Epitaksjalne warstwy CoO(111)/Fe(110) i NiO(111)/Fe(110) czyli jak ferromagnetyk steruje antyferromagnetykiem

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A. Locatelli

Plan prezentacji

- Inżynieria anizotropii magnetycznej na powierzchni Fe(110):
    - **Reorientacja spinowa (SRT) w Fe(110)**
    - Au/Fe(110)

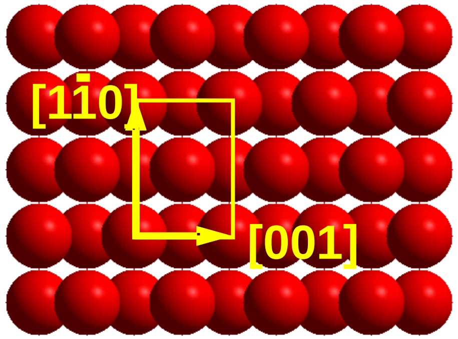
- Inżynieria anizotropii magnetycznej w **antyferromagnetykach**:
    - Efekt polaryzacji wymiennej (Exchange Bias**)**
    - CoO(111)/Fe(110) – „zamrażanie" spinów AFM
    - NiO(111)/Fe(110) – reorientacja spinów AFM

- Plany na przyszłość

Wprowadzenie

Reorientacja spinowa (Spin Reorientation Transition) w Fe/W(110)

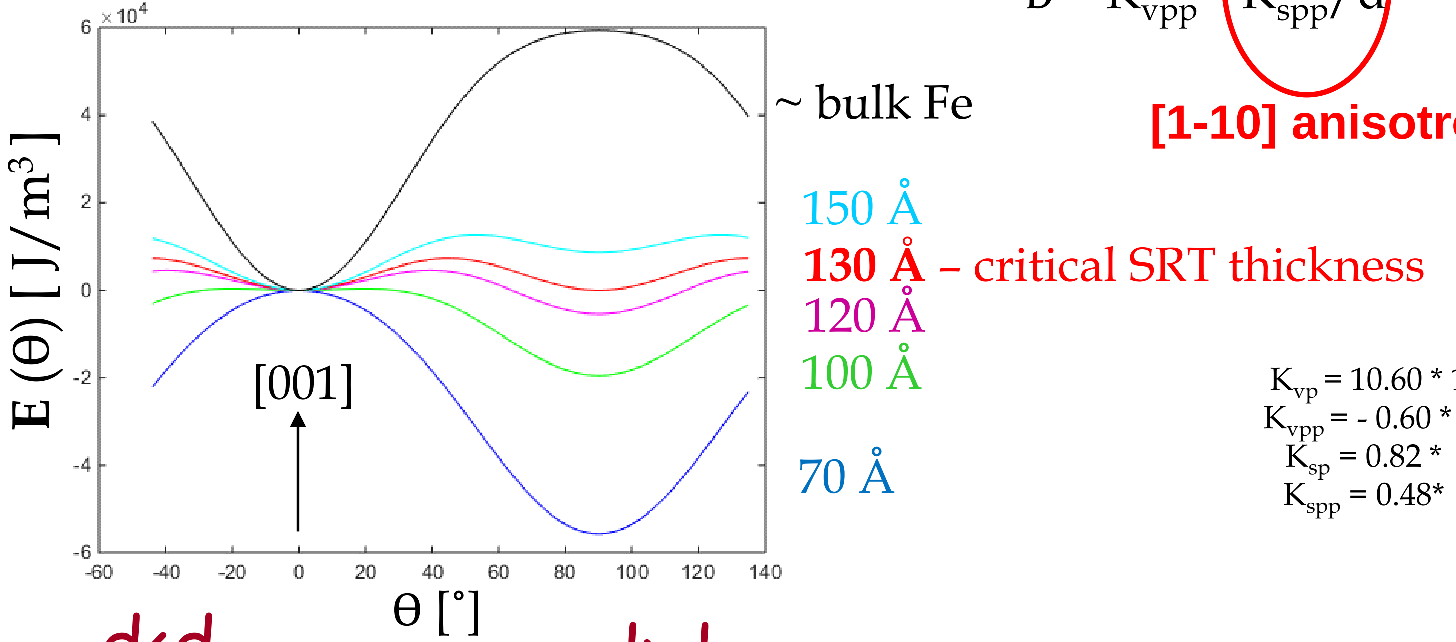
Fe(110)



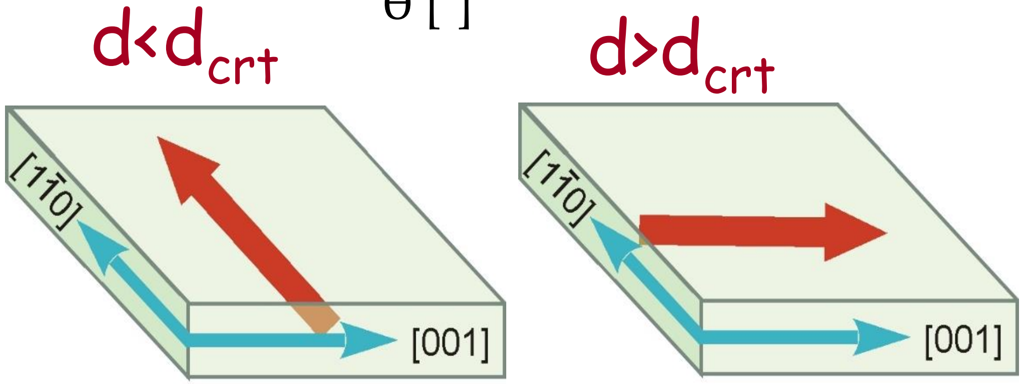
$$E_{m\ in\text{-}plane}(\Theta) = A \sin^2(\Theta) + B \sin^4(\Theta)$$

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

[1-10] anisotropy

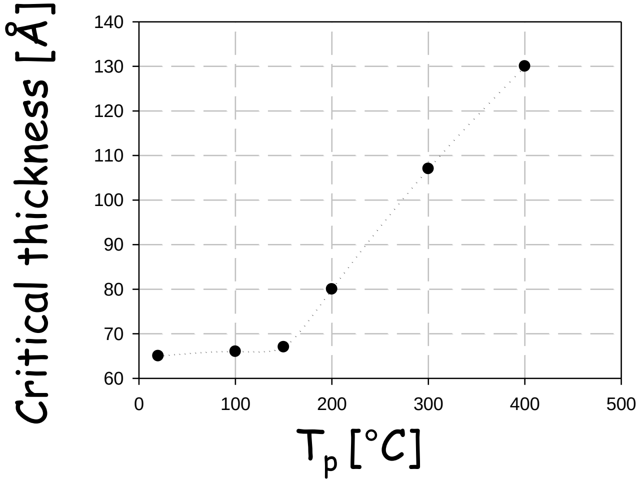


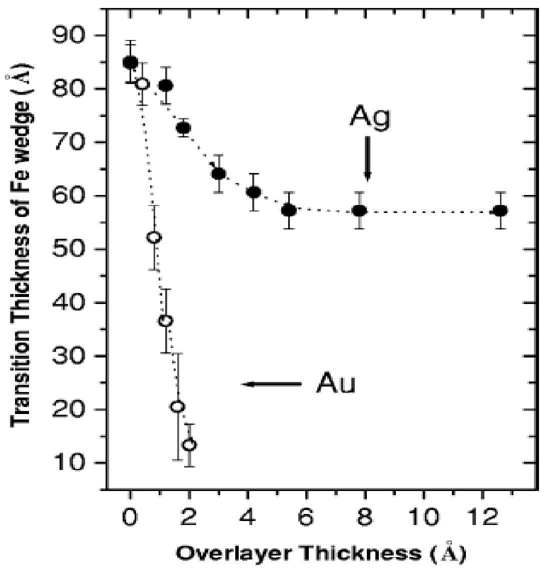
$K_{vp} = 10.60 * 10^4\ J/m^3$
$K_{vpp} = -\ 0.60 * 10^4\ J/m^3$
$K_{sp} = 0.82 *\ mJ/m^2$
$K_{spp} = 0.48 *\ mJ/m^2$



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

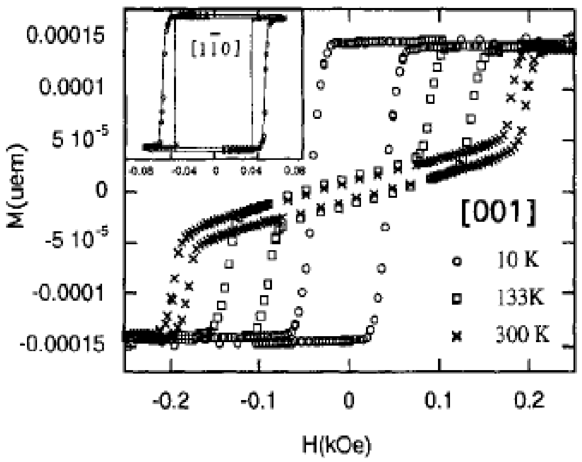
Magnetic surface anisotropy modifications





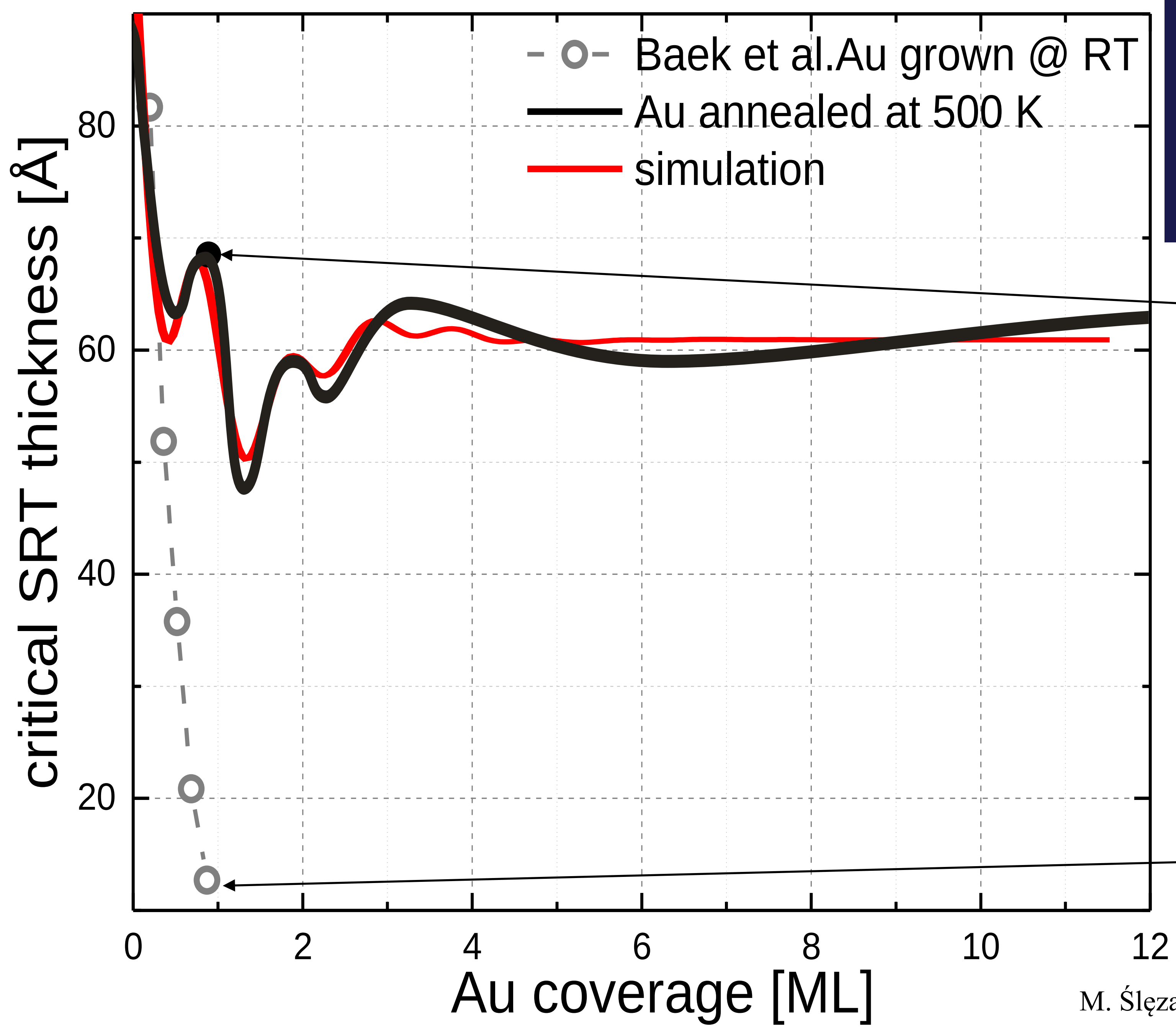
Albrecht et al., *JMMM 113 (1992) 207-220*

