Micromagnetic Simulation of the Pinning and Depinning Process in Permanent Magnets

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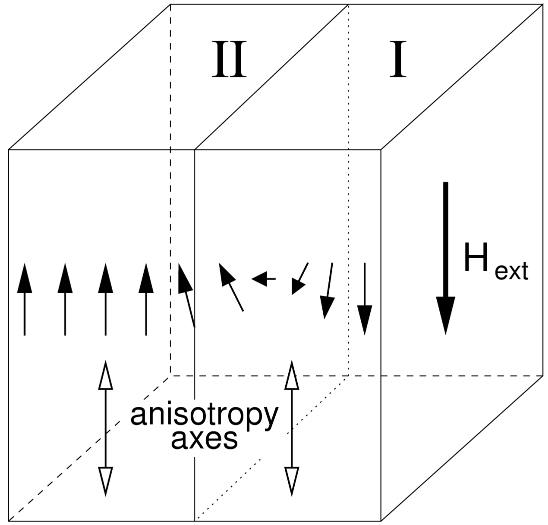
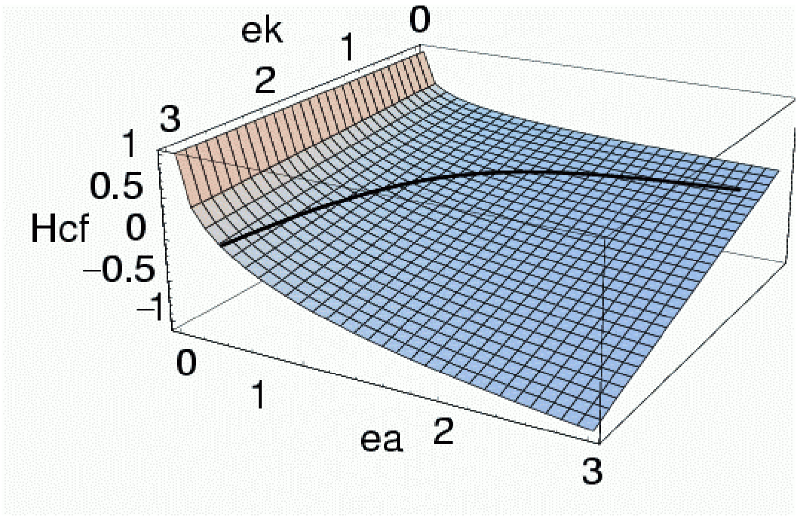
Outline

- Pinning on a planar interface
- Comparison with an analytical model
- Pinning on the intercellular phase
- Attractive and repulsive pinning
- Pinning on the cell structure
- Summary

Pinning on a planar interface





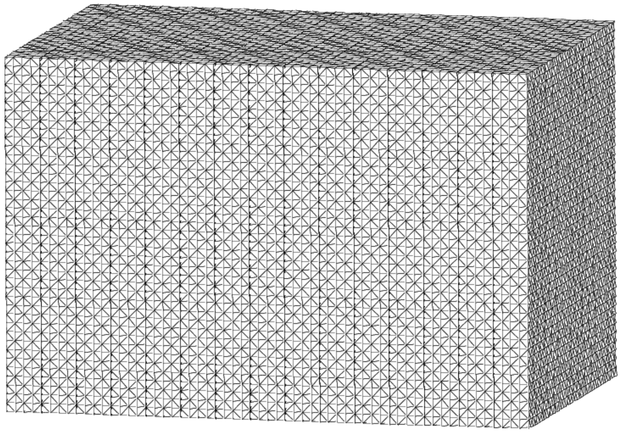
- Perfect planar interface
- Step like change in material parameters
- Strayfield omitted

