Nanosphere lithography

a powerful tool for the research of magnetic nanomaterials

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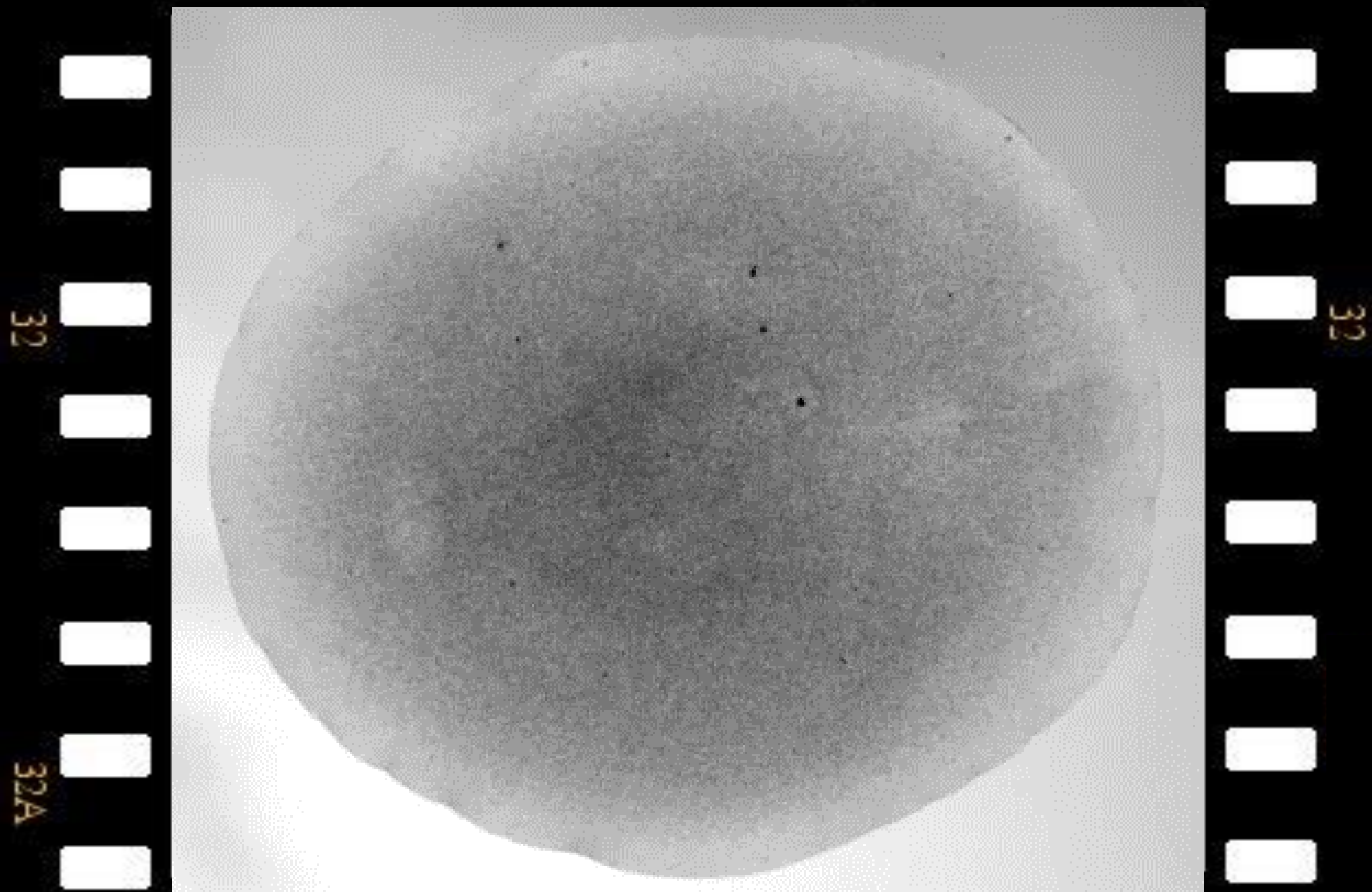


P.J. Yunker, T. Still, M.A. Lohr, A.G. Yodh, „Suppression of the coffee-ring effect by shape-dependent capillary interactions”, *Nature* **467** (2011) 308-311

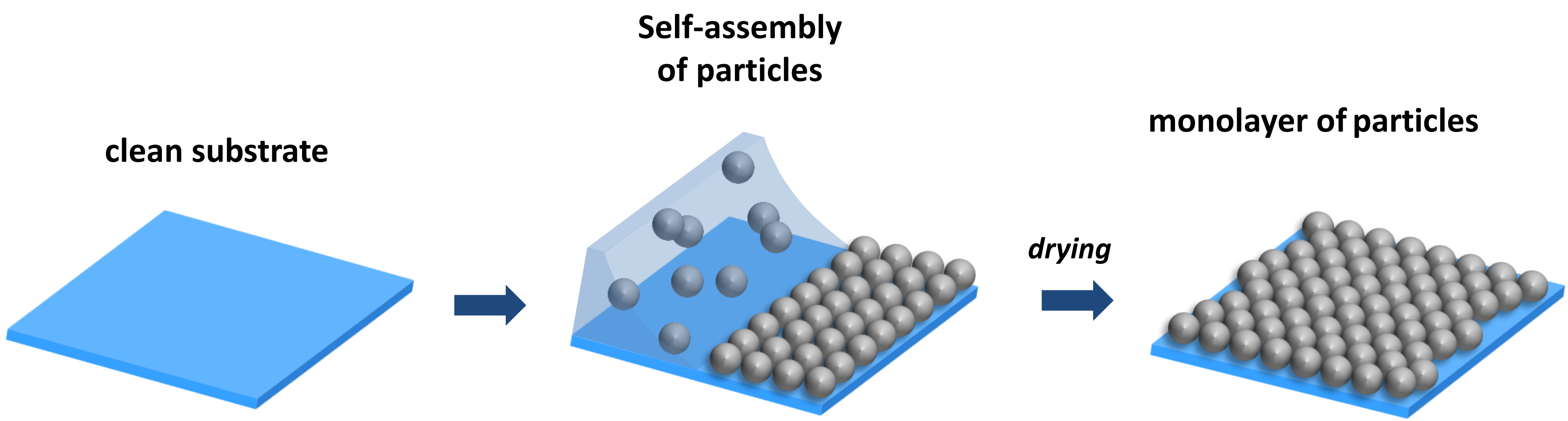
Appl. Phys. Lett. 41(4), 15 August 1982

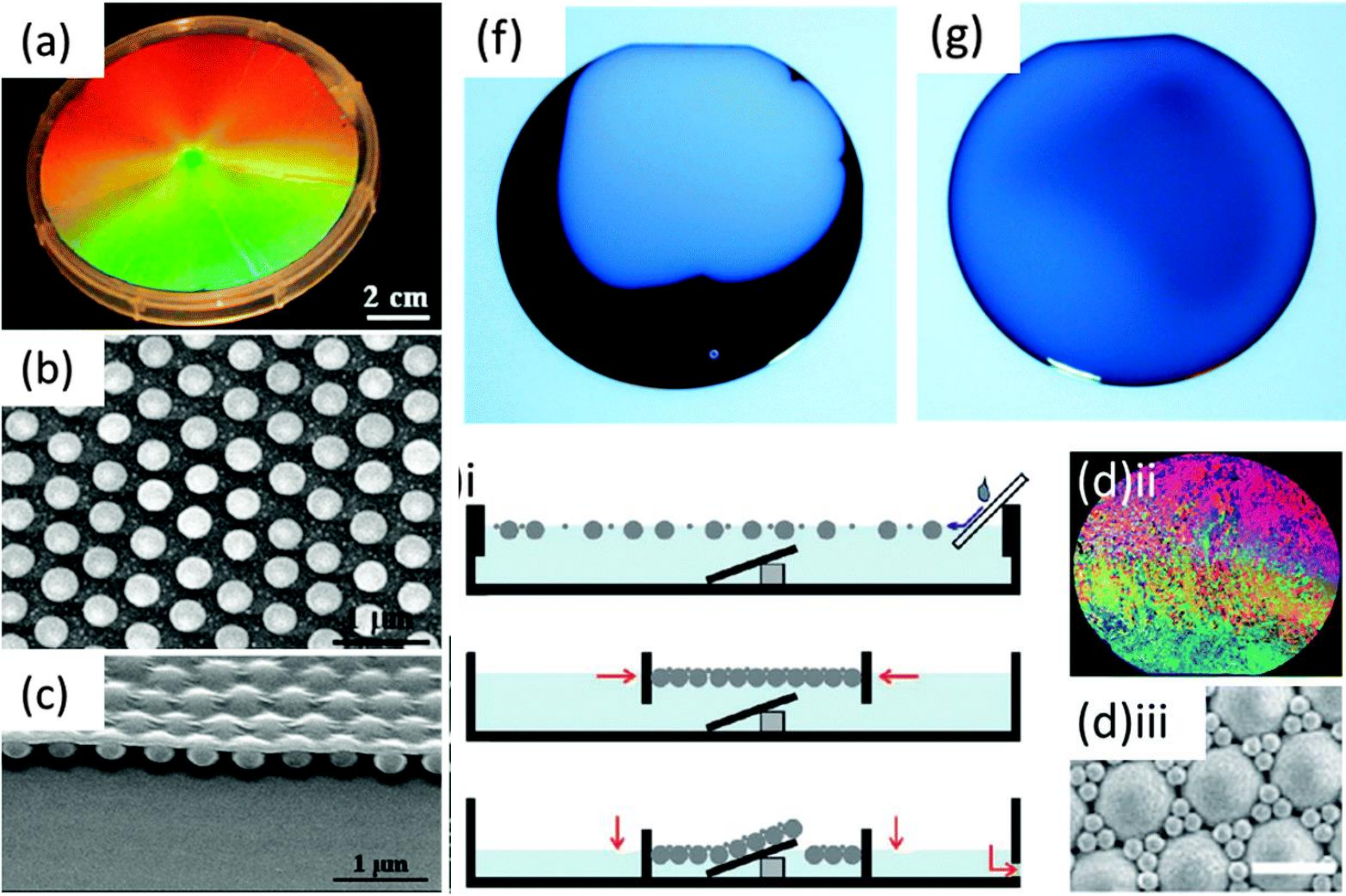
Natural lithography

H. W. Deckman and J. H. Dunsmuir
Exxon Research and Engineering Company, P. O. Box 8, Linden, New Jersey 07036

(Received 23 April 1982; accepted for publication 17 May 1982)

A new form of microfabrication is presented in which spherical colloidal particles are used to define a large area lithographic mask. A monolayer of colloidal particles is deposited in either random or ordered arrays over the entire surface of a macroscopic substrate. Large area random or ordered mosaic arrays of identical submicron microcolumnar structures are produced by using the colloidal particles as either an etching or deposition mask.





