# Micromagnetic simulations of magnetic particles embedded in magnetic or non-magnetic matrices

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## Magnetic nanodot arrays

- Magnetic properties and magnetization reversal of single nanoparticles / nanoparticle arrays are defined by dimensions / shapes + materials

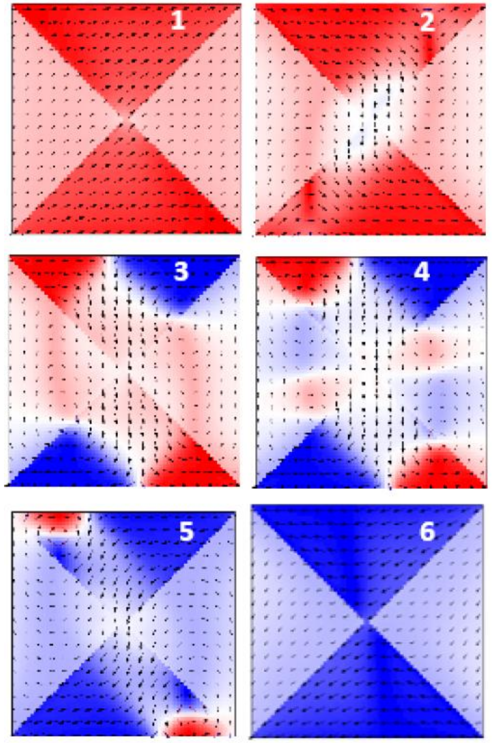
- Interplay between magneto-crystalline and shape anisotropy can lead to unexpected and technologically applicable effects

- Nanodots (round and square) / nanodot arrays are often examined since they allow for reaching vortex states with reduced in-plane stray fields

- Combining different materials as thin layer stacks or in one plane offers new possibilities of controlling magnetization reversal processes

# Previous experiments on hard/soft magnetic features

- Double-wedges from iron and permalloy [1]
- Neighboring rectangles from iron and permalloy [1]
- Double-bow-tie structures from iron and permalloy [2]




[1] Sudsom, D.; Blachowicz, T.; Hahn, L.; Ehrmann, A. Vortex nucleation and propagation in magnetic double-wedges and semi-squares for reliable quaternary storage systems. *J. Magn. Magn. Mater.* **2020**, *514*, 167294

[2] Sudsom, D.; Juhász Junger, I.; Döpke, C.; Blachowicz, T.; Hahn, L.; Ehrmann, A. Micromagnetic Simulation of Vortex Development in Magnetic Bi-Material Bow-Tie Structures. *Cond. Matter* **2020**, *5*, 5.

# Simulations

Simulation parameters (original OOMMF material parameters were used in agreement with typical literature values):

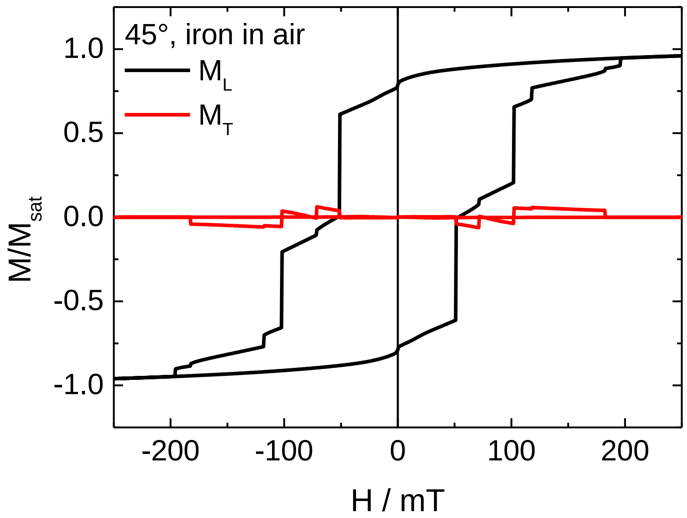
- saturation magnetization $M_{S,Fe} = 1700 \cdot 10^3$ A/m ($M_{S,Ni} = 490 \cdot 10^3$ A/m)
- exchange constant $A_{Fe} = 21 \cdot 10^{-12}$ J/m ($A_{Ni} = 9 \cdot 10^{-12}$ J/m)
- anisotropy constant $K_{1,Fe} = 48 \cdot 10^3$ J/m³ ($K_{1,Ni} = -5.7 \cdot 10^3$ J/m³)
- Gilbert damping constant $\alpha = 0.5$ (quasi-static case)
- mesh size d = 3 nm

