Phase field simulation of magnetization vortex in ferromagnetic nanomaterials

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Magnetization vortices in ferromagnetic nanostructures have attracted considerable attention due to their potential application in nanoscale memory devices. A magnetization vortex with in-plane curling magnetization and out-of-plane magnetization at the core is a unique stable state. The out-of-plane magnetization at the core can be switched from an upward state to a downward state or from a downward state to an upward state by a magnetic field or a spin-polarized current. This switchable property makes magnetization vortex a promising candidate for memory cells in future non-volatile data-storage devices.

In this work, a real-space phase field model is developed to investigate the switching behavior of magnetization vortex in ferromagnetic nanostructures subjected to different mechanical strains. Based on the time-dependent Ginzburg-Landau (TDGL) equation, the phase field model takes into account the Dzyaloshinskii-Moriya (DM) interaction of magnetizations, which includes the coupling between the magnetization and magnetization gradient. The governing equations in the phase field model are solved simultaneously by means of a nonlinear finite elements method, which can be employed to simulate magnetization vortex without periodic boundary condition. The phase field simulations demonstrate that the vortex polarity of a circular ferromagnetic nanodot can be switched by torsion when the sign of the torsion is opposite to that of vortex chirality, whereas switching does not take place if the sign of torsion is the same as that of vortex chirality. The magneto-elastic coupling and demagnetization field play a decisive role in the polarity switching, which involves an intriguing interplay of magnetization, strain and demagnetization. The results suggest another way to control vortex polarity and vortex stability by mechanical field other than magnetic field and electric current.

It is also found that the DM interaction has significant influence on the structure of the magnetization vortex. The DM interaction induces an out-of-plane magnetization on the edge of the vortex and enlarges the size of the vortex core. The magnitude of the out-of-plane magnetization at the vortex core and the edge increases with the increase of DM constant. Besides, the handedness of magnetization vortex also changes when the sign of DM constant changes.

The financial support from the National Natural Science Foundation of China (Grant Nos. 11321202, 11472242).

References:

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