Magnetic pinning in hybrid $YBa_2Cu_3O_{7-x}$/ferromagnetic nano-dot structures obtained by di-block copolymer self-assembly method

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UNIVERSITATEA TEHNICĂ DIN CLUJ-NAPOCA

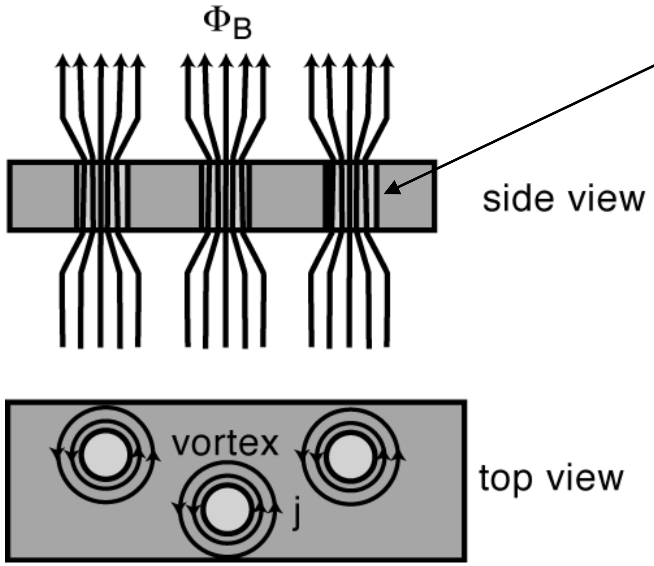
Magpin

Nano-engineered Magnetic Pinning Centers in High Temperature Superconducting Epitaxial Thin Films - MAGPIN
PNII – RU – TE – 2014 - 2848

The challenge of vortex pinning in type II superconductors

- Maximum current density carried by a superconductor (type II) is limited by the motion of ***vortices***

Vortex → Normal core
Vortex → Magnetic moment



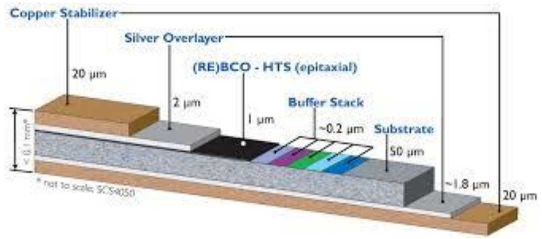
http://users-phys.au.dk/philip/pictures/physicsfigures/node12.html

Improve the current transport capabilities of a superconductor

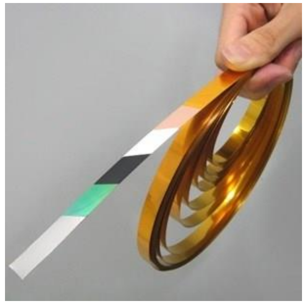
⇕

Stop vortex motion

VORTEX PINNING



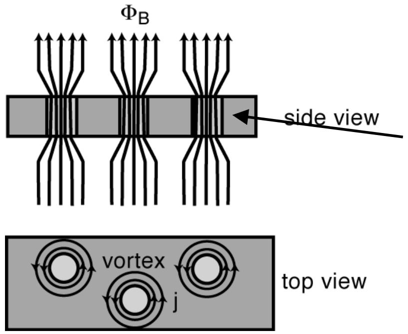
SuperPower Inc.



Fujikura Ltd.

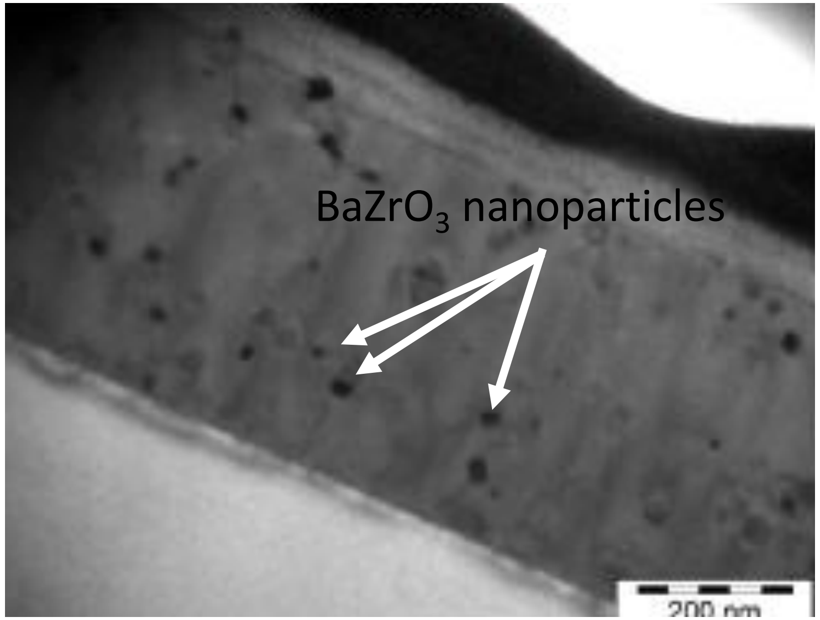
The challenge of vortex pinning in type II superconductors

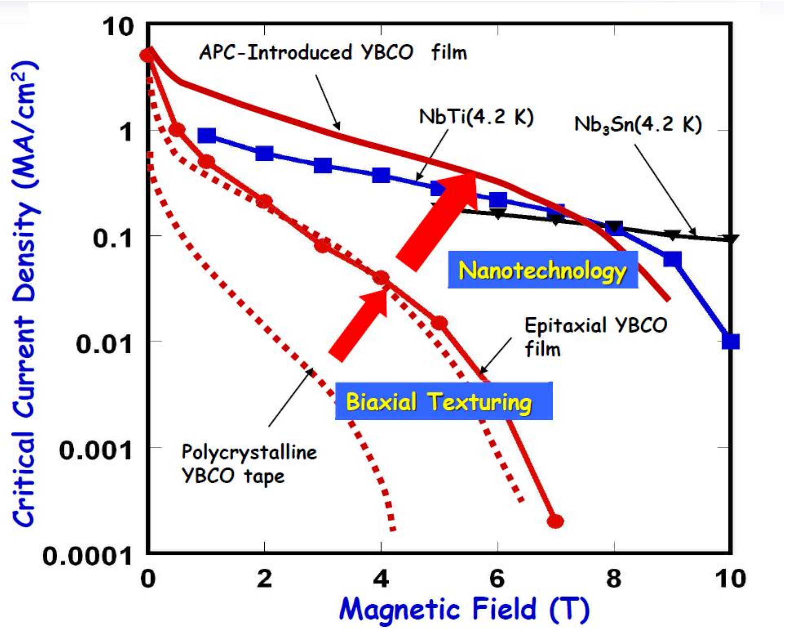
Stop vortex motion (vortex pinning)



