Reorientacja spinowa i kontrola anizotropii magnetycznej w niskowymiarowych układach ferro- i antyferromagnetycznych

WFiIS, 8.03.2019

dr inż. Michał Ślęzak

Katedra Fizyki Ciała Stałego
Wydział Fizyki i Informatyki Stosowanej AGH

1. X-ray photoemission electron microscopy study of the in-plane spin reorientation transitions in epitaxial Fe films on W(110).
M. Ślęzak, T. Giela, D. Wilgocka-Ślęzak, A. Kozioł-Rachwał, T. Ślęzak, R. Zdyb, N. Spiridis,
C. Quitmann, J. Raabe, N. Pilet, J. Korecki
Journal of Magnetism and Magnetic Materials 348 (2013) 101–106

2. Prospects of X-ray photoemission electron microscopy at the first beamline of the Polish synchrotron facility SOLARIS.
M. Ślęzak, T. Giela, D. Wilgocka-Ślęzak, N. Spiridis, T. Ślęzak, M. Zając, A. Kozioł-Rachwał,
R.P. Socha, M. Stankiewicz, P. Warnicke, N. Pilet, J. Raabe, C. Quitmann, J. Korecki
X-Ray Spectrometry 44 (2015) 317–322

3. Giant in-plane magnetic anisotropy in epitaxial bcc Co/Fe(110) bilayers
M. Ślęzak, T. Ślęzak, K. Matlak, B. Matlak, P. Dróżdż, T. Giela, D. Wilgocka-Ślęzak,N. Pilet, J. Raabe, A. Kozioł-Rachwał, J. Korecki,
Physical Review B 94 (2016) 014402

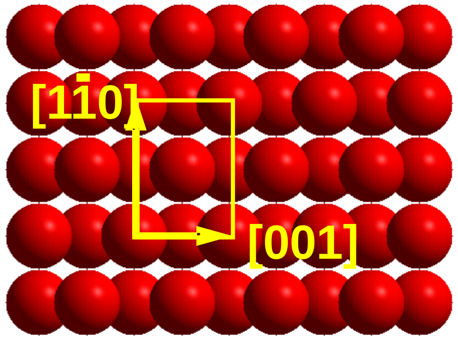
4. Adsorption induced modification of in-plane magnetic anisotropy in epitaxial Co and Fe/Co films on Fe(110)
M. Ślęzak, T. Ślęzak, K. Matlak, P. Dróżdż, J. Korecki
AIP Advances 8 (2018) 056806

5. Multiple spin reorientation transitions and large in plane magnetic anisotropy in epitaxial Au/Co/Fe(110) films
M. Ślęzak, P. Dróżdż, K. Matlak, A. Kozioł-Rachwał, J. Korecki, T. Ślęzak
Journal of Magnetism and Magnetic Materials 475 (2019) 195–200

6. How a ferromagnet drives an antiferromagnet in exchange biased CoO/Fe(110) bilayers
M. Ślęzak, T. Ślęzak, P. Dróżdż, B. Matlak, K. Matlak, A. Kozioł-Rachwał, M. Zając, J. Korecki
Scientific Reports 9 (2019) 889

Introduction

Spin Reorientation Transition in Fe/W(110)

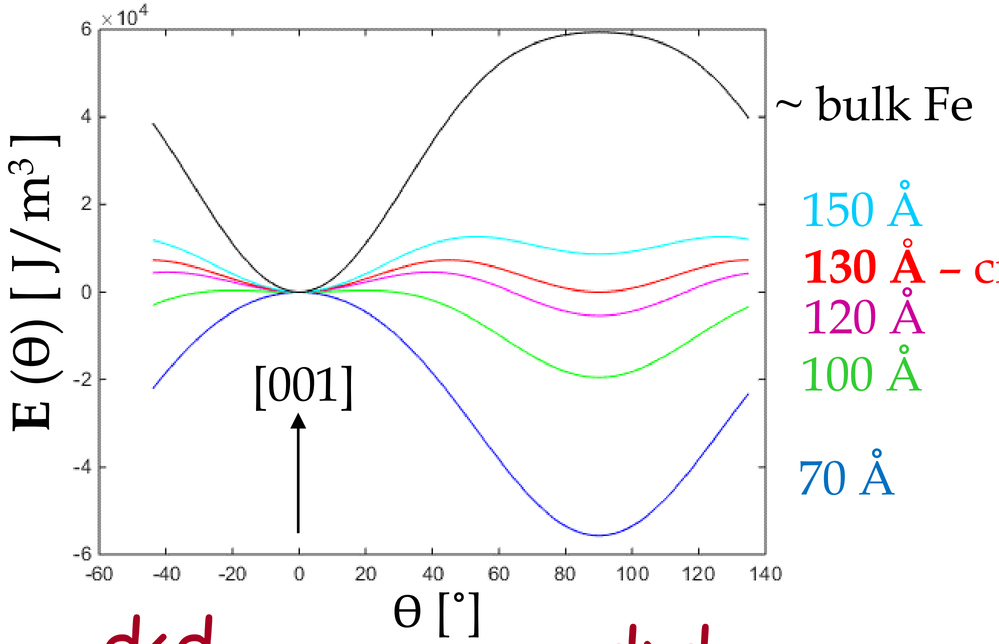


d_{crt} is a good measure of in-plane magnetic anisotropy

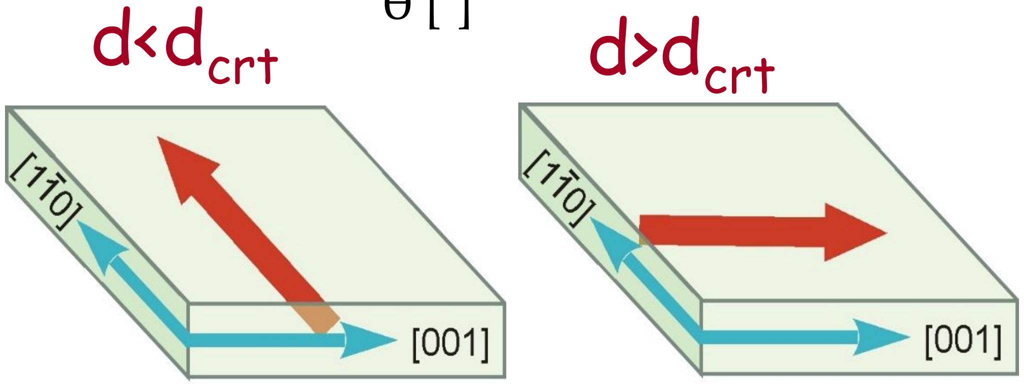
$$E_{m\ in\text{-}plane}(\Theta) = A\sin^2(\Theta) + B\sin^4(\Theta)$$

$$A = K_{vp} - K_{sp}/d$$
$$B = K_{vpp} - K_{spp}/d$$

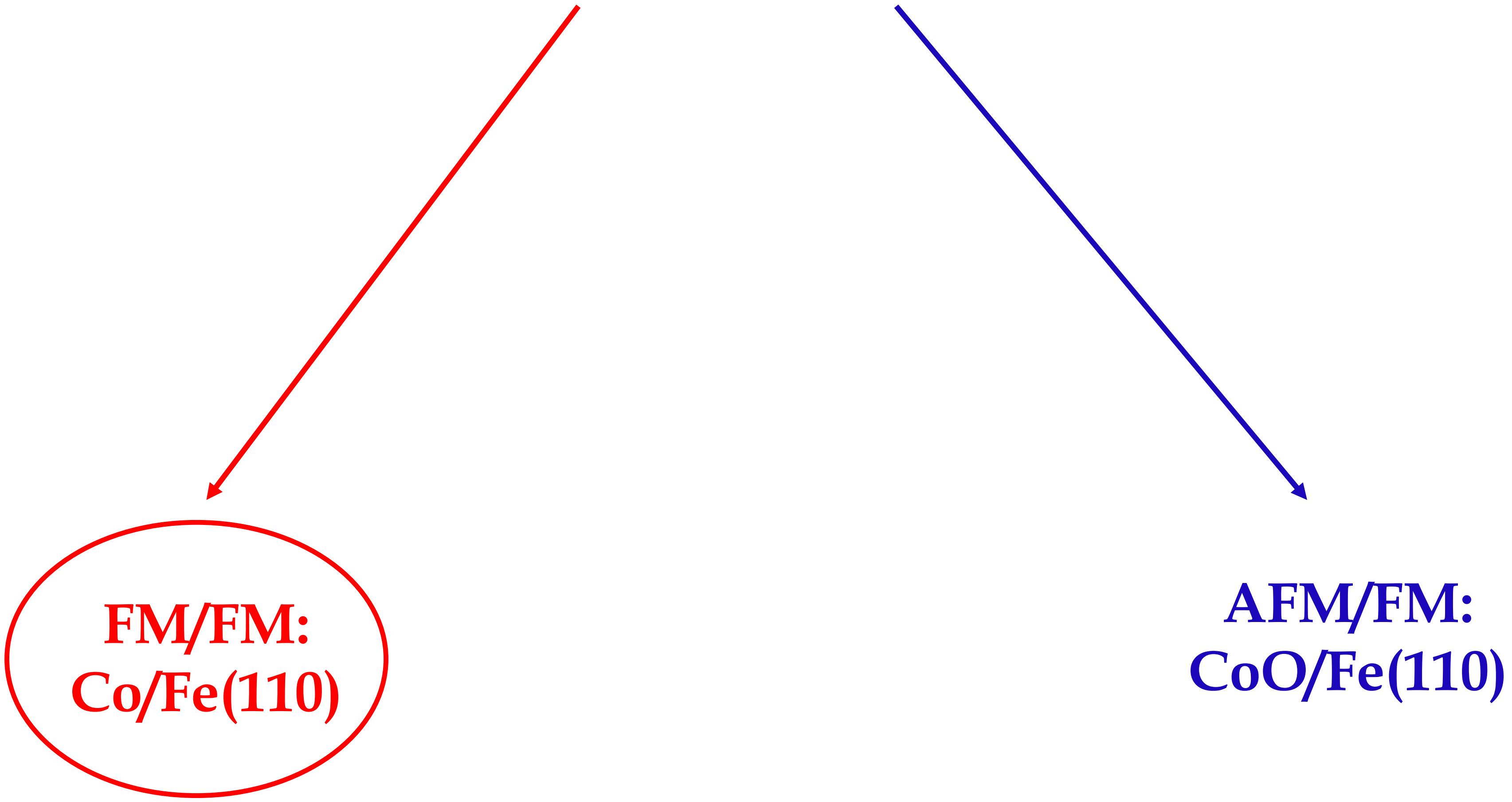
[1-10] anisotropy



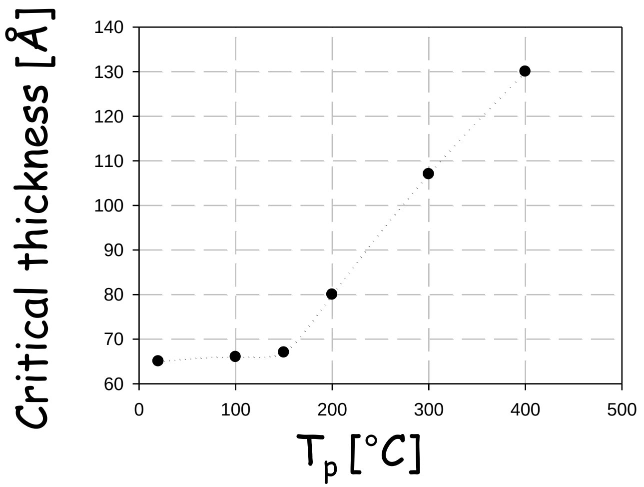
$K_{vp} = 10.60 * 10^4\ J/m^3$
$K_{vpp} = -0.60 * 10^4\ J/m^3$
$K_{sp} = 0.82 *\ mJ/m^2$
$K_{spp} = 0.48 *\ mJ/m^2$



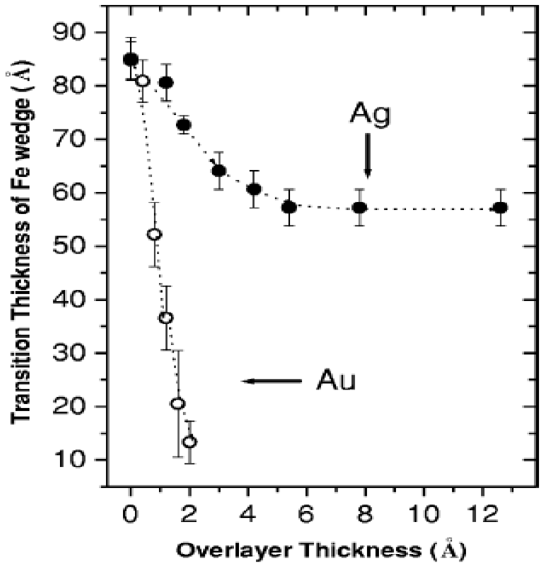
Gradmann et al., Appl. Phys. A 39, 101-108 (1985)

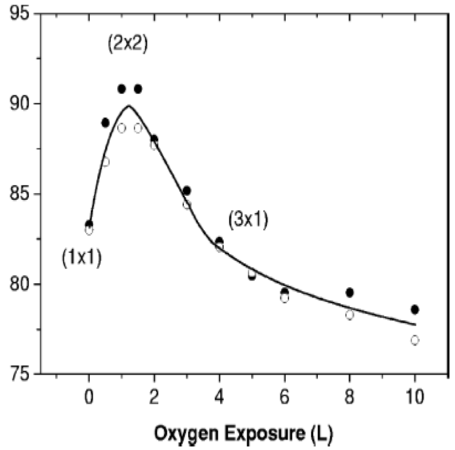

FM/FM:
Co/Fe(110)
AFM/FM:
CoO/Fe(110)

