On the modification of the magnetic properties of Fe nanoparticles and nanometric Co films as a function of the surrounding environment

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Magnetic Imaging and Spectroscopy Workshop
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CSIC ICMM

On the modification of the magnetic properties of Fe nanoparticles and nanometric Co films as a function of the surrounding environment

- Motivations
- Nanometric Fe particles
- Nanometric Co films
- Acknowledgments

Motivations

Applied & fundamental

Dimensions of magnetic and magneto-optical devices (data storage, sensors) must be reduced in order to increase the performances

Use of low-dimensional entities (nanoparticles, ultra thin films)

Evolution of physical properties as a function of size, shapes
Interaction between entities
Interaction between entities and surrounding material (matrix)

Need of understanding and control of all these phenomena for the successful integration of nano-entities into devices

Motivations

Applied & fundamental

Dimensions of magnetic and magneto-optical devices (data storage, sensors) must be reduced in order to increase the performances

Use of low-dimensional entities (nanoparticles, ultra thin films)

Evolution of physical properties as a function of size, shapes
Interaction between entities
Interaction between entities and surrounding material (matrix)

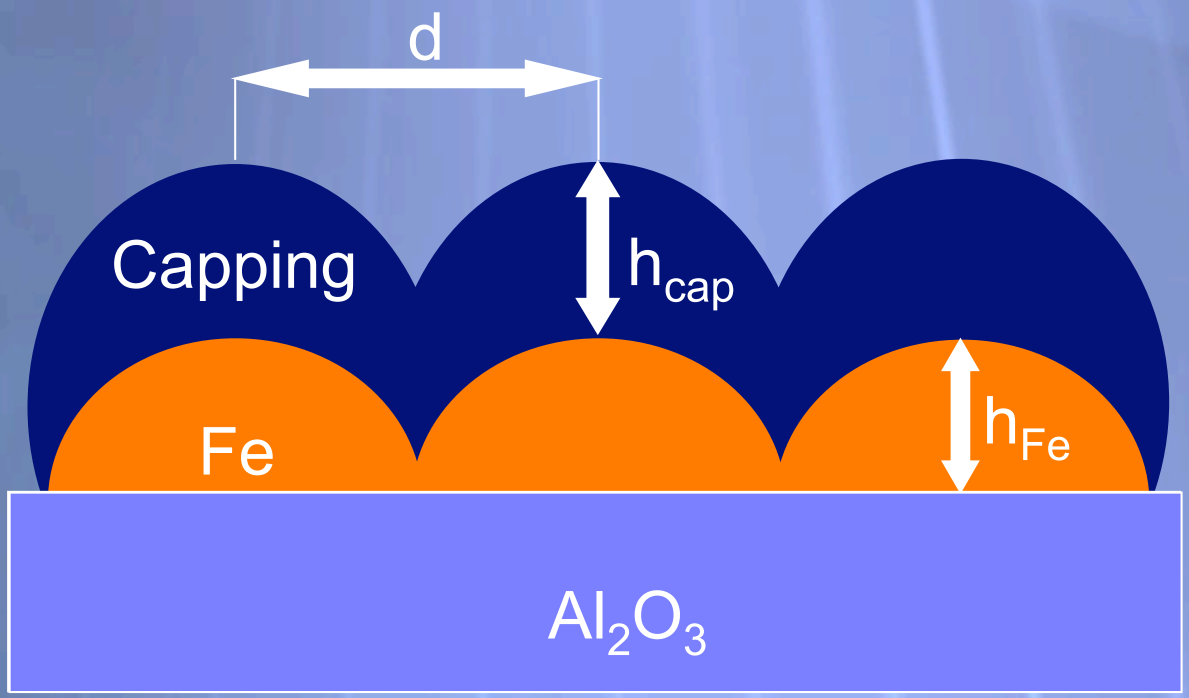
Expected to be mandatory for nanoparticles and ultra thin films

Need of understanding and control of all these phenomena for the successful integration of nano-entities into devices

Sample preparation and structure

(IMM)

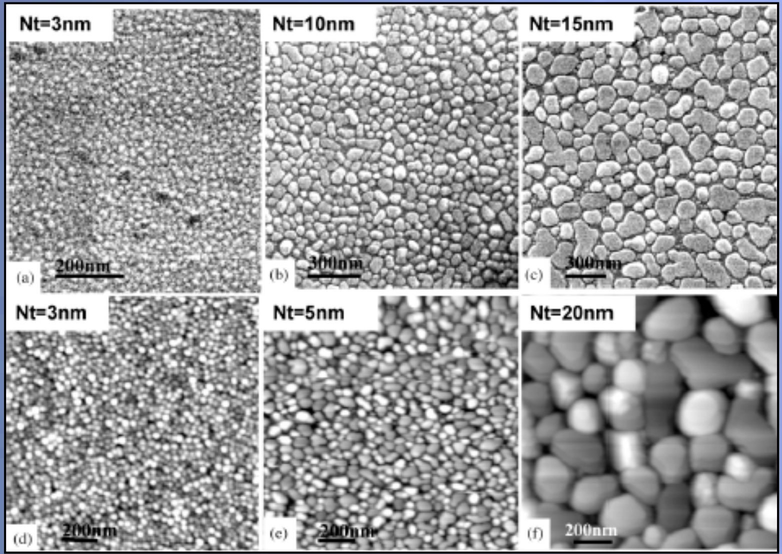
Deposition: triode-sputtering in ultra high vacuum system (IMM)
Substrate: Sapphire Al_2O_3(0001)
Cleaning: annealing in UHV at 1100 K
Substrate temperature during Fe deposition ≈ 1000 K
Room temperature deposition of capping layers

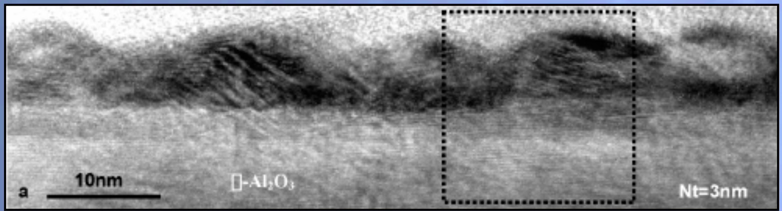


$h_{Fe} \approx 3 - 4$ nm
$h_{cap} > 3$ nm
$d \approx 10 - 12$ nm

Sample preparation and structure

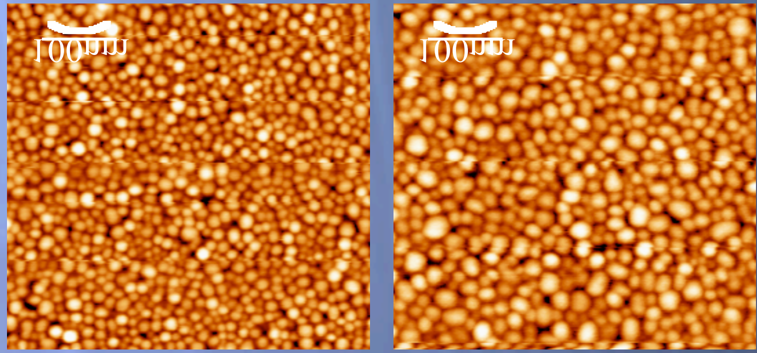
Morphology - SEM, TEM

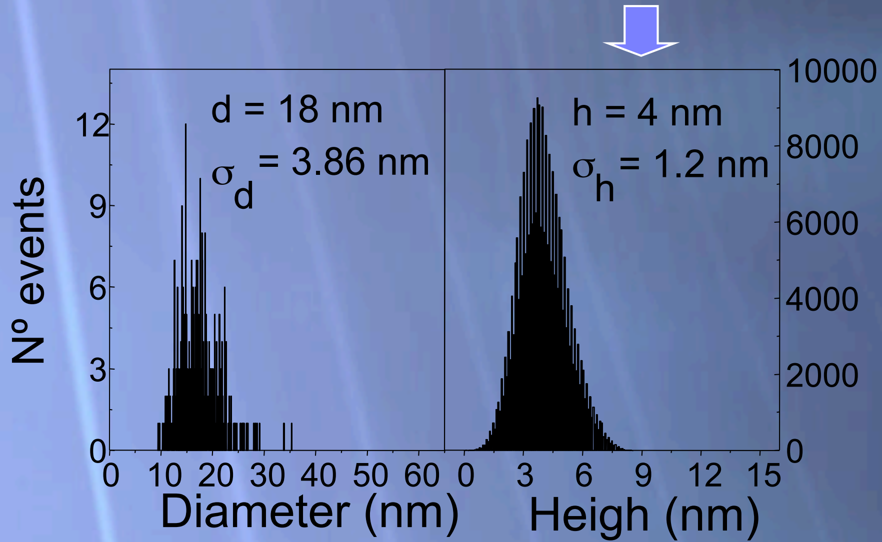




Morphology - AFM

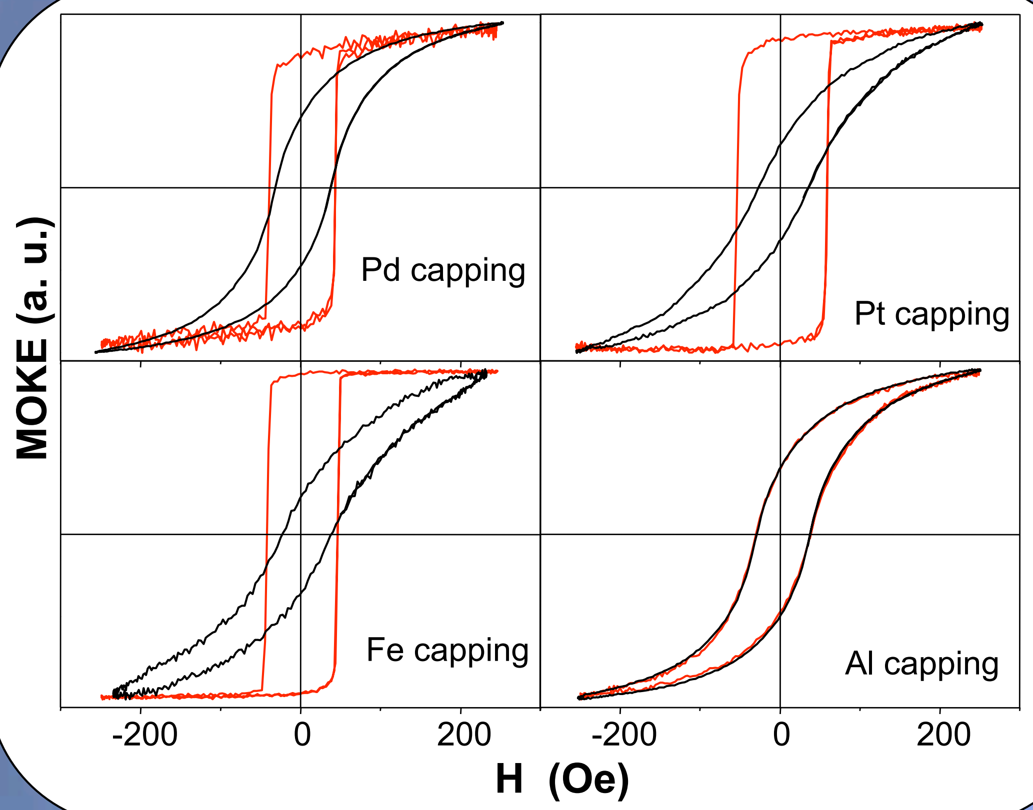
1.6 nm Fe 2.0 nm Fe





C. Quintana et al., Thin Solid films, 434, 228-238 (2003).
E. Navarro, Y. Huttel et al., App. Phys. Letters 84, 2139 (2004)
E. Navarro, Y. Huttel et al., Phys. Rev. B 69, 224419 (2004)

