Ultrathin Co layers with artificially modified magnetic anisotropy - magnetization reversal and applications

Spintronics - from new materials to applications
Warszawa 2011.11.16-18

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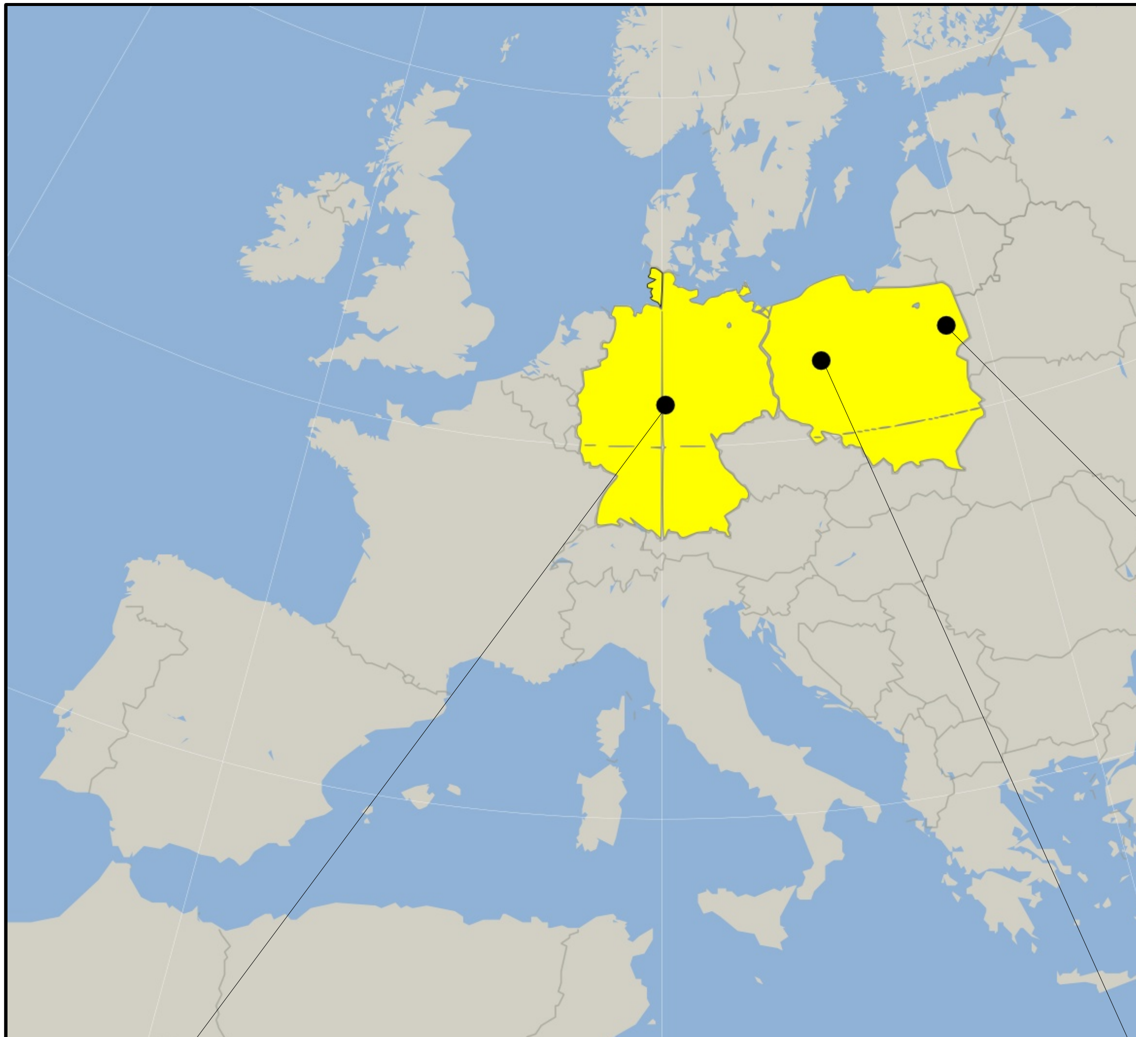
Ultrathin Co layers with artificially modified magnetic anisotropy - magnetization reversal and applications



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Map template taken from Wikimedia Commons (Europe_polar_stereographic_Caucasus_Urals_boundary.svg, authors: Ssolbergj derivative work: Dbachmann (talk))

Ultrathin Co layers with artificially modified magnetic anisotropy - magnetization reversal and applications

1. Introduction

2. Magnetic properties of ultrathin Co in Au/Co/Au multilayers

3. Ion beam patterning
   - influence of ion bombardment on magnetic anisotropy
   - 2D nanostructured arrays
   - structures with coercive field gradient (particle transport, magnetoresistive sensors)

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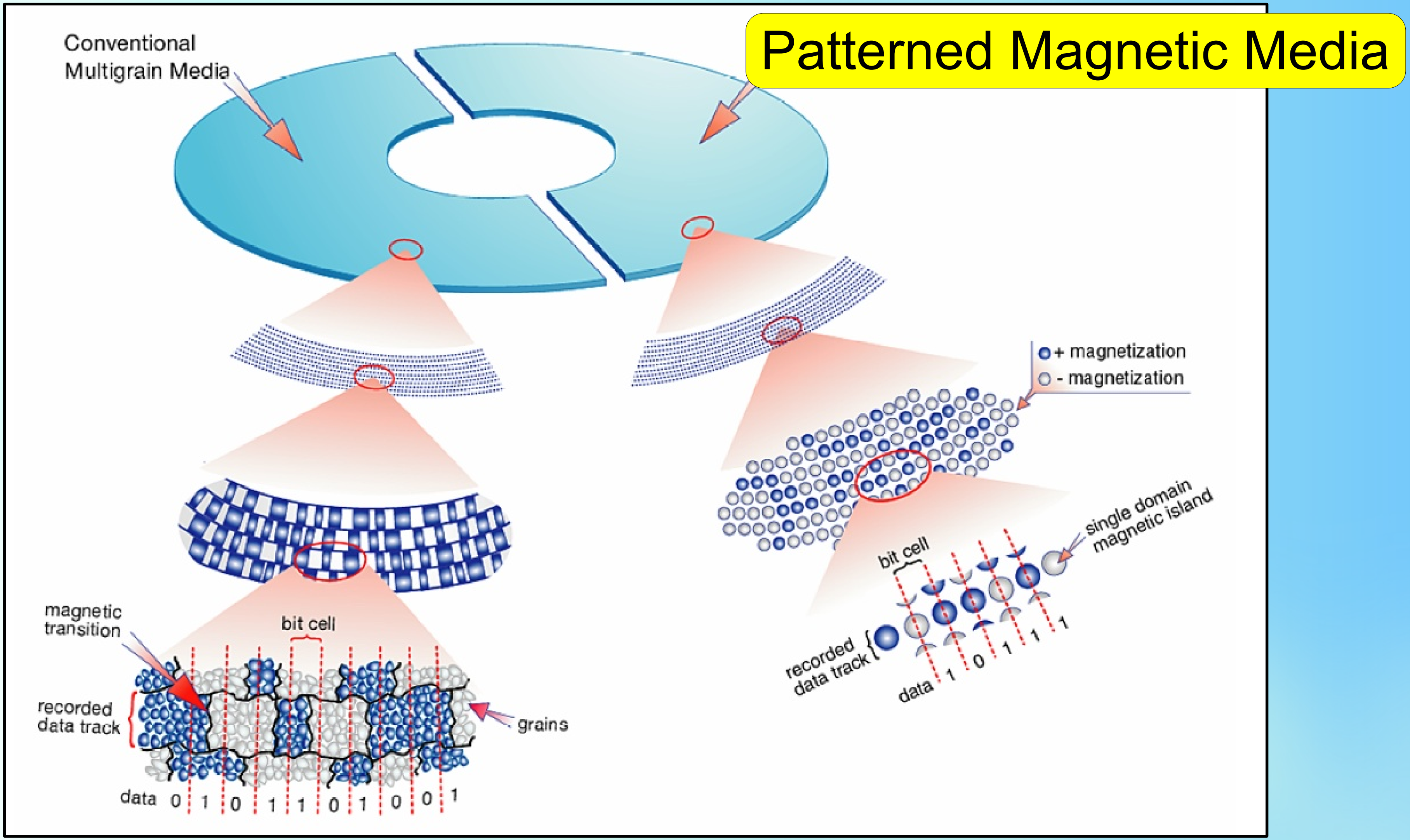
Why investigate perpendicular anisotropy media?



www.hitachigst.com

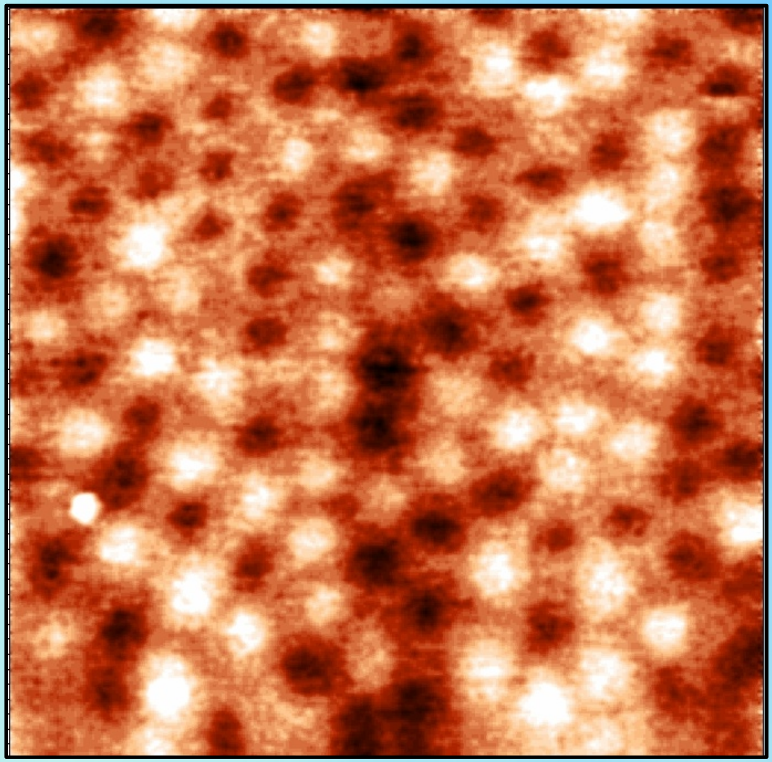
Why investigate perpendicular anisotropy media?

Patterned Magnetic Media

Topological patterning

Image removed due to copyright concerns

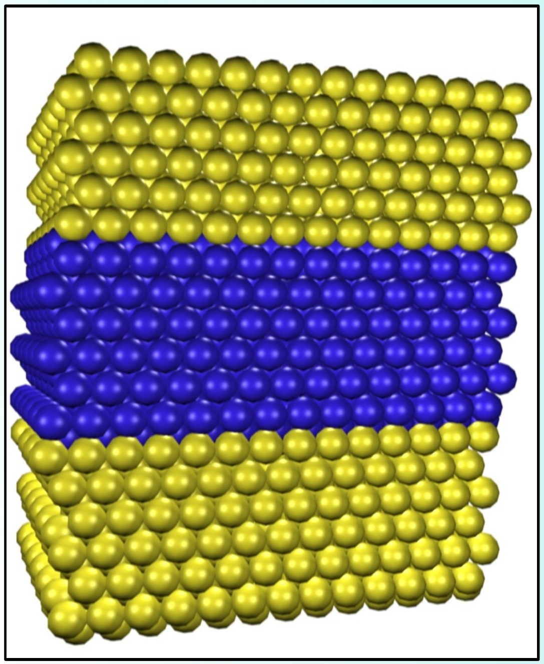
Magnetic patterning



Magnetic patterning

Local change of magnetic properties without (or with negligible) modifications of a surface topograpy.

Ion bombardment*



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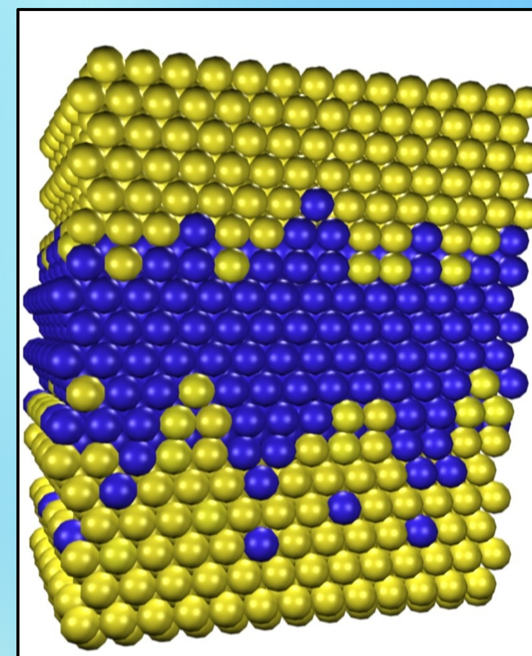
Ion bombardment leads to:

-movement of atoms changing the structure of the interfaces between ferromagnetic and non-ferromagnetic layers

-as a result surface and thus the effective anisotropy changes



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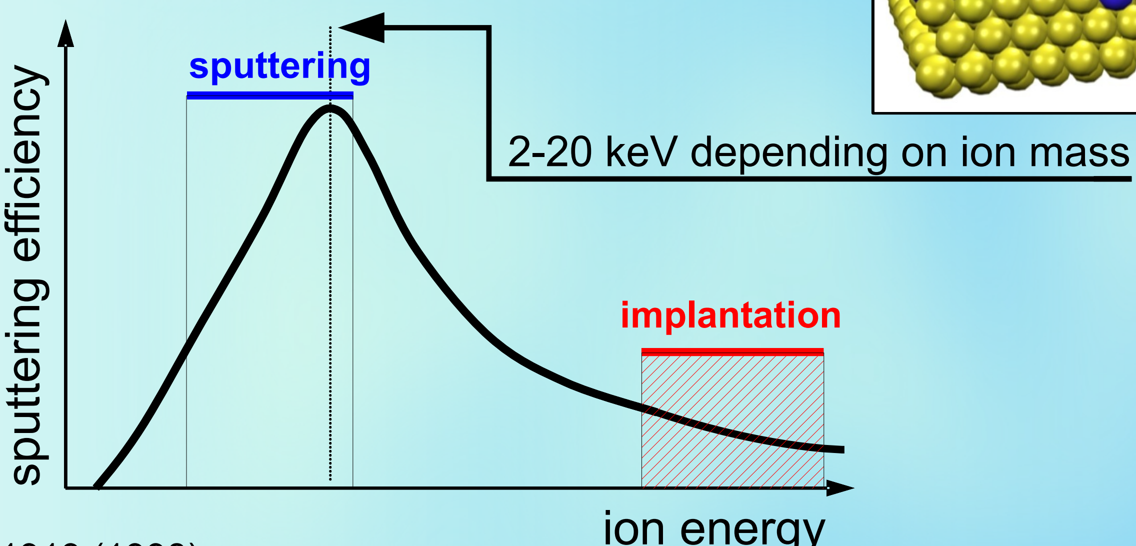
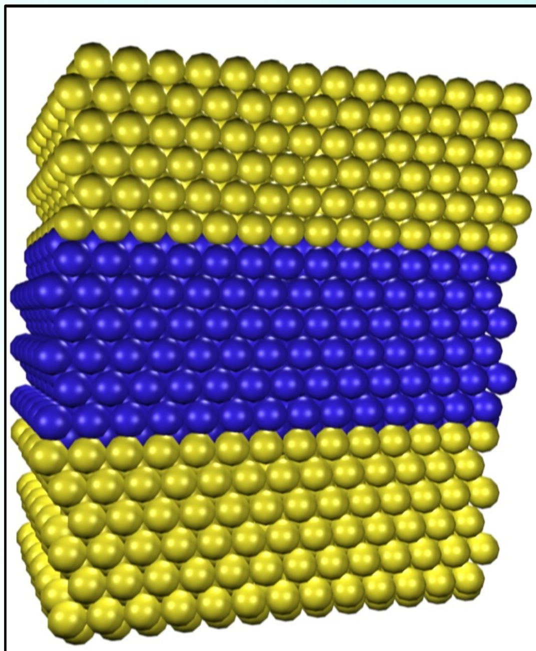


*see C. Chappert et al, Science 280, 1919 (1998)

Magnetic patterning

Local change of magnetic properties without (or with negligible) modifications of a surface topograpy.