d=6nm



Fruchart et al., *PRB 67, 075401 (2003)*
Baberschke et al. *PRB 47 (1993) 11204*

Au/Fe(110): oscillating magnetic anisotropy



KS orientation of Au(111)/Fe(110)
$[1\text{-}10]_{Au}$ II $[111]_{Fe}$

2 oscillating components:

- **Au monolayer** period
- ~ **4 ML Au** period

NW orientation of Au(111)/Fe(110)
$[1\text{-}10]_{Au}$ II $[001]_{Fe}$

M. Ślęzak, P. Dróżdż, K. Matlak, A. Kozioł-Rachwał, J. Korecki, T. Ślęzak, JMMM 497, 165963 (2020)

Układy dwuwarstwowe AFM/FM

CoO/Fe(110)

NiO/Fe(110)

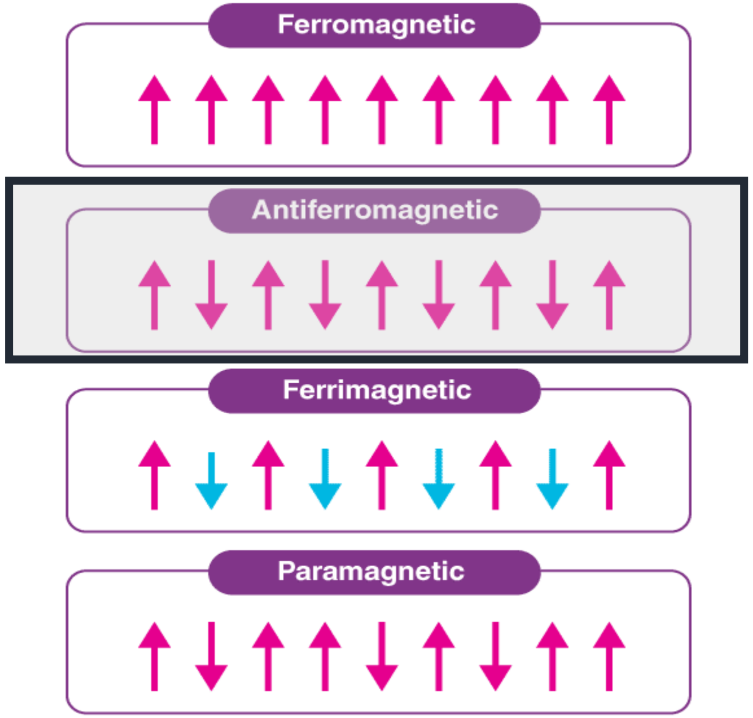
Antyferromagnetyki - motywacja

LOUIS NÉEL

Magnetism and the local molecular field

Nobel Lecture, December 11, 1970

„They are **extremely interesting** from the theoretical viewpoint, but do not seem to have **any applications**"



The 2020 magnetism roadmap

E. Y. Vedmedenko et al 2020 J. Phys. D: Appl. Phys.53 453001

„the future of spintronics is related to new materials, with **antiferromagnets** as promising nominees."

- robust against external magnetic fields
- produce no stray fields
- display ultrafast dynamics
- large magnetotransport effects

Odkrycie zjawiska *exchange bias*

Phys. Rev., 105, 904 (1957)

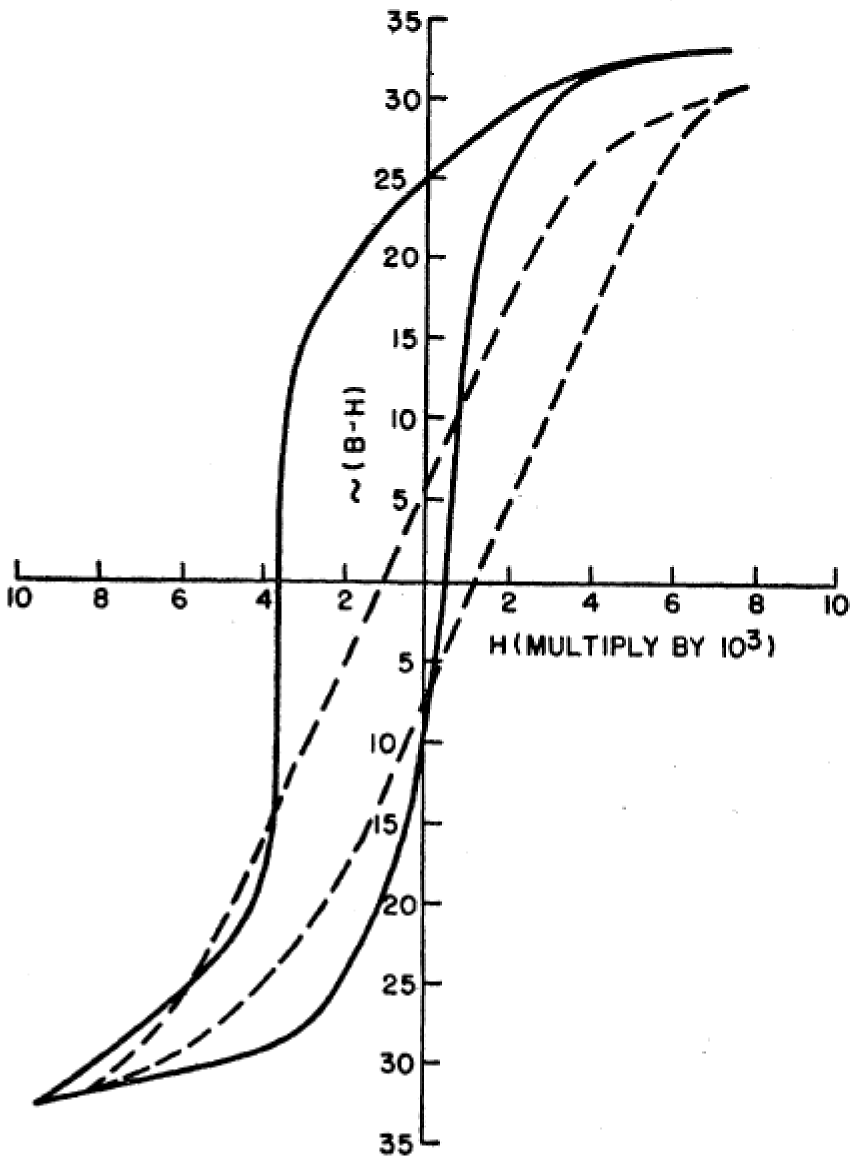
New Magnetic Anisotropy

W. H. Meiklejohn and C. P. Bean

General Electric Research Laboratory, Schenectady, New York

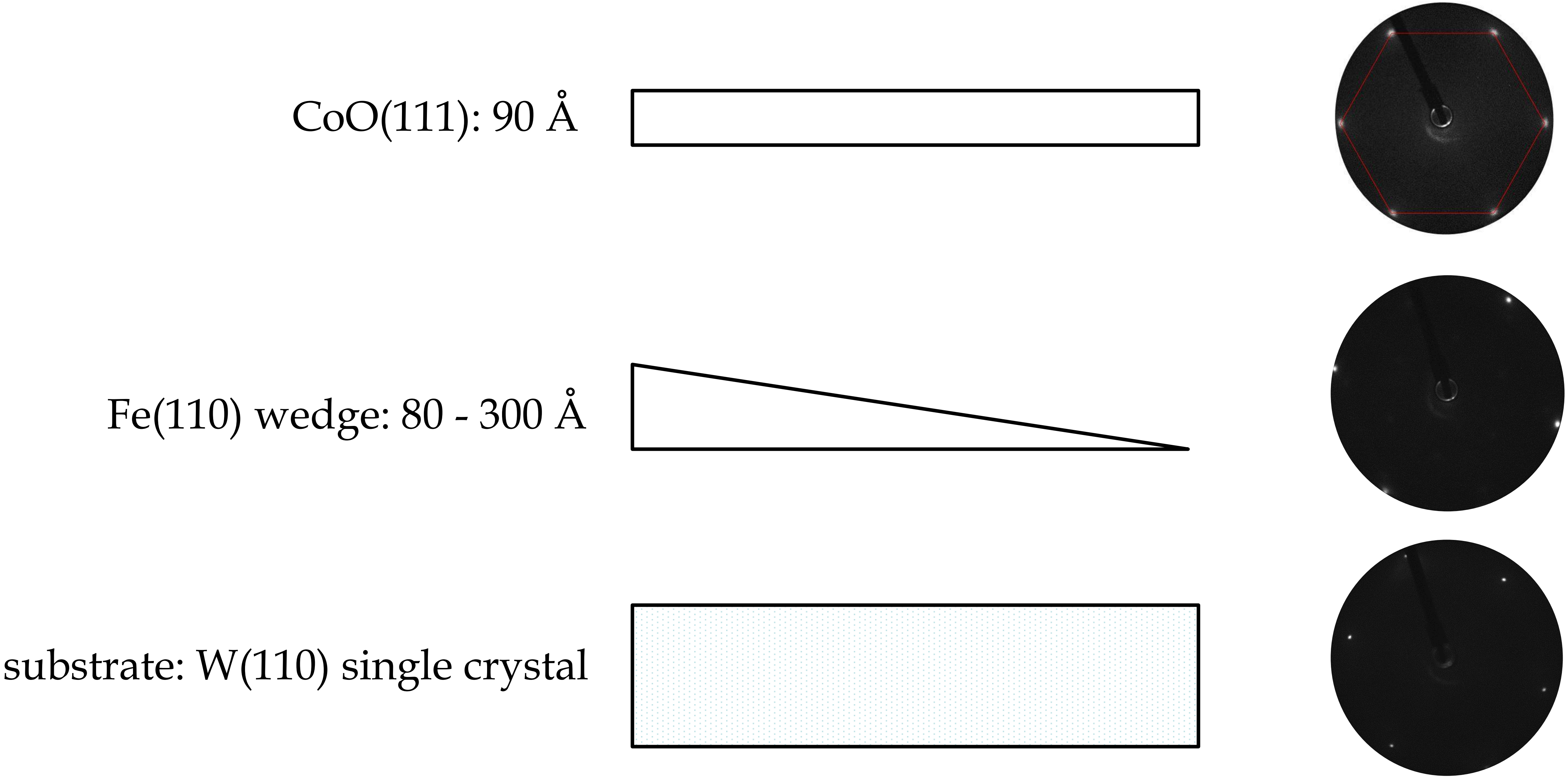
(Received March 7, 1956)

