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The chiral splitting of spin wave eigen modes in the 120-nm-radius FeB disk shaped nano-magnet

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Abstract

We investigate the spin wave (SW) eigen modes in the disk shaped FeB nano-magnet. We have measured the ferromagnetic resonance of 120-nm-radius disk shaped nano-magnet using thermally exited ferromagnetic resonance (TE-FMR) and analyzed the result with micro-magnetic simulations for various applied magnetic field. We find that the chiral splitting of SWs exist in the nano-magnet caused by dipole interaction.

1. Introduction

Ferromagnetic nanostructures including magnetic tunnel junctions (MTJs) with a MgO barrier have attracted interest for the potential application in spintronics area especially spun transfer torque magnetic random access memory [1]. It is well known that the detail spin dynamics of nanostructure is far from the bulk's because of mainly different boundary conditions.

In this study, 120-nm-radius disk shape of nano-magnet are prepared by photo and e-beam lithography for the spin wave(SW) eigen modes. Also we extract SW eigen modes using micromagnetic simulations.

2. General Instructions

The sample structure for the Thermally excited ferromagnetic resonance (TE-FMR) measurement as below; PtMn(15nm)/CoFe (2.5 nm)/Ru(0.85 nm)/ CoFeB (3 nm)/MgO barrier (1.1 nm)/FeB (2 nm)/MgO Capping (1.2 nm)/ Ta (5 nm)/top electrode on the Si substrate/buffer layer. The CoFe/Ru/CoFeB layer is a synthetic ferrimagnetic structure, in which the magnetization of lower CoFe layer and CoFeB layers align in an anti-parallel configuration. The magnetization of the CoFe is pinned uni-directionally by an exchange bias field from the PtMn antiferromagnetic layer. Tunnel junctions are fabricated using optical and electron beam lithography combined with an Ar-ion etching technique and a lift-off process. The designed junction had a disk shape with a diameter of 120 nm. The MgO capping layer induces a perpendicular anisotropy in the FeB[2]. The resistance area product and magnetoresistance ratio were 5.7 $\Omega\mu m^2$ and 110%, respectively. Since the CoFeB reference layer has an in-plane magnetization, the MTJ is very sensitive to the fluctuation of the FeB free layer magnetization along the perpendicular direction. TE-FMR [3] spectra are measured with spectrum analyzer using lock-in technique.

Figure 1 shows the magnetic field sweep TE-FMR spectrum taken at 4.0 GHz, the open circles are experimental result and solid red line is Lorentzian fitted result. We find six resonance frequencies as shown in Fig. 1. The symbols represent as eigen modes of the sample.

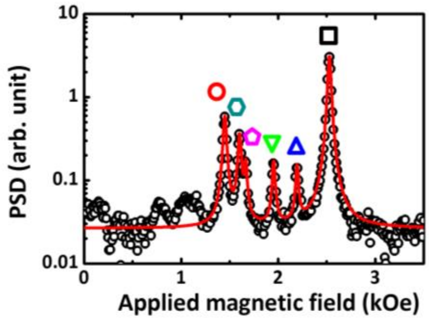

Fig. 1. TE-FMR spectrum measured at 4.0 GHz

The applied magnetic field dependence resonance frequencies in the nano-magnet are plotted in Fig. 2. The resonance frequencies is measured by TE-FMR The symbols indicate by the same modes shown Fig. 1.

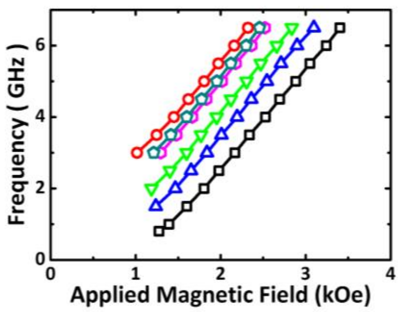

Fig. 2. The Magnetic field dependent SWs frequencies using TE-FMR.