Ion bombardment



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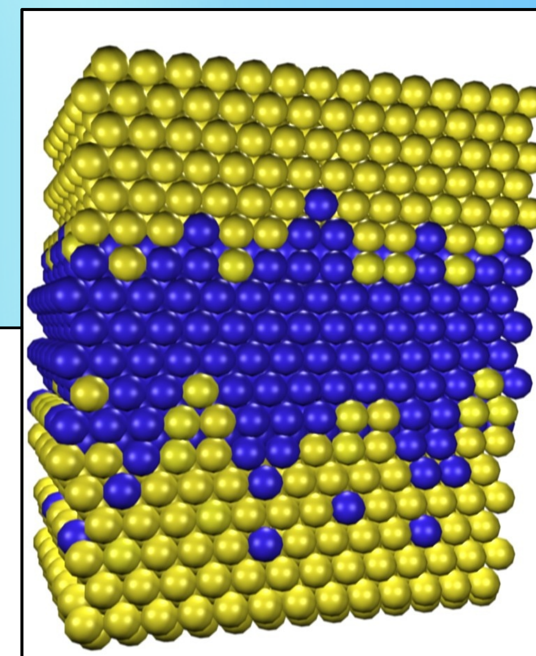
to pattern one uses either focused ion beam (FIB) or **masks**



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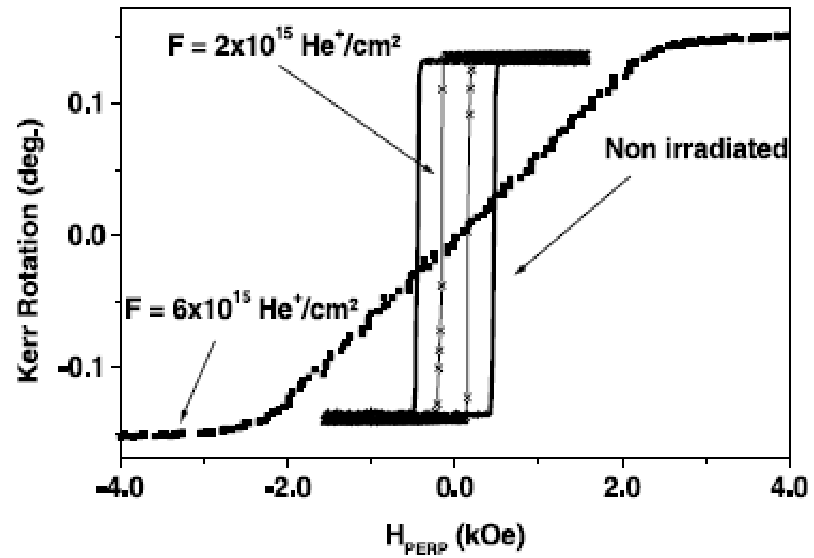
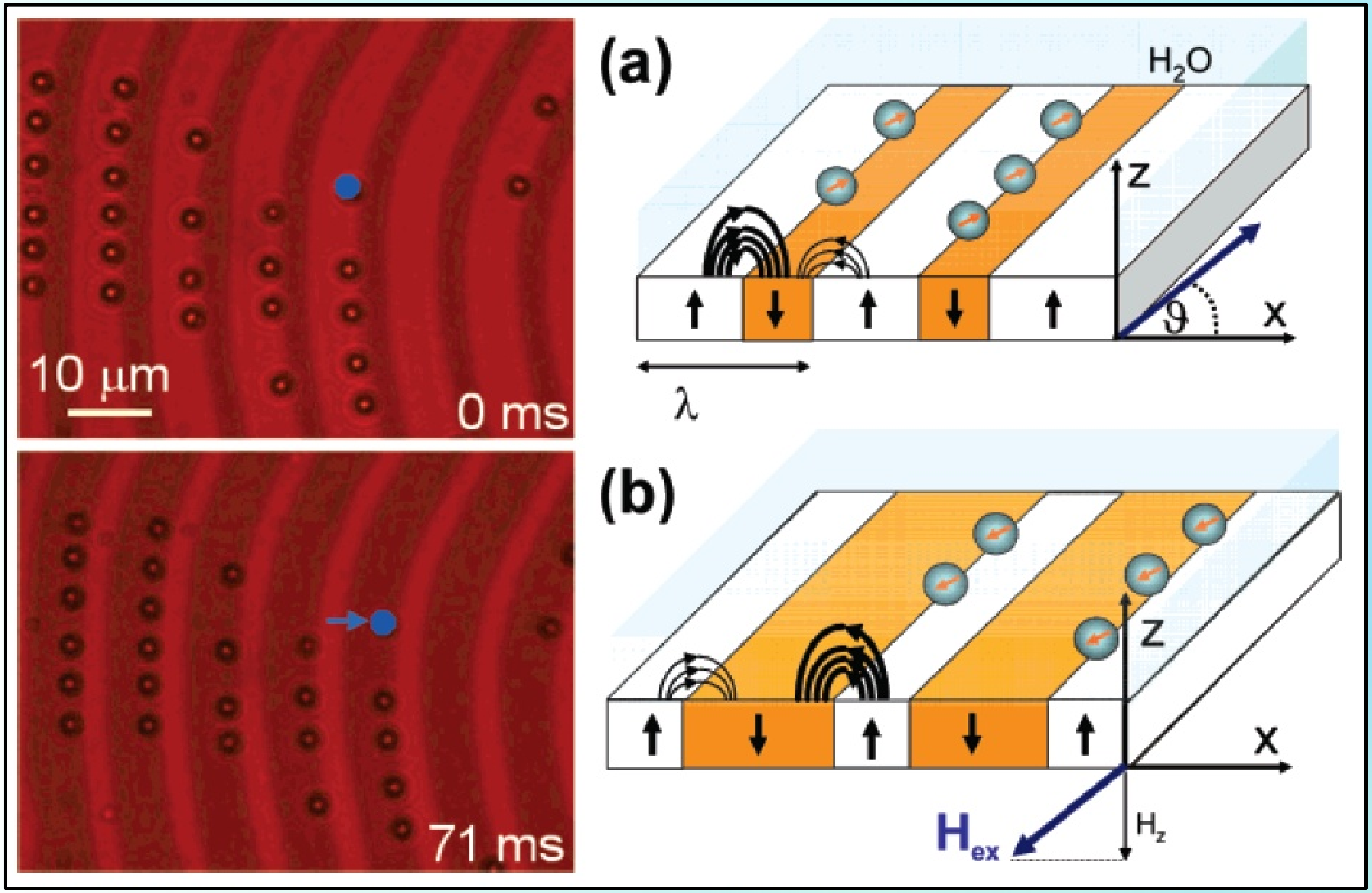


Fig. 1. Polar Magneto-Optical Kerr Effect hysteresis loops of Pt(28 Å)/[Pt(6 Å)/Co(3 Å)]$_6$/Pt(65 Å)/SiO_2 multilayers, in perpendicular applied magnetic field.

T. Devolder et al., Nuclear Instruments and Methods in Physics Research B 175, 375 (2001)

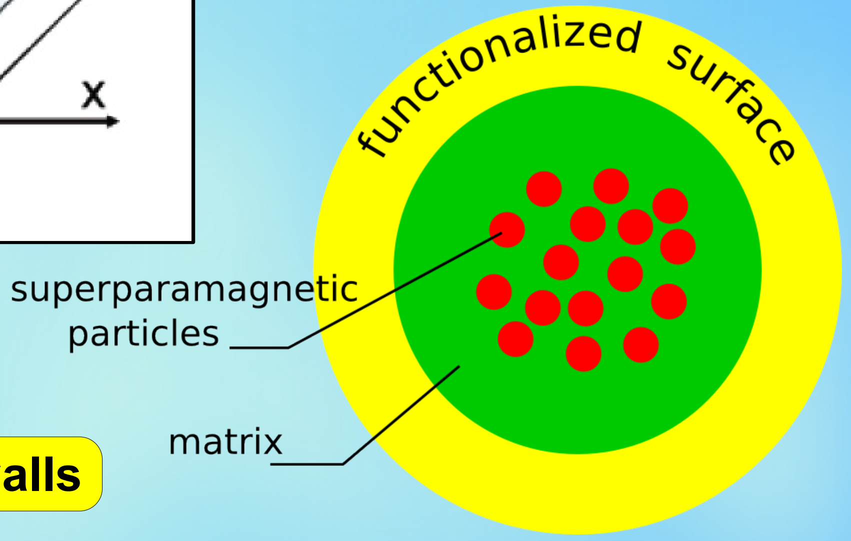
Why investigate perpendicular anisotropy media?

Colloidal magnetic shift register – controllable magnetophoresis



Stripe domain walls stray fields attract magnetic beads placed on the film

λ=10.9 μm



Magnetic beads move alongside moving domain walls

[5] P. Tierno, S. V. Reddy, J. Yuan, T. H. Johansen, and T. M. Fischer, J. Phys. Chem. B , **111**, 13479 (2007)

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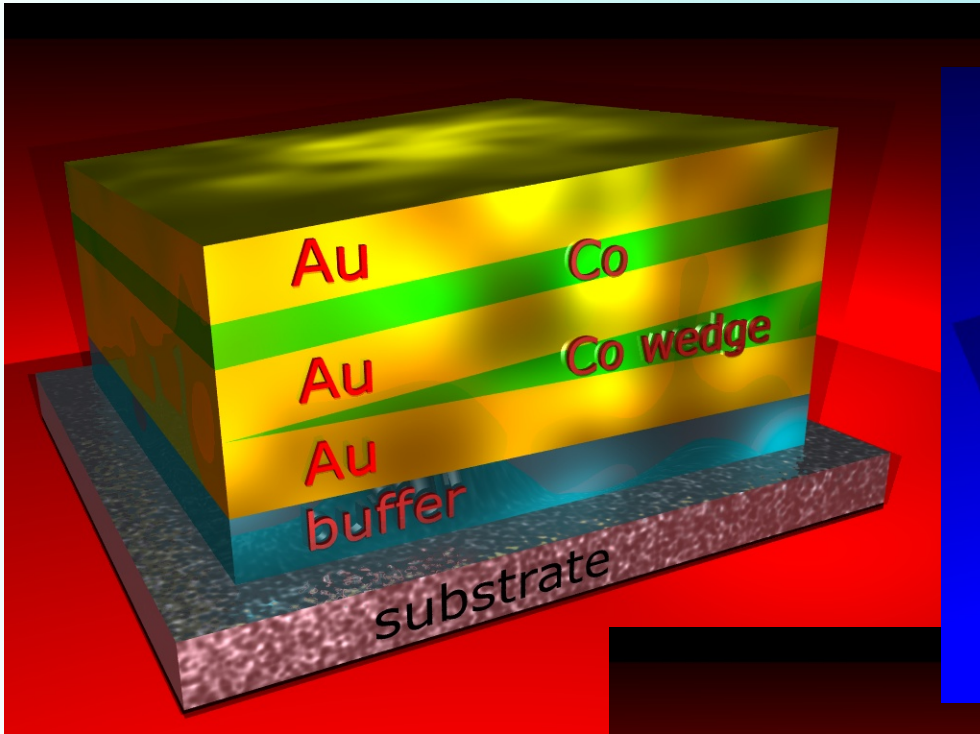
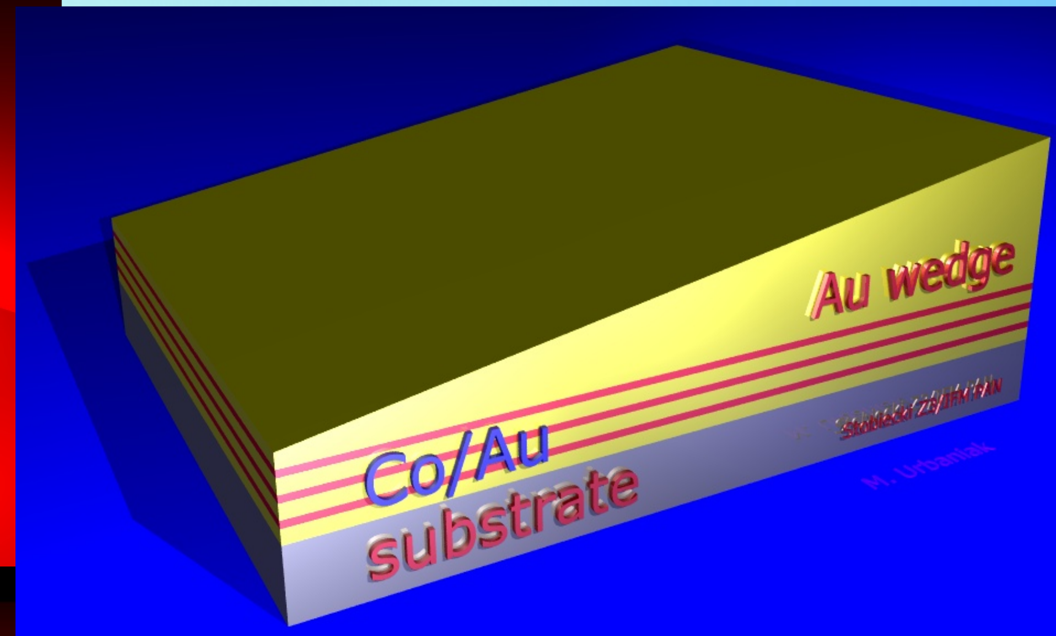
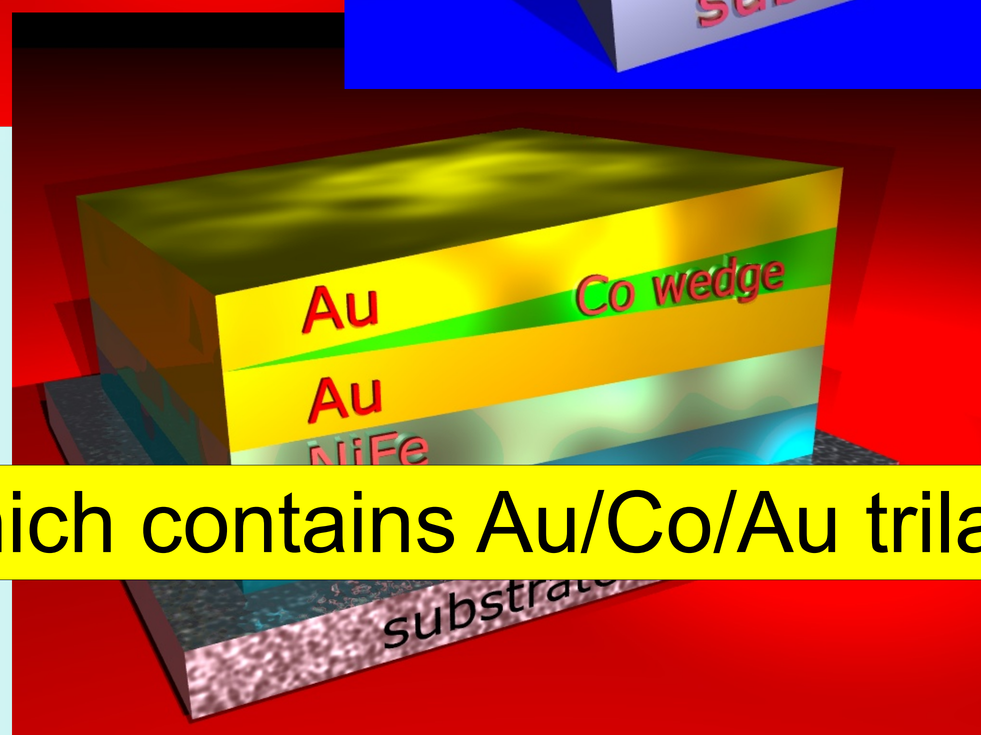
We have investigated the following structures:

