Defect Related Switching Field Reduction in Small Magnetic Particle Arrays

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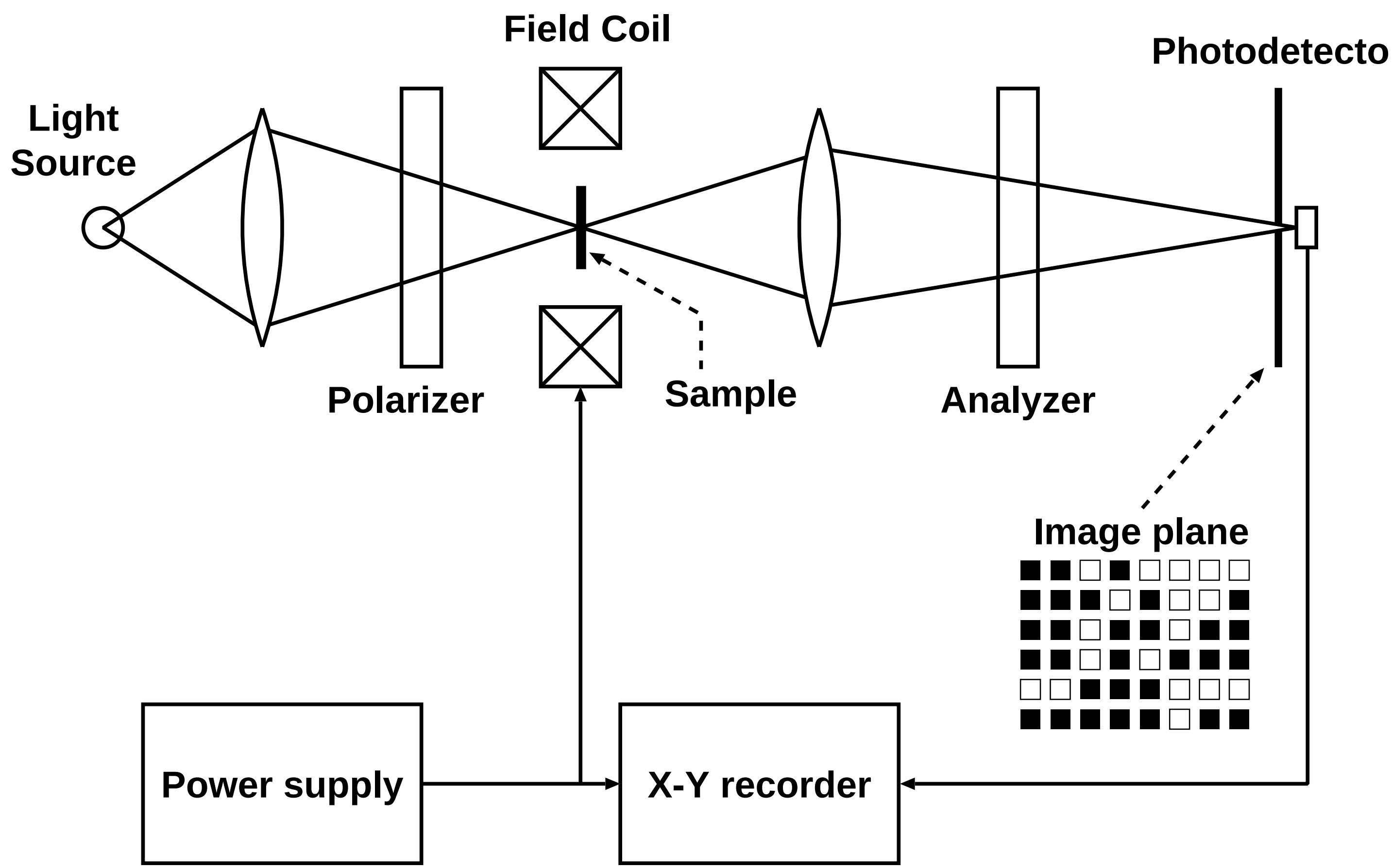
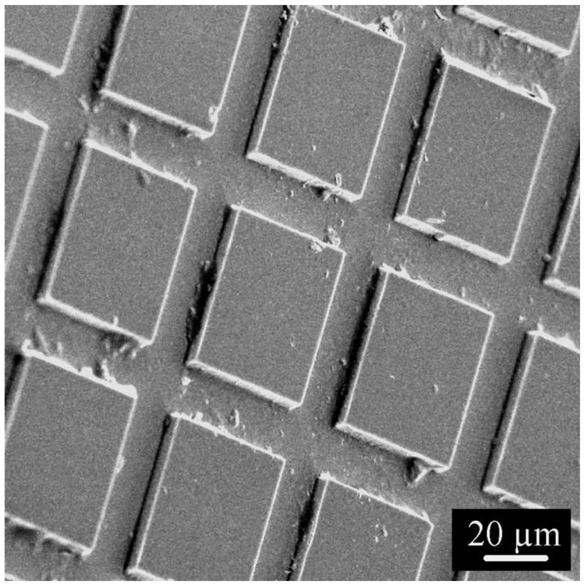
Optical magnetometer