Introduction to part I: modifications of magnetic anisotropy and SRT in Fe/W(110)



Albrecht et al., *JMMM 113 (1992) 207-220*





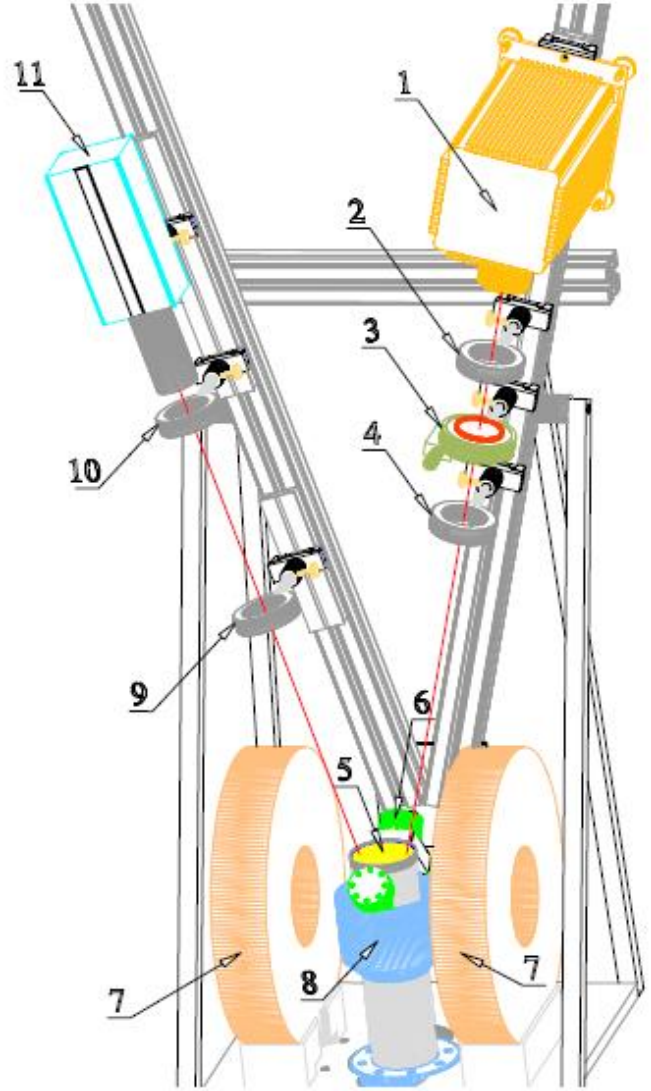
Baek et al., *PRB 67, 075401 (2003)*

μMOKE (in-situ) imaging

CCD camera

Analyser

Lens



Xenon arc lamp

Lens

Polariser

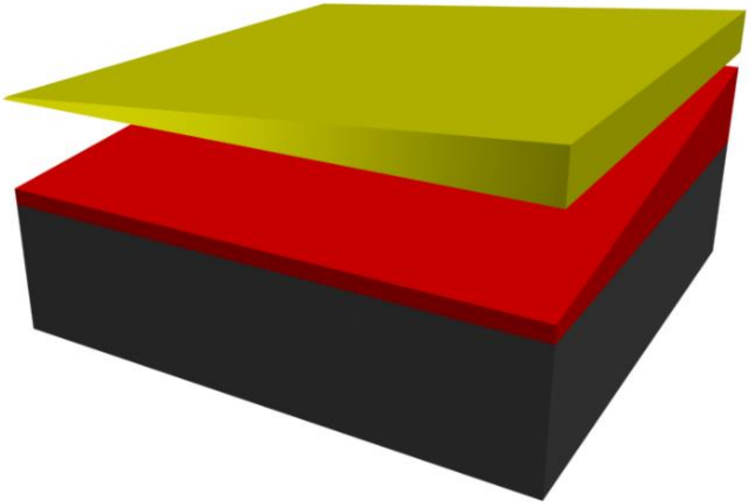
Lens

Magnetic field coils and
vacum window

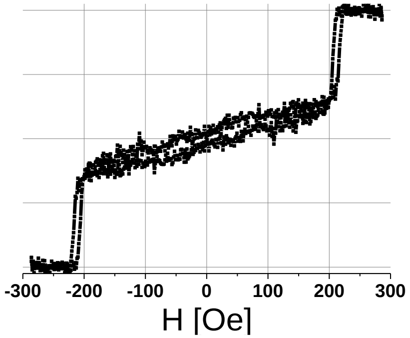
Krzysztof Matlak, PhD thesis

Co influence on SRT in Fe(110):

double wedge samples at AGH



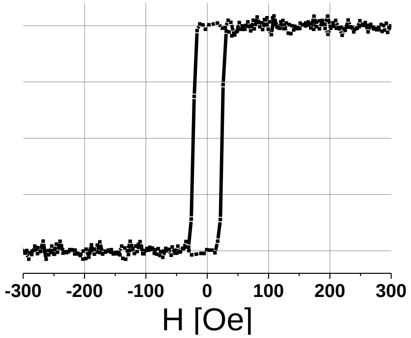
Co influence on SRT in Fe(110):
in-situ μMOKE results

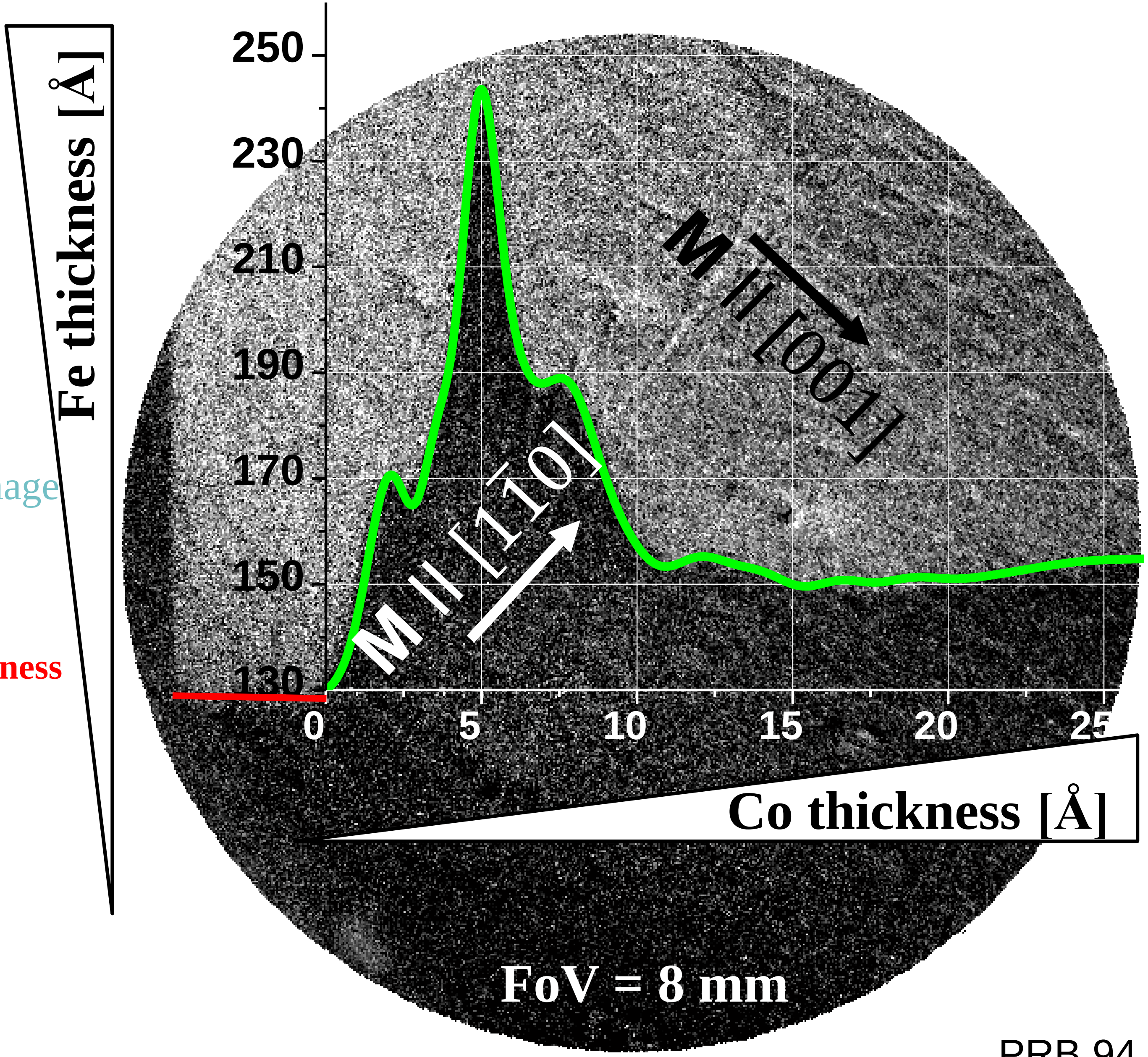


- double-wedged samples
- Fe and Co MBE grown on W(110)
- Fe 80 – 300 Å
- Co 0 – 30 Å

Remanent MOKE image
B II [1-10]

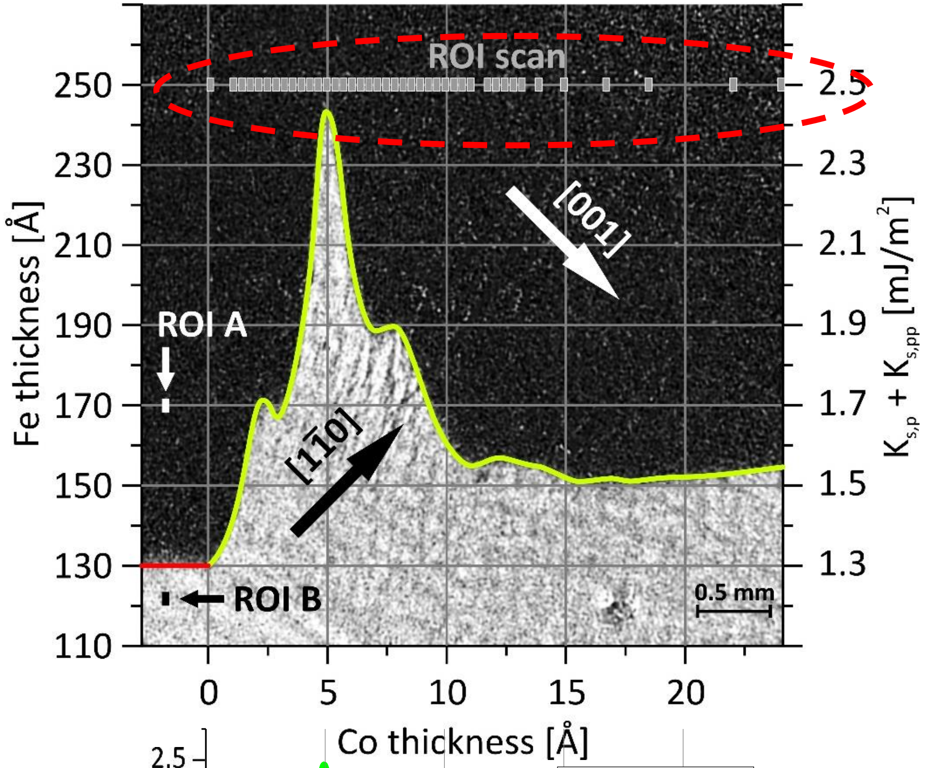
Critical thickness Fe\UHV

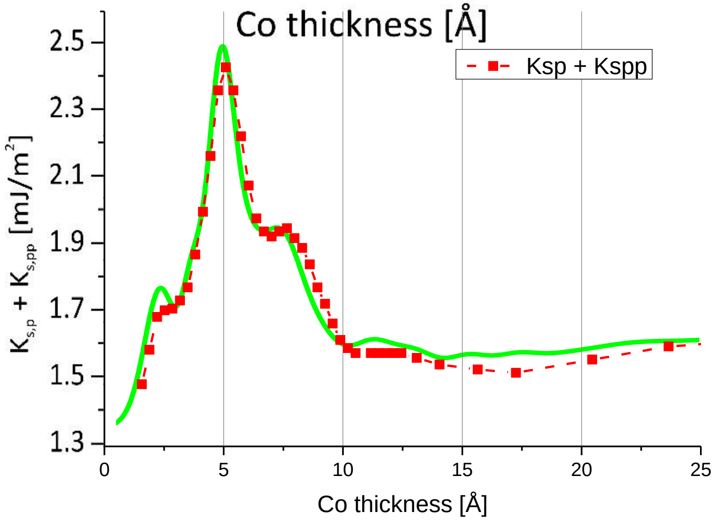


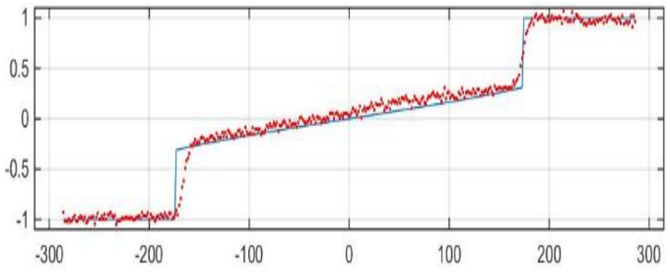


PRB 94 (2016) 014402

Magnetic anisotropy at the Co/Fe(110) interface:
magnetic hysteresis loops simulations







Model (coherent rotation of magnetization)

