Controlled Vortex-core Switching in Micron-size Permalloy Disks by Orthogonalunipolar Gaussian-pulse Currents

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1. Introduction

The well-known magnetic-vortex spin structure is characterized by an in-plane-curling magnetization and its out-of-plane core orientation of either upward or downward magnetization. Owing to the binary-state core orientation, as well as the energetically very stable configuration, the vortex-core object has been considered to be potentially an ideal candidate for information storage applications. Very recently, low-power driven switching is available only by assistance of the resonant excitation of vortex-core gyration [1,2]. As a necessary step towards implementation of magnetic vortices in actual nonvolatile magnetic random access memory (VRAM) as proposed in Ref. [3, 4], we experimentally demonstrated a low-power recording scheme using orthogonal and unipolar pulse currents based on the existing cross-point architecture.

2. Experiments

Permalloy (Py, $Ni_{80}Fe_{20}$) films were deposited by magnetron sputtering under base pressures of less than 5×10^{-9} Torr and then were patterned by typical e-beam lithography (Jeol, JBX9300FS) and subsequent lift-off processes to obtain Py disks of radius R=2.5 μm and thickness L=70 nm. Each Py disk was placed at the intersection of 50-nm-thick crossed-stripline Au electrodes and was capped with 2-nm-thick Pd layers (without breaking the vacuum) to prevent oxidation. The crossed-stripline has a single intersection 50 nm thick and 20 m wide on which a single Py disk is placed. In order to obtain sufficient soft x-ray transmission through the samples, the electrodes were deposited onto 200-nm-thick Si_3N_4 membranes of a 5 mm-by-5 mm window by electron-beam evaporation under base pressures of less than 1×10^{-8} Torr. The local out-of-plane magnetizations of the vortex cores in the Py disks were measured using a full-field soft x-ray transmission microscope through x-ray magnetic circular dichroism contrast at the Fe L_3 edge at the Advanced Light Source (Beamline 6.1.2) in Berkeley, California, USA [5].

3. Results and Discussion

For efficient vortex-core switching, we used two short (~ns) unipolar and Gaussian-pulse currents orthogonally applied along two crossed striplines with pulse width (σ) and time delay (Δt). The superposition of the Oersted fields induced by the orthogonal Gaussian-pulse currents yields pulse-type rotating fields locally at the intersection of the two orthogonal current paths. To obtain the optimal pulse parameters of currents that are close to ideal circular-rotating fields and hence most efficient to switch the vortex-core with the lowest strength of them, we performed analytical calculations and numerical simulations and found the optimal values to be $\sigma = 1/\omega_D$ and $\Delta t = p\left(2n+\frac{1}{2}\right)\pi/\omega_D$ with n = 0, 1, 2,, where p is the vortex polarization of the initial state and ω_D is the eigenfrequency for the given dots. Using those optimal pulse parameters, we then experimentally measured vortex-core switching events driven by aforementioned pulse-type rotating fields with different values of pulse amplitude (H_0), σ, and Δt. The experiment results showed that the vortex core can be manipulated according to the polarization of the pulse-type rotating fields and that a remarkable one- or two-orders-of-magnitude reduction of the threshold field strength can be achieved simply by optimizing the values of σ and Δt.

4. Conclusion

The results of this work, gleaned from the exploration of a new device based on a new material, that is, a medium composed of patterned vortex-state disks, and together with the new physics on ultrafast vortex-core switching dynamics, then, should boost the impetus of research into conventional MRAM, based on the unique vortex structure and its novel dynamic properties.

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5. References

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