Investigations of switching field in nanodots with perpendicular magnetization

E. Sieczkowska[1], **A. Petroutchik[1]**, **T. Wojciechowski[1]**, **P. Aleszkiewicz[1]**, **L.T. Baczewski[1]**, **Z. Kurant[2]**, **A. Maziewski[2]**, **A. Wawro[1]**

[1] *Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland*

[2] *Faculty of Physics, University of Białystok, 41 Lipowa str., 15-424 Białystok, Poland*

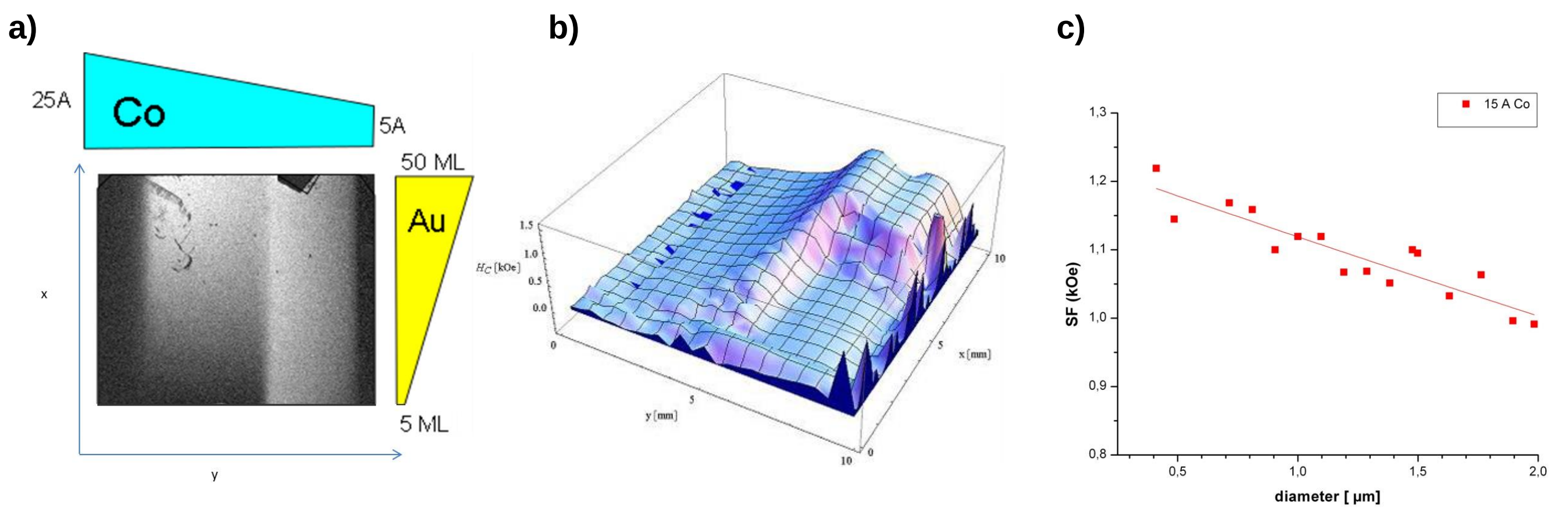
INTRODUCTION

The MBE-grown magnetic nanodots are formed by part of a Co layer which is placed on the top of Au islands self-assembled on a Mo layer surface [1, 2]. A surrounding magnetic matrix is formed by remaining part the Co layer deposited between the islands directly on the Mo surface. Formation of the magnetic dots is a result of strong dependence of magnetic anisotropy on an interface type. The dots exhibit perpendicular or in-plane oriented magnetization, which depends on the Co layer thickness.

The Au islands determine the shapes of the magnetic dots. Observed experimentally (e.g. SEM images) regular shapes can be categorized in three groups: oval, hexagonal and hybrid. Thus the static properties and magnetization reversal of the dots can be controlled by the growth conditions of the Au islands which affect their size, shape and surface density. Presented here micromagnetic modelling has been conducted for several different parameters characterizing the dots (shape and size) and their edges (width and magnetic anisotropy, different than the interior of the dots).