Sample system



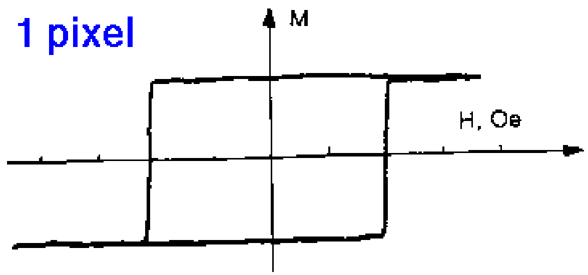
SEM photo: Zofia Vértesy,
HAS, Budapest, Hungary

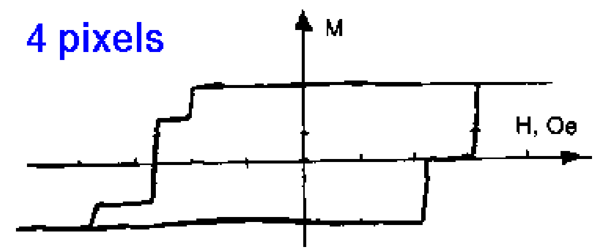
- Single crystal $Y_3Fe_5O_{12}/Gd_3Ga_5O_{12}$
- 42 μm $\times$ 42 μm $\times$ 3 μm particles, 12 μm grooves, 1 cm^2 chips
- Strong uniaxial anisotropy, stable axis $\perp$ to surface

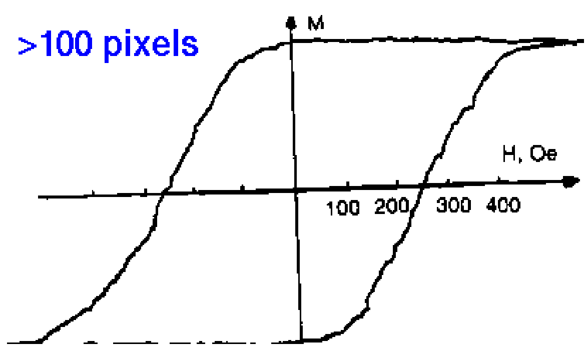
Material parameters

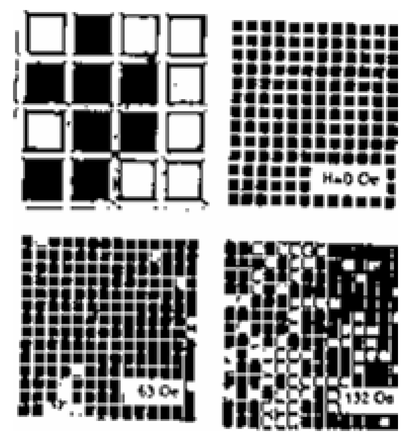
- M_s = 12.7 kA/m ($4\pi M_\mathrm{s}$ = 160 G)
- H_u = 170 kA/m (2100 Oe)
- $\sqrt{A/(0.5\mu_0 M_s^2)} = 170$ nm
- $\sqrt{A/K} = 47$ nm

