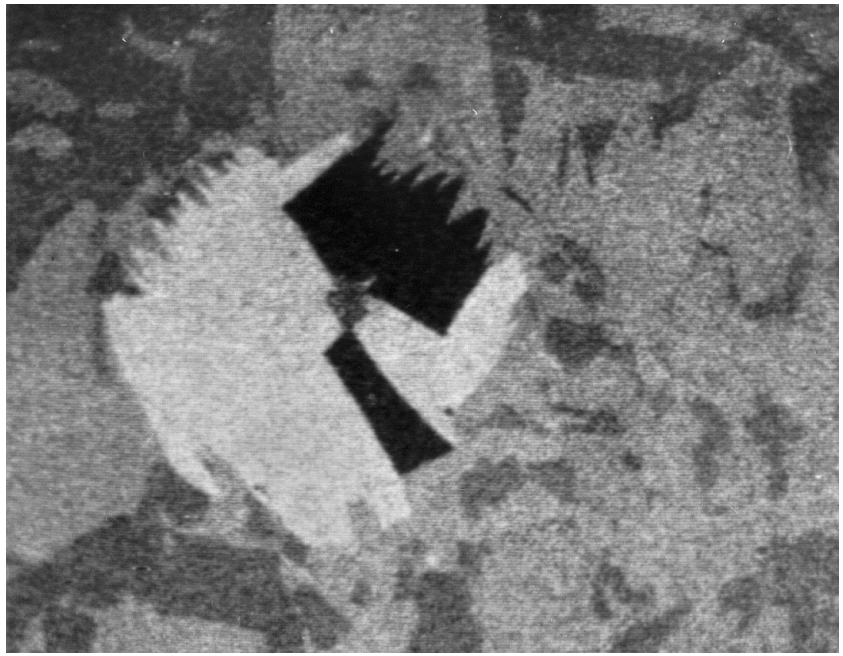


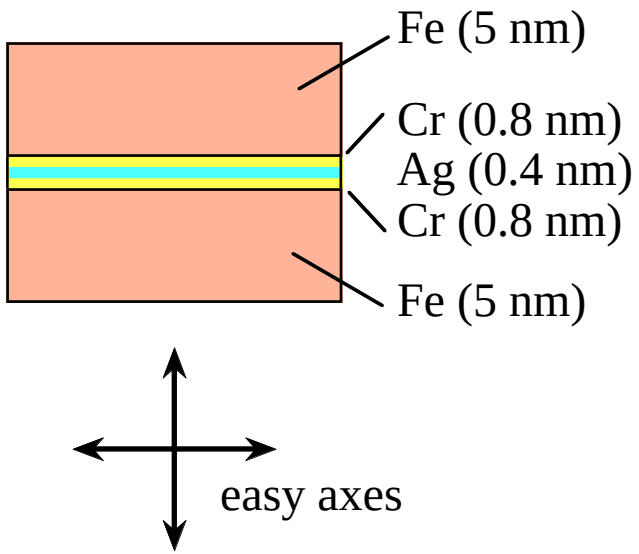


Kerr effect



Voigt effect





F-coupling around a defect
in a 90°coupled environment

Possibilities of Kerr microscopy for domain studies in magnetic multilayers

Fast and versatile method,
observation at wide temperature range

Compatible with fields,
study of magnetization processes at reasonable resolution (300 nm)

Depth sensitivity (20 nm) can be exploited by using compensator

Combination of m.o. Kerr-, Voigt-, and Gradient effects