Switching of the Polarity of Vortices in Magnetic Nanodots by a Spin-polarized Electric Current

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Abstract— The ground state of a flat cylindrical ferromagnetic nanodot is a non-planar vortex, if the radius of the dot is large enough. A non-planar vortex is characterized by two topolocigal charges: vorticity q and polarity $p = \pm 1$ (the spins in the vortex core are parallel or antiparallel to the cylinder axis). Both q and p are constants of motion in the continuum limit. However, in discrete spin systems the polarity can be switched in different ways: scattering with spin waves, thermal noise, a magnetic field pulse, a rotating magnetic field, or a spin-polarized electrical current.

We investigate the latter effect. We perform spin-lattice simulations for a nanodot using a spin model with Heisenberg exchange and dipole-dipole interactions. A spin-polarized dc current produces a spin torque (Slonczewski-Berger term) in the Landau-Lifshitz equation, which is solved numerically. The initial condition is an up-vortex ($p = +1$) in the middle of the system. The vortex center moves away from the middle and certain magnon modes are excited. Thereby a negative peak (a dip) in the out-of-plane spin structure appears close to the vortex. When this peak has reached its maximal depth, it splits into a vortex and an antivortex which both have polarity $p = -1$. Then the new antivortex and the original vortex annihilate and the new vortex with $p = -1$ remains. Thus effectively an up-vortex is replaced by a down-vortex. Using typical parameters for a Permalloy disk (radius 100 nm, thickness 20 nm), we find much faster switching times (about 50 ps) than in the rotating field method (about 200 ps). The critical current density is about $0.1\,\mathrm{A}/\mu\mathrm{m}^2$.

Interestingly, the above scenario is generic, because it has been observed both experimentally and numerically using different switching methods. As the formation of the dip close to the vortex seems to be essential for the switching process, we study in detail under which conditions the dip appears and how it is created.

To this end we perform spin-latttice simulations for different situations: A fixed planar vortex at the center of the system, and a planar vortex at the center of a small ring, situated either at the system center or at a distance from the center. One of the results is that the out-of-plane structure of the vortex core is not essential for the dip formation. This is confirmed by micromagnetic simulations.