Vortex → Normal (not superconducting) core (~4 nm) ✓

Vortex → Magnetic moment





Normal core pinning

- introduction of non-superconducting (*e.g.* $BaZrO_3$) nanoparticles;
- achieved and used at an industrial level;
- Pinning energy:

$$U_{cp} \approx \left[\Phi_0 / 8\pi\lambda(T)\right]^2$$

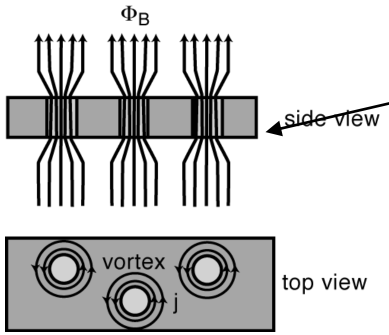
decreases as $T \rightarrow T_c$ due to

$$\lambda^2(T)/\lambda^2(0) \approx (1 - T/T_c)^{-1}$$

Normal core pinning becomes ineffective near T_c (working temperature)

The challenge of vortex pinning in type II superconductors

Stop vortex motion (vortex pinning)



Vortex → Normal (not superconducting) core ✓

Vortex → Magnetic moment ✗

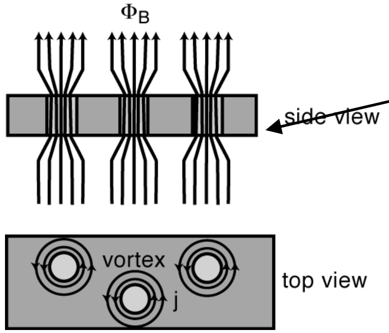
<u>Magnetic pinning</u>

- has been proposed, some results, not yet a scalable solution;
- magnetic pinning energy: $U_{mp} \approx \Phi_0 M$ (M-magnetization of the ferromagnetic layer/particle);
- magnetic pinning force: $F_{mp} \approx -\Phi_0 \partial M(x) / \partial x$ needs high magnetization gradient
  use of **domain walls** and/or **magnetic nanoparticles**;
- **temperature independent**, effective near T_c (**high** temperature superconductors)

<u>Objectives of the present project</u>: Explore alternative, scalable routes for producing effective magnetic vortex pinning in superconducting thin films

The challenge of vortex pinning in type II superconductors

Stop vortex motion (vortex pinning)



Vortex → Normal (not superconducting) core ✓
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Magnetic pinning

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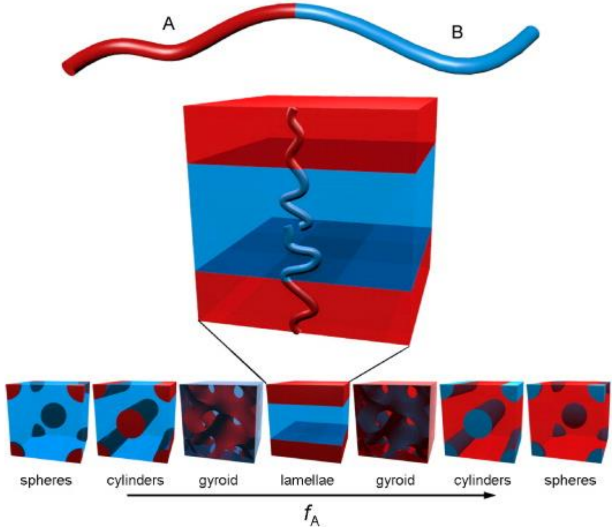
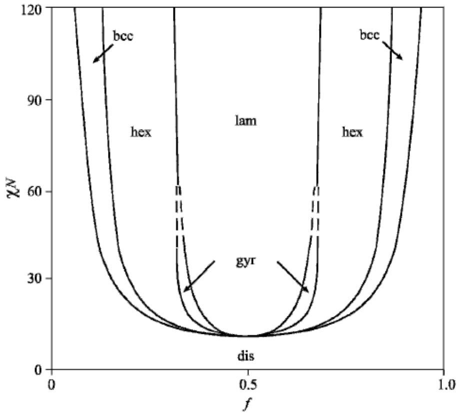
Objectives of the present project: Explore alternative, scalable routes for producing effective magnetic vortex pinning in superconducting thin films