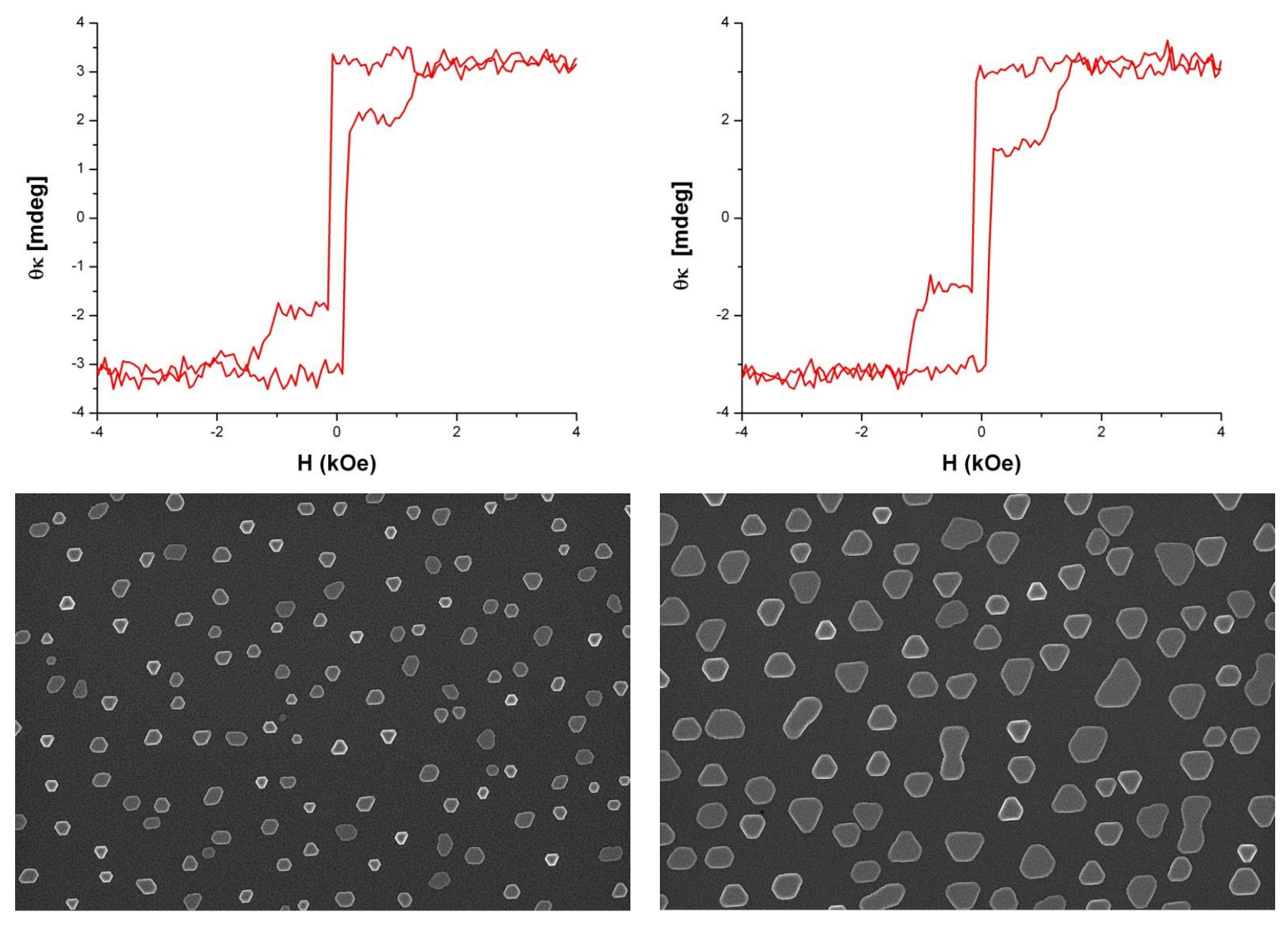
RESULTS OF THE EXPERIMENT AND MICROMAGNETIC SIMULATIONS

A pattern of the sample:



Left: a) Remanent image of the sample, four different regions can be distinguished.
b) Map of coercivity fields of the sample, which were extracted from PMOKE measurements.
c) Dependence of switching field (SF) as a function of dot diameter. The values of SF were obtained from the PMOKE hysteresis loops.

SEM and PMOKE results:



Right: SEM and PMOKE measurements:
top: hysteresis loops,
bottom: SEM images.
Hysteresis loops correspond to the different size of the dots. For the bigger dots wider switching field distribution is observed.

Micromagnetic simulations results:

The post-growth-treated structures have often destroyed edges due to patterning processes. In consequence their magnetic anisotropy is lower than that of the dot interior. For self-organized process possibility to obtain periodic array of dots with uniform shapes is limited. However, the crystalline structure contains substantially lower amount of defects. The edges may display a higher magnetic anisotropy. These effects are taken into account in performed micromagnetic simulations.