Co particles embedded in their native antiferromagnetic oxide CoO

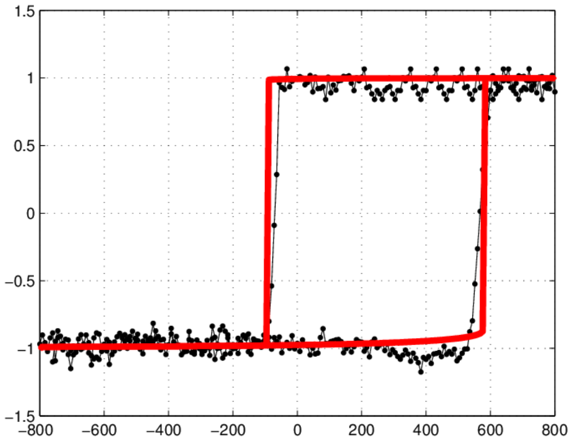


W. H. Meiklejohn and C. P. Bean, Phys. Rev. 102, 1413 (1956).
W. H. Meiklejohn and C. P. Bean, Phys. Rev. 105, 904 (1957).

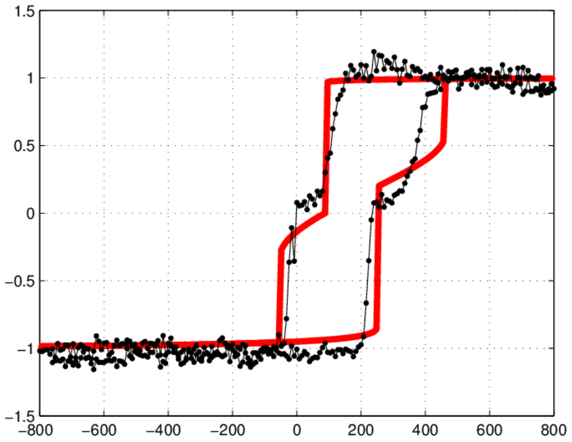
CoO/Fe(110)


CoO(111): 90 Å
Fe(110) wedge: 80 - 300 Å
substrate: W(110) single crystal

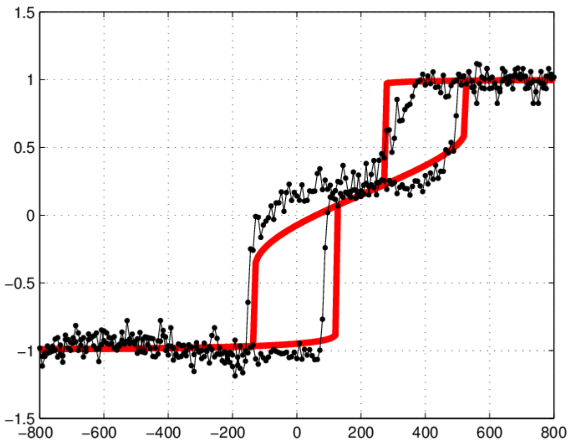
CoO(111) on Fe(110): simulations vs MOKE results



