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Magnetic Vortex-Antivortex Dynamics in Rectangular Permalloy Patterns on Picosecond Timescale

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Dynamics of magnetic vortex and antivortex structure has attracted much attention due to their possible applications for magnetic memory and logic devices. A gyrotropic motion of magnetic vortex core around the equilibrium position of patterned ferromagnet under a short external pulse field has been intensively studied. Recently, the vortex core switching has been experimentally explored by applying short burst of AC field[1] or by injecting spin-polarized electrical current[2]. Numerical studies have been carried out to investigate vortex core switching phenomenon[3], where most of calculations predict a switching mechanism involved with generation of a vortex-antivortex pair during the core switching. In this work, we report our observation of the vortex-antivortex pair dynamics in patterned Permalloy rectangles. Soft X-ray transmission microscopy at the beamline 6.1.2 of Advanced Light Source has been adopted to carry out a time-resolved observation on picoseconds timescale. Samples were prepared on 100-nm Si3N4 membrane substrate. 100-nm coplanar Au waveguide structure were patterned and 50-nm thin PY rectangles of various sizes on the waveguide structure. A stroboscopic pump-probe measurement was performed to observe a fast spin dynamics. The pump electric pulse of 1-ns duration is generated by pulser and then guided through the Au waveguide, yielding a 1-ns magnetic field pulse coming from the Oersted field. The pumping field direction is shown in Fig. 1. The probes are X-ray flashes of the synchrotron and the X-ray flash has 70-ps pulse duration with each X-ray flash separated by 328 ns. The pump is controlled to be delayed with 100-ps time step up to 8 ns stroboscopic time window. We have observed the dynamics of two magnetic vortices placed in a 2x4 um2 PY rectangle with ground state of 7-domain flux closure state, as shown in Fig. 1. The pattern is initially reset by a saturating field. By applying a pulse field of 1-ns duration, the two vortices are excited. Very interestingly, it has been found that there exists a connecting domain structure between the left and the right excited cores. Repeated observations revealed that the connecting domain only survived less than 1 ns. The contrast of the connecting domain becomes either dark or bright, as demonstrated in Fig. 2, depending on the initial saturating field direction. Micromagnetic simulation fully supports our experimental observation with prediction that the excited vortex core generates a pair generation of vortex and antivortex and that a connecting domain is formed between the two antivortex cores surviving only surviving very shortly.
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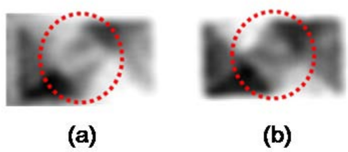
Ground state magnetic domain image of 2 x 4 um2 PY rectangle. Dotted arrow denotes the direction of the external pulse field.



Magnetic domain configuration at t = 800 ps with (a) bright contrast connecting domain and (b) dark contrast connecting domain.