Pixel magnetization curves

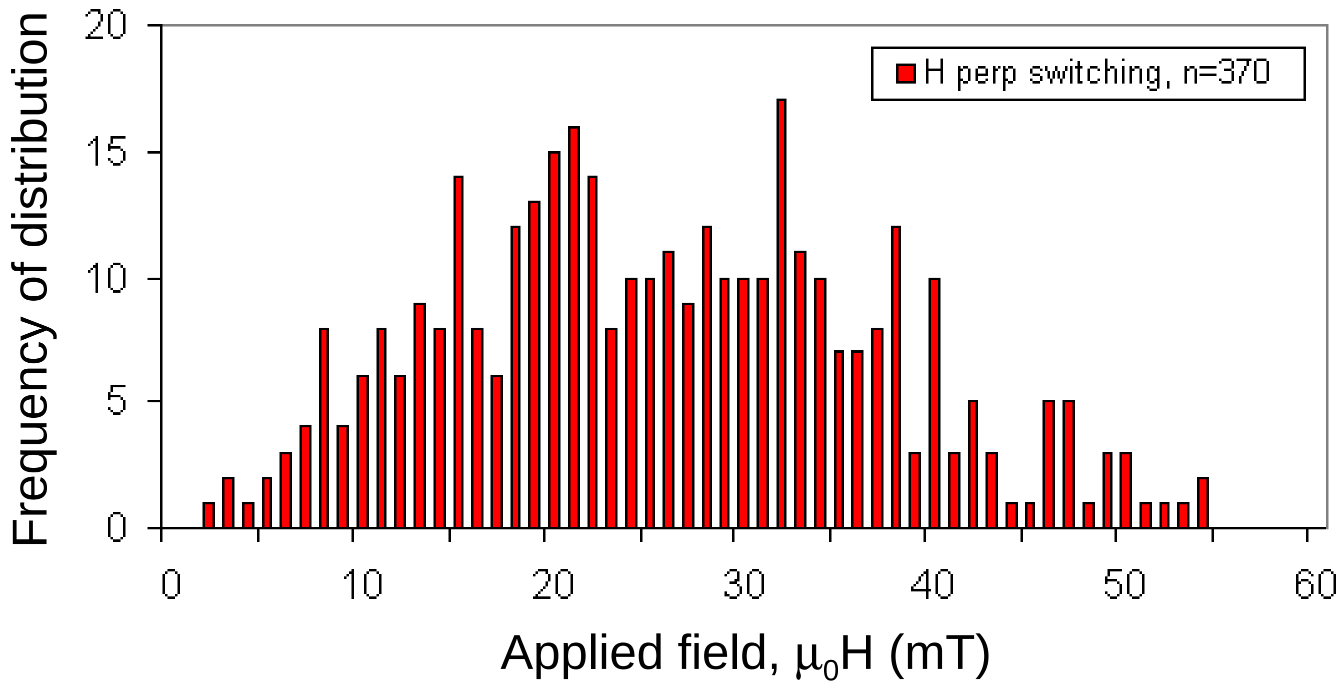




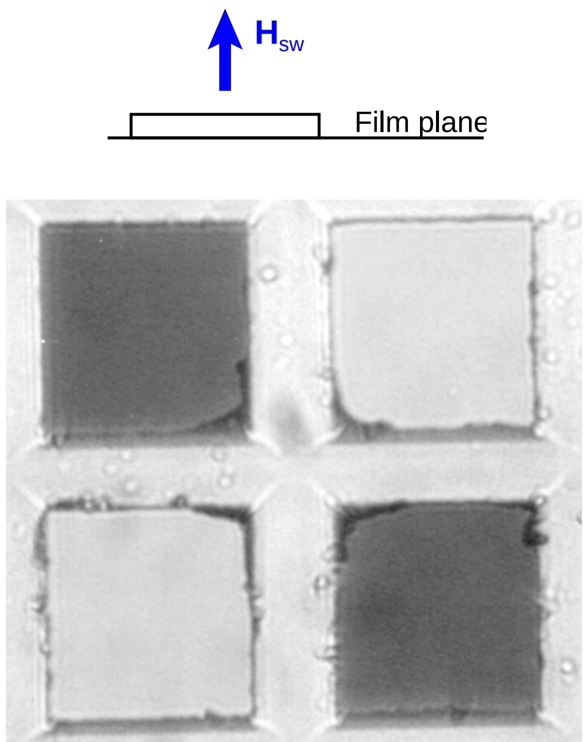




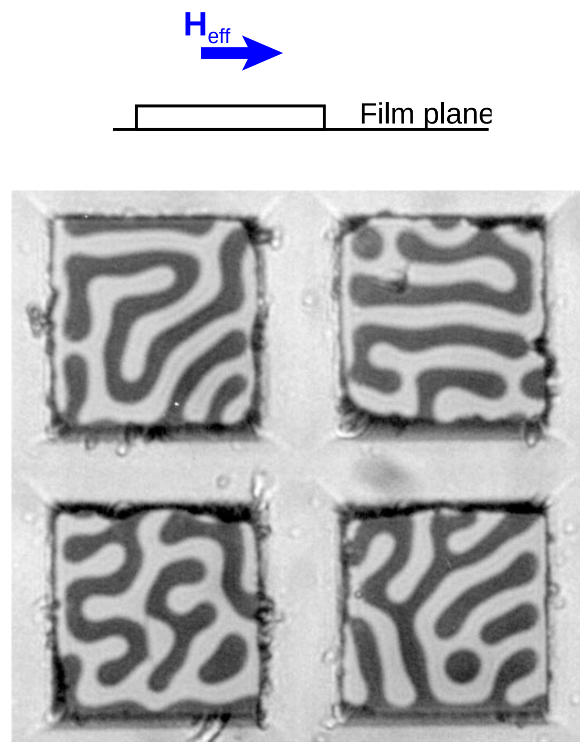
Distribution: H_{sw}



Magnetization states

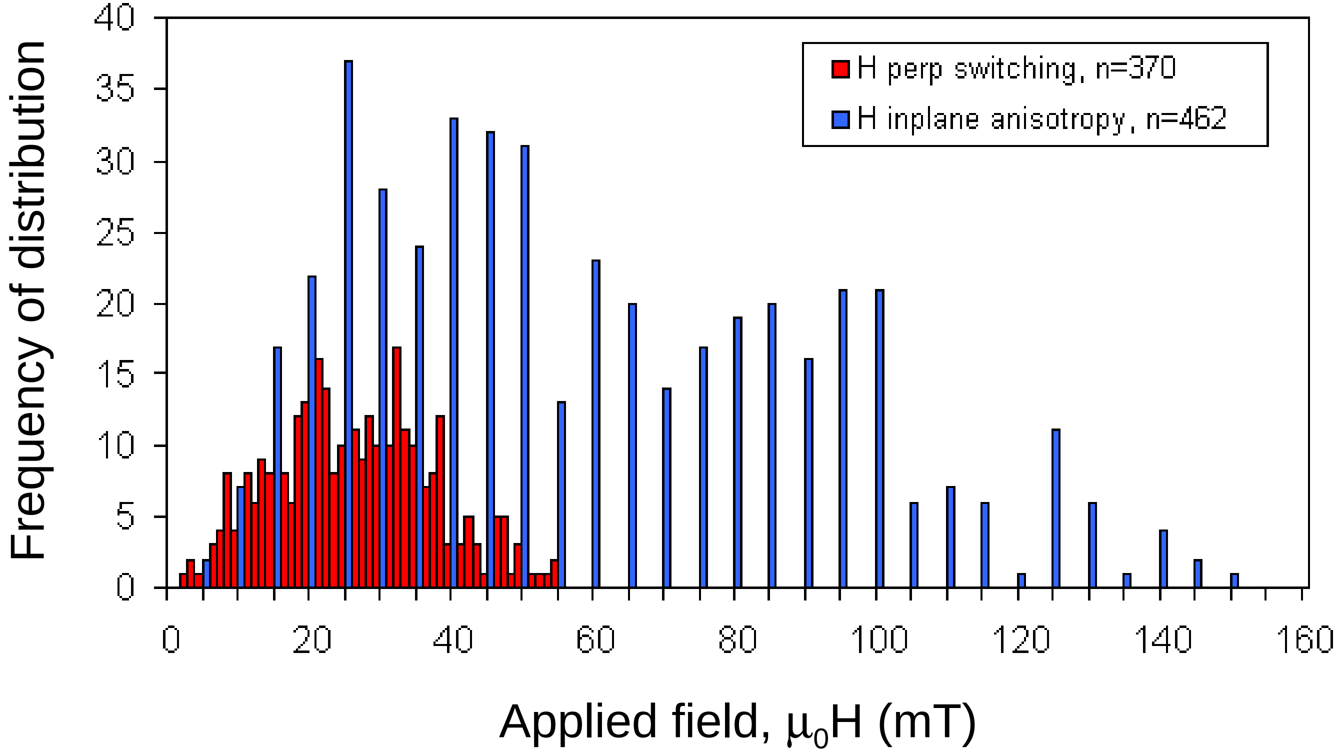


Stable

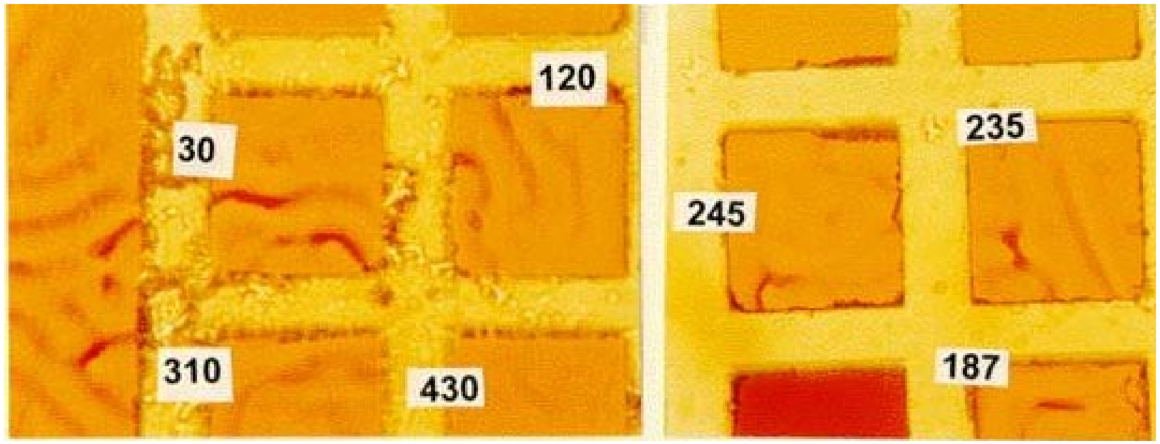


Metastable

Distribution: H_{eff}