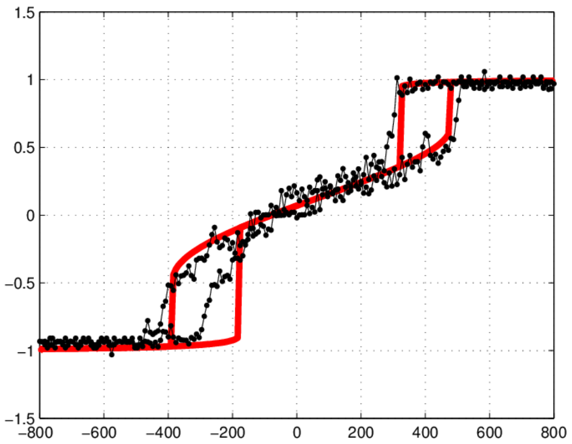
d_{Fe} = 80 Å



d_{Fe} = 110 Å

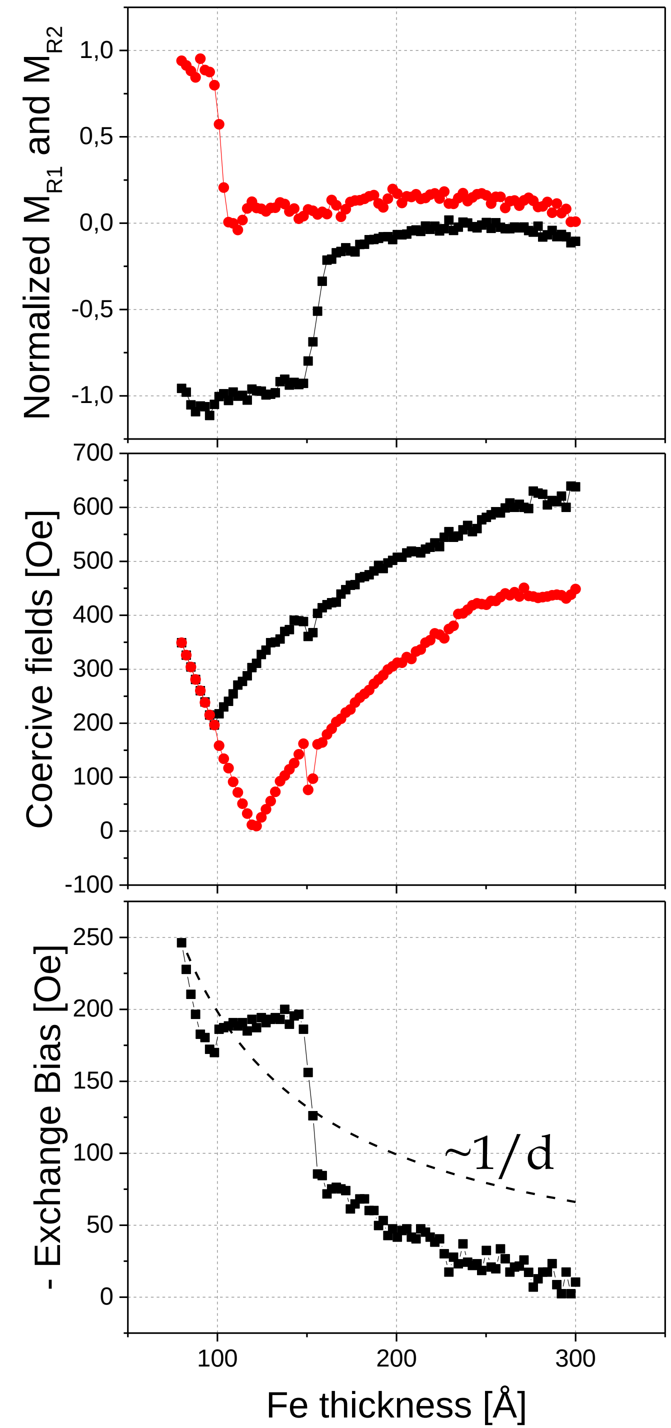


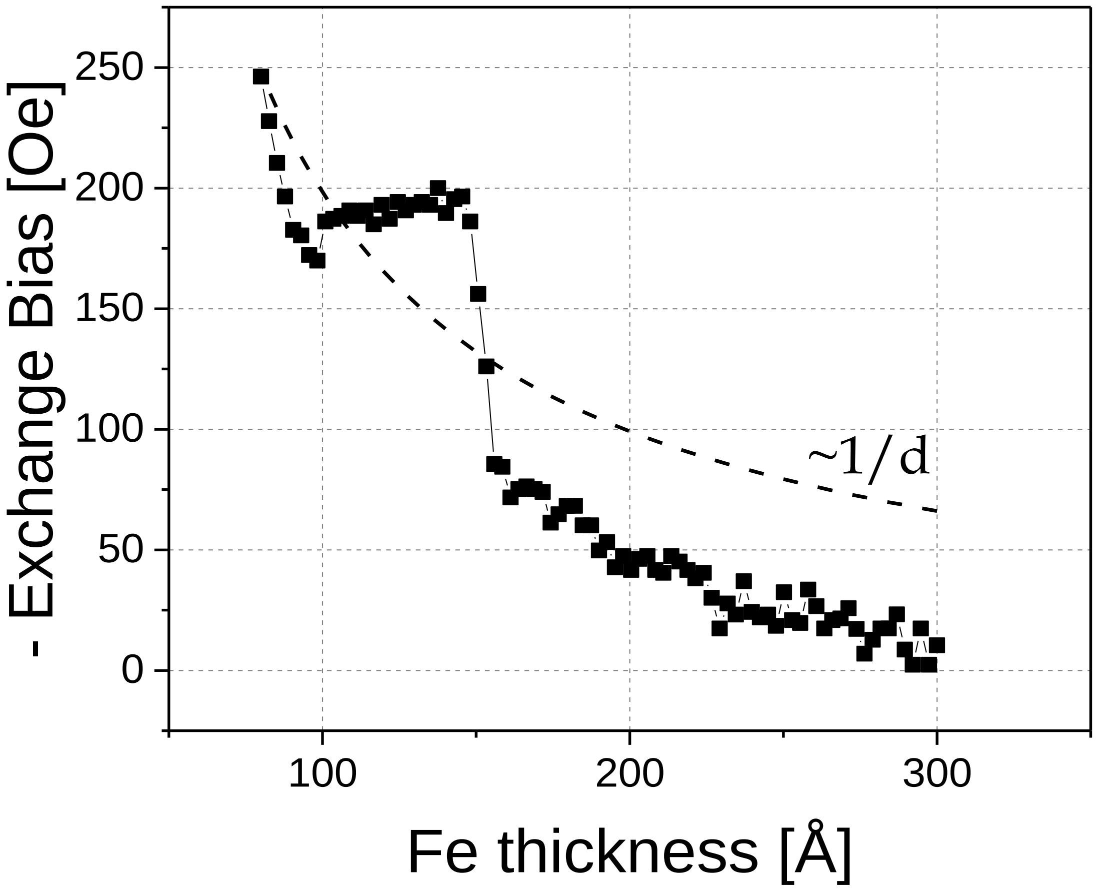
d_{Fe} = 140 Å



d_{Fe} = 200 Å

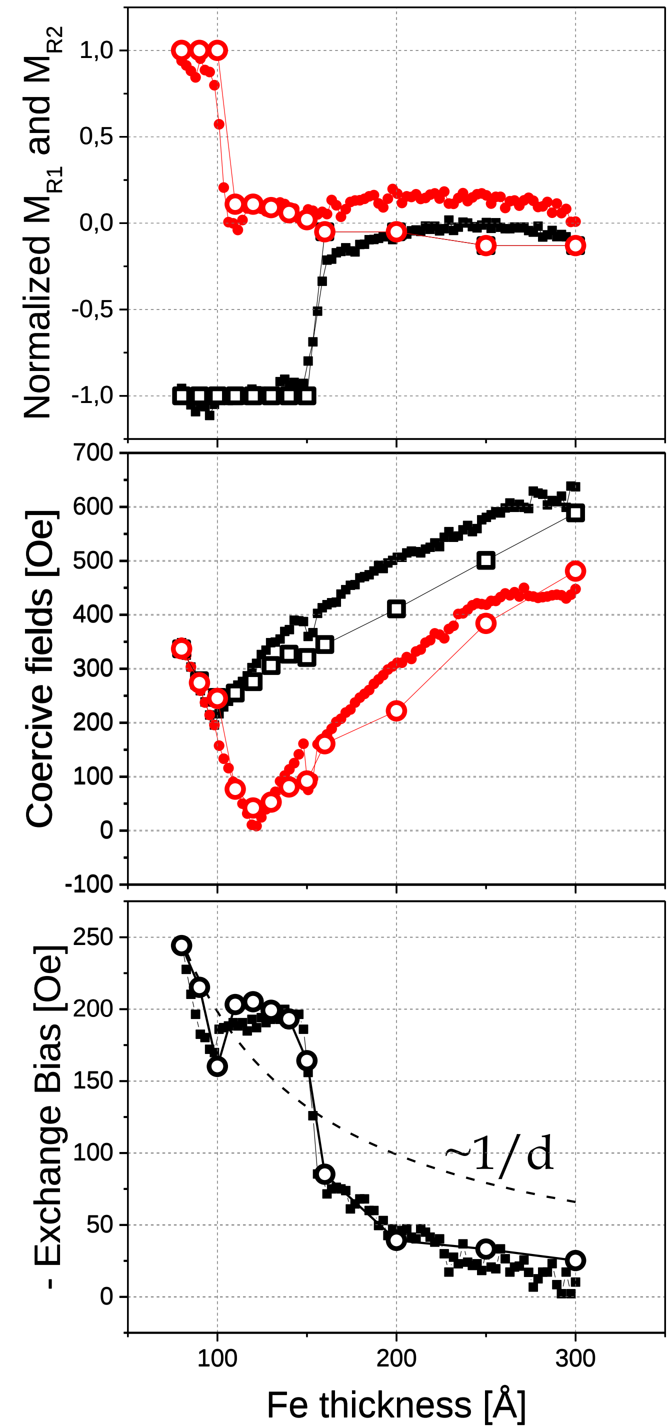
CoO(111) on Fe(110): evolution of magnetic hysteresis loops

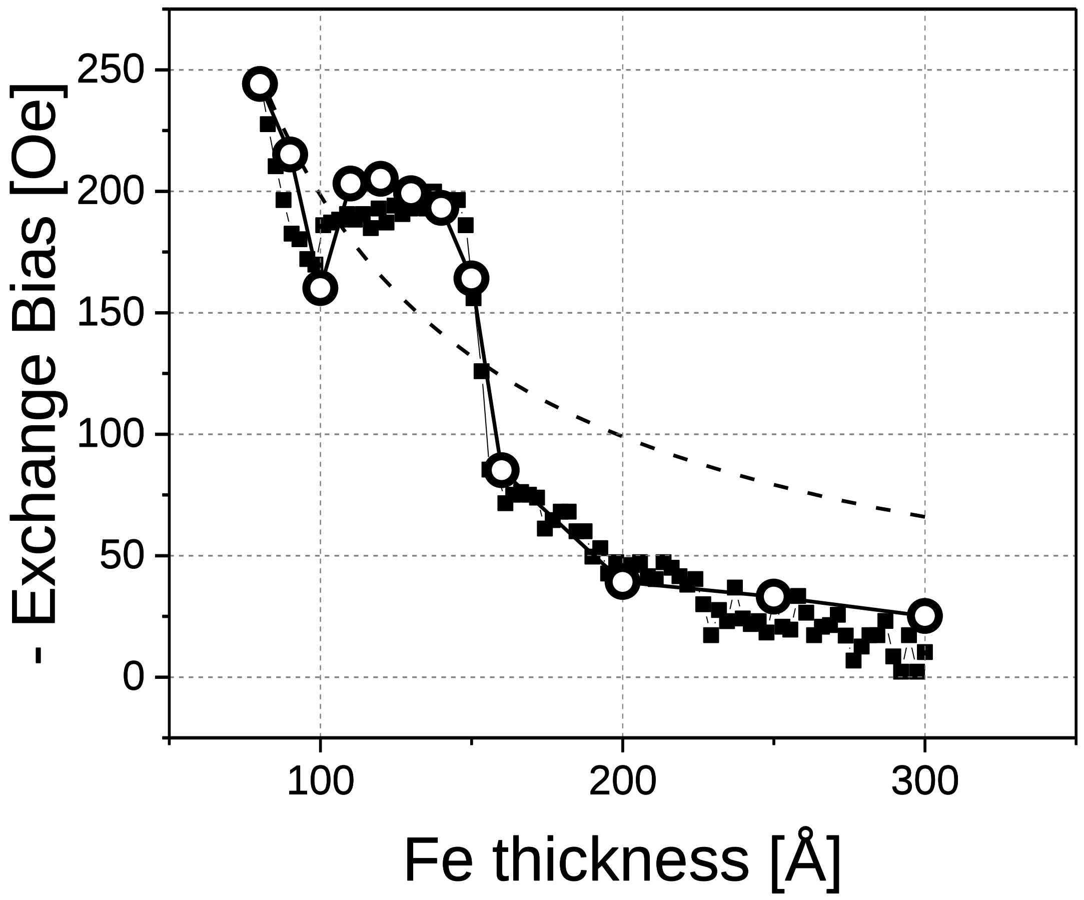




- Non-monotonous H_{eb} vs d dependence
- Not proportional to 1/d

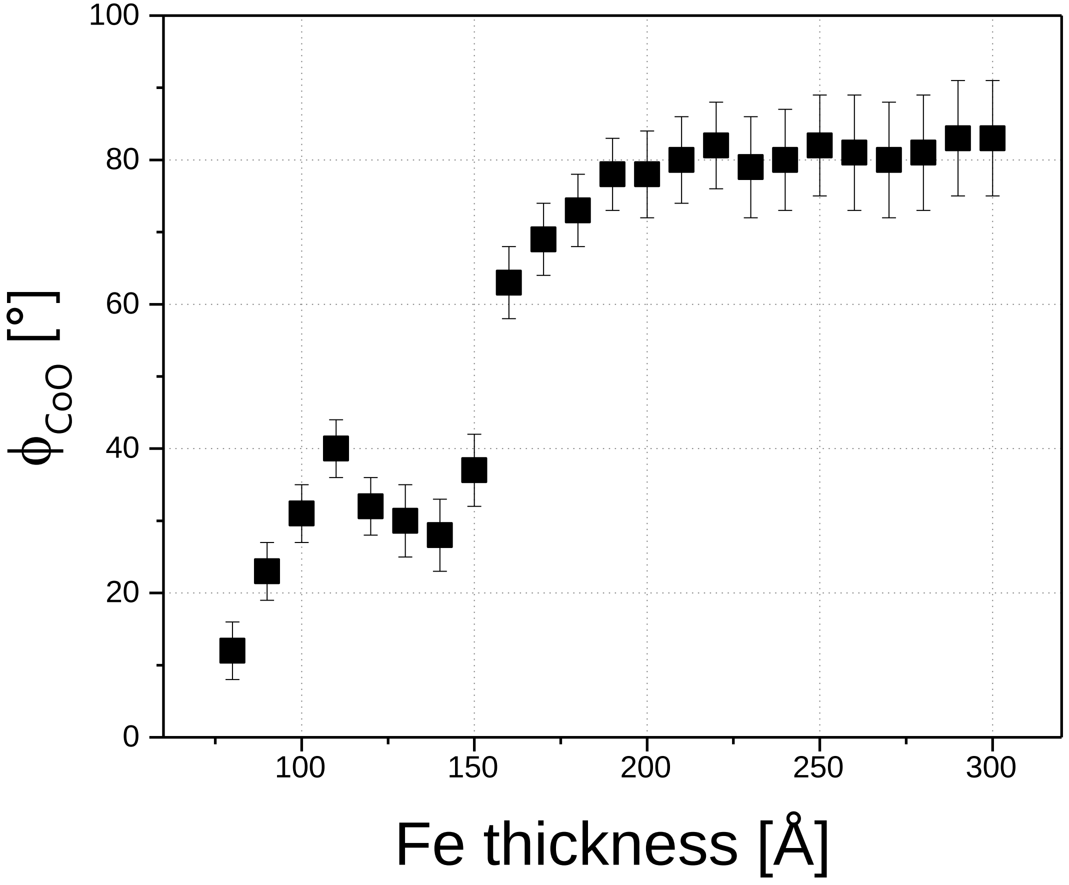
CoO(111) on Fe(110): simulations vs MOKE results

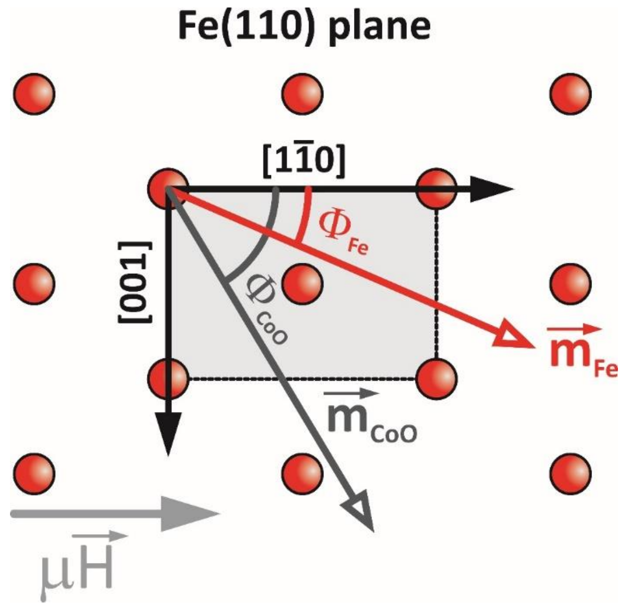




M. Ślęzak et al., Scientific Reports 9 (2019) 889

Reorientacja spinowa w CoO(111)

