Proceedings of the

XI[TH] INTERNATIONAL YOUNG SCIENTISTS' CONFERENCE ON APPLIED PHYSICS

June, 15-18, 2011, Kyiv, Ukraine

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Faculty of RadioPhysics

Збірник наукових праць

ОДИНАДЦЯТОЇ МІЖНАРОДНОЇ КОНФЕРЕНЦІЇ МОЛОДИХ УЧЕНИХ З ПРИКЛАДНОЇ ФІЗИКИ

15-18 червня 2011 року, Київ, Україна

Київський національний університет
імені Тараса Шевченка
Радіофізичний факультет

VORTEX POLARITY SWITCHING IN MAGNETIC NANODISK MEDIATED BY THE BLOCH POINT INJECTION

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***Abstract**: Vortex polarity switching process in magnetic nanodisks of is mediated by Bloch point (BP) injection. Using spin-lattice simulations we studied in details BP dynamics for two types of ferromagnets: (i) isotropic magnet with a dipolar interaction and (ii) Heisenberg one with easy-plane single-ion anisotropy. Analytical description of the BP structure was proposed.*

Magnetization curling takes place for submicron sized soft type magnetic particles, leading to the various closed flux nonuniform structures. In particular, the ground state of the disk shaped particle can form the magnetic vortex, which is a perspective candidate for a high speed MRAM and a high density magnetic storage devices; one bit of information can be associated with vortex polarity, i.e. the upward or downward magnetization direction in centre of the vortex core. To this effect one needs to control the switching process of the vortex polarity. The simplest way to switch the vortex polarity is to apply the dc magnetic field, opposite to the direction of the vortex polarity. Under such a field, the vortex loses its stability, which finally causes polarity switching. This type of the switching was observed experimentally in Py disks [1]. Micromagnetic simulations [2] demonstrated that the switching is mediated by the Bloch point (BP) injection on face surfaces of the disk for thick enough samples with a typical BP size of about 20 nm. Another reversal mechanism was proposed in [3] for thin disks, where the vortex switching occurs through the temporary formation of pure planar vortex, i.e. without the BP formation. Note that all mentioned switching processes are forbidden in the continuum theory, hence micromagnetic simulations cannot provide adequate physical picture and the switching process should be revised.

In the present work we study the switching process for thin disks, using in-house-developed 3D spin-lattice simulator SlaSi [4], which extends quasi 3D simulator [5]. We consider the switching process in a DC perpendicular field for two models: (i) isotropic magnets with dipolar interaction and (ii) Heisenberg magnets with easy-plane single-ion anisotropy. In both cases the main energy contribution is Zeeman one. The "exchange explosion" effect [6] takes place, which means the fast decrease of exchange energy during the BP injection and its motion inside sample.

(i) Dipolar energy is shown to be affected by the sample geometry ratios (thickness L and diameter 2R), and the applied field amplitude H. The following parameters were used: applied field $h_l=H/4\pi M_S = 2.03$ (where M_S is a saturation magnetization) for aspect ratios $\alpha = L/2R$ equals 0.039 and 0.24; and $h_l = 0.59$ for $\alpha = 0.196$. The exchange energy is a linear function of a field amplitude for weak enough fields, while it becomes nonlinear one for strong fields, just before the vortex core reversal. Increasing of sample height is attended by formation of local minimum of dipolar energy. For strong fields this occurs before the reversal and for weak ones after the reversal. The switching process by vertical magnetic field in all these simulations is attended by injection of one BP. Before the reversal moment the magnetization distribution breaks the axial symmetry. For all simulations with upward and downward field directions the vortex core width decreases faster on bottom of the sample and the BP injected from the bottom face surface. Exchange energy is decreased linearly during its motion. The BP moves from the bottom to the top of the sample. We determined its position by the isosurface method [6]. Reverse process is finished under cross-section of all three isosurfaces and vortex polarity directed upward. Above the BP the vortex polarity in different lattice cuts is opposite to external magnetic field direction. The most time

motion of the BP is linear on speed; it does not depend on thickness of the sample for the same field amplitudes. The BP speed is nonlinear only in the first moments after injection. In wide range of aspect ratios from $\alpha = 0.039$ to $\alpha = 0.325$ the average velocity is not affected by the field.

(ii) We discuss two kinds of anisotropies: single-ion anisotropy and exchange one. While different anisotropy types are very similar in the continuum bulk theory, they can provide different mechanisms for the vortex polarity switching in the discrete system: the switching process is mediated by the BP in the case of exchange anisotropy, while it is mediated by the Bloch line in the case of single ion anisotropy. However the BPs appears if one takes into account the surface anisotropy terms, because they break the symmetry along sample thickness.

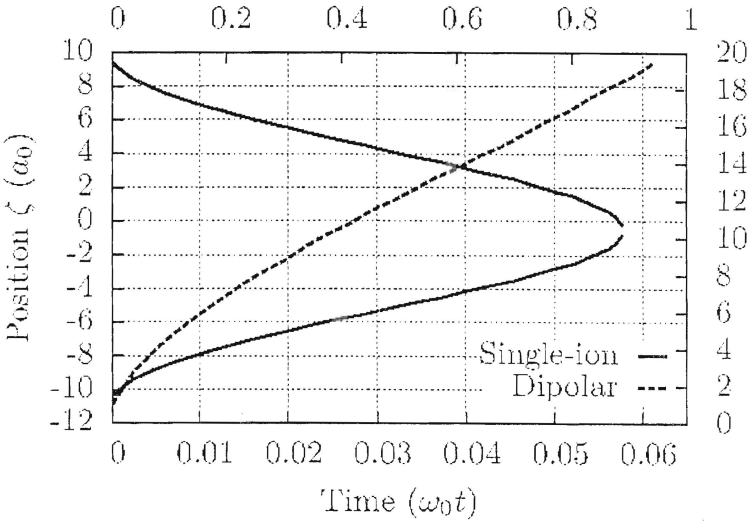

Fig.1 BP trajectories for different thicknesses. Left and bottom axes correspond to single-ion approach with two BPs injection (solid); right and top axes correspond to dipolar approach with one BP observed (dashed).

In all simulations with the BP dynamics the switching process is accompanied by two BPs, injected on face surfaces. Trajectories of BPs are almost linear except moments of injection and annihilation, see Fig. 1. BPs motion for thick samples is accompanied by formation of "magnetic drops", similar to the modeling of long cylinders [7]. Speed of each of BPs increases while height of disk decreases. Also nonlinear dependency on Gilbert relaxation coefficient was observed for wide interval of its values.

In order to gain some insight into the switching process, we describe analytically the magnetization structure with two BPs. Using the cylindrical coordinates (r, χ, z), we propose the following Ansatz for the normalized magnetization structure $\mathbf{m} = \mathbf{M}/M_S$:

$$m_x + im_y = i\sqrt{1-m_z^2}\,e^{i\chi}, \quad m_z = e^{-r^2/2\ell^2}\left(\frac{z-\varsigma}{\sqrt{r^2+(z-\varsigma)^2}} - \frac{z+\varsigma}{\sqrt{r^2+(z+\varsigma)^2}} - h\right) + h,$$

where ℓ is exchange length, $\varsigma \in (0, L/2)$ is BP coordinate, and h is external field normalized to anisotropy field. Using this Ansatz we calculated the energetic characteristics of the switching process, which are in qualitative agreement with simulated data.

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