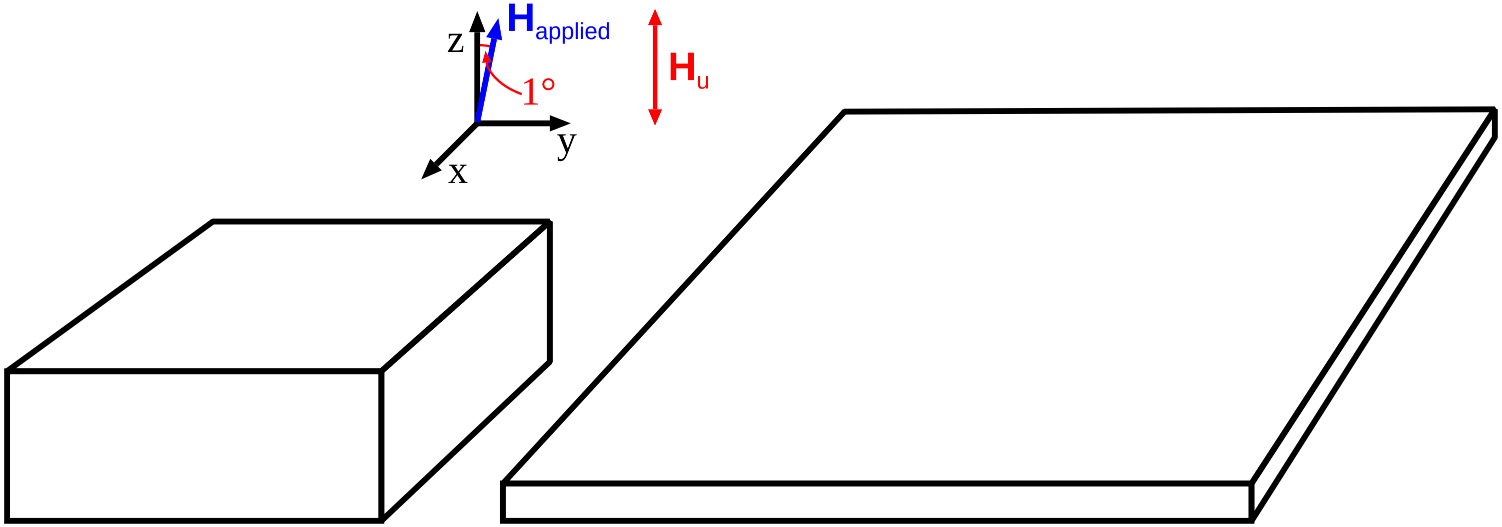


Defects



Defects decorated by AC field
Particles' H_{sw} marked, in Oe

Micromagnetic model



2 µm x 2 µm x 500 nm
$\mu_0 H_{sw}$ = 182 mT

4 µm x 4 µm x 125 nm
$\mu_0 H_{sw}$ = 176 mT

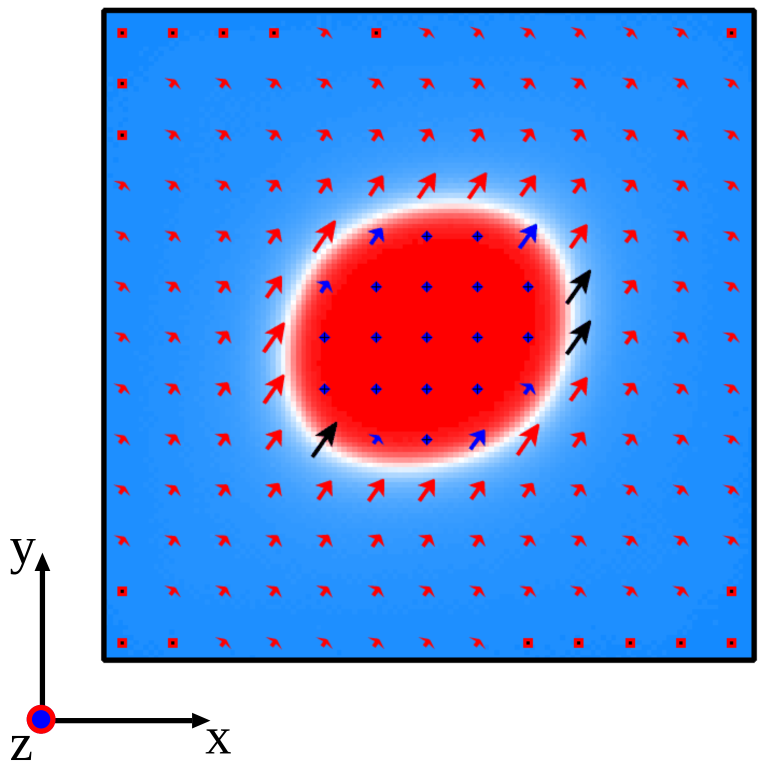
Discretization length Δ = 15.625 nm

Stopping criteria: $|\mathbf{M} \times \mathbf{H}|/M_s^2 < 0.008$

Switching fields

Geometry (nm)	Stoner-Wohlfarth (mT)	Micromagnetic (mT)
1000 x 1000 x 31.25	177.7	[175,180]
4000 x 4000 x 125	177.7	[175,180]
8000 x 1000 x 250	179.9	[175,180]
1000 x 1000 x 250	183.5	[182,184]
2000 x 2000 x 500	183.5	[180,185]
2000 x 1000 x 1000	187.5	[180,185]