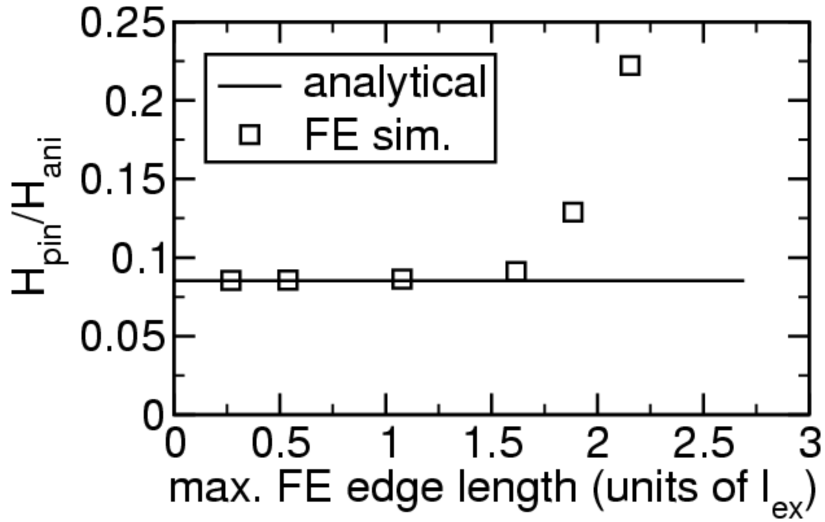
- Analytical 1D model
  Kronmüller, Goll, Physica B 319 (2002) 122-126
- Step-like or smooth transition of material parameters
  E. Della Torre, C. M. Perlov,J. Appl. Phys. 69 (1991) 4569-4598.

$$\varepsilon_A = \frac{A^{\mathrm{I}}}{A^{\mathrm{II}}},\ \varepsilon_J = \frac{J_s^{\mathrm{I}}}{J_s^{\mathrm{II}}},\ \varepsilon_K = \frac{K_1^{\mathrm{I}}}{K_1^{\mathrm{II}}}$$

$$H_c = \frac{2K_1^{\mathrm{II}}}{J_s^{\mathrm{II}}} \frac{1-\varepsilon_K \varepsilon_A}{(1+\sqrt{\varepsilon_A \varepsilon_J})^2}$$