E. Armstrong C. O'Dwyer, J. Mater. Chem. C 3, 6109-6143 (2015)

nature materials | VOL 4 | MARCH 2005 | www.nature.com/naturematerials

Magnetic multilayers on nanospheres

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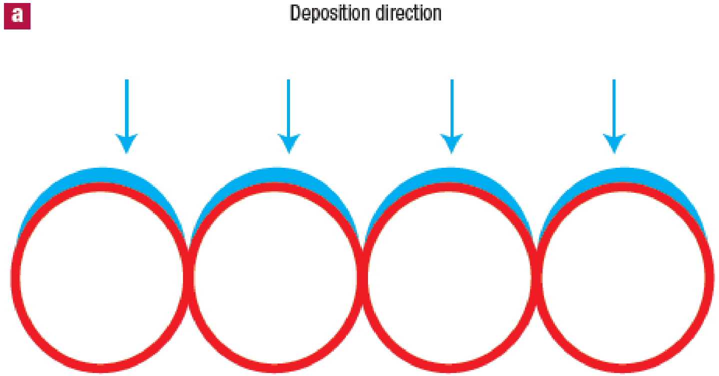
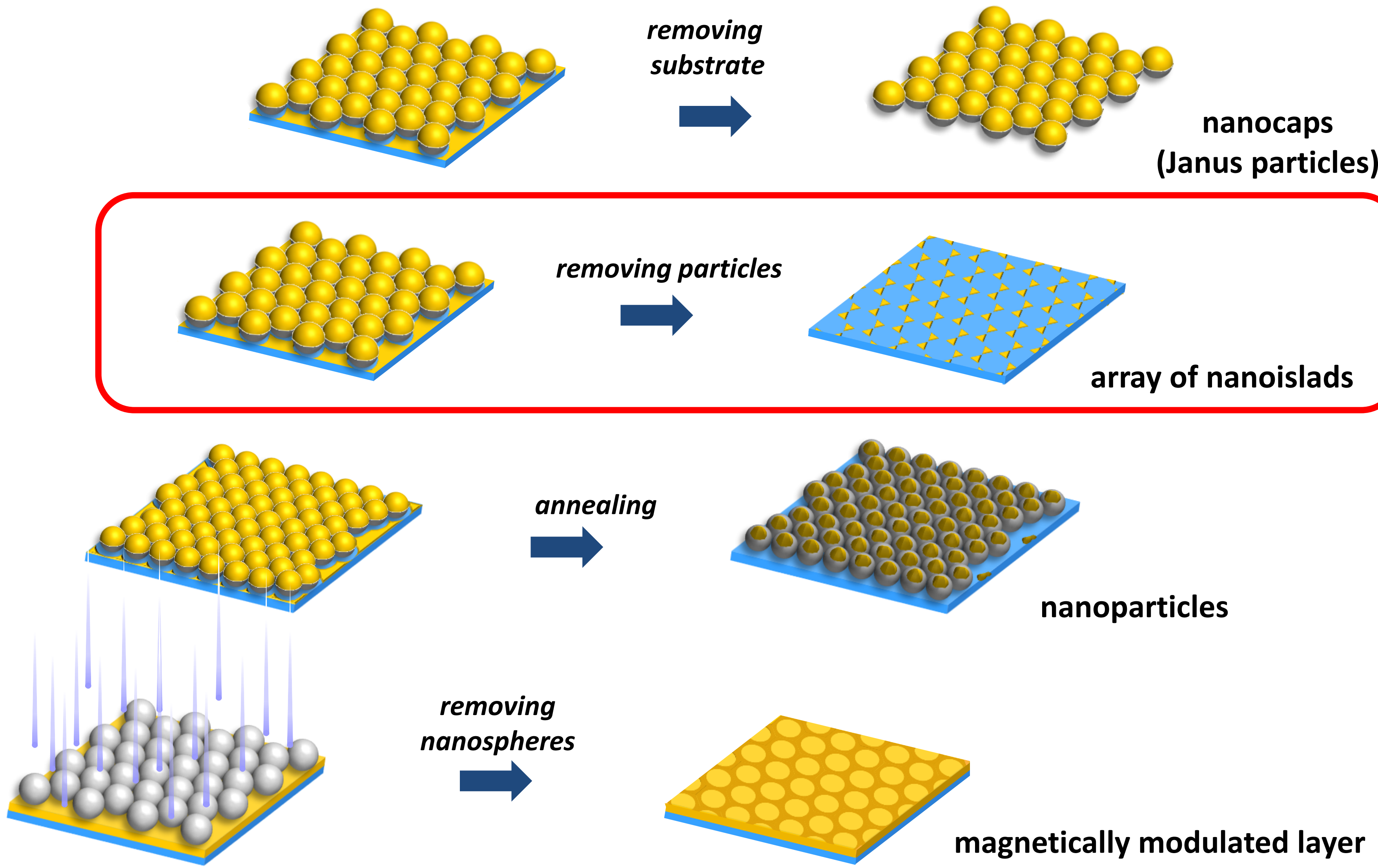
Thin-film technology is widely implemented in numerous applications[1]. Although flat substrates are commonly used, we report on the advantages of using curved surfaces as a substrate. The curvature induces a lateral film-thickness variation that allows alteration of the properties of the deposited material[2,3]. Based on this concept, a variety of implementations in materials science can be expected. As an example, a topographic pattern formed of spherical nanoparticles[4,5] is combined with magnetic multilayer film deposition. Here we show that this combination leads to a new class of magnetic material with a unique combination of remarkable properties: The so-formed nanostructures are monodisperse, magnetically isolated, single-domain, and reveal a uniform magnetic anisotropy with an unexpected switching behaviour induced by their spherical shape. Furthermore, changing

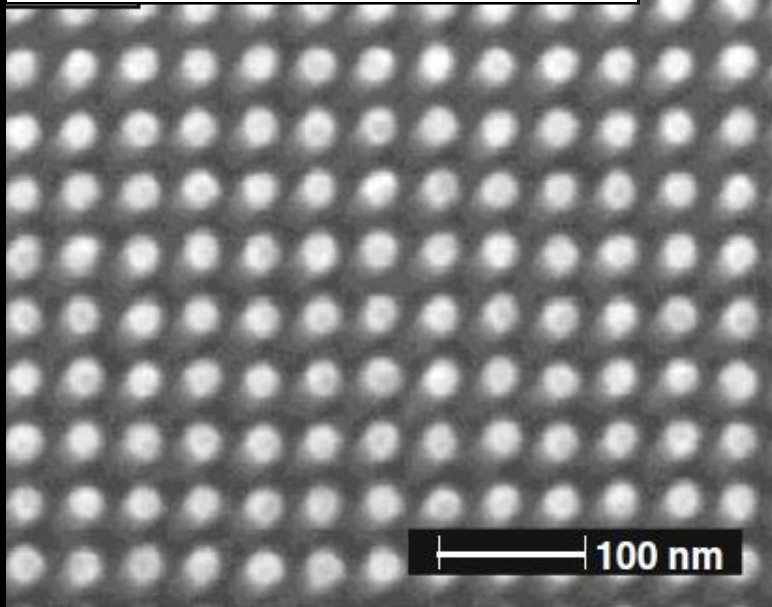
a



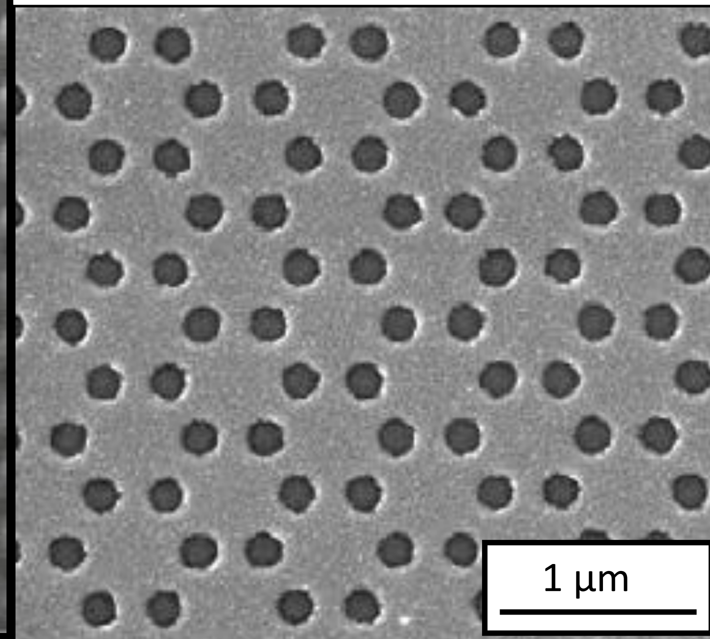
Nanosphere lithography offers wide range of possibilities



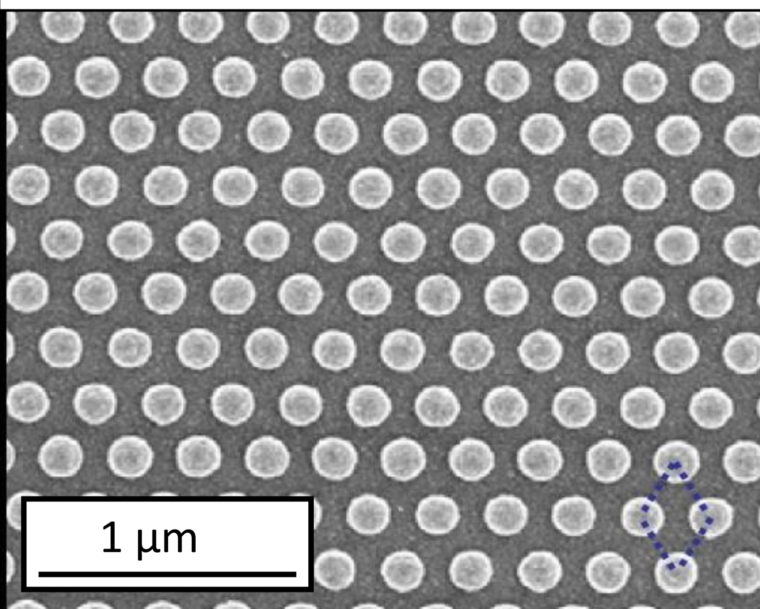
C. Choi et al., *JOM* 64 (2012) 1165



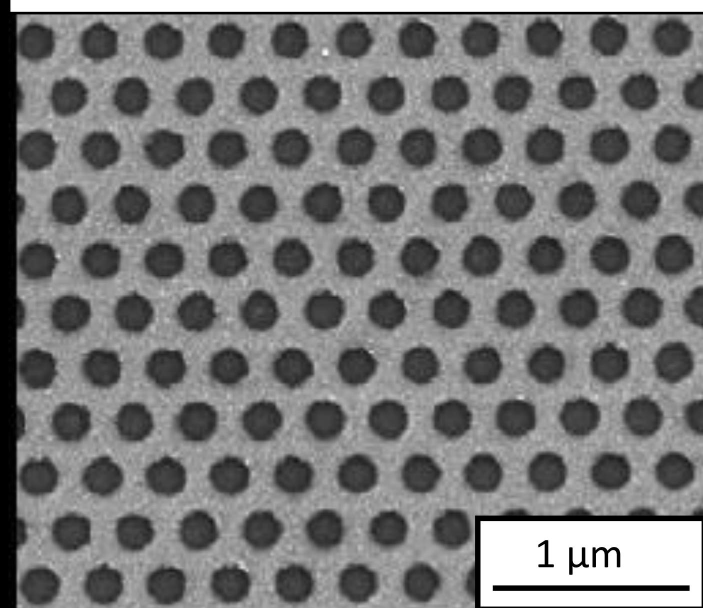
C. Wang et al., *Nanotech.* 17 (2006) 1629



C. Wang et al., *Nanotech.* 17 (2006) 1629

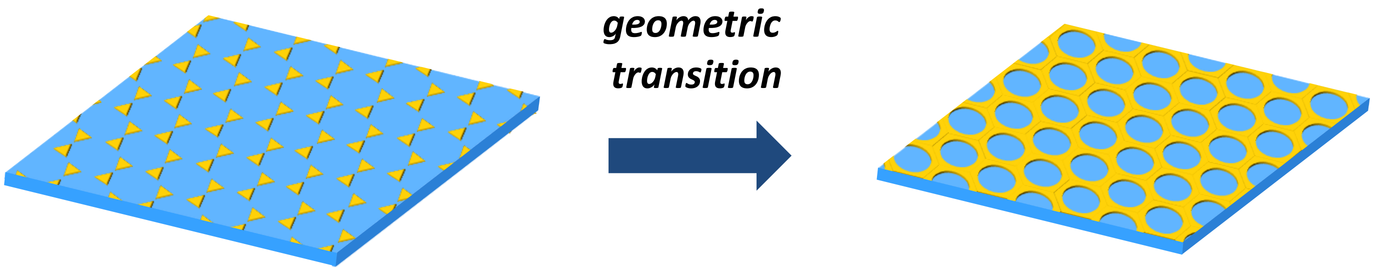


C. Wang et al., *Nanotech.* 17 (2006) 1629



What scientific problem we want to solve?