Magnetization reversal



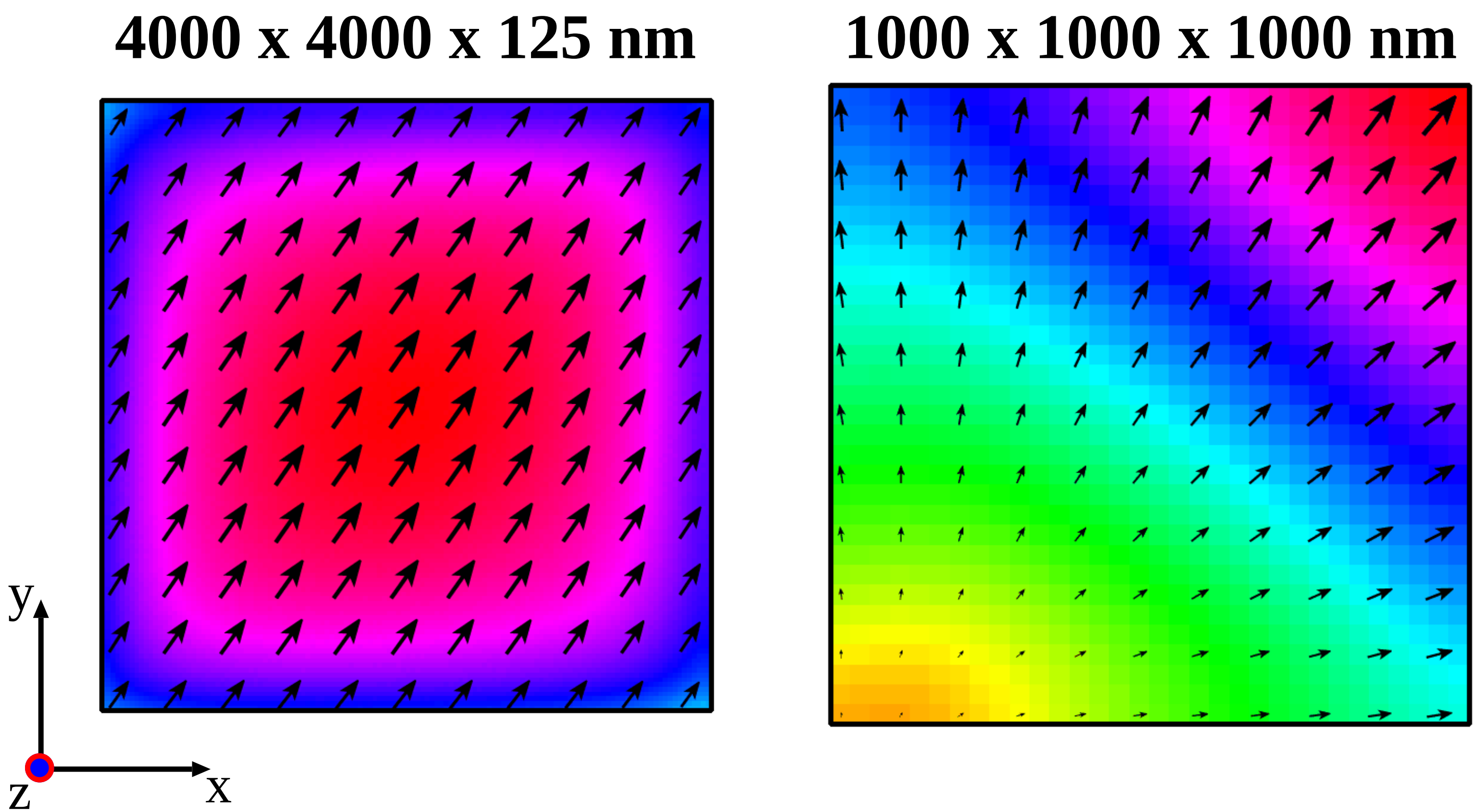
Transient state

Plate geometry

4 μm $\times$ 4 μm $\times$ 125 nm

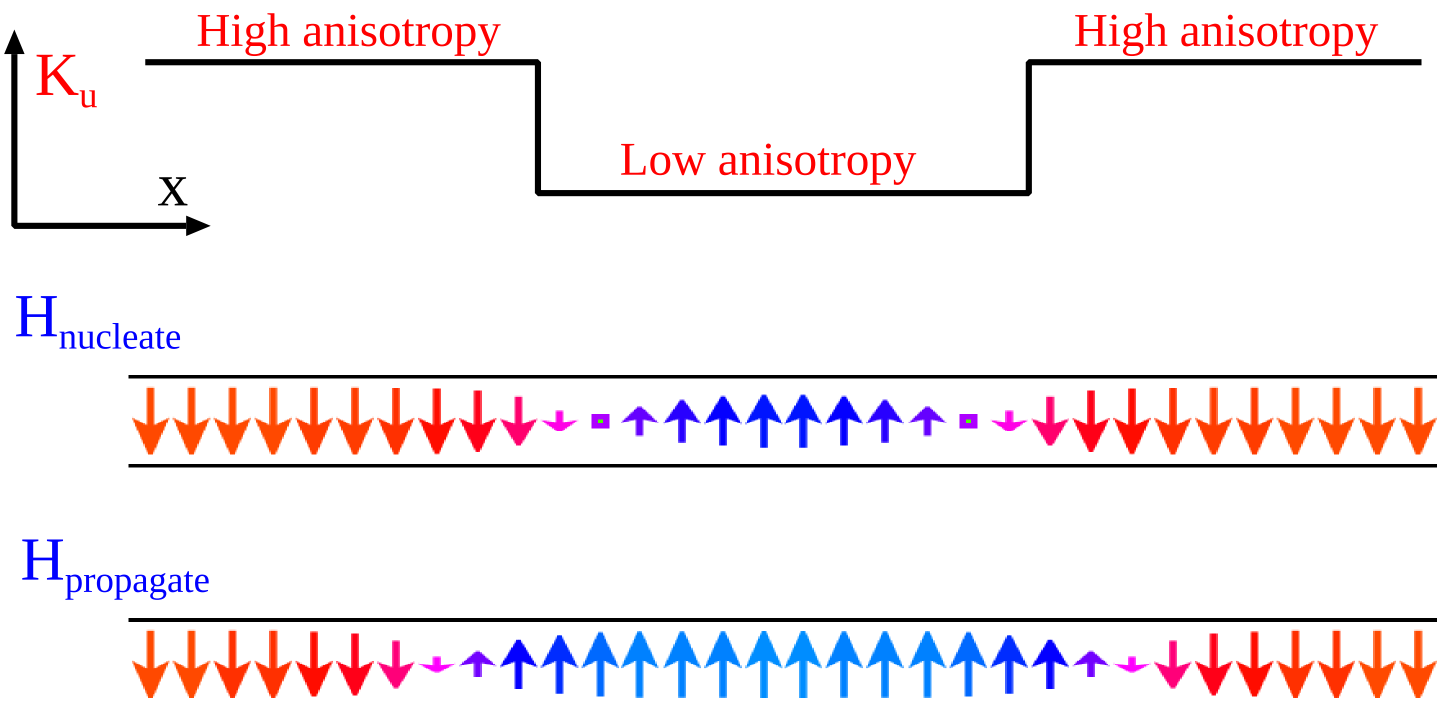
Reversal nucleates in center

Reversal torques



$\mathbf{m} \times \mathbf{H} \times \mathbf{m}$ preceding reversal
