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Факультет радіофізики,
електроніки
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систем

Радіофізичний факультет
Київського
національного
університету
імені Тараса Шевченка

CHIRAL SYMMETRY BREAKING IN THE VORTEX CORE REVERSAL PROCESS IN MAGNETIC NANOCAPS

M. I. Sloika*, D. D. Sheka*, V. P. Kravchuk, Y. B. Gaididei****

** Taras Shevchenko National University of Kyiv, 64/13, Volodymyrs'ka St., 01601, Kyiv, Ukraine*

e-mail: sloika.m.i@gmail.com

*** Bogolyubov Institute for Theoretical Physics, 14-b Metrolohichna St., Kyiv, 03680, Ukraine*

Magnetic vortex as a ground state of a submicrone sized magnetic particle is a perspective candidate for fabrication of nonvolatile memory devices. For this purpose one needs to efficiently control the vortex polarity switching process. We studied numerically switching of the polarity of magnetic vortex for a hemispherical nanocap under the action of magnetic field pulse. The pulse amplitude intensity required for the switching essentially depends on the vortex chirality and it does not depend on the initial vortex polarity. This is a fundamental difference of curvilinear systems from planar ones, where the chirality does not effect the switching phenomena.

During the last decade the main attention in studying of sub-micron sized ferromagnetic nanoparticles was paid to planar nanostructures such as magnetic nanodisks, nanorings, etc. Due to the competition between the exchange and magnetic dipol-dipole interaction these nanoparticles can have a single vortex in ground state[1]. The in-plane curling magnetization in vortex state turns out of the plane at the center, avoiding a singularity and forming the vortex core. Thus the vortex is characterized by two discrete indices: chirality (counterclockwise, $c=+1$, or clockwise, $c=-1$), the sense of magnetization circulation, and polarity (up, $p=+1$ or down, $p=-1$), the sense of the core magnetization direction. Such structure means that the magnetic vortex is a promising candidate for the high-density magnetic storage and high-speed magnetic random access memory because it can store two bits of information. For this one needs to control vortex core reversal. In this work we study the vortex polarity switching in spherical caps of different curvature radii.

We base our study on the numerical micromagnetic MAGPAR[2] simulations of Permalloy samples (exchange constant $A=1.05\cdot10^{-11}\,J/m$, saturation magnetization $M_S=796\,kA/m$, and damping constant $\alpha=0.01$). We start from the hemispherical cap with inner radius $R=50$ nm and thickness $h=10$ nm which correspond to the vortex ground state for such geometries[3]. Using numerical integration of the Landau-Lifshitz-Gilbert equation we simulated vortex dynamics under action of time dependent magnetic pulse $\vec{b}(t)$ with Gauss profile $\vec{b}=\vec{e}_y b_0 \exp\left[-(t-3\tau)^2/\tau^2\right]$, where t denotes time and $\tau=100$ ps is the pulse duration. Similarly to the case of disk[4], the vortex polarity p is switched to the opposite value via the vortex-antivortex pair creation when the amplitude b_0 exceeds some critical value b_c, otherwise the vortex core relaxes to the cap center without polarity switching.

For all possible combinations of initial chiralities and polarities we determine the value of critical amplitude b_c and find out that b_c depends on the chirality c but it does not depend on the polarity p, see the circled points in Fig. 1. Since in planar structures the polarity switching process does not depend on the vortex chirality we simulated vortex polarity switching for spherical caps with different curvature radii. Keeping the sample volume V and thickness h constant, we increase the inner radius R with the corresponding decreasing of the cutoff angle θ, see Fig. 2. As one can see (Fig. 1), the vortex with chirality $c=-1$ always requires lower pulse amplitude for switching, the difference between switching amplitudes for opposite chiralities vanishes with the curvature radius increasing.

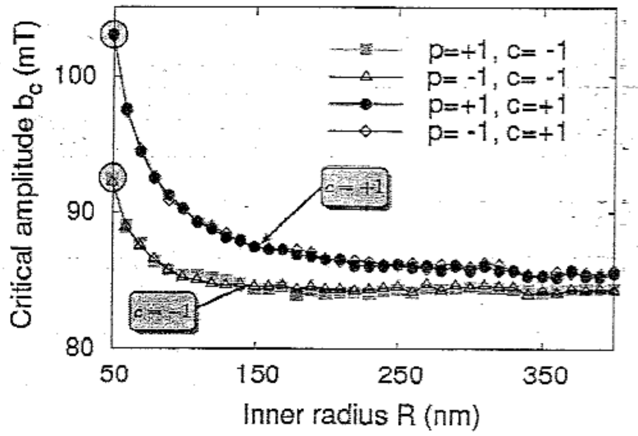

Fig1. Switching amplitude of the field pulse for all possible polarity-chirality combinations as a function of the curvature radius of the cap. The cycled symbols correspond to the hemispherical shell with R = 50 nm.

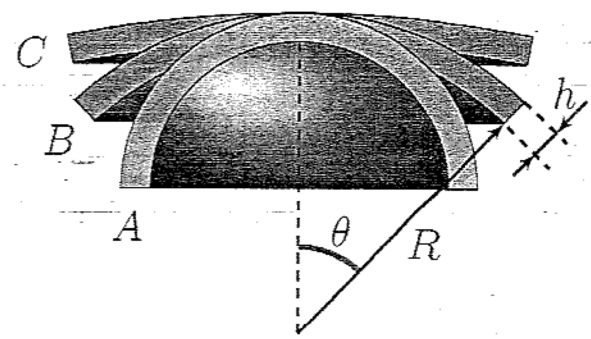

Fig2. Continuous transition from a hemispherical cap to a planar disk: (A)-the hemispherical shell with inner radius R=50 nm, (B)-R=100nm, (C)-R=400nm. Thickness h=10 nm and volume are kept constant.

It was shown that the critical vortex core velocity, which is required for the polarity switching, depends on the perpendicular component of the magnetic field[5]. Namely, the switching is "hard" (the critical velocity is hiegher and so the more strong magnetic field is needed) when the external field direction coincides with the polarity vector $\vec{p}$ (the unit magnetization vector in the vortex center) $\vec{b}\cdot\vec{p}>0$ and for case $\vec{b}\cdot\vec{p}<0$ the switching is "easy" (the critical velocity is lower and so the less magnetic field is needed). One always has $\vec{b}\cdot\vec{p}=0$ if the in-plane field applied to the planar nanoparticle. But when field is applied to spherical shells, since $\vec{p}$ always stay normal to the surface, the sign of the product $\vec{b}\cdot\vec{p}$ depends on the direction of shift with respect to the field vector $\vec{b}$. In the initial moment of time this direction can be determined using Thiele equation $\dot{\vec{\mathfrak{R}}}\propto c p \vec{b}$ [6], where $\vec{\mathfrak{R}}$ gives the position of the vortex core. As one can see if $c=+1$ the product $\vec{b}\cdot\vec{p}>0$ (the switching is "hard") and if $c=-1$ the product $\vec{b}\cdot\vec{p}<0$ (the switching is "easy"). This is the reason why the vortex with chirality $c=-1$ requires less excitation amplitude for the polarity switching as compared with $c=+1$.

In conclusion, for the spherical magnetic caps we have studied the vortex polarity switching process by a magnetic field pulse applied in the cut plane. In contrast to the core switching process in planar nanoparticles, the switching process depends on the vortex chirality for hemispherical shell.

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