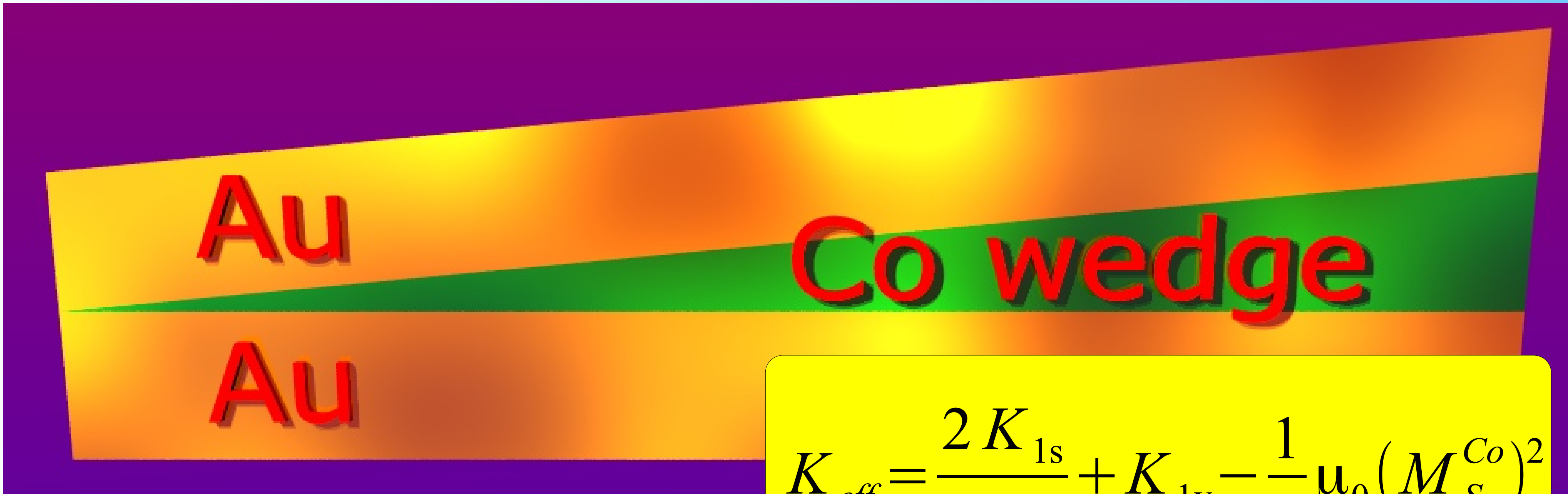






Each of which contains Au/Co/Au trilayers

A few words about Au/Co/Au trilayares

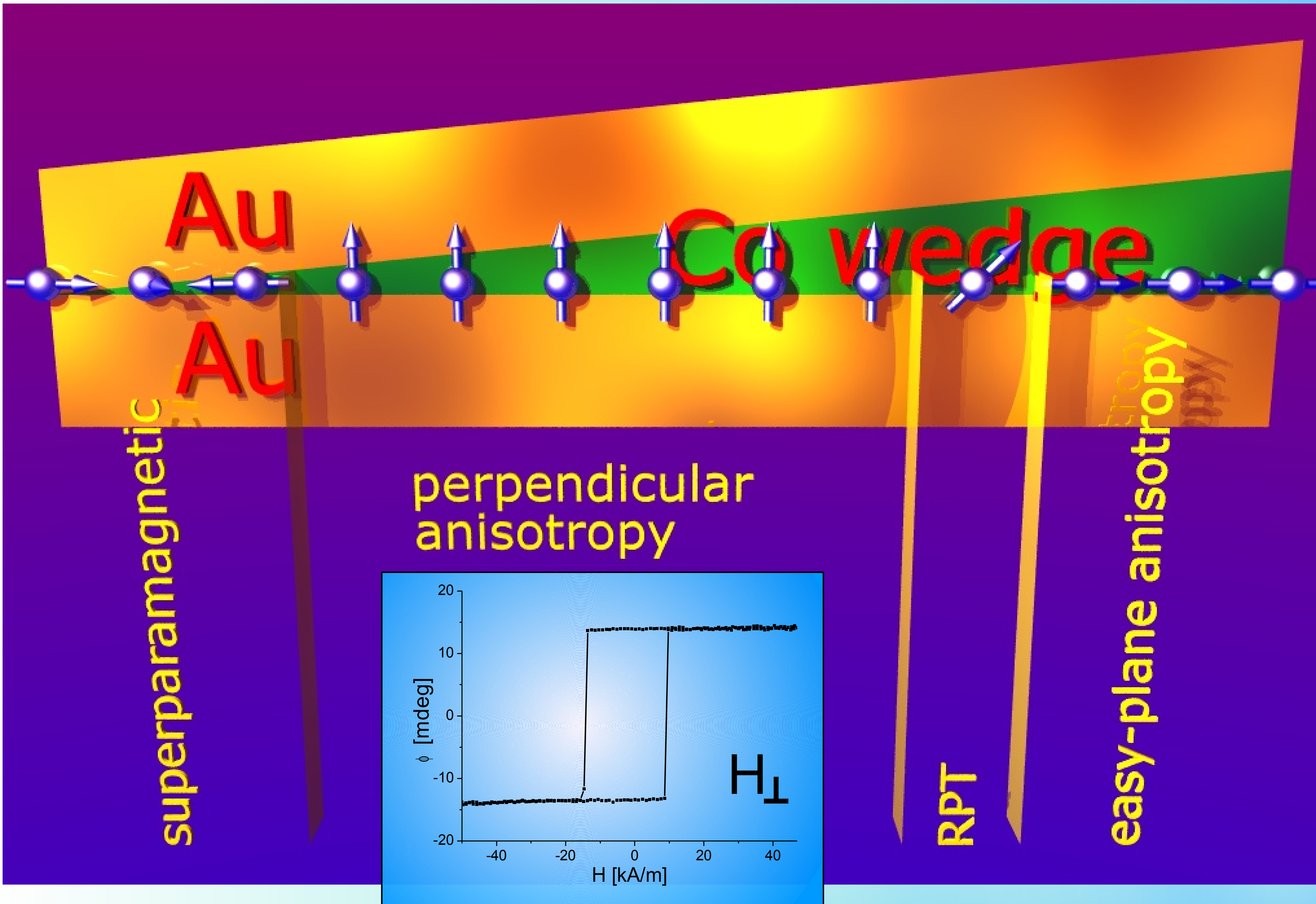


$$K_{eff} = \frac{2K_{1s}}{t_{Co}} + K_{1v} - \frac{1}{2}\mu_0 \left(M_S^{Co}\right)^2$$

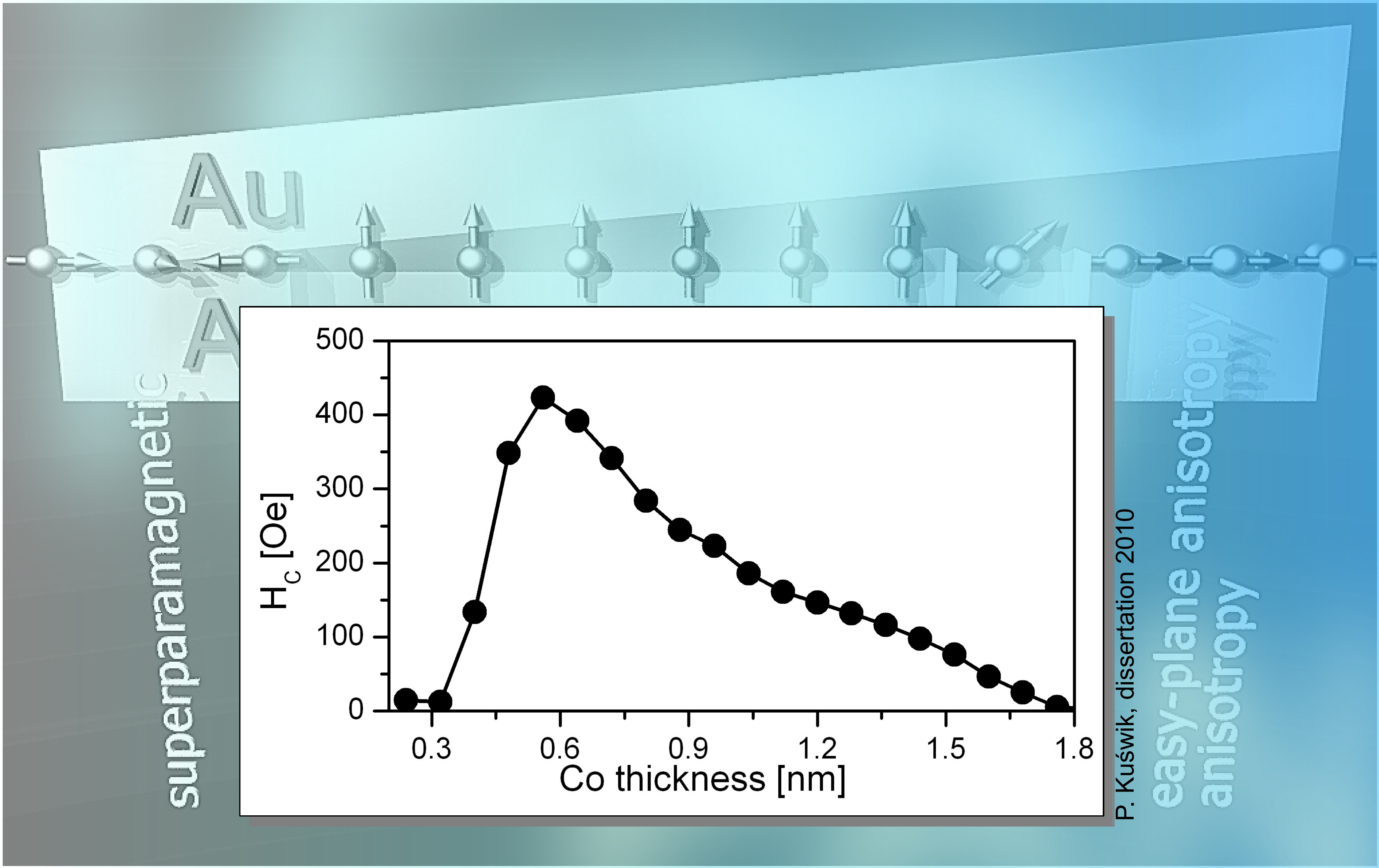
- Symmetry breaking at Au/Co interfaces leads to the appearance of the energy term (K_{1s}) favoring perpendicular orientation of Co magnetic moments

- Competition between that term and the magnetocrystalline and shape anisotropies can lead to the perpendicular anisotropy.

A few words about Au/Co/Au trilayares



A few words about Au/Co/Au trilayares



K_{1s}=4.3±0.4 $10^{-4}$$Jm^{-2}$ K_{1v}=450±50 $10^3$$Jm^{-3}$ Bulk hcp Co: K_{1v}=430 $10^3$$Jm^{-3}$

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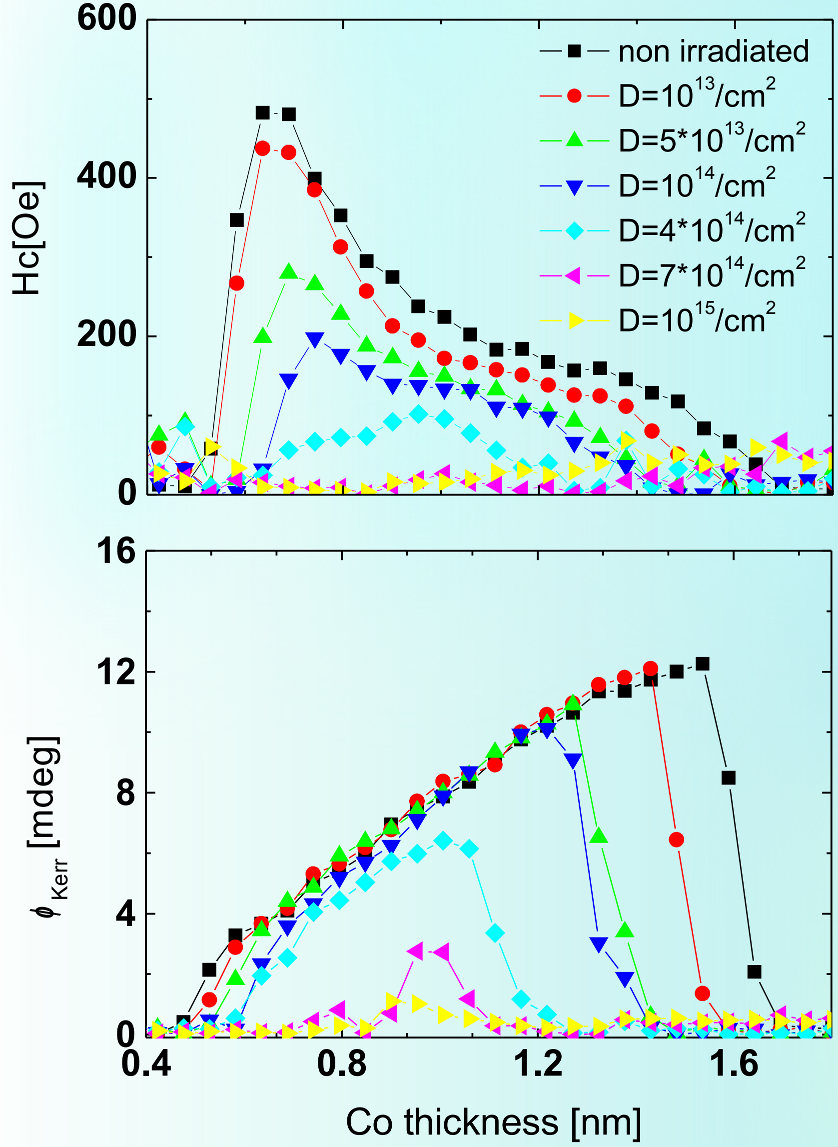
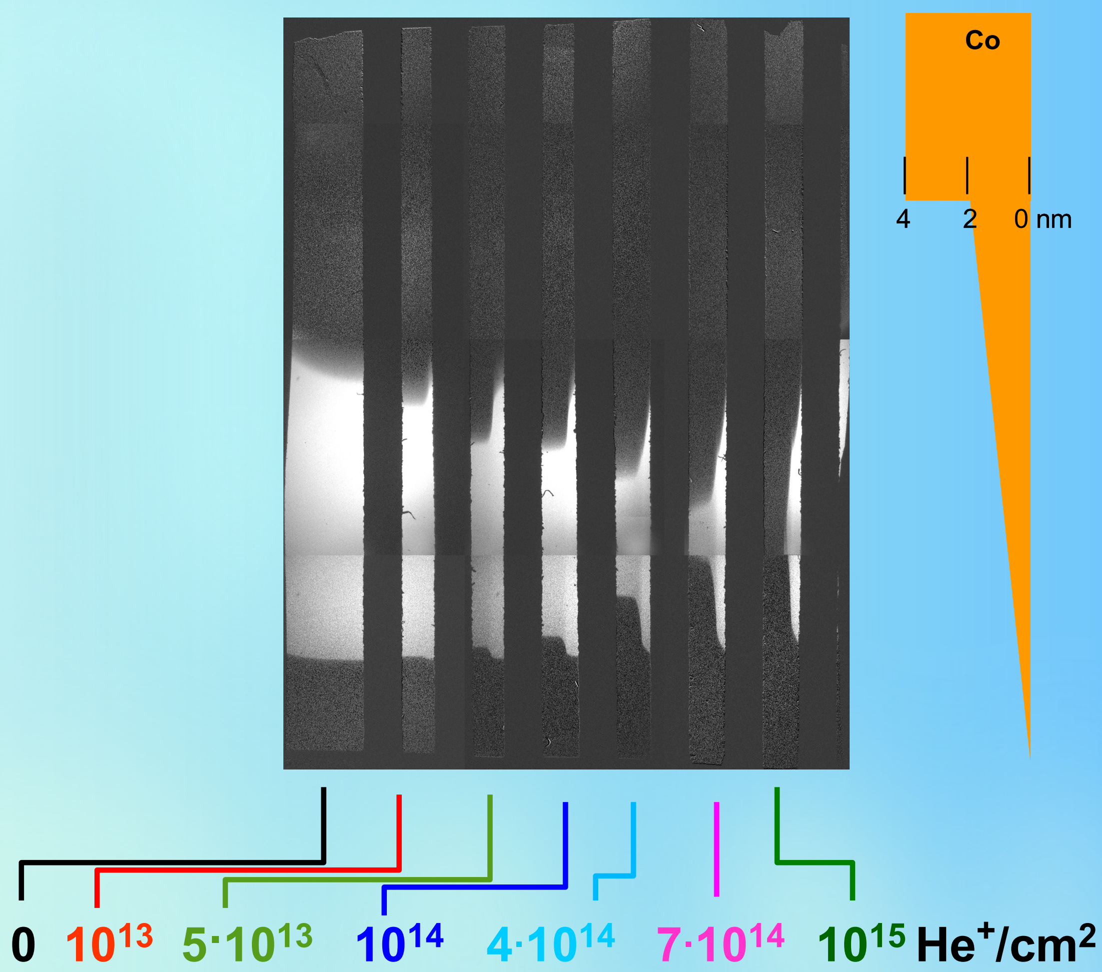
- structures with coercive field gradient (particle transport, magnetoresistive sensors)