Micro-phase separation of diblock copolymer thin films

Diblock copolymer

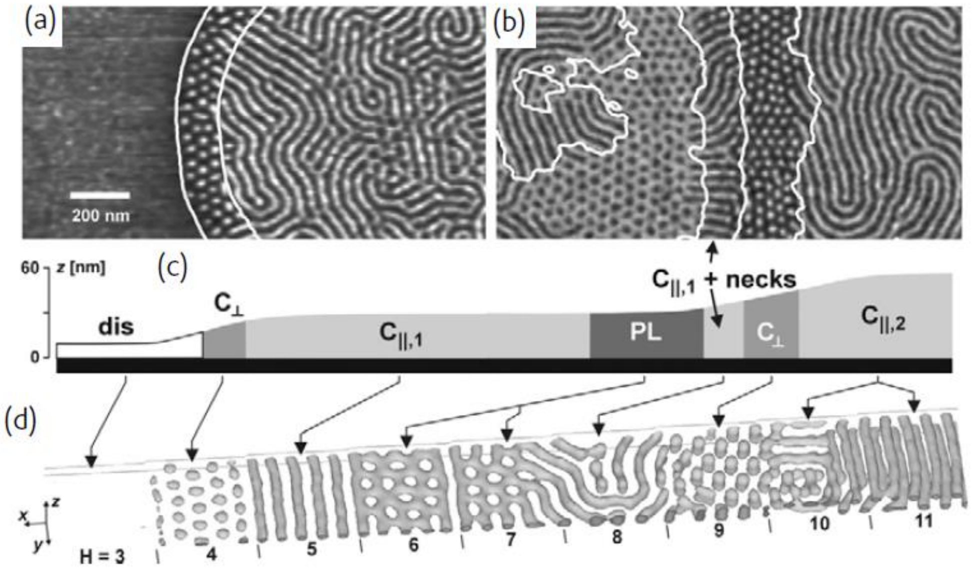


S. B. Darling, Progress in Polymer Science **32**, 1152 (2007)



I. W. Hamley, *Developments in Block Copolymer Science and Technology*, Wiley (2004)

Block copolymer thin film morphology variation as a function of film thickness



S. Krishnamoorthy *et al.*, Materials Today **9**, 40 (2006)

Micro-phase separation of diblock copolymer thin films

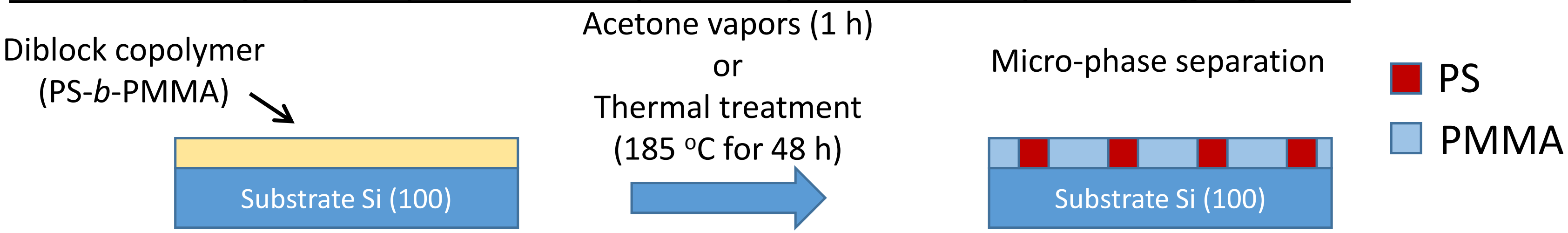
Diblock copolymer nanostructure fabrication

Poly (Styrene-block-Methyl Methacrylate)

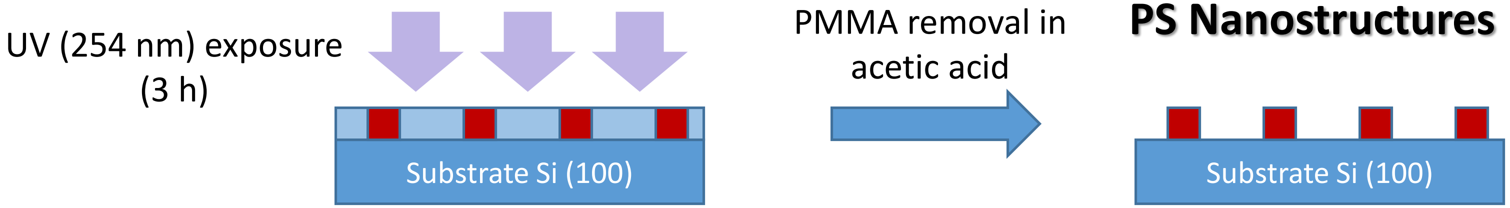
30% PS  70% PMMA

PS-b-PMMA
63.000-b-142.000
c=3 mg/ml
(solvent-toluene)

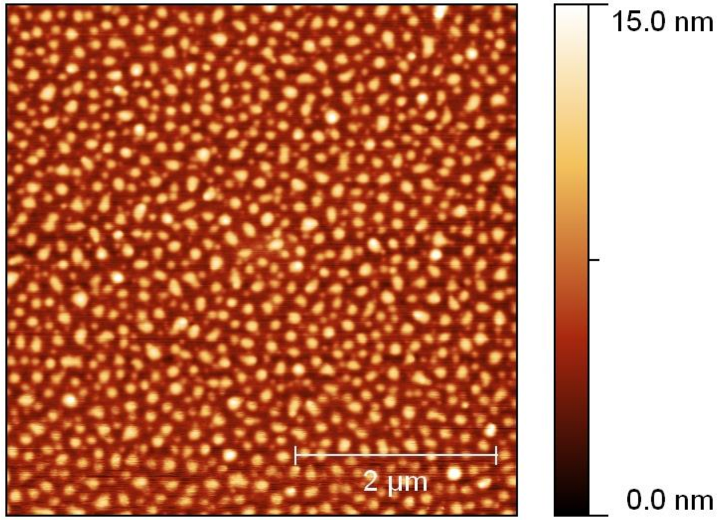
1. Diblock copolymer (PS-b-PMMA) film deposition and phase segregation