Calibration of the FE simulation





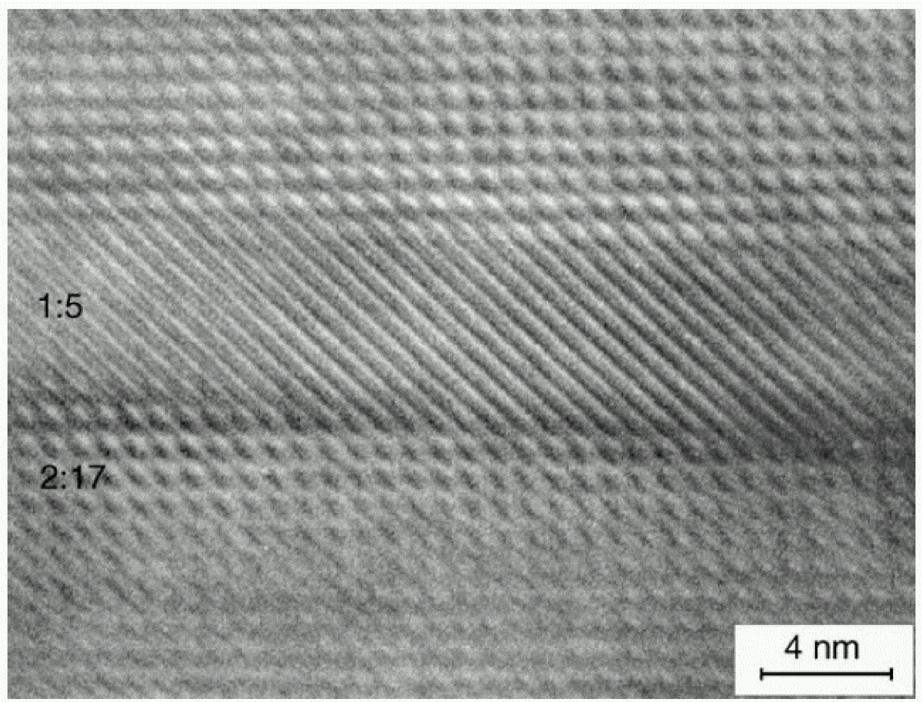
FE model of size 10x10x15

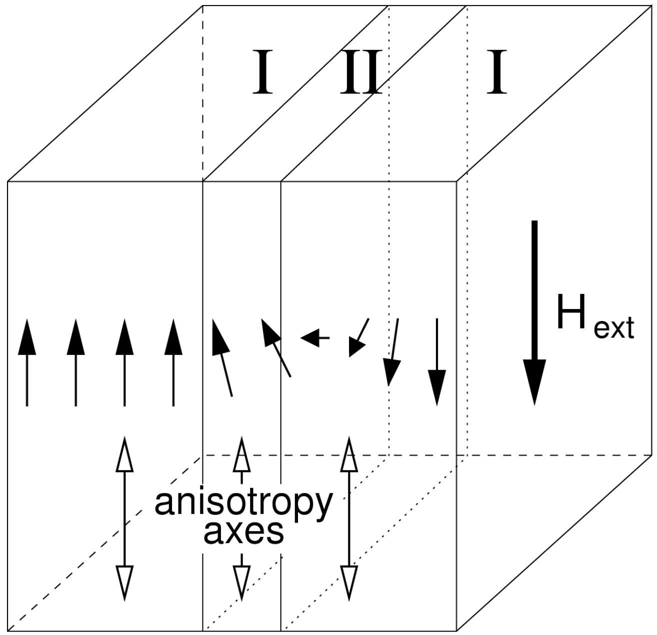
Discretized with tetrahedral finite elements

Nodes	102541
Elements	480000
$Edge_{min}$	0.25
$Edge_{max}$	0.35

	„2:17“ cells	Boundary phase
J_s (T)	1.3	0.8
A (pJ/m)	14.0	14.0