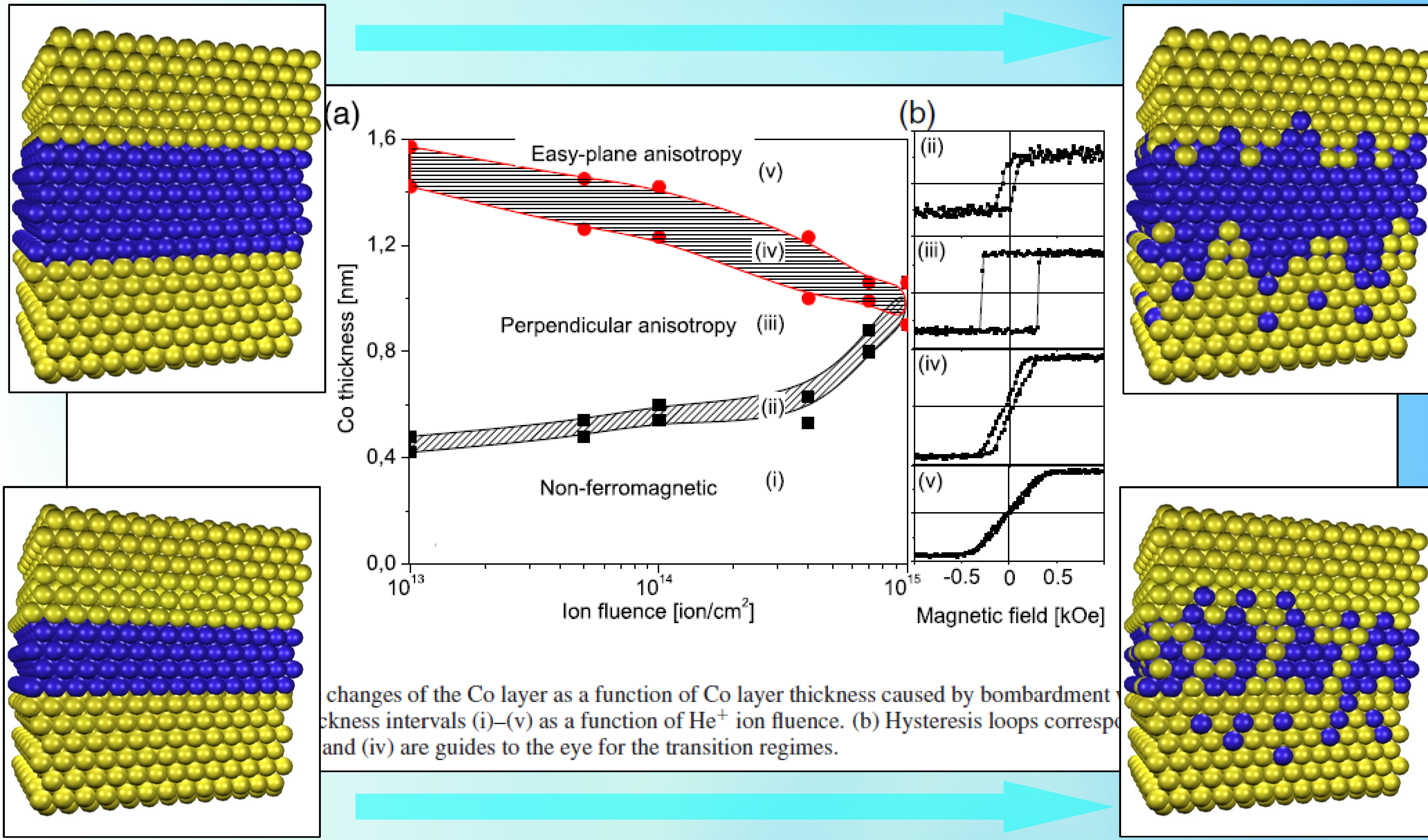
Change of the coercive field and remanence magnetization of Co wedge-shaped layer under the influence of He^+ 10keV bombardment





P. Kuświk, dissertation 2010

Change of the magnetic properties under the influence of He^+ 10keV bombardment for *different Co thicknesses*



P. Kuświk *et al*., Nanotechnology **22,** 095302 (2011)

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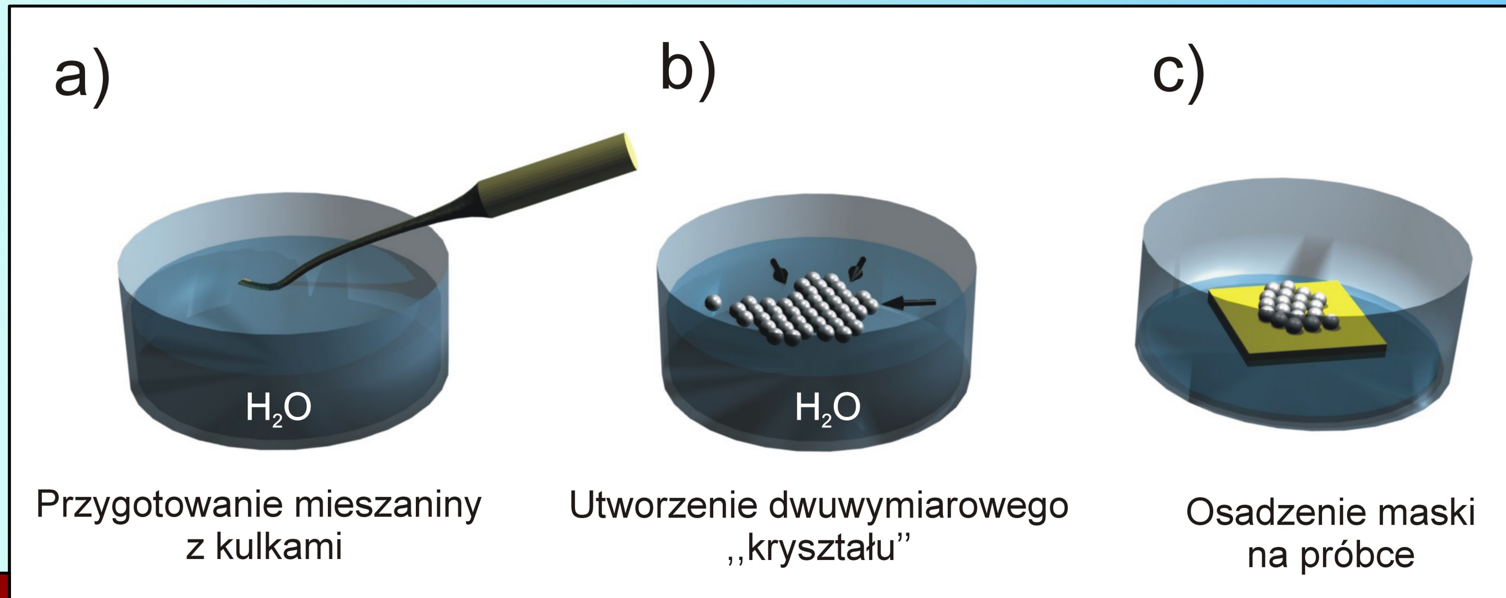
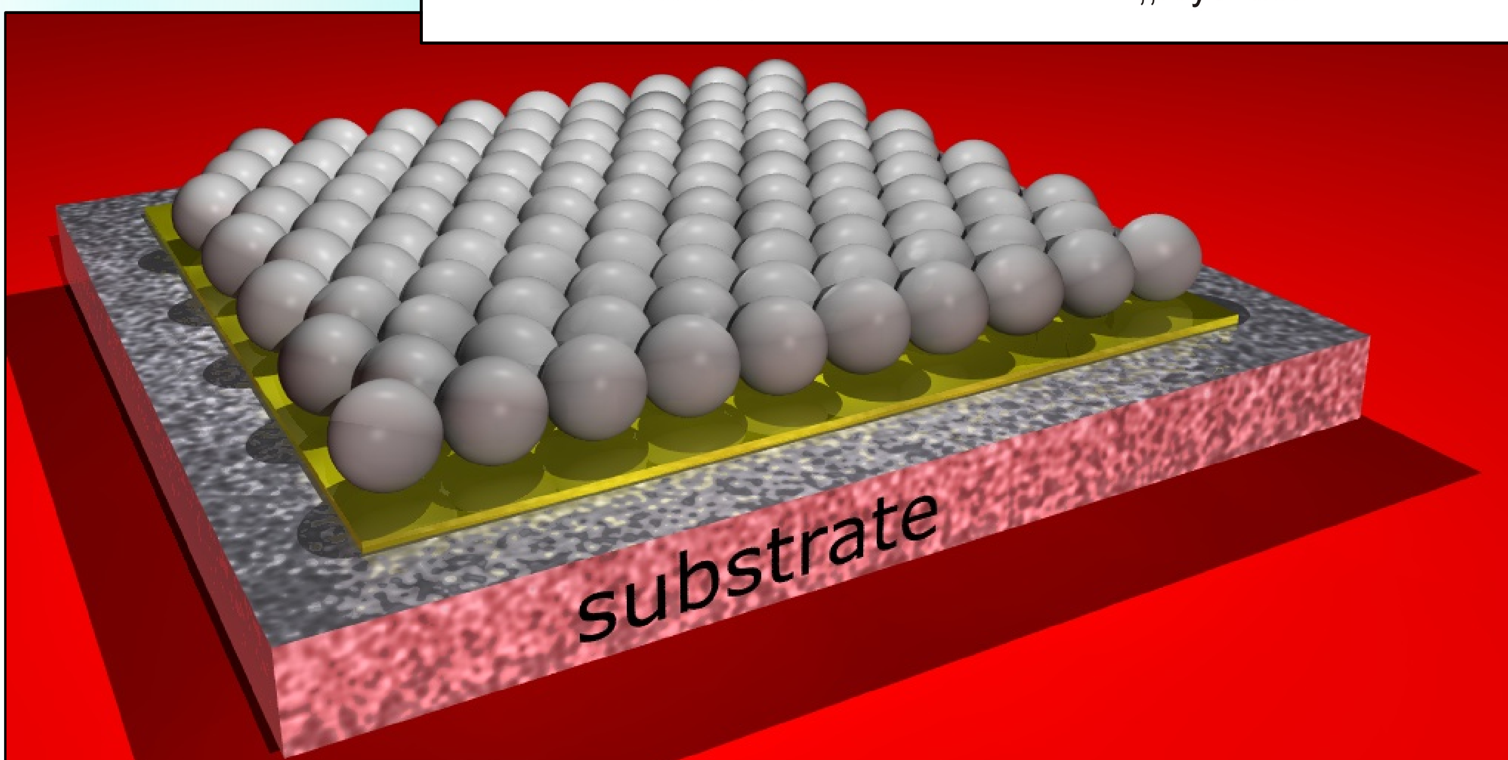
Magnetic patterning through nanospheres mask

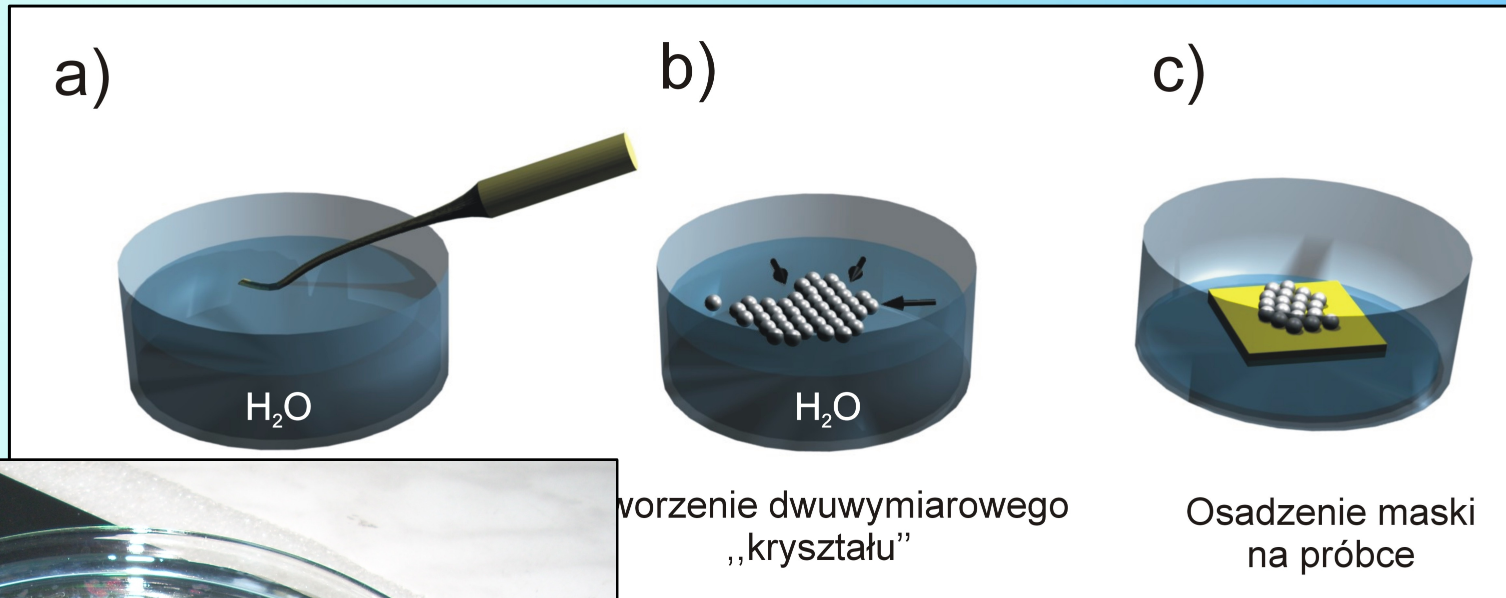


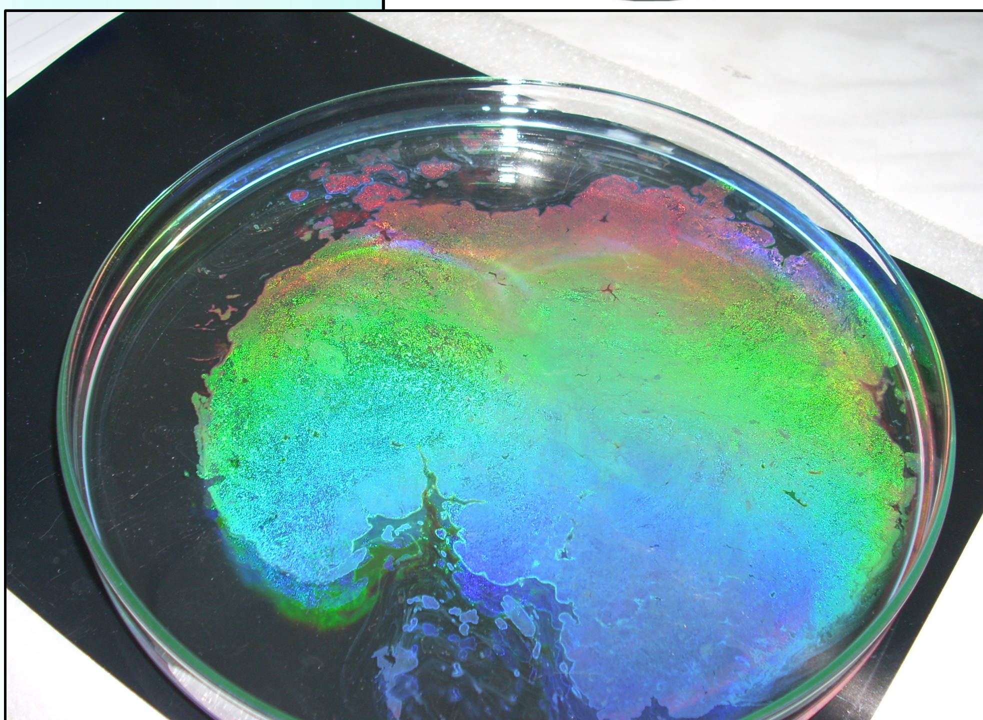


Nanospheres:
D=470nm

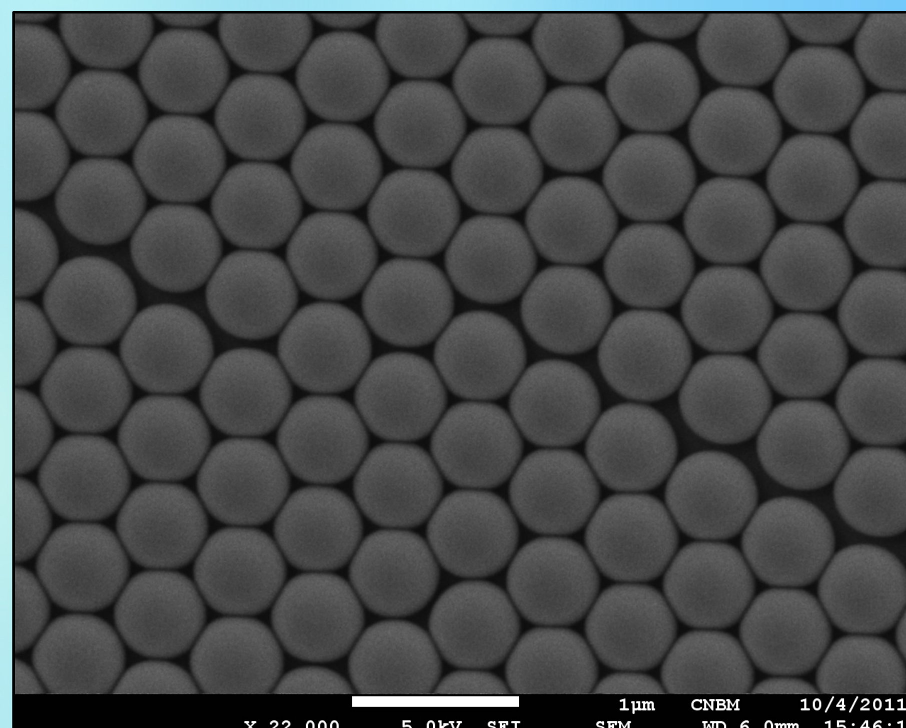
A. Kosiorek et al., Nano Lett. **4**, 1359 (2004), Small **1**, 439 (2005)