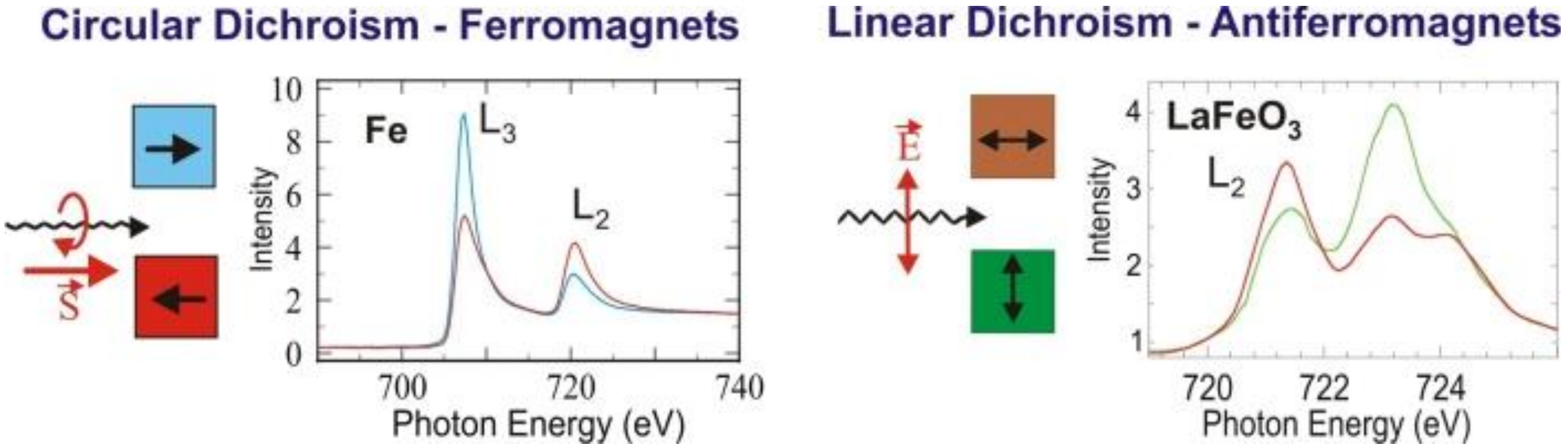




- Fe działa jak lokalne pole magnetyczne przy przekraczaniu T_N
- Fe „zamraża” spiny CoO wzdłuż wybranego kierunku

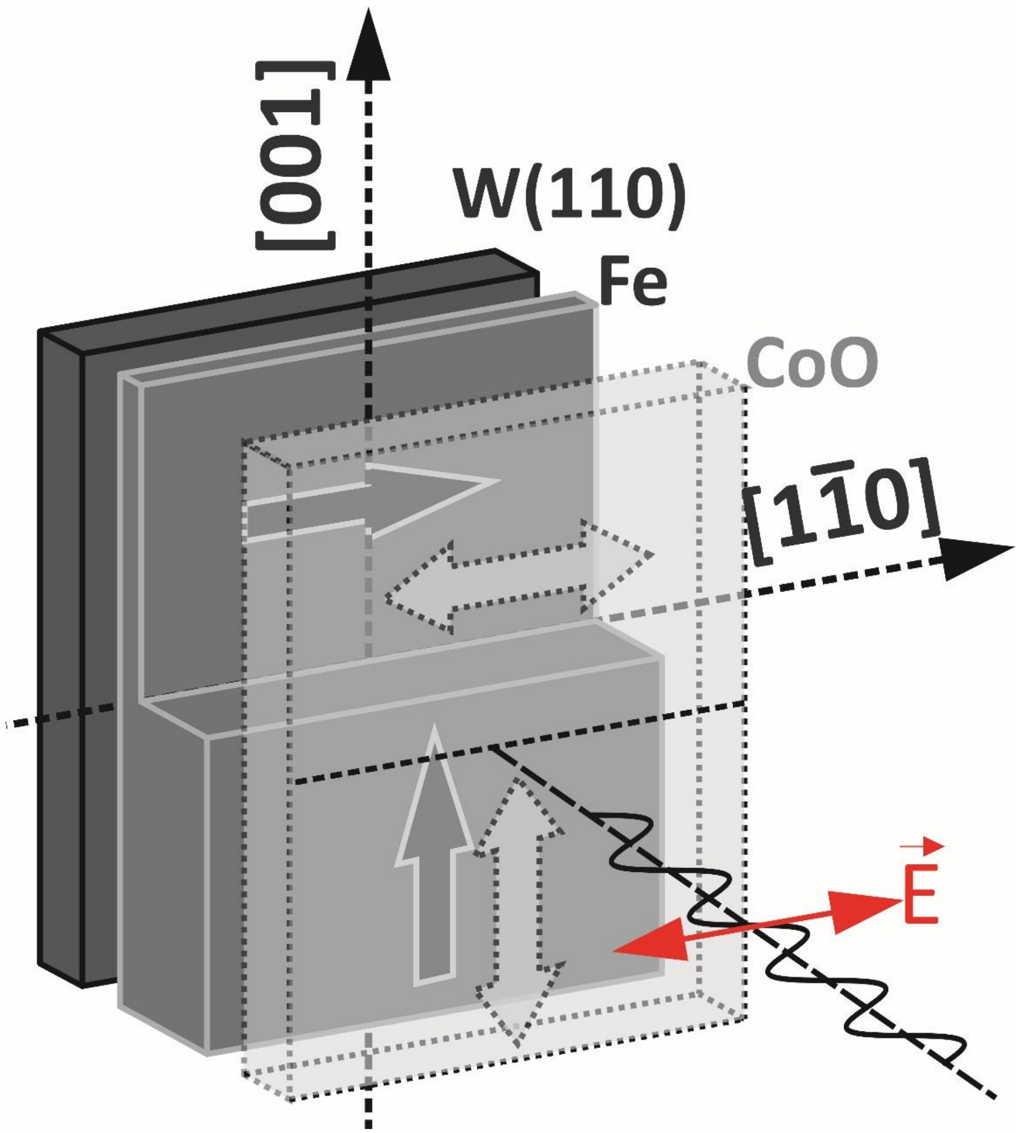
M. Ślęzak et al., Scientific Reports 9 (2019) 889

XMCD i XMLD

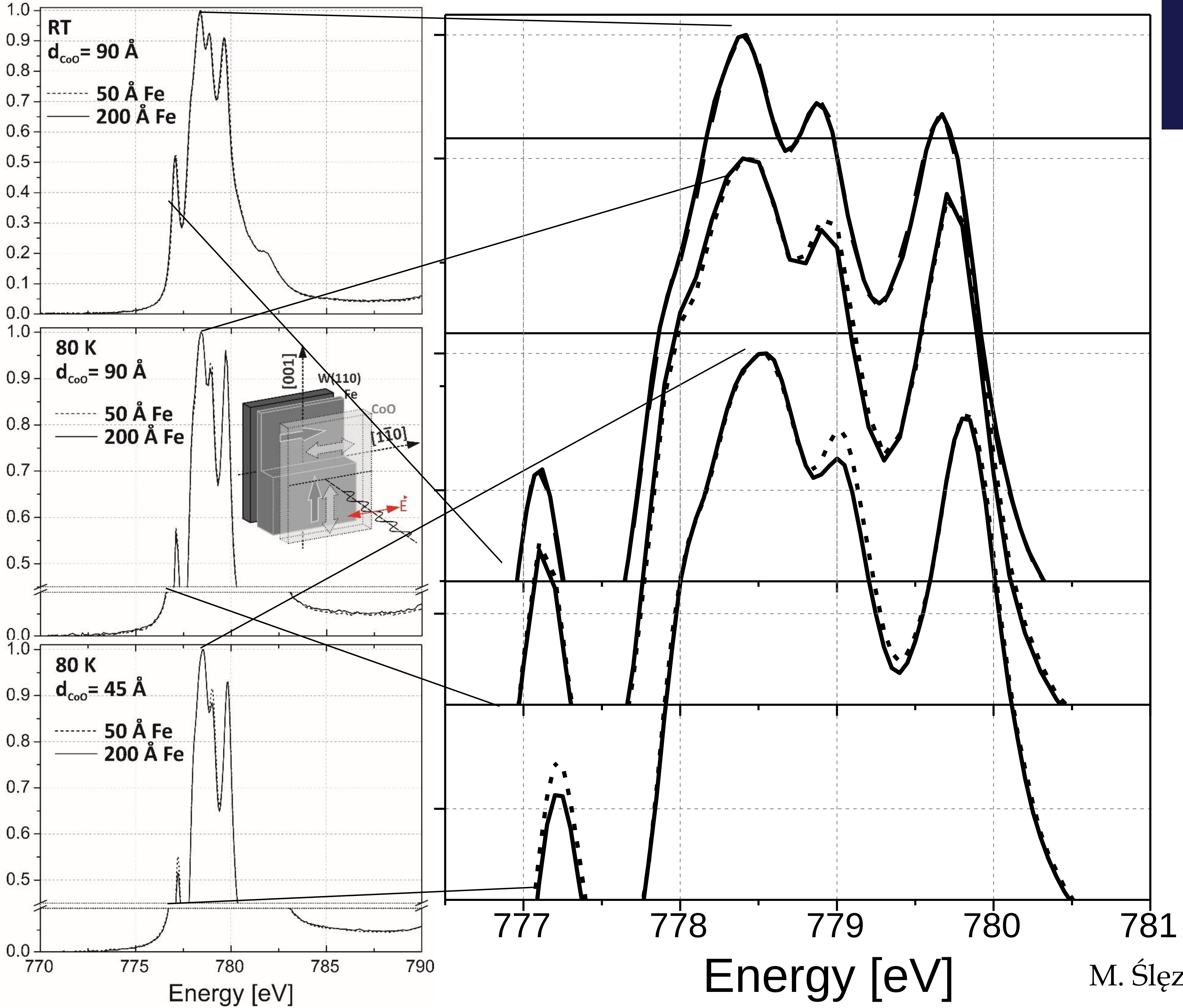


Circular Dichroism - Ferromagnets
Linear Dichroism - Antiferromagnets
Fe
L3
L2
Intensity
Photon Energy (eV)
0
2
4
6
8
10
700
720
740
S
E
LaFeO3
L2
Intensity
1
2
3
4
720
722
724
Photon Energy (eV)

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]

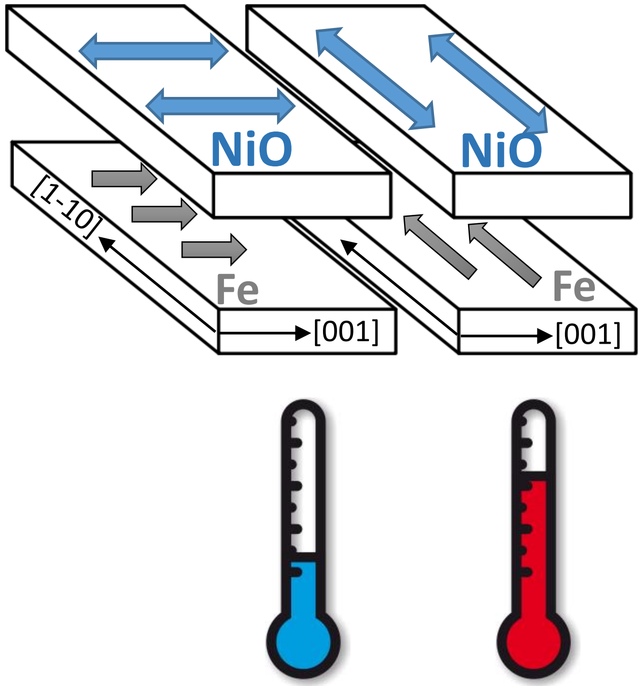
following the XMLD analysis by Li et al., Phys. Rev. B **91,** 104424 (2015)

M. Ślęzak et al., Scientific Reports 9 (2019) 889

NiO(111)/Fe(110):

idea przełączania spinów AFM w układzie jednorodnym, bez użycia pola, prądu, itp.