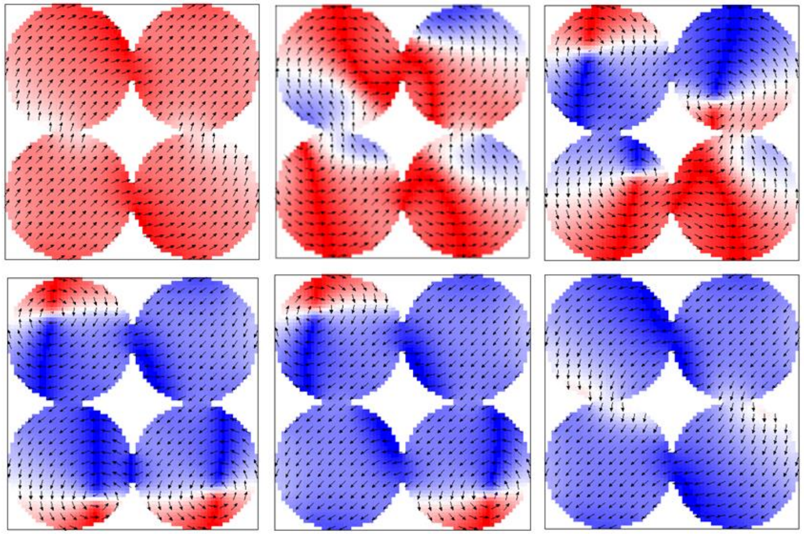
- Dimensions of arrays: 210 nm x 210 nm x 15 nm
- Random anisotropy axes were modeled, as typical for sputtered systems without any thermal after-treatment etc.
- Simulations were performed for a temperature of 0 K

# Results

Array from pure iron nanodots in air

- Complex magnetization reversal due to touching points between neighboring dots reducing shape anisotropy
- Subsequent magnetization reversal of the dots into and out of the intermediate vortex states
- Magnetization reversal not reliable -> technologically challenging

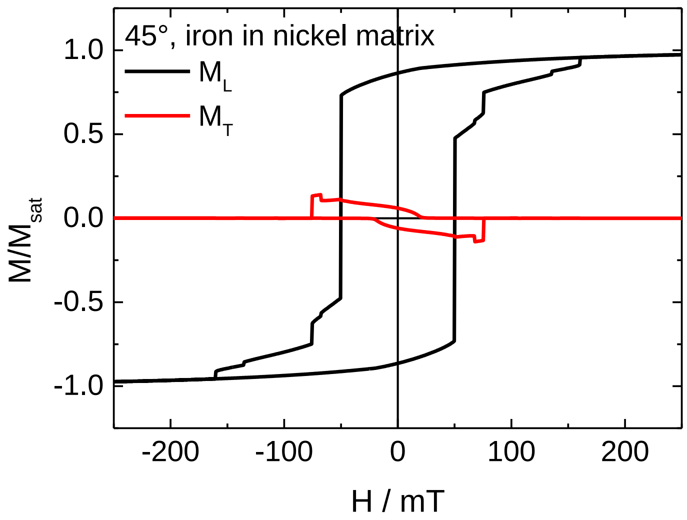


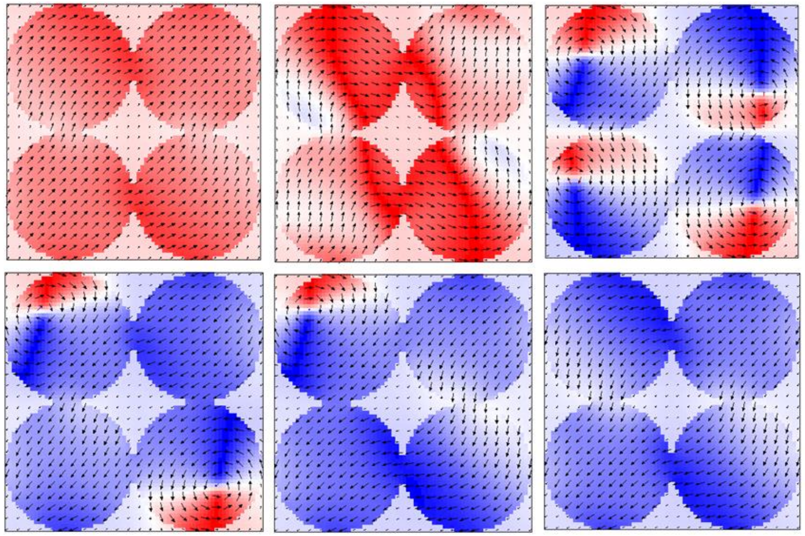



## Results

Array from iron nanodots in a nickel matrix

- Significantly less steps –> more consistent magnetization reversal throughout the system
- Abrupt switching into vortex state, switching further into negative saturation more independently
- Nickel matrix seems to stabilize magnetization reversal in iron nanodots, makes it less arbitrary -> applicable