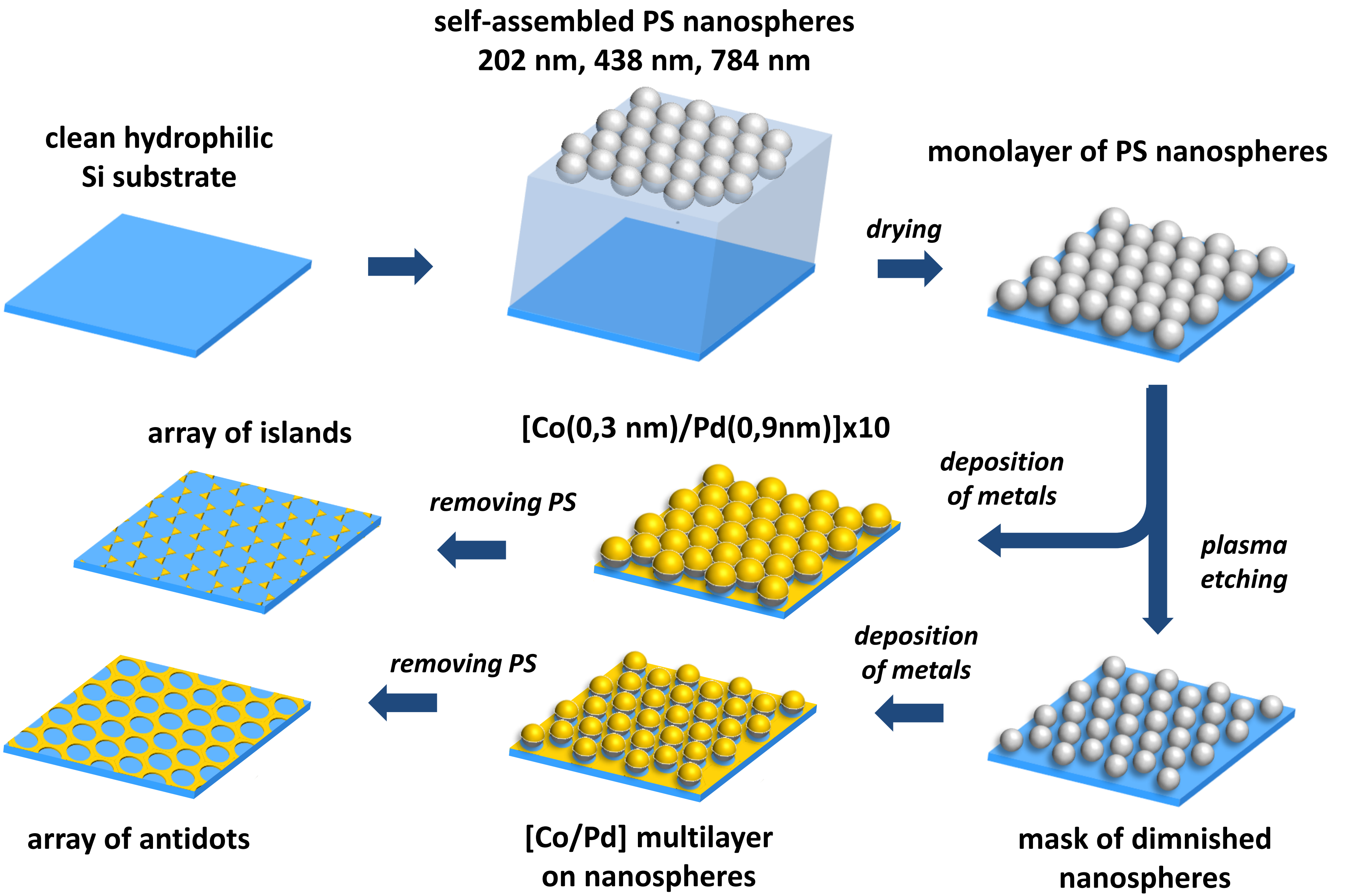
How do the magnetic properties change during the transition from island arrays (dots) to hole patterns (antidots)?

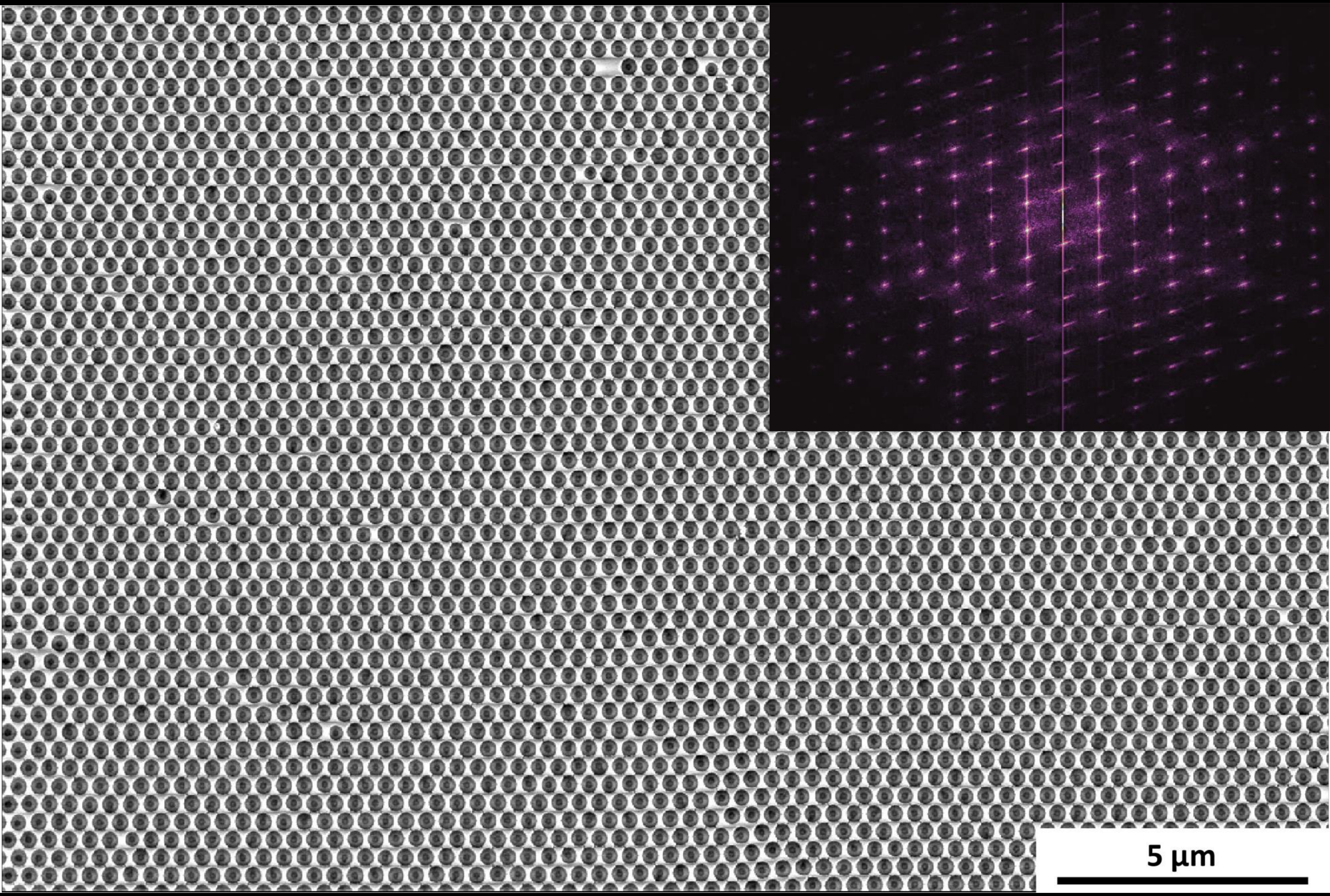


We are interested not only in macroscopic (coercivity, anisotropy constant etc.) but also microscopic (domain size, domain wall configuration etc.) properties.

Nanosphere lithography fits perfectly this type of scientific problems.

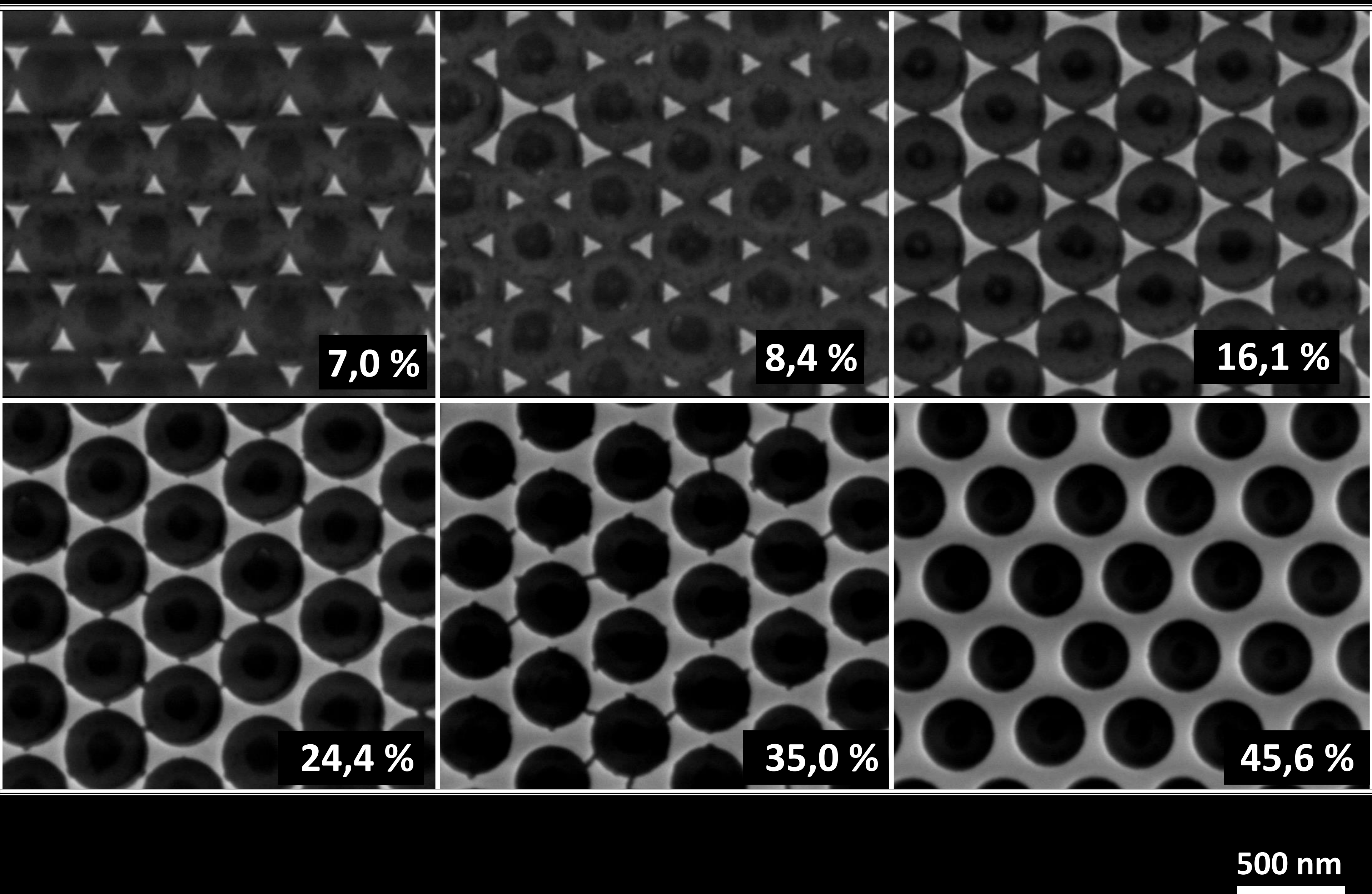
How to prepare arrays of magnetic nanostructures on a large area?

