# Magnetic nanostructures at IMN: multilayers, patterned elements & antidots

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IMN micro nano

CSIC

Consejo Superior de Investigaciones Científicas

GOBIERNO DE ESPAÑA

# Activities

*Projects*

- Spintronic devices for microwave detection and energy harvesting applications (NATO- Science for Peace and Security Programme, ref. SPS G5792)
- Magnetic Antidots (CSIC i-LINK program, ref.: i-LINK0783)

*Collaborators*

ICMM

**Manuel Vázquez's group ➡ VSM, nanoMOKE**

UNIVERSIDAD COMPLUTENSE MADRID

**Elena Navarro ➡ SQUID**

DEMOKRITOS
NATIONAL CENTER FOR SCIENTIFIC RESEARCH

**D. Niarchos & Andreas Kaidatzis ➡ Indust. Sputtering**

UdeSantiago de Chile

**Juan Escrig's group ➡ Micromagnetic simulations**

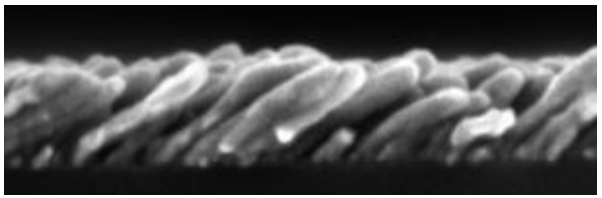
UNICAMP

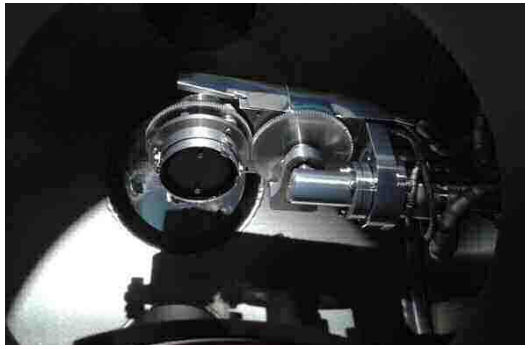
**Fanny Beron & Kleber Pirota ➡ FORC**

# Main equipment

## UHV Sputtering

- 6 magnetron sources (AJA)
- DC and RF power supplies
- Fully moveable holder: tilt and rotation, i.e. suitable for **GLAD**
- Heater up to 700 ºC






## Focused Ion Beam - FIB

- nanoFIB IonLINE: ion-beam lithography, nanofabrication & engineering workstation , **resolution: 15 nm**
- Interferometer controlled stage, fabrication **area up to 100 cm$^2$**

## Electron Beam Lithography - EBL

- Hot cathode of W or LaB6, Beam Energy: 25 KeV
- stiching 2.500 working fields (typical size 100 x 100 µm$^2$ ) with error < 60 nm to get a maximum fabricated area of 25 cm$^2$

# Main equipment


## SEM ( Extreme High Resolution)

- **Subnanometer** Spatial resolution: 0.6 nm at 15 kV / 0.7 nm at 1 kV
- 5 different detectors for simultaneous and uncoupled topography / material contrast
- Extreme performance with **isolating / fragile samples** at very low landing energies down to 20 eV
- Quantitative element/phase anaylisis and mapping by **EDX**

## Magnetic Force Microscopy

- Dimension Icon from Bruker
- Tip scanning: **large samples** can be analyzed
- Other modes: Quantitative nanomechanical properties (QNMP): Young modulus, adhesion, dissipation, and deformation