Magnetic and Chemical characterizations



UHV in-situ transverse Kerr (IMM)

☞ Direct evidence of magnetic connection of the islands through the Pd and Pt capping layers

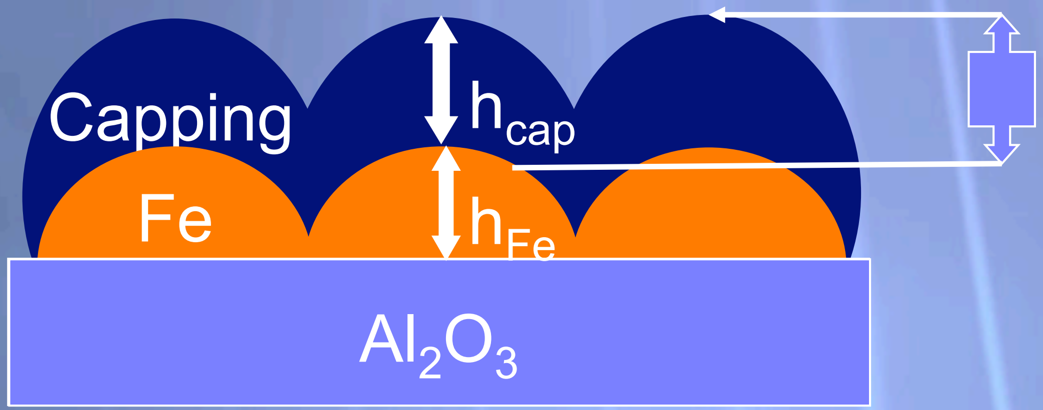
☞ Polar Kerr spectroscopy + simulations
➜ Pd and Pt are polarized at the Fe/ Capping layer interface; polarized thickness ≈ 0.7 nm.

App. Phys. Letters 84, 2139 (2004); Phys. Rev. B 69, 224419 (2004)

Magnetic and Chemical characterizations

ex-situ XMCD (X-ray Magnetic Circular Dichroism)
(Daresbury synchrotron)

Atomic spin and orbital magnetic moments as a function of capping layer



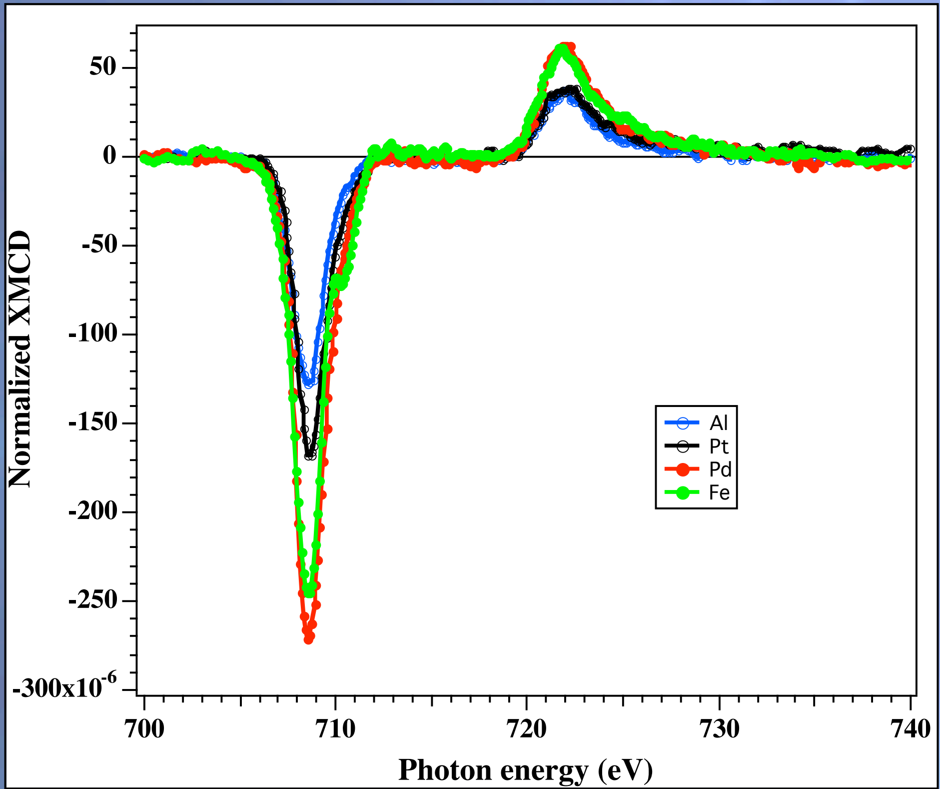
Thickness probed by XMCD ≈ 4 nm

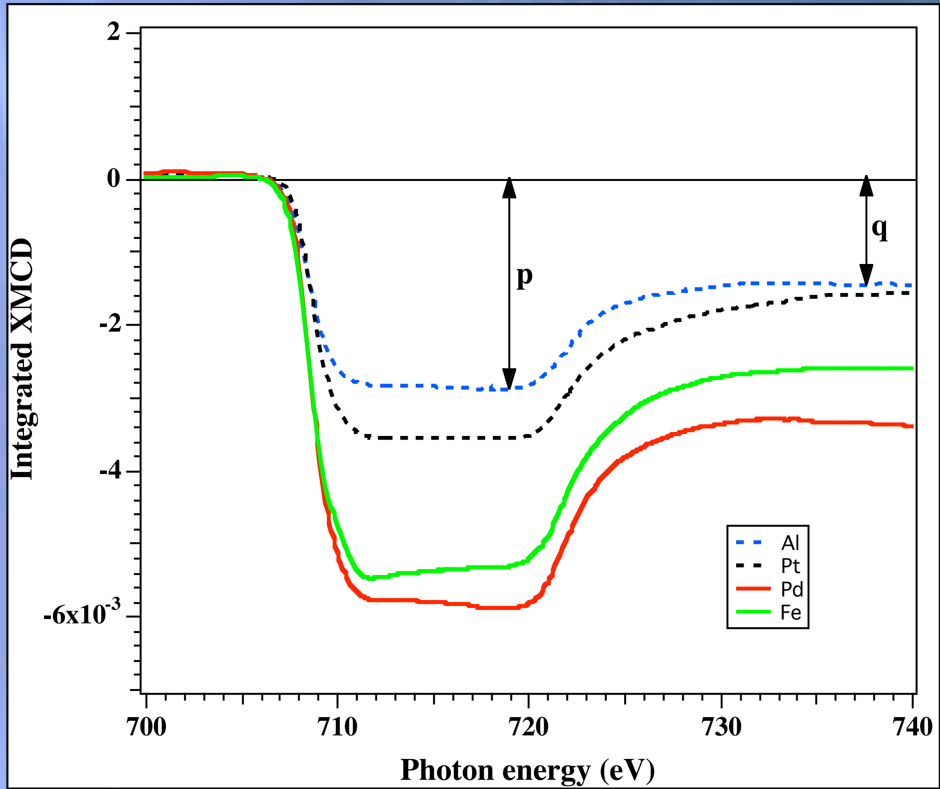
$h_{cap} \approx 3$ nm

High sensitivity to possible capping layer effects

PROPERTIES OF NANOMETRE SIZE Fe(110) ISLANDS GROWN ON SAPPHIRE

XMCD





Sum rules

$$\mu_{orb} \propto -4q/3$$

$$\mu_{spin} \propto -(6p - 4q)$$

Phys. Rev. B 78, 104403 (2008)

