FE-Simulation of fast switching behavior of granular nanoelements

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Motivation

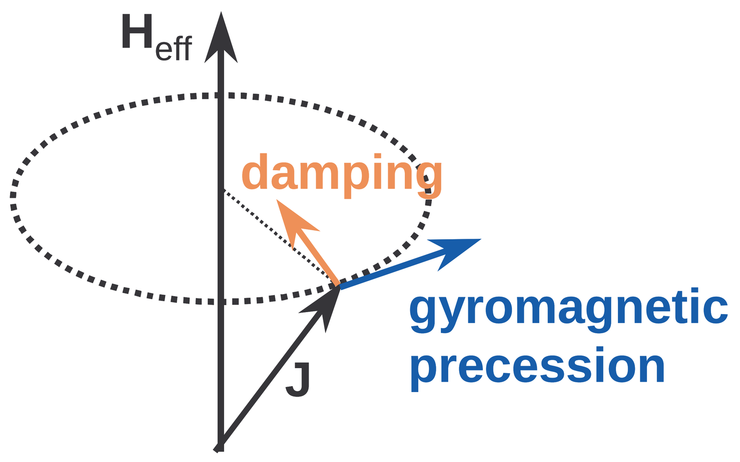
Magnetic recording devices (heads and media) must be designed to produce higher output signals and lower noise to achieve higher recording densities. Numerical micromagnetic simulation of future ultra-high density magnetic recording media up to 500 Gbit/in^2 reveals details of the magnetization reversal processes. The magnetic switching behavior is studied using a 3D hybrid finite element/ boundary element micromagnetic model. Transient magnetization states during switching are investigated in thin square shaped nanoelements with uniaxial (Co-hcp), cubic (Co-fcc) and zero ($Ni_{80}Fe_{20}$) anisotropy with 10 nm grain size, taking into account randomly oriented grains. In-plane switching dynamics are calculated for applied fields with constant sweep rates [16 - 2800 kA/(m.ns)] Thermal fluctuations and eddy currents are neglected.

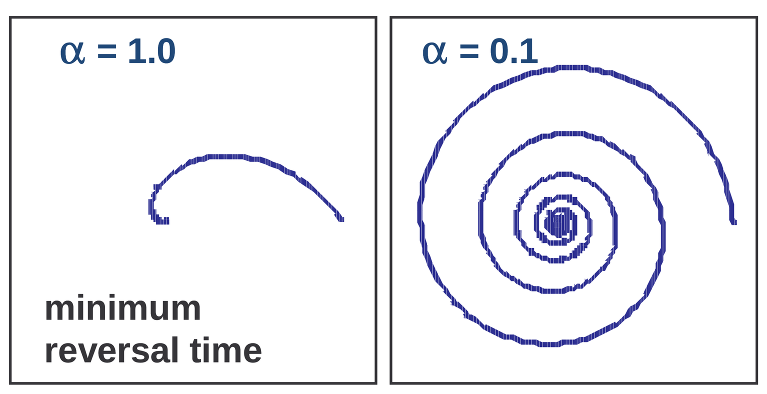
Micromagnetic framework Finite Element model

Precession of magnetic polarization:

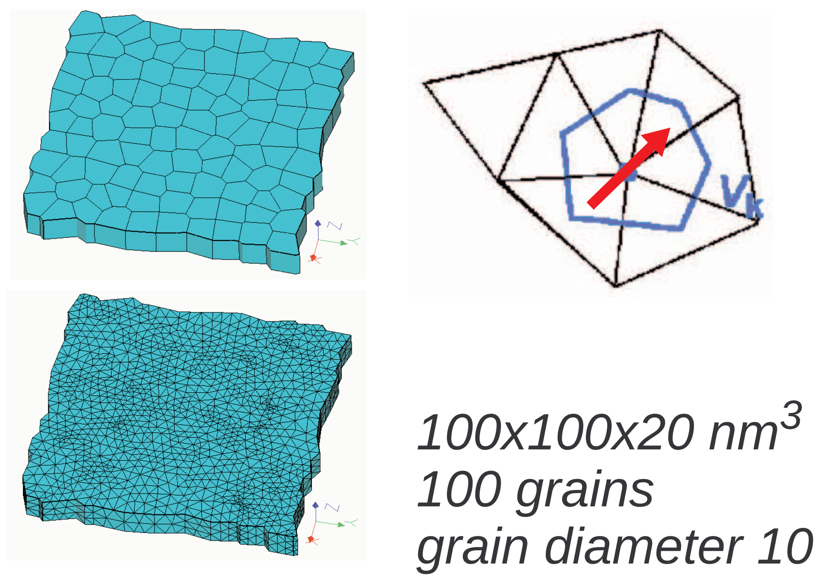
$$\frac{\partial \mathbf{J}}{\partial t} = -|\gamma|(\mathbf{J} \times \mathbf{H}_{eff}) + \frac{\alpha}{J_s}\left(\mathbf{J} \times \frac{\partial \mathbf{J}}{\partial t}\right)$$