K_1 (MJ/m³)	5.0	9.0
L_{ex} (nm)	1.7	1.3
d_{Bloch} (nm)	5.3	3.9
H_{ani} (kA/m)	7692	22500

Pinning on the intercellular phase



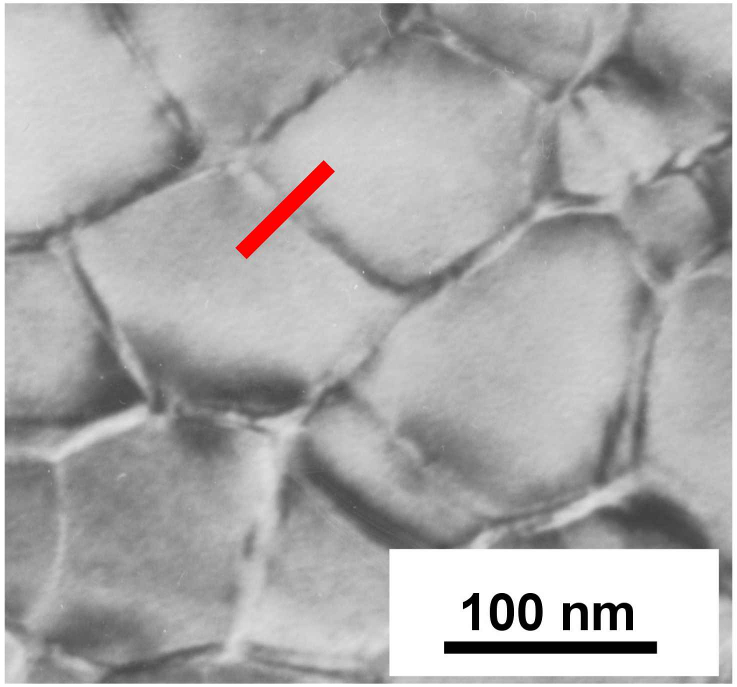


HRTEM of a $Sm(Co_{bal}Cu_{0.07}Fe_{0.22}Zr_{0.04})_{7.4}$ magnet

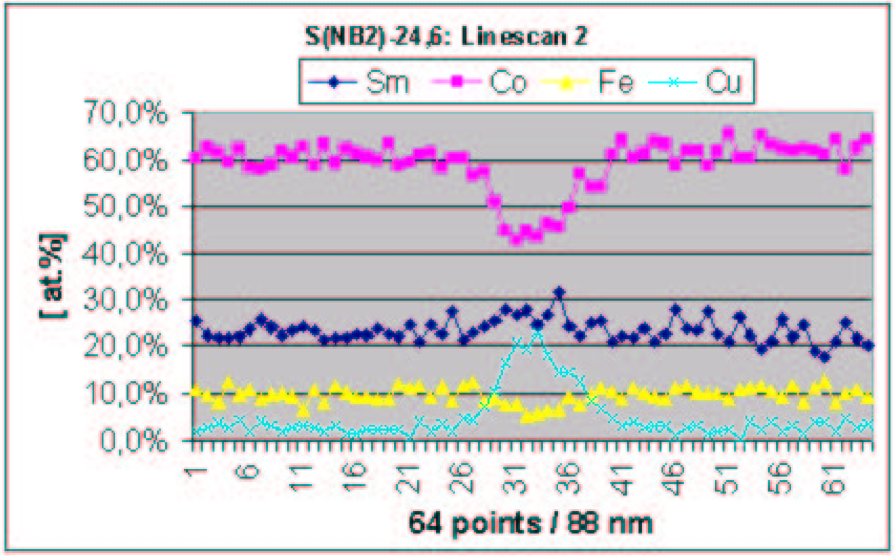
H. Kronmüller, D. Goll, Physica B 319 (2002) 122-126