XMCD

Atomic Magnetic spin and orbital moments as a function of capping layer

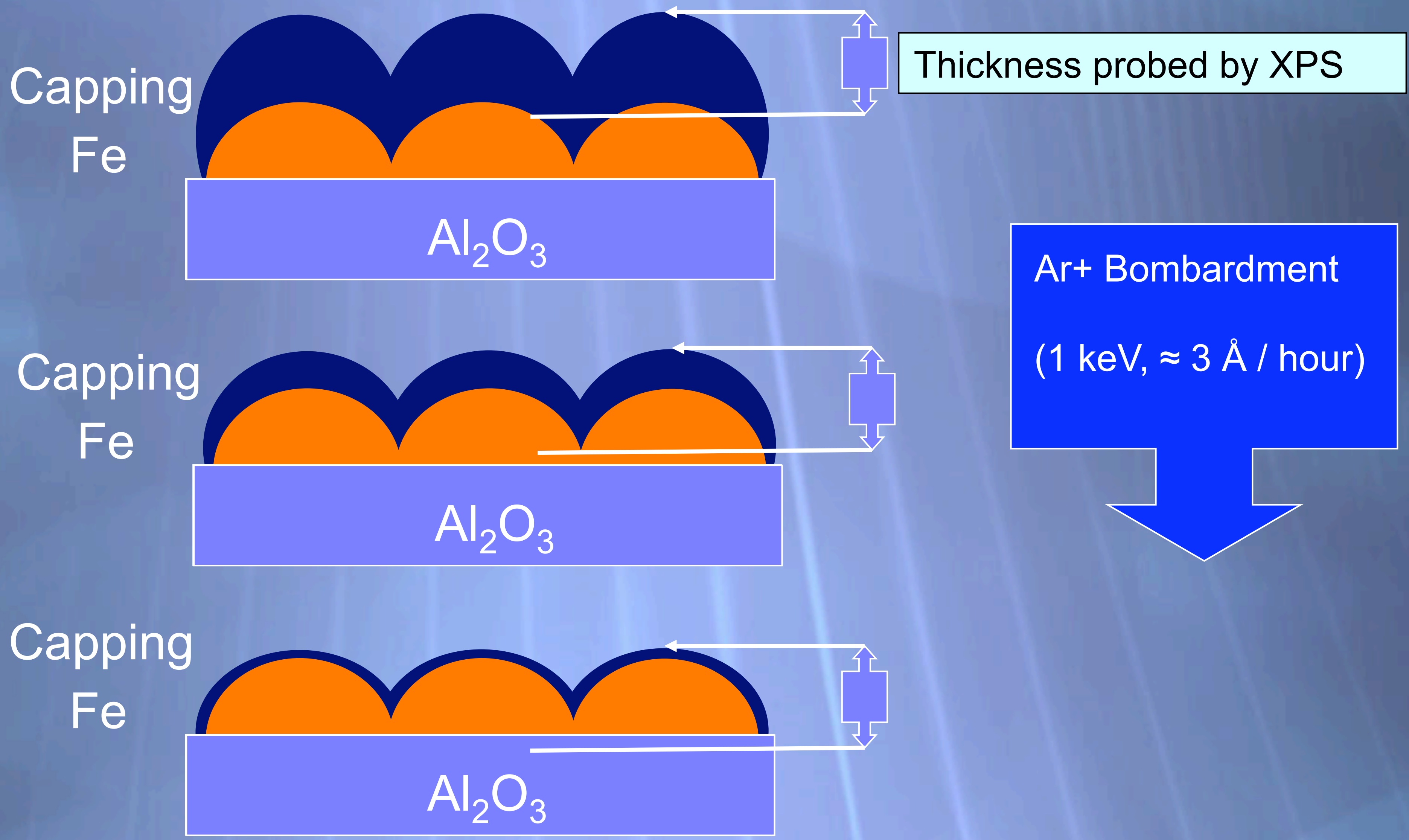
	«μ_{orb}»/Fe	«μ_{spin}»/Fe	«μ_{orb}/ μ_{spin}» / Fe
Fe	1	1	1
Pd	0.61	0.35	1.74
Pt	0.34	0.33	1.03
Al	0.22	0.18	1.22

Atomic Magnetic moments: Fe/Fe > Pd/Fe > Pt/Fe > Al/Fe

PROPERTIES OF NANOMETRE SIZE Fe(110) ISLANDS GROWN ON SAPPHIRE

Chemical characterization

ex-situ UHV XPS depth profiles
ICMM



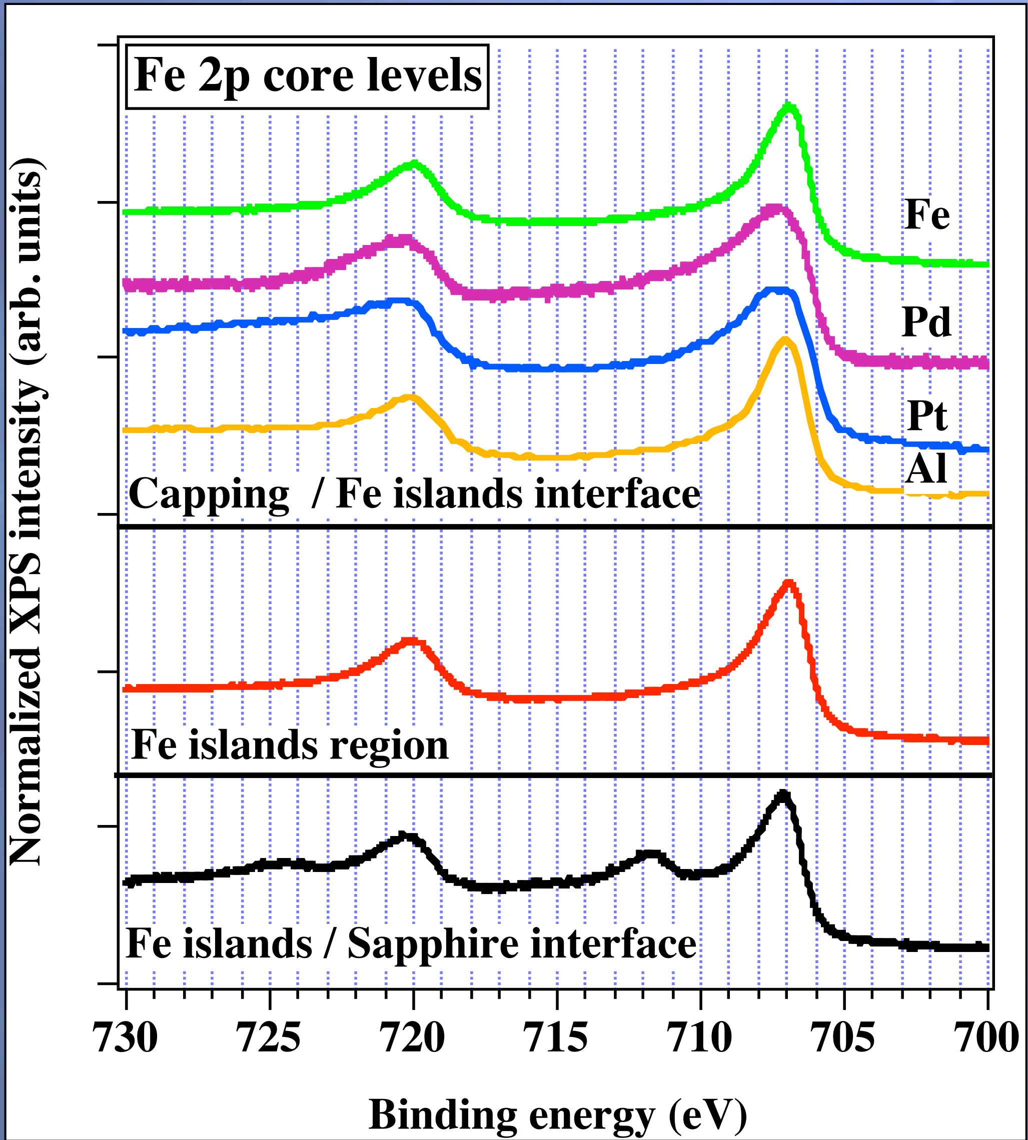
Ar+ Bombardment

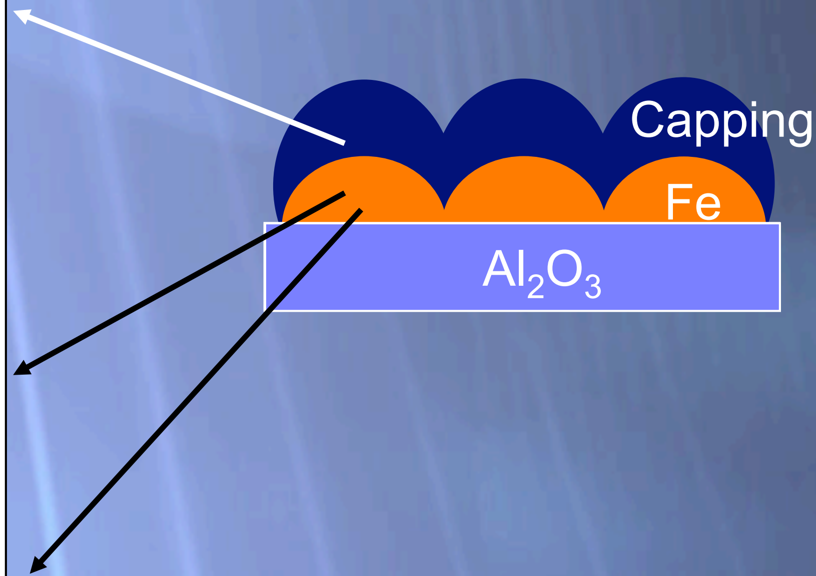
(1 keV, ≈ 3 Å / hour)