Landau-Lifshitz-Gilbert equation





Discretization into finite elements:



$$\vec{H}_k = -\frac{1}{V_k}\frac{\partial E(\vec{J}_1, \vec{J}_2 ....\vec{J}_N)}{\partial \vec{J}_k}$$

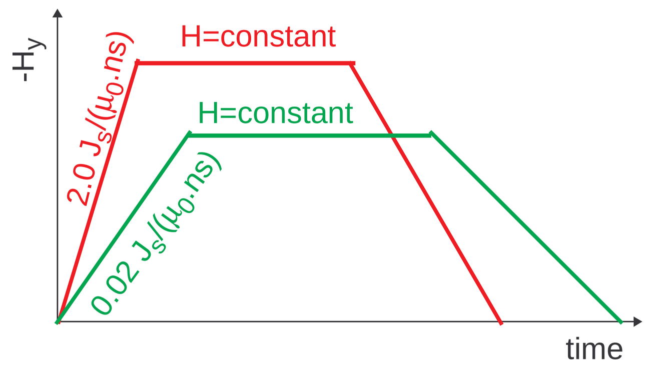
Element size about 5 nm up to 500 000 elements

effective field on irregular grids rigid moment at the nodes

100x100x20 nm^3
100 grains
grain diameter 10 nm

Applied magnetic field profiles:

unidirectional reversed field with different sweep rates and constant field values H_y=H_c