Nanoanalytical investigations

Analysis of the elemental distributions across the precipitates on a nanometer scale; requires field emission gun TE



$Sm(Co_{0,77}Fe_{0,12}Cu_{0,09}Zr_{0,02})_{7.8}$

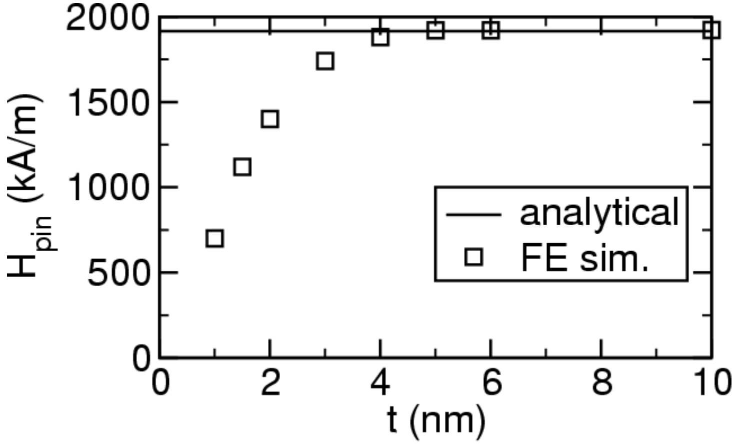


Cell boundaries: high Cu, Sm

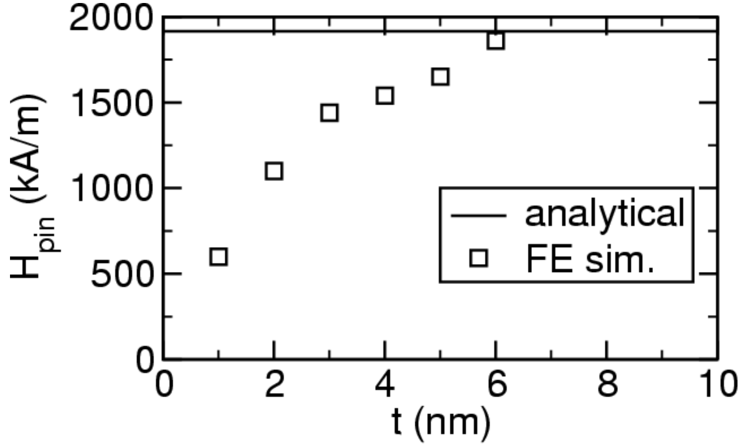
Cell matrix: high Fe, Co

Matthias et al., IEEE Trans Magn. 38 (2002) 2943-2945

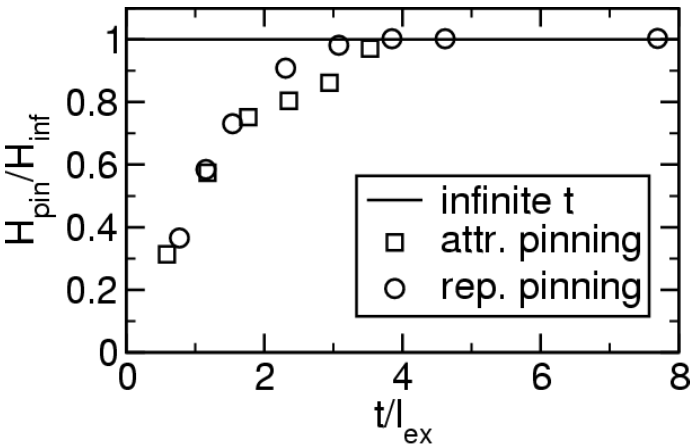
Pinning fields



Repulsive pinning



Attractive pinning

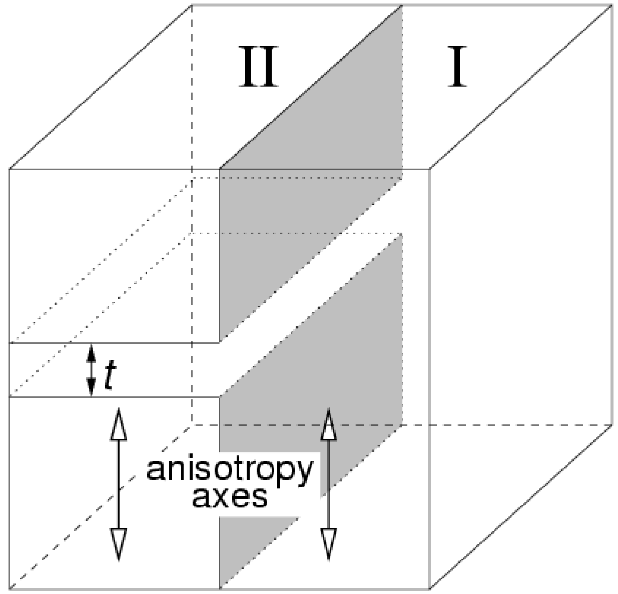


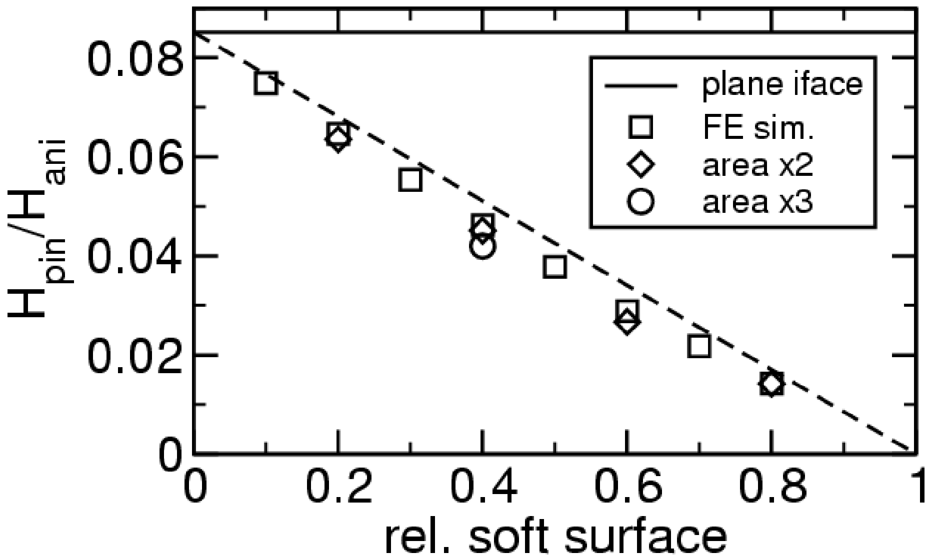
H_{inf} = 1916 kA/m

t scaled with l_{ex} of the intercellular phase

	„2:17“ cells	Boundary phase
J_s (T)	1.3	0.8
A (pJ/m)	14.0	14.0
K1 (MJ/m³)	5.0	9.0
L_{ex} (nm)	1.7	1.3
d_{Bloch} (nm)	5.3	3.9
H_{ani} (kA/m)	7692	22500