(ustalona grubość warstw Fe i NiO)



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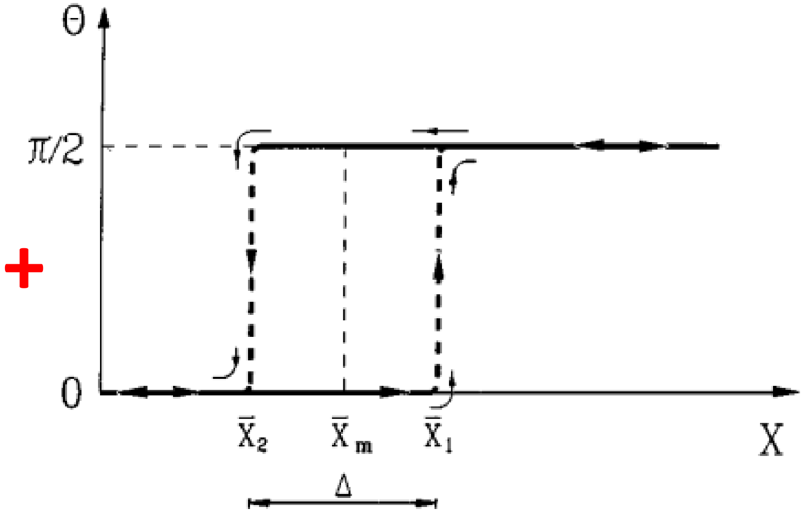

Y.Millev, J. Kirschner, PRB 54 (1996) 6

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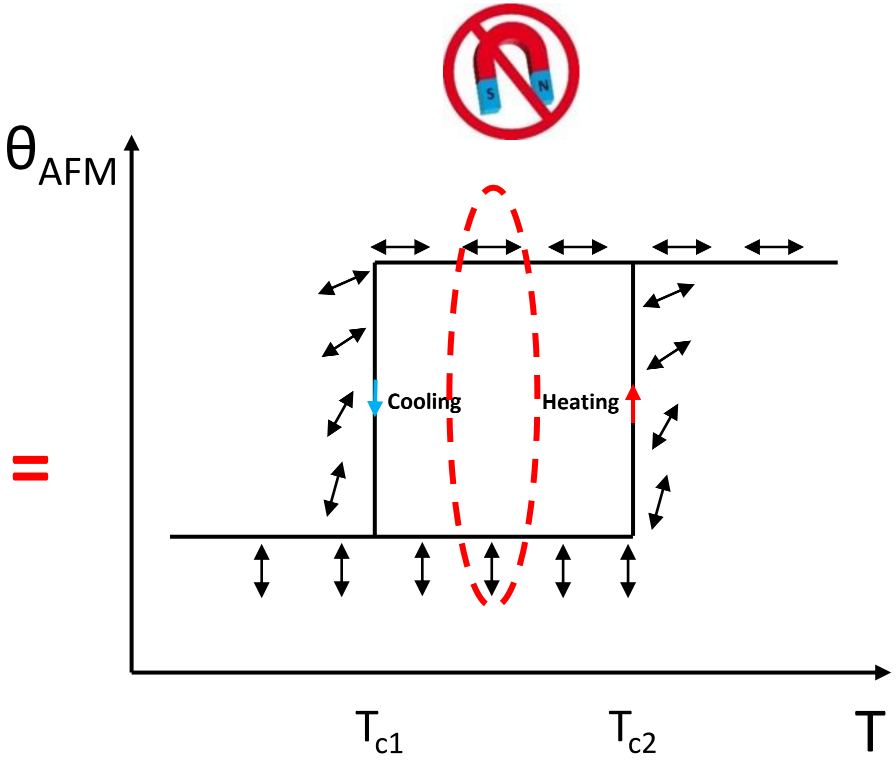
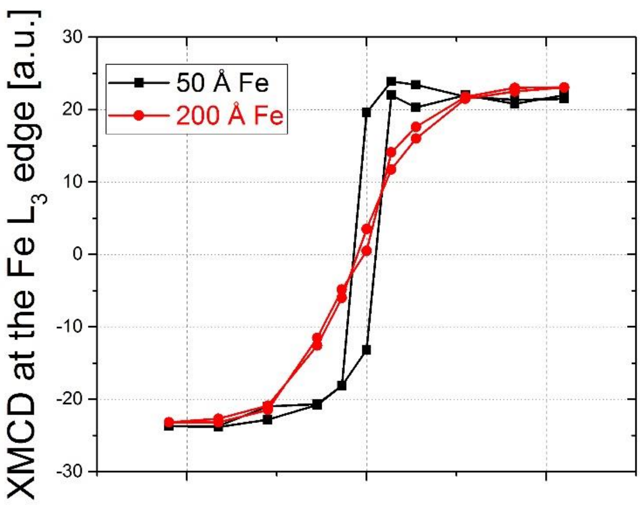


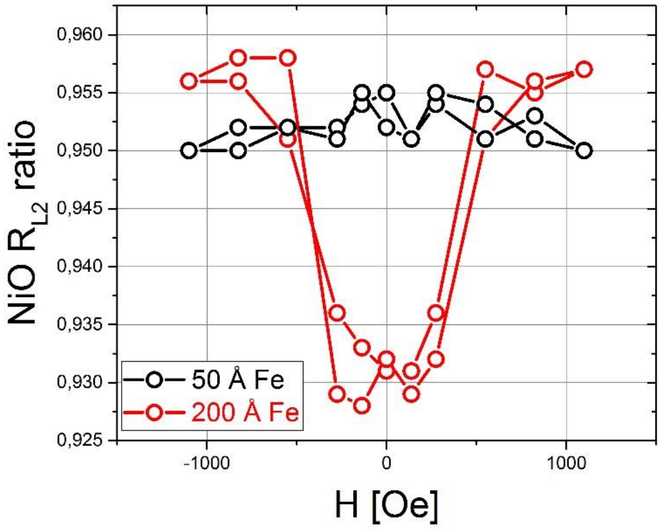
NiO: mała anizotropia magnetyczna
→ spiny NiO „**rotatable**"

Temperaturowe **SRT** w Fe, **histereza**

2 możliwe orientacje spinów AFM w NiO, w danej temperaturze przełączanie „field-free"

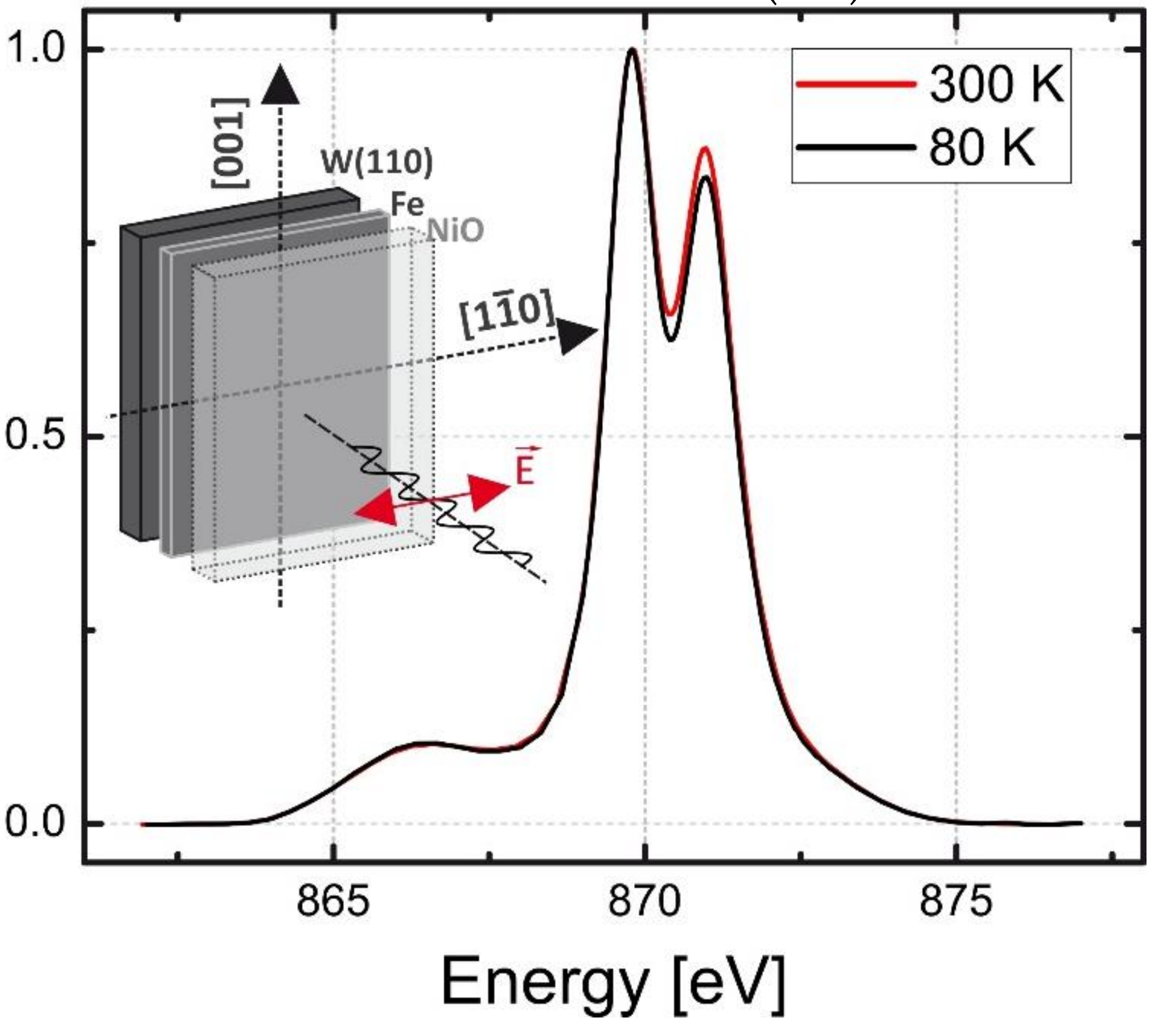
NiO(111)/Fe(110): field-free switching of AFM spins