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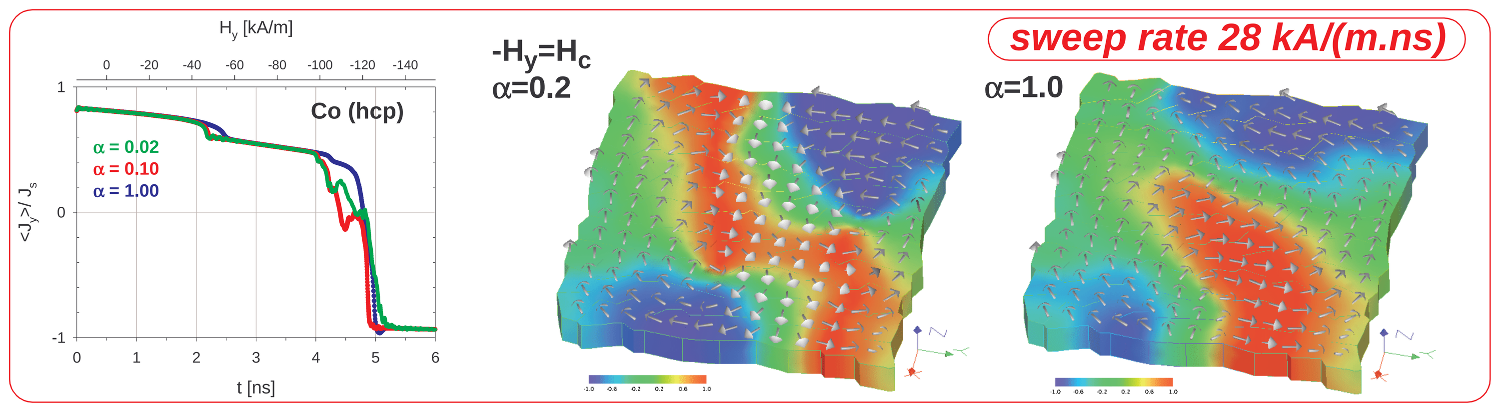
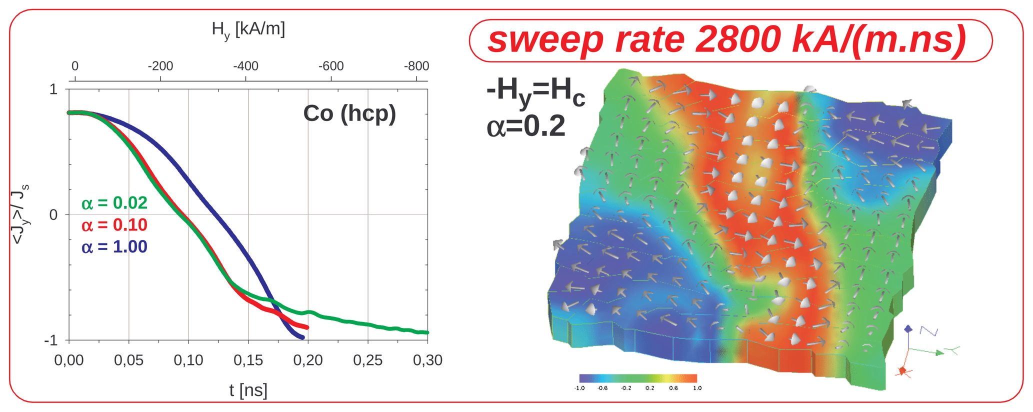
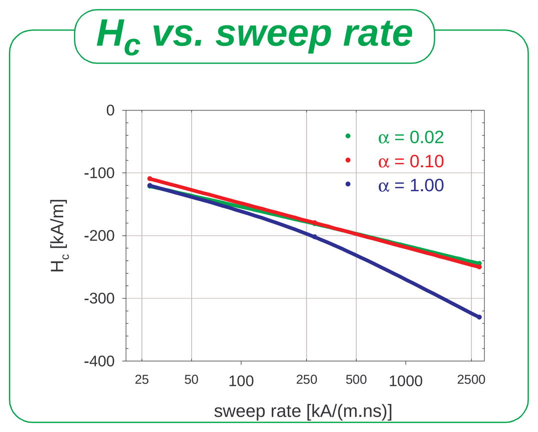
Switching of Co-hcp grains