PROPERTIES OF NANOMETRE SIZE Fe(110) ISLANDS GROWN ON SAPPHIRE

Chemical characterization

ex-situ UHV XPS depth profiles





Chemical characterization

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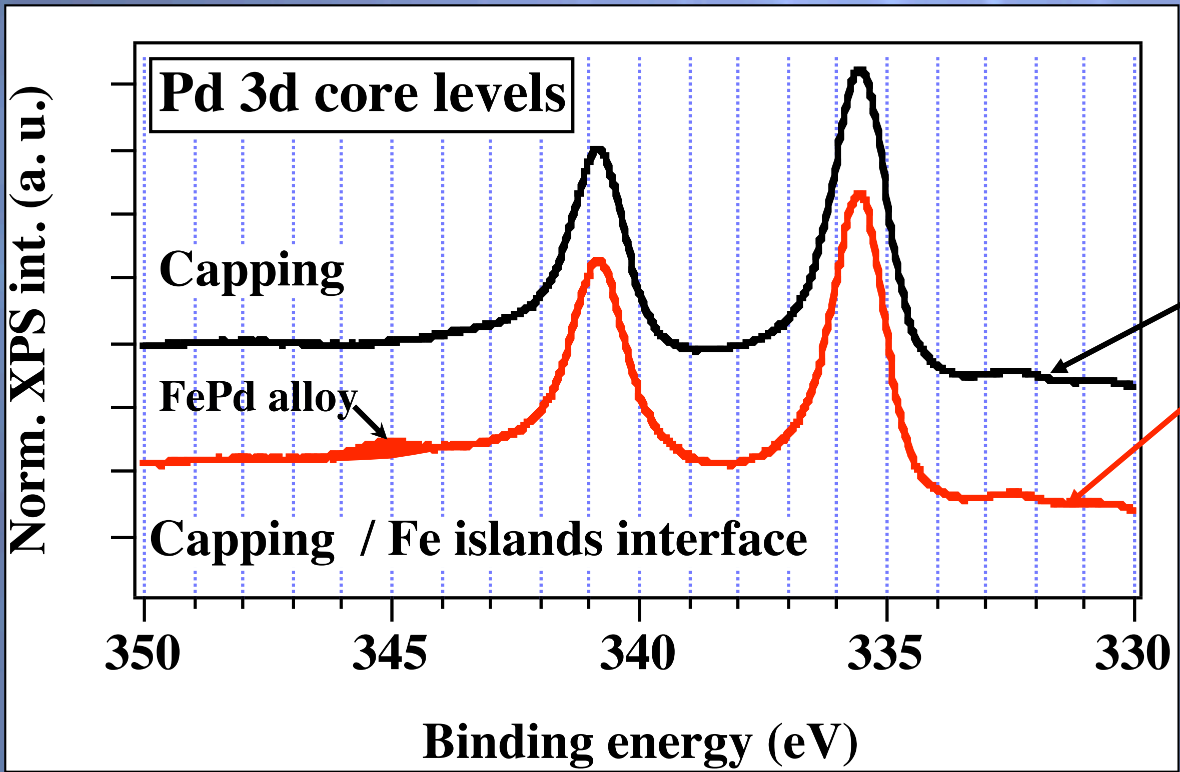
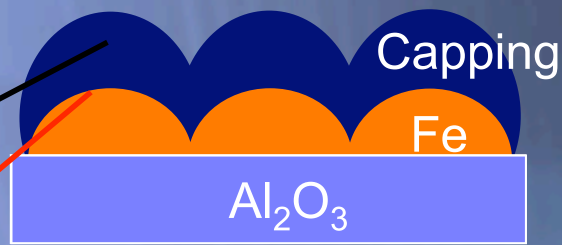
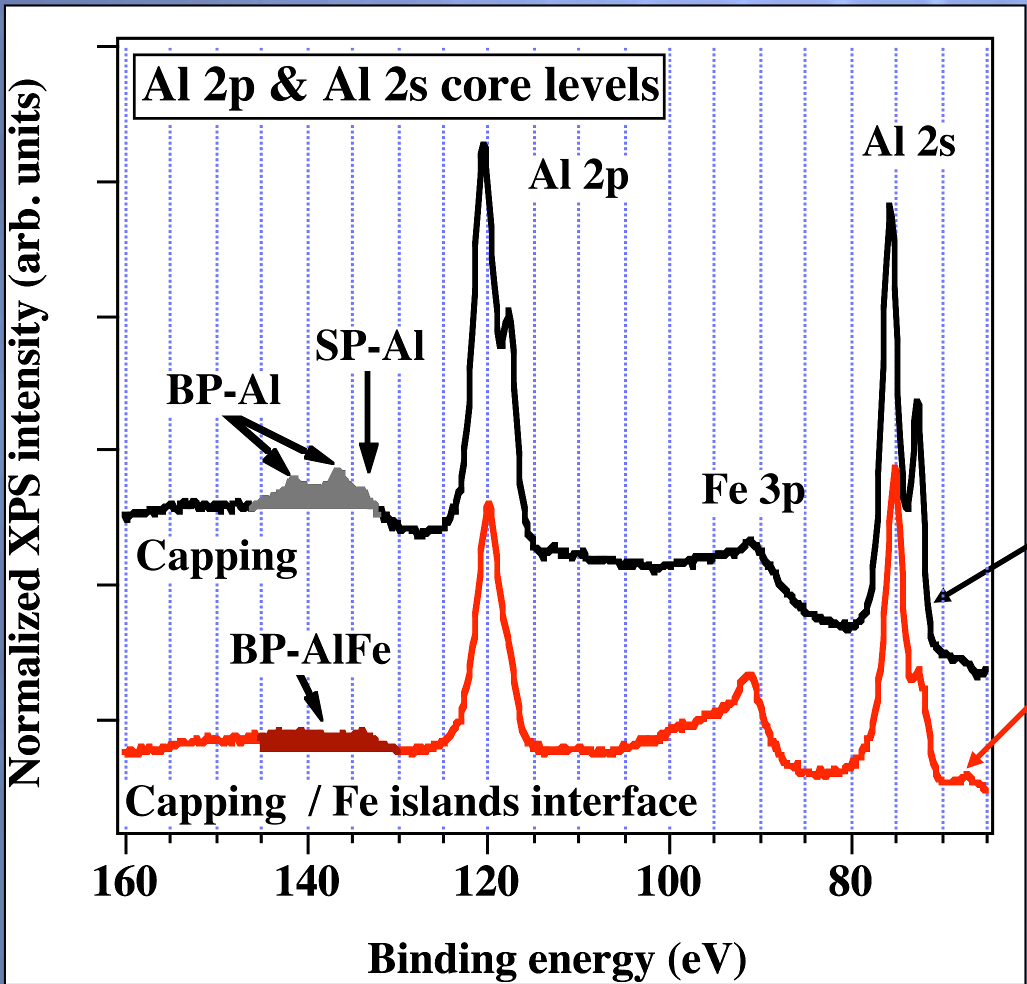


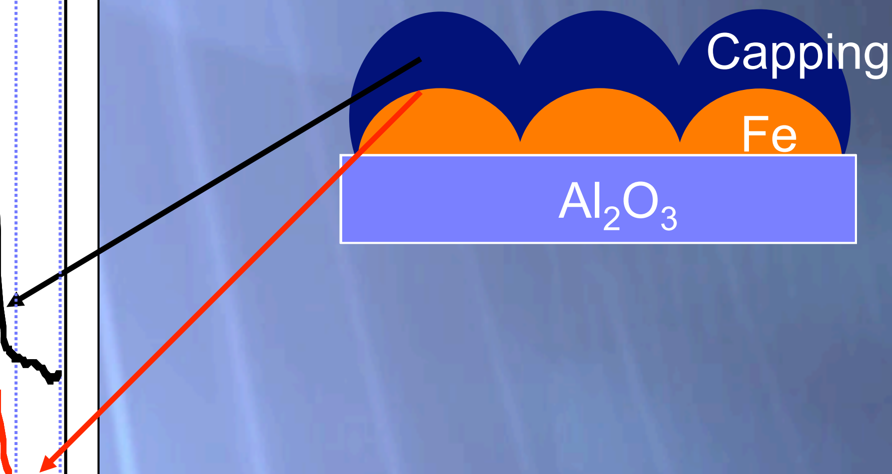


PROPERTIES OF NANOMETRE SIZE Fe(110) ISLANDS GROWN ON SAPPHIRE

Chemical characterization

ex-situ UHV XPS depth profiles

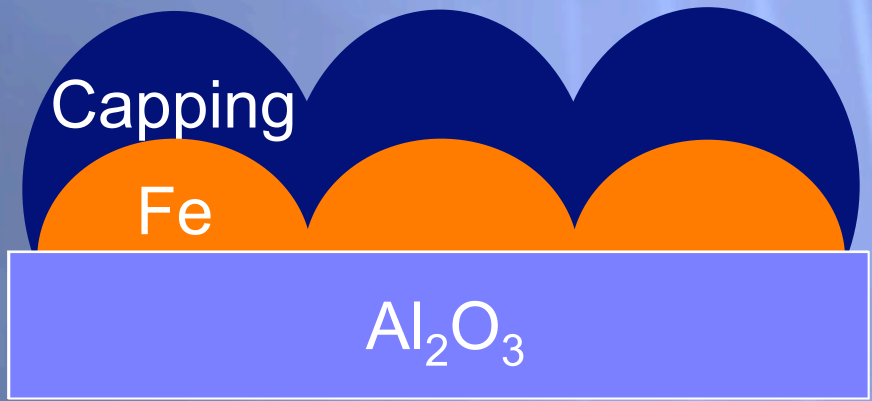


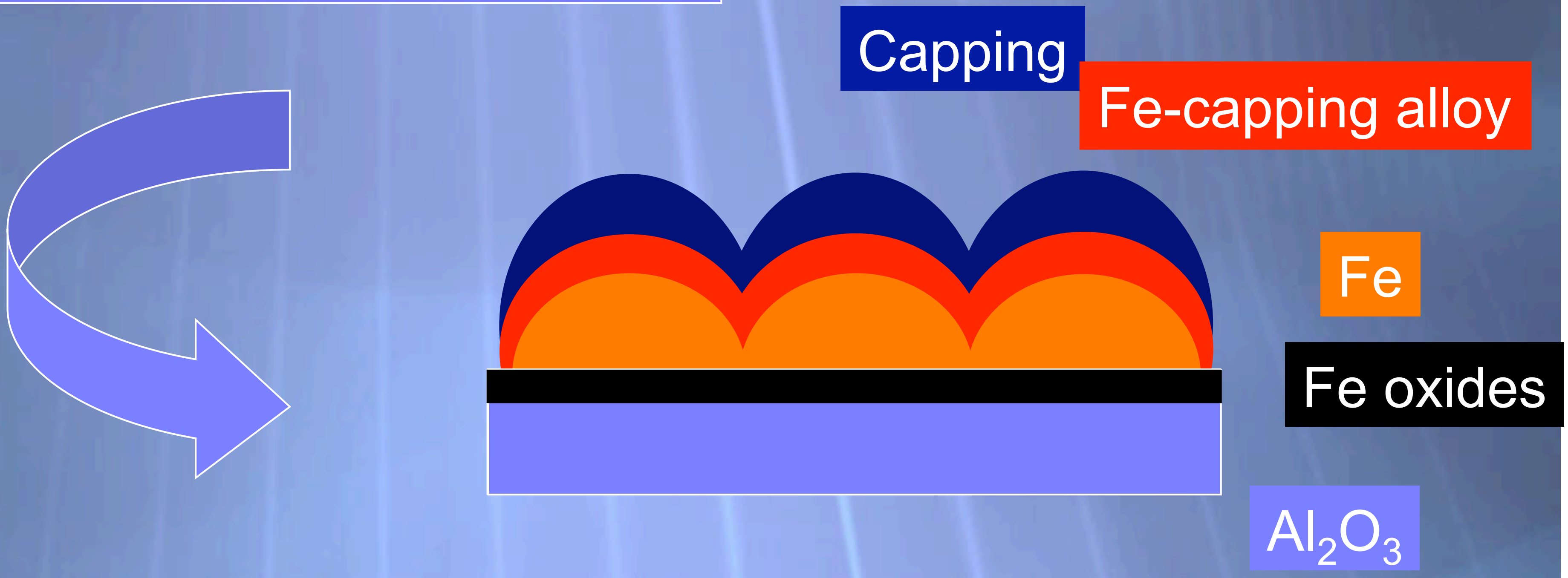


Phys. Rev. B 78, 104403 (2008)

Chemical characterization

ex-situ UHV XPS depth profiles





Summary

PROPERTIES OF NANOMETRE SIZE Fe(110) ISLANDS GROWN ON SAPPHIRE

Strong modification of the magnetic properties of an assembly of Fe nanoparticles through the capping layer:

- Pt and Pd cappings: magnetic connection of the nanoparticles.
- Al: no modification of the hysteresis loops (Kerr) and strong reduction of Fe atomic moments.