# Systems

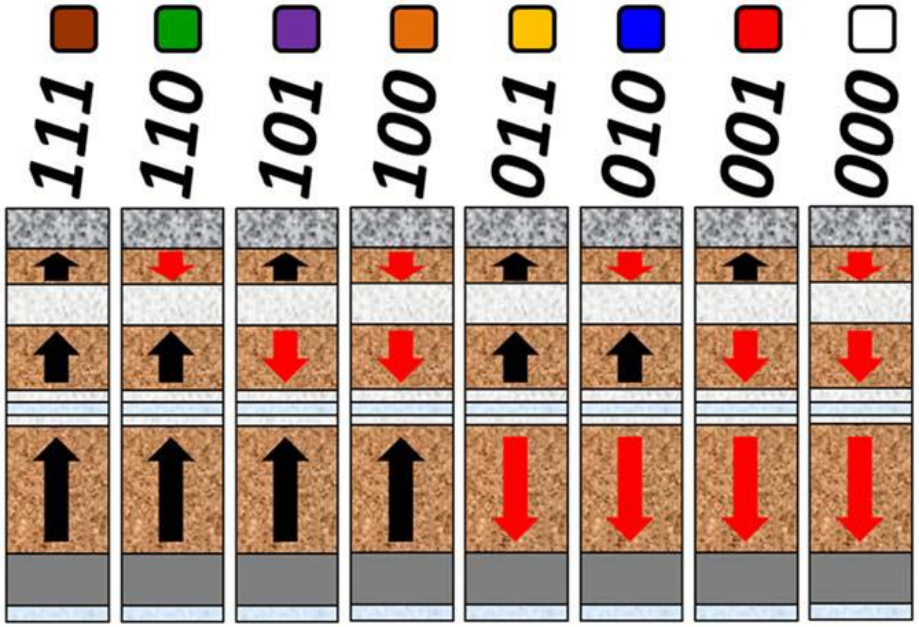
**FePt multilayers for 3D Recording**

**$Fe_{80}B_{20}$ Microsquare Arrays**

**Magnetic Antidots**

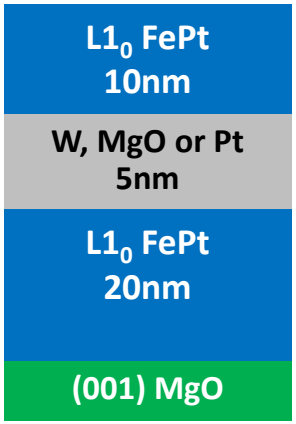
# **3D Recording**: Storing more than 1 bit

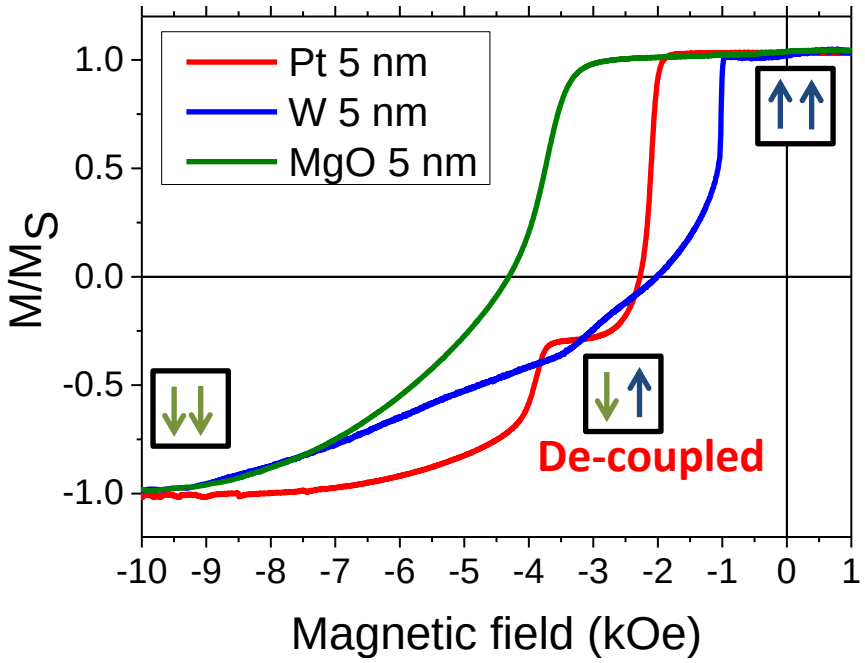
**Multilevel Bits**



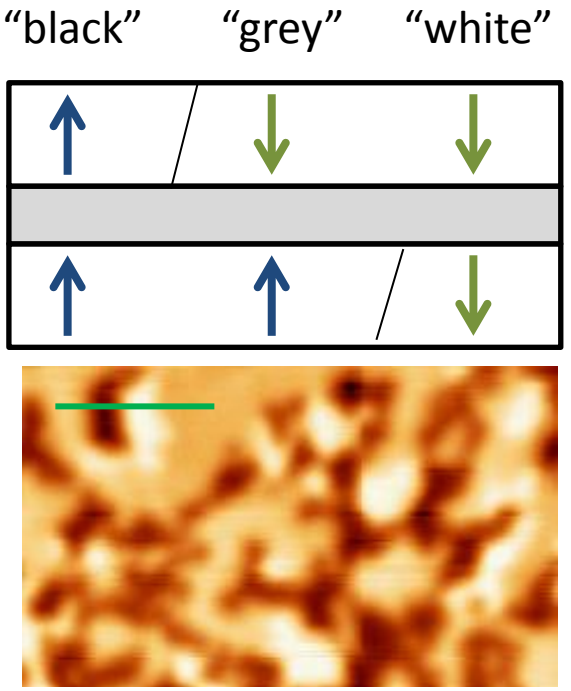

Amos *et al.* PLoS ONE e40134 (2012)

