THEORETICAL STUDY OF SPIN WAVE EXCITATION IN PERPENDICULARLY MAGNETIZED SINGLE LAYER

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I. INTRODUCTION

Microwave assisted switching (MAS) of magnetization has attracted much attention as a novel switching technique to reduce the switching field of ultra-high-density magnetic recording media [1]. The reduction of the switching field of MAS of a nano-magnet is well understood by analyzing the dynamics of a macrospin-model in a rotating frame synchronized with the applied radio frequency (rf) field. In the rotating frame, the rf field acts as a static field parallel to the rotating axis and reduces the switching field. For MAS, however a certain critical frequency, f_c exits [1-2]. A switching field, h_{sw} monotonically decreases with increase of rf frequency, f and it takes a minimum value h_{min} at f_c. Once f exceeds f_c the h_{sw} shows sudden increase and takes almost the same value as that without rf field. Thus in principle the h_{sw} can't be reduced below the h_{min} on MAS.

Recently S. Okamoto et al. has reported that a significant reduction of the h_{sw} is realized in a single Co/Pt nanodot with perpendicular magnetic anisotropy by applying a large rf field but one much smaller than the effective anisotropy field [2]. The large amplitude nonuniform magnetization motion, that is, spin wave (SW) was exited in the Co/Pt nanodot with the large diameter whereas that was not observed in the Co/Pt nanodot with the small diameter. The h_{sw} of the Co/Py with the small diameter was conventionally analyzed by the macrospin model. It was found that the f_c increase due to the excitation of the large amplitude SW and the reduction of the h_{sw} is consequently much more significant than the theoretical prediction based on the single macrospin model.

So far we have studied the MAS behavior and its dynamics of a perpendicularly magnetized single layer by a Landau-Lifshitz-Gilbert (LLG) numerical simulation and theoretical analysis. It was revealed from the LLG numerical simulation that the large amplitude SW is exited above a certain critical layer thickness, $d_{c(SW)}$ and that the f_c increases due to the excitation of the large amplitude SW above a certain critical layer thickness $d_{c(f)}$. It was furthermore found that the $d_{c(SW)}$ is not equal to $d_{c(f)}$ ($d_{c(SW)} < d_{c(f)}$). In this study the analytical estimation of the $d_{c(SW)}$ a was established from the analysis of **P**-modes and SW instabilities on LLG phase diagram.

II. P-MODE AND SPIN WAVE INSTABILITY

By setting $d\theta/dt = d\varphi/dt = 0$ in a normalized LLG equation expressed by the zenith and azimuth angles, θ and φ, one obtains the equations (1) and (2) for the fixed points, i.e., **P**-modes of the magnetization dynamics in the rotating frame:

$$\nu_0 = \frac{\mathrm{h_{az}} - \omega}{\cos\theta_0} + \kappa_{\mathrm{eff}}, \tag{1}$$

$$\nu_0^2 = \frac{\mathrm{h}_{\mathrm{a}\perp}^2}{\sin^2\theta_0} - \alpha^2\omega^2, \tag{2}$$

where $\nu_0 = \alpha\omega\cot\varphi_0$. α and ω are the damping constant and the angular frequency of the rf field. $\mathrm{h_{az}}$ and $\mathrm{h}_{\mathrm{a}\perp}$ are the static magnetic field, H_{dc} and the circularly polarized rf field, H_{rf} normalized by the saturation magnetization, M_s, respectively. θ_0 and φ_0 are the angles identifying the **P**-modes. The effective anisotropy field, κ_{eff}:

$$\kappa_{\mathrm{eff}} = \kappa + N_\perp - N_z \tag{3}$$

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where the normalized anisotropy field $\kappa = 2K_1 / \mu_0 M_s^2$. K_1 is the physical anisotropy constant, μ_0 is the magnetic permeability of vacuum. $N_\perp$ and N_z are the demagnetization factors. The demagnetization factors satisfy the relation: $N_z + 2N_\perp = 1$.

The SW instability matrix A_q is as follows,

$$A_q = \frac{1}{1+\alpha^2}\begin{pmatrix} 1 & -\alpha \\ \alpha & 1 \end{pmatrix}\begin{pmatrix} -\alpha\omega\cos\theta_0 & -\nu