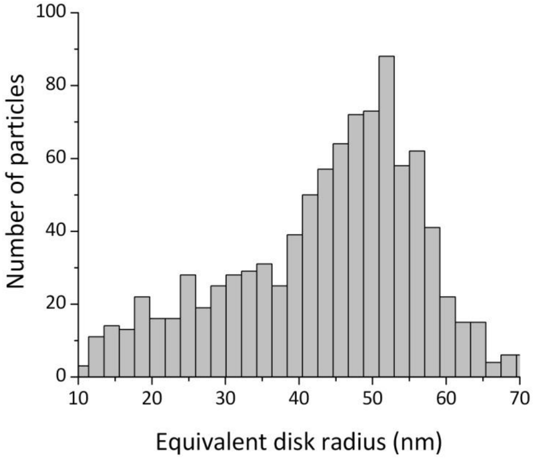


2. PMMA matrix UV degradation and removal

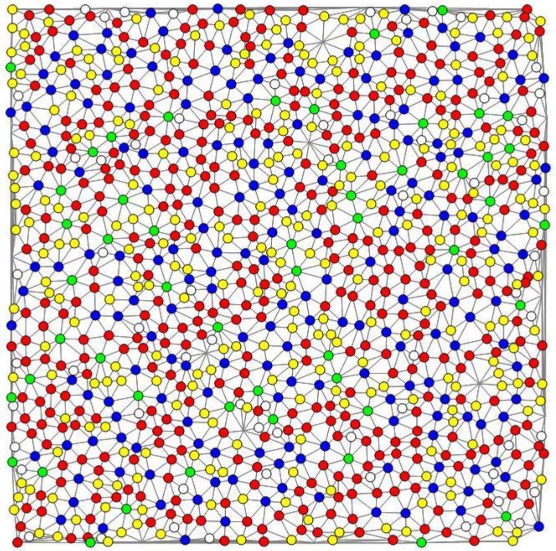


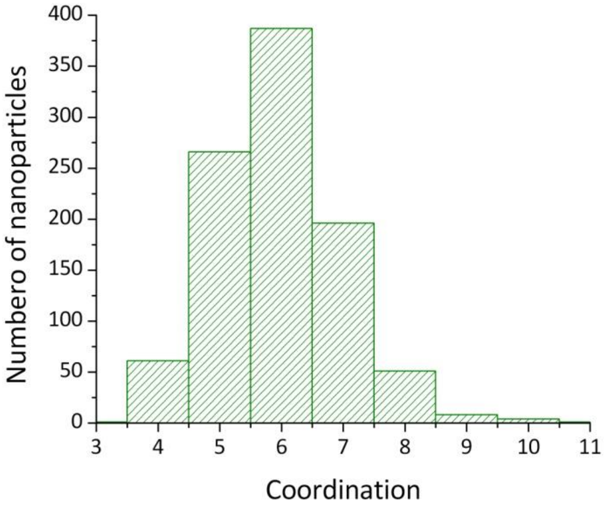
Poly-styrene nano-dot morphology



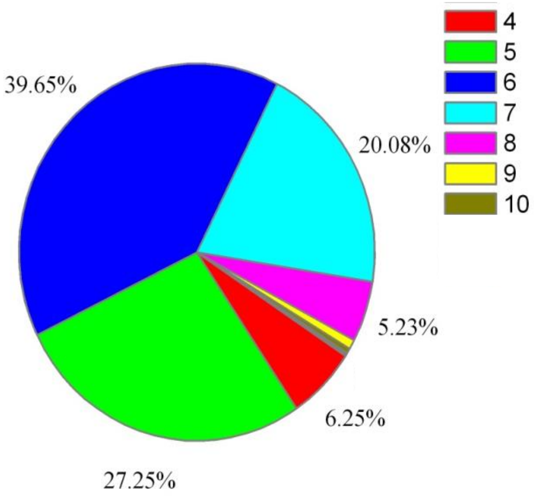


Nanoparticle **radius** distribution centered **~50 nm**, **Height** = **5 nm**





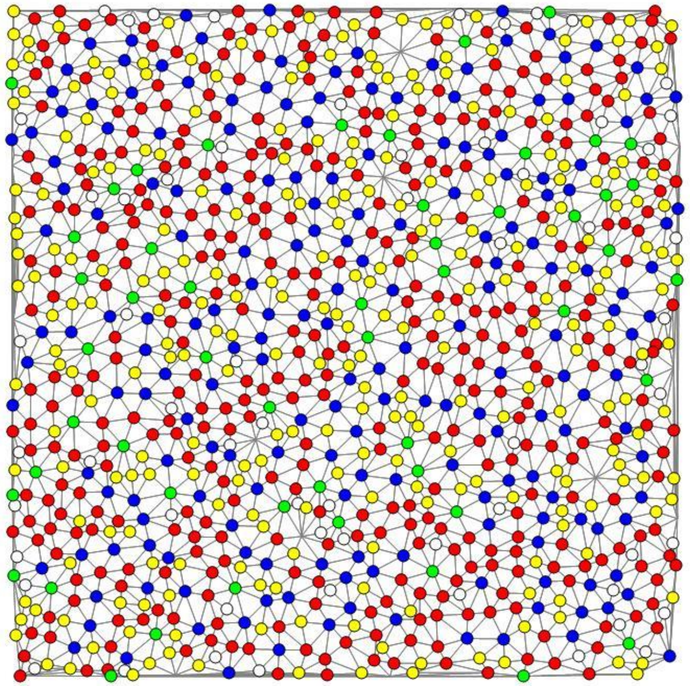
Delaunay Triangulation – Nanoparticle coordination



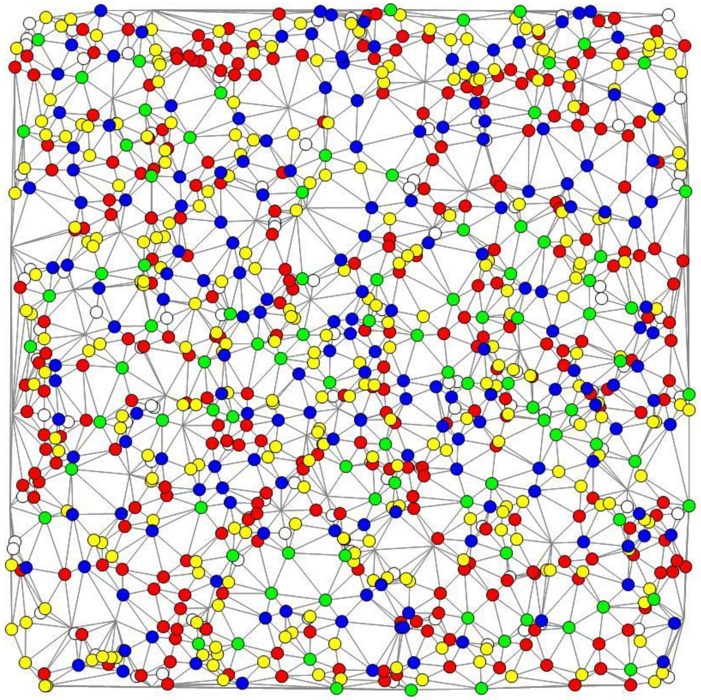
Poly-styrene nano-dot morphology

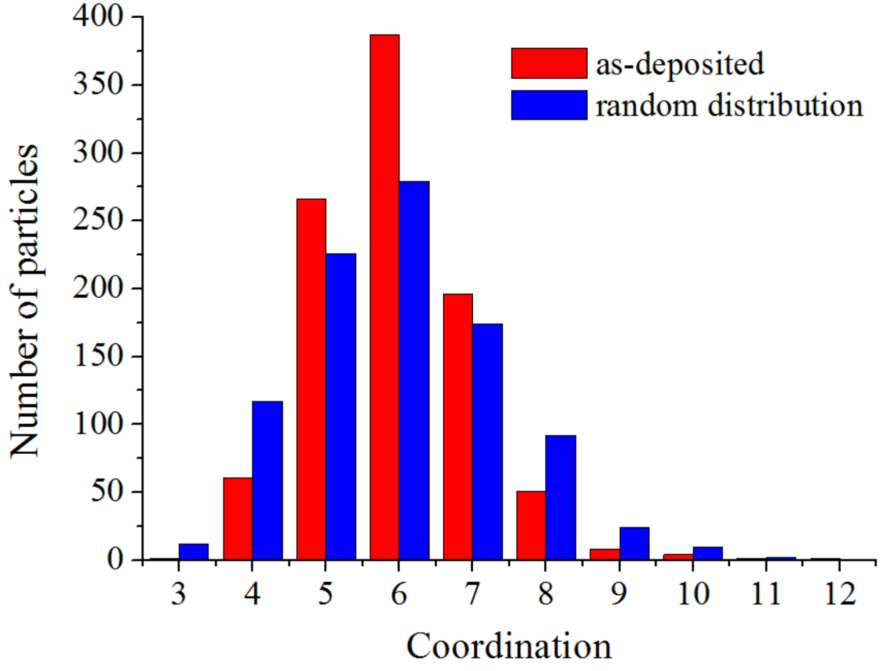
Delaunay Triangulation –Nanoparticle coordination