Global minimum of energy:

$$E = A \sin^2(\theta) + B \sin^4(\theta) - M_s H \sin(\theta)$$

θ – angle between **M** and **[001]**

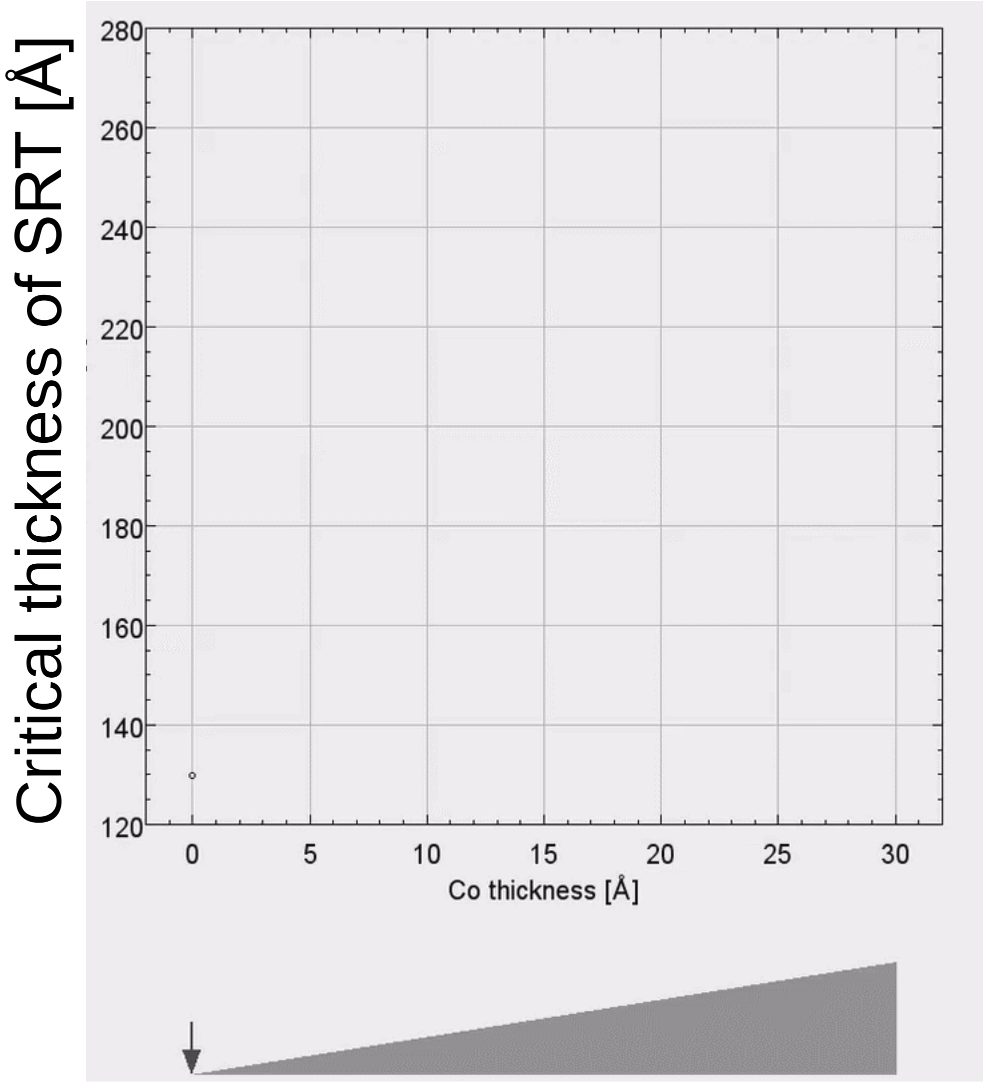
$$A = K_{vp} - K_{sp}/d$$
$$B = K_{vpp} - K_{spp}/d$$

d_{Fe} = 250 Å = const.

K_{vp}=10.6 * 10^4 J/m^3=const.
K_{vpp}=-0.60 * 10^4 J/m^3=const.

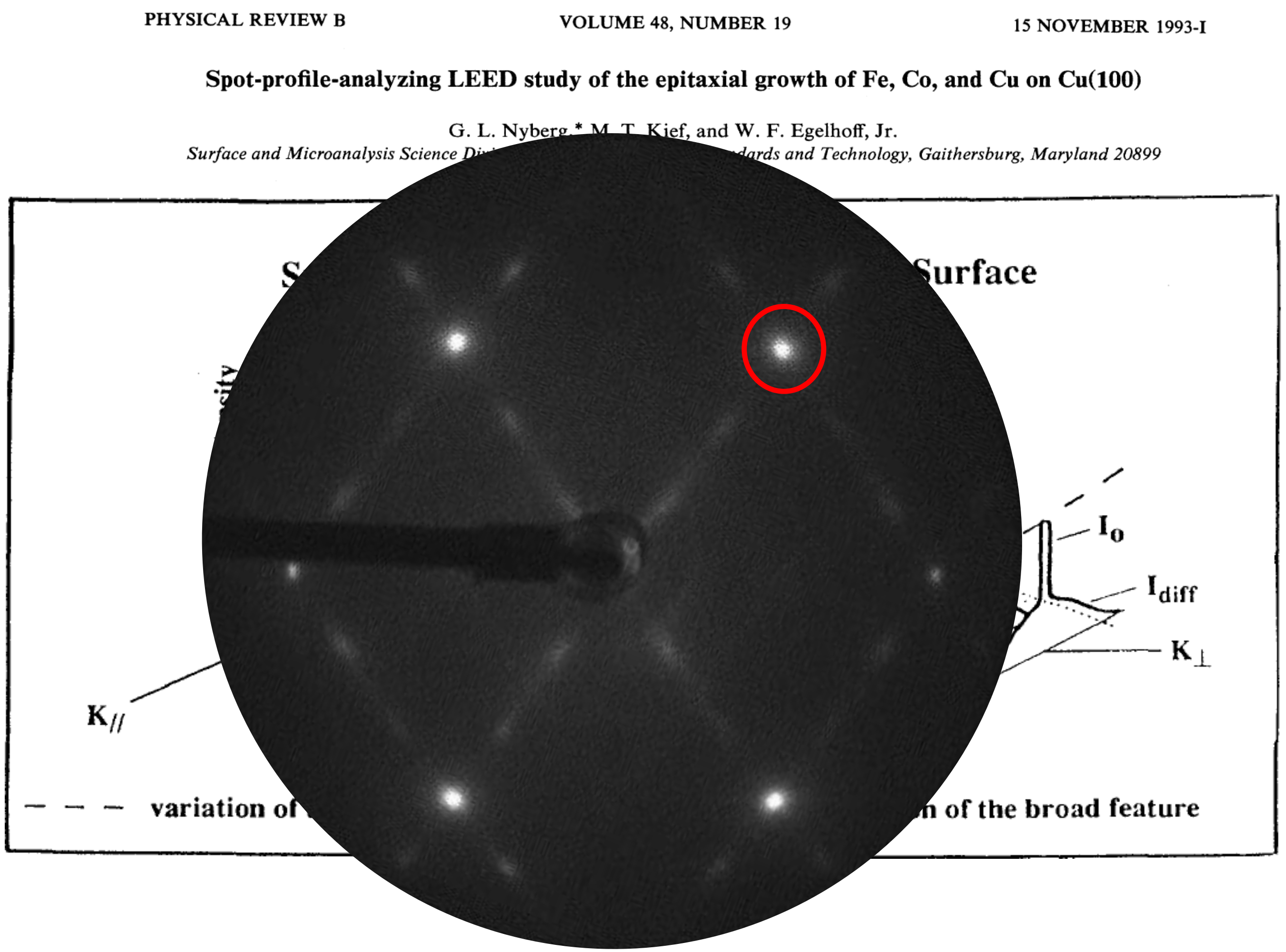
PRB 94 (2016) 014402

Magnetic Anisotropy and SRT in Co/Fe(110)



PRB 94 (2016) 014402

Oscillations of Ks– morphology of Co film

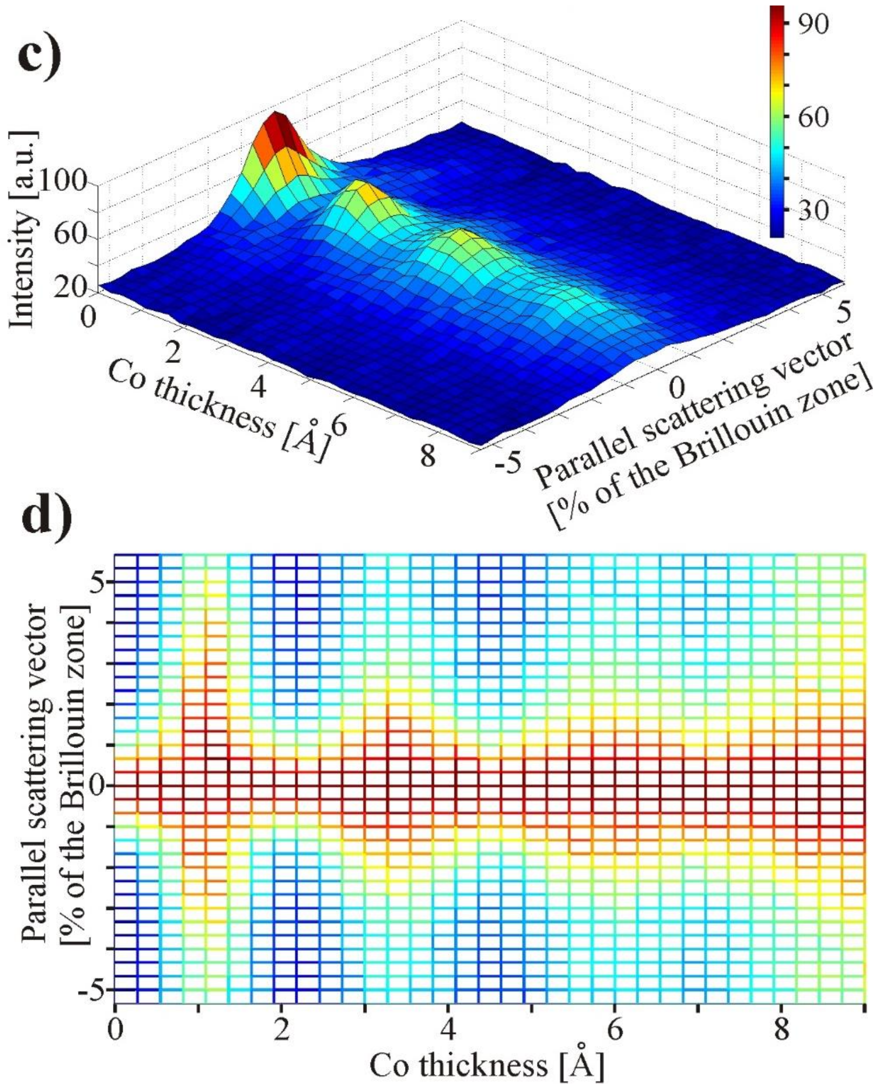

PHYSICAL REVIEW B VOLUME 48, NUMBER 19 15 NOVEMBER 1993-I

Spot-profile-analyzing LEED study of the epitaxial growth of Fe, Co, and Cu on Cu(100)

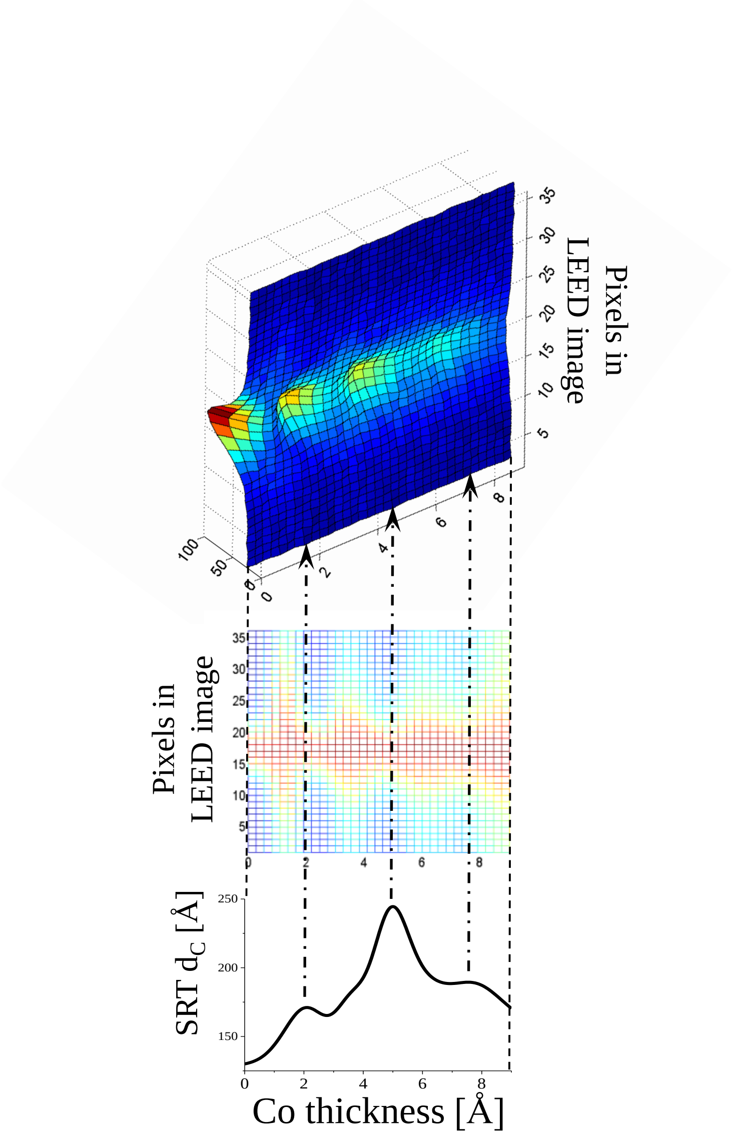
G. L. Nyberg,* M. T. Kief, and W. F. Egelhoff, Jr.