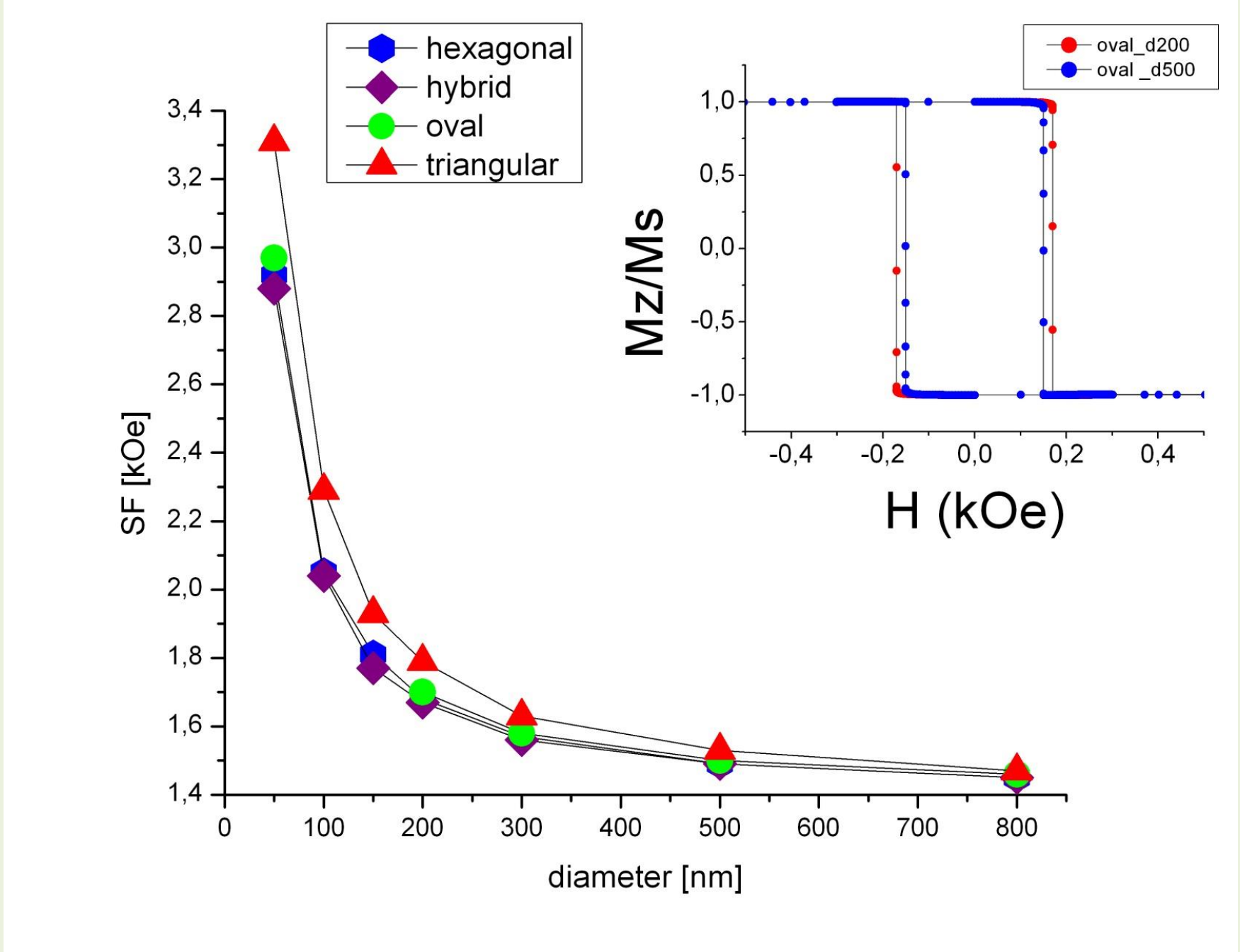
The simulations of the dot magnetization reversal have been done with the help of OOMMF [3] using the Landau-Lifshitz-Gilbert equation. Calculations have been performed for different shapes and diameters of the dots magnetized in perpendicular direction to the film plane in accordance with experimental observations. The following parameters were taken for simulations: saturation magnetization Ms = 1.4 MA/m; anisotropy energy density K = 1.35 MJ/m^3; Gilbert damping constant α = 0.5; exchange stiffness constant A = 1.3·10^{-11} J /m. Simulations were done for isolated dots in the applied field slightly tilted from the normal to the dot plane to break the symmetry. The cell size was equal to 1x1x1.5 [nm]. For larger dots the cell size was increased to reduce a simulation time, but always the size of the cell was smaller than the exchange length for the cobalt. Calculated switching field is defined as a field necessary to reverse the whole dot in the opposite direction to the initial state.