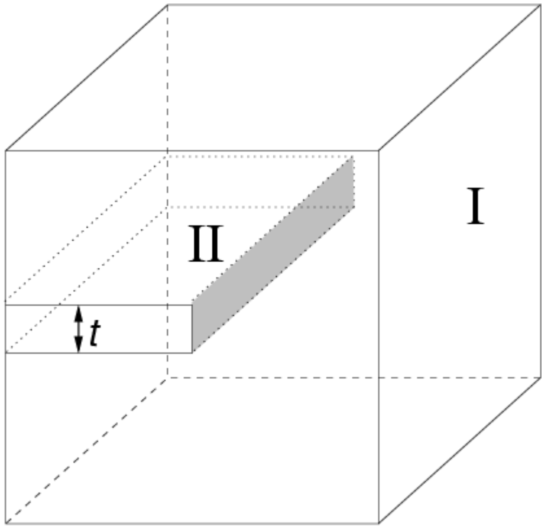
Pinning on the cell structure



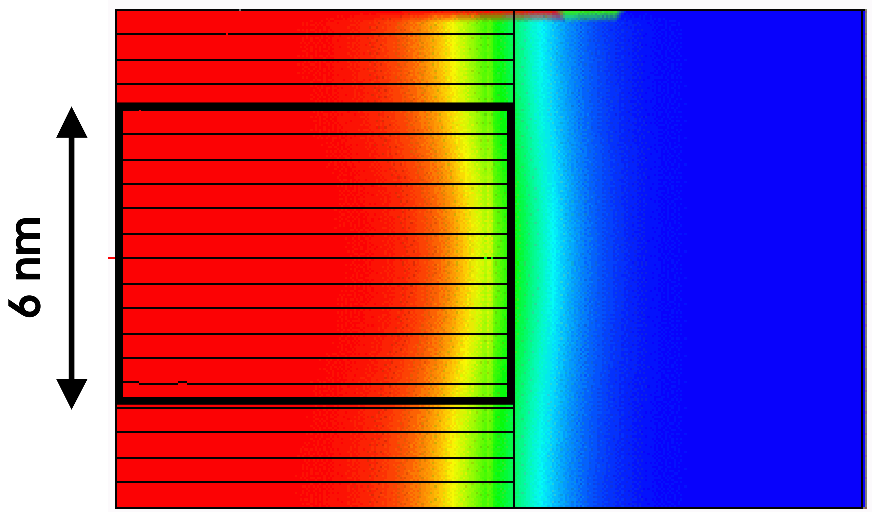


Pinning field depends on the surface ratio between hard and soft areas (i.e. on ratio of cross section between cells and cell boundary phase)

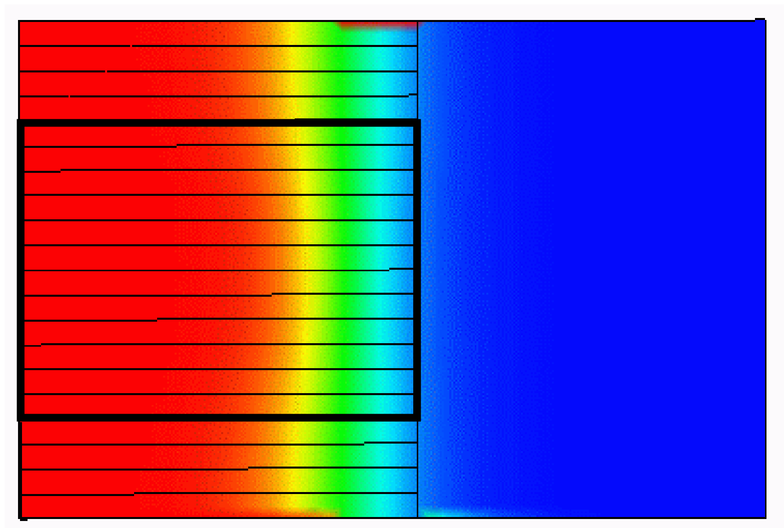
Magnetization distribution



- Dynamic micromagnetic simulation: integration of Landau-Lifshitz-Gilbert equation
- Competition between Zeeman and domain wall energy
- Domain wall moves into the hard defect

