One-dimensional magnonic crystals of dipolar coupled vortex lattice

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1. Introduction

Recently, technological interest in the practical applicability of MCs to future information processing devices [1] is rapidly growing. In patterned MCs, magnonic band structures including band widths and gaps can, in principle, be controlled and varied through their constituent materials and the isolated elements' dimensions and separation distance [2]. However, despite recent elucidations of the allowed magnonic modes in a rich variety of MCs, relatively low-frequency, collective vortex-gyration modes in vortex-state arrays remain elusive, notwithstanding theoretical prediction [3] of dipolar-coupled vortices in 2D magnetic disk arrays and the experimental demonstrations of vortex-gyration transfer between two coupled disks [4] and among more than two disks [5].

2. Experimental and Numerical Calculation Method

In the experiment, we used a chain of five Py disks fabricated onto a 100-nm-thick silicon-nitride membrane using electron-beam lithography and lift-off techniques. Each disk had a thickness of 60 nm and a diameter of 2 μm. The center-to-center distance between neighboring disks was 2.25 μm. An 800-nm-wide Cu stripline of 120 nm thickness (with a gold cap of 5 nm thickness) was deposited onto the first disk for the purpose of excitation of vortex gyration. We directly observed the trajectories of the core motions of all of the individual disks by STXM measurement of the out-of-plane core magnetizations at the MAXYMUS beamline (BESSY II; Helmholtz-Zentrum Berlin, Germany). The experimental results, obtained from the STXM measurement, were compared with micromagnetic simulations obtained using the OOMMF code (version 1.2a4) and numerical calculation of coupled Thiele equation. In the micromagnetic simulations and numerical calculation, dimensions identical to those of the sample applied in the experiment were used. We applied the following material parameters for Py: saturation magnetization $M_s = 780\times10^3$A/m, exchange stiffness constant $A_{ex}=1.3\times10^{-11}$J/m, and Gilbert damping constant $\alpha=0.01$.

3. Results and Conclusion

The results reveal that characteristic dispersions can be expressed simply in terms of the intrinsic angular eigenfrequency of isolated disks and their specific polarization (*p*) and chirality (*C*) ordering. The dynamic dipolar interaction determined by the specific *p* and *C* orderings governs the magnonic band structure of a given one dimensional array. Accordingly, and promisingly, the propagation property of collective vortex gyration and its dispersion can be manipulated by vortex-state ordering, the dimensions of each disk, and the nearest-neighbouring disks's interdistance [7]. Such dispersion of those modes is controllable by changing the eigenfrequency of vortex gyration, and dipolar coupling strength between neighboring disks as well as polarization and chirality ordering. This substantial work can provide a new class of magnetic metastructures based on collective modes of vortex gyrations in 1D or 2D magnonic crystals composed of periodic magnetic dot arrays with vortex-state ordering, promising for their potential implementation into information processing devices.

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4. Reference

[1] A. V. Chumak *et al.*,Phys. Rev. Lett. 108, 257207 (2012); J. Ding, M. Kostylev and A. O. Adeyeye, Phys. Rev. Lett. 107, 047205 (2011);

[2] K.-S. Lee, D.-S. Han, and S.-K. Kim, Phys. Rev. Lett. 102, 127202 (2009); A. V. Chumak *et al.*, Appl. Phys. Lett. 95, 262508 (2009)

[3] H. Jung *et al.*, Appl. Phys. Lett. 97, 222502 (2010); H. Jung, *et al.*, 1, 59; DOI:10.1038/srep00059 (2011); S. Sugimoto *et al.*, Phys. Rev. Lett. 106, 197203 (2011); A. Vogel *et al.*, Phys. Rev. Lett. 106, 137201 (2011).

[4] S. Barman, A. Barman, Y. Otani, IEEE Trans. Magn. 46, 1342 (2010); A. Vogel, M. Martens, M. Weigand, G. Meier, Appl. Phys. Lett. 99, 042506 (2011).