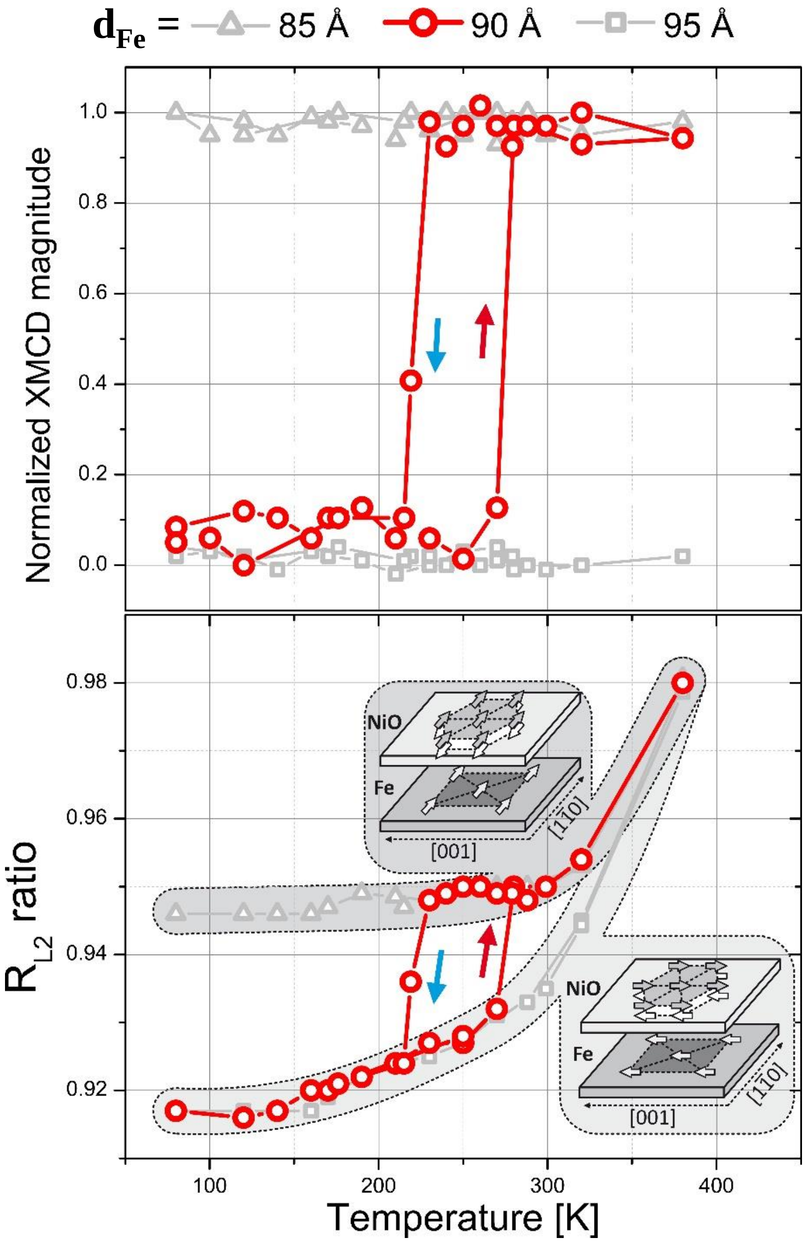


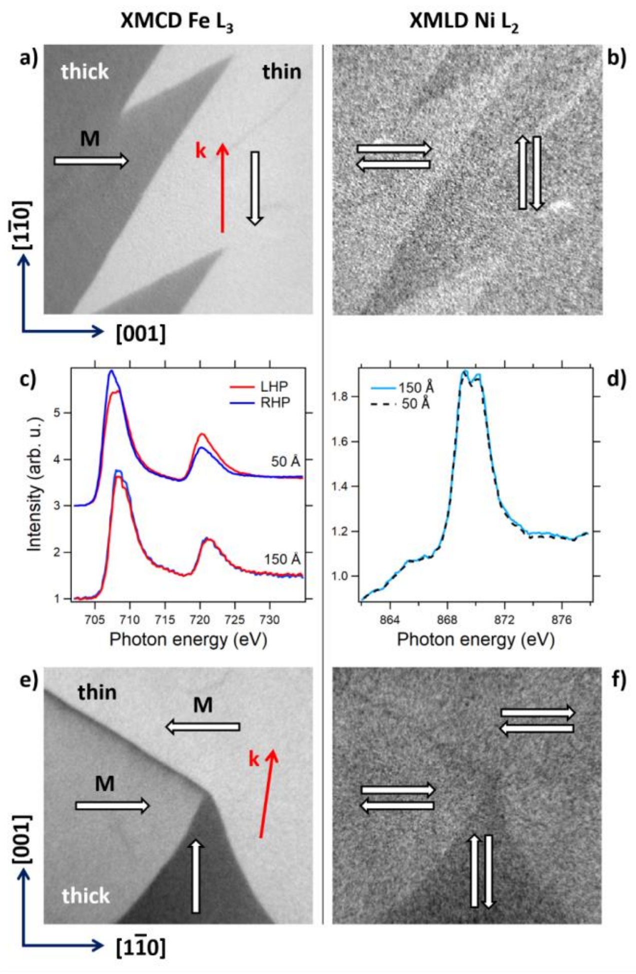
Indeed, NiO spins are rotatable

Temperature induced SRT in NiO on Fe(110)



XMLD-PEEM at Nanospectroscopy beamline (Elettra, Trieste)





M. Ślęzak, P. Dróżdż, W. Janus, H. Nayyef, A. Kozioł-Rachwał, M. Szpytma, M. Zając, T. O. Menteş, F. Genuzio, A. Locatelli, T. Ślęzak, Nanoscale 12 (2020) 18091

Plany na przyszłość:

- nanostruktury
- układy stricte AFM (bez ferromagnetyków)

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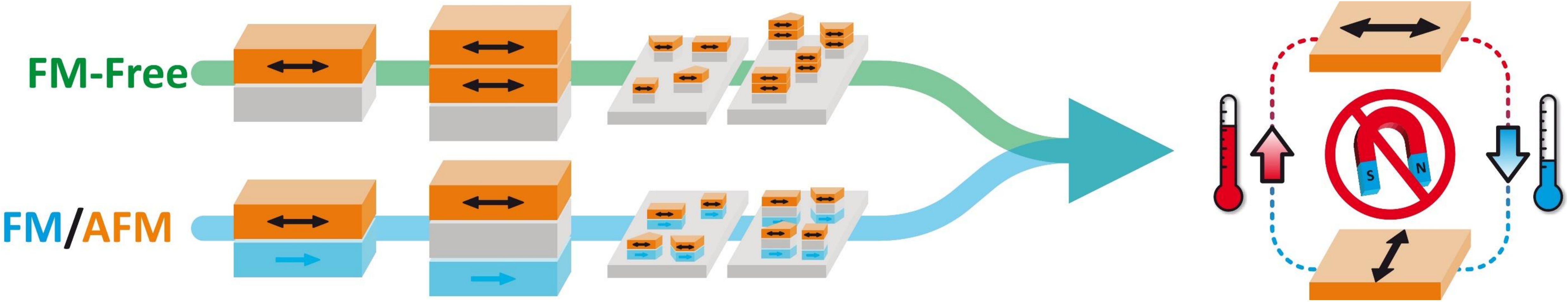
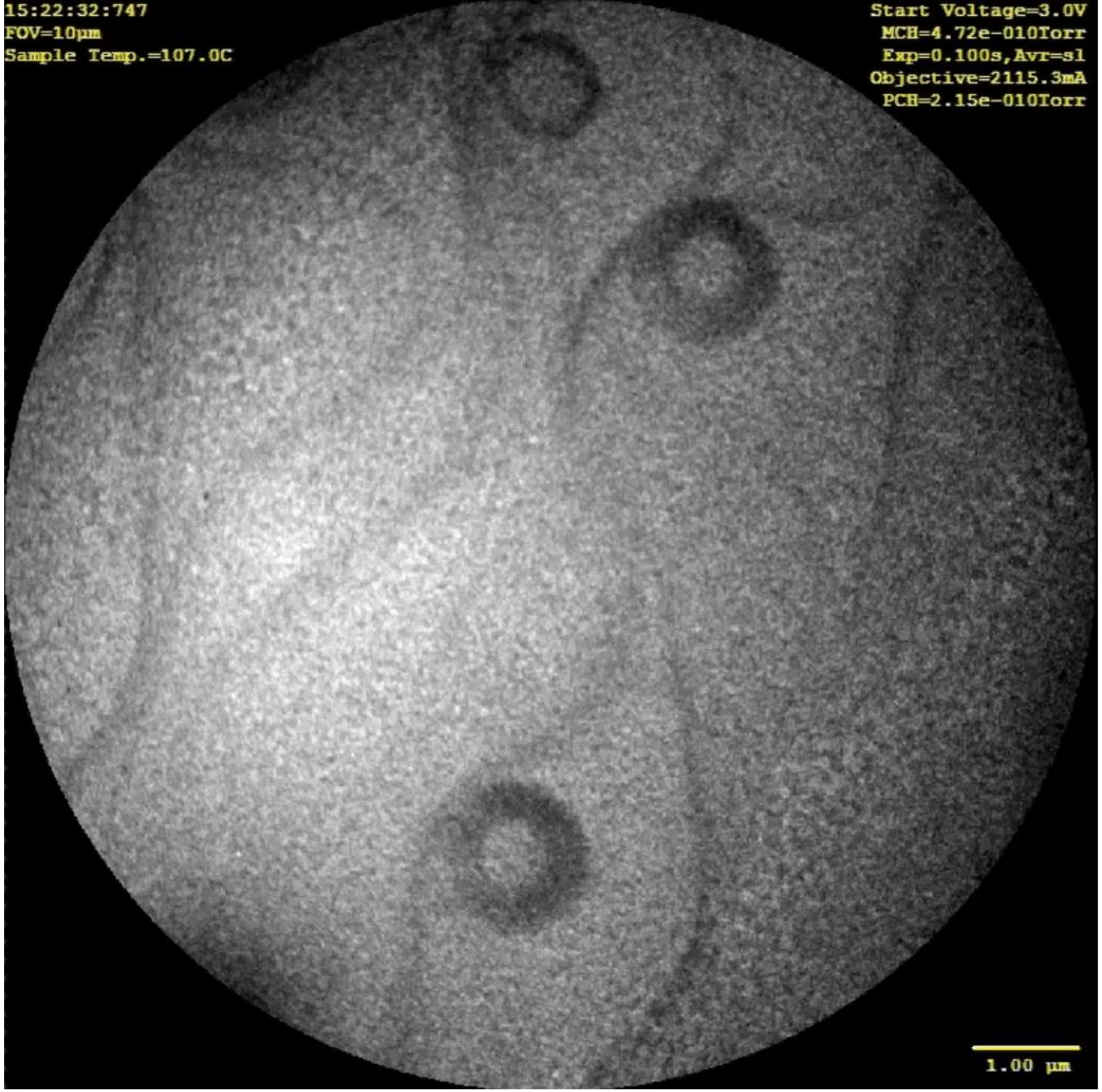


Nanostruktury

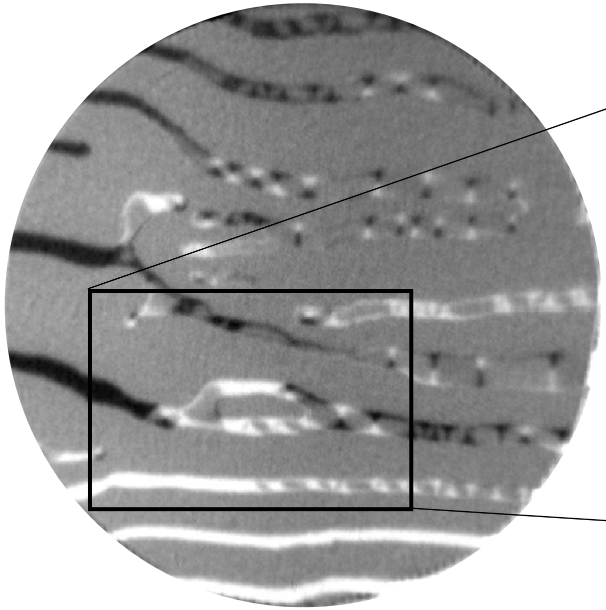


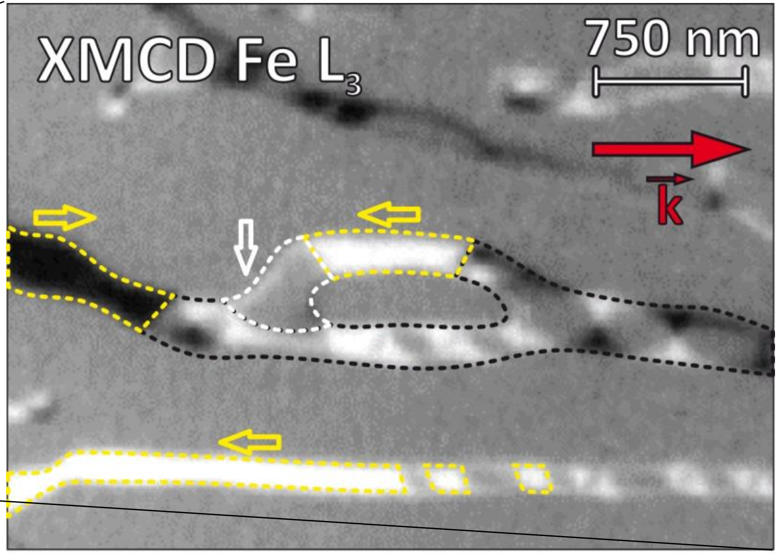
Recorded with D. Wilgocka-Ślęzak and T. Giela in Jerzy Haber Institute of Catalysis and Surface Chemistry PAS, Kraków, Poland