Magnetic patterning through nanospheres mask





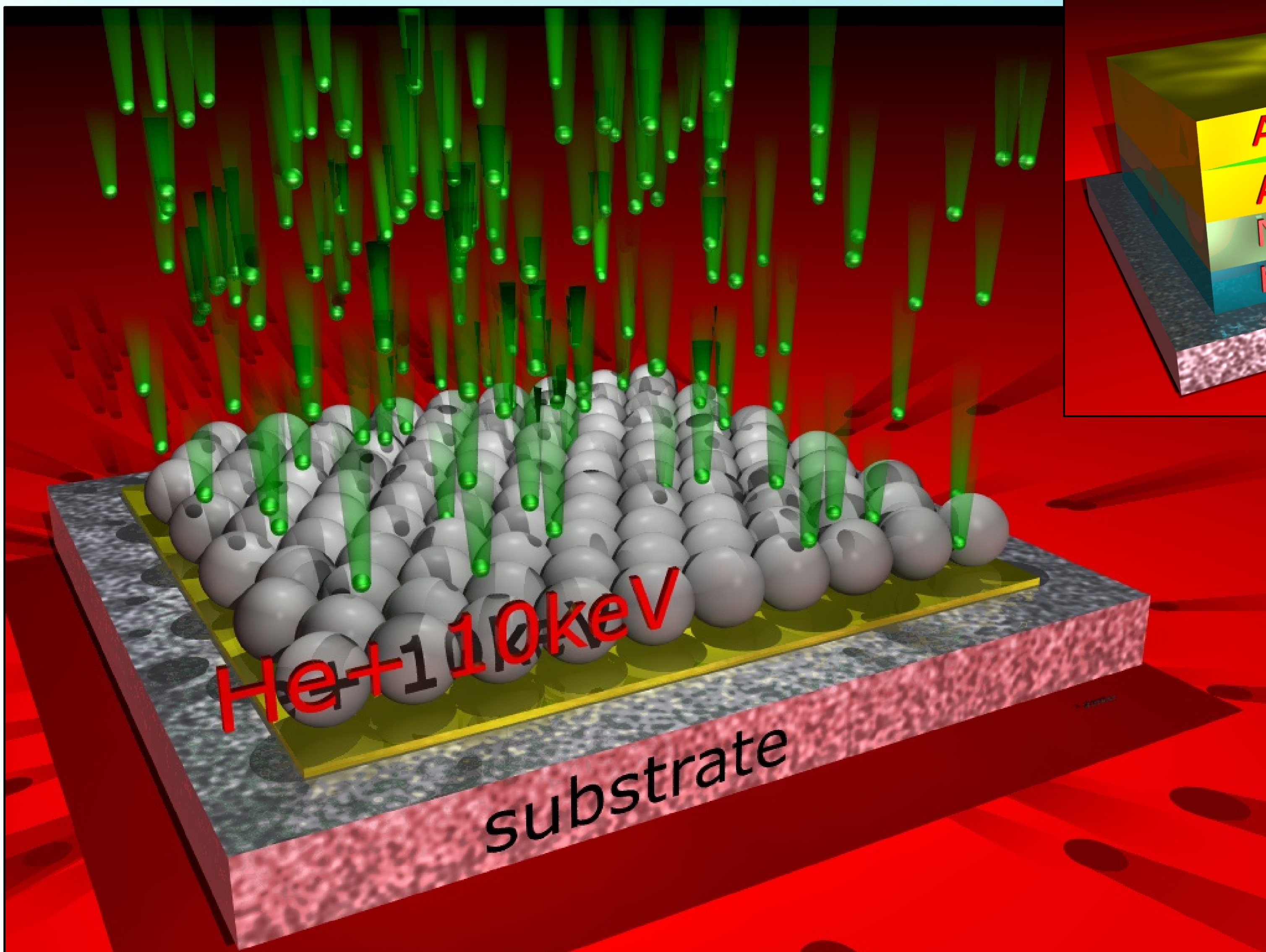
P. Kuświk, Dissertation

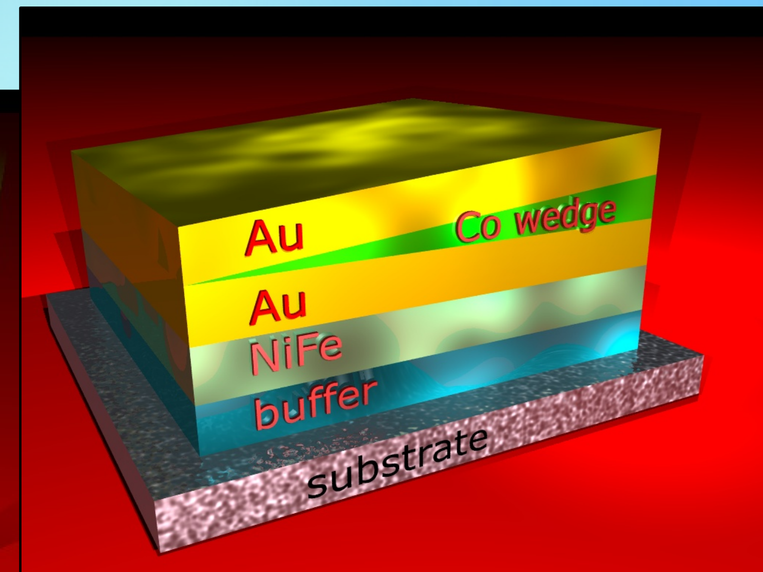


Magnetic patterning through nanospheres mask

Ion bombardment:

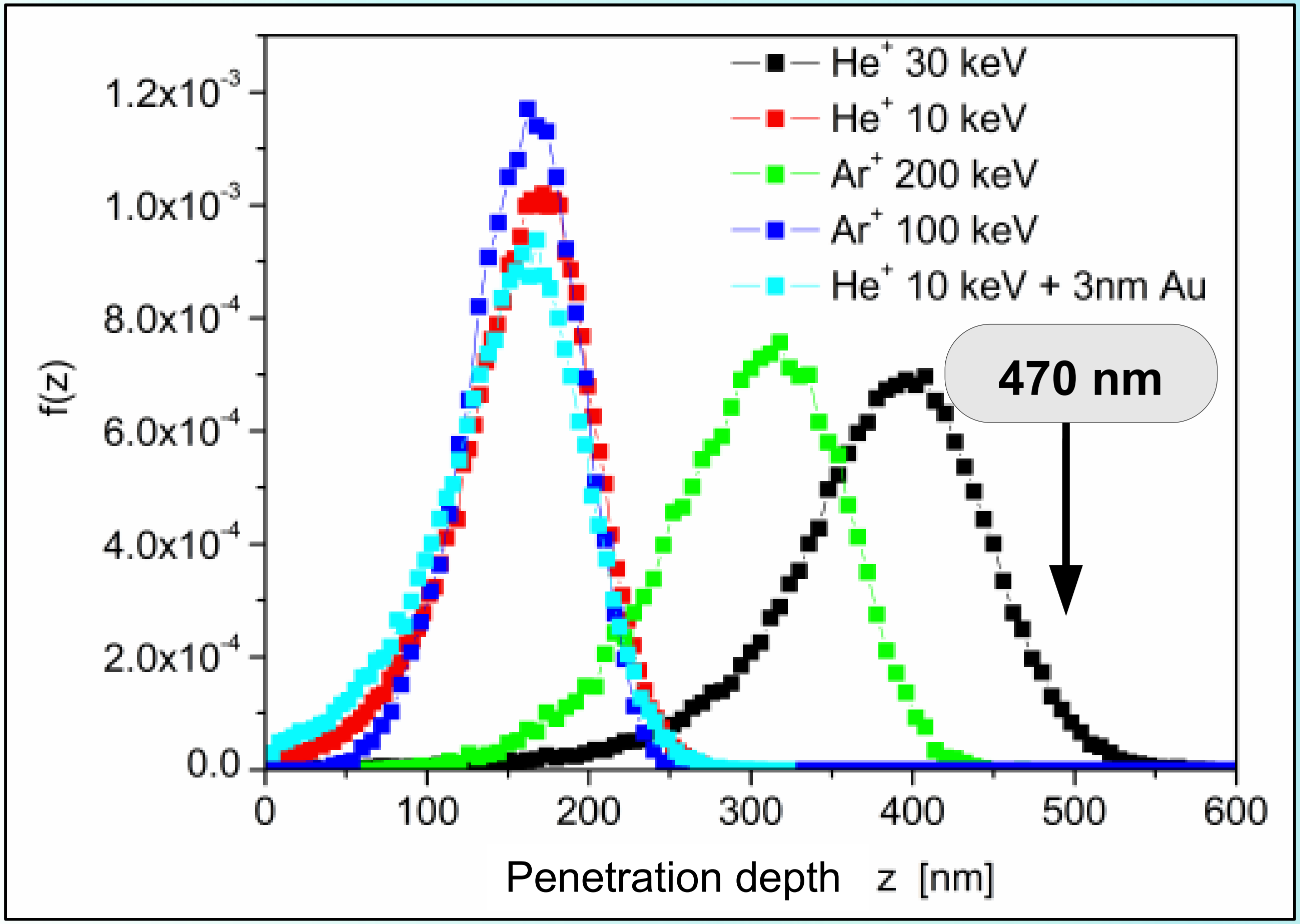
t_{Co}=1.2 nm   D=10^{16}He+/cm^{-2} 10keV, 30keV



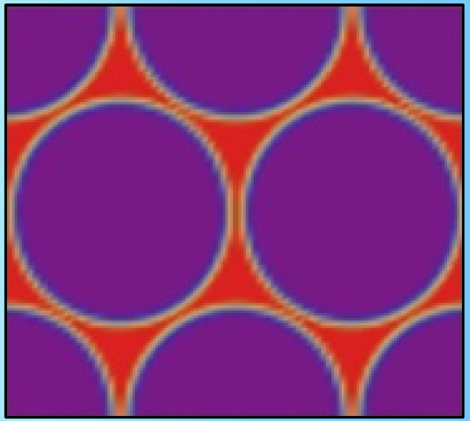


Magnetic patterning through nanospheres mask

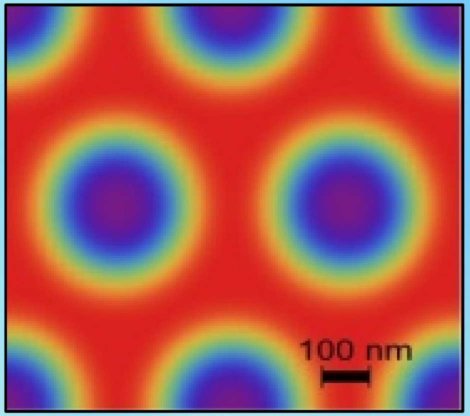
► Adjusting bombardment parameters to the size of nanospherse ◄



10keV He^+



30keV He^+



Simulations with **SRIM** software:
SRIM 2003 J. F. Ziegler J. Nucl. Instr. And Meth. In Phys. Res. B **219**, 1027 (2004)