as-obtained nanodots



simulated random distribution



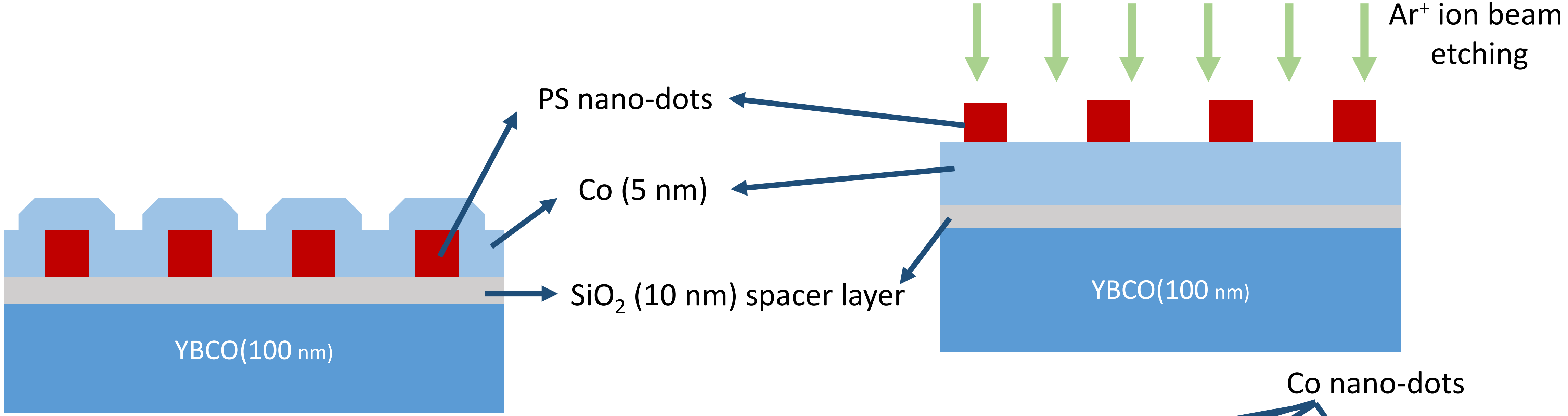


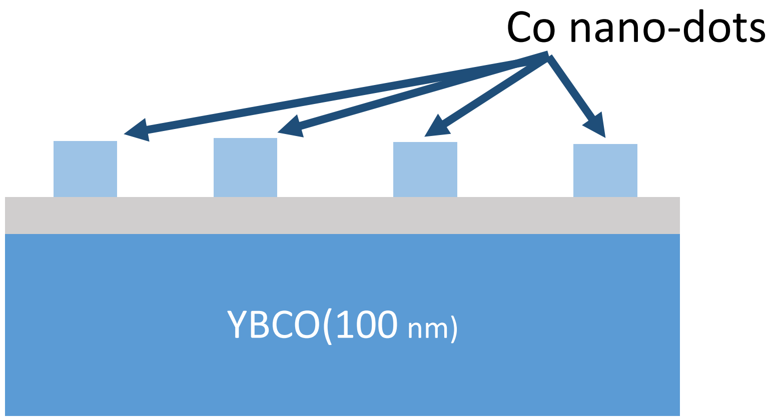
Random, but highly uniform, distribution of PS nano-dots on substrate surface

Use of PS nano-dots for magnetic gradient generation

1. Cobalt thin film deposition on top of PS nano-dots

2. PS nano-dot as etch mask for cobalt nano-dot fabrication



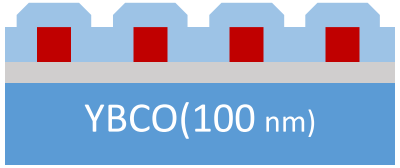


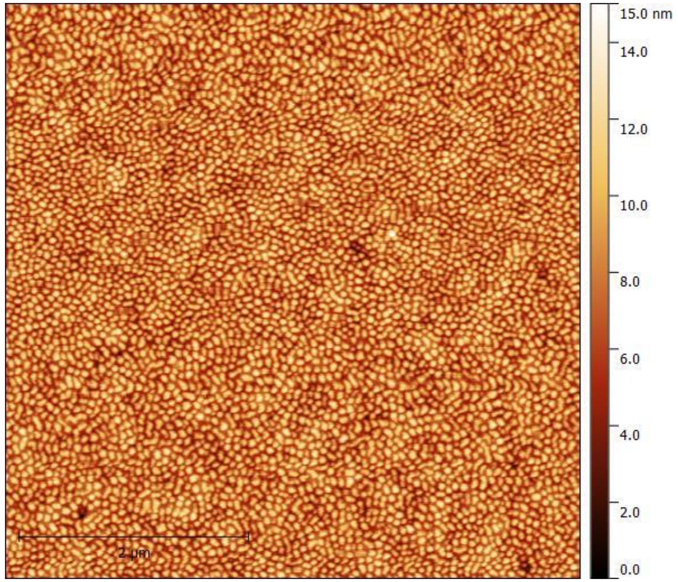
Commercially available low roughness, RMS=2 nm, YBCO layer

