11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

Micromagnetic Simulation of Current-Driven Domain Wall Propagation

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MOTIVATION

In the recent years ideas of 'magnetic computing' emerged such magnetic field-coupling [1] or computing with domain walls [2]. Proposed spintronic devices also use the magnetic degree of freedom for information processing.

Any implementation of magnetic information processing is plagued by the difficulty of creating localized and strong magnetic fields which can be switched rapidly as well. Magnetic fields created by current-carrying wires are relatively weak and dispersed; coils are bulky, slow and dissipate a large amount of power.

Direct control of magnetic domain structures by electricity could eliminate the need for externally applied magnetic fields and bring magnetic computing close to real-world, practical applications. That is why the subject of current-driven domain wall propagation received considerable attention recently [3].

DESCRIPTION OF WORK

We introduce an effective-field approach to simulate the interaction of currents with a localized domain wall. This current-induced effective field is superposed over the other effective field terms (such as the external and dipole magnetic fields, anisotropy fields, etc.) and can move the domain wall. The physics of the interaction between domain walls and currents is complex and not yet completely understood. For thick walls in metallic nanowires the spin (angular momentum) transfer is dominant [4] and we focus on its modeling. The current-induced effective field distribution (resulting from the spin transfer effect) is illustrated in Fig. 1 for a particular wall structure.

Our effective-field approach can be extended to include momentum transfer and parasitic effects, such as the magnetic field generated by the current. We will demonstrate how these new field components can be implemented in the OOMMF program, which is a widely-used micromagnetic simulator [5].

While this effective-field approach does not contain new physics compared to already used methods (such as adding a diffusive term to the Landau-Lifshitz equation [6], it fits better into the framework of micromagnetics and easier to implement in existing codes.

RESULTS

We will simulate current-induced domain wall propagation in nanowires with different shape, surface roughness and notches. We examine how domain walls can be pinned at and released from artificially created notches, as it is illustrated in Fig. 2. Our model gives relatively low spin transfer efficiencies, in accordance with experimental results [3]. Most of the recent studies are dealing with idealized domain structures – we will point out the importance to treat the micromagnetic problem accurately. We will also discuss the prospects of using current-driven domain walls in field-coupled computing devices.

REFERENCES

[1] A. Imre, G. Csaba, L. Ji, A. Orlov, G. H. Bernstein, W. Porod: Majority Logic Gate for Magnetic Quantum-Dot Cellular Automata SCIENCE VOL 311 13 JANUARY 2
[2] D. A. Allwood, Gang Xiong, M. D. Cooke, C. C. Faulkner, D. Atkinson, N. Vernier, R. P. Cowburn: Submicrometer Ferromagnetic NOT Gate and Shift Register Science 14 June 2002 296: 2003-2006
[3] A. Yamaguchi, T. Ono, and S. Nasu, K. Miyake, K. Mibu, T. Shinjo: Real-Space Observation ofCurrent-Driven DomainWall Motion in Submicron MagneticWires Phys. Rev. Lett, 92 7
[4] L. Berger: Exchange interaction between ferromagnetic domain wall and electric current in very thin metallic films J. Appl. Phys, 55 6 1984
[5] http://math.nist.gov/oommf/
[6] A. Thiaville, Y. Nakatani, J. Miltat,N. Vernier: Domain wall motion by spin-polarized current: a micromagnetic study J. Appl. Phys.. 95, 11

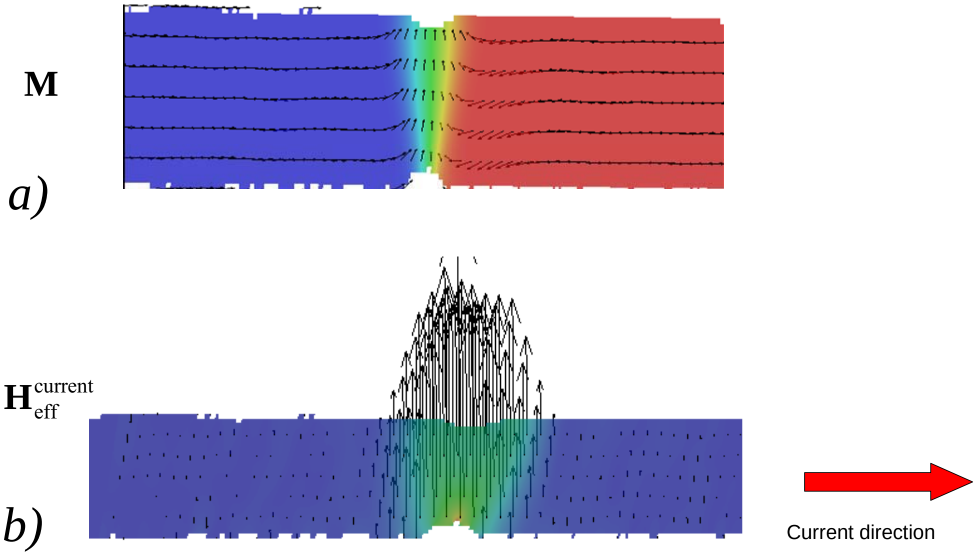

Figure 1. Part a) shows the magnetization distribution for a particular domain wall in a permalloy wire. Arrows indicate magnetization direction and the coloring indicates the strength of magnetization component parallel to the current direction. Transport currents interact with the fixed spins of the wire and generate an effective field, as it is shown in part b). If the current is sufficiently strong, it can displace the wall.

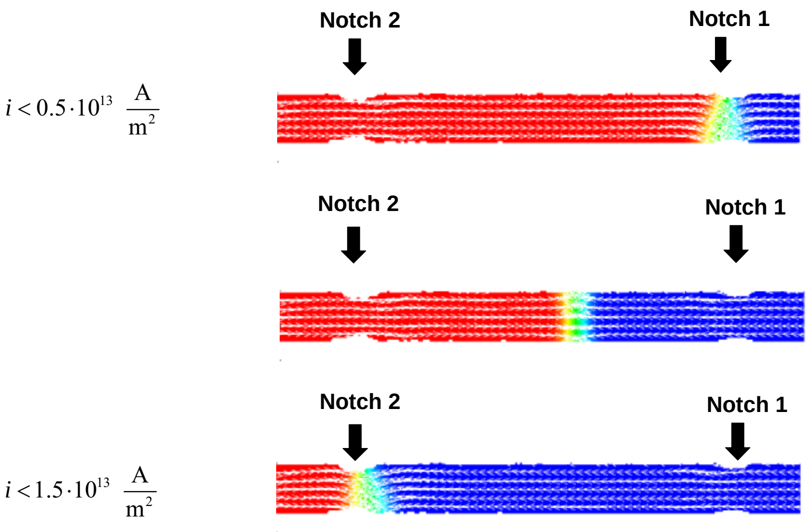

Figure 2. Domain walls can be pinned and released in a controlled way in a nanomagnet wire with notches of different depth. The figure shows snapshots of a time-dependent simulation. A domain wall, propagating from right is pinned at the right notch. When the current density exceeds $i = 0.5 \cdot 10^{13}$ A/m^2, the wall leaves the right notch and quickly (with a speed of few hundred meters per seconds) propagates to the left. The notch at the left side is deeper and represents a stronger pinning potential. A current density exceeding $i = 1.5 \cdot 10^{13}$ A/m^2 is required to de-pin the wall from this position.