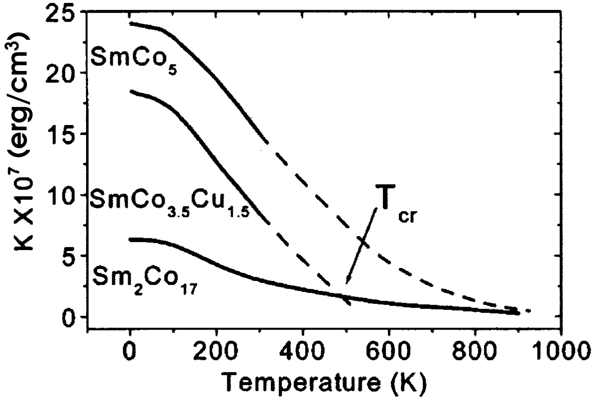


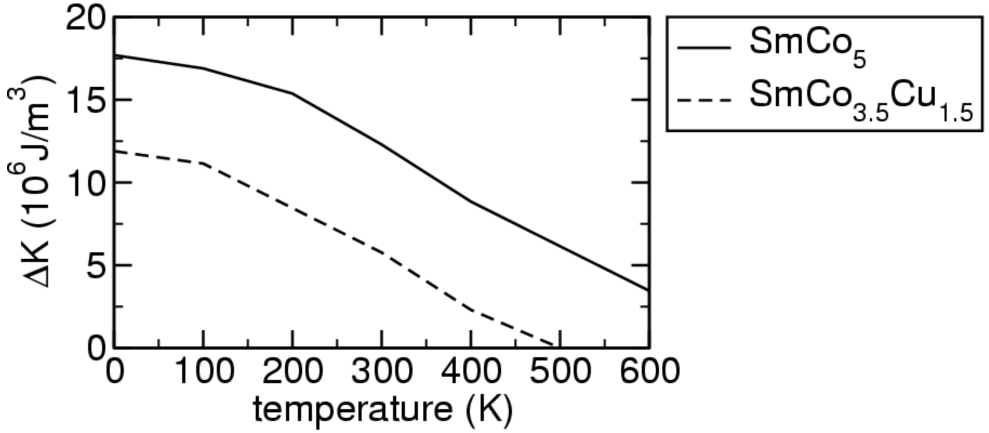
Last stable configuration



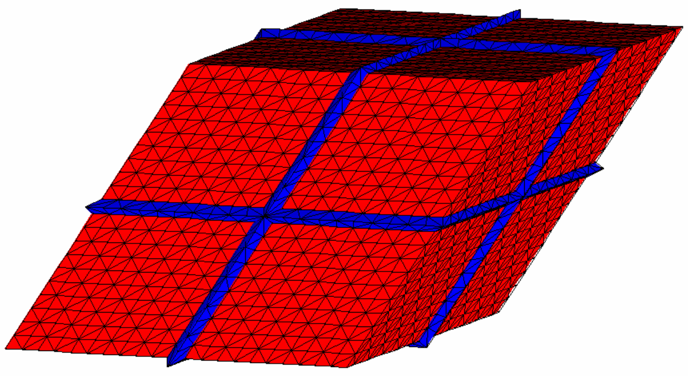
Domain wall breaks free

Temp. dependent pinning fields



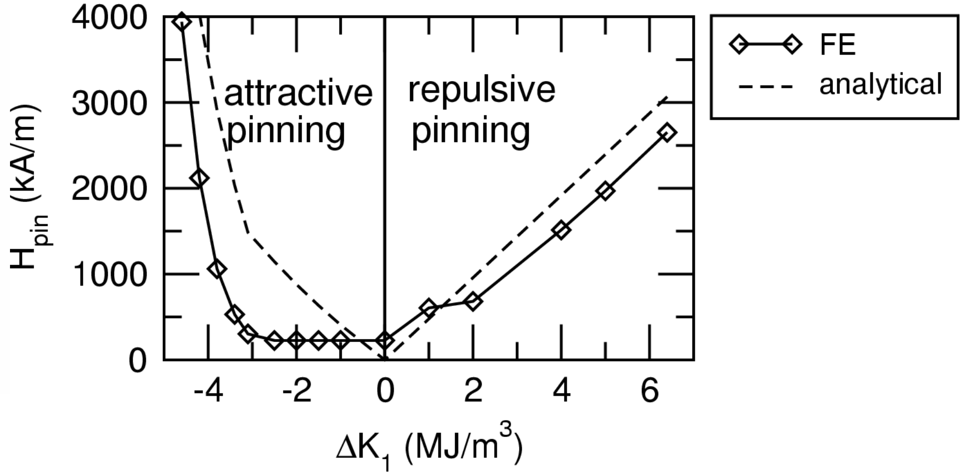


W. Tang, A. M. Gabay, Y. Zhang, G. C. Hadjipanayis, H. Kronmüller, IEEE Trans. Magn. 37 (2001) 2515-2517



Cell size: 125 nm

Thickness of intercellular phase: 5 nm



Summary

- Simple comparison with 1D analytical result
- Exchange decoupling important
- Anisotropy gives linear contribution to coercivity
- Thickness of the intercellular phase has to be larger than the domain wall width to have maximum pinning effect
- Precipitation structure reduces the pinning field
- Optimum properties for large cells