II-2

Switching of vortex chirality in $Ni_{80}Fe_{20}$/Cu/Co nanopillars by a spin-polarized current pulse

B.C. Choi[1]*, Y.K. Hong[2], J. Rudge[1], J. Kolthammer[1], A. Lyle[2], S. Bae[2], and G.W. Donohoe[3]

[1]Department of Physics & Astronomy, University of Victoria, Victoria, BC, Canada.

[2]Department of Electrical and Computer Engineering, University of Alabama, Tuscaloosa, AL, USA.

[3]Department of Electrical and Computer Engineering, University of Idaho, Moscow, ID, USA.

1. Introduction

The magnetization dynamics of vortex structures in patterned elements has received considerable attention during the last few years due to its possible applications in high-density magnetic storage devices [1-4]. Recently, it was found that the vortex core magnetization can be switched by applying a short magnetic field pulse with an appropriate strength and duration [2,3]. For practical applications, current-driven switching of the magnetization state of the vortex was proposed [4]. Here we report detailed micromagnetic studies of the spin-transfer effect on the vortex magnetization in magnetic multilayer structures.

2. Method of Micromagnetic Modeling

The micromagnetic modeling has been carried out using a code based on the Landau-Lifshitz equation; $d\mathbf{M}/dt = -|\gamma/(1+\alpha^2)|(\mathbf{M}\times\mathbf{H}_{eff}) - |(\alpha\gamma)/[M_s(1+\alpha^2)]|(\mathbf{M}\times(\mathbf{M}\times\mathbf{H}_{eff})$. Here, γ is the gyroscopic ratio, and α is a phenomenological damping constant. $\boldsymbol{H}_{eff}$ is the total effective field acting on the magnetization **M**, which mainly includes the applied external field, the exchange interaction, and the demagnetizing field. The spin-transfer torque effect is taken into account by including the Slonczewski term, $d\mathbf{M}_{1,2}/dt=\beta[\mathbf{M}_{1,2}\times(\mathbf{M}_1\times\mathbf{M}_2)]$, to the Landau-Lifshitz equation [5]. Here, the $\mathbf{M}_1$ and $\mathbf{M}_2$ are sequential along positive z, and β represents the driving term of the spin-momentum transfer and includes the degree of spin polarization of the current (η). In the simulations η = 0.26 (0.4) for Py (Co) are used, and the element is subdivided into unit cells of the dimension of 2×2×2 nm^3. The other parameters used are the saturation magnetization M_s = 800 (1414) emu/cm^3 for Py (Co), exchange constant A = 1.0510^6 (3.0510^6) erg/cm for Py (Co), and zero magnetic anisotropy constant.

3. Results and discussions

Fig. 1(a) is a schematic of the multilayered structure used in our study. The diameter is 100 nm, and the fixed magnetic layer (Co) is separated from the free magnetic layer (Py) by a 4 nm thick Cu layer. The bottom panel of Fig. 1 shows the initial magnetization configurations in the Py (b) and Co (c) layers, respectively. Each layer contains a single vortex core located at the center of the disk, and M_{Py} and M_{Co} are aligned close to parallel forming a small angle between M_{Py} and M_{Co}. To study the dynamic response of the vortex magnetization to the spin-polarized current pulse, the equilibrium micromagnetic distributions of M_{Py} and M_{Co} are excited by injecting a short current pulse. The current direction is denoted positive when it flows from Py to Co layer. Fig. 2 shows a series of the nonequilibrium configurations of M_{Py} captured at selected times after a negative current pulse of 30 mA ($\approx 1\times10^8$ A/cm^2) with the duration of 200 ps is applied. Following the temporal evolution of the micromagnetic configuration, one finds that individual M_{Py} undergoes the CW rotation, while the whole vortex configuration appears to circulate CCW around the disk center. The image (b), captured at 84 ps after the current pulse is applied, reveals that M_{Py} rotates by ~90°, and with increasing time M_{Py} further rotates by ~180°, as shown in (c) captured at 144 ps. Finally, the vorticity of M_{Py} switches to CW (d). M_{Py} of the switched vortex state, however, is still in a nonequilibrium state, and the dynamics of the energy dissipation after the initial vortex chirality switching involves a series of complex magnetization processes. The magnetization configuration in (d), for instance, reveals a high degree of complexity both due to the nonunifrom distribution of $M_{Py}$and the creation of an additional vortex-antivortex pair. The pair is found to be a metastable micromagnetic state, and it vanishes without undergoing the annihilation process. As shown in Fig. 2(e), a full relaxation of $M_{Py}$is reached after about 2 ns after the excitation. By contrast, the micromagnetic distribution of M_{Co} is only slightly perturbed from the initial state through the entire process of the chirality switching of M_{Py}, and no switching of vortex chirality of M_{Co} occurs(f). After the reversal of the vortex chirality of M_{Py} is completed, the curling in-plane magnetizations of M_{Py} and M_{Co} remain aligned nearly antiparallel to each other, implying that the vortex configuration shown in (e) and (f) is an energetically stable micromagnetic state in the nanopillar. Finally, the switchedvortex chirality is reversed back to the initial vortex configurations of M_{Py} and M_{Co} by applying a positive current pulse, 25 mA in amplitude and 200 ps in duration. The critical current density required for the back-switching is reduced to about 8×10^7 A/cm^2, which is about 20% lower than the value needed for the negative current pulse discussed in Fig. 2.

4. Conclusions

In conclusion, the switching of the vortex chirality of $M_{Py}$is understood in terms of the spin-transfer torque exerted on M_{Py}. The dynamics of the energy dissipation in the chirality switching involves a series of complex magnetization processes, which includes the magnetization precession and creation of additional vortex and antivortex cores. From an application point of view, the results suggest opportunities to implement the novel switching mechanism to memory device applications, in which vortex states with opposite chiralities in the free layer of a magnetic multlayer may be used as memory bits.

5. References

[1] B. Van Waeyenberge et al, Nature 444, 461 (2006).
[2] Q.F. Xiao et al, Appl. Phys. Lett. 89, 262507 (2006).
[3] R. Hertel et al, Phys. Rev. Lett. 98, 117201 (2007).
[4] B.C. Choi et al, Appl. Phys. Lett. 91, 22501 (2007).
[5] J.C. Slonczewski, J. Magn. Magn. Mater. 159, L1 (1996).

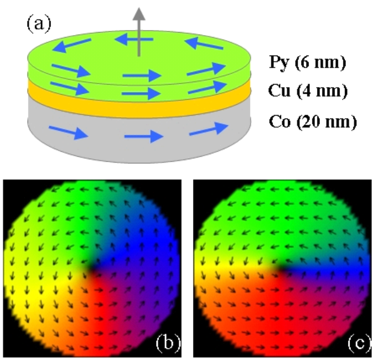

Fig. 1.

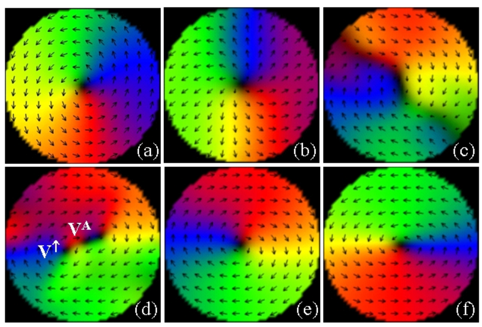

Fig. 2.