Nucleation in polycrystalline thin films using a preconditioned finite element method

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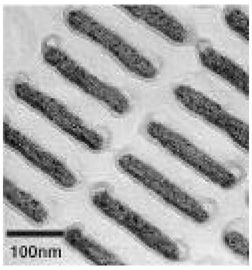
INTRODUCTION

The dynamic response of a 80 nm x 400 nm x 25 nm Co element with and without polycrystalline grains is calculated. In polycrystalline thin film elements the nucleation of reversed domains occurs randomly at grain boundaries and sharp edges. The numerical method combines a finite element scheme for space discretization with an advanced time integration scheme for the LLG equation. The use of appropriate preconditioners for the linear equations considerably reduces the computation time.

granular Co elements



TEM micrographs of polycrystalline Co nanoelements (Kirk, 1997).

Magnetic nano-elements have important applications as magnetic field sensors and might be used in future discrete storage media.

Surface irregularities and grain structure drastically changes the reversal mechanism of thin film elements.

Applications require:
- ⇨ well defined switching field
- ⇨ predictable domain structure
- ⇨ fast switching

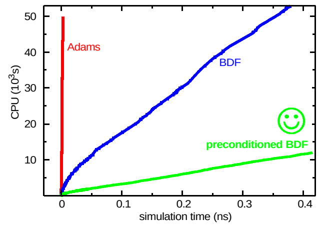
numerical methods

Microstructure forces small finite elements which cause a small time step solving the LLG equation.

large time steps are possible using a **backward differention method:**

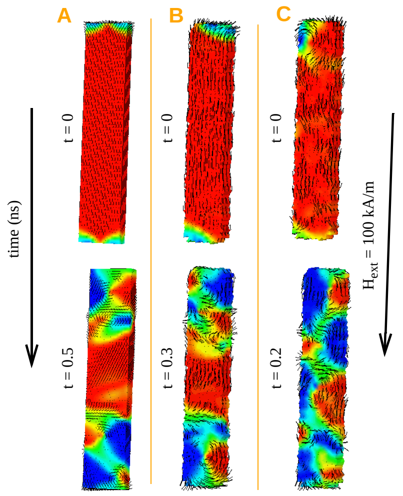
$M_{t+\Delta t} = F(M_{t+\Delta t}, M_t)$

- ⇨ nonlinear system of equations
- ⇨ Newton method
- ⇨ linear system



preconditioning provide curvature information ➔ reduces the cost per time step due to faster convergence

FEM simulation



Remanent states and transient states during the magnetization reversal of 80 nm x 400 nm x 25 nm Co elements.

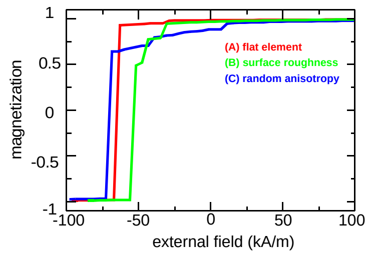
Microstructure models

(A) flat element, zero anisotropy
(B) surface roughness zero anisotropy
(C) polycrystalline, random anisotropy (8 nm grain size)

Reversal occurs by the nucleation of a vortex and the successive expansion of reversed domains.

Edge irregularities and random anisotropy facilitate the formation of vortices.

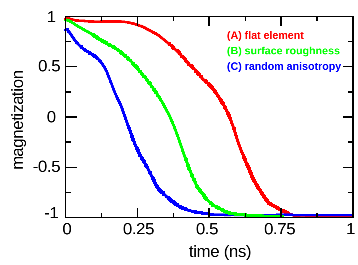
coercivity and reversal time



Hysteresis properties

Surface roughness leads to a reduction of the coercive field of about 20%.

Grain boundaries hinder vortex motion. Thus the granular element has the largest coercive field.



Switching dynamics

A reverse field of 100 kA/m is applied to the remanent state (Gilbert damping constant $\alpha = 0.1$).

Fast switching occurs in the polycrystalline sample with random anisotropy.

Kirk, K. J., Chapman, J. N., and Wilkinson, C. D. W. (1997). "Switching fields and magnetostatic interactions of thin film magnetic nanoelements." Appl. Phys. Lett., 71, 539-541.
Cohen, S. D., and Hindmarsh, A. C. (1996). "CVODE, A Stiff/Nonstiff ODE Solver in C." Computers in Physics, 10, 138-143

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