(top slice)

Simple defect (1D)



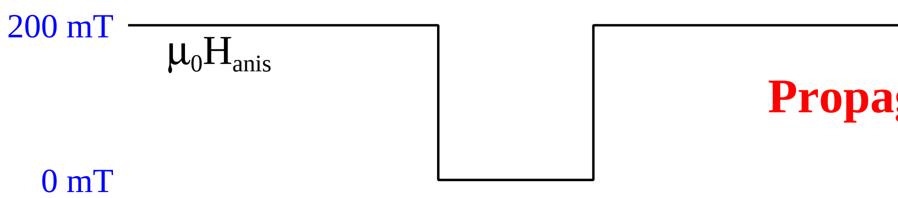
$$\mathbf{H}_{\text{propagate}} = (\mathbf{H}_{\text{u,bulk}} - \mathbf{H}_{\text{u,defect}})/4$$

$$\mathbf{H}_{\text{switch}} \geq \mathbf{H}_{\text{u,bulk}}/5$$

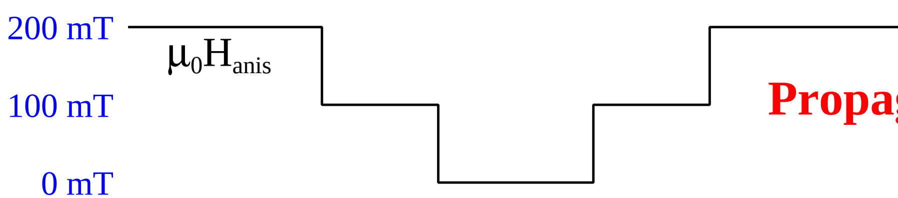
(Aharoni, 1960)

