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Asymmetric and Stochastic Behavior in Magnetic Vortices Studied by Soft X-ray Microscopy

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Asymmetry and stochasticity in spin processes are not only long-standing fundamental issues but also highly relevant to technological applications of nanomagnetic structures to memory and storage nanodevices. Those nontrivial phenomena have been studied by direct imaging of spin structures in magnetic vortices utilizing magnetic transmission soft x-ray microscopy (BL6.1.2 at ALS). Magnetic vortices have attracted enormous scientific interests due to their fascinating spin structures consisting of circularity rotating clockwise ($c = +1$) or counter-clockwise ($c =$-1) and polarity pointing either up ($p = +1$) or down ($p =$-1). We observed a symmetry breaking in the formation process of vortex structures in circular permalloy ($Ni_{80}Fe_{20}$) disks. The generation rates of two different vortex groups with the signature of $cp= +1$ and $cp=$-1 are completely asymmetric. The asymmetric nature was interpreted to be triggered by intrinsic Dzyaloshinskii-Moriya interaction (DMI) arising from the spin-orbit coupling due to the lack of inversion symmetry near the disk surface and extrinsic factors such as roughness and defects. We also investigated the stochastic behavior of vortex creation in the arrays of asymmetric disks. The stochasticity was found to be very sensitive to the geometry of disk arrays, particularly interdisk distance. The experimentally observed phenomenon couldn't be explained by thermal fluctuation effect, which has been considered as a main reason for the stochastic behavior in spin processes. We demonstrated for the first time that the ultrafast dynamics at the early stage of vortex creation, which has a character of classical chaos significantly affects the stochastic nature observed at the steady state in asymmetric disks. This work provided the new perspective of dynamics as a critical factor contributing to the stochasticity in spin processes and also the possibility for the control of the intrinsic stochastic nature by optimizing the design of asymmetric disk arrays.

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