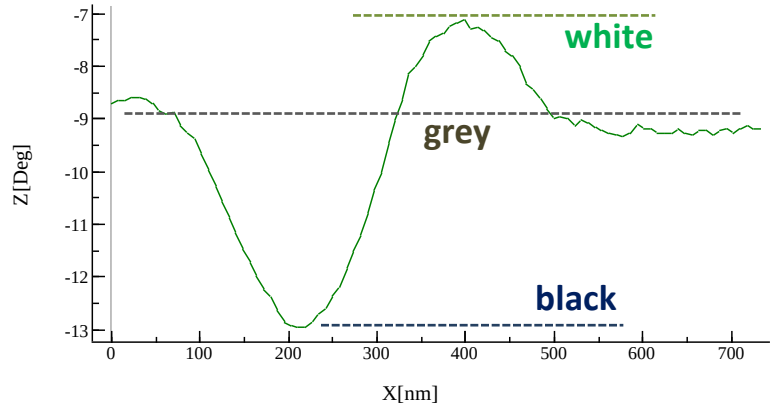
# **3D Recording**: Storing more than 1 bit




**MFM**

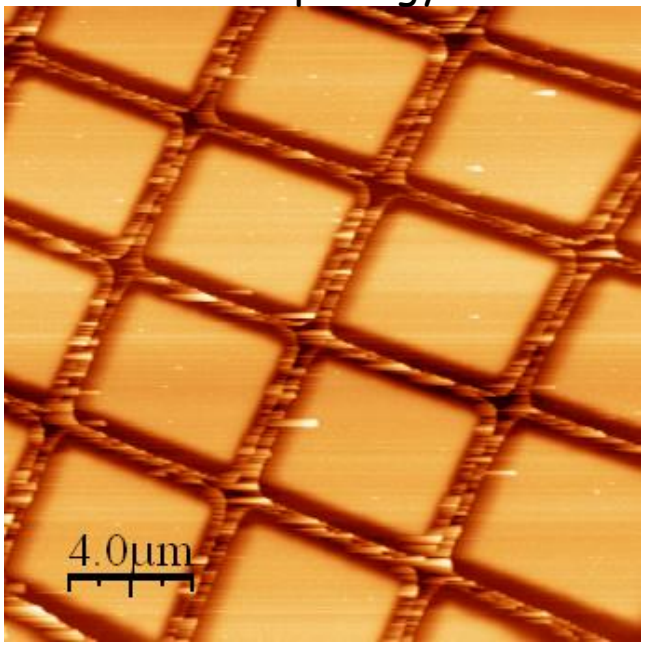


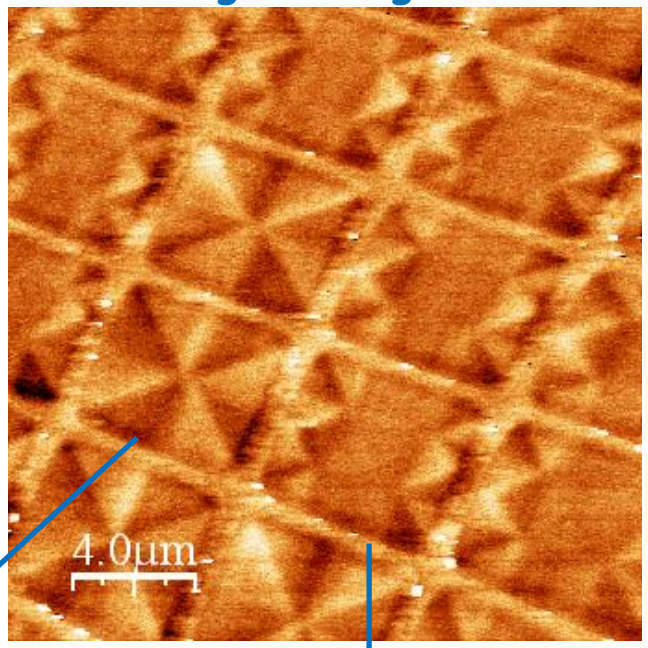

Kaidatzis *et al.*, J. Phys. D: Appl. Phys. **50,** 445002 (2017)