Surface and Microanalysis Science Di... ...dards and Technology, Gaithersburg, Maryland 20899

Co / Fe(110): oscillations of Ks vs oscillations of LEED spot profile



PRB 94 (2016) 014402

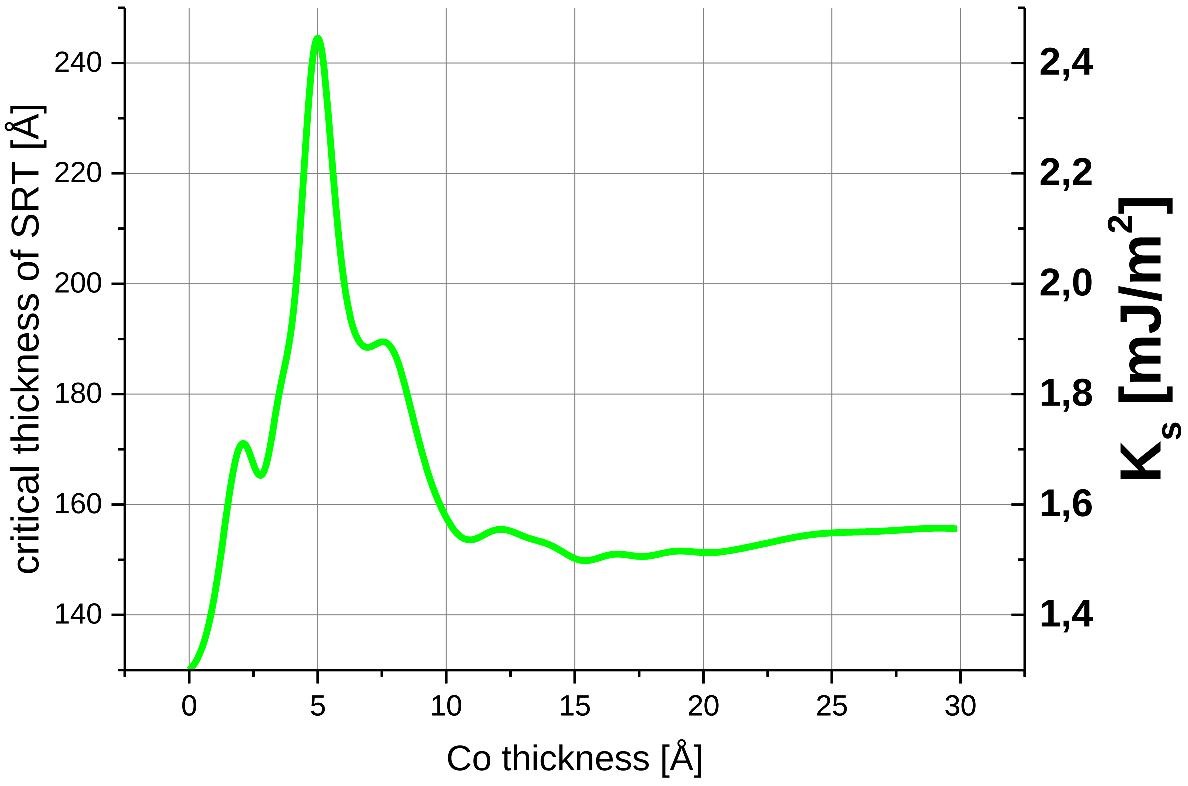


Pixels in LEED image
Pixels in LEED image
SRT d_C [Å]
Co thickness [Å]

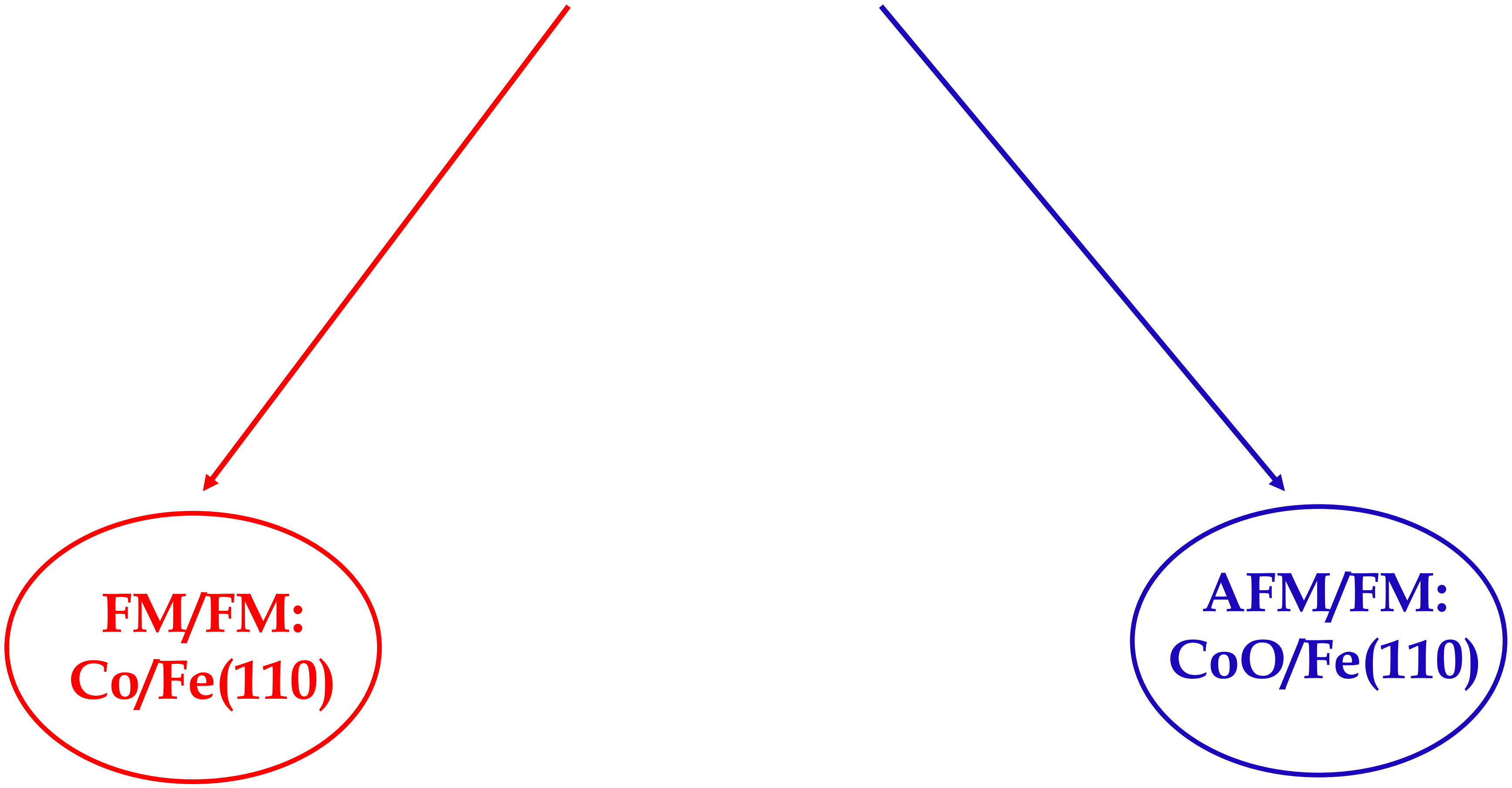
Summary: Co/Fe(110)

→ **huge magnetic anisotropy at the Co/Fe(110) interface**

→ **monolayer (Co) period oscillations of magnetic anisotropy**



Physical Review B 94 (2016) 014402


FM/FM:
Co/Fe(110)
AFM/FM:
CoO/Fe(110)

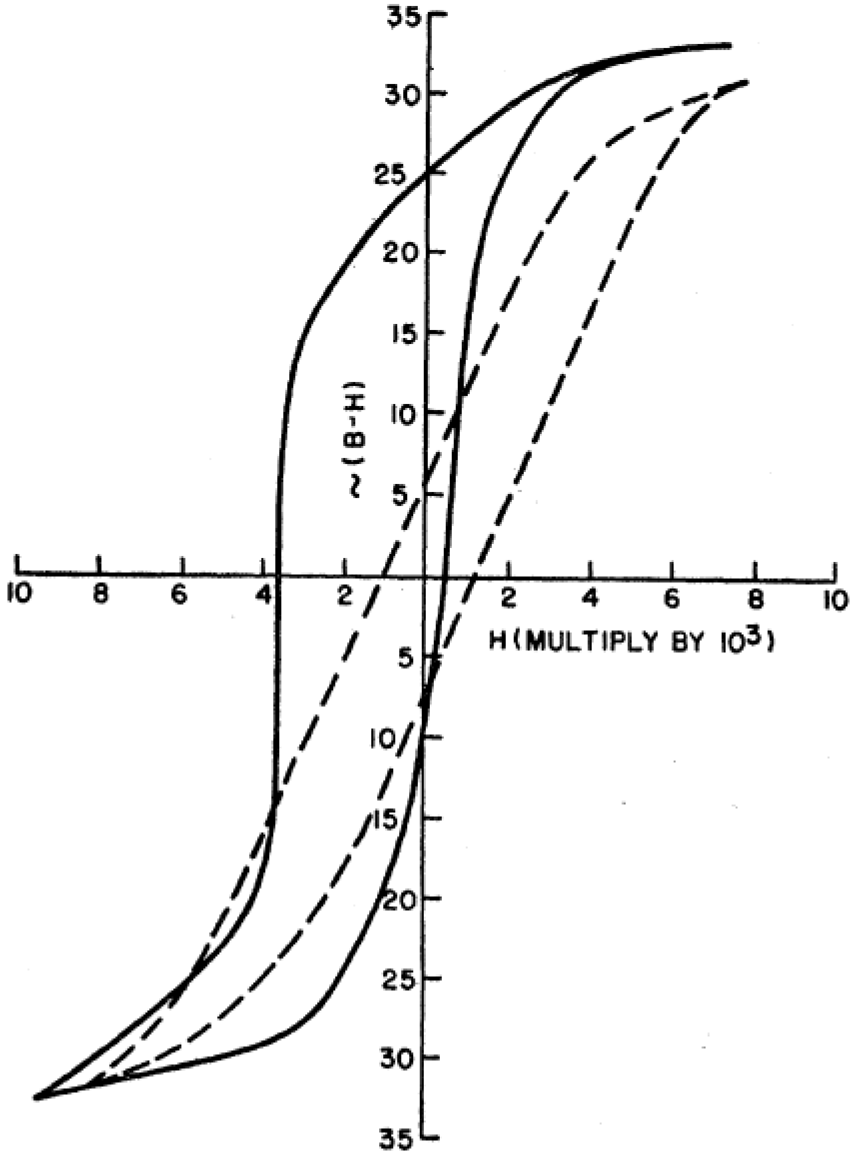
Discovery of *exchange bias*

Phys. Rev., 105, 904 (1957)

New Magnetic Anisotropy

W. H. MEIKLEJOHN AND C. P. BEAN
General Electric Research Laboratory, Schenectady, New York
(Received March 7, 1956)

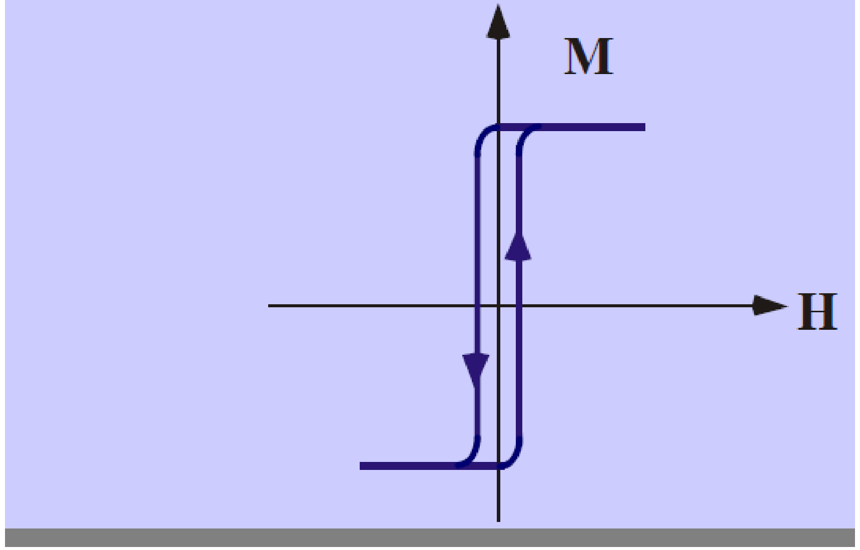
Co particles embedded in their native antiferromagnetic oxide CoO



W. H. Meiklejohn and C. P. Bean, Phys. Rev. 102, 1413 (1956).
W. H. Meiklejohn and C. P. Bean, Phys. Rev. 105, 904 (1957).