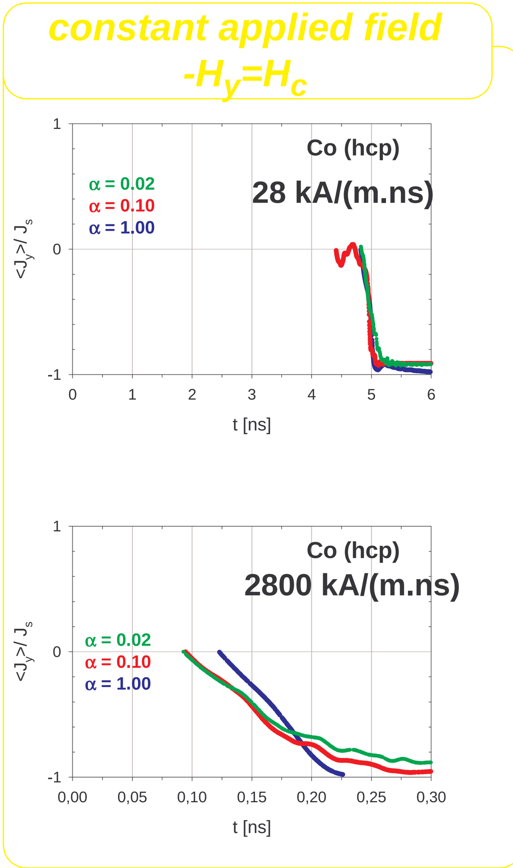


J_s=1.76 T
K_1=0.45 MJ/m^3
A=13 pJ/m

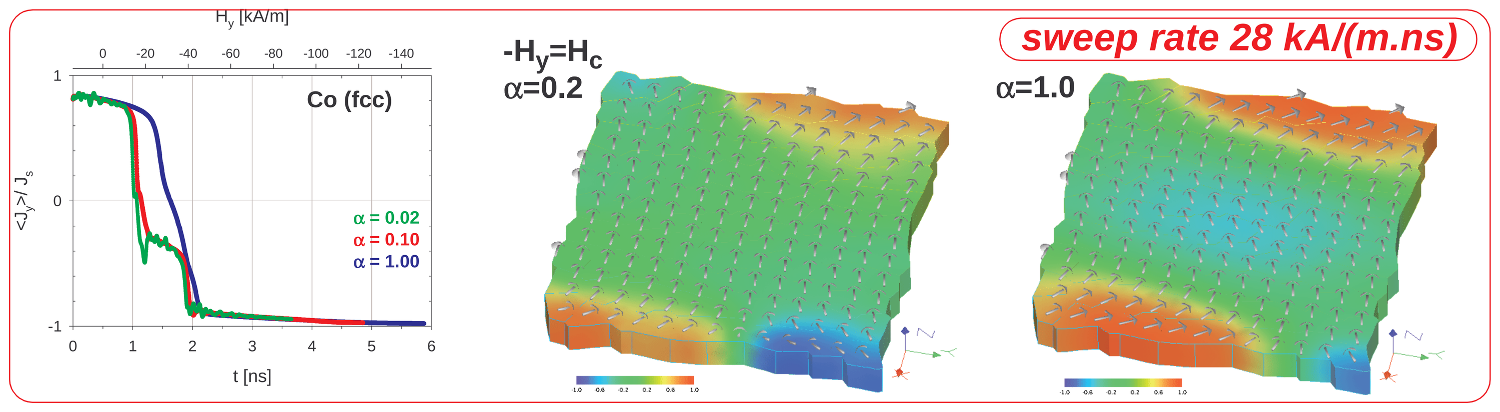


$H_{applied}$

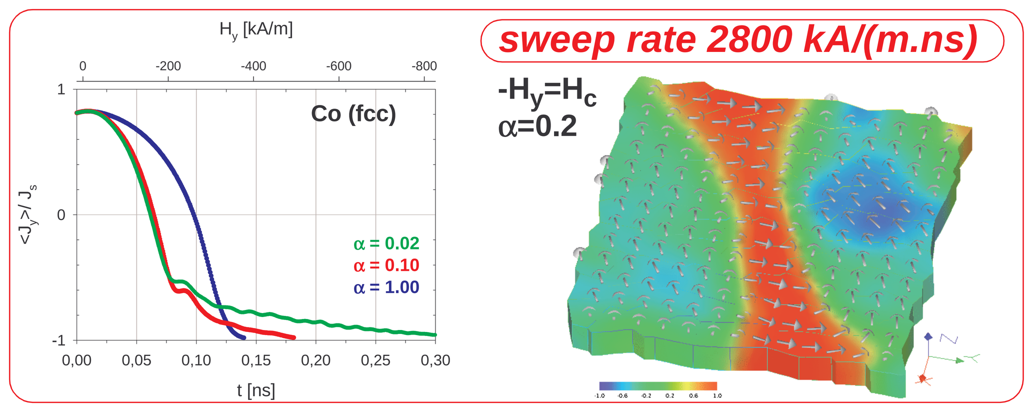




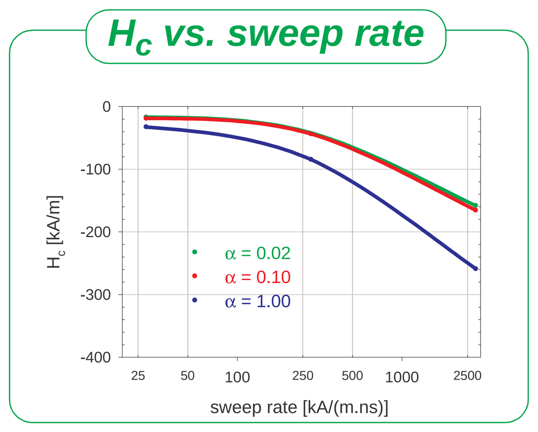
Switching of Co-fcc grains

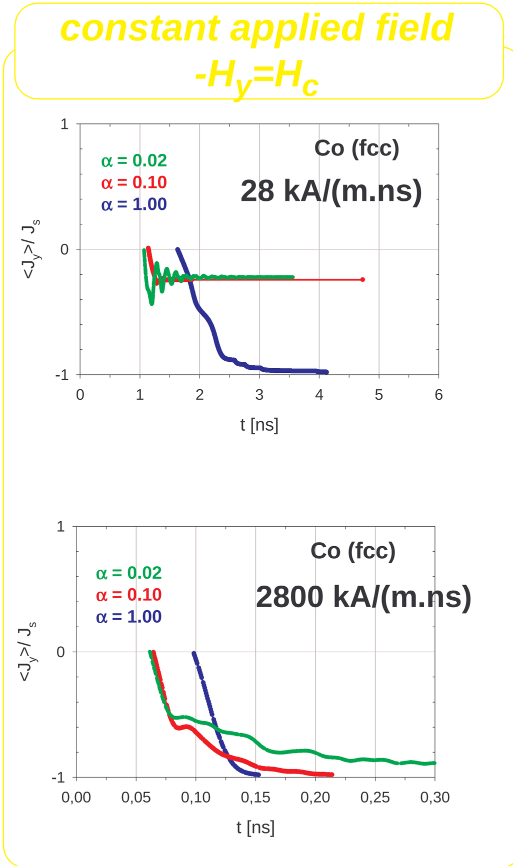


J_s=1.76 T
K_1=0.05 MJ/m^3
A=13 pJ/m

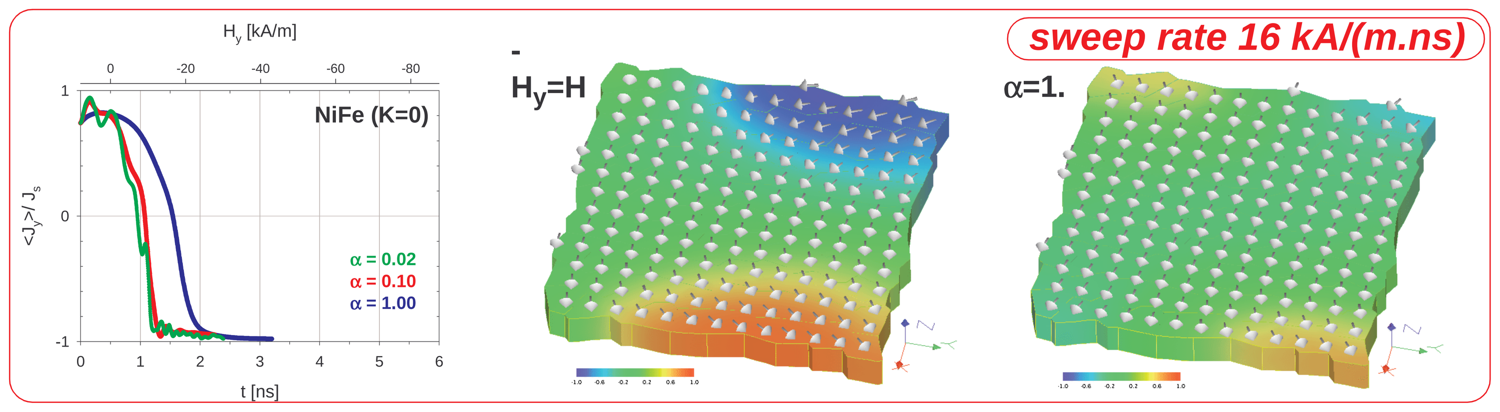