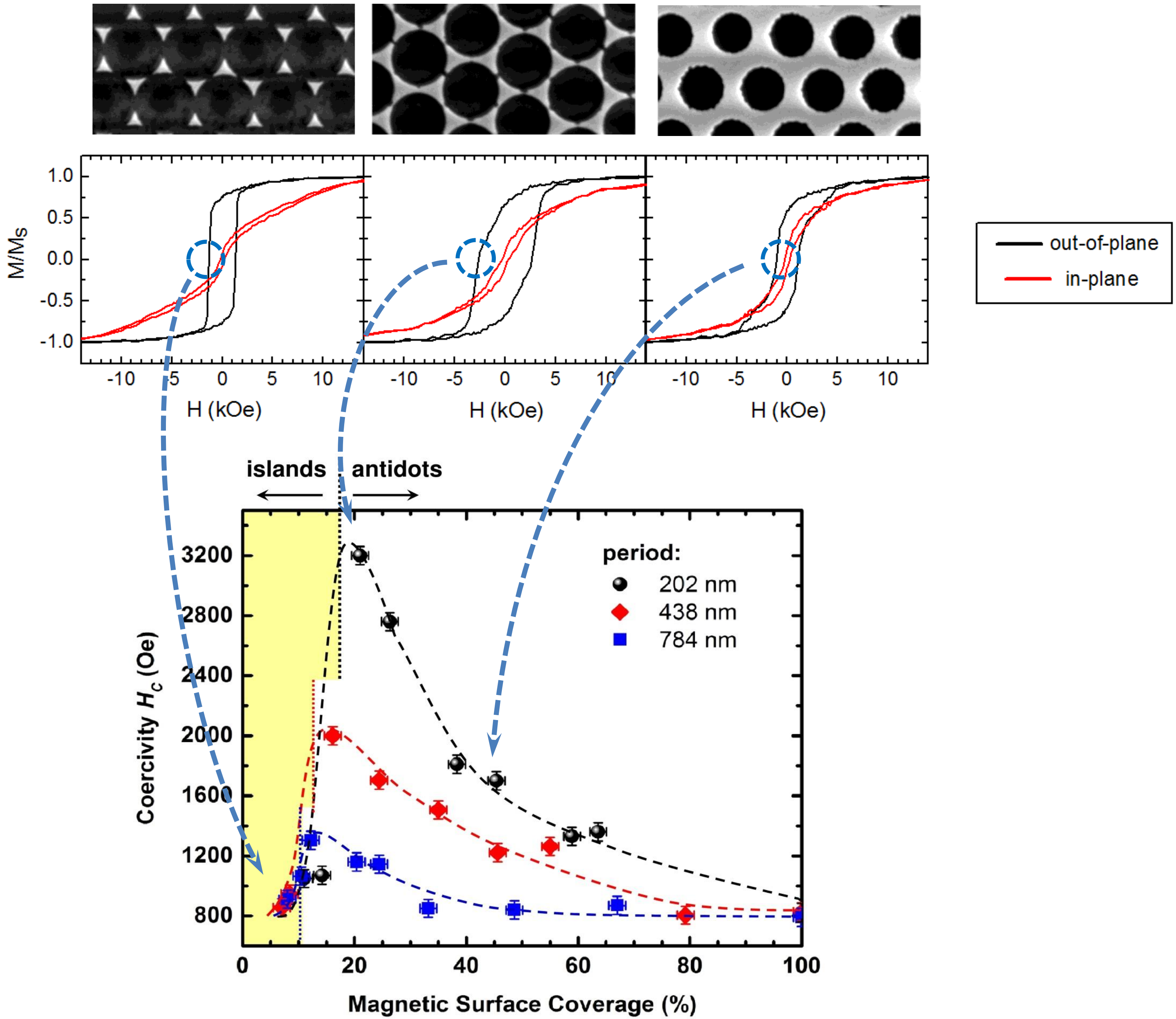




5 µm

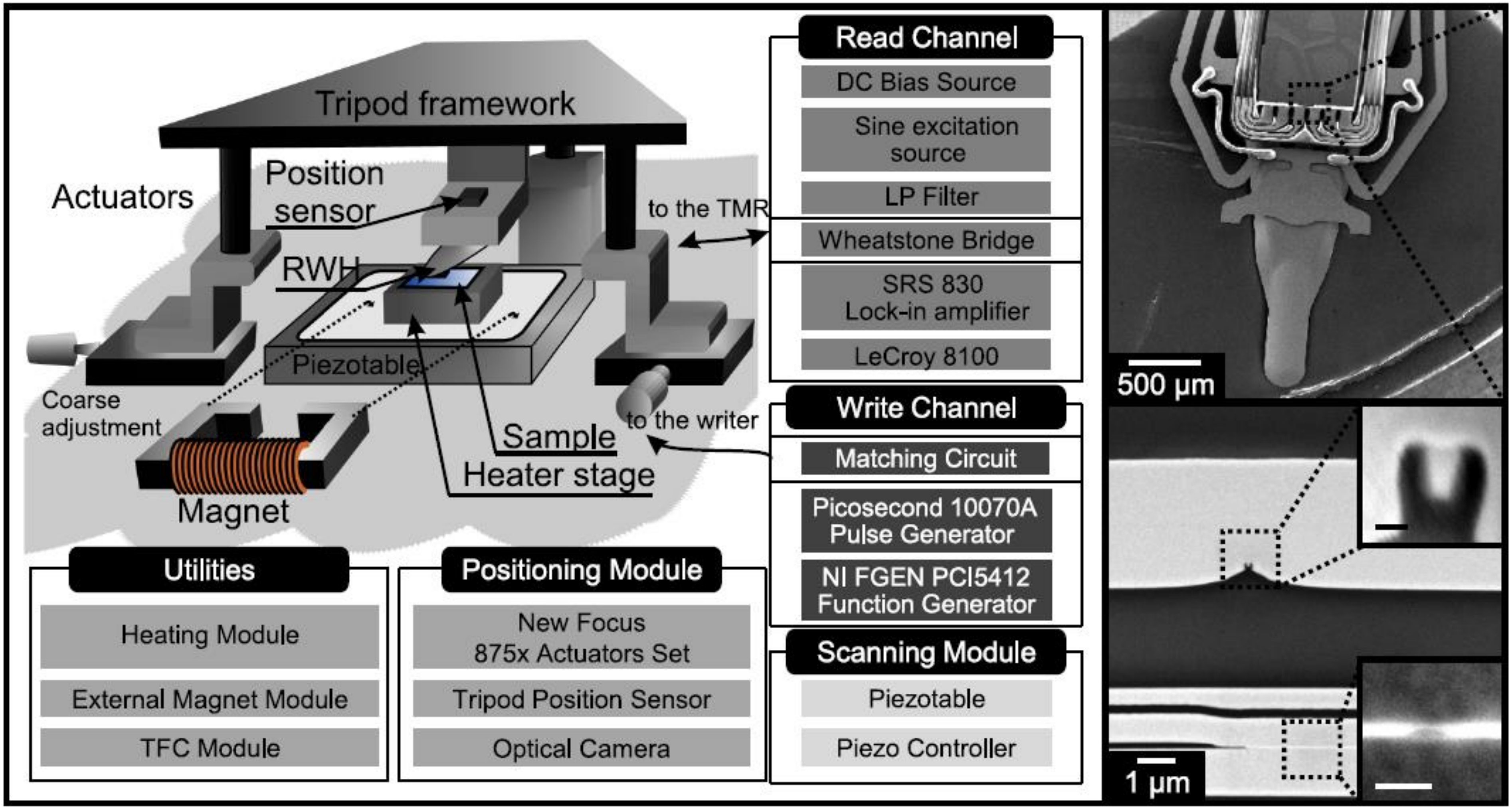
period 438 nm





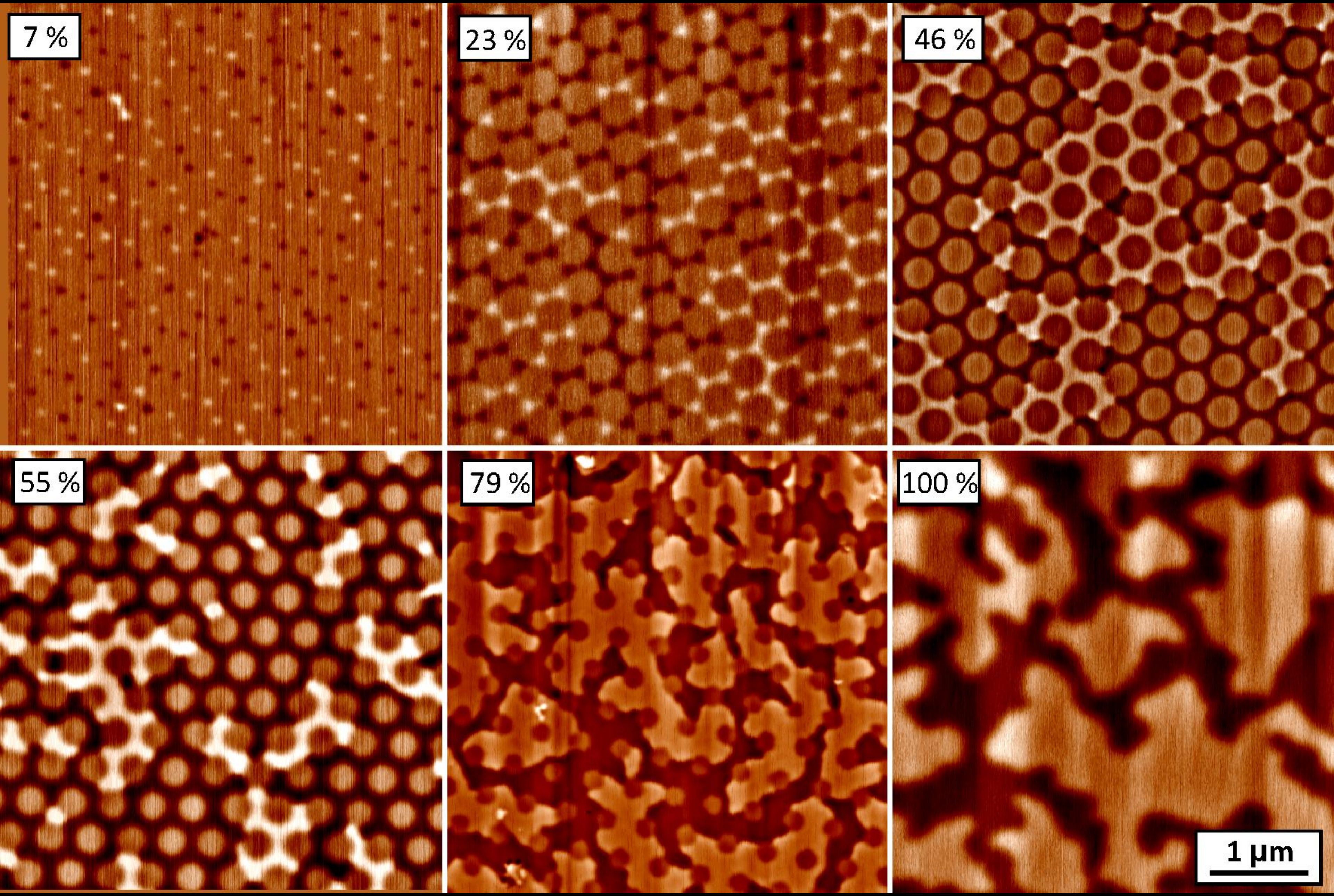
M/Ms
1.0
0.5
0.0
-0.5
-1.0
-10
-5
0
5
10
H (kOe)
out-of-plane
in-plane
islands
antidots
Coercivity H_C (Oe)
3200
2800
2400
2000
1600
1200
800
period:
202 nm
438 nm
784 nm
0
20
40
60
80
100
Magnetic Surface Coverage (%)

