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Theoretical Modeling, Simulation and X-ray Microscopy Measurements of Magnetic Vortex and Antivortex Dynamics

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Magnetic vortices are interesting because of their potential application in non-volatile memory devices. Due to their high spatial symmetry they also facilitate the study of the fundamental mechanisms of the interaction between the itinerant and localized electron spins through spin-torque transfer. That vortices gyrate on elliptical orbits around their equilibrium position when excited by field pulses or alternating fields[1]. Vortex cores can switch their polarization when the excitation exceeds a certain threshold amplitude [2], however, the exact mechanism of the switching as well as of the development towards the switching is still being actively investigated. Recently it was shown by time-resolved X-ray microscopy that vortices also gyrate when excited by in-plane alternating spin-polarized currents, but it was experimentally shown that a part of the excitation derives from the currents' attending Oersted field. This has grave consequences for the interpretation of current-driven vortex-core switching in experiments. The findings could be matched to micromagnetic simulations as well as an analytical model that describes the gyrating vortex by a harmonic oscillator[3]. At sufficiently high current densities we also observed vortex-core switching due to linear ac currents. Switching caused by rotating spin-polarized currents at much lower current densities. After the switching the vortex would not move anymore since rotating currents favor the corresponding gyrotropic mode.

The dynamics of the antivortex, the vortices' topological counterpart, has been studied much less, even though both occur naturally in thin films, e.g., in crosstie domain walls. This is in part due to the difficulty to isolate individual antivortices. We simulated the field- and current-driven dynamics of single antivortices[4] and found that their gyration can also be modelled by harmonic oscillators[5]. We isolated individual antivortices in specially shaped microstructures and investigated their dynamics by time-resolved X-ray microscopy. It was shown that antivortices indeed gyrate in analogy to magnetic vortices, even though their gyration amplitude and phase differs from corresponding vortices.

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CB04

Giant Resonance Asymmetry of Circularly Rotating Eigenmodes in Vortex Gyrotropic Motions in Soft Magnetic Circular Nanodots

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The magnetic vortex observed in continuous [1] or patterned [2] submicron-size (or smaller) thin films, is a unique micromagnetic structure as a ground state of the in-plane curling magnetizations (Ms) with the out-of-plane M at the core, the so-called vortex core (VC). Such a peculiar M structure shows a rich spin excitation spectrum including the vortex translational, radial, and azimuthal modes [3]. For example, when the VC is shifted from its equilibrium center position, the translational mode is excited; the VC gyrates around its equilibrium position with an eigenfrequency. Quite recently, owing to the experimental finding of dynamic VC switching through a resonant VC gyrotropic motion [4], much attention has been paid to the resonant excitation of the vortex gyrotropic motion driven by single harmonic oscillating magnetic fields or currents. However, the true eigenmodes of vortex gyrotropic motion have not been clarified.

In this presentation, we report on the clockwise (CW) and counter-clockwise (CCW) rotating circular eigenmodes of linear-regime vortex motions in response to pure CW and CCW rotating magnetic fields or currents, based on linearized Thiele's equation of motion. In addition, the asymmetric resonance effect of the two eigenmodes were found; CCW (CW) eigenmode of the up- (down) core vortex state shows a strong resonance at the resonance frequency. Such asymmetric resonance effect originates from a broken time reversal symmetry of the VC motion due to the presence of the gyroforce on VC. Furthermore, it was found that the relative magnitude in the orbital radius and phase between the two eigenmodes determine the shape of elliptical orbital trajectories observed at off-resonance VC motions driven by linearly polarized oscillating magnetic fields [5]. To verify above analytical calculations, we conducted micromagnetic simulations. These works offer not only fundamental understanding of vortex gyrotropic motions but also a practical method of reliable low-power control of the VC orientation by utilizing the asymmetric resonant effect of vortex eigenmodes.

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