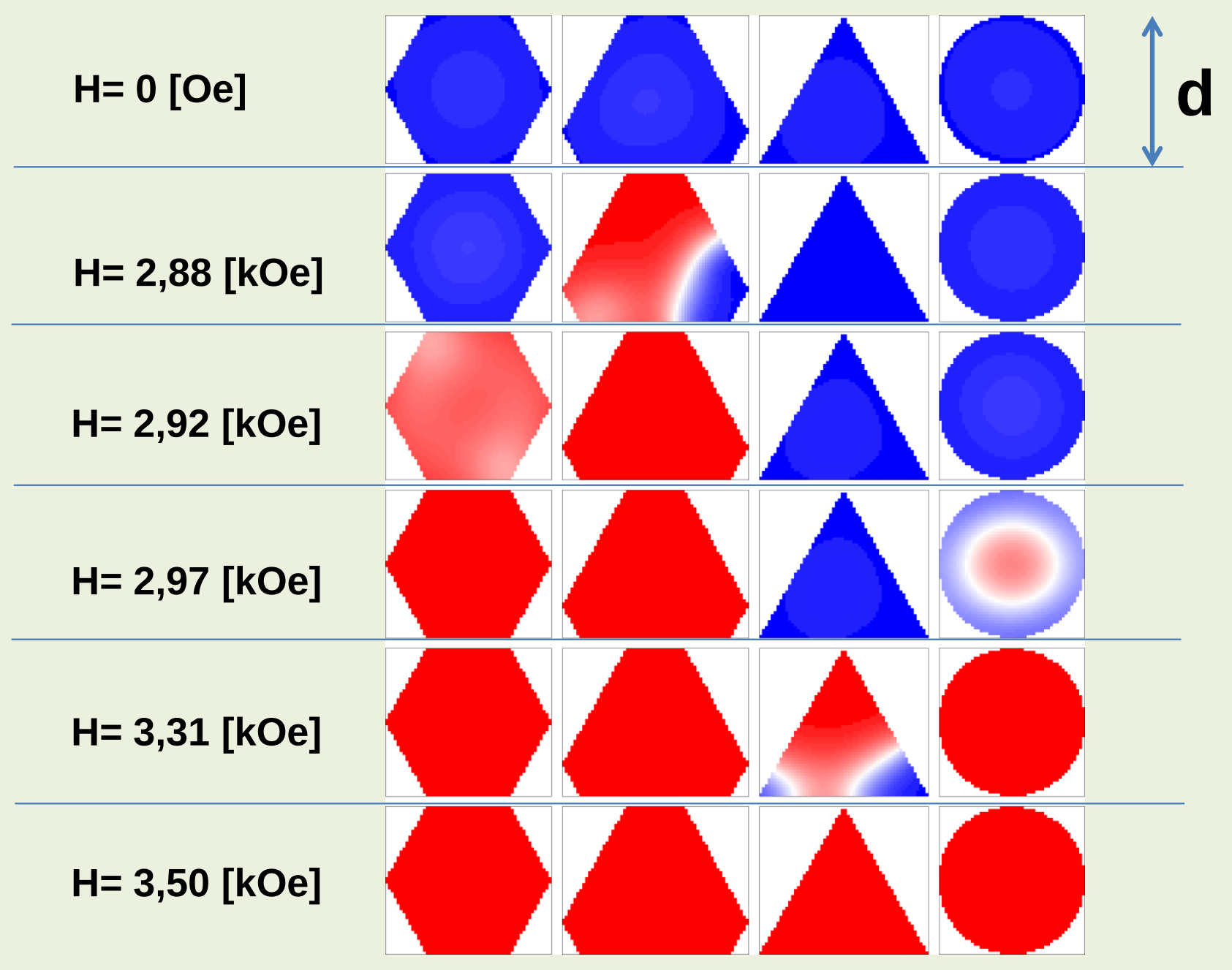
Landau-Lifshitz-Gilbert equation

$$\frac{d\vec{M}}{dt} = -|\gamma|\vec{M}\times\vec{H}_{eff} - \frac{|\gamma|\alpha}{M_S}\vec{M}\times\left(\vec{M}\times\vec{H}_{eff}\right)$$

$$E_{tot} = E_{ex} + E_a + E_H + E_d \qquad \vec{H}_{eff} = -\frac{\partial E_{tot}}{\partial\left(M_S\alpha\right)}$$