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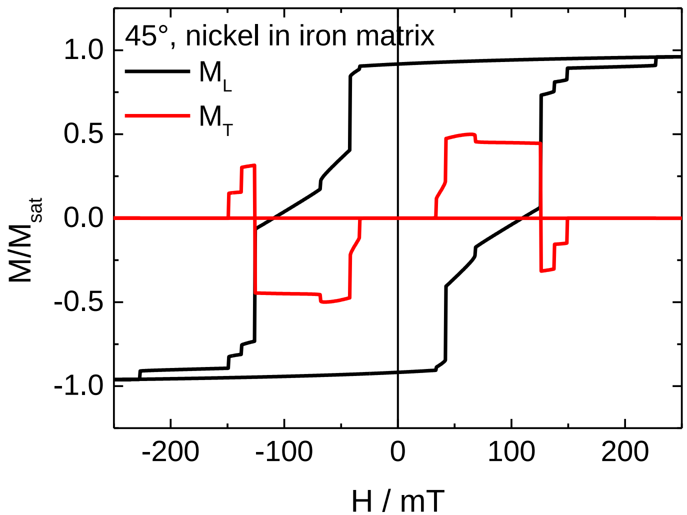
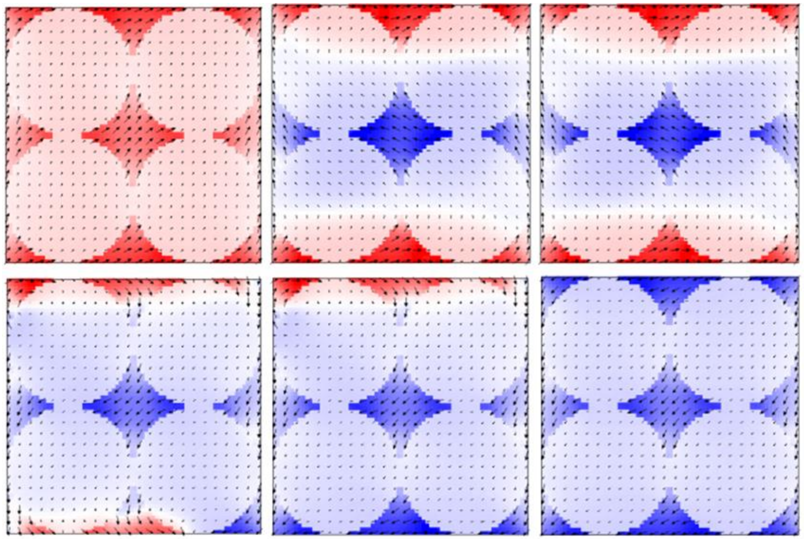
# Results

Array from nickel nanodots in an iron matrix

- Strong jumps in the hysteresis loops
- Large transverse magnetization component (avoided in previous systems by vortex formation)
- Magnetization reversal occurs via domain wall nucleation and propagation – preferably inside the nickel nanodots (due to their small anisotropy)





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# Conclusions

- Arrays of hard/soft magnetic material nanodots inside an antidot matrix of the opposite material were investigated by micromagnetic simulations

- Magnetization reversal of Fe nanodots can be made more reliable and predictable by embedding them into a Ni matrix

- Oppositely, Ni nanodots in an Fe matrix seem to be not technologically useful since magnetization reversal occurs via large domain walls through the whole system, located mostly inside the nickel nanodots

→ More investigations on different distances between the dots necessary to study possible other magnetic states, e.g. horseshoe or onion states in the Fe antidot matrix

# Thanks for your attention!

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## Literature (excerpt):

- Sudsom, D.; Blachowicz, T.; Hahn, L.; Ehrmann, A. Vortex nucleation and propagation in magnetic double-wedges and semi-squares for reliable quaternary storage systems. *J. Magn. Magn. Mater.* **2020**, *514*, 167294
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- Sudsom, D.; Ehrmann, A. Micromagnetic simulations of magnetic particles embedded in magnetic or non-magnetic matrices. *Proceedings*, submitted.