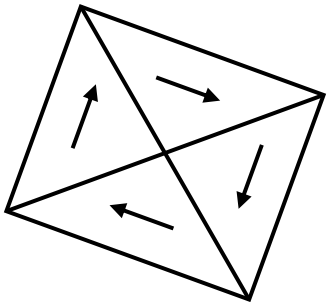
# $Fe_{80}B_{20}$ Microsquare Arrays

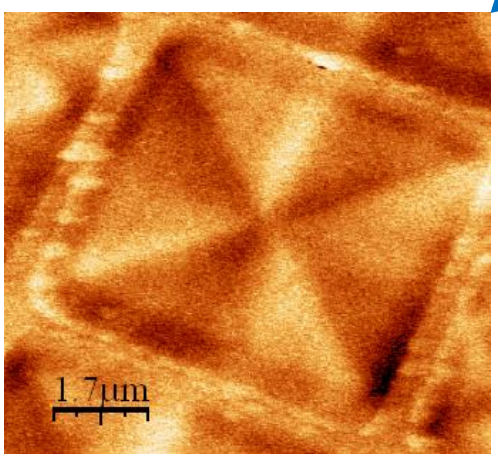
Morphology

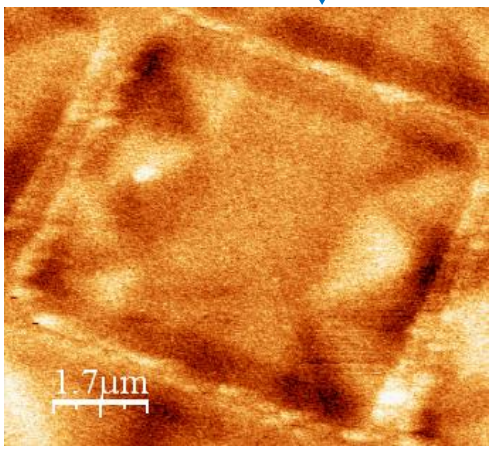


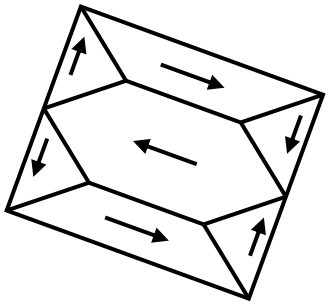

Magnetic signal





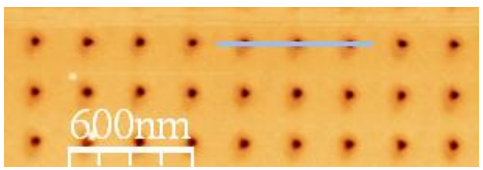



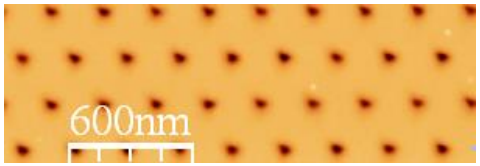
Álvarez-Sánchez *et al.,* Magnetochemistry **6**, 50 (2020)