Introduction

exchange bias

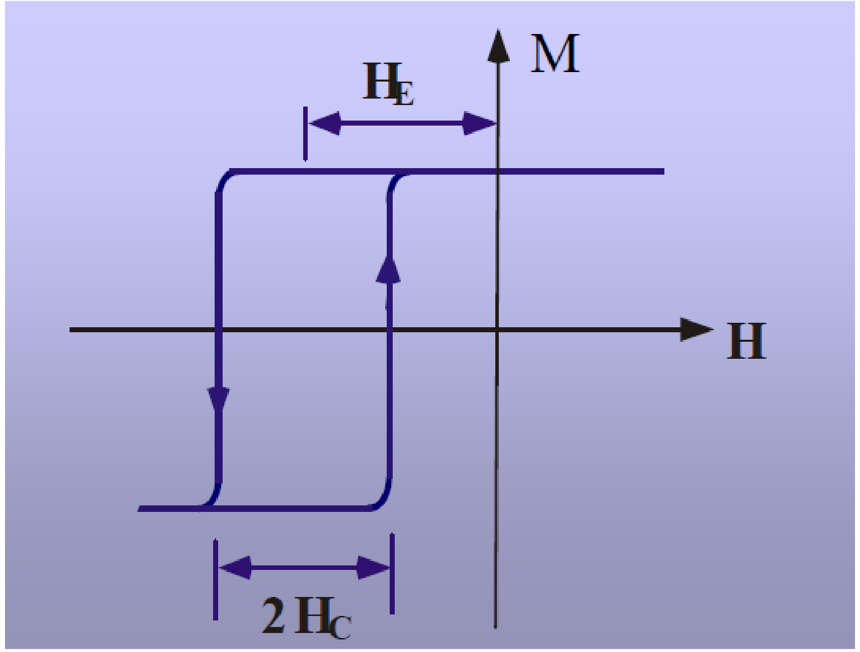


Free FM

Exchange field H_E=0

Small coercivity H_C

Symmetric



Pinned FM

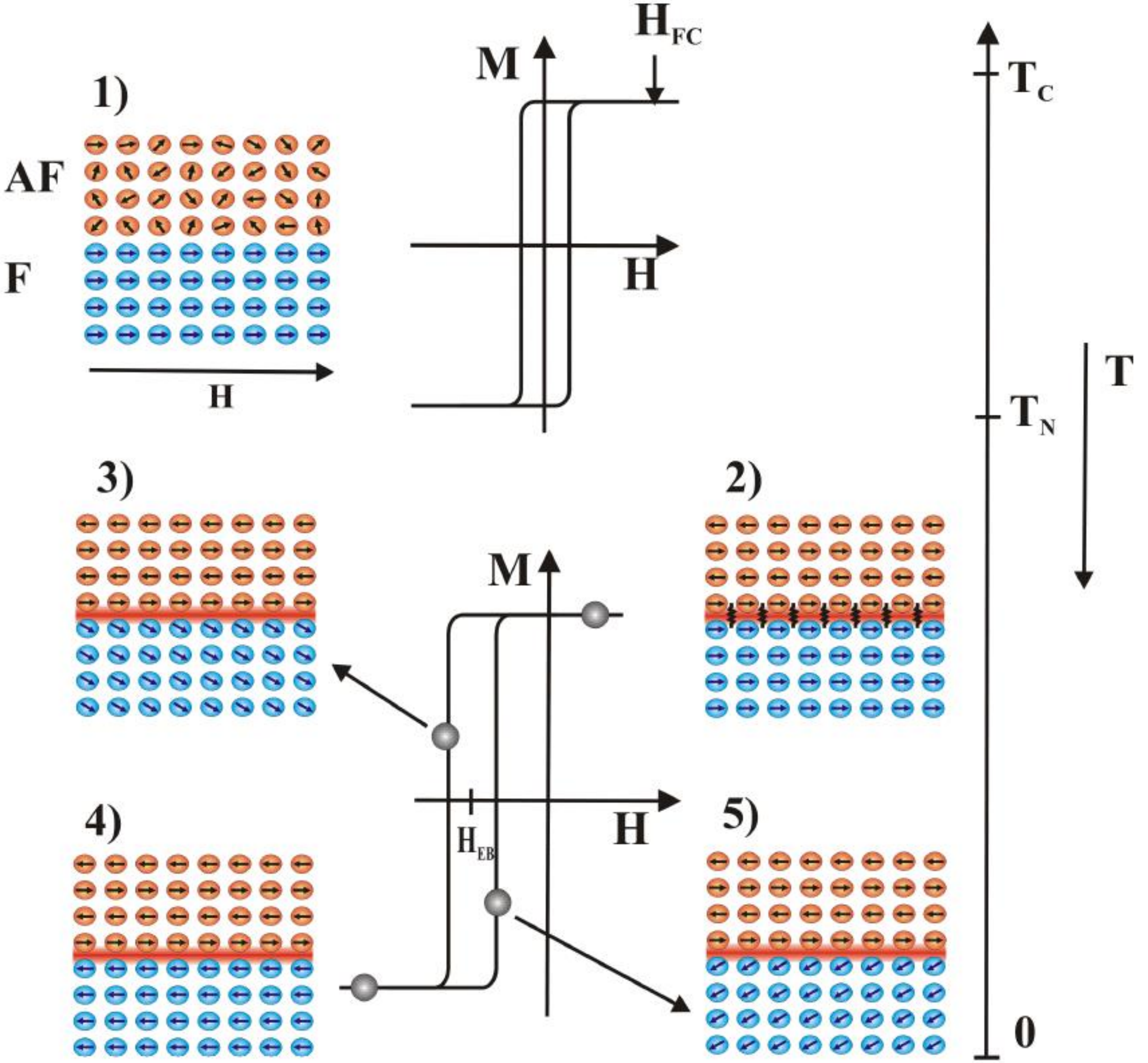
Large H_E

Large H_C

Ivan K. Schuller
(www)

Introduction

exchange bias



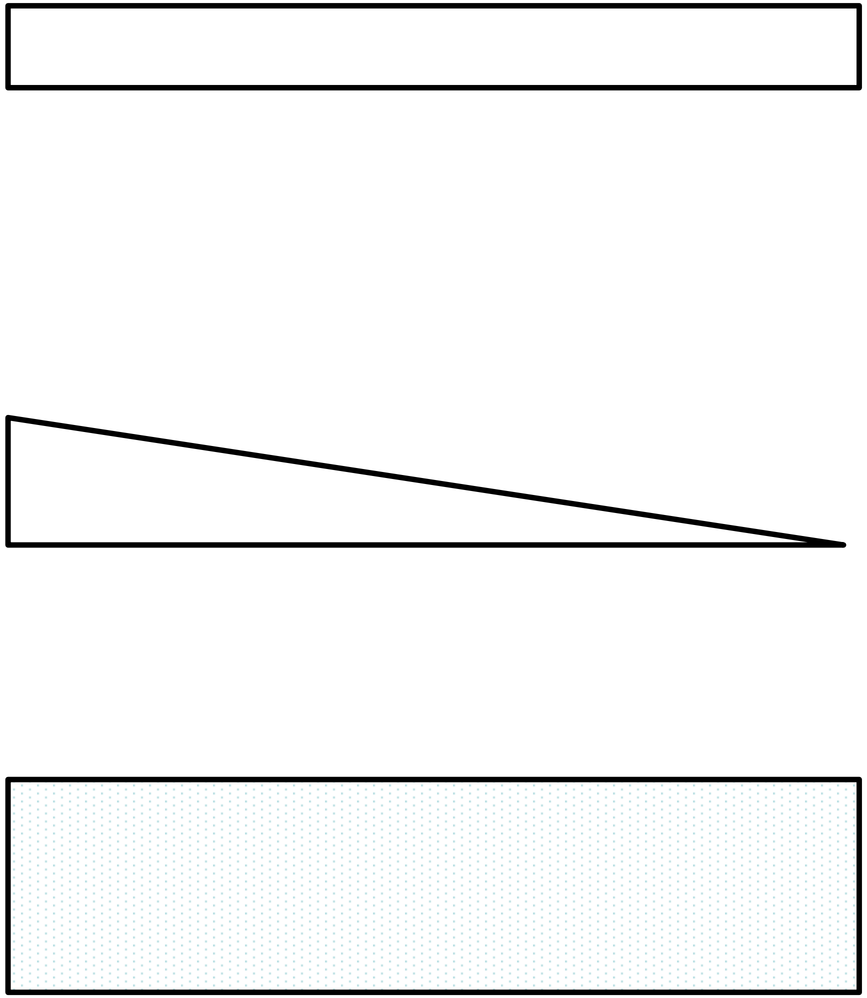
Florin Radu PhD

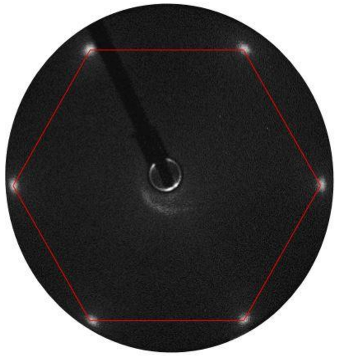
CoO/Fe(110) sample(s)

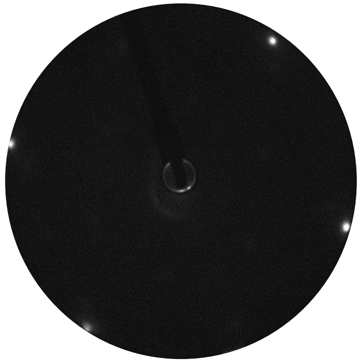
CoO(111): 90 Å

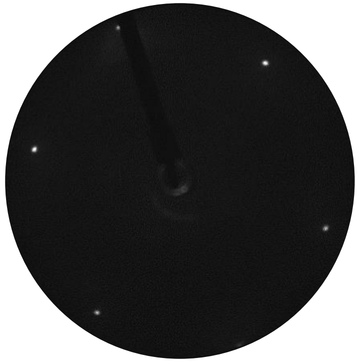
Fe(110) wedge: 80 - 300 Å

substrate: W(110) single crystal



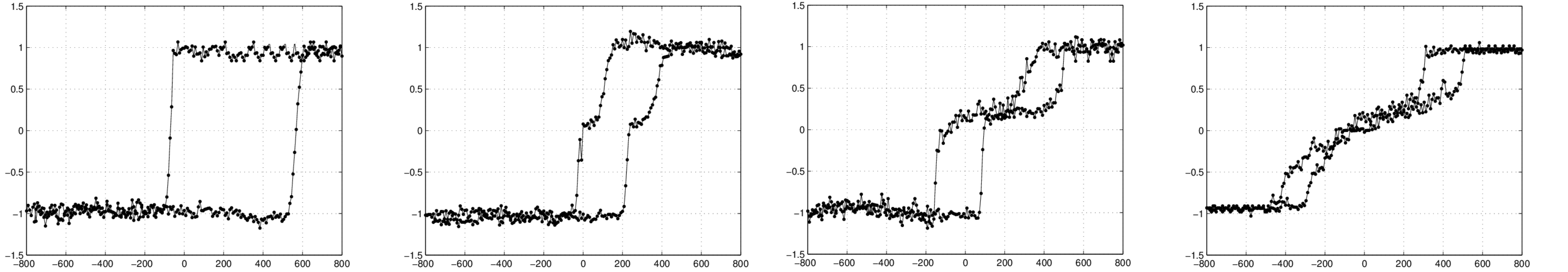






CoO(111) on Fe(110): evolution of magnetic hysteresis loops @ 183 K

B II [1-10]

