Control of the nonreciprocity of magnetostatic surface wave in a ferromagnetic metal

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1. Introduction

Magnetostatic surface wave (MSSW) has been explored owing to its large signal, long attenuation length, and nonreciprocal wave propagation. While this nonreciprocal feature has been investigated to be utilized as a bandpass filter and an isolator, it has impeded development of spin-wave logic devices. So, it is necessary for developing a high-performance MSSW device to reveal its mechanism and control it.

The origin of the nonreciprocity of MSSW has frequently been discussed and it is inferred that this feature is caused by interference of MSSWs excited by the in-plane (h_{in}) and out-of-plane (h_{out}) components of microwave field.[1, 2] P. Deorani *et al.*[2] suggested the theoretical explanation for this feature using the following formula:

$$m_{\pm} \propto \frac{2\pi f}{M_s} \pm \frac{1}{M_s^2}\left[\left(\frac{2\pi f}{\gamma}\right)^2 - (\mu_0 H)^2\right], \qquad (1)$$

where $m_{\pm}$ is the spin wave amplitude in the positive and negative direction from the source, f is the frequency of spin wave, M_s is the saturation magnetization of the propagation medium, $\mu_0 H$ is the applied magnetic field, and γ is the gyromagnetic ratio. Recently, we have observed the enhancement of the nonreciprocity of MSSW in Py with increasing distance between the Py layer and the excitation antenna.[3] This phenomenon cannot be explained by Eq. (1) because this formula have ignored the change of the difference between the magnitudes of the MSSWs excited by h_{in} and h_{out}. In this study, we investigate the change of the influence of h_{in} and h_{out} on the nonreciprocity of the MSSW by varying the distance between the Py layer and the excitation antenna.

2. Experimental procedure

We fabricated the MSSW devices with various distance between a Py ($Fe_{19}Ni_{81}$) layer and an excitation antenna by changing the thickness of a SiO_2 isolation layer (t_{SiO2}). The distance between an excitation and a detection antennas (w) was 20 μm. The measurement of MSSW signals was carried out by using a microprobe station and a vector network analyzer. We fixed the MSSW propagation direction and change the direction of $\mu_0 H$. A nonreciprocal parameter (NR) have been defined as a ratio of maximum $|\Delta S_{21}|$ under $\mu_0 H < 0$ to that under $\mu_0 H > 0$.

3. Results and discussion

Figure 1(a) shows the NR as a function of f. The NR value decreases with increasing t_{SiO2} value. Considering the change of difference between the magnitudes of the MSSWs excited by h_{in} and h_{out} in Eq. (1), we can describe NR as

$$NR = \frac{\frac{2\pi f}{M_s\gamma} - \frac{A_{out/in}}{M_s^2}\left[\left(\frac{2\pi f}{\gamma}\right)^2 - (\mu_0 H)^2\right]}{\frac{2\pi f}{M_s\gamma} + \frac{A_{out/in}}{M_s^2}\left[\left(\frac{2\pi f}{\gamma}\right)^2 - (\mu_0 H)^2\right]} \times 100, \qquad (2)$$

where $A_{out/in}$ is a parameter which is tentatively introduced to consider for the difference between the magnitudes of the MSSWs excited by h_{in} and h_{out}. It is like a ratio of the MSSW excitation efficiency of h_{out} to that of h_{in}. The fitting curves (solid lines) are shown in Fig. 1(a). The fitting curves are in good agreement with the experimental results. Figure 1(b) shows the $A_{out/in}$ as a function of t_{SiO2}. The $A_{out/in}$ value increases with increasing t_{SiO2} value. This result indicates that the influence of h_{out} increases with increasing t_{SiO2} value as compared with that of h_{in}. We will also discuss this phenomenon using the numerical data obtained by micromagnetic simulations.

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[2] P. Deorani et al., Curr. App. Phys. **14**, S129 (2014).
[3] M. Nakayama *et al.*, The 63rd JSAP spring Meeting, 19p-P1-61 (2016).

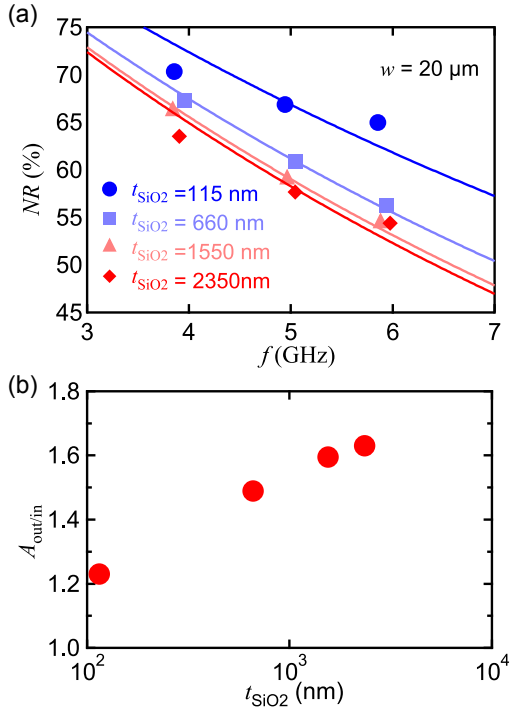

Fig. 1. (a) $NR - f$ characteristics for the devices with an each t_{SiO2} of 115, 660, 1550, and 2350 nm. The solid lines show the fitting results from Eq. (1). (b) shows SiO_2-thickness dependence of the $A_{out/in}$.