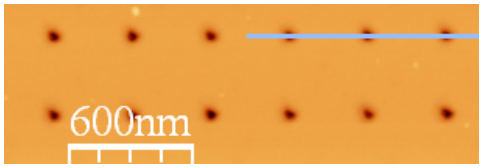
# Magnetic Antidots: top-down approach


**Square arrays** | Lattice constant | **Hexagonal arrays**

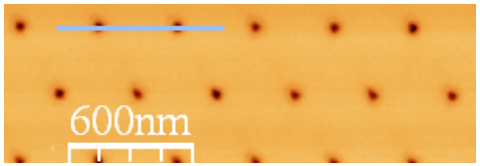


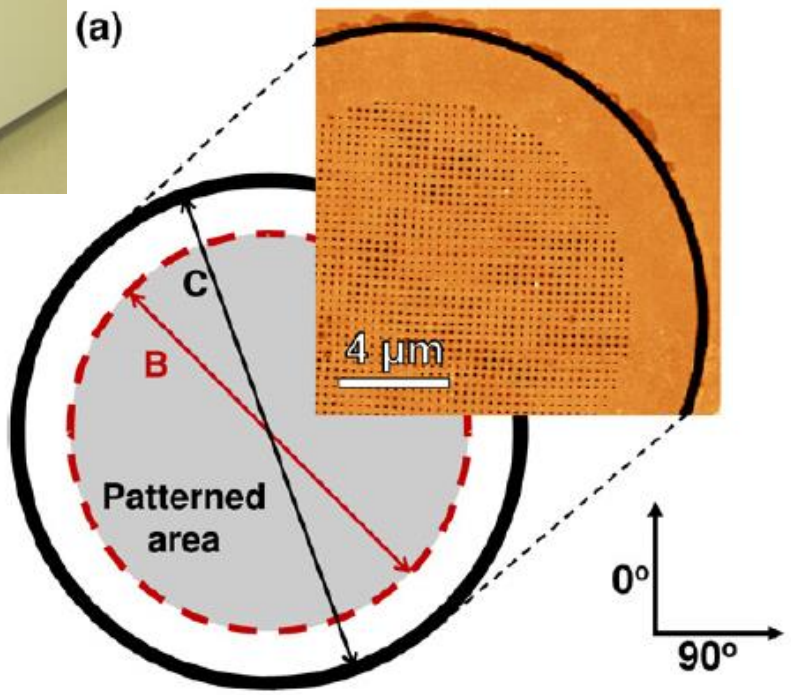

240nm



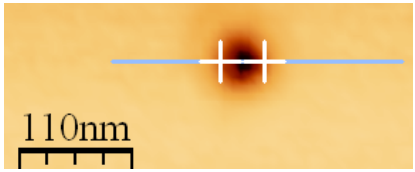



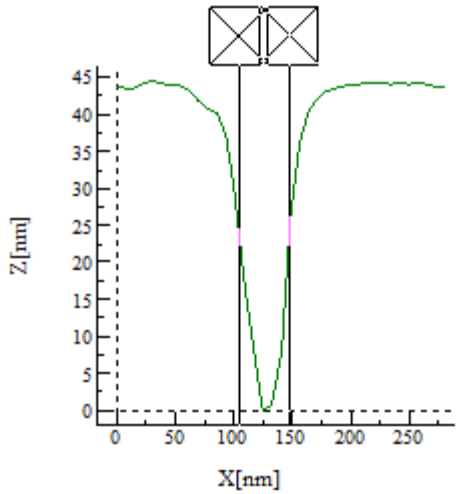

360nm




**Hole diameter: 40 nm**




Films

