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Low-Frequency Nonlinear Vortex Core Dynamics in Submicron Ferromagnetic Circular Dots

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Understanding of magnetization (**M**) dynamics in geometrically confined thin-film magnetic elements is crucially important in the future advancements of nanomagnetism and spintronics. The understanding of spin excitation spectra in restricted geometries can be achieved by combining theoretical approach, micromagnetic simulations, and sub-ns time-resolved and sub-m space-resolved measurements. In mesoscopic and nanoscale patterned elements (dots), non-uniform "vortex" **M** configurations are typicallyobserved at equilibrium. The magnetic vortex consists of a core with **M** perpendicular to the dot plane and a curling in-plane **M** configuration. The vortex ground state is stable within a wide range of dot sizes. Vortex excitation phenomena [1] offer insight into **M** dynamics on a fundamental level, and also govern field- (or current-) induced magnetization reversals in submicron patterned elements [2].

In this talk, we will present calculationsthe low-frequency (sub-GHz range) vortex dynamic excitations in submicron-size circular Permalloy dots, induced by a variable in-plane magnetic field of different amplitude and frequency. We consider vortex dynamical response to the oscillation field with the amplitudes below a critical threshold for the vortex-core (VC) reversal [2]. The observed low-frequency oscillations of the VC position are described as a gyrotropic motion of the VC around its equilibrium position induced by a gyroforce andmagnetostatic restoring forces. The topological charges such as vorticity and polarization determine the vortex gyrovector that is essential for the vortex dynamics [1]. We derived analytical equations of the VC field-driven motion in the non-linear regime in circular shaped thin dotsand compared them with micromagnetic simulations. The main source of the nonlinearity for the sufficiently large shifts of VC positionfrom the equilibrium is magnetostatic energy. The VC motion can be described in the terms of the variable core orbit radius and phase angle. For small-field amplitudes the VC orbit is elliptic. The exact form of the orbit depends on the relative value of the field frequency and vortex gyrotropic eigenfrequency. Increasing the field amplitude and keeping the frequency near the vortex eigenfrequency lead to the core oscillations with variable orbit radius. The vortex trajectory radius and phase angle oscillate with an eigenfrequency, which is proportional to the nonlinear coefficient of the magnetostatic energy and is essentially lower than the translation mode eigenfrequency. This picture is qualitatively the same for circular dots as well as single-vortex elliptic dots. There exists a threshold in the oscillating field magnitude to observe this complicated vortex motion. The developed model is beyond the standard "fold-over" model of the non-linear resonance.

This work was supported by the Creative Research Initiatives (Research Center for Spin Dynamics & Spin-Wave Devices) of *MOST/KOSEF*.

REFERENCES

[1] K. Yu. Guslienko et al., Phys. Rev. Lett., **96**, 067205 (2006) Appl. Phys. Lett., **89**, 022510 (2006).
[2] S. Choi, K.-S. Lee, K.Y. Guslienko, and S.-K. Kim, Phys. Rev. Lett. (in press).

CC03

Dynamics of Magnetic Vortex Core Switching in Fe Nanodisks by Applying an in-Plane Magnetic Field Pulse

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Magnetic vortex core switching has attracted much attention due to a wealth of scientific interest and their potential technological application for spintronic devices. Recently it has been demonstrated that the polarity of the vortex core can be switched by applying an in plane magnetic field pulse [1,2]. In the present work, the effect of the magnitude and duration of the magnetic pulse to the core switching is numerically investigated for 30 nm thick Fe disks with diameters between 100 nm and 1 μm. The modeling has been carried out by using OOMMF [3], which is based on Landau-Lifshitz-Gilbert (LLG) equation. We found that the process of vortex core switching strongly depends on the condition of the magnetic field pulse. In the initial state (i.e., at zero field) the vortex structure contains a single vortex core located at the disk center. When the magnetic pulse with an appropriate strength and duration is applied, the vortex configuration is perturbed away from the equilibrium state, and the circular symmetric distribution of the in plane magnetization around the vortex core deforms. The deformation originates from the opposite torque exerted on the in plane magnetization. Consequently the core shifted from the center leads to the charged area at the disk edges. In order to cancel out the edge charges the area close to the vortex core deforms, and the deformed area further develops to the region, where the spins strongly rotate into the plane in order to avoid the high energetic cost from the anti parallel in plane alignments of the nearest spins. This leads to the creation of a new vortex core with the opposite polarity and an antivortex. With increasing time, the vortex antivortex pair annihilates, and at this instant the energy concentrated in the vortex antivortex pair is rapidly dissipated into the surrounding area in the form of the spin wave. As a result of the annihilation, a single vortex core with opposite polarity remains and a vortex core switch is realized. The process of core switching, however, strongly depends on the amplitude and duration of the magnetic pulse. Fig. 1 is the diagram showing the pulse condition for vortex core switching for a 500-nm-diameter disk. When a magnetic pulse of 250 Oe in amplitude and 200 ps in duration is applied, for example, the core switching occurs via a single annihilation of vortex-antivortex pair. However, if the vortex state is excited by a magnetic pulse with higher amplitude or longer duration, it may result in multiple core switches. For example, keeping the pulse amplitude for 250 ps and increasing the field duration for 400 ps leads to a double annihilation, which is equivalent to a non core switch. This result implies that the core switches in vortex state can be controlled by varying the amplitude and duration of the pulse. It is suggested that this core switching mechanism could be applied to magnetic information technologies.

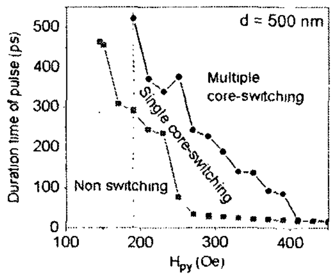

Fig. 1. Diagram of vortex core switching.

REFERENCES

[1] Q.F. Xiao, J. Rudge, B.C. Choi, Y.K. Hong, and G. Donohoe, Appl. Phys. Lett. **89**, 262507 (2006).
[2] B. Van Waeyenberge, A. Puzic, H. Stoll, K. W. Chou, T. Tyliszczak, R. Hertel, M. Fähnle, H. Brückl, K. Rott, G. Reiss, I. Neudecker, D. Weiss, C. H. Back, and G. Schütz, Nature **444**, 461 (2006).
[3] J. Donahue and D.G. Porter, OOMMF User's Guide, Version **1.0**, NIST (Sept 1999)