Scanning Magnetoresistive Microscopy



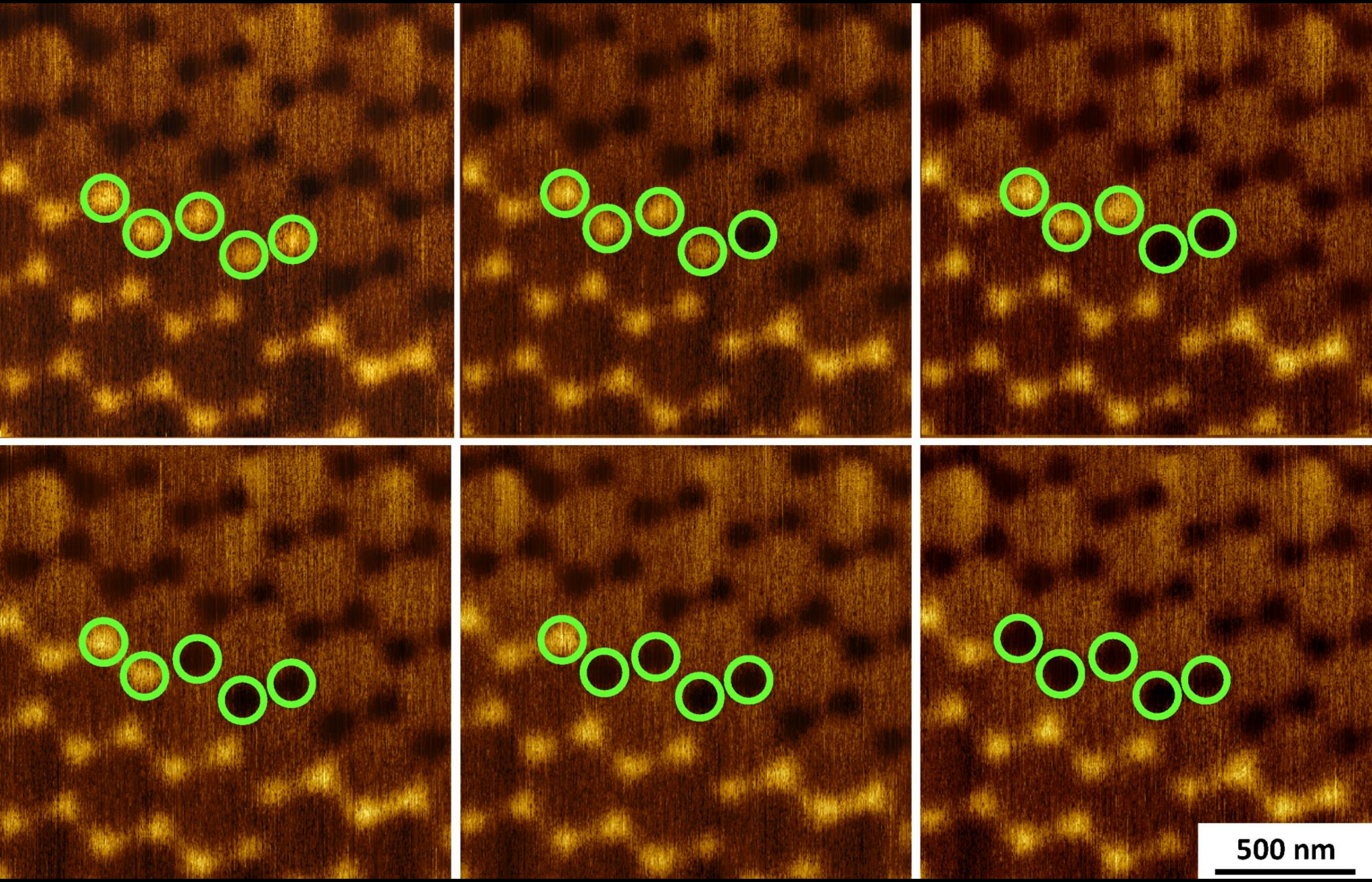
D. Mitin et al. *Rev. Sci. Instrum.* **87**, 023703 (2016)