Staircase defect

Anisotropy staircase lowers propagation field:

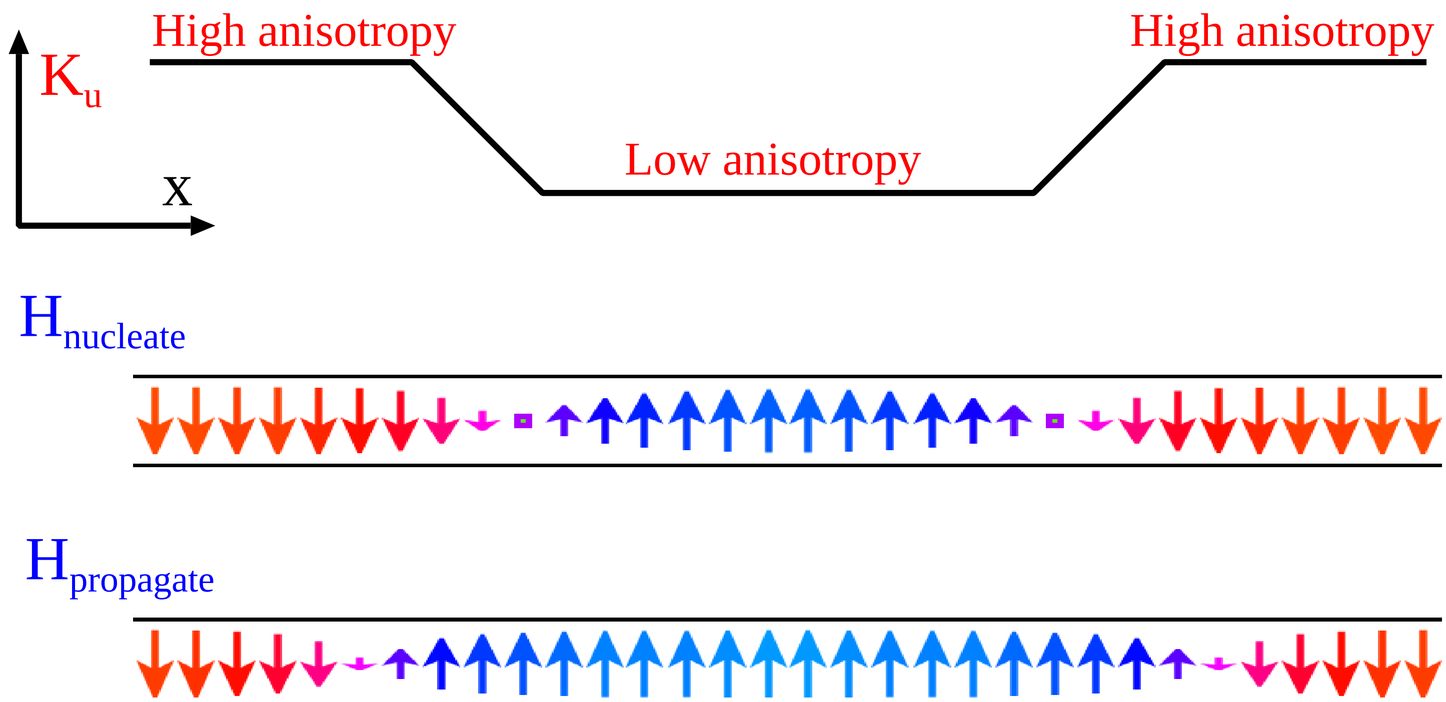


Propagation field = 50 mT



Propagation field = 25 mT

Linear defect (1D)



$$\mathbf{H}_{\mathrm{propagate}} \to 0 \quad \text{as} \quad \partial K_{\mathrm{u}}/\partial x \to 0$$

(Abraham & Aharoni, 1960)

Conclusions

Experimental:

- $\mu_0 H_{\mathrm{sw}} = 28.5$ mT $\pm\ 8.5$ mT $\ll \mu_0 H_{\mathrm{u}} = 210$ mT
- H_{eff} distribution higher and broader than H_{sw}

Simulations:

- Reversal by nucleation + propagation
- Nucleation in center for defect-free plates
- Simple defect model yields H_{sw} too large
- Linear defect model OK for transitions > 1 μm