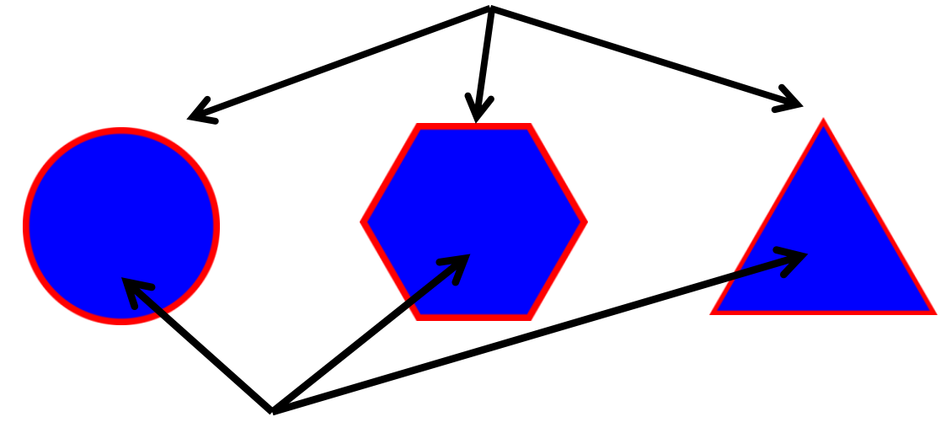
Homogeneous dots with different shapes:





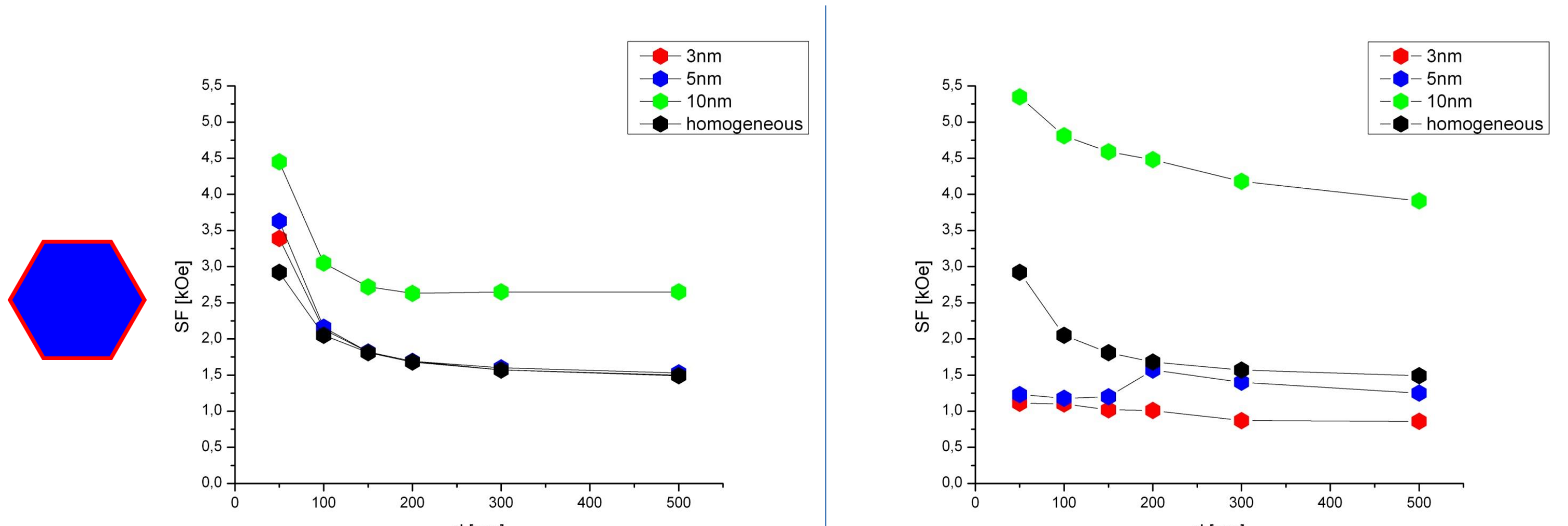
Dots with modified edges and with different shapes:

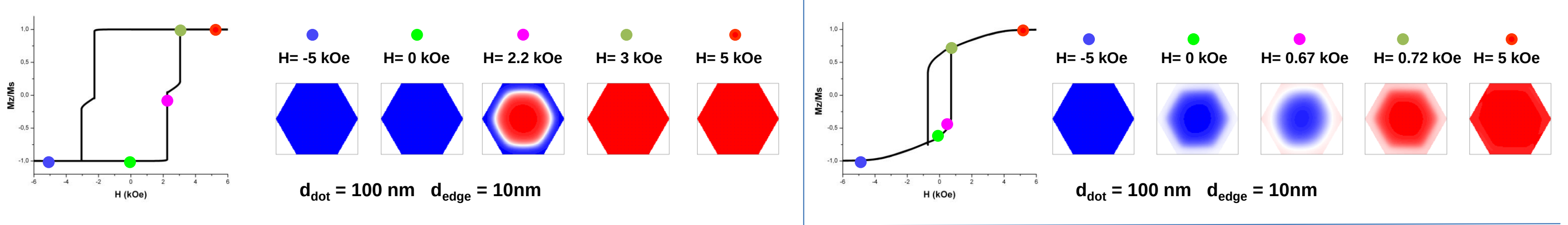
K_{edge}= 1.5 K_{in} K_{edge}= 0.5 K_{in}