ceraco ceramic coating

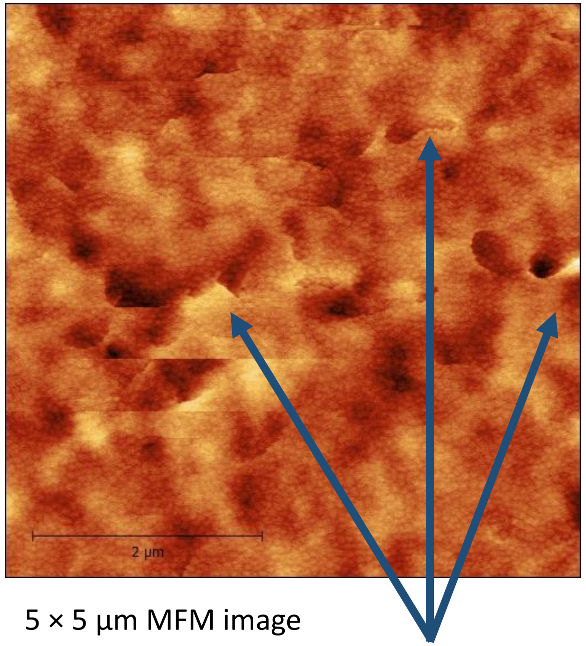
Use of PS nano-dots for magnetic gradient generation

1. Cobalt thin film deposition on top of PS nano-dots



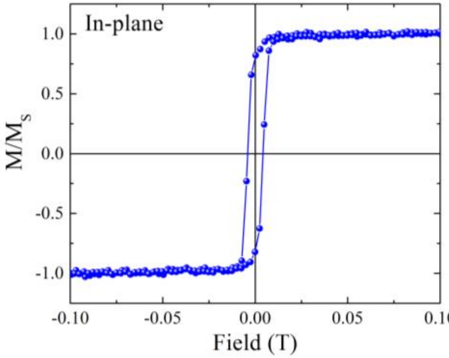


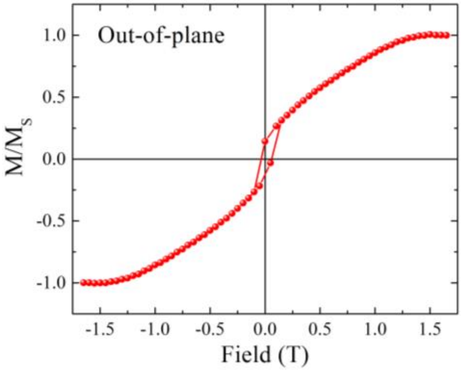
5 × 5 µm AFM image



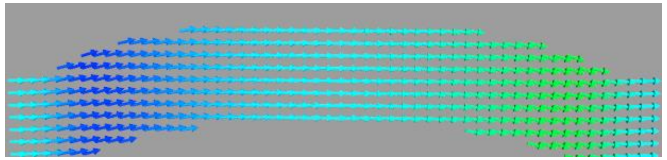
5 × 5 µm MFM image

Domain wall contrast





- typical film like M(H) response (in-plane magnetization, out-of-plane DW contribution)



mumax-micromagnetic simulation

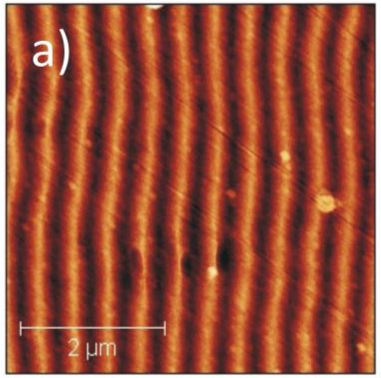
- the Co thin film reproduces the PS nano-dot morphology;
- No nano-patterning signature in MFM image, just domain wall signature;
- Film-like magnetic characteristics;

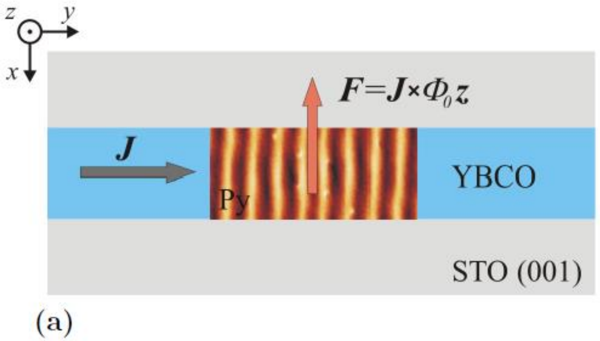
- high aspect ratio 60:5
- low out-of plane magnetization deflection

Use of PS nano-dots for magnetic gradient generation

Domain wall pinning in YBCO thin films

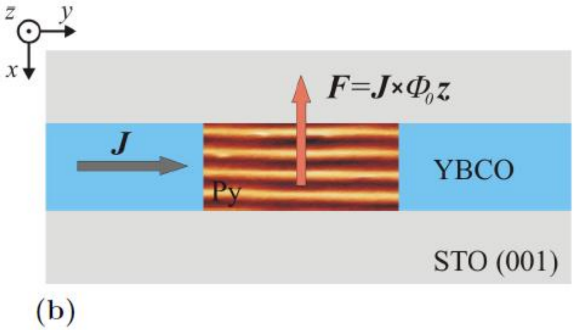
Weak-stripe domains in Permalloy (250 nm) films