In all cases (Pt, Pd, Al cappings):

- formation on an Fe-capping alloys at the Fe nanoparticles/capping interface.
- the formation on Fe oxides has been evidenced at the Fe nanoparticles/Sapphire interface.

Sample preparation and structure

(IMM)

<u>Deposition</u>: triode-sputtering in ultra high vacuum system (IMM)

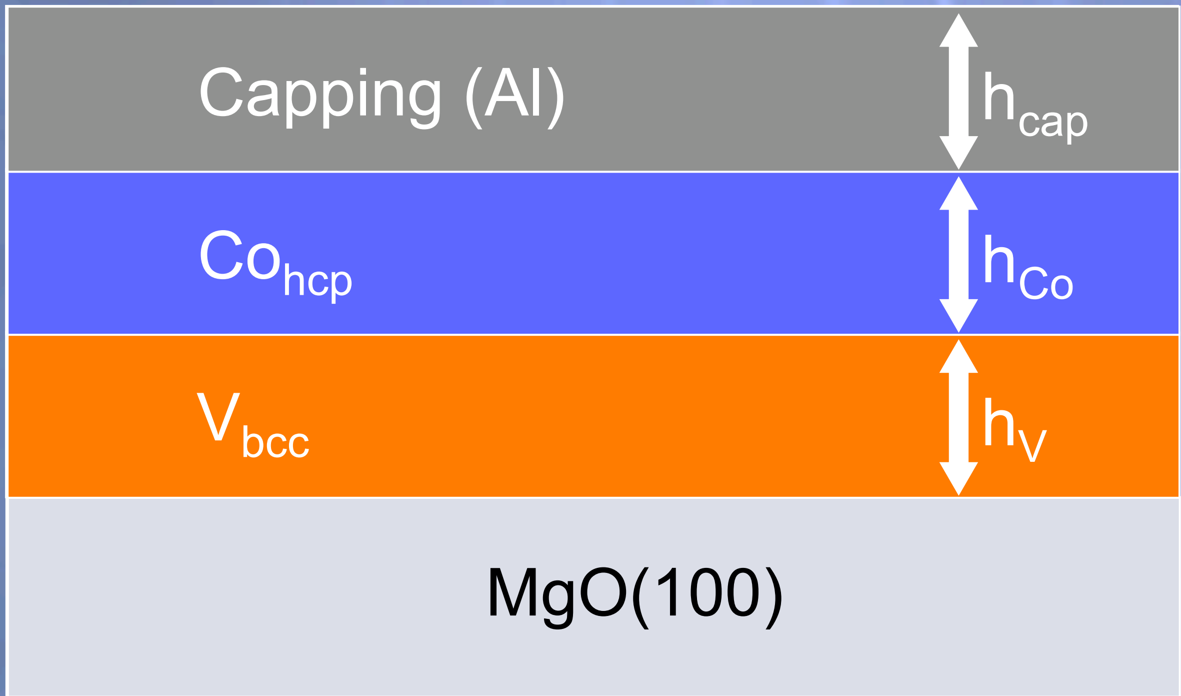
Substrate: MgO(100)

Cleaning: annealing in UHV at 750 K

Substrate temperature during V deposition ≈ 750K

Room temperature deposition of Co layers

Room temperature deposition of Al capping



$h_{cap} \approx 3$ nm

$1\ \text{nm} < h_{Co} < 20\ \text{nm}$

$1\ \text{nm} < h_V < 8\ \text{nm}$

J. Crystal Growth 273, 474 (2005)
J. Appl. Phys. 100, 053917 (2006)

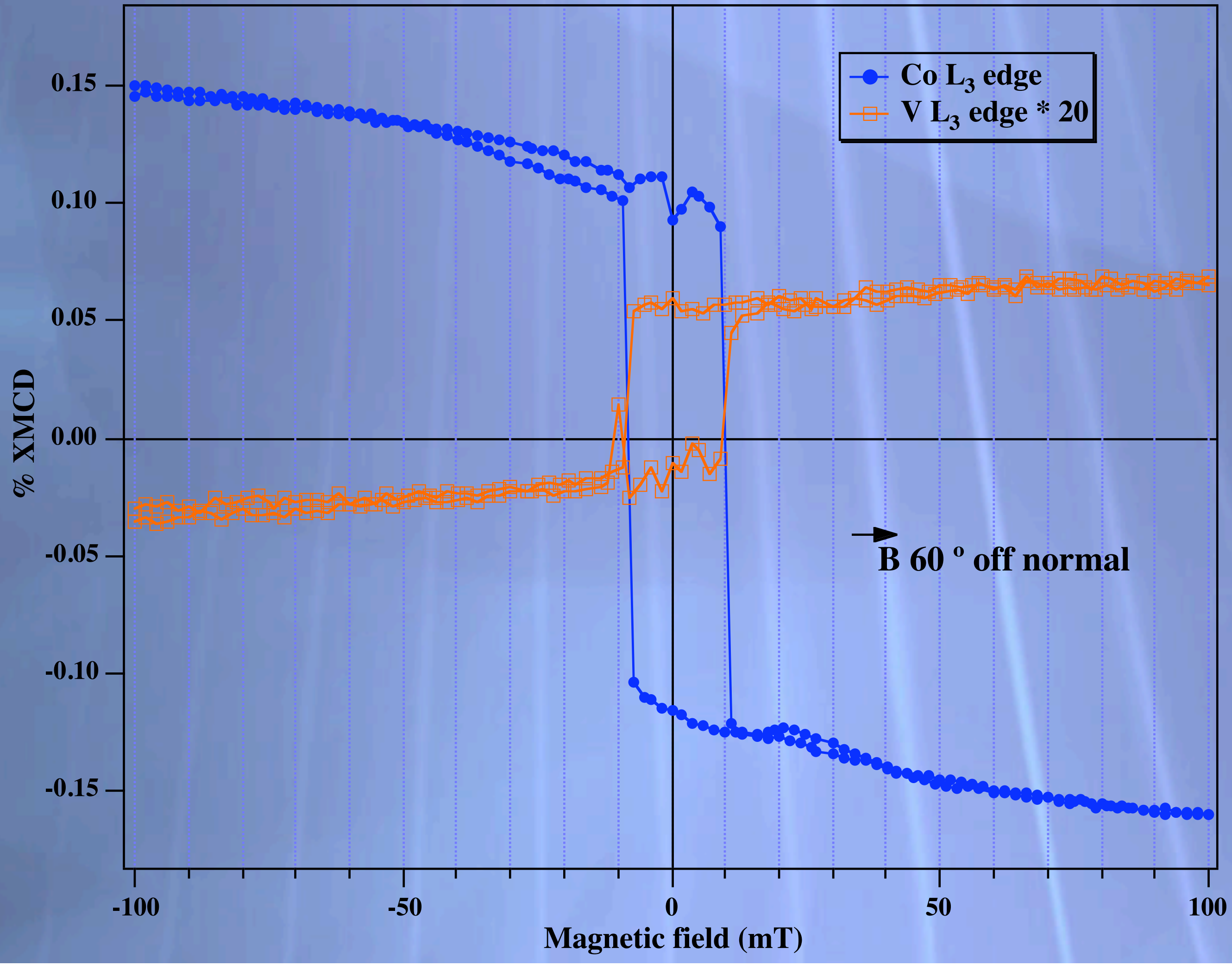
PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

Magnetic characterization

XMCD (ID8 - ESRF)

3 nm Al / 5 nm Co / 8 nm V / MgO(100)

Element specific XMCD hysteresis loops



XMCD direct evidence of strong magnetic polarization of V and same switching magnetic field for both V and Co thin layers

