Dipolar-interaction induced vortex gyrations in coupled vortex oscillators

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The unique spin configuration of the in-plane curling magnetization and out-of-plane core magnetization in magnetic vortices found in restricted geometries is an interesting object, and thus becomes one of central research issues in the fields of nanomagnetism and spin dynamics owing to its novel dynamic properties recently found from experimental, theoretical, and numerical studies[1-3]. Among those dynamic properties, persistent vortex-core oscillations and ultrafast core switching, which are driven by oscillating fields or currents of frequencies close to the characteristic eigenfrequencies, can potentially be implemented in future nano-oscillators and nonvolatile memory devices, respectively. For the practical applications of vortices, arrays of vortices periodically arranged with a certain interdot distance are supposed. Therefore, it is interesting to see how fundamental dynamic behaviours of a single vortex in a dot are affected by dipolar interactions between the neighboring dots, when they are close enough [4].

In the present work, we performed, for the first time, real-time and real-space imaging of vortex gyrations in physically disconnected vortex-state dots, driven directly by field pulses as well as driven indirectly by the dipolar interaction, using a 70-ps-time- and 20-nm-space-resolved magnetic transmission soft x-ray microscope (MTXM) at beamline 6.1.2 at Advanced Light Source, Berkeley. We observed dipolar-interaction induced gyrations in coupled two Permalloy (Py) cylindrical dots [see Fig. 1(a)]. Only one of the vortices was excited by the Oersted field of an overlaid copper stripline while the second vortex-state dot placed at a specific interdot distance could only be excited indirectly. We measured the gyration amplitudes of the vortices in both dots for about 60 ns following field pulses of 5 ns or 30 ns length. We observed a decrease in the amplitude in the originally excited vortex, much stronger than the free damped oscillation of a single vortex. At the same time the amplitude of the vortex in the second dot increased about threefold suggesting dipolar-interaction induced gyration in the two coupled dots [see Fig. 1(a) and (b)].

In order to understand the dipolar-interaction effect on the observed vortex gyrations, we also performed micromagnetic numerical calculations of dipolar-coupled vortex gyrations in the Py dots separated by different distances. The simulation results reveal good agreements with the experimental results, oscillatory changes in the orbital amplitude of the vortex core motions in the two dots and their phase difference, depending on the relative configurations of both chirality and

polarization between the two single vortices. Also, a splitting of the vortex eigenfrequency into the high and low frequencies is observed. It is found that the high and low frequencies correspond to the in-phase and out-of-phase of the relative core motions in the two dots, respectively. With decreasing the interdot distance between the two dots, the splitting gap between the high and low frequencies increases, revealing their strong coupling.

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References: [1] R. Hertel, S. Gliga, M. Fähnle, and C. M. Schneider, Phys. Rev. Lett. 98, 117201 (2007); K.-S Lee, K. Y. Guslienko, J.-Y. Lee, and S.-K. Kim, Phys. Rev. B 76, 174410 (2007).
[2] B. V. Waeyenberge, A. Puzic, H. Stoll, K. W. Chou, T. Tyliszczak, R. Hertel, M. Fähnle, H. Brückl, K. Rott, G. Reiss, I. Neudecker, D. Weiss, C. H. Back, and G. Schütz, Nature 444, 461 (2006); K. Yamada K. Yamada, S. Kasai, Y. Nakatani, K. Kobayashi, H. Kohno, A. Thiaville, and T. Ono, Nature Mater. 6, 296 (2007).
[3] S.-K. Kim, K.-S. Lee, Y.-S. Yu, and Y.-S. Choi, Appl. Phys. Lett. 92, 022509 (2008); Y.-S. Choi, K.-S. Lee, and S.-K. Kim, Phys. Rev. B 79, 184424 (2009).
[4] J. Shibata, K. Shigeto, and Y. Otani, Phys. Rev. B 67, 224404 (2003); J. Shibata and Y. Otani, Phys. Rev. B 70, 012404 (2004); K. S. Buchanan et al., Nature Phys. 1, 172 (2005).

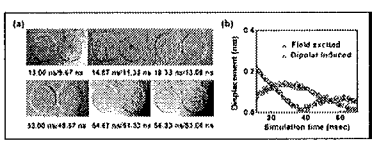

Fig. 1. (a) Differential images of the two MTXM images taken at the indicated times, corresponding to the 180° phase difference of the relative core position in each dot. Two Py dots have a 120 nm interdot distance, each of 2.4 μm diameter and 50 nm thickness. On the right dot, 1.5 μm wide, 60 nm thick Cu stripline electrode was deposited to excite only one dot in the pair by applying magnetic fields. The images were taken at the indicated times after the excitation by a 9-ns-long pulse field. (b) Simulation results: Vortex core radius vs time after turning off a 9-ns-length pulse for a dot pair of 300 nm diameter, 6 nm thickness, and 15 nm interdot distance. Field excited and dipolar-interaction induced vortex gyrations are distinguished by different symbols, as indicated.