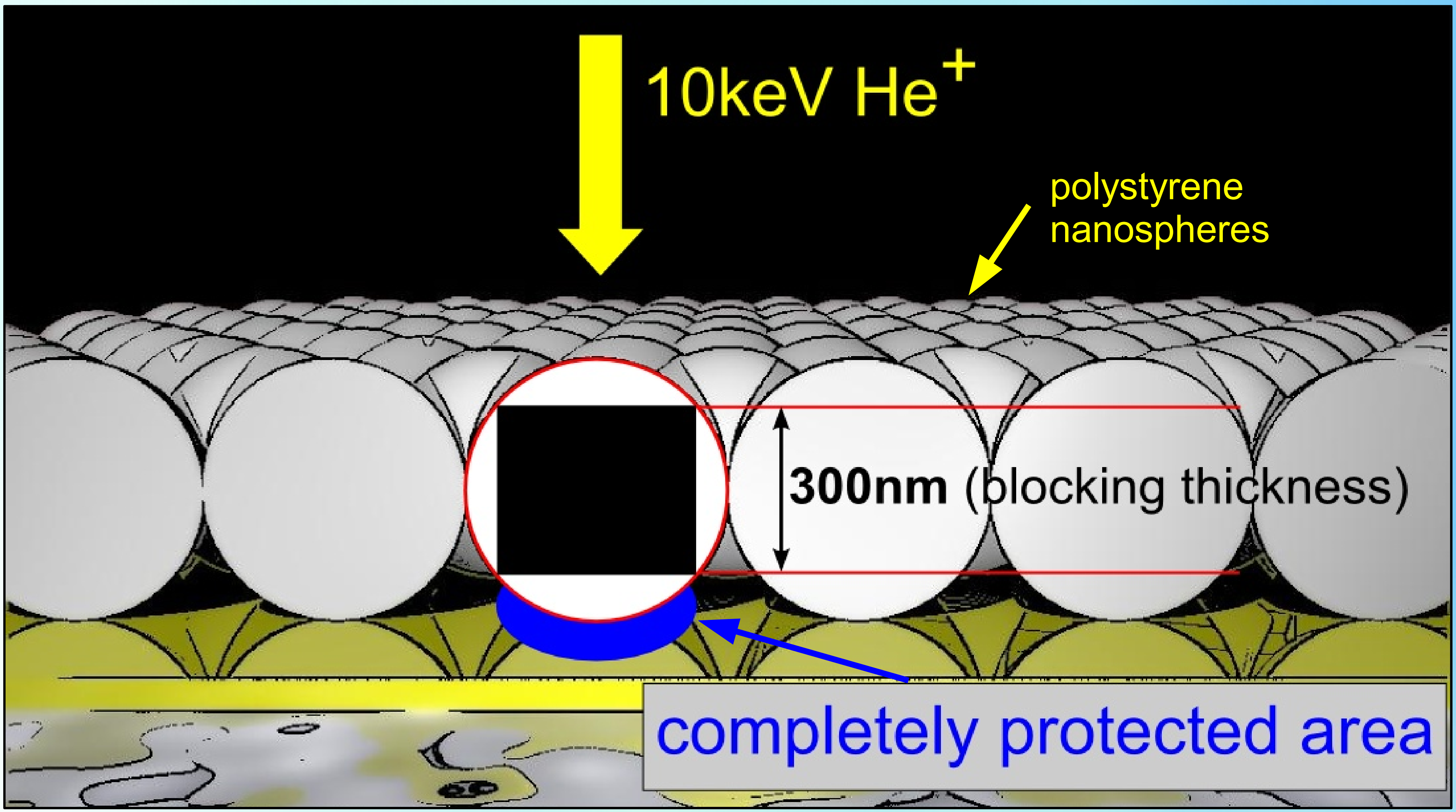
Nanospheres diameter: **470 nm**

300 nm of polystyrene completely blocks 10keV He^+ ions

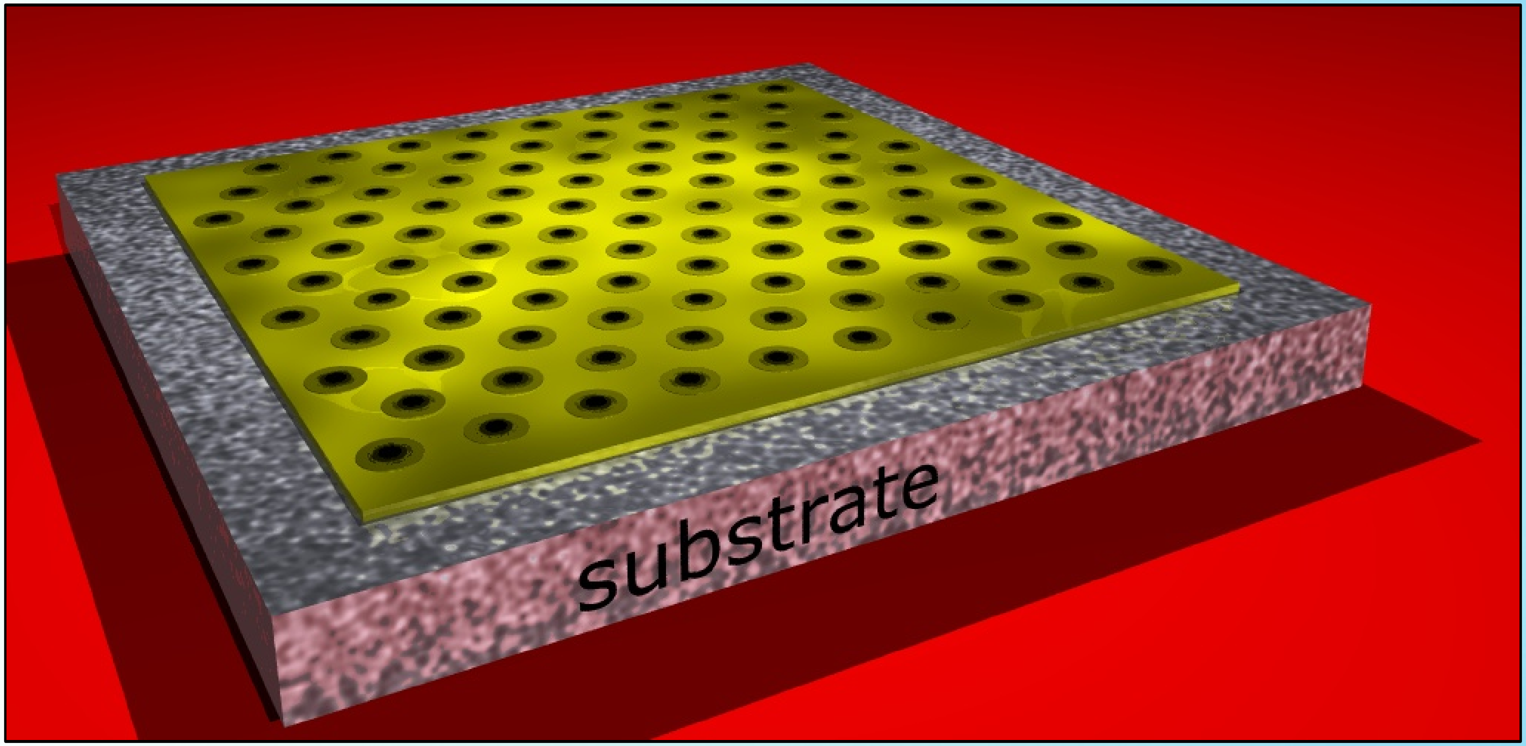
P. Kuświk *et al.*, Nanotechnology **22,** 095302 (2011)

Magnetic patterning through nanospheres mask

► Adjusting bombardment parameters to the size of nanospherse ◄



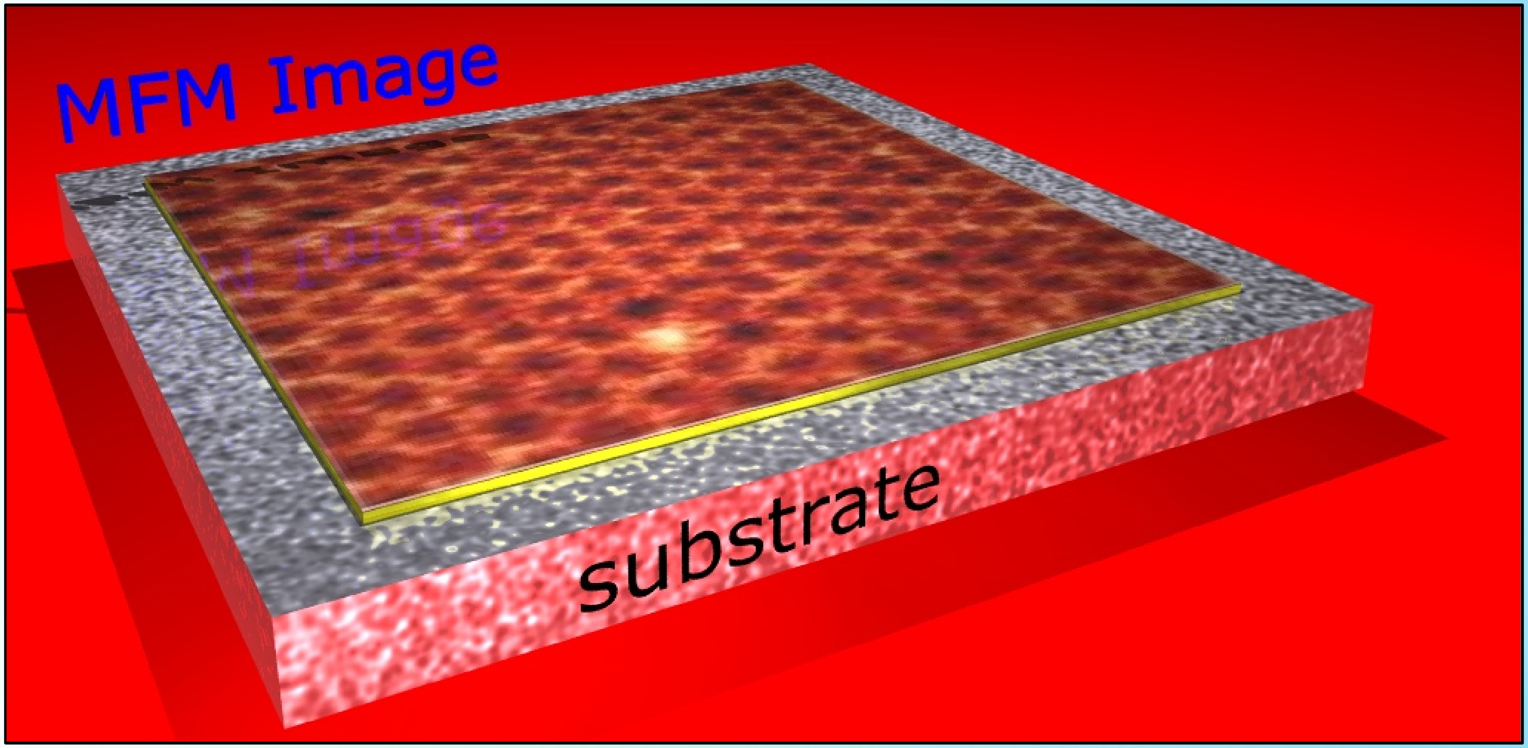
Magnetic patterning through nanospheres mask



- Bombardment through the mask of self-assembled nanosphers leads to magnetic patterning of the Au/Co/Au multilayer

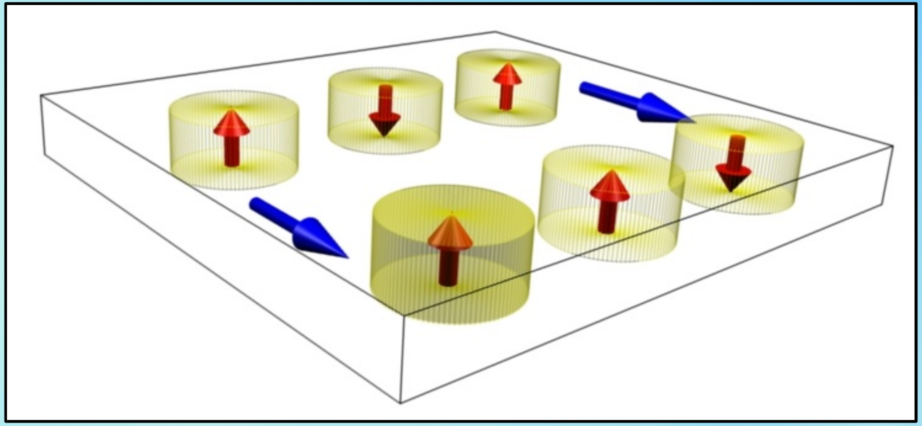
- The hexagonal lattice of areas with perpendicular anisotropy (not influenced by bombardment) is immersed in a matrix with the easy-plane anisotropy

Magnetic patterning through nanospheres mask



$H_{\perp}$=3.2 kA/m

- MFM images confirm the existence of hexagonal lattice of perpendicular anisotropy areas
- Magnetic moments of neighboring perpendicular anisotropy areas reverse independently



P.Kuświk

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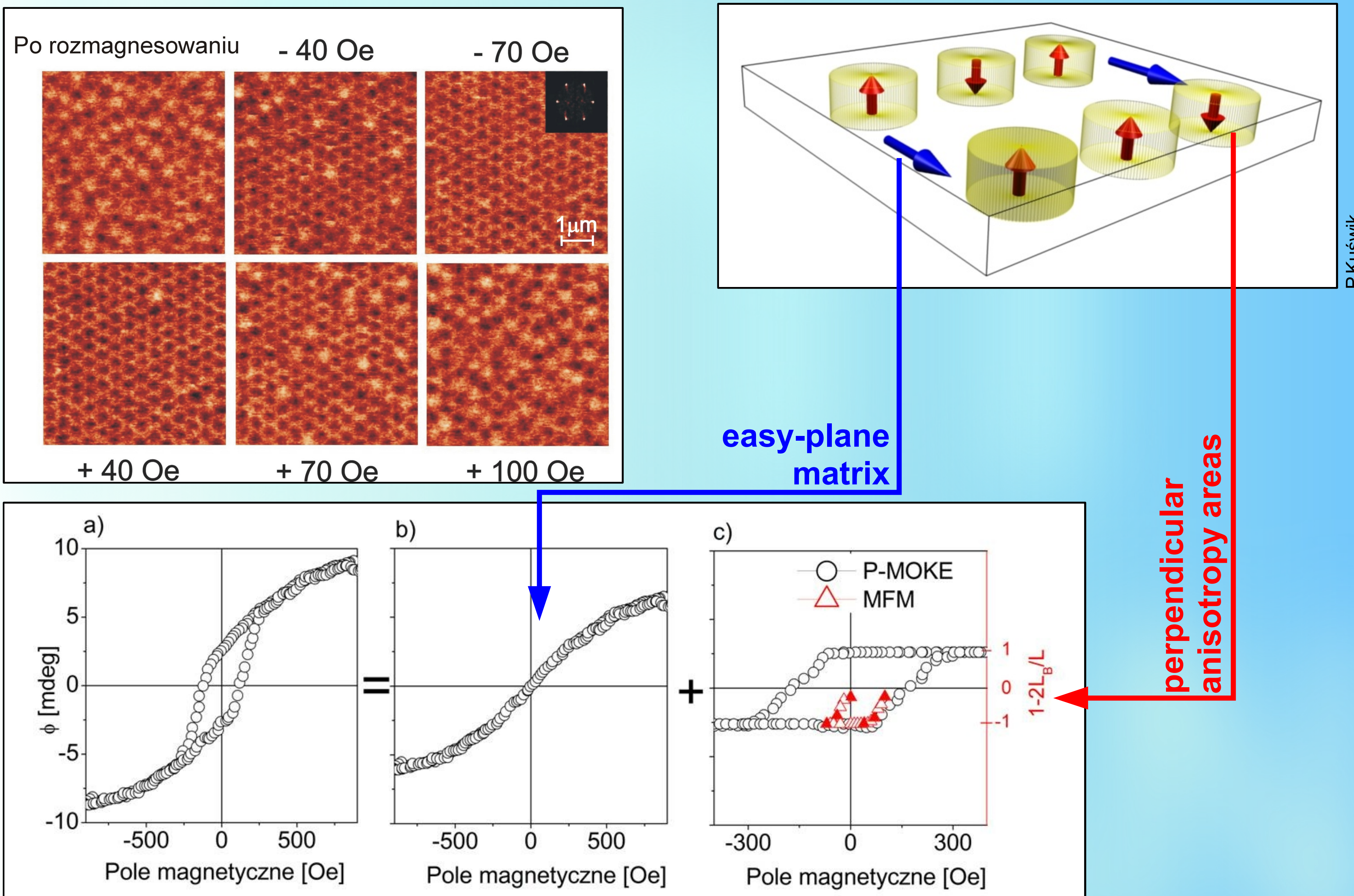
Magnetic patterning through nanospheres mask



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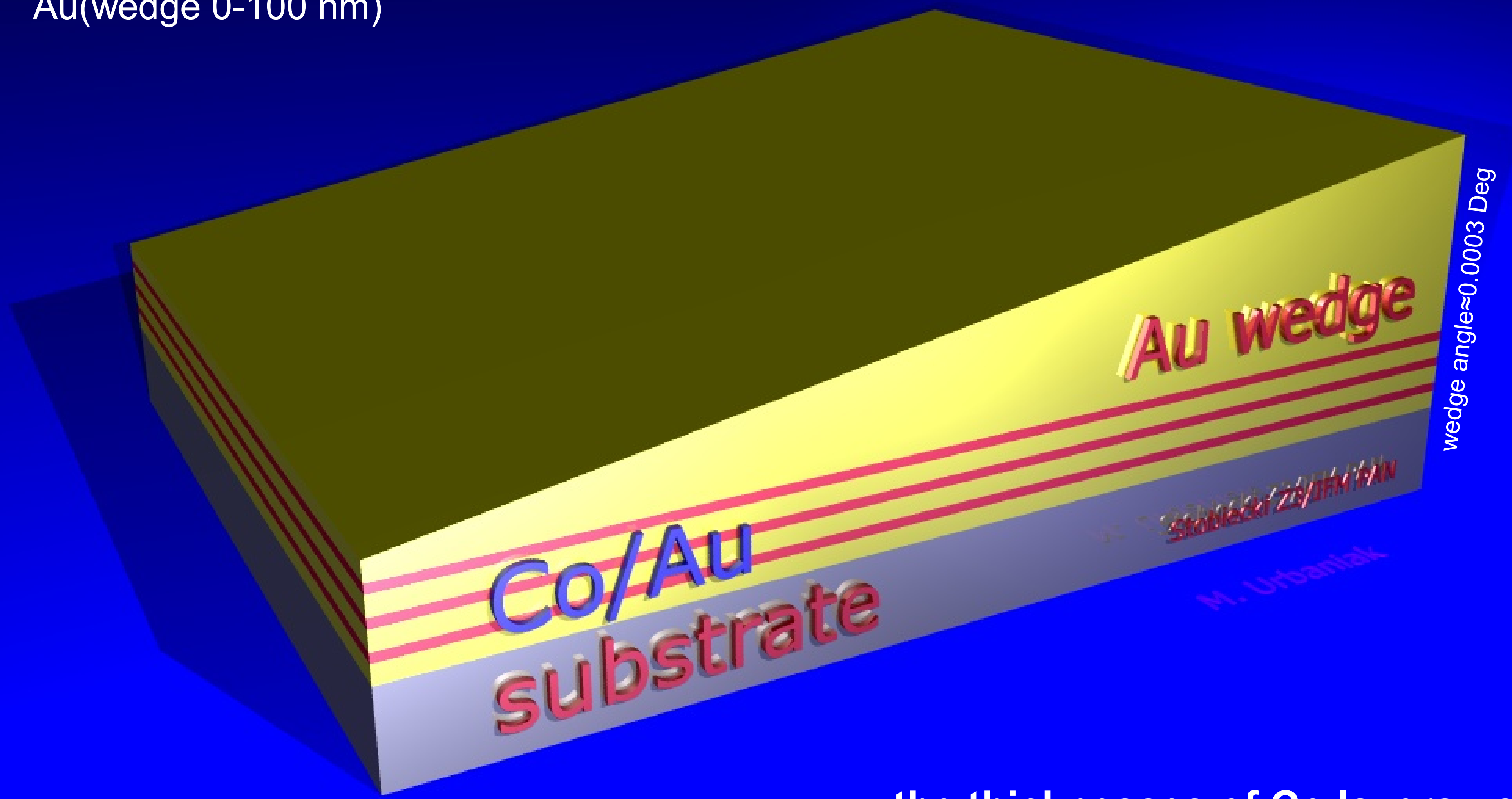
Multilayer system for controllable domain walls positioning