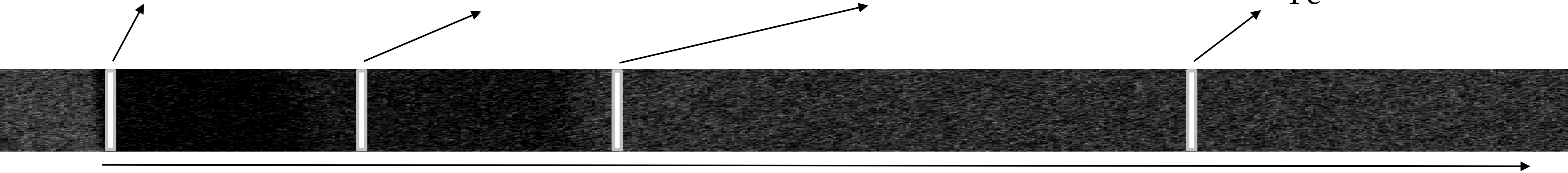


d_{Fe} = 80 Å

d_{Fe} = 110 Å

d_{Fe} = 140 Å

d_{Fe} = 200 Å

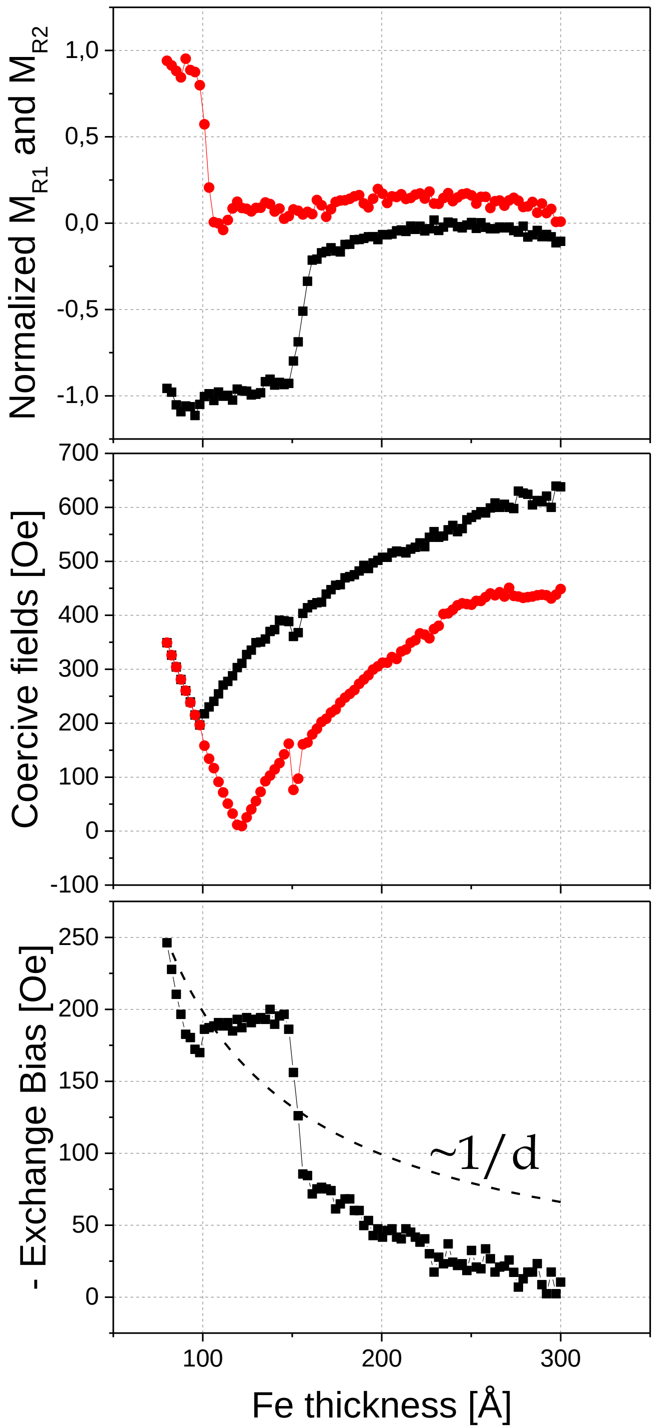


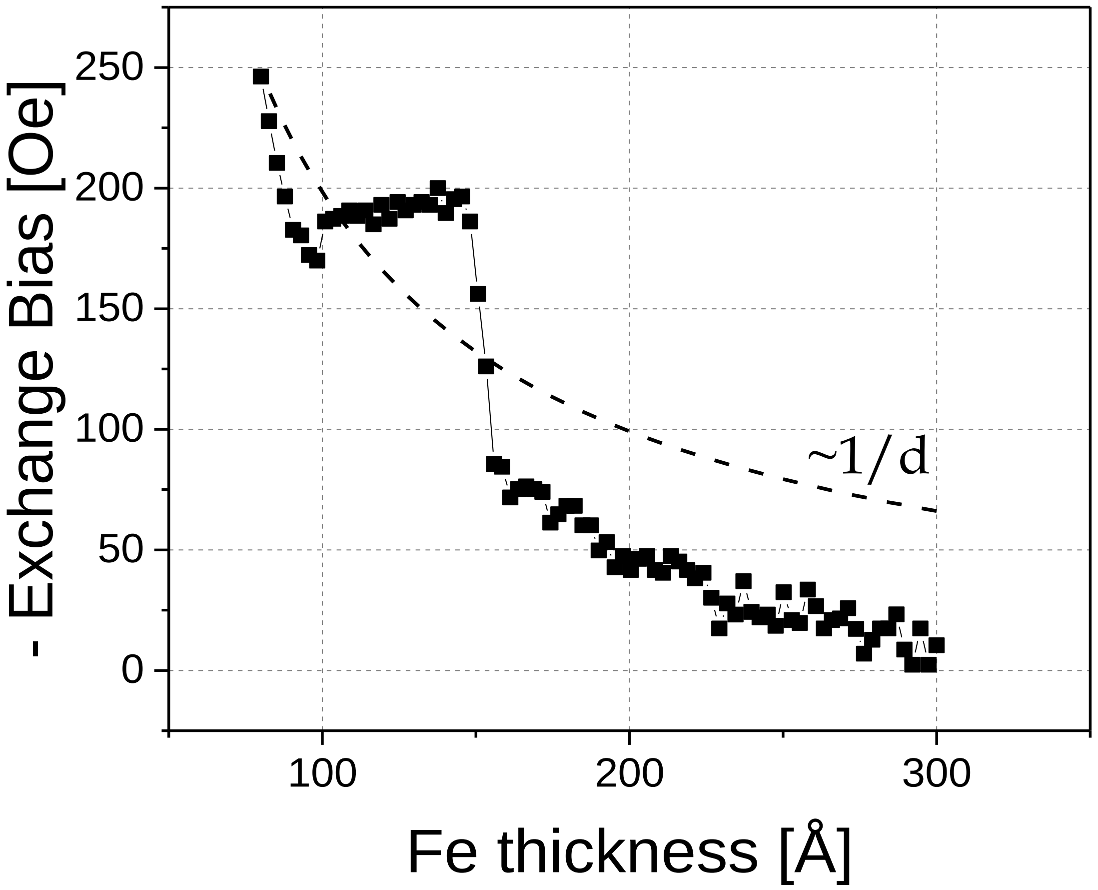
SRT in CoO/Fe

EB in CoO/Fe

Fe thickness

CoO(111) on Fe(110): evolution of magnetic hysteresis loops

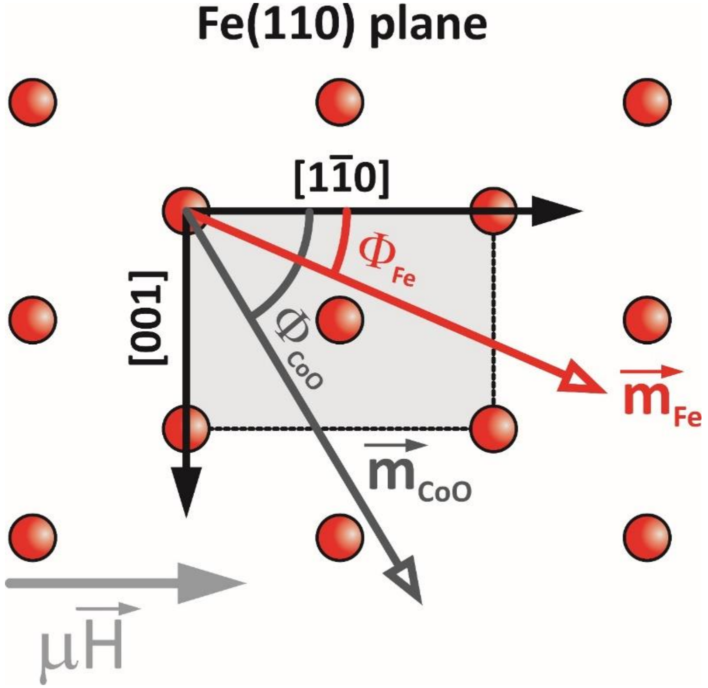




- Non-monotonous H_{eb} vs d dependence
- Not proportional to 1/d

CoO(111) on Fe(110): simulations of magnetic hysteresis loops

$$G(d_{Fe}, \Phi_{Fe}, \Phi_{CoO}) = E_{CoO}(\Phi_{CoO,} d_{Fe}) + E_{CoO\text{-}Fe}(\Phi_{CoO}, \Phi_{Fe}) + E_{Fe}(\Phi_{Fe,} d_{Fe}) + E_H$$



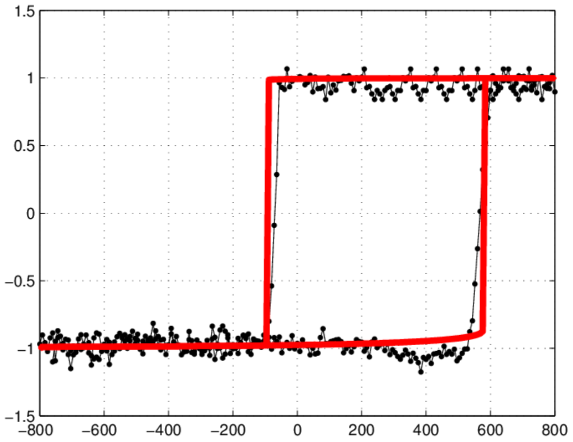
$$E_{CoO\text{-}Fe}(\Phi_{CoO}, \Phi_{Fe}) = - K_{EB}/d_{Fe} \cos(\Phi_{Fe} - \Phi_{CoO})$$

$$E_{Fe}(\Phi_{Fe,} d_{Fe}) = A \cos^2(\Phi_{Fe}) + B \cos^4(\Phi_{Fe})$$

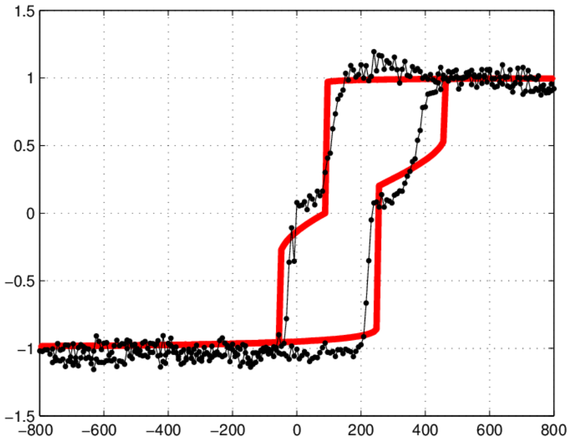
$$E_H = - M_s H \cos(\Phi_{Fe})$$

$G(\Phi_{Fe})$ minimization for each value of H → simulation of hysteresis curve

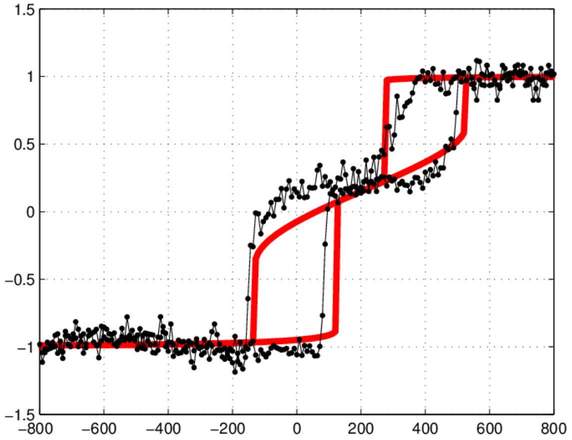
CoO(111) on Fe(110): simulations vs MOKE results