The SW eigen modes have been calculated Landau-Lifshitz-Gilbert equation with exchange and dipole boundary conditions.

$$\omega_{n,l}^{(0)} = \omega_{eff} + \frac{\lambda_{ex}^2}{R^2}\omega_M A_{n,l}^2 \qquad (1)$$

$$\omega_{n,l}^{(1)} = \omega_{n,l}^{(0)} - \langle n,l | \{ \omega_{dipole,xx} + \omega_{dipole,yy} + i\left(\omega_{dipole,xy} - \omega_{dipole,yx} + \omega_{DMI,xy} - \omega_{DMI,yx}\right)\} | n,l \rangle \qquad (2)$$

Here, ω_{eff} is SW frequency including external magnetic field, saturation magnetization and anisotropy of the sample. λ_{ex} is exchange length of the ferromagnetic layer, R is radius of the junction, ω_M is M_s/γ (γ is gyromagnetic ratio). $A_{n,l}$ is satisfies $J_l(A_{n,l}) = 0$ for rigid edge, $J'_l(A_{n,l}) = 0$ for free edge, respectively, when J_l is the Bessel function of 1st kind. $\omega_{dipole,ij}$ ($\omega_{DMI,ij}$) ($i,j = x, y$) are the components of dipole (DMI) field. Values (n, l) denote the number of nodal circles n and nodal diameters l.

The micromagnetic simulations are performed by using the Objective Oriented Micromagnetic Framework (OOMMF)[4]. We select a disk shape of 120 nm × 120 nm × 2 nm with a cell size of 2 nm × 2 nm × 2 nm at zero temperature as the same situation of the FeB free layer of the nano-magnet structure. The material parameters in our simulation are used as determined by previous results[2][5].In order to investigate the l = 0 mode, a positive sign of rf-field amplitude(H_0) is applied whole disk shape nanomagnet while external field is applied H_{ext}. For the l = 1 mode, a positive (negative) sign of H_0 is applied the left (right) half area of the sample. For the l = 2 mode, a positive sign of H_0 is applied the right upper and left lower quadrant areas and a negative sing of H_0 is applied the right lower and left upper quadrant areas. More details for obtained FMR spectra can be described elsewhere[6][7].

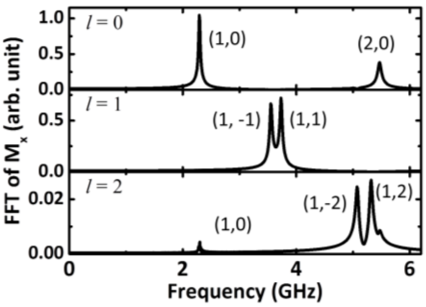

Fig. 3 FFT spectra of the Mx for the disk shape nano-magnet

Fig. 3 shows the FFT spectra of the M_x for the 120-nm-radius disk shape nano-magnet with H_{ext} = 2.0 kOe. The number with bracket is SW eigen mode as (n,l) as determined by analytic calculations using eq. (1) and (2). We clarify the resonance frequency near 2.29 and 5.47 GHz are from l = 0 mode, near 3.56 and 3.70 GHz are from l = 1 mode, and 5.07 and 5.32 GHz are from l = 2 mode.

The SW frequencies which are calculated using simulations as a function of applied magnetic field are displayed in Fig. 4. The open black rectangles are represented as (1,0), open blue up triangles are represented as (1,-1), open down green are represented as (1,1), open magenta pentagon are represented as (1,-2), open hexagonal dark cyan are represented as (1,2) and open red circles are represented as (2,0) respectively. The SW frequencies both experimental and simulations result have similar tendency each other.

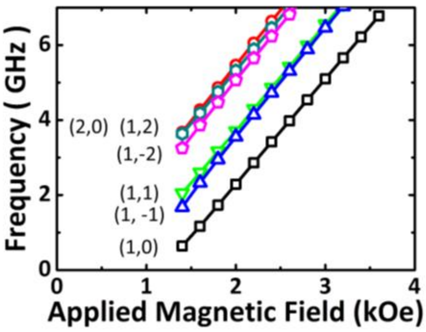

Fig. 4. The Magnetic field dependent SWs frequencies using micromagnetic simulations

Let us discuss about the large chiral splitting between l = ±1 mode in experimental result. The possible scenarios are below: (1) Dzyaloshinskii-Moriya interaction (DMI) from symmetry breaking between MgO buffer/FeB/MgO capping layer leads increasing splitting of eigen mode for the nodal diameter mode[8] (2) the sample has not sharp edge but sloped edge caused poor electron beam lithography process. The sloped edge could increase demagnetization energies in the edge, increase chiral splitting between l = ±1 mode.

3. Conclusions

In conclusion, the TE-FMR experiments is employed to understand the SW eigen modes in the 120 nm disk shape nano-magnet and the micromagnetic simulations is proposed to clarify the SW eigen mode with chiral splitting. We find that similar tendency between experimental and simulation results. Large chiral splitting in (1, ±1) mode, can be explain large DMI and/or disk shape could not be exist sharp edge but sloped edge

Acknowledgements

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