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Time-resolved X-ray microscopy of ac-field-driven coupled magnetic vortices

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The dynamics of magnetic vortices has recently become a popular research field [1, 2], because it allows to study fundamental interactions between a body's magnetization with other constituents, e.g., electrical currents via the spin-transfer torque [3], and because magnetic vortices can potentially be used in non-volatile solid-state memory [4] or high-frequency data transmission devices [5]. Although the gyrotropic mode and switching of a single vortex core seem to be quite well understood [6, 7], understanding the interaction between several vortices [8, 9] has still been lacking. This coupling would cause a surprisingly rich variety in the dynamics of the participating vortices.

We used time-resolved soft X-ray microscopy supported by micromagnetic simulation to investigate the coupling between two neighboring micro- and nanodisks in which each contains a single vortex. We prepared pairs of permalloy microdisks with variable interdisk distance. In this study, we excited one vortex-state disk in a pair with alternating magnetic fields with different frequencies via a copper stripline deposited onto one disk of each pair (see Figure 1). The other vortex is then excited indirectly through dipolar interaction of the first vortex (positioned on the right). We observe the magnetization dynamics in both disks using the XMCD contrast mechanism and the 25 nm spatial and temporal resolution of the XM-1 full-field X-ray microscope at the Advanced Light Source in Berkeley, USA (see Figure 2). While from the absolute images the direction of the in-plane magnetization could be extracted, the differential images allowed the determination of the sense of gyration, and hence the polarization of the vortex cores, as well as the amplitudes and phases of the gyrations. The phase difference in the gyration of the two vortices allows an estimate of the coupling strength as opposed to the Oersted field of the stripline. The measurements revealed several fascinating insights: Firstly, the images show a decreasing gyration amplitude in the coupled vortex for increasing interdisk distance, in agreement with micromagnetic simulations and an analytical model. The gyration amplitudes also show a strong dependence on the relative vortex configuration (chirality and polarization) of each disk in a pair as well as on the excitation frequency, thus allowing one to test present models for vortex pairs as coupled harmonic oscillators.

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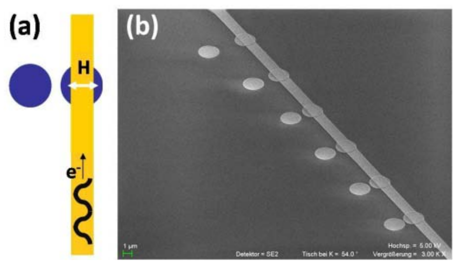

Figure 1: (a) Sketch and (b) scanning electron microscopy image of the sample layout, a pair of thin permalloy microdisks in which one is covered by a copper stripline. The right vortex is excited by an alternating magnetic field in the horizontal (x-) direction. Disk pairs with several interdisk distances were investigated.

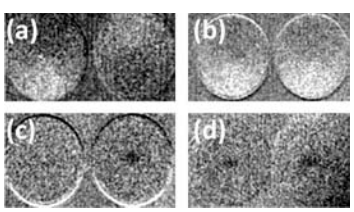

Figure 2: X-ray images of two 2.4 µm large and 50 nm thick permalloy disks separated by 120 nm, using the absolute and differential XMCD contrast. Images (a) and (b) show the in-plane magnetization of the two vortex disks having opposite and same chirality, respectively. Images (c) and (d) show the differential image between the minimum and maximum vortex-core position in y-direction of the images shown in (a) and (b). The vortex pair having opposite chirality (c) shows no excitation in the left vortex, while the vortex pair with equal chirality (d) has almost equal gyration amplitude in both vortices.