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Manipulating domain wall mobility by cross section tailoring in ferromagnetic nanostripes

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Manipulation of nanoscale ferromagnetic stripes' magnetic structure can play a pivotal role in the development of high-density, ultrafast magnetic memory and offers a significant potential to enhance the performance of spintronic devices [1,2].

This work is devoted to the theoretical and numerical study of the domain wall motion in straight ferromagnetic nanostripes with variable cross section in the presence of an external magnetic field. It was already shown that the cross-section gradient in a ferromagnetic nanostripe creates a driving force for a domain wall motion [3,4]. However, earlier studies did not account for the potential presence of an external magnetic field, which is necessary for both experimental confirmation of the results and practical applications. Here, we analyze the interaction and competition of the effects caused by the cross-section gradient and the external magnetic field on the domain wall dynamics in a ferromagnetic nanostripe.

The behaviour of the magnetization in a ferromagnetic nanostipe with variable cross section is investigated using the micromagnetic framework introduced in [4]. In this study, we apply the collective variable approach to describe the domain wall. To derive the equations of motion for the collective variables, we employ the Lagrange-Rayleigh formalism, incorporating the spatial variation of the cross-sectional area into both the Lagrangian and the dissipative function.

This study examines the magnetic properties of two distinct nanostripe geometries: one with a localized constriction (Fig. 1a) and another — a wedge-shaped nanostripe (Fig. 2a). For each case, we derive the equation of domain wall motion under the influence of an external magnetic field.

We demonstrate that the cross-section gradient creates an internal driving force, which, under certain conditions, counteracts the external magnetic field's influence on the domain wall. This results in the formation of a new pinning position, with its value calculated for both geometries. The linear dynamics near the pinning position are analyzed, and it is shown that in both geometries, small deviations from the pinning position give rise to damped oscillations.

We also show that for sufficiently large values of the external magnetic field, the domain wall depinning occurs, with the critical depinning field value h_d being found for both geometries. Additionally, magnetization hysteresis curves are obtained for both geometries, providing a basis for experimental validation of the theoretical predictions (Figs. 1b and 2b). On top of that, the modification of the inertial (Döring) domain wall mass by the cross section variation is found for both cases for small deviations from the pinning position and the absence of damping. All analytical predictions are validated by the full-scale NMAG micromagnetic simulations [5].

While the focus of this work is primarily on the interplay between cross-sectional area gradient and external magnetic field, the model developed also enables the extension of these findings to account for the combined effects of curvature and variable cross section. This research was supported by DFG via Grant No. MC 9/22–1.

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