MICROMAGNETICS STUDY ON STRONGLY EXCITED SPINWAVES IN SUB-µm-WIDE NiFe STRIPS

G. OKANO[1] and Y. NOZAKI[1,2]

1) Keio Univ., Yokohama, Japan, {g.okano, nozaki.a2}@keio.jp

2) Center for Spintronics Research Network, Keio Univ., Yokohama, Japan, nozaki@phys.keio.ac.jp

I. INTRODUCTION

A fluctuation in local magnetic ordering propagates as spin-waves and corresponding bosonic quanta are called magnons. Magnons attract a strong attention in both fundamental physics and practical applications. Indeed, information transfer and data processing can be realized by utilizing magnons. A variety of alternative devices to traditional electric ones have been proposed; such as spinwave logic gates [1], spinwave interferometers [2], magnon transistors [3] and magnonic crystals [4]. Meanwhile, the excitation of a large amount of magnons leads to Bose-Einstein condensation (Magnon-BEC) [5]. In magnonic devices and magnon-BEC experiments, nonlinear interactions such as 3-magnon scattering play a significant role. Figure 1 shows the schematic 3-magnon scattering process where a k = 0 magnon is destroyed followed by a creation of two magnons having half the energy and opposite wave vectors. When the bottom of the magnon bands is lower than the half of the frequency f_0 of pumped field, 3-magnon scattering can occur. The band profile is, therefore, essential to identify the magnons. However, in narrow NiFe strips which is usually used for the spinwave devices, it is hard to obtain the band profile analytically. As a consequence, few studies on nonlinear magnon scattering processes in the confined metallic ferromagnets, such as NiFe strips, have been demonstrated, although many researches on bulk and solid films were conducted. The study on nonlinear scattering process in sub-µm scale ferromagnets are essential for realizing the nanoscale magnonic devices. In this study, we numerically investigated the magnetization dynamics and the consequent magnon interaction processes in sub-µm-wide NiFe strips. The numerical results are consistent with our previous experimental results.

II. MICROMAGNETICS SIMULATIONS – LINEAR REGIME

Micromagnetics simulations were demonstrated by using MuMax3 [6]. The numerical parameters used in the simulations are as follows; We used the magnetic parameters for NiFe; saturation magnetization M_s = 10 kG, exchange stiffness $A_{ex} = 1.3 \times 10^{-6}$ erg/cm^3, Gilbert damping constant α =0.01. The geometry of NiFe strip was 60 nm-thick and 5 µm-long with a periodic boundary condition along its length.

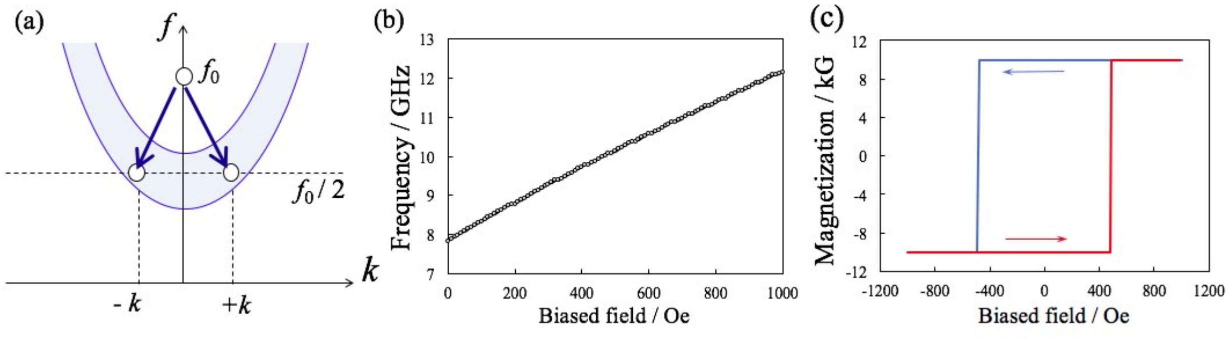

Fig. 1 (a) Schematic 3-magnon scattering process. (b) H_{ex} dependence of the resonant frequency in a linear regime. (c) Magnetization hysteresis of the NiFe strip.

The width of the NiFe strips were varied to discuss the dependence of the magnon scattering on the shape anisotropy. The numerical grid was a cube, 10 nm each side and a thermal fluctuation was not considered. Figure 1(b) shows H_{ex} dependence of the resonant frequency calculated for a 700 nm wide NiFe strip. Here, the resonant frequency was evaluated from the fast Fourier transformation of temporal variation of

GENKI OKANO
E-mail: g.okano@keio.jp
tel: +81-45-5661677

magnetization relaxation from a uniformly magnetized state at an angle of 1° from the longitudinal direction of the NiFe strip. The oscillation of magnetization during the relaxation is sufficiently small to simulate the linearly responding regime. Figure 1(c) shows a magnetic hysteresis loop of the NiFe strips. An external magnetic field was applied at an angle of 1° from the longitudinal direction of the NiFe strip. The rectangular shape of the magnetic hysteresis loop indicates a strong shape anisotropy of the 700 nm wide and 60 nm thick NiFe strip.