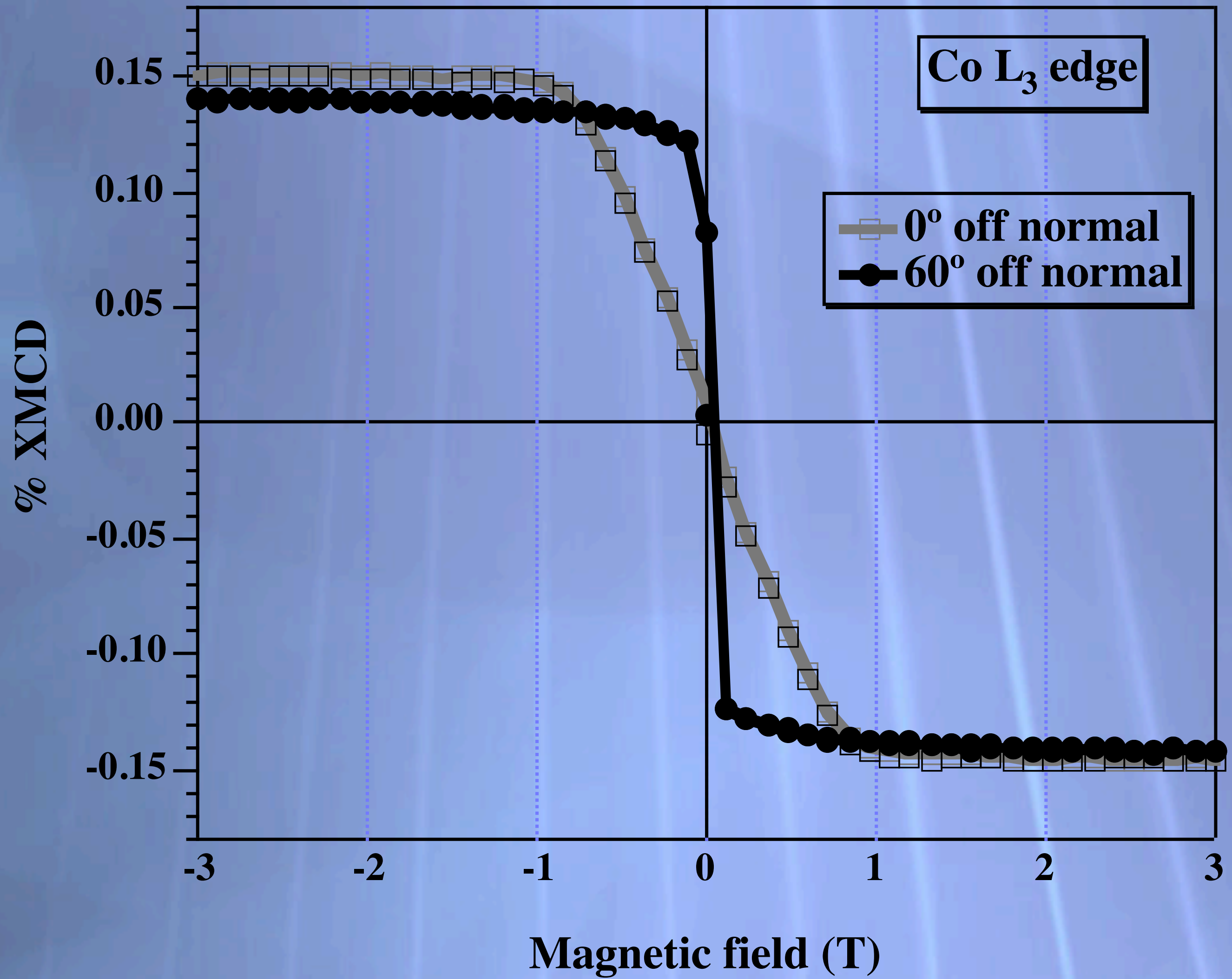
XMCD direct evidence of anti-parallel magnetization of Co and V thin layers

PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

Magnetic characterization

XMCD (ID8 - ESRF)

3 nm Al / 2 nm Co / 2 nm V / MgO(100)



XMCD gave direct evidence that the easy axis of magnetization lies in the surface plane

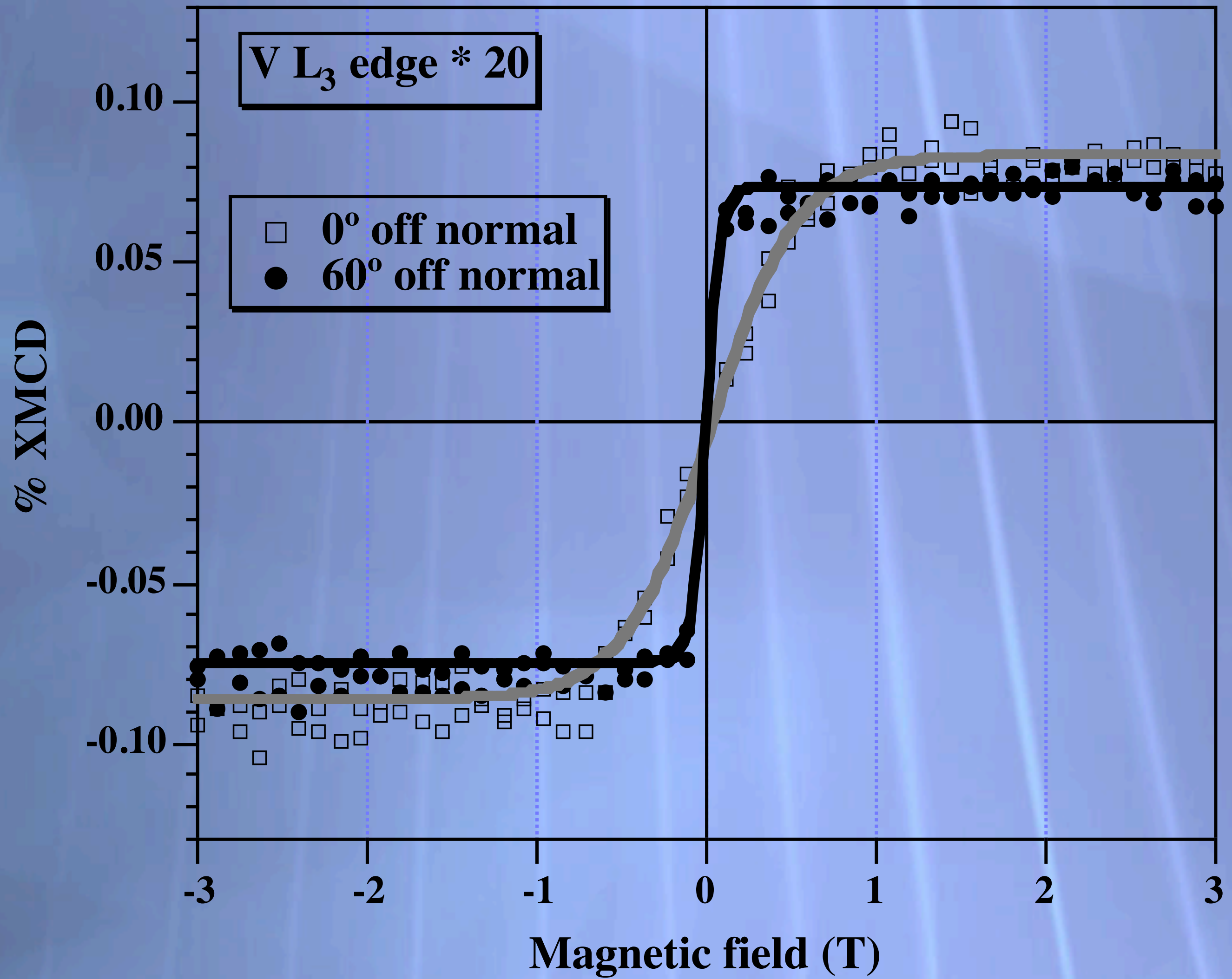
Phys. Rev. B 77, 064411 (2008)

PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

Magnetic characterization

XMCD
(ID8 - ESRF)

3 nm Al / 2 nm Co / 2 nm V / MgO(100)



XMCD gave direct evidence that the easy axis of magnetization lies in the surface plane

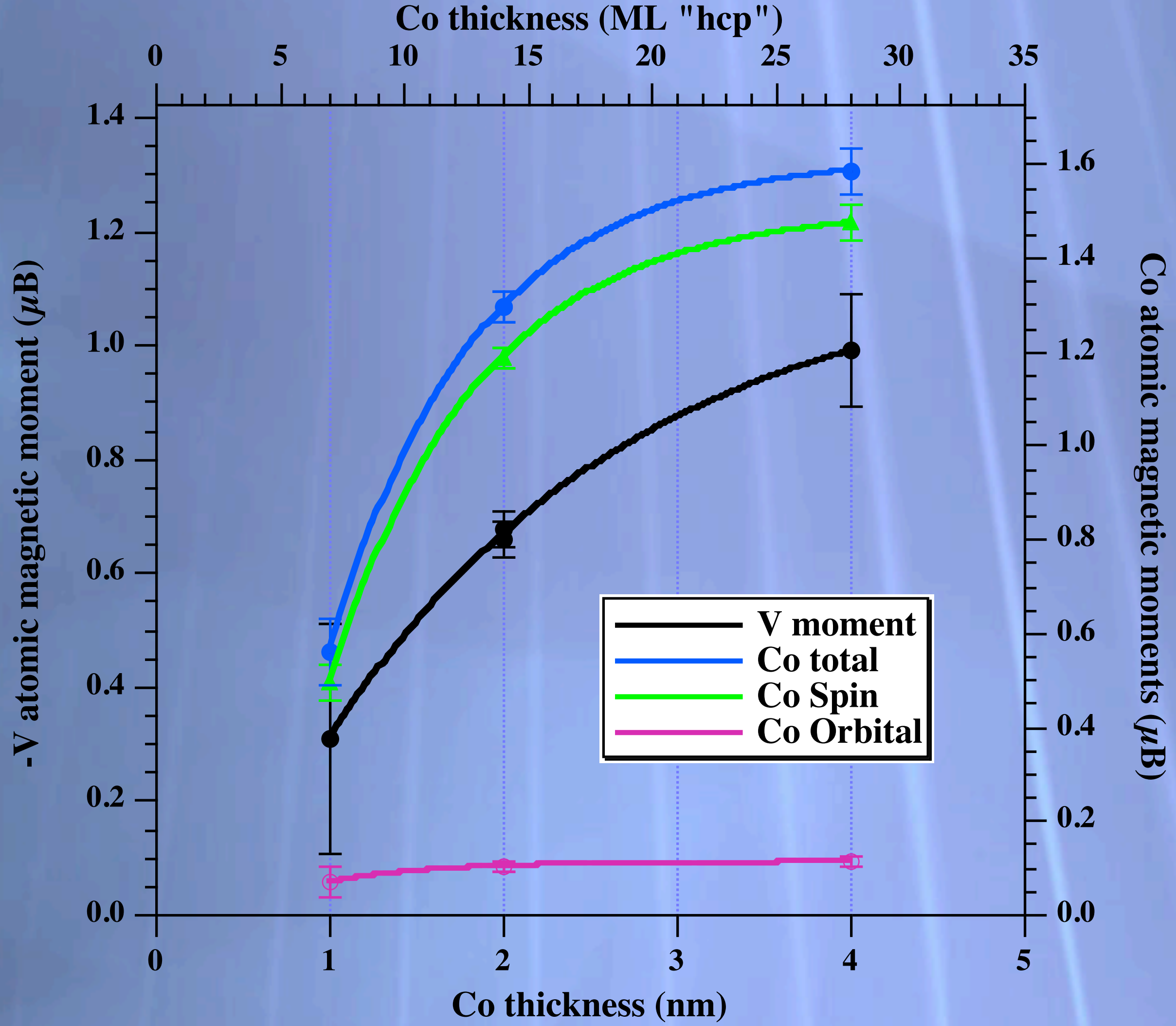
Phys. Rev. B 77, 064411 (2008)

PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

Magnetic characterization

XMCD
(ID8 - ESRF)