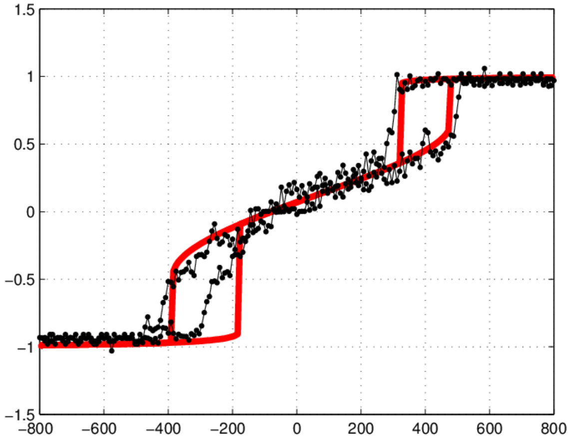
$d_{Fe} = 80$ Å



$d_{Fe} = 110$ Å

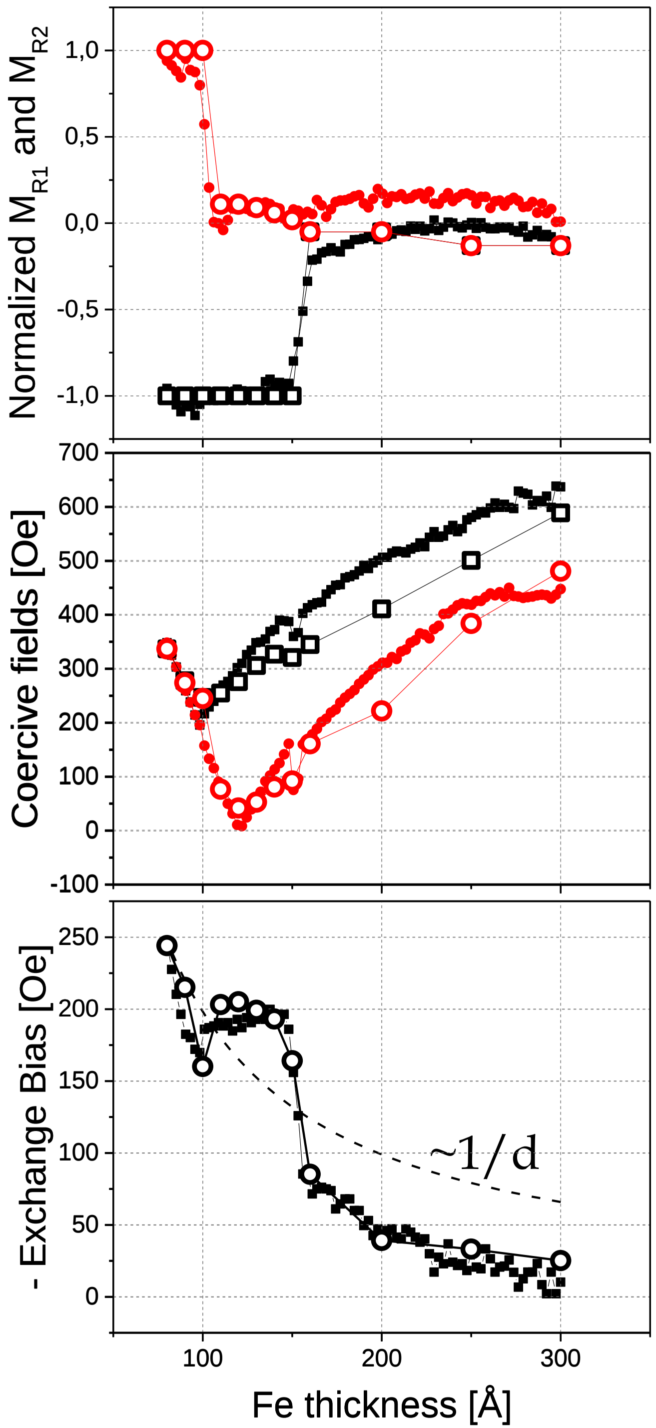


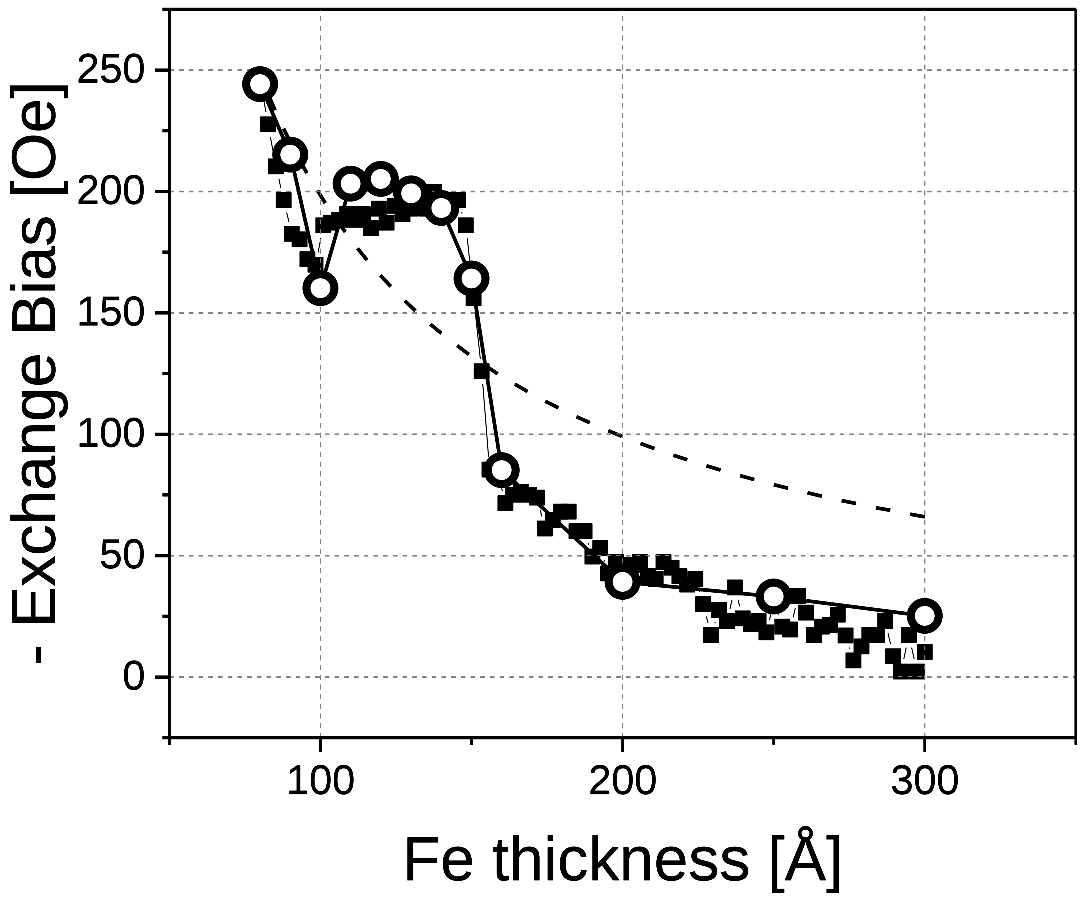
$d_{Fe} = 140$ Å



$d_{Fe} = 200$ Å

CoO(111) on Fe(110): simulations vs MOKE results





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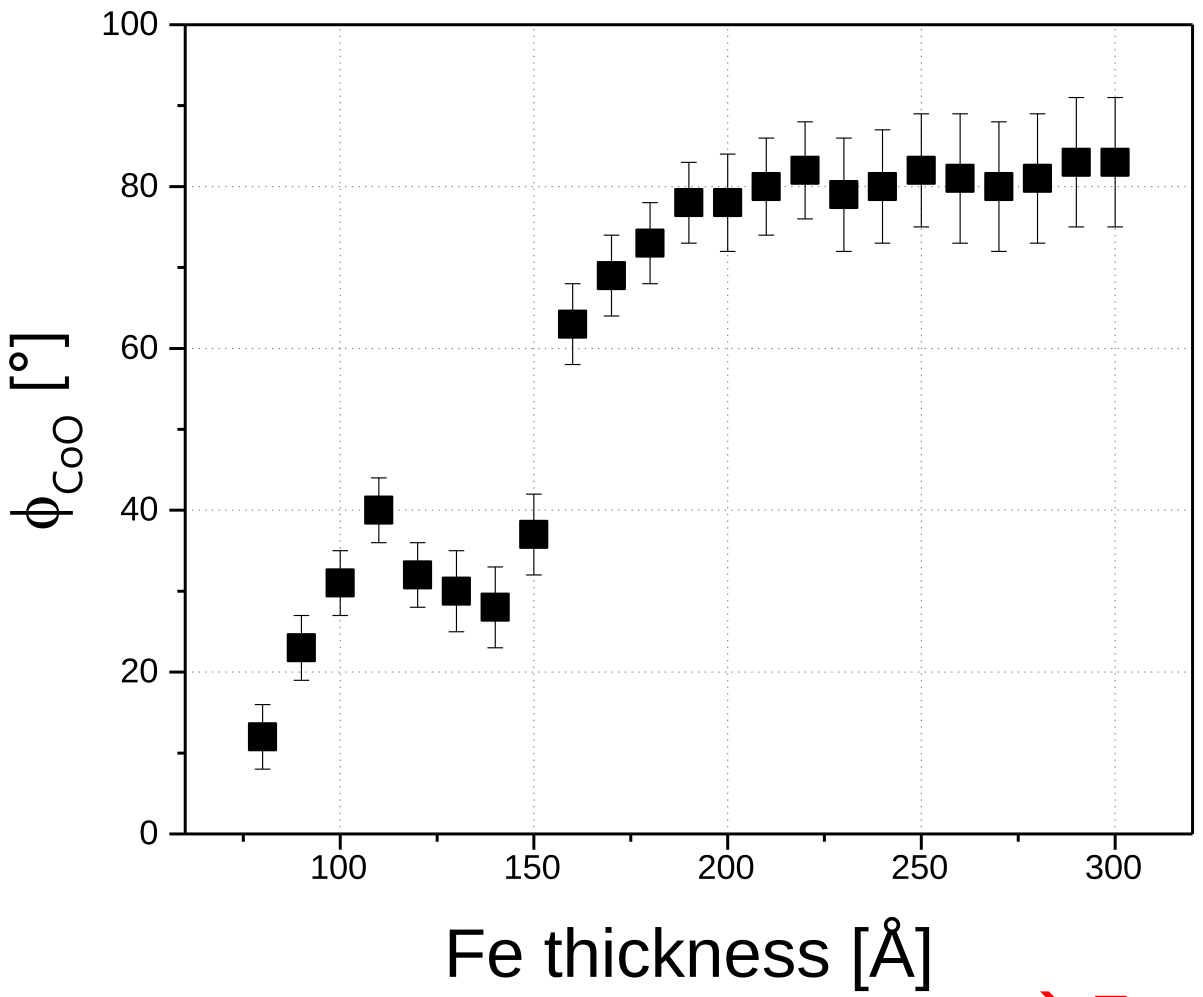
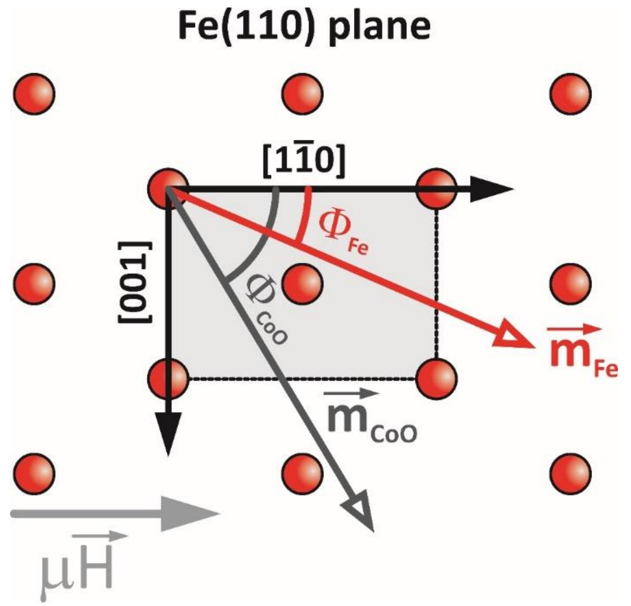
SRT in CoO(111)





→ Fe acts as a local magnetic field when passing T_N
→ Fe imprints magnetic anisotropy in CoO
→ SRT in Fe drives SRT in CoO