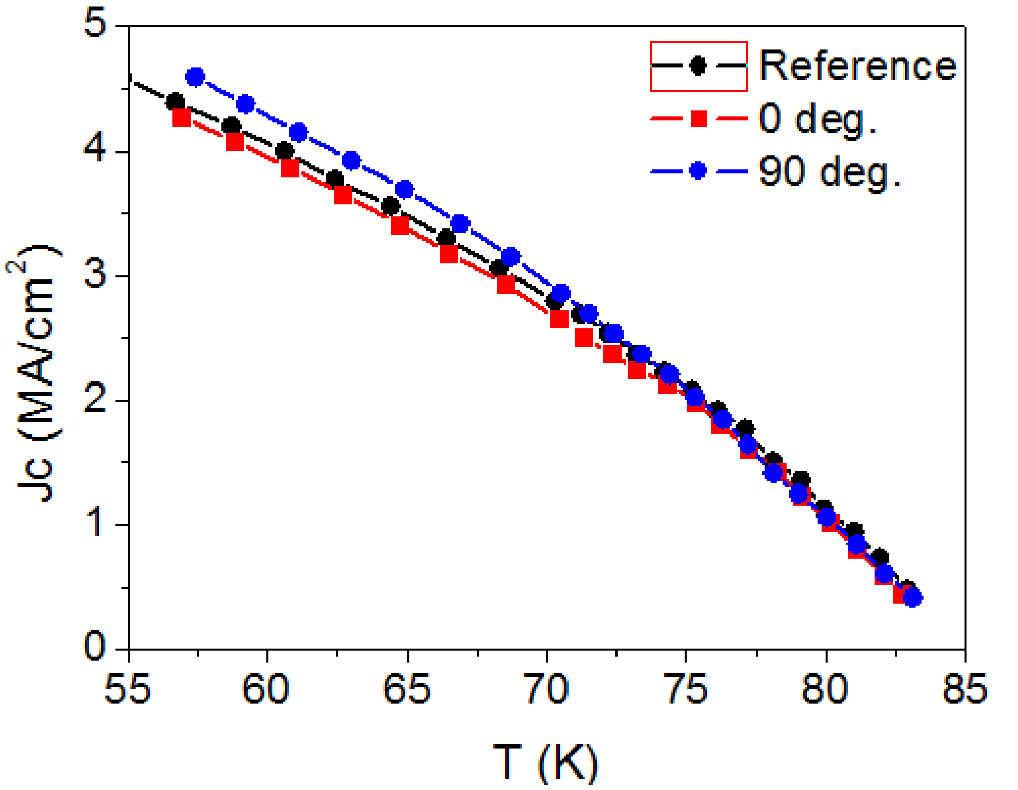
No gradient

90° configuration (Vortex Guide)



Max. gradient

0° configuration (Vortex Pinning)

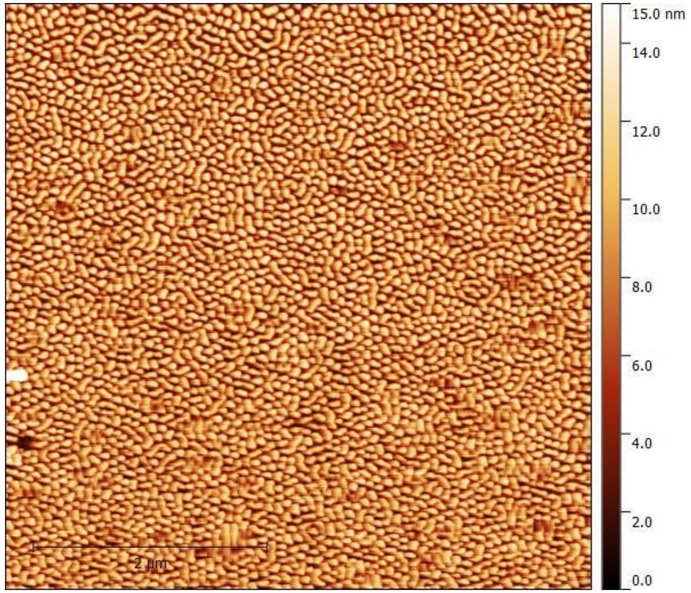


No improvement of the critical current density, J_c

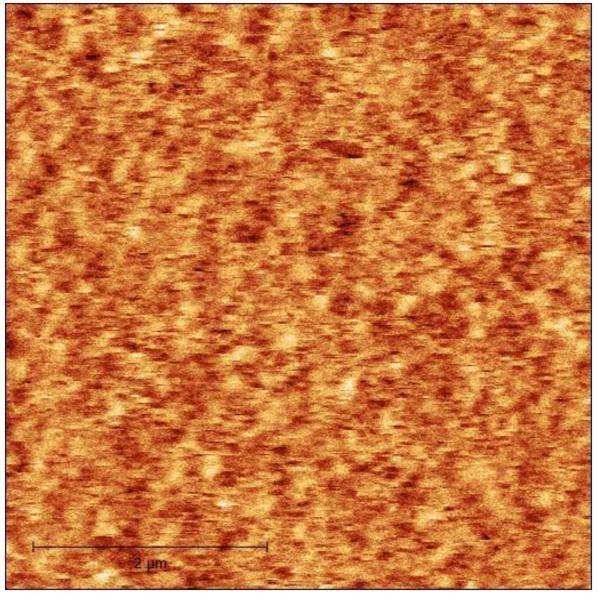
Domain wall vortex pinning is ineffective