Deposited with magnetron sputtering

Si(100)/Ti(4 nm)/Au(60 nm)/[Co(0.6 nm)/Au(2 nm)]$_3$/
Au(wedge 0-100 nm)



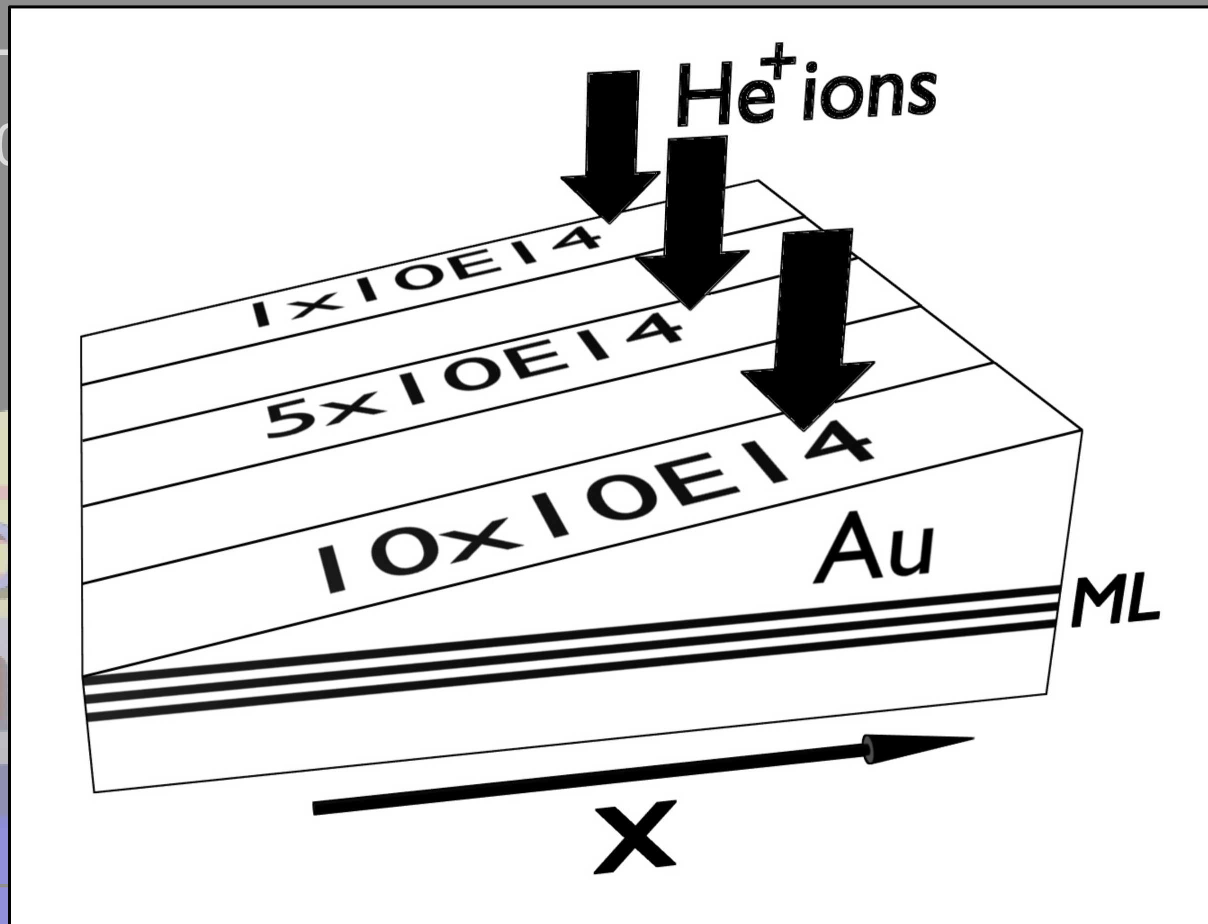
the thicknesses of Co layers used guarantee their perpendicular magnetic anisotropy.

Phys.Rev.Lett. **105**, 067202 (2010)

He^+ ion bombardment

Au wedge: 0 -

Ion energy: 10

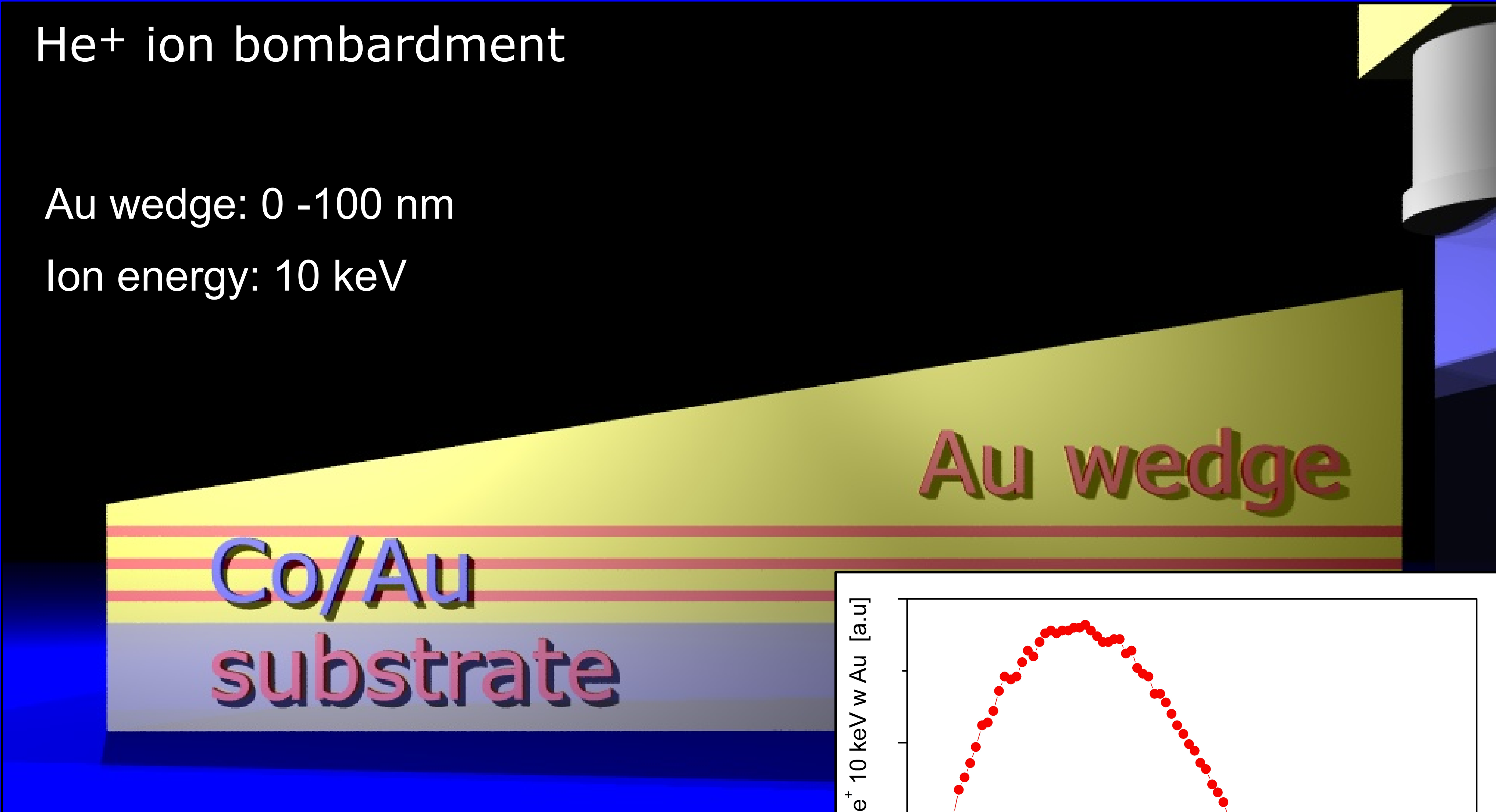


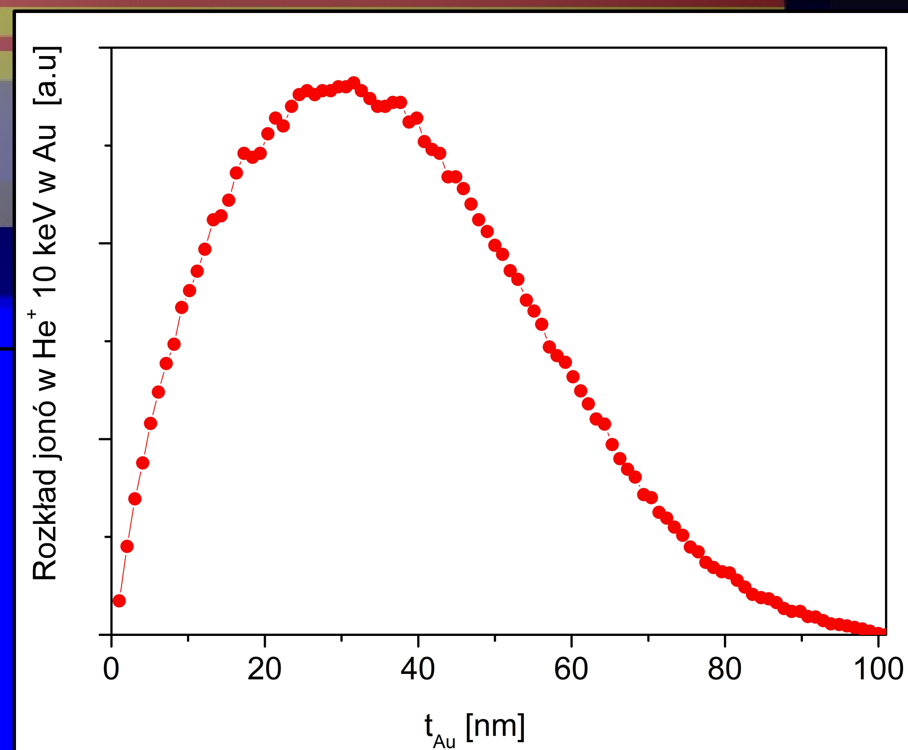
100 nm thick Au layer completely prevents He^+ ions from reaching Co/Au multilayer

He^+ ion bombardment

Au wedge: 0 -100 nm

Ion energy: 10 keV



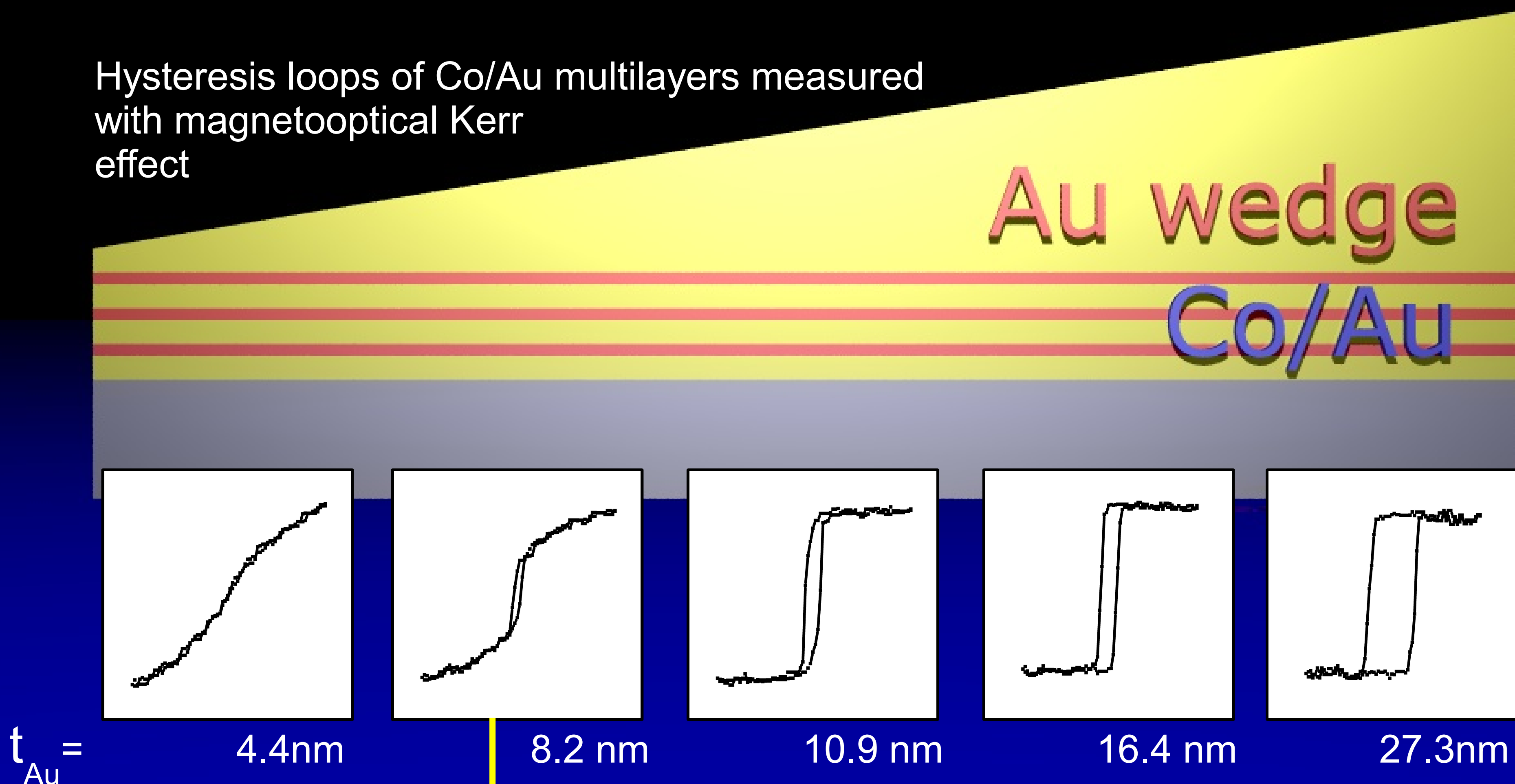


100 nm thick Au layer completely prevents He^+ ions from reaching Co/Au multilayer