3 nm Al / n nm Co / 4 nm V / MgO(100)



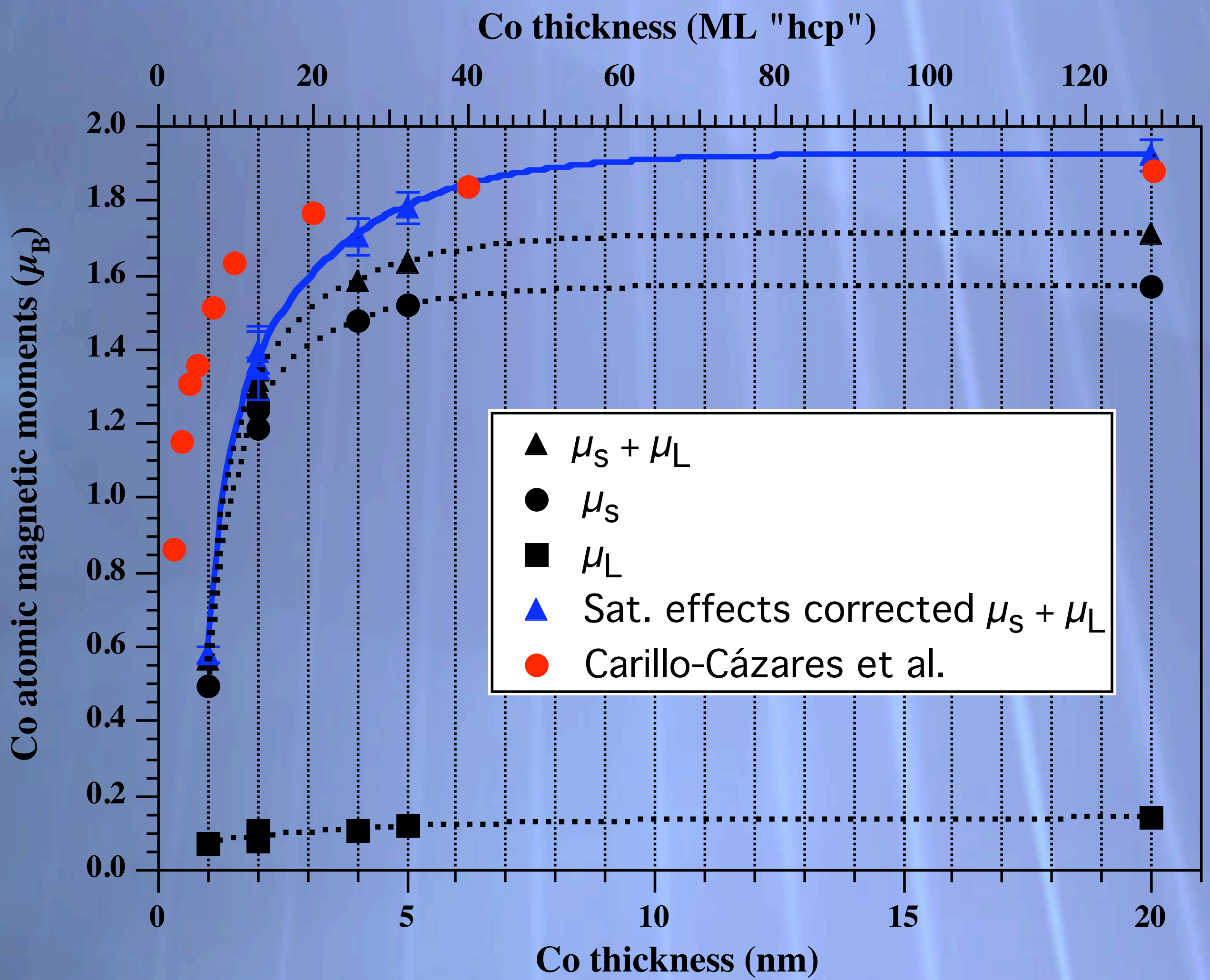
Strong V magnetic polarization.
The atomic magnetic moment of V increases with increasing Co thickness and decreases with decreasing V thickness

Phys. Rev. B 77, 064411 (2008)

PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

Magnetic characterization

XMCD (ID8 - ESRF)



XMCD results indicate a Long range magnetization of the V layer together with a long range reduction of the Co magnetic moment in contradiction with the expected picture.

Strong Co and V intermixing?

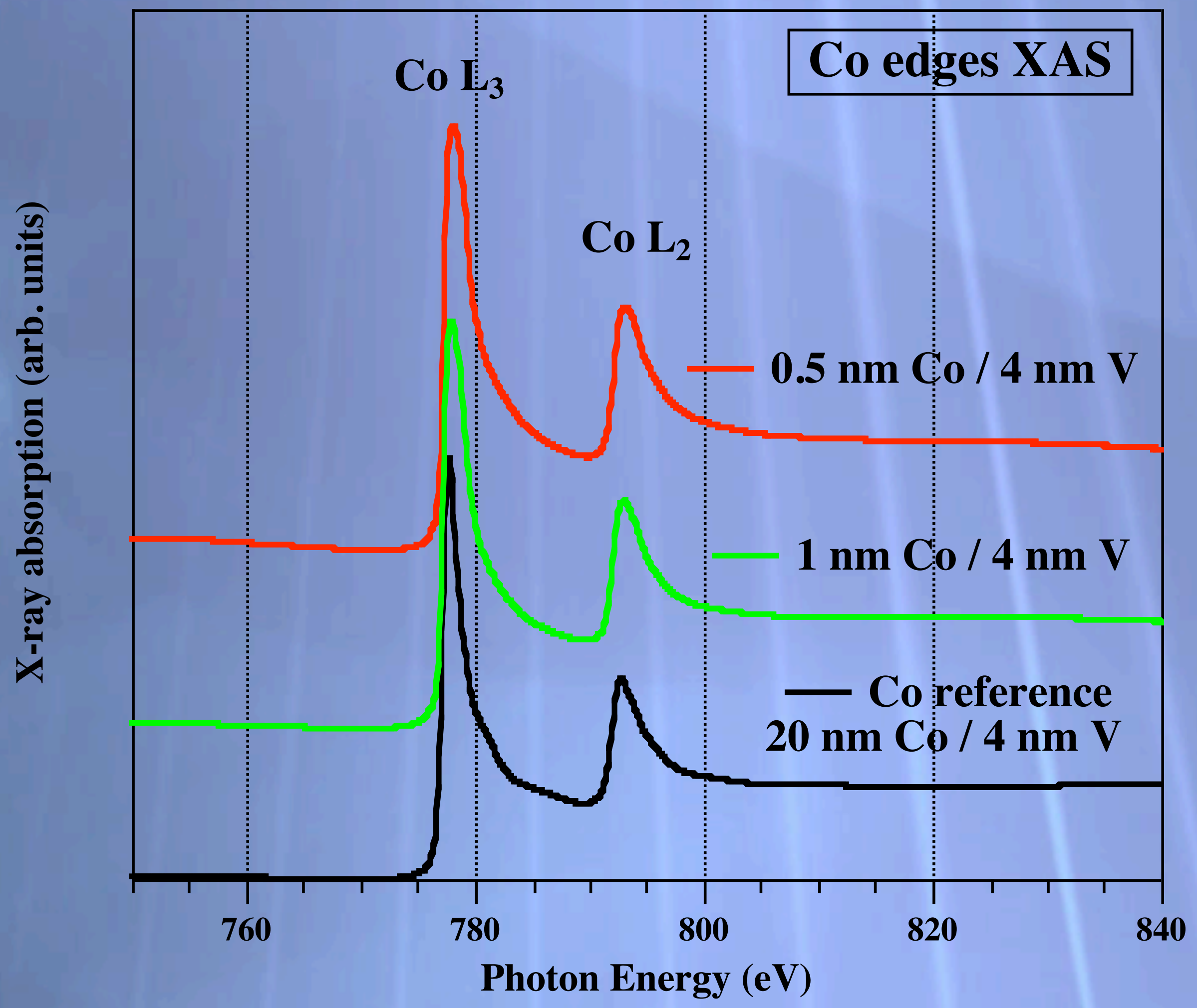
Solid State Commun. **144, 94 (2007)**

Phys. Rev. B 77, 064411 (2008)

PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

Electronic characterization

XAS
(ID8 - ESRF)