period 438 nm

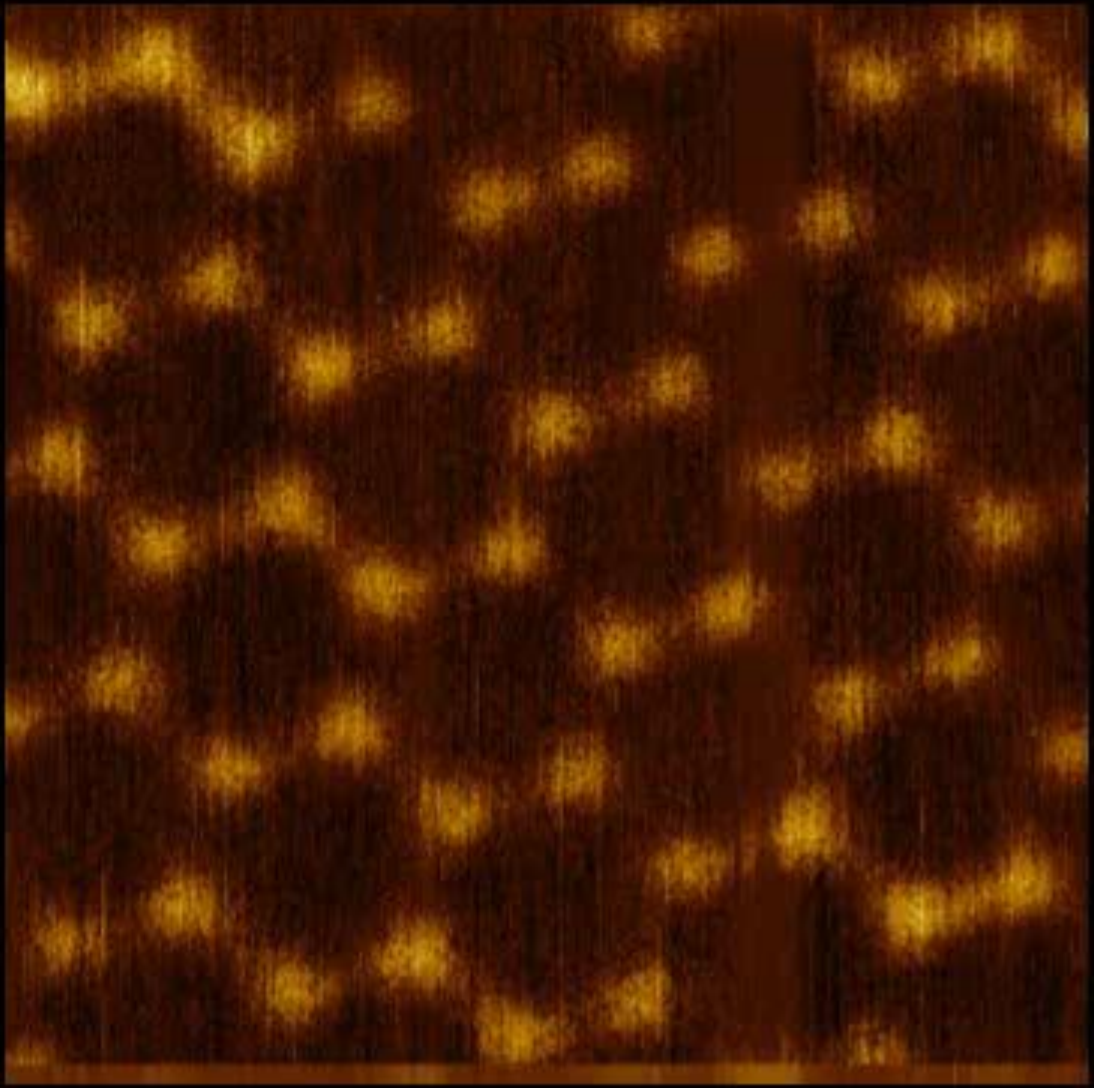


M Krupinski et al., Nanotechnology 28 (2017) 085302

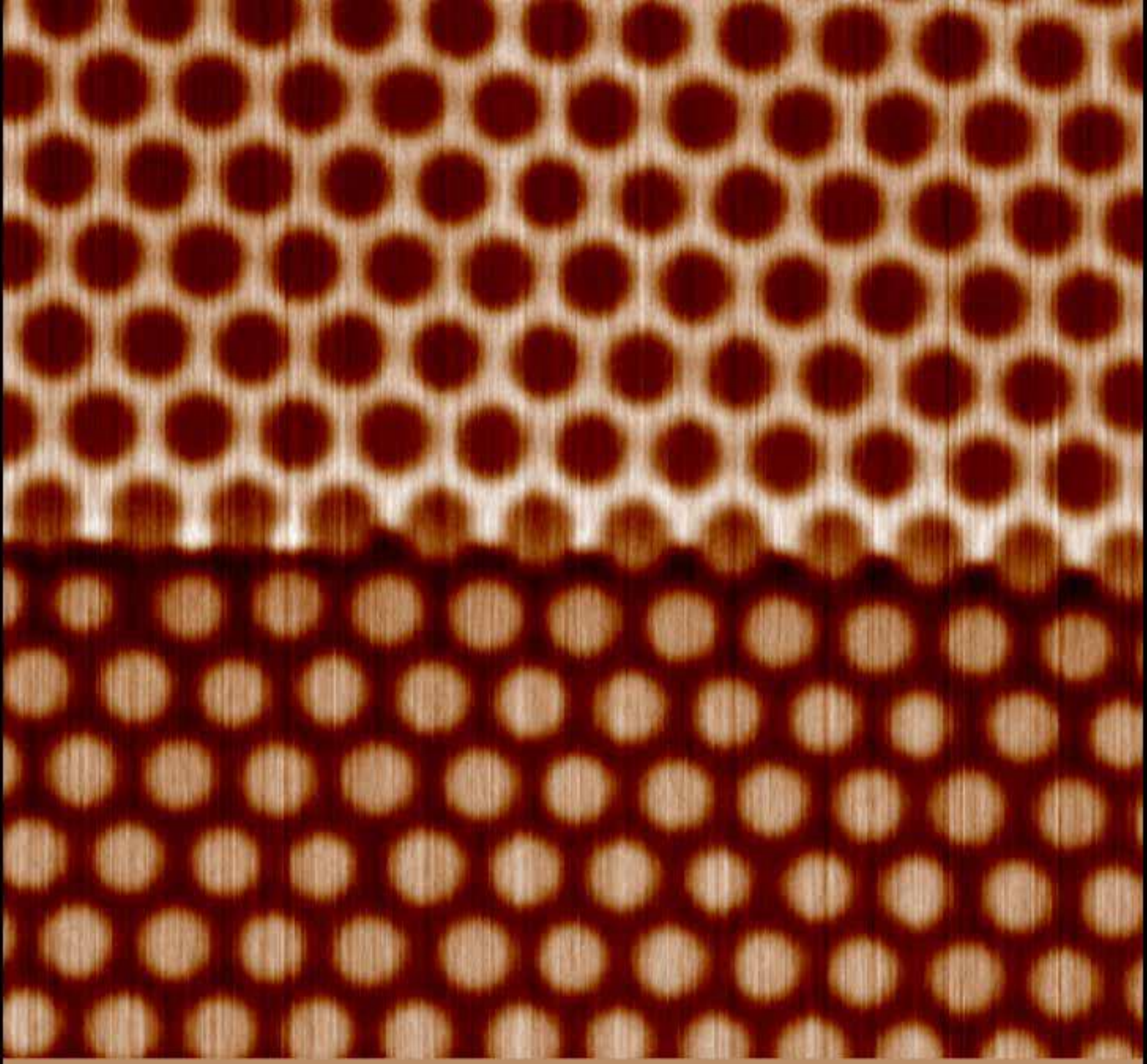
coverage ratio: 23% **period: 438 nm**



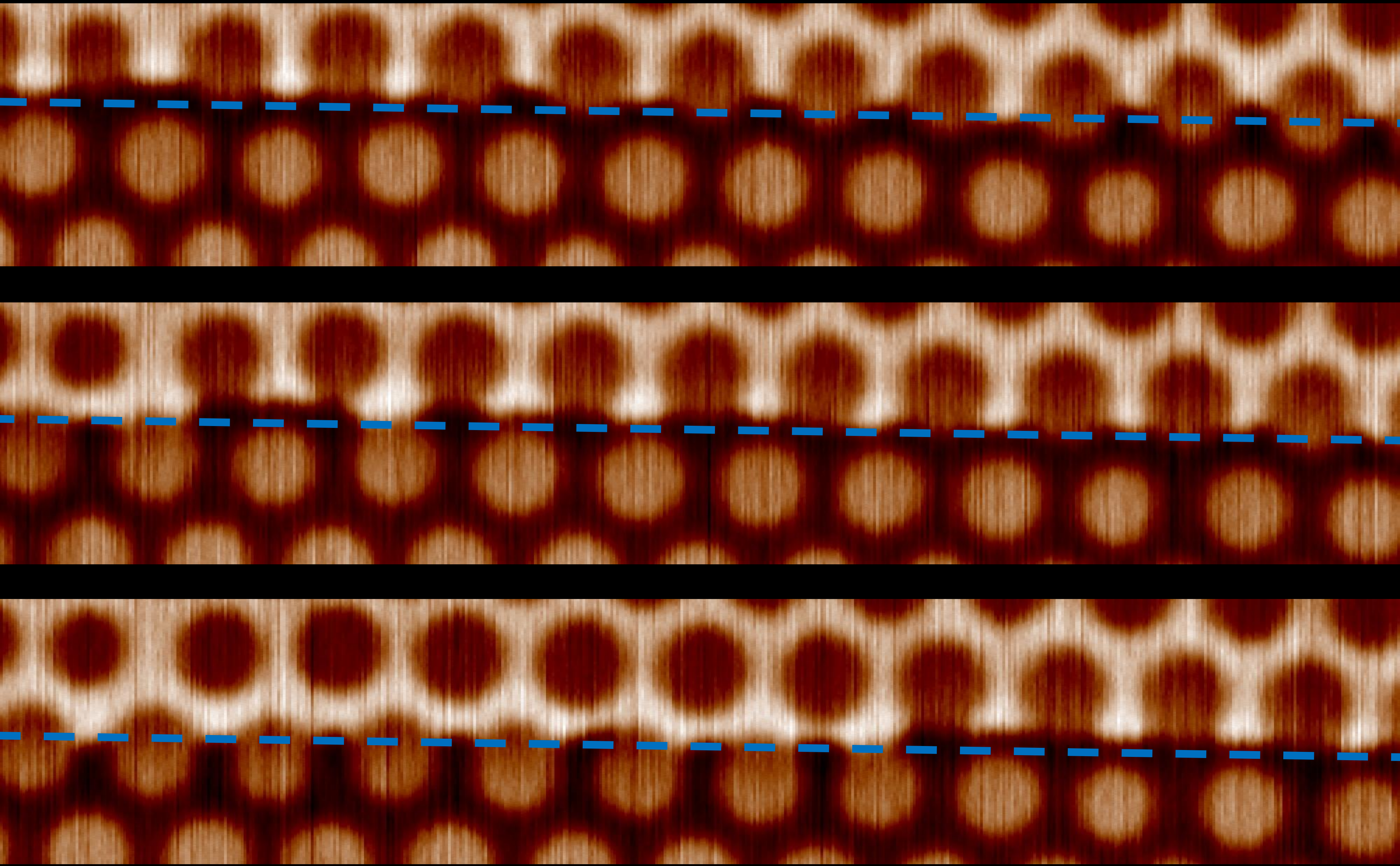
M Krupinski et al., Nanotechnology 28 (2017) 085302



M Krupinski et al., Nanotechnology 28 (2017) 085302

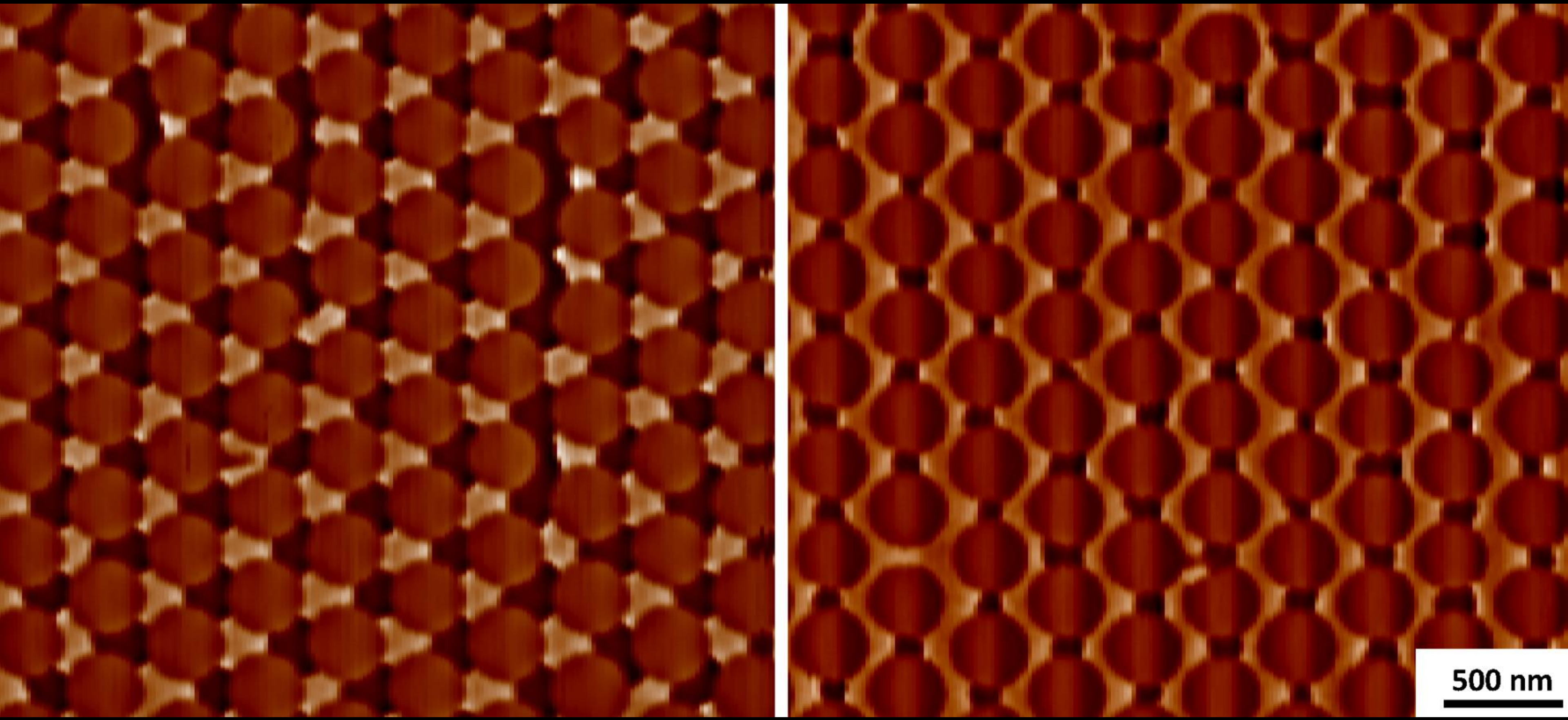


coverage ratio: 55% **period 438 nm**



M Krupinski et al., Nanotechnology 28 (2017) 085302

coverage ratio: 55% **period 438 nm**



M Krupinski et al., Nanotechnology 28 (2017) 085302

Micromagnetic model for reference flat sample

Material parameters:

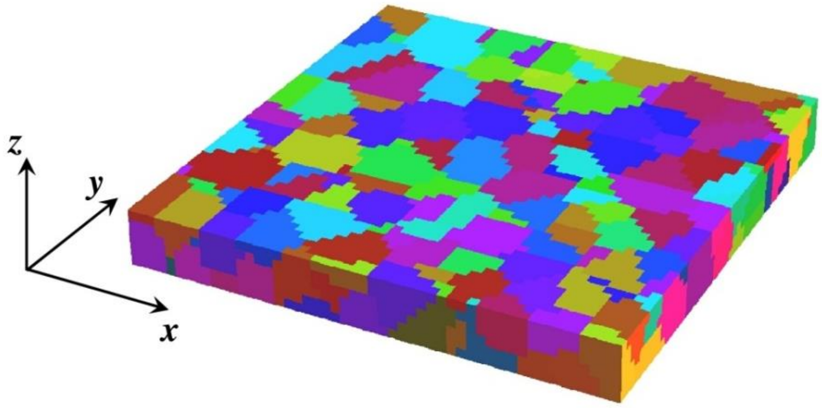
- damping constant: $\alpha = 0.15$
- exchange stiffness: $A_{ex} = 10^{-11}$ J/m
- anisotropy constant: $K_u = 9.0 \times 10^5$ J/m^3
- saturation magnetization: $M_S = 8.0 \times 10^5$ A/m

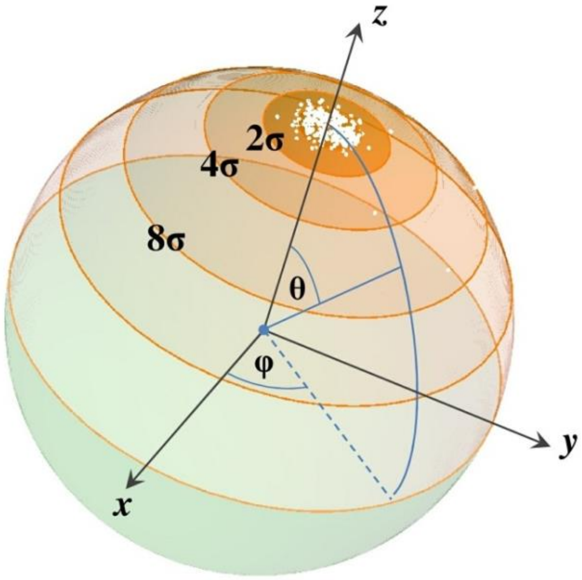
Simulation approach:

- MuMax3 software
- voxel size: 2 nm x 2 nm x 2 nm ($l_{ex} \approx 5$ nm)
- sample size: 2048 nm x 2048 nm x 12 nm
- periodic boundary conditions

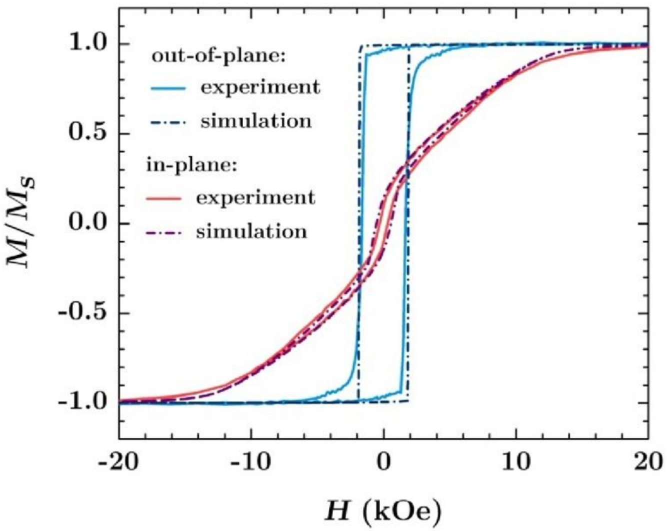
Intrinsic defects:

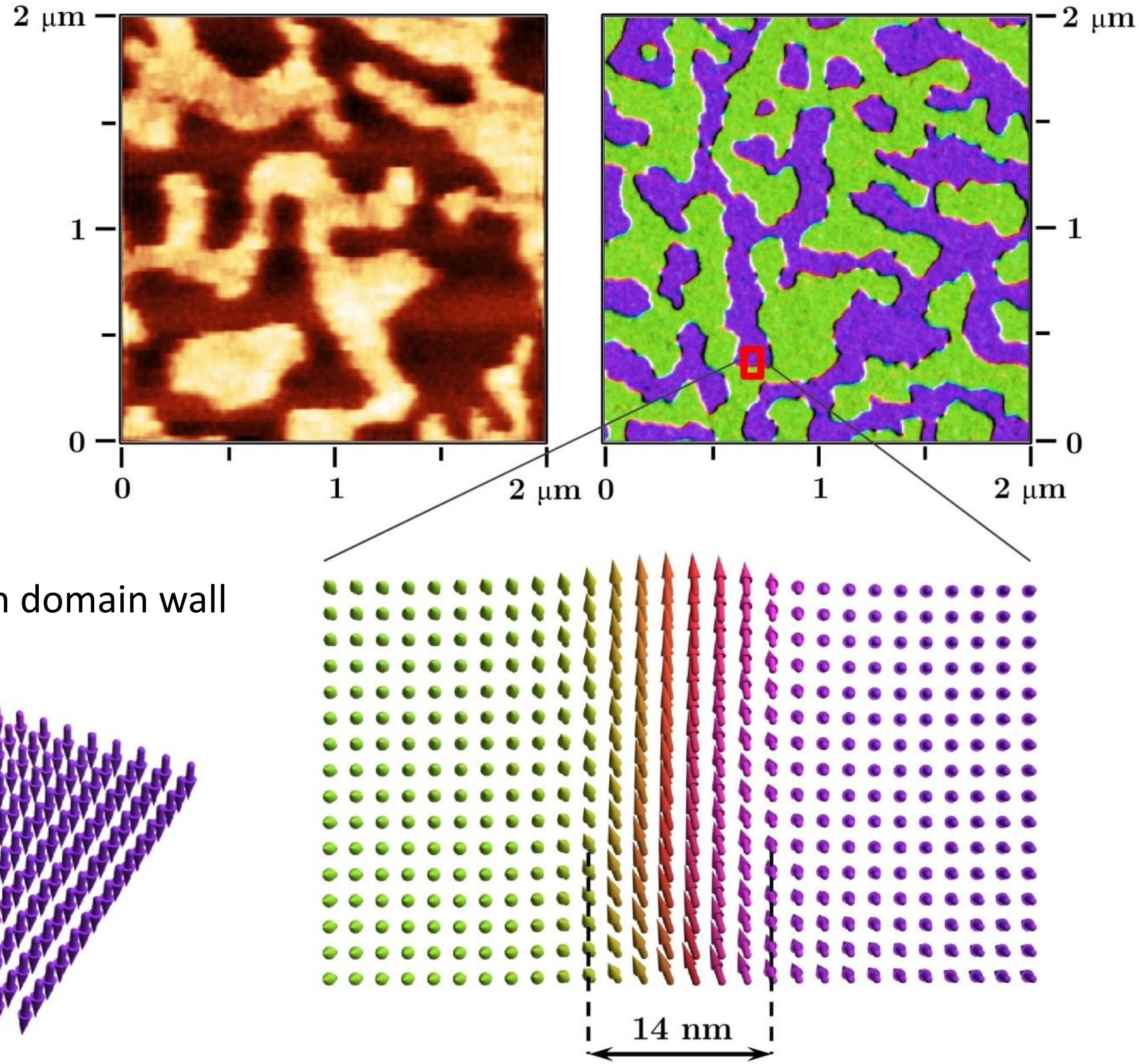
- polycrystalline (grain size 10 nm, std dev. 2.5 nm)
- 10% of grains are „easy-switchers” with $K_u = 0$
- each grain has a unique direction of K_u axis (std. dev of 5 deg)
- additional random distribution of K_u directions for 2% of grains