$H_{applied}$

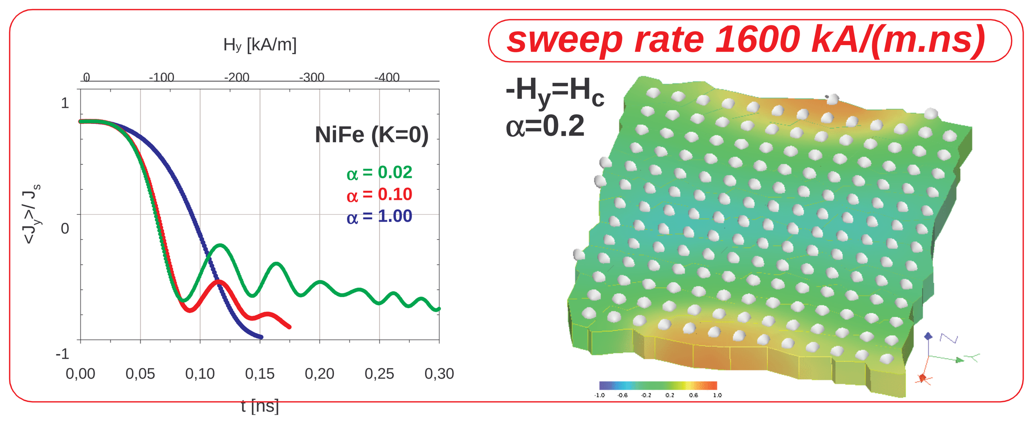




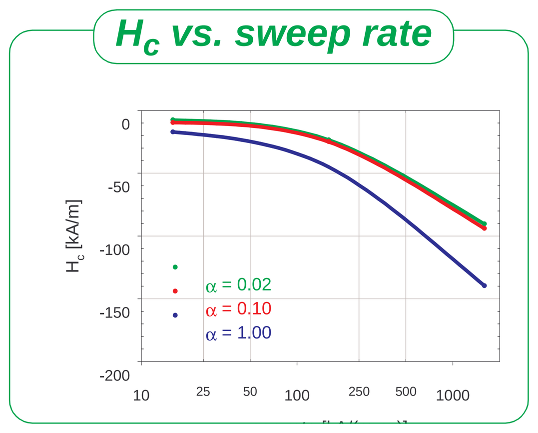
Switching of $Ni_{80}Fe_{20}$

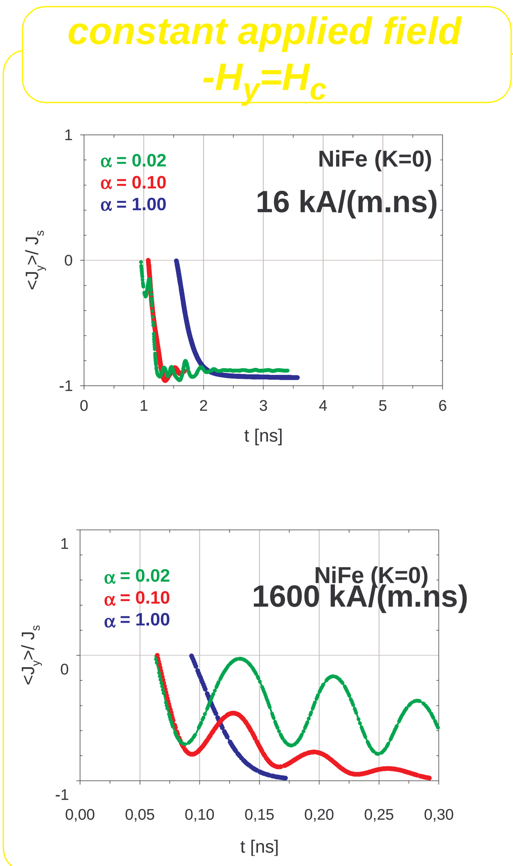


J_s=1.00 T
K_1=0
A=13 pJ/m



$H_{applied}$





Summary

In nanostructured magnets the switching fields and times are controlled by the geometric shape of the magnets, the intrinsic properties, the orientation and strength of the applied field and the damping parameter α. Small α leads to shorter switching times at fast sweep rates. A high sweep rate and a small α lead to precessional oscillation effects of the polarization in NiFe. The transient magnetization states during reversal vary from nucleation and expansion of reversed domains (Co-hcp) to inhomogeneous rotation (Co-fcc and NiFe).