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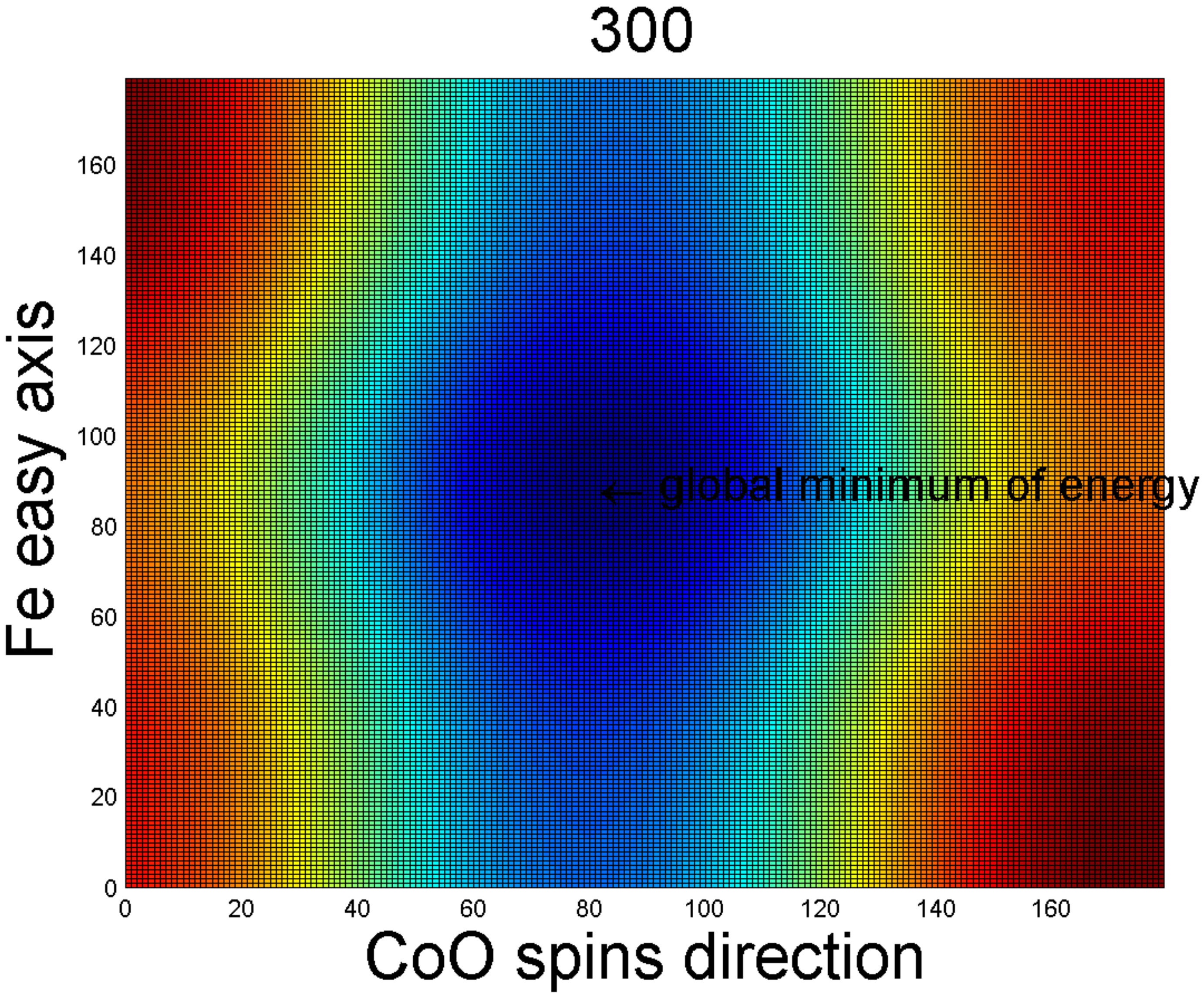
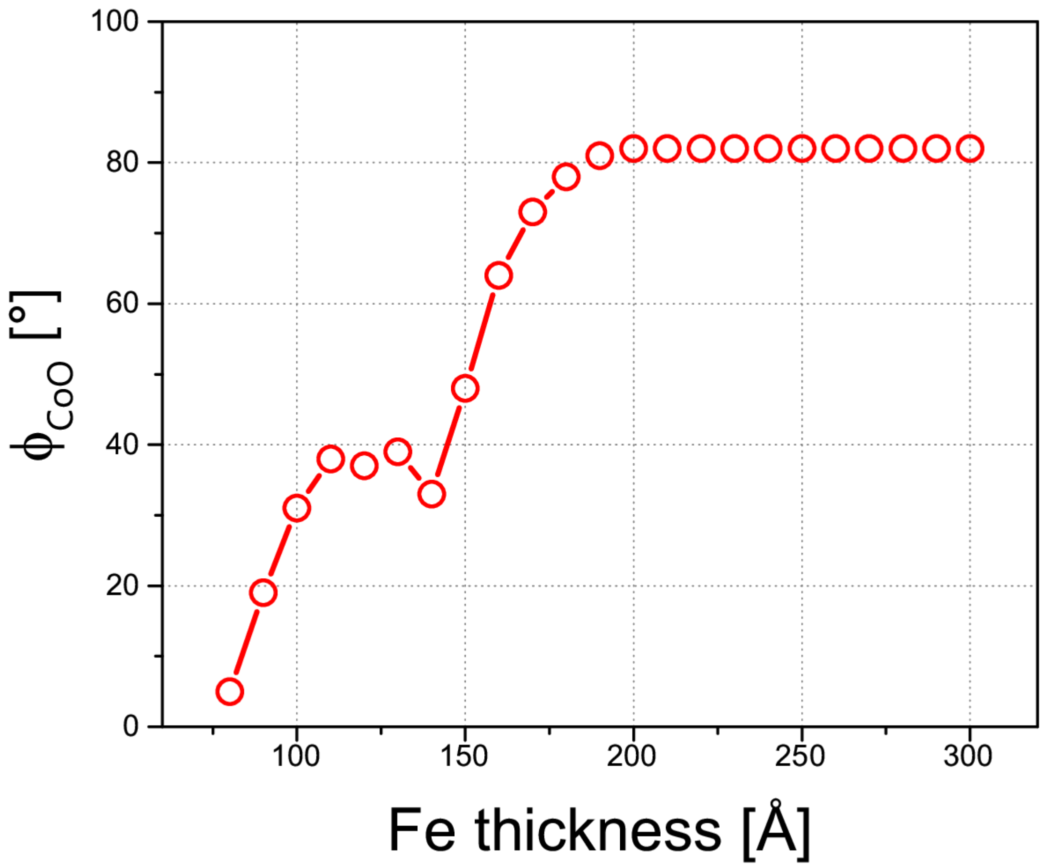
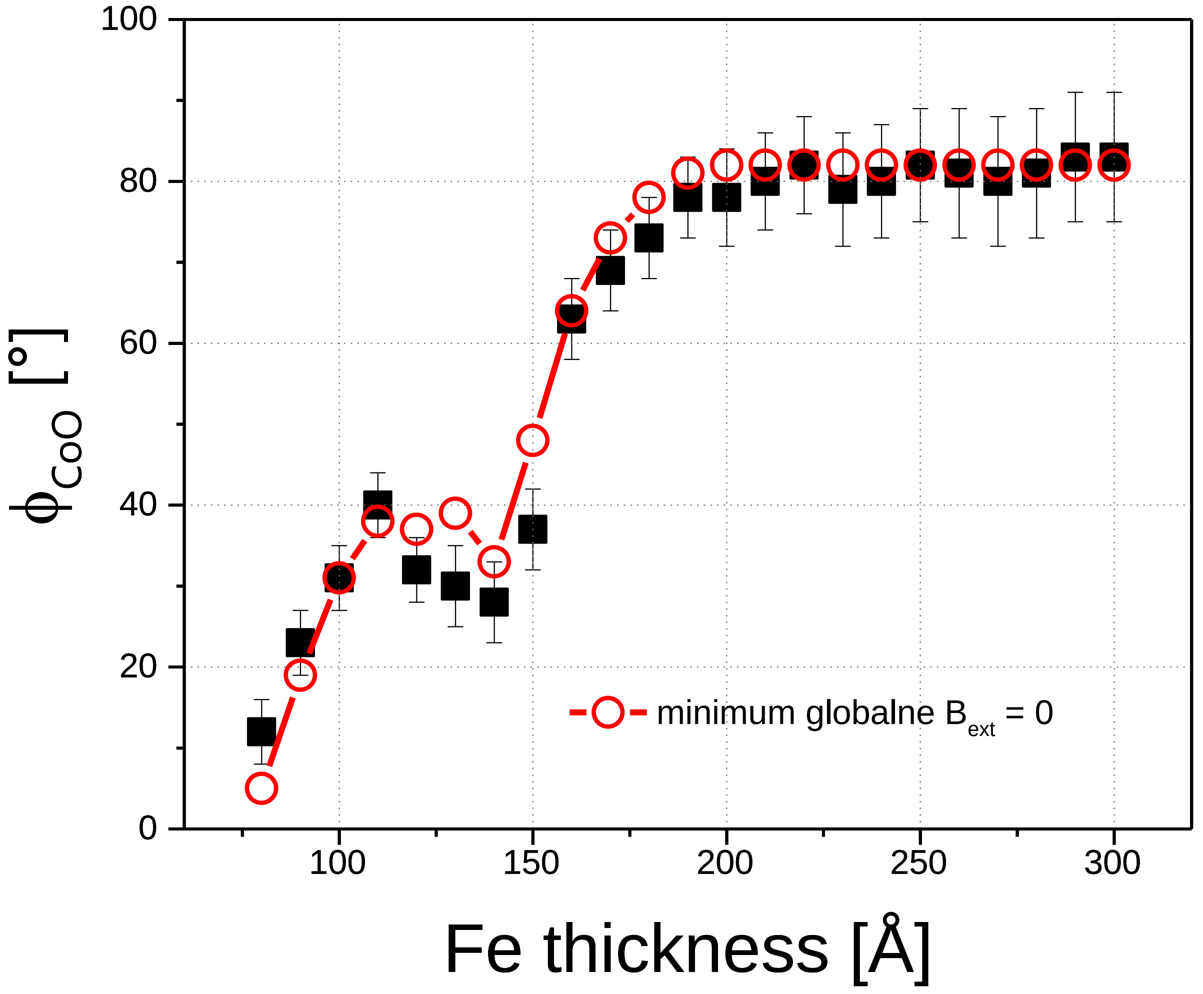
Mechanism of SRT in CoO(111): simulations





Origin of SRT in CoO(111)



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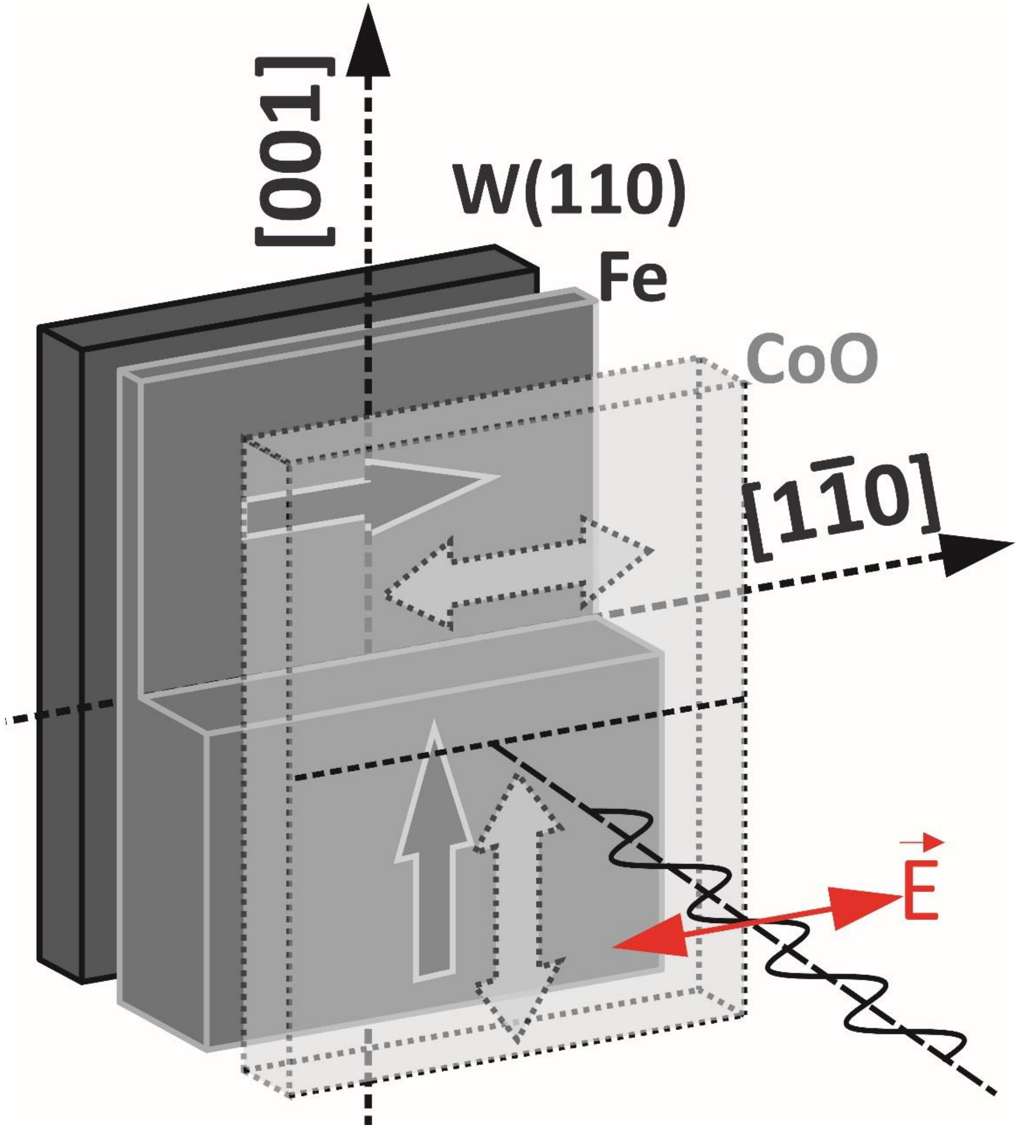
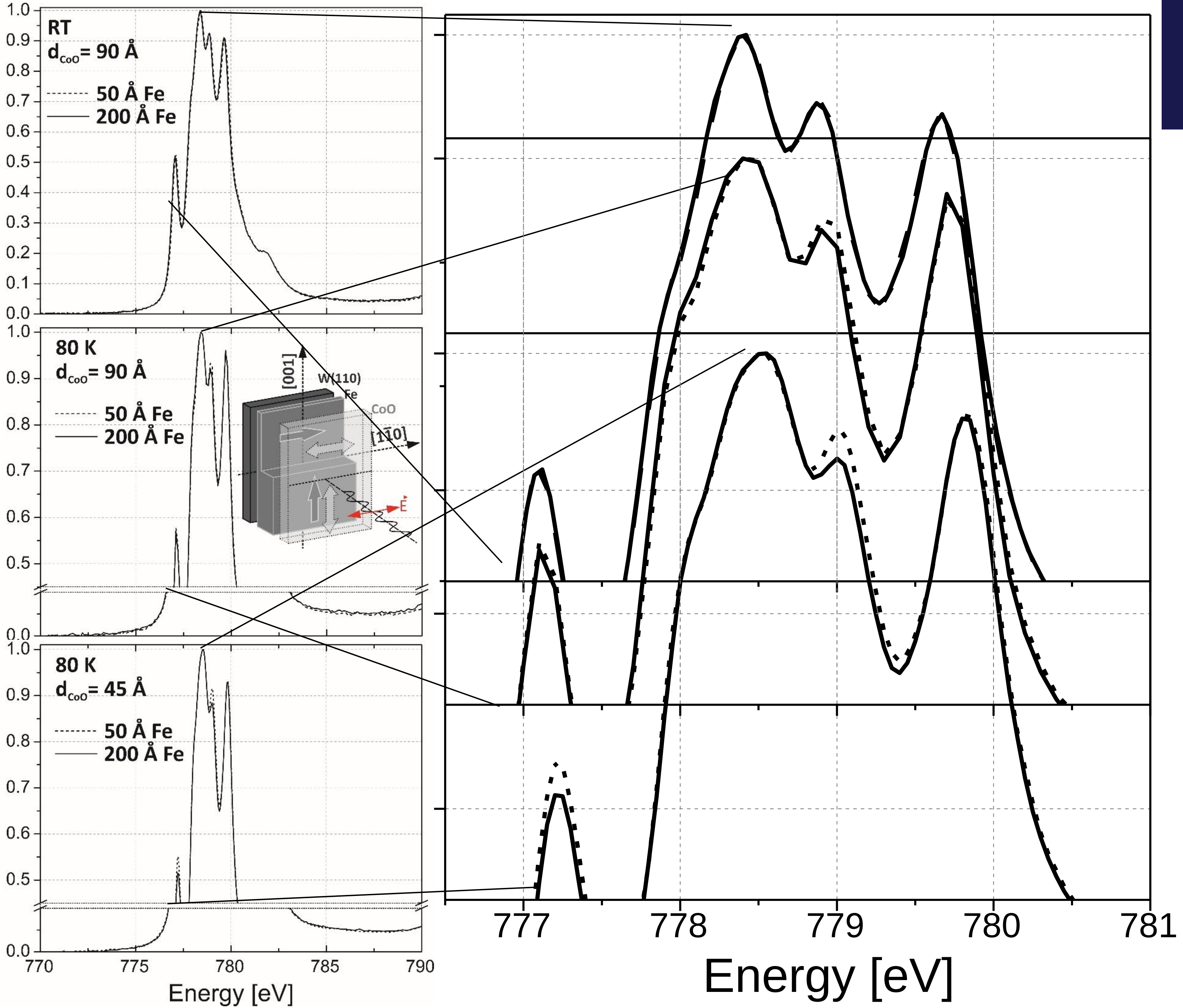
Looking for direct evidence of SRT in CoO: XMLD @ Solaris, XAS end-station



Direct evidence of SRT in CoO: XMLD



→ rotation of CoO spins from Fe[1-10] to Fe[001]

following the XMLD analysis by Li et al., Phys. Rev. B **91,** 104424 (2015)

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