Use of PS nano-dots for magnetic gradient generation

2. PS nano-dot as etch mask for cobalt nano-dot fabrication

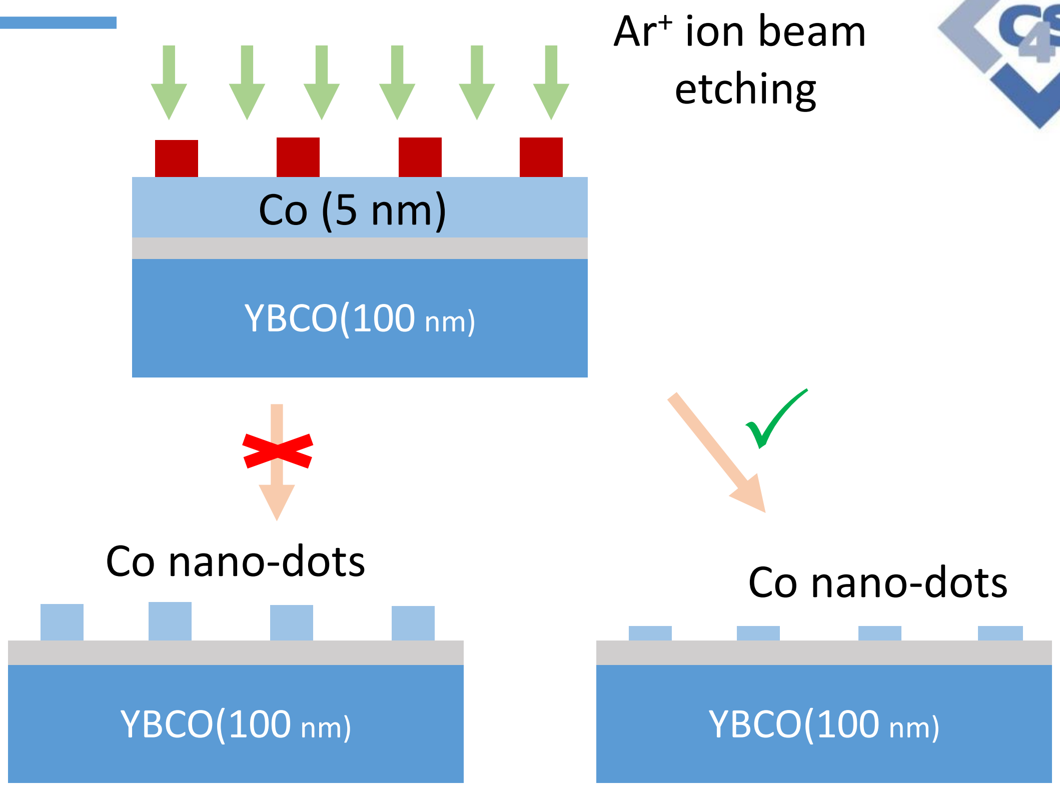


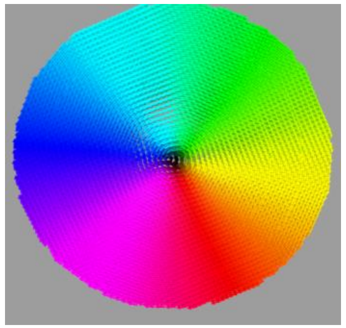
5 × 5 µm AFM image



5 × 5 µm MFM image

- More localized magnetic contrast due to etching;
- **No etching selectivity** provided by the PS nano-dots;
- Etching of both Co and PS;
- Extremley high **time sensitive** process;





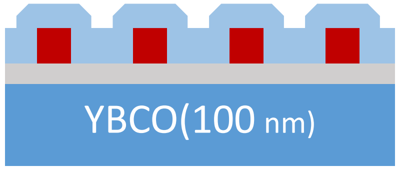
Magnetic vortex configuration
mumax-micromagnetic simulation

Rapid etching of Co
No magnetic vortex configuration was observed

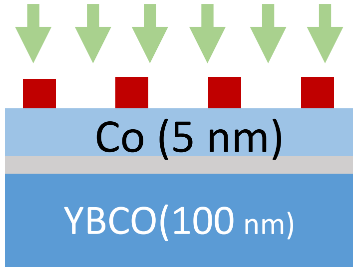
Conclusions and Acknowledgements

- Successful demonstration of uniform PS nano-dot array fabrication over large areas, >100 μm^2;
- Random distribution of nano-dots was observed;
- Limited applicability of the di-block copolymer approach for strong magnetic gradient generation

High aspect ratio of PS nano-dot template

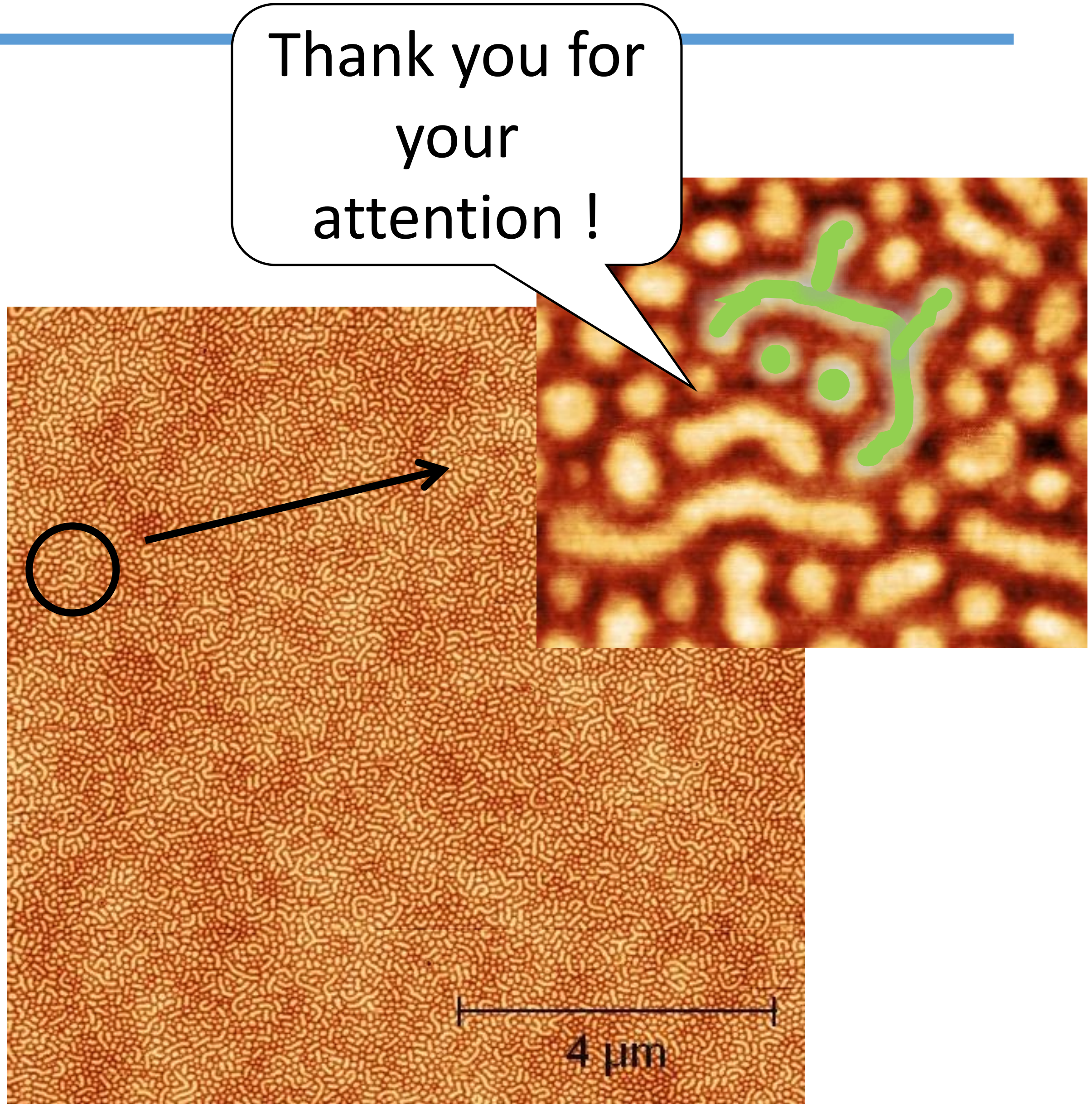


No etching selectivity of PS nano-dots



Acknowledgements

This work was supported by a Grant of the Romanian National Authority for Scientific Research CNCS-UEFISCDI, Project number PN II-RU-TE-2014-4-2848, MAGPIN


Thank you for your attention !
4 µm