K_{edge}= 1.5 K_{in} or K_{edge}= 0.5 K_{in}

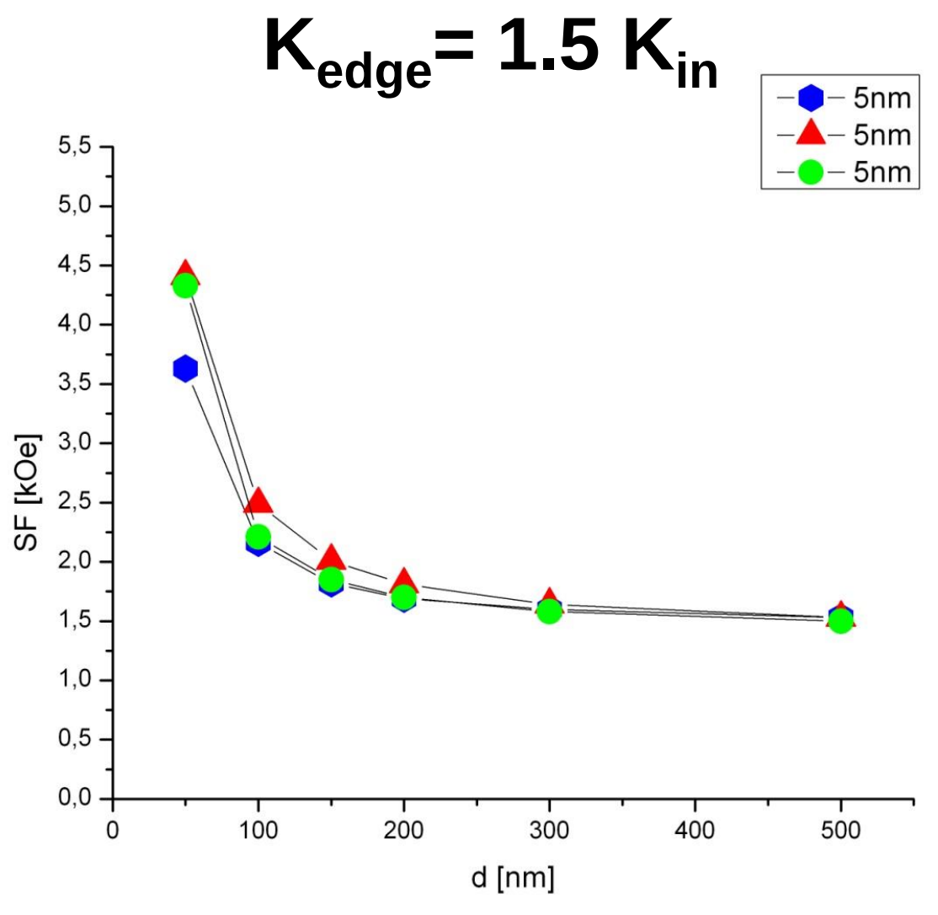
K_{in}= 1.35 E6 J/m^3

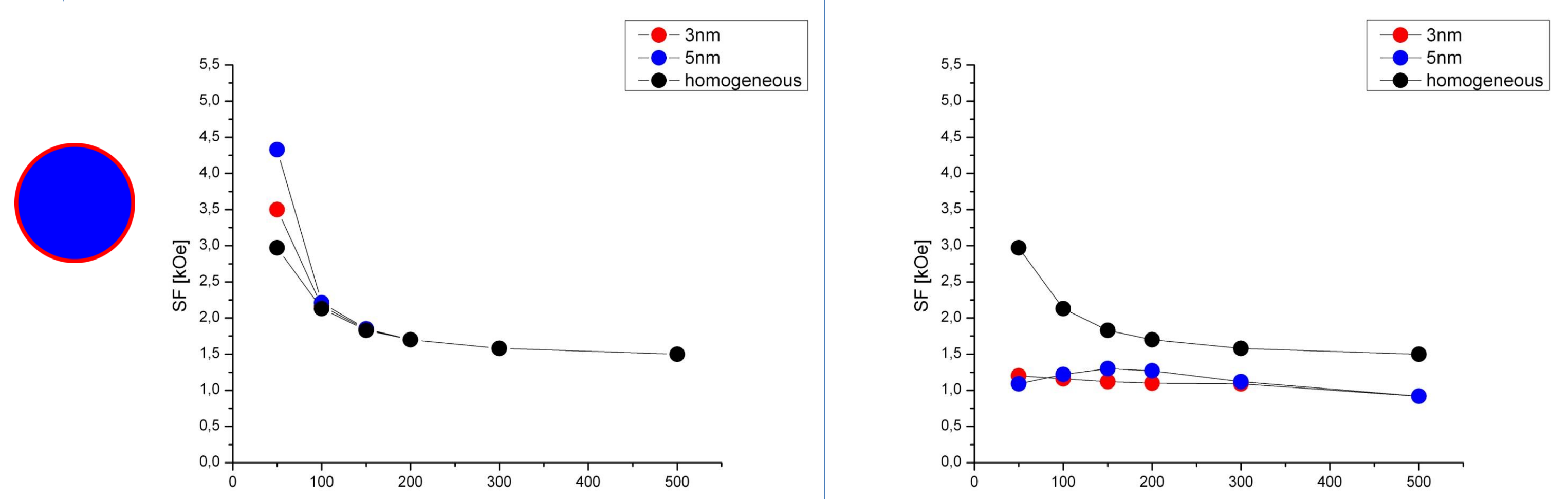


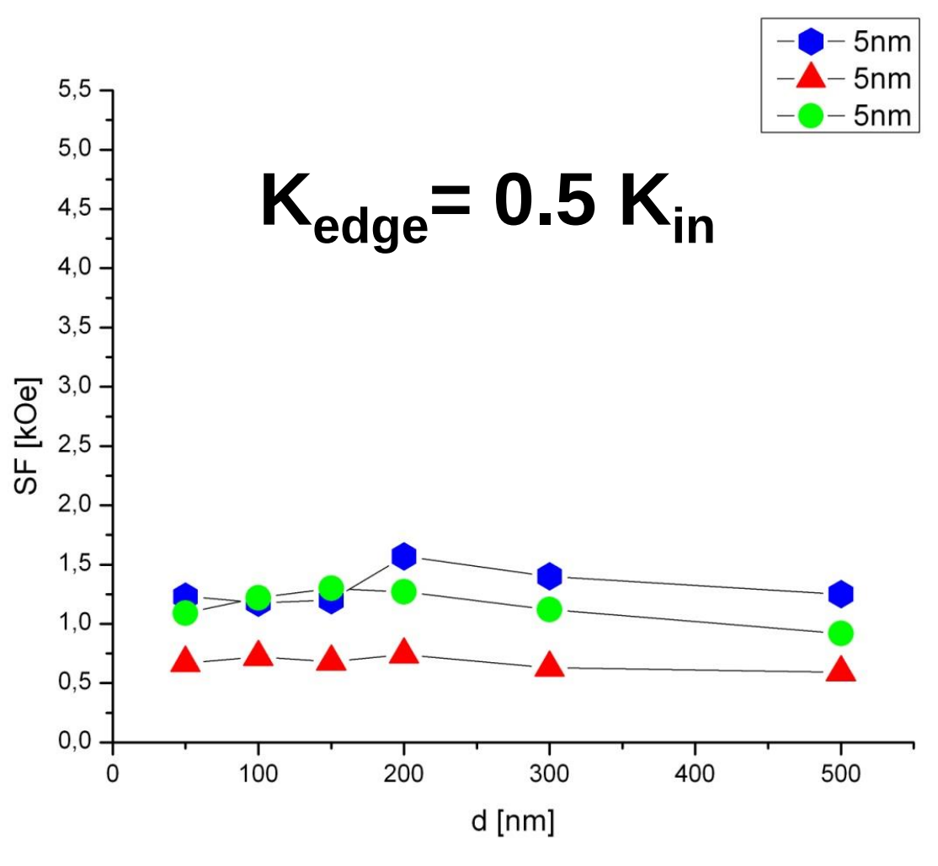


d_{dot} = 100 nm d_{edge} = 10nm d_{dot} = 100 nm d_{edge} = 10nm

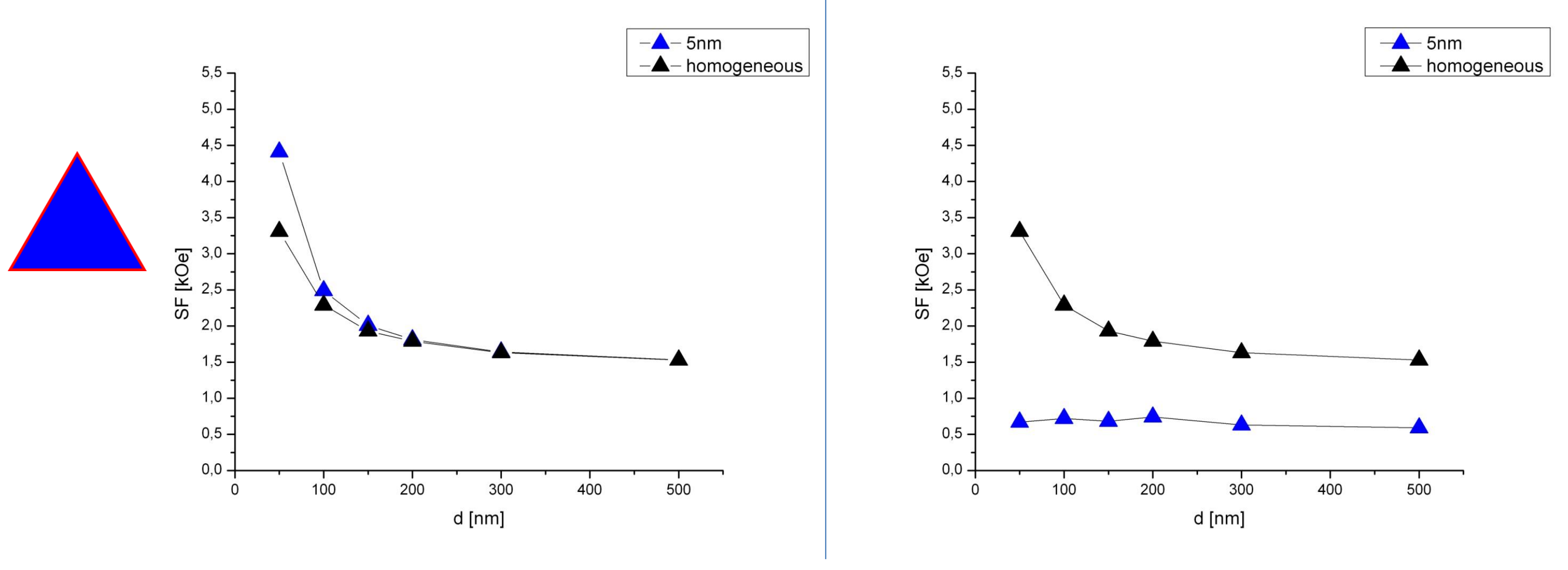
K_{edge}= 1.5 K_{in}







K_{edge}= 0.5 K_{in}



SUMMARY

Performed micromagnetic simulations reveal the switching field of the individual dots dependent on the dot shape, size and magnetic anisotropy. The uniform triangular dots have the highest SF from among remaining dots with other shapes.

The as-grown dots (with higher anisotropy at the edge) adopt a single domain structure – most of the simulated hysteresis loops have a rectangular shape. The small dots display higher switching fields then homogeneous ones. For bigger dots, narrow