Nanostruktury NiO(111)/Fe(110)

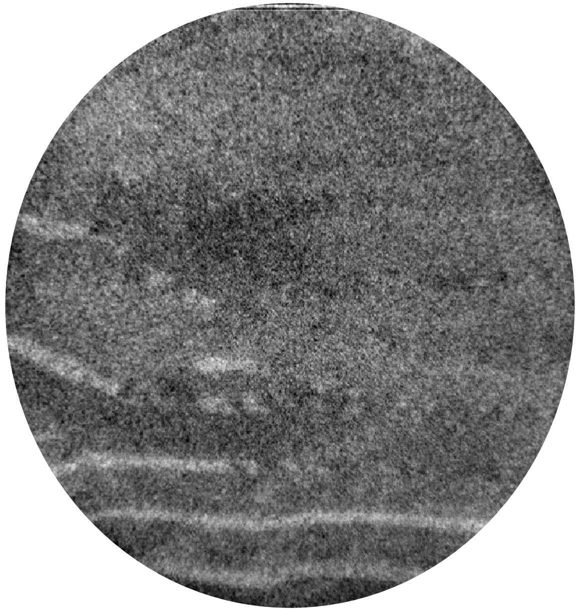
XML(C)D-PEEM at Nanospectroscopy beamline
(Elettra, Trieste)

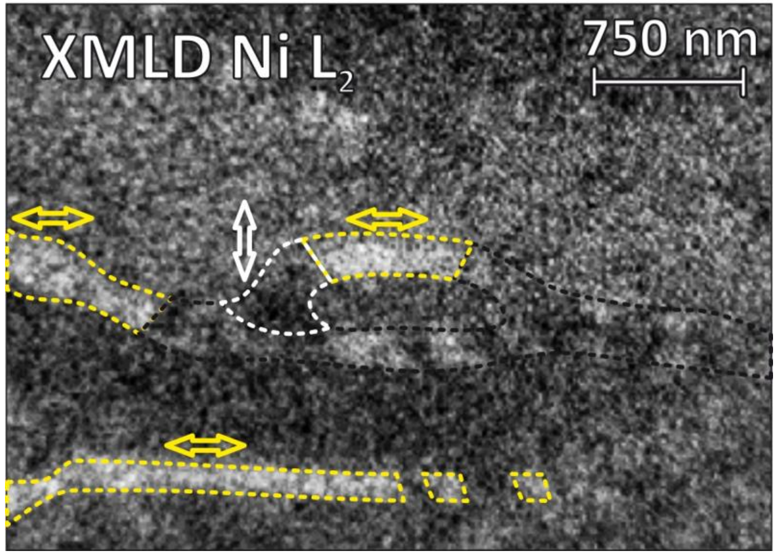
XMCD: Fe





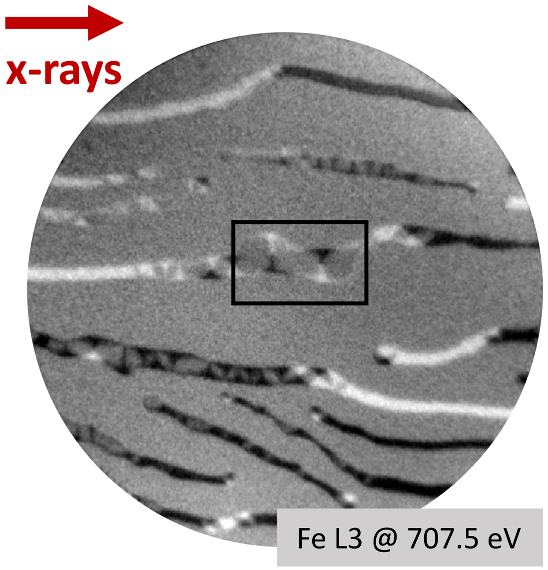
XMLD: NiO





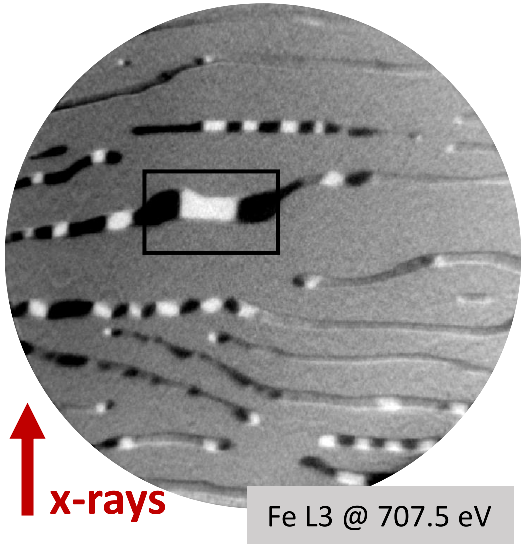
Nanostruktury NiO(111)/Fe(110)

XMCD



XMCD

Po obrocie próbki



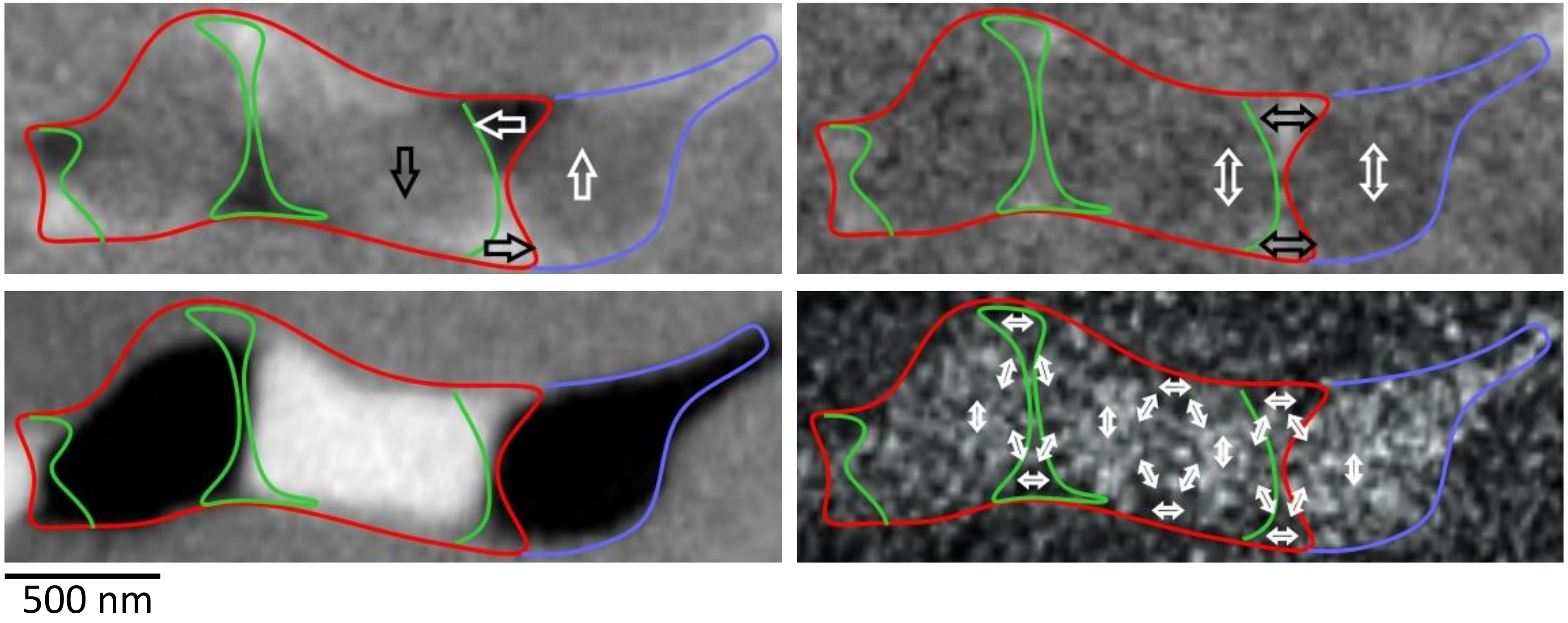
XML(C)D-PEEM at Nanospectroscopy beamline
(Elettra, Trieste)

Nanostruktury NiO(111)/Fe(110)

XMCD

XMLD

Po obrocie próbki



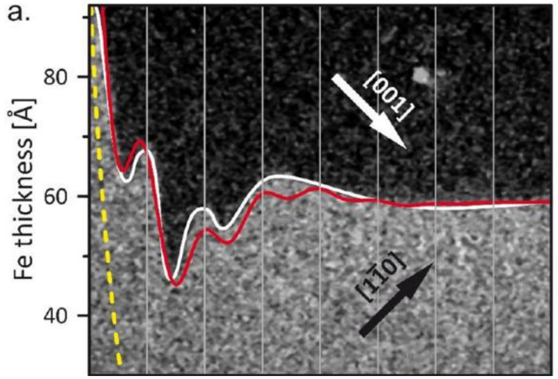
Pomiar: T. O. Menteş, F. Genuzio, A. Locatelli, XML(C)D-PEEM, Nanospectroscopy beamline (Elettra, Trieste)

Wizualizacja proponowanej struktury magnetycznej: D. Wilgocka-Ślęzak

Podsumowanie

- **Inżynieria anizotropii magnetycznej na powierzchni Fe(110)**

Physical Review B 94 (2016) 014402
JMMM 497, 165963 (2020)

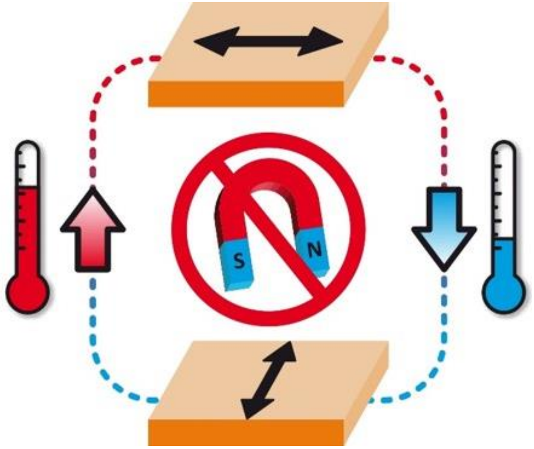


- **AFM/Fe(110):**
  - CoO/Fe(110) – „zamrażanie” spinów AFM

Scientific Reports 9 (2019) 889

  - NiO/Fe(110) – wzbudzona temperaturowo reorientacja AFM

Nanoscale 12 (2020) 18091



- **Nanostruktury**