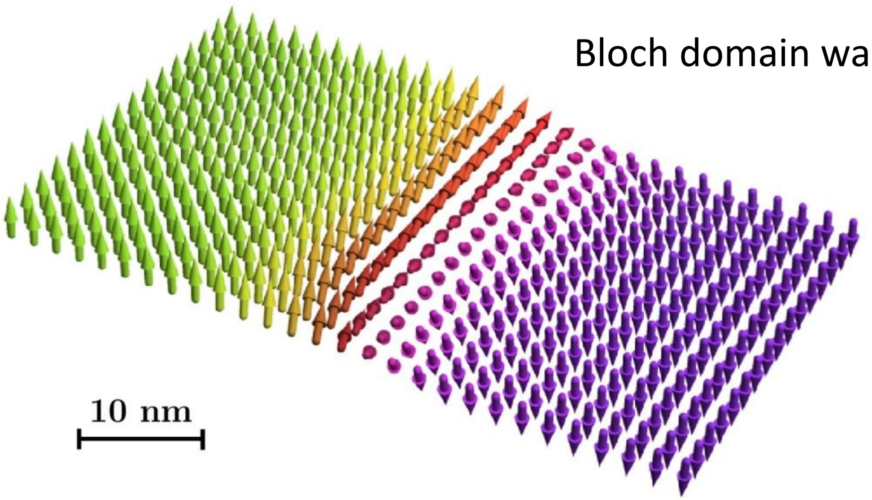


Magnetic reversal and domain structure for reference sample

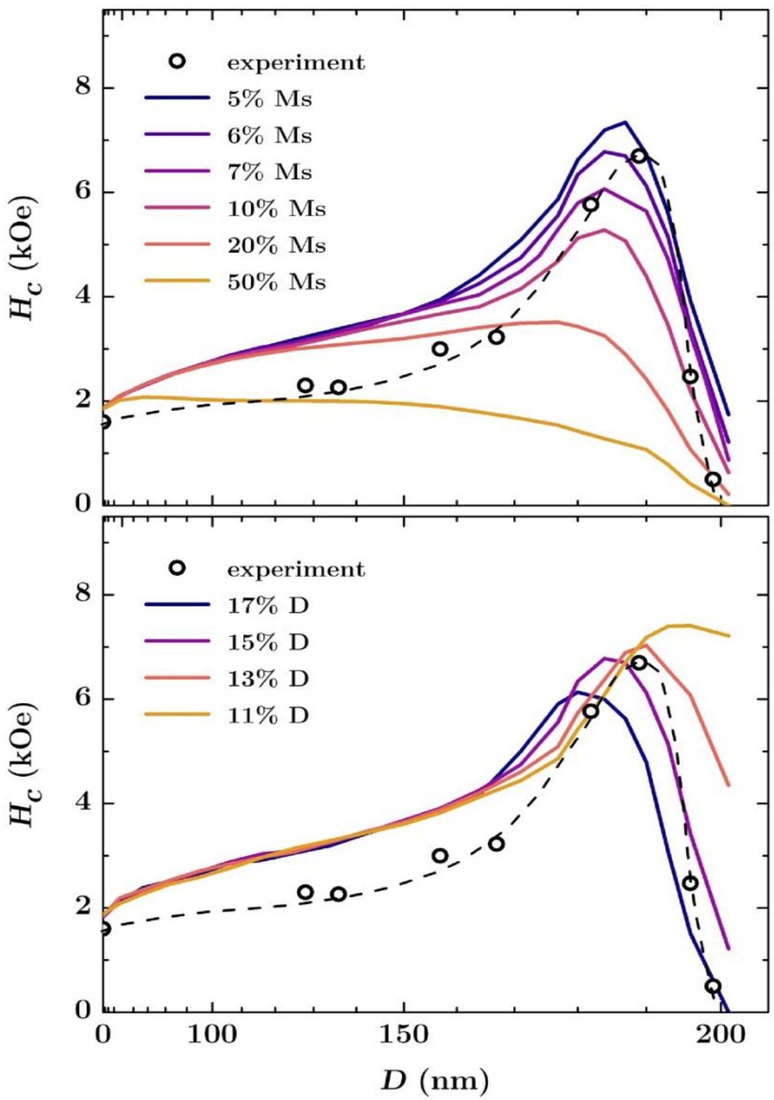


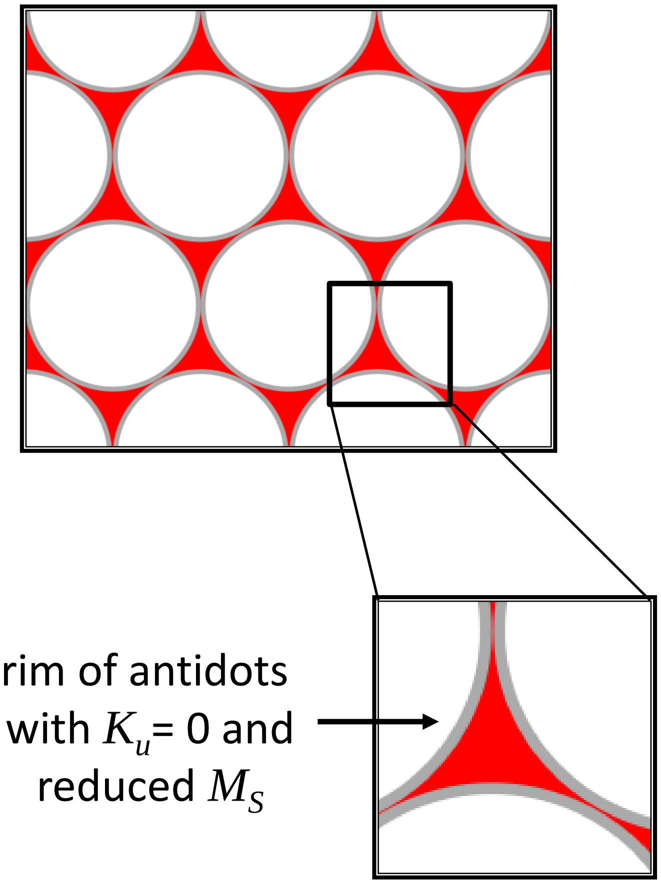


Bloch domain wall



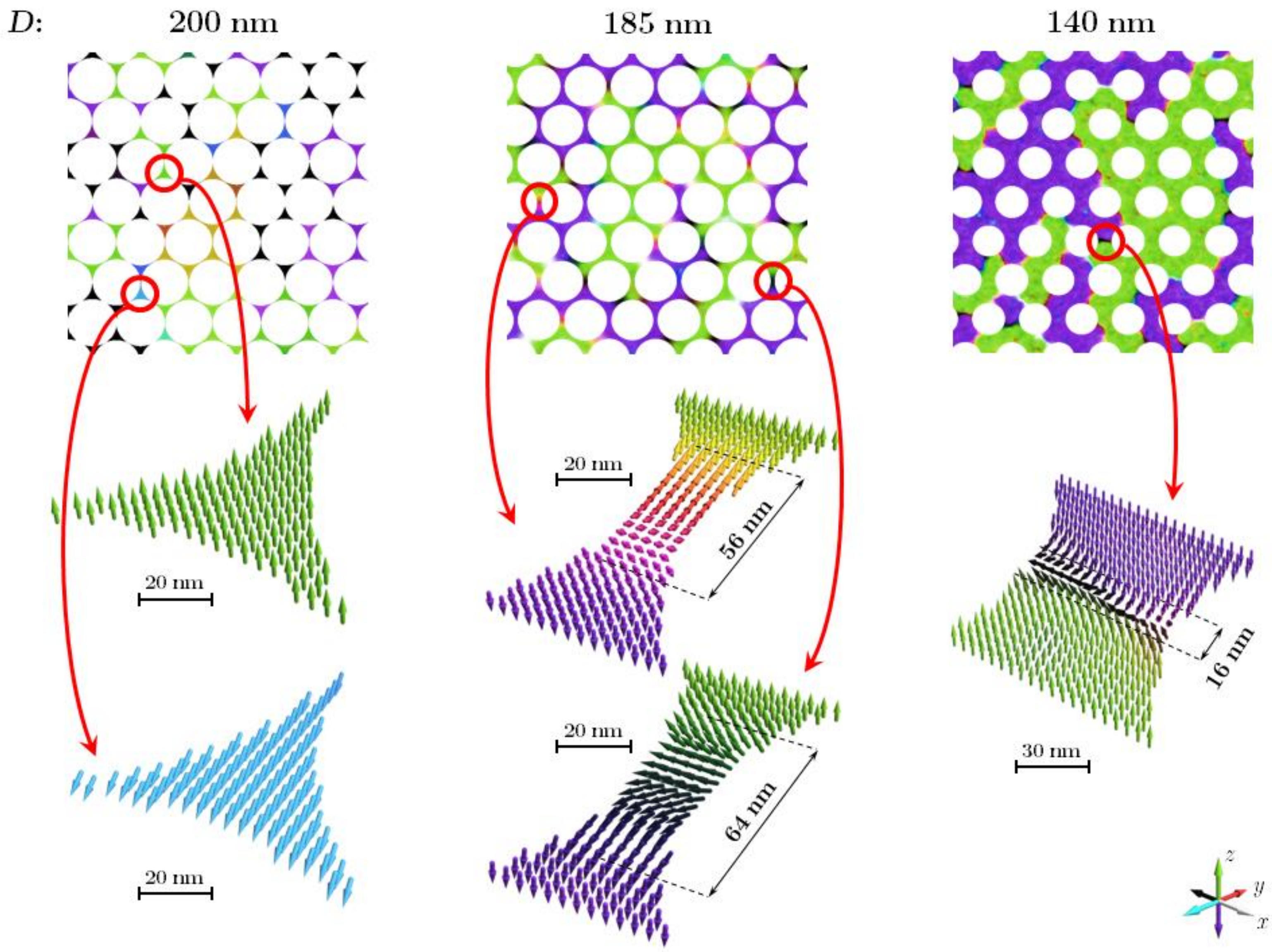
Micromagnetic model for antidot array



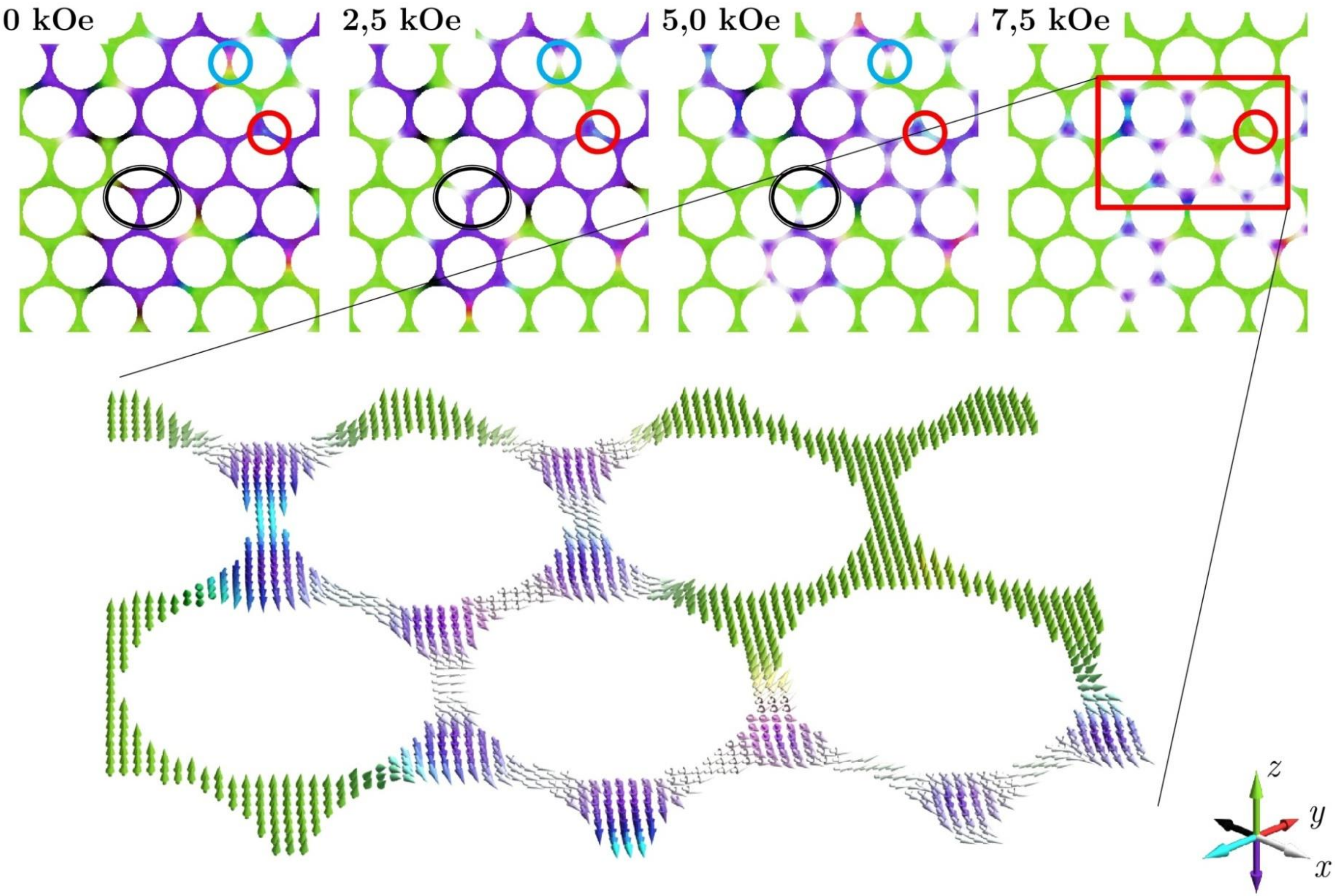


M. Krupinski et al. Scientific Reports 9 (2019) 13276

Antidot size determines domain wall type

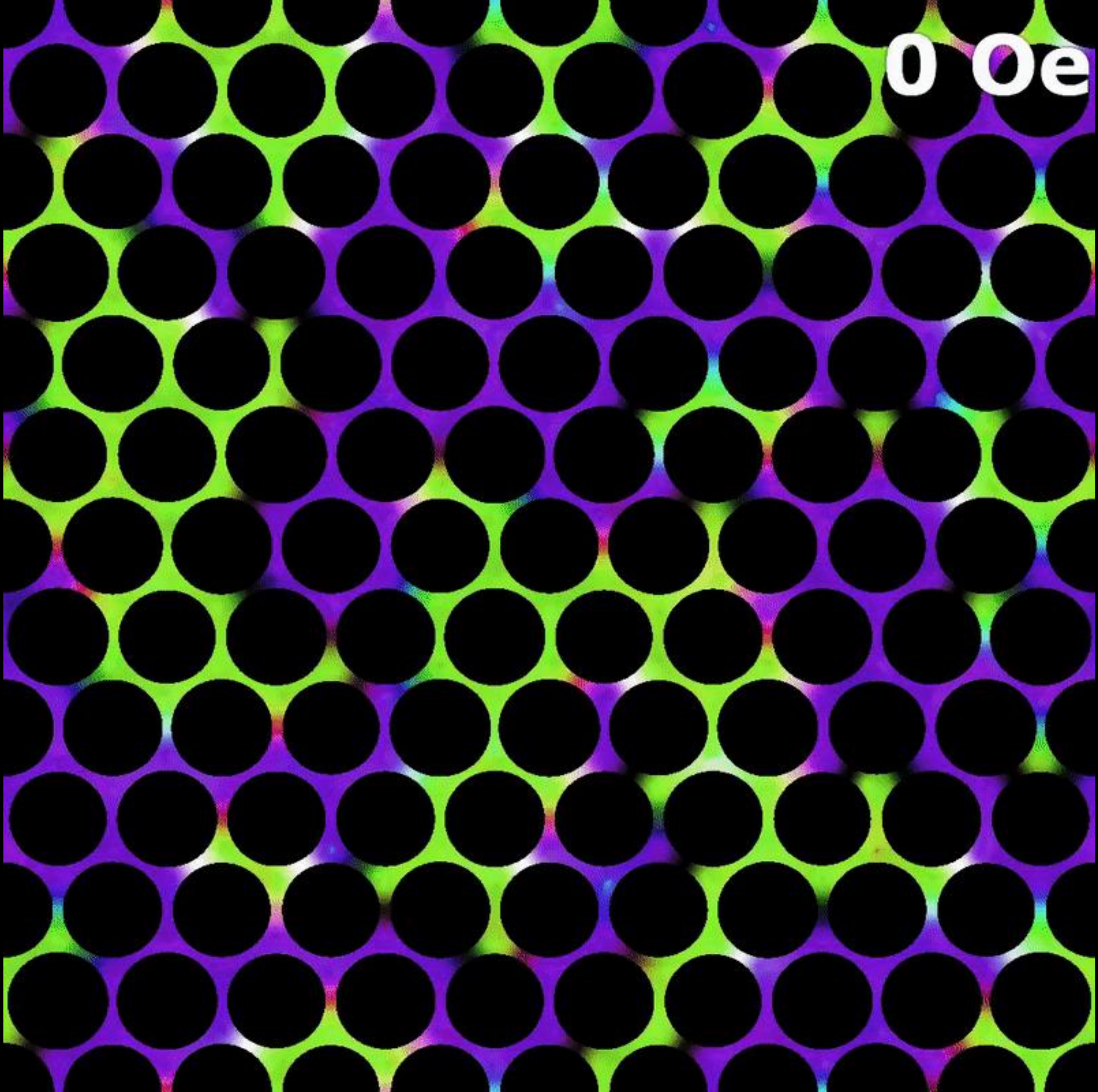


Domain pattern changes during magnetic reversal



antidot diameter = 182 nm

M. Krupinski et al. Scientific Reports 9 (2019) 13276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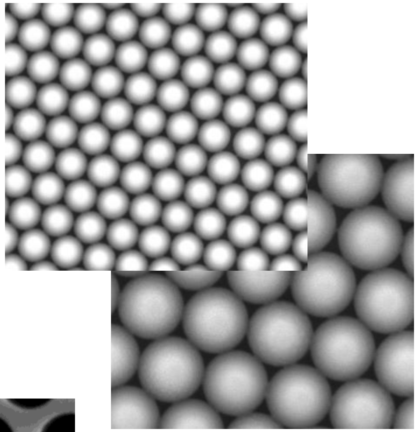
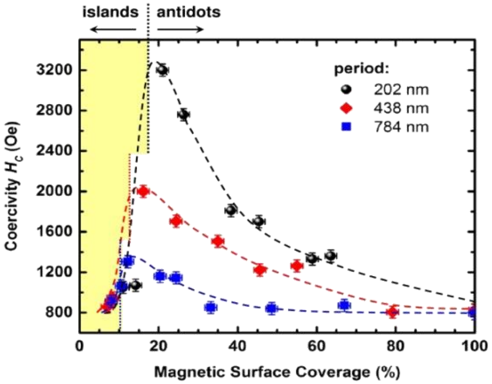
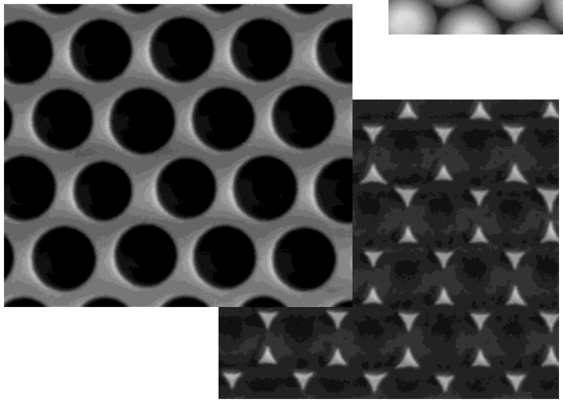
Summary



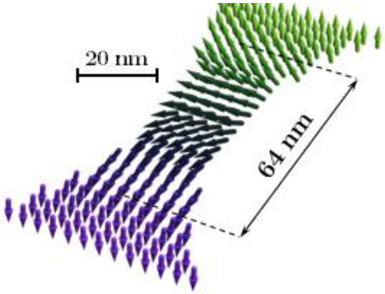
- Nanosphere lithography is a feasible route to obtain highly ordered large scale magnetic arrays

- Coercive field, saturation magnetization and magnetic anisotropy constant can be widely adjusted in such structures





- Transition from the Bloch to the Néel domain walls occurring for the arrays with the narrow necks between the antidots has been found. The antidot lattice geometry can form a network of magnetic bubbles.



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