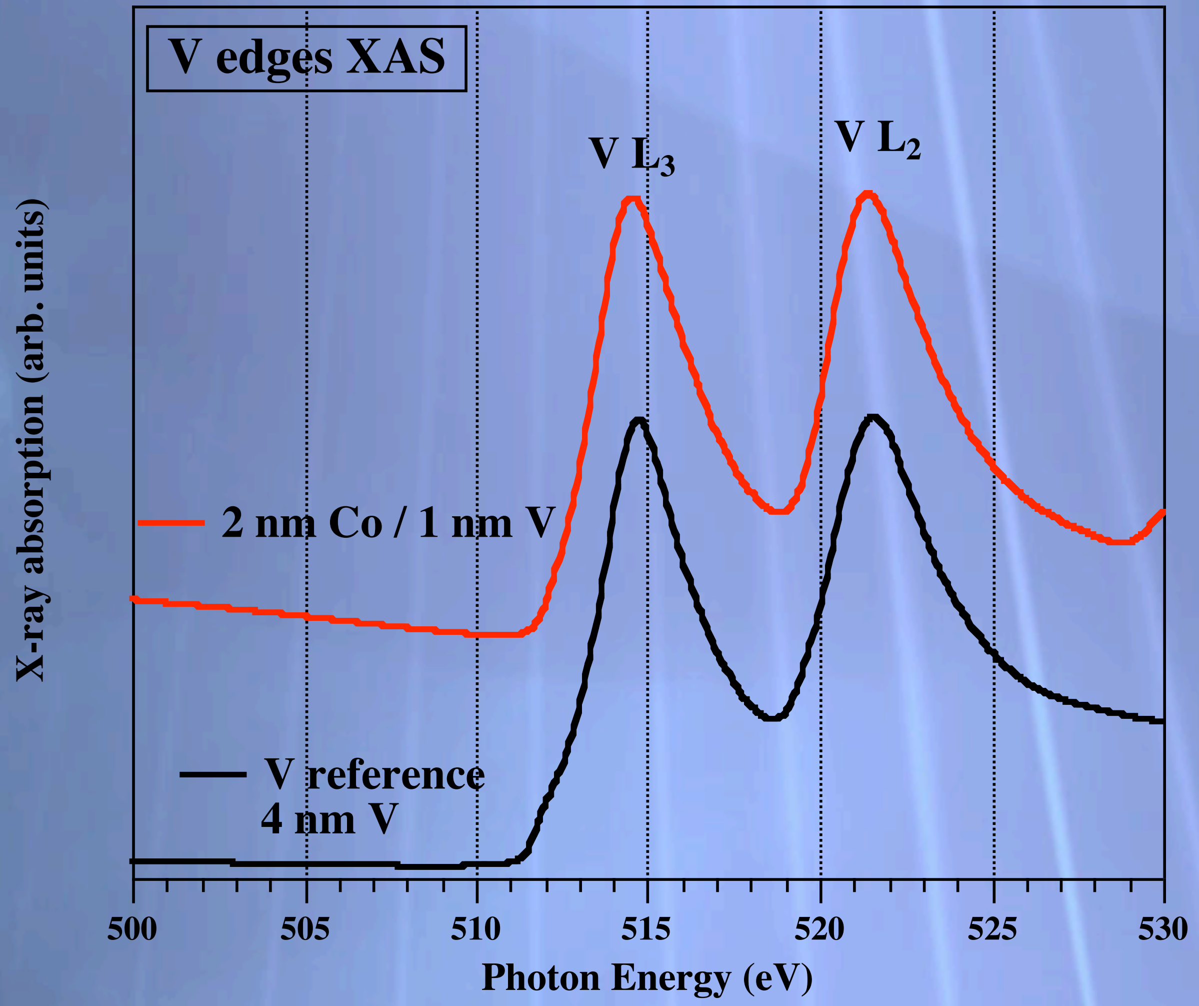


No evidence of strong Co and V intermixing

Phys. Rev. B 77, 064411 (2008)

Electronic characterization

XAS (ID8 - ESRF)



No evidence of strong Co and V intermixing

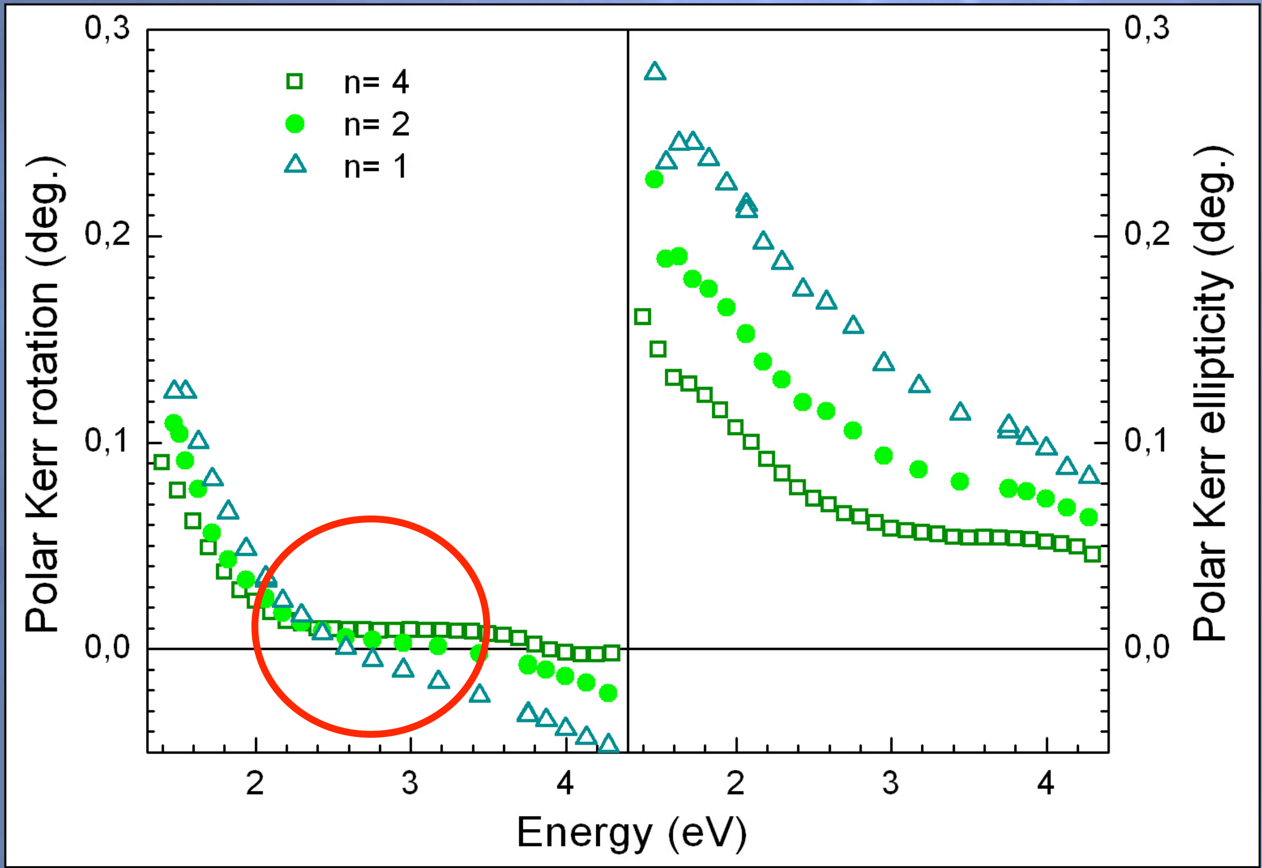
Phys. Rev. B 77, 064411 (2008)

PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

Magneto-optical characterization

Kerr (IMM)

3 nm Al / 2 nm Co / n nm V / MgO(100)



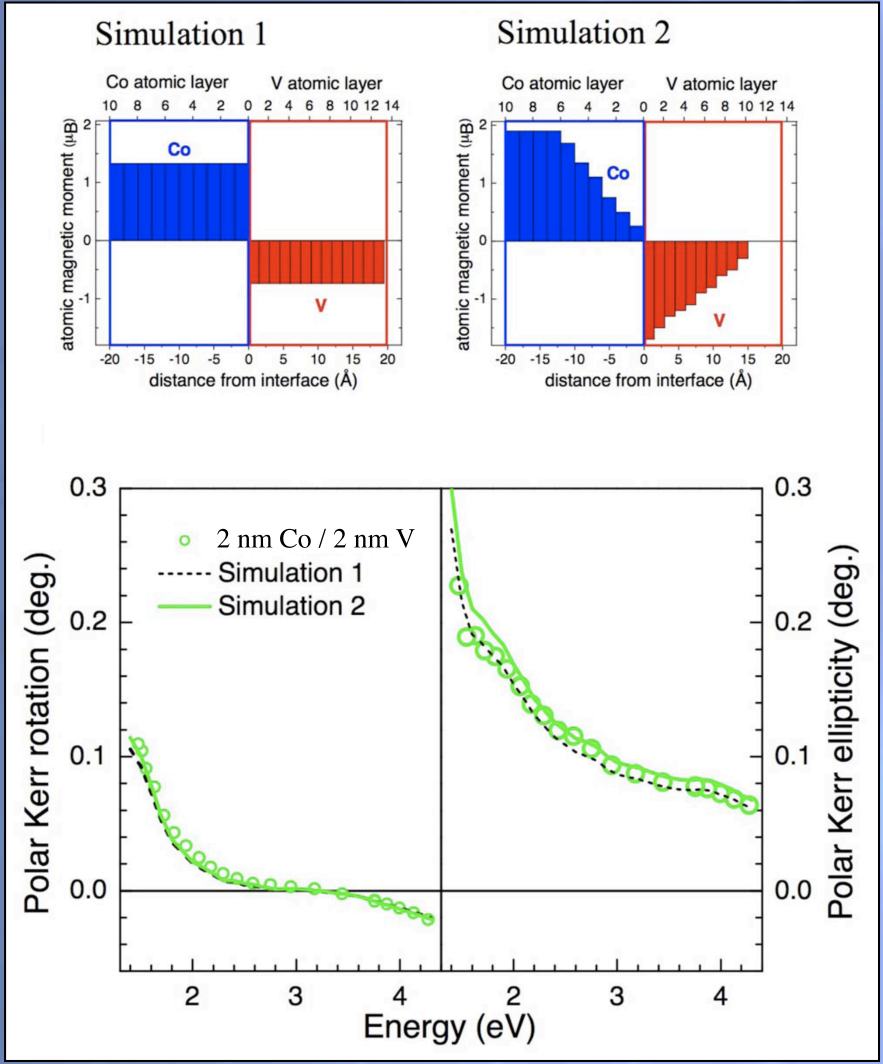
Spectral modification of the magneto-optical response of the system as a function of V thickness

Phys. Rev. B 77, 064411 (2008)

PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

Magneto-optical characterization

Kerr (IMM)



Large amount of polarization in the V films in order to obtain a satisfactory agreement with the experimental spectra

Recent Medium Energy Ion Scattering results indicate some intermixing of Co and V, but rather limited at the interface with a temperature diffusion threshold of 300 °C

Phys. Rev. B 77, 064411 (2008)
Surface Science Letters 602, L139 (2008)

Summary

PROPERTIES OF NANOMETRE Co LAYERS IN CONTACT WITH V LAYERS

- Strong magnetic polarization of the V layer in contact with the Co layer together with a reduction of the Co atomic magnetic moment.
- V and Co layers with anti-parallel magnetization and same coercive field.
- In-plane magnetization.

- Evidence of long-range magnetic polarization of V and magnetization reduction of Co.
- No evidence of strong Co and /or V diffusion that would explain such long-range magnetization.

Collaborators - Acknowledgments

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MAT2005-05524-C02-02

Magnetoplasmónica: Nanoestructuras Hibridas con propiedades magnéticas y plasmónicas.
MAT2008-06765-C02-02

Materiales avanzados y **NANOtecnologíaS para dispositivos y sistemas eléctricos, ELECTrónicos y magnetoelectrónicos innovadores" (NANOSELECT)**

PROGRAMA RAMÓN Y CAJAL

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Nanoestructuras magnéticas:
fabricación, propiedades y aplicaciones biomédicas y tecnológicas.
S-0505/MAT/0194

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La Suma de Todos

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