Fast Vortex Core Switching in Nanoscale Magnetic Elements

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Introduction

The prospect of using magnetic nanostructures for ultra fast storage applications is one of the important driving forces for the research efforts in modern magnetism. The recent discovery of an easy switching mechanism of the core polarization of magnetic vortices [1] made magnetic vortex structures a the focus of attention.

The magnetic vortex state, characterized by an in-plane curling magnetization, is one of the common equilibrium configurations of thin film ferromagnetic structures [2]. In the centre of the element the magnetization avoids the energy cost of anti-aligned magnetic moments by turning perpendicular to the sample surface, forming a vortex core with a diameter in the range of 10-20 nm [3]. As magnetic vortex structures are intrinsically very stable and have low stray fields, they are ideal candidates for high density integration.

Micromagnetic simulations indicate that vortex core switching could be extremely fast (below 50 ps) when short magnetic field pulses are used [4]. It surpasses the fastest switching schemes known up to now which is precessional switching [5]. However, the experimental confirmation of switching with short pulses is still missing.

Science

By taking advantage of the X-ray magnetic circular dichroism (XMCD) [6] high resolution X-ray microscopy allows us to study the magnetization dynamics in nano- scaled magnetic elements, like vortex core polarization switching. State-of-the-art Fresnel zone plates allow lateral resolutions below 30 nm to be achieved in scanning transmission X-ray microscopy (STXM), like at the Soft X-ray Spectromicroscopy beam line (10ID-1).

By exploiting the pulsed nature of the synchrotron light, time resolved imaging was implemented at the STXM. A fast pulse generator, synchronized with the accelerator, is used to excite the sample. A current pulse is sent through a strip line below the sample and generates a magnetic field pulse. In addition, a fast X-ray detector combined with a fast data acquisition system allowed us to record the intensity of the individual photon flashes of the synchrotron. In this way, we are able to track the changes of the magnetization with a time resolution of about 70 ps as determined by the width of photon flashes.

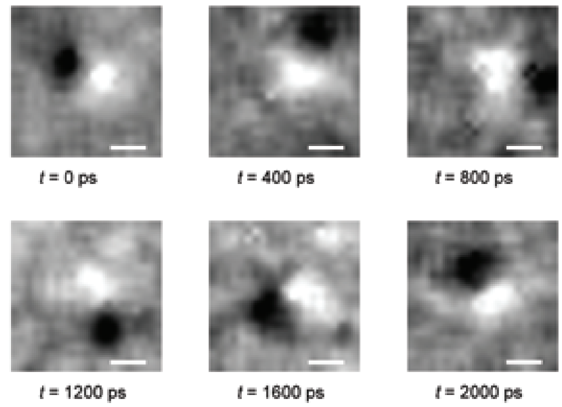

Figure 1: Observation of the vortex gyration at a time t after the application of 700 ps long, 50 mT high magnetic pulse. The out-of-plane magnetization from the vortex core is directly imaged. To enhance the contrast, each frame of the image was divided by the frame before the pulse was applied and the structure was fully relaxed. The black contrast is the signal from the gyrating vortex core, the white contrast is the signal from the static vortex core in the relaxed position. The length marker is 50 nm.

Square shaped Permalloy ($Ni_{80}Fe_{20}$) elements with a size of 500 nm x 500 nm x 50 nm, were lithographically patterned on copper strip lines and exhibit a vortex configuration as their magnetic ground state. These elements where excited by magnetic field pulses with different lengths and heights. A field pulse will move the vortex away from its equilibrium position, after which it will spiral back to its equilibrium position (see Figure 1). If the field accelerates the vortex sufficiently and the critical switching speed is reached [7], the vortex will change it vortex core polarization which can be directly evaluated with STXM [8]. For the structures investigated, we found that magnetic field pulse of 700 ps length and 60 mT strength could induce core reversal. Decreasing or increasing the pulse length at this field strength did no longer switch the core polarization.

Discussion

The parameters for vortex core reversal coincide with an area in the pulse length versus pulse strength plane identified with micromagnetic simulations, where a single core reversal results from the consecutive kicks which the vortex receives from both, the leading and falling edge of the pulse. As the pulse length corresponds to the vortex gyration frequency both “opposite” kicks accelerate the vortex to the critical switching speed. The experimental identification of this area is an important confirmation of the micromagnetic simulations.

Further investigations should enable us to evaluate the other area the pulse length versus pulse strength plane and confirm the claimed ultimate switching speeds.

Conclusion

The implementation of time-resolved magnetic microscopy at the STXM allowed the investigations of the magnetization dynamics in nano magnets. We have studied the switching behaviour of the core polarization in magnetic vortex structures excited by short magnetic field pulses. Such a reversal scheme might open new ways for using vortex structures in ultra fast, high-density data storage applications.

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