II-21

Radiation, Propagation, Transmission, and Reflection Properties of Spin Waves in Confined Magnetic Thin-Film Model Systems

Ki-Suk Lee*, Sangkook Choi, Sang-Koog Kim
Research Center for Spin Dynamics and Spin-Wave Devices (ReC-SDSW)
and Nanospintronics Laboratory Seoul National University

1. Introduction

Spin-wave excitations in confined magnetic thin films begin to attract much attention because of its practical applications to magnetic logic devices [1] as well as its fundamental interest [2]. Both theoretical and experimental studies have thus been increased in numbers for the exploration of the spatial and temporal characteristics of spin waves excited in micrometer-scale magnetic elements. From a technological point of view, a logical operation using traveling spin waves is also of a great interest because they can deliver information with a controllable phase of them being propagating in magnetic media. In order to make those spin waves practical in the applications, it is required that they should be produced in a radiation manner and then propagate well inside variously shaped waveguides. In this work, we report on the radiation behaviors of spin waves produced around magnetic vortex cores in rectangular and circular shaped magnetic elements and their propagation behaviors along nanowire-type waveguides, which are examined in the present modeling study [3][4].

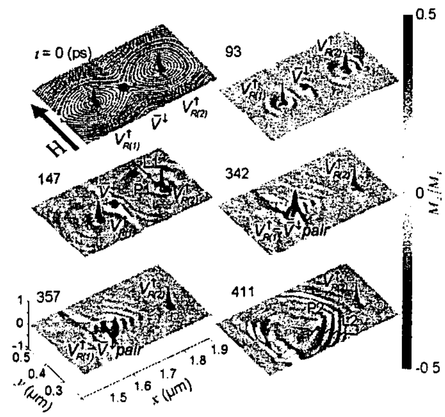

FIG. 1. Perspective view images of the temporal evolution of the spatial configuration of local magnetizations under a static magnetic field of H_a=100 Oe applied along the direction noted by the black arrow. The colors indicate the magnitudes of the local M_z/M_s values.

2. Simulations

Micromagnetic simulations were performed using the OOMMF code [5] on two different micromagnetic modelings: 1) a rectangular shaped Fe film, which includes 5 vortices and 2 antivortices at an equilibrium state without a magnetic field is perturbed by a static magnetic field of H_a=100 Oe, approaching a new equilibrium state. 2) A model system consisting of a circular shaped Permalloy (Py) disk connected to a stripe-shaped Py nanowire is perturbed by a sinusoidal magnetic field pulse with amplitude of H_a=300 Oe, which is applied only to the circular disk element.

3. Results and discussion

Figure 1 shows snapshot images of the temporal evolution of a rectangular shaped Fe film taken at given times t, as noted. For t=93 ps, the spin waves radiated around each vortex core driven by their dynamic motions further spread into their surrounding areas. Much stronger spin waves with large amplitudes start to be radiated at t=342 ps, when the vortex and the antivortex meet, and then collapse. From the calculation of the temporal evolution of total torques exerting on the unit magnetization vector **m** of individual cells and the individual contributions of the exchange, the demagnetization, and the Zeeman field to the total torque, it is found that large torques applied at the local area of the vortex cores during their dynamic motion and collapse, induce a rapid energy dissipation into their surrounding areas through the spin-wave excitation and subsequent propagation.

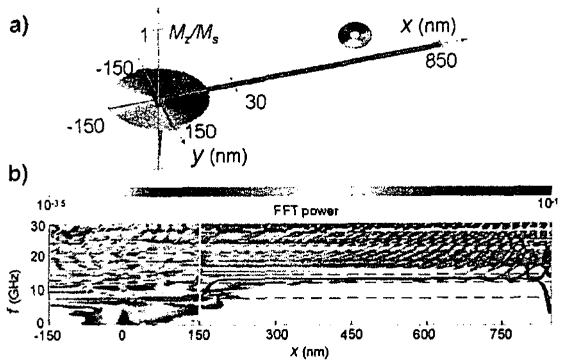

FIG. 2. (a) Thin-film model geometry made of a 10 nm thick Py, as well as its lateral dimension, which is composed of a circular shaped disk and a long-stripe nanowire waveguide. The colors represent the in-plane orientations of the local magnetizations indicated by the color-coded wheel, while the z-axis indicates the M_z/M_s. (b) Frequency spectra along x with y = 0 nm, obtained from the Fast-Fourier-Transforms (FFTs) of the M_z/M_s oscillations as a function of t in the areas of the circular disk (left column) and the nanowire (right column).

Figure 2 shows the injection and propagation of the radiated waves. The injected spin waves propagate well into a long stripe-shaped magnetic wire and those spin waves have the wave characteristics, such as propagation, reflection, transmission, dispersion, interference, and the filtering of specific frequencies. For example, the frequency spectra of the traveling waves along the nanowire-type waveguide (Fig. 2(b)) exhibit a forbidden band (analogous to an electronic band) in lower frequency region. The spin waves excited within the vortex state, whose frequencies are lower than f = 14 GHz, do not propagate through the nanowire but, on the contrary, are reflected backwards into the circular disk. On the other hand, the spin waves, whose frequencies are higher than f = 14 GHz, propagate well through the entire nanowire. When approaching the right-side edge, they are reflected backwards, thereby producing a definite form of standing waves due to superposition of the forward and backward traveling waves, as is evidenced by the number of nodes with a length of $\lambda/2$ along the x-direction in the vicinity of the right-side edge.

4. Conclusions

The radiation behavior of spin waves and the wave properties of these spin waves traveling through a nanowire-type waveguide might open up a new avenue of researches in the area of logical operations.(This work was supported by the Korean Ministry of Science & Technology through the Creative Research Initiative program.)

5. References

[1] R. Hertel, W. Wulfhekel, and J. Kirschner, Phys. Rev. Lett. **93**, 257202 (2004).
[2] S. O. Demokritov , B. Hillebrands, and A. N. Slavin, Phys. Rep. **348**, 441 (2001).
[3] K.-S. Lee, S. Choi, and S.-K. Kim, Appl. Phys. Lett. **87**, 192502 (2005).
[4] S. Choi, K.-S. Lee, and S.-K. Kim, Phys. Rev. Lett. (in review).
[5] For details, see http://math.nist.gov/oommf/.