edge doesn't significantly affect SF and dots behavior is similar to the homogeneous case. A thick edge with high anisotropy can result in the multidomain state of the dot.

Reduction of anisotropy constant at the edge of the dot causes that magnetization of the edge favors in-plane configuration. In consequence , the much higher fields than coercivity are needed to reverse the whole dot in the opposite direction (higher switching fields). Such behavior is observed for all shapes, when the edge with reduced anisotropy is significantly thick. For thin edge switching fields are lower in comparison with the homogeneous one. Additionally, for dots with lower anisotropy at the edge and with small size a maximum in SF is observed.

In the remanent state the dots with the higher anisotropy at the edge maintain their configuration as in saturation whereas those with the lower anisotropy of the edges may change it.

REFERENCES

[1] A. Wawro, E. Sieczkowska, A. Petroutchik, L.T. Baczewski, Z. Kurant, and A. Maziewski, *Phys. Rev. B* **83** (2011) 092405.
[2] E. Sieczkowska, A. Petroutchik, L. T. Baczewski, P. Aleszkiewicz, Z. Kurant, A. Maziewski, A. Wawro, IEEE **47** (2011) 2632.
[3] J. Donahue, D. G. Porter, *National Institute of Standards and Technology, Interagency Report No. 637*6, NIST, Gaithersburg, 1999, http://math.nist.gov/oommf

ACKNOWLEDGMENT

This work was partially supported from the research funds of the National Science Centre in Poland, under the project DEC-2011/03/N/ST3/02662, 2012-2014, and by Foundation for Polish Science under the SYMPHONY project operated within the Team Program, co-financed by the EU European Regional Development Fund, OPIE 2007-2013.