III. MICROMAGNETICS SIMULATIONS – NONLINEAR REGIME

The magnetization dynamics under the simultaneous applications of H_{dc} and microwave field with an amplitude of h_{ac} and a frequency of f_{ac}, were calculated for 10 ns. Here, a temporally averaged precession angle given by $\langle\theta_{cone}\rangle = \mathrm{Cos}^{-1}\langle M_x\rangle$ is used to evaluate the magnetization dynamics quantitatively, where $\langle M_x\rangle$ is a M_x value time-averaged from 9.5 to 10 ns. The averaging period of 500 ps is long enough to evaluate the stationary magnetization dynamics because f_{ac} is in the range from 5 to 15 GHz whose period is shorter than 200 ps. Figures 2(a)-2(c) show the color plots of $\langle\theta_{cone}\rangle$ in the parameter space of H_{dc} and f_{ac} calculated for (a) h_{ac}=10 Oe, (b) 50 Oe and (c) 100 Oe, respectively. It is clear that a subsidiary peak of $\langle\theta_{cone}\rangle$ appears along the dashed line in Fig. 2(c). The subsidiary resonance is attributable to the 3-magnon scattering. The detail of the numerical result will be presented at the conference.

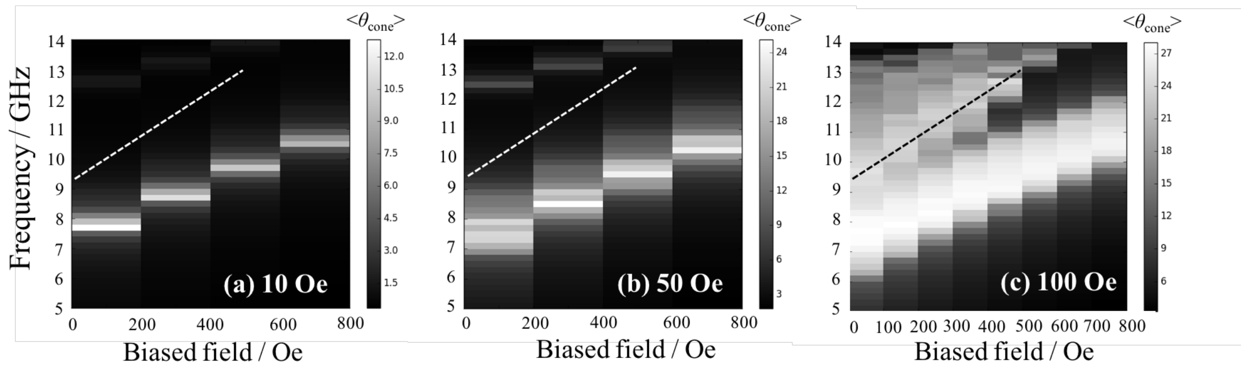

Fig. 2 Color plots of $\langle\theta_{cone}\rangle$ calculated for h_{ac} with an amplitude of (a) 10, (b) 50, and (c) 100 Oe.

REFERENCES

1) T. Schneider, A. A. Serga, B. Leven, B. Hillebrands, R. L. Stamps and M. P. Kostylev, "Realization of spin-wave logic gates", *Appl. Phys. Lett.* **92**, 022505 (2008).
2) K. S. Lee and S. K. Kim, "Conceptual design of spin wave logic gates based on a Mach-Zehnder-type spin wave interferometer for universal logic functions", *J. Appl. Phys*, **104**, 053909 (2008).
3) A. V. Chumak, A. A. Serga and B. Hillebrands, "Magnon transistor for all-magnon data processing", *Nat. Comms.,* **5**, 4700 (2014).
4) V. Cherepanov, I. Kolokolov and V. L'vov, "Spectra, thermodynamics, interaction and relaxation of magnons in a complex magnet", *Phys. Rep.,* **229**, 81-144 (1993).
5) S. O. Democritov, V. E. Demitov, O. Dzyapko, G. A. Melkov, A. A. Serga, B. Hillebrands and A. N. Slavin, "Bose-Einstein condensation of quasi-equilibrium magnons at room temperature under pumping", *Nature,* **443**, (2006).
6) A. Vansteenkiste, J. Leliaert, M. Dvornik, M. Helsen, F. Garcia-Sanchez and B. V. Waeyenberge, "The design and verification of MuMax3", AIP Advances, **4**, 107133, (2014).