Thermally activated reversal modes in infinite periodic ferromagnetic wires

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I. Introduction

Micromagnetic simulations are suited to describe the magnetic hysteresis behavior of ferromagnetic samples. By time stepping the Landau-Lifshitz equation, the micromagnetic equilibrium states corresponding to successive applied fields can be determined. This approach results in the macroscopic hysteresis loops, but also gives an insight in the microscopic magnetization processes in the sample. The growing computer resources combined with efficient numerical techniques, make it possible to vary the sample size from a nanometer scale to a micrometer scale. In this contribution the hysteresis properties of infinite periodic ferromagnetic wires are discussed. From the simulations it is clear that, depending on the cross section dimensions, different dominant micromagnetic energy terms initiate different reversal modes.

II. Simulations

In the micromagnetic simulations iron wires with square cross sections are considered, taking into account the Zeeman, exchange, (cubic) anisotropy and magnetostatic interaction together with thermal fluctuations [1]. The computations are restricted to a computational domain of $N \times N \times N$ finite difference (FD) cells. This computational domain is repeated periodically along the infinite z-direction. When a FD cell at $\mathbf{r}_i$ interacts with a FD cell at $\mathbf{r}_j$, also the interactions with all periodic images at $\mathbf{r}_j + kL\mathbf{e}_z$ ($k = -\infty \ldots + \infty$, L period dimension) is accounted for. The field is applied along the axis of the wire.

In most finite nanowire simulations (see e.g. [2]), a constant external field is applied in the opposite direction of the uniformly magnetized nanowire. The magnetization reversal is initiated at the ends of the finite structure or at a local variation in the geometry. In contrast, in the simulations presented here, a decreasing external field is applied starting from saturation. The reversal processes are initiated by thermal fluctuations of different amplitude.

III. Results

Depending on the cross section dimensions $L \times L$ and the material parameters, different reversal modes are distinguished having different dominant interaction terms (except for the Zeeman interaction):

- for $L \leq L_1$ the exchange interaction is dominant leading to a 3D reversal mode combining buckling and precessional switching, see Fig. 1.a.

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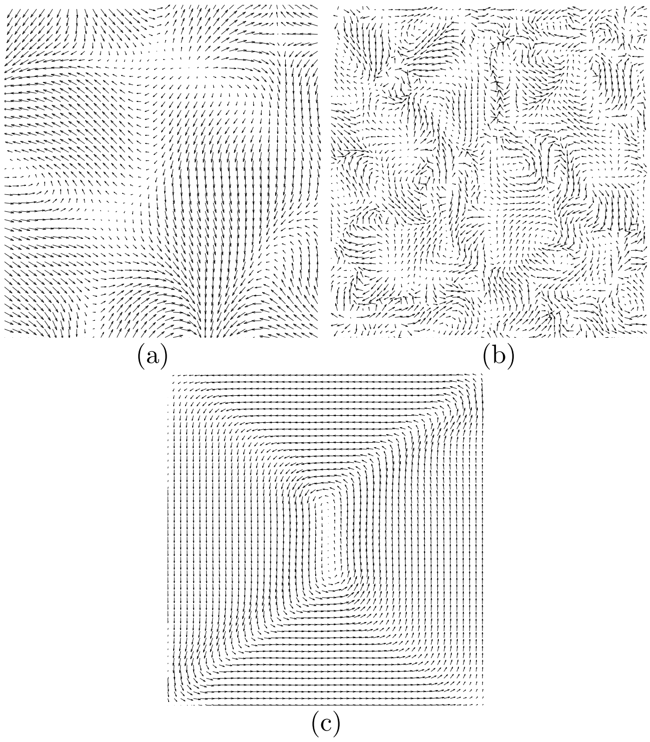

Fig. 1. Magnetization patterns perpendicular on the infinite direction during the reversal of iron wires with cross sections $40\,nm \times 40\,nm$ (a), $200\,nm \times 200\,nm$ (b) and $800\,nm \times 800\,nm$ (c). With the $< 110 >$ direction of the crystallographic axes lying along the infinite direction $L_1 = 100\,nm$ and $L_2 = 500\,nm$.

- for $L_1 < L < L_2$ the exchange interaction is less dominant due to the larger sample dimensions: multiple vortex states are nucleated by the fluctuating thermal field, resulting in a chaotic magnetization, see Fig. 1.b.
- for $L \geq L_2$ the magnetostatic and anisotropy interactions become more important: domains are formed, avoiding of magnetic charges and minimizing the anisotropic energy, see Fig. 1.c.

Larger coercive fields are encountered when the cross section dimensions diminish. By considering the periodic repetition of the computational domain in the infinite direction, the 3D nature of the magnetization processes is fully accounted for, which is not the case in a 2D or 2.5D scheme. From the simulations it is clear that only in the reversal mode where domains are formed the magnetization is invariant in the infinite direction.

References

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