P. Kuświk, Dissertation, Poznań 2010

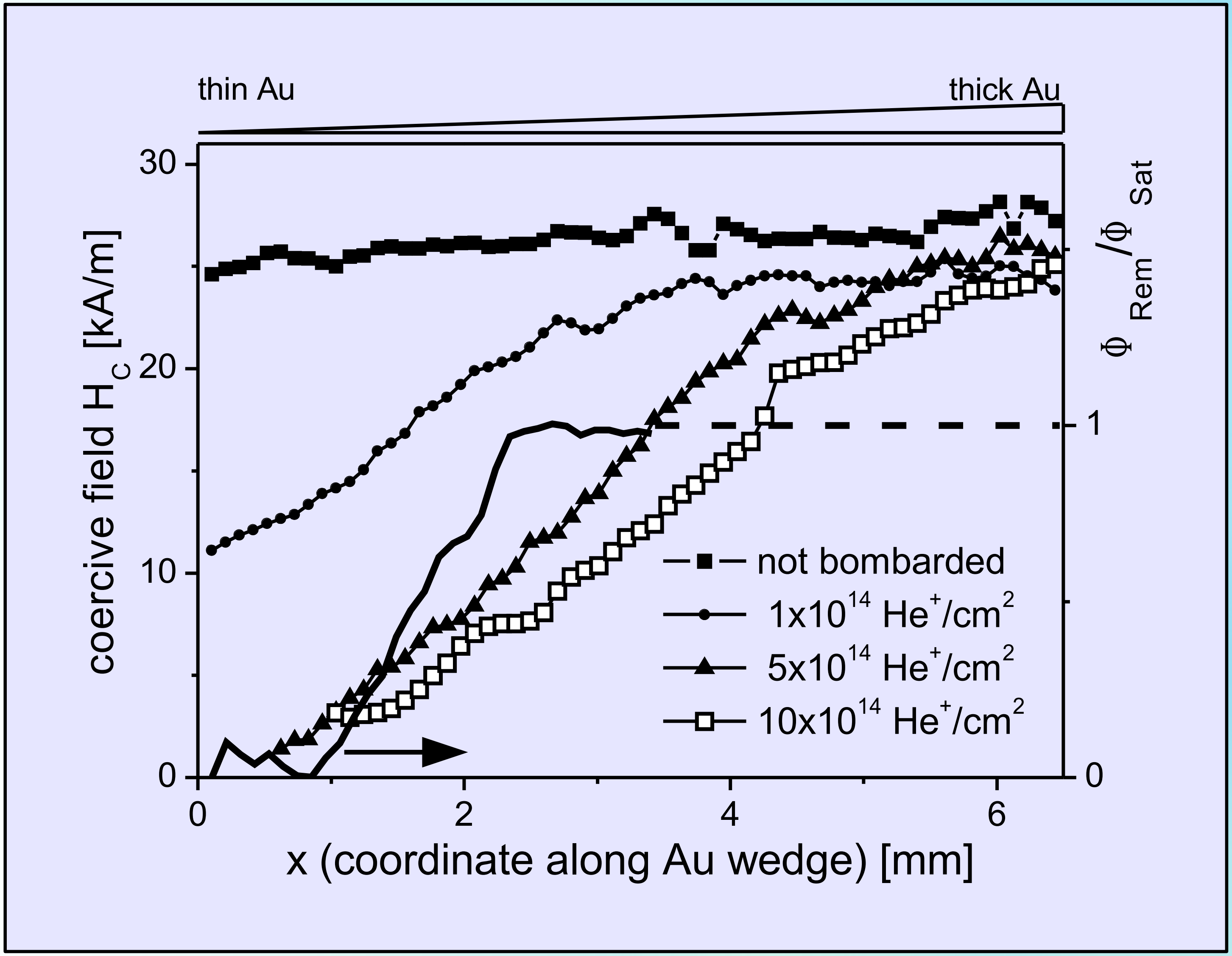
He+ ion bombardment – change of a coercivity

Hysteresis loops of Co/Au multilayers measured with magnetooptical Kerr effect



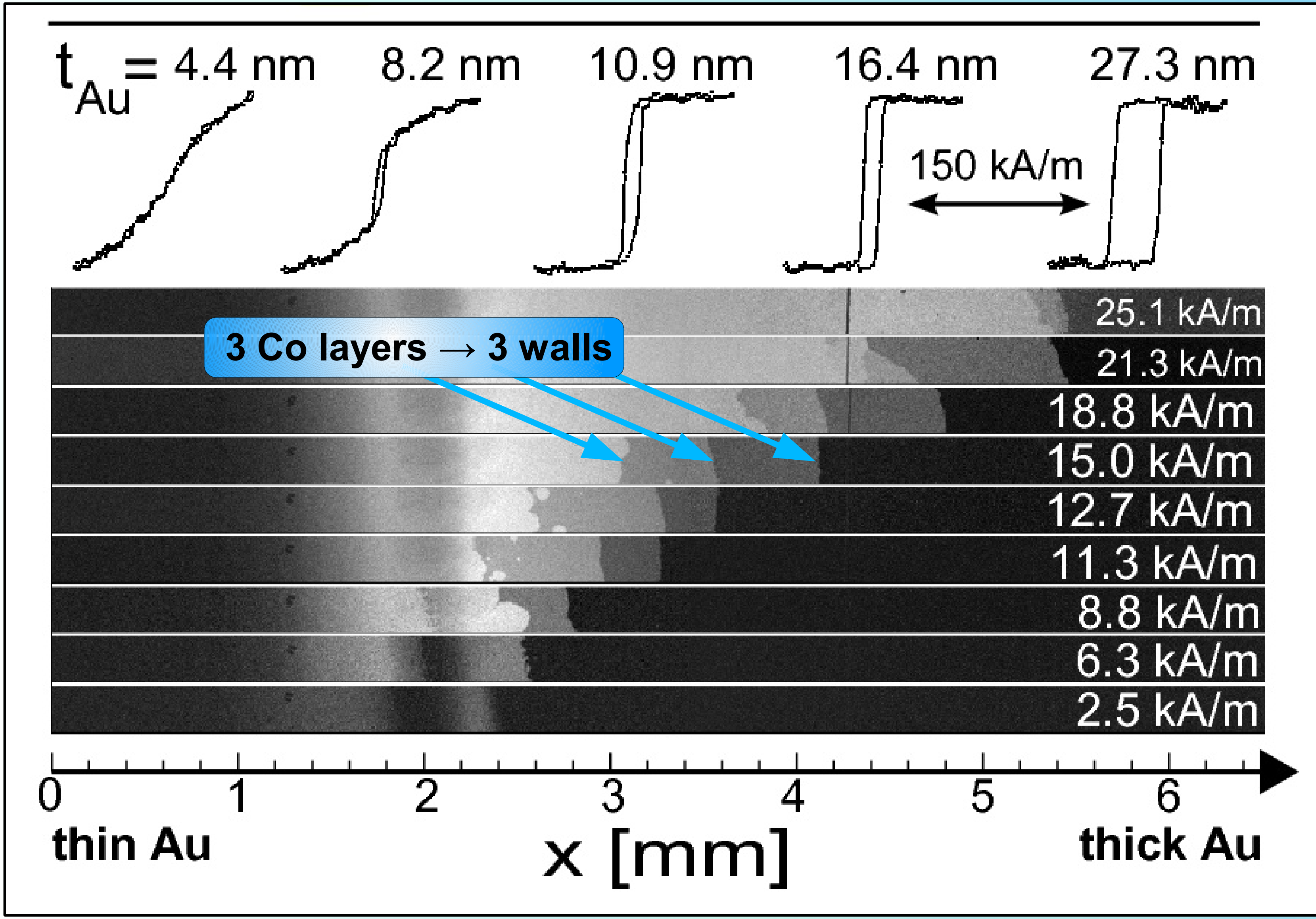
vanishing of perpendicular anisotropy due to bombardment

Change of the coercivity due to bombardment



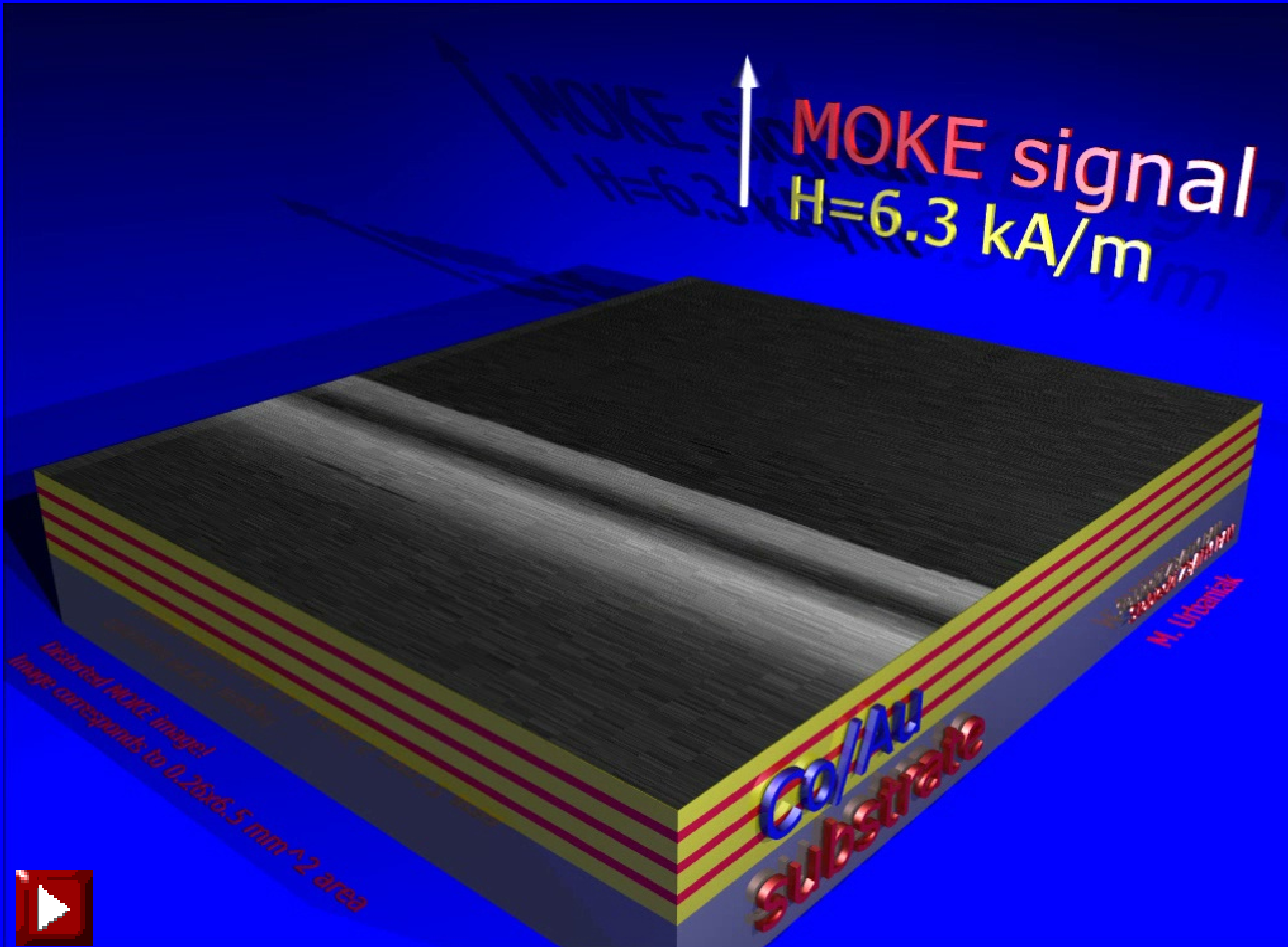
- in areas that were not bombarded H_C does not depend on position
- for high ion fluences and low thickness of Au protective layer anisotropy of Co layers turns in-plane (easy-plane anisotropy)

Position of the domain walls as a function of the external field

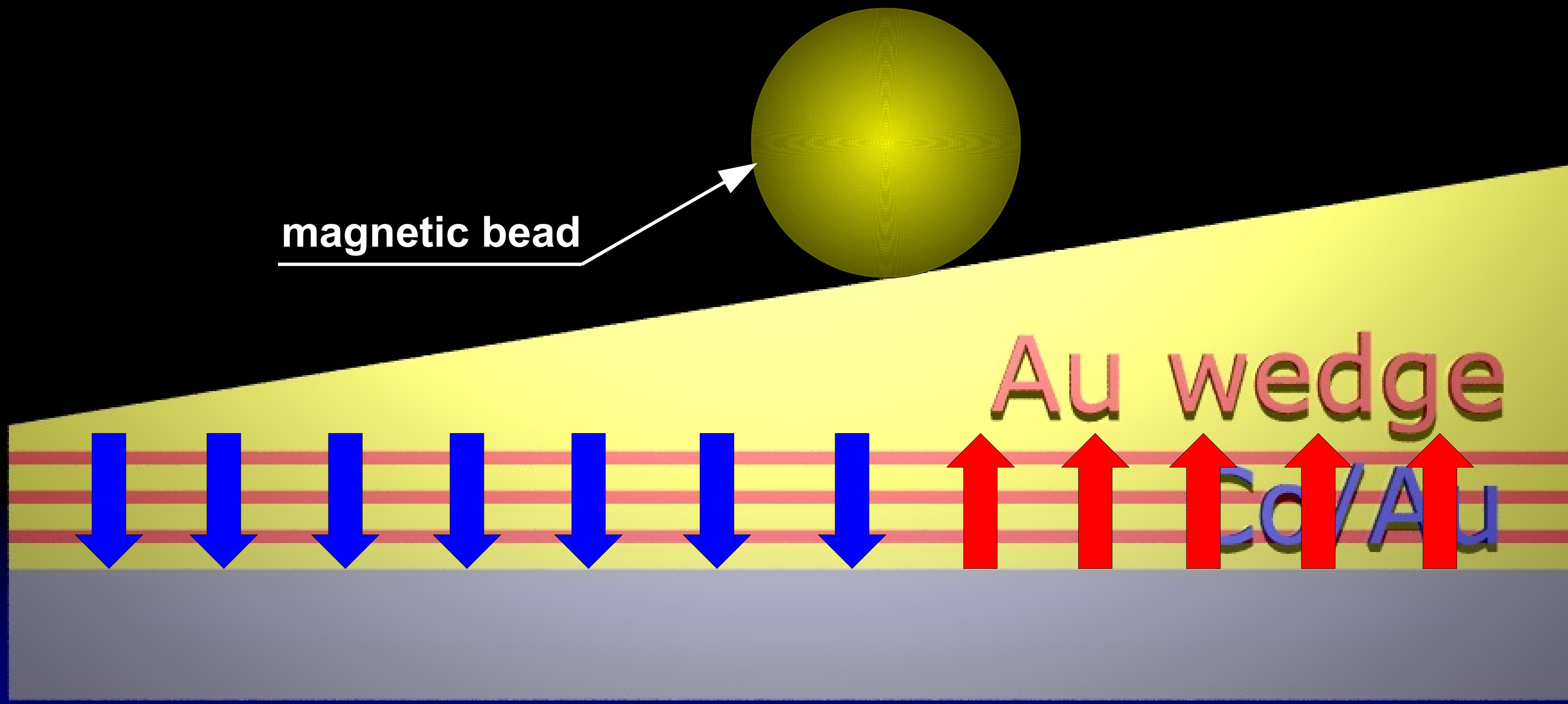


MOKE

Differential images: MOKE measurements performed in remanence; after the application of external field of the given magnitude


MOKE signal
H=6.3 kA/m
Co/Au
Substrate
Distorted MOKE image!
Image corresponds to 0.26x6.5 mm^2 area
M. Urbaniak

Magnetophoresis induced by “gradientless” magnetic field

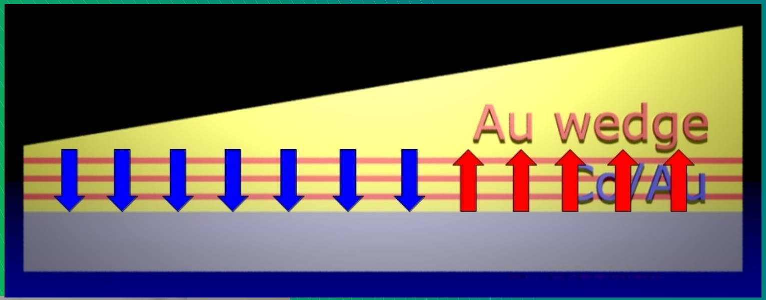


Force on superparamagnet

$$\vec{F} = \frac{1}{2\mu_0}\chi V \nabla\left(B^2\right)$$

Transport of magnetic beads on the domain walls

initial position of the domain wall



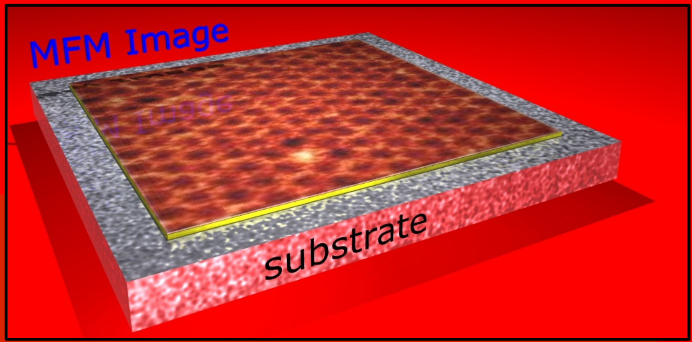
Field range (start-stop):
7.1 - 8.7 kA/m
(90-110 Oe)
bead diameter:
2μm
Image height:
~0.5mm

Szymański *et al.*

viewing speed: true speed×**30**

Content of 3 slides removed due to copyright concerns

Conclusions



- Ion bombardment of Au/Co/Au multilayers through the polystyrene nanospheres masks leads to a formation of 2D hexagonal array of the perpendicular anisotropy areas.

- The gradient of the coercive field (in the structures with perpendicular anisotropy of Co layers) can be created by:
  - -ion bombardment
  - -the change of Co layers thickness

- The movement of domain walls towards areas of higher coercivity may be utilized in magnetophoresis and magnetic sensors.