Cr2/Py27/Pt5

Cr2/Co20/Pt5

Cr2/Co20/Py9/Pt5

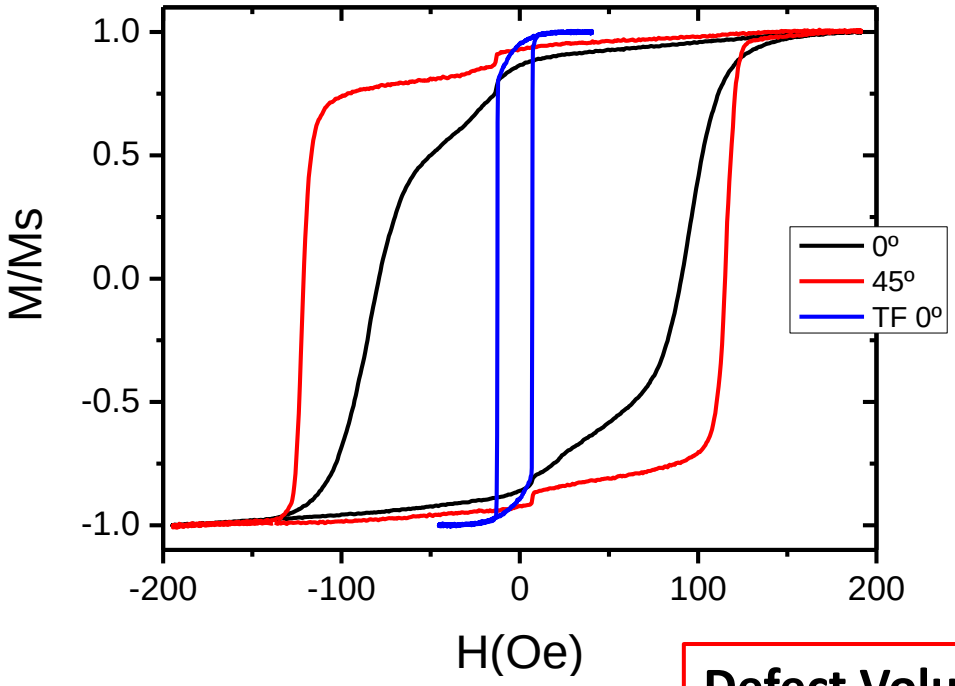
Cr2/Co20/Py27/Pt5

Subst: Si / 500 nm $SiO_2$

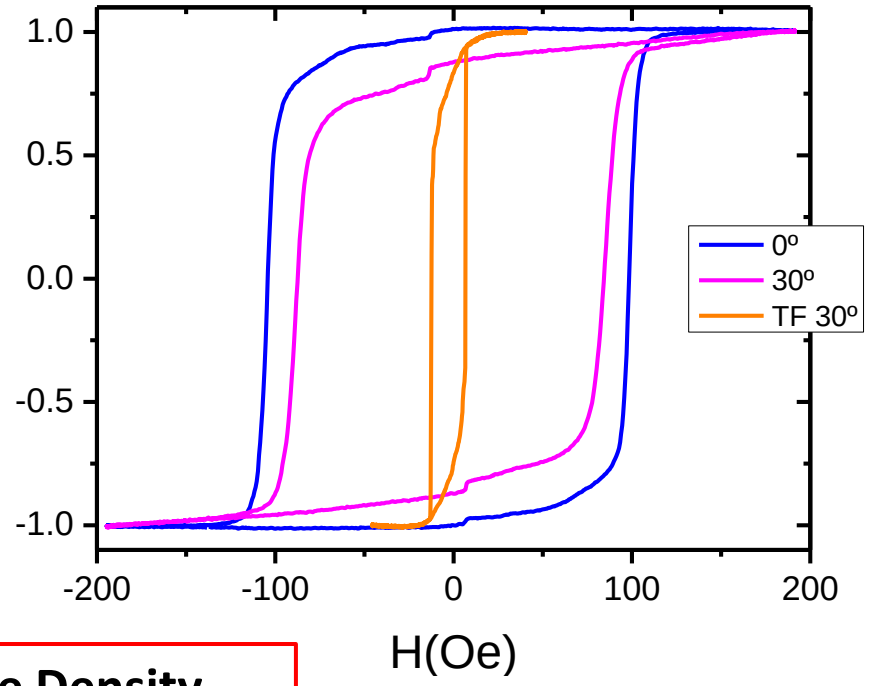
# Magnetic Antidots: hysteresis loops

Cr2/Co20/Py9/Pt5

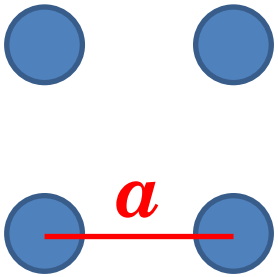
**Square array 240 nm**



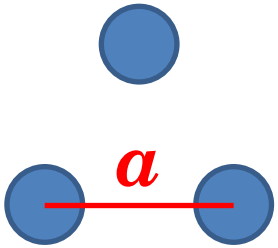

