Collective gyration modes in one-dimensional skyrmion lattices

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1. Introduction

Magnetic skyrmions are topologically protected spin textures, which are promising potential candidates for information-storage and -processing device applications due to their characteristic features including nano-scale size, topological stability, and ultra-low threshold current density necessary for their motions [1]. From the fundamental interest as well as technological applications, several internal modes of skyrmion crystals, such as gyration mode and breathing mode have been explored [2,3]. Furthermore, collective excitations in 1D chains of single-skyrmion nanodisks along with spin-wave propagations and their dispersion in 1D periodic skyrmion lattice nanostrips have been investigated as well [4,5]. However, collective skyrmion gyration modes in narrow nanostrips still remain elusive. Here, we report on a micromagnetic numerical simulation study of coupled skyrmion gyration modes in 1D periodic skyrmion lattices in narrow-width nanostrips and their applications for reliable information carriage in straight and curved nanostrips.

2. Methods and Results

In the present study, we employed the Mumax3 code [6] to numerically calculate the coupled gyration modes and their characteristic dispersions. Two, five and more skyrmions are periodically arranged in continuous thin-film narrow-width nanostrips. The first skyrmion core at the left end was displaced and relaxed to study dynamic coupled motions. The collective motions of the individual skyrmion cores show unique standing-wave forms of different wavelengths. The dispersion curves in the reduced zone scheme were obtained and the overall shape was concave up. Additionally, the band structure of 1D skyrmion lattices was varied by changing the skyrmion interdistances (d_{int}) and perpendicular field (H_z). As d_{int} decreases, the band width $\Delta\omega$ and the angular frequency ω_{BZ} at $k = k_{\mathrm{BZ}}$ increase. Also, $\Delta\omega$ and ω_{BZ} of the resultant band structures decrease with increasing H_z.

3. Discussion

Such collective dynamic motions are determined predominantly by a strong exchange interaction according to the relative positions of the nearest-neighboring skyrmion cores. Also, the linear dependences of ω_{BZ} on H_z are mostly associated with the variation of the ω_0 of the isolated skyrmions. From a technological point of view, such gyration-signal propagation in a 1D skyrmion array can be used as a reliable information carrier. The propagation speeds generally follow the dependence of ω_{BZ} on d_{int} and H_z. The results are promising for potential signal-processing applications.

4. Conclusion

In summary, we explored the gyration modes of coupled skyrmions and their dispersions in 1D skyrmion lattices. The modes and their characteristic dispersion relations were examined for different skyrmion interdistances and perpendicular magnetic fields externally applied to the nanostrips. Additionally, the controllability of the dispersion curves and skyrmion gyration propagation were demonstrated. The strong exchange coupling between neighboring skyrmions leads to the propagation of skyrmion gyrations as fast as ~135 m/s, which value, significantly, are controllable by applied perpendicular fields. This work provides not only a fundamental understanding of the dynamics of coupled skyrmions but also a new type of skyrmion magnonic crystal applicable to future information processing devices.

5. References

[1] A. Fert, V. Cros, and J. Sampaio, Nature Nanotech. 8, 152 (2013).

[2] M. Mochizuki, Phys. Rev. Lett. 108, 017601 (2012).

[3] Y. Onose, Y. Okamura, S. Seki, S. Ishiwata, and Y. Tokura, Phys. Rev. Lett. 109, 037603 (2012).

[4] M. Mruczkiewicz, P. Gruszecki, M. Zelent, and M. Krawczyk, arXiv:1502.08024v1 (2015).

[5] F. Ma, Y. Zhou, H.-B. Braun, and W. S. Lew, Nano Letter 15, 4029 (2015).

[6] A. Vansteenkiste, J. Leliaert, M. Dvornik, F. Garcia-Sanchez, and B.V. Waeyenberge, AIP advances 4, 107133 (2014).