**Hexagonal arrays 240 nm**




**Defect Volume Density**

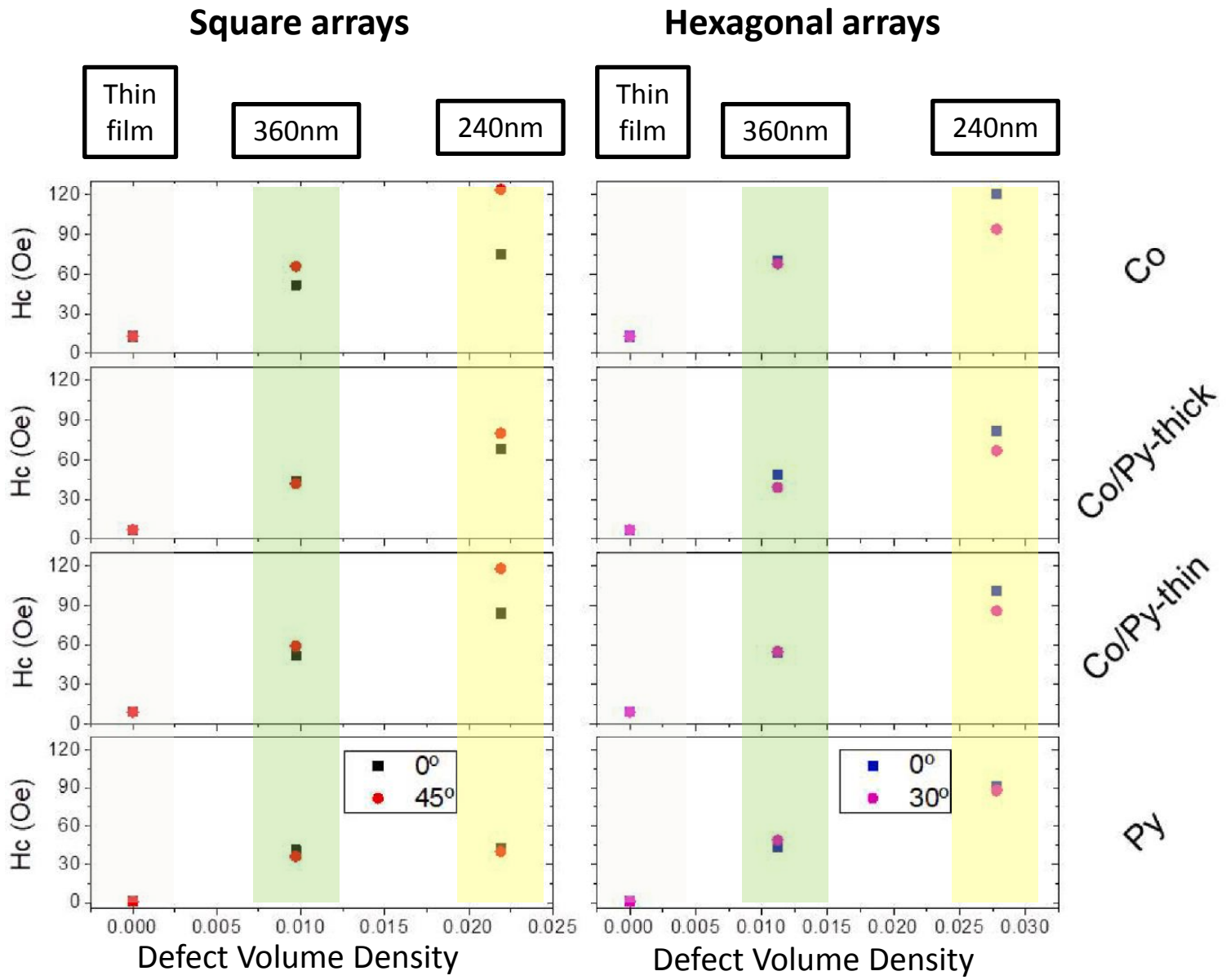



$$\frac{\pi}{4}\left(\frac{d}{a}\right)^2$$



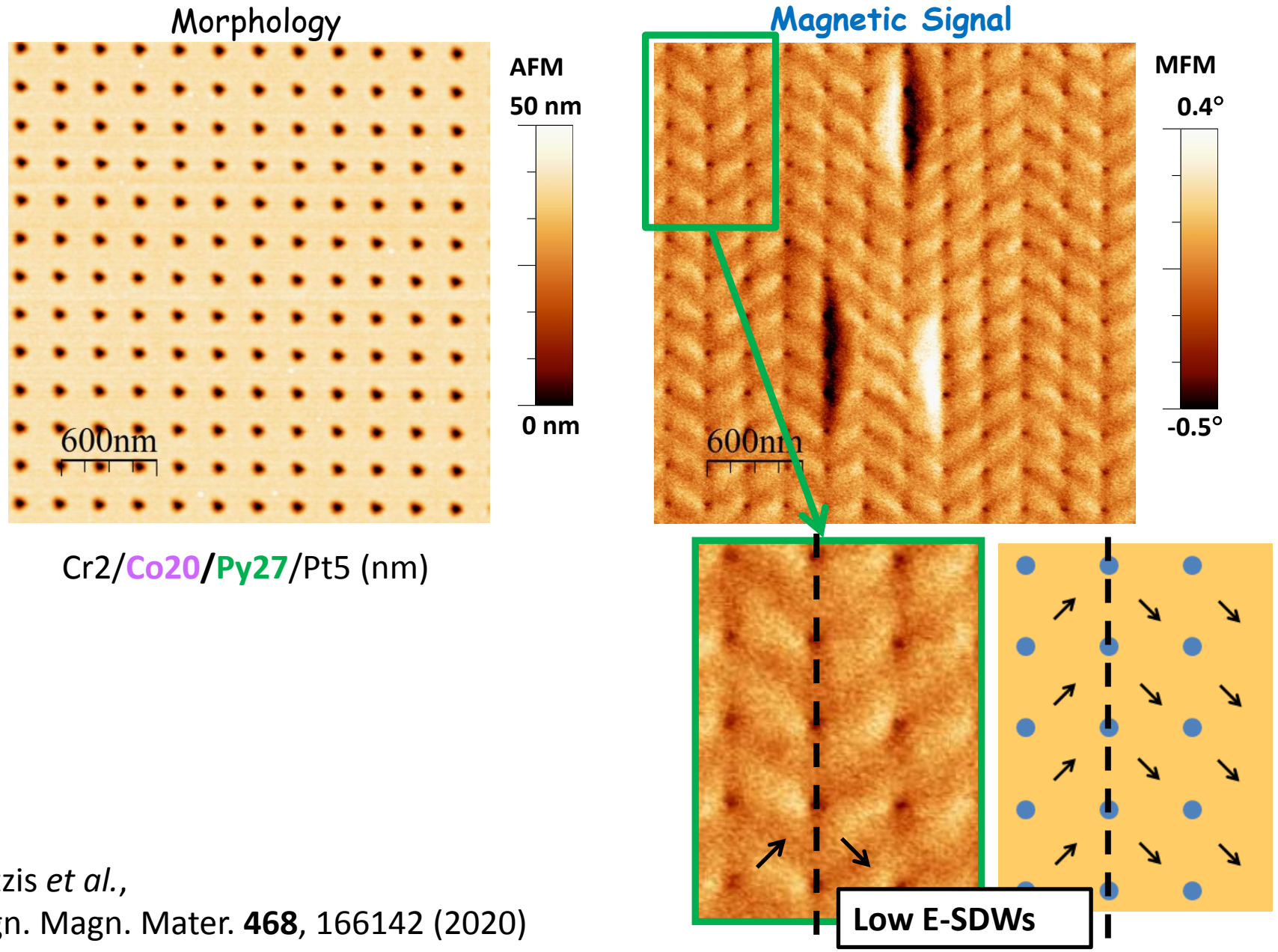

$$\frac{\pi}{2\sqrt{3}}\left(\frac{d}{a}\right)^2$$

# Coercivity *vs*. Defect Volume Density




Kaidatzis *et al.*, J. Magn. Magn. Mater. **468**, 166142 (2020)

# Magnetic Antidots: domain structure




Cr2/Co20/Py27/Pt5 (nm)

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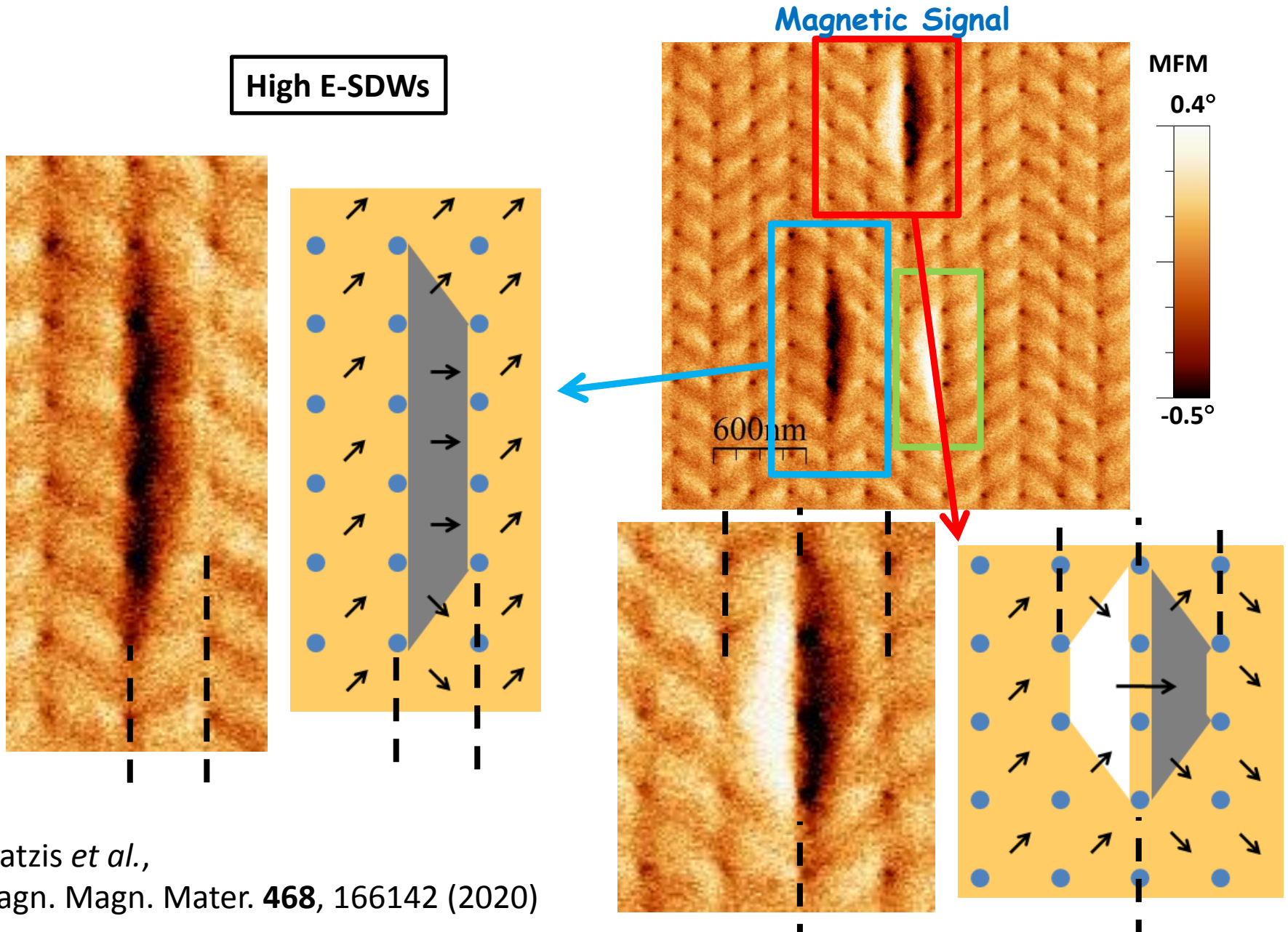


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# Summary

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- Magnetic Antidots (CSIC programa i-LINK, ref.: i-LINK0783)

**Equipment**

- UHV Sputtering
- FIB & EBL
- XHR-SEM
- MFM

**Systems**

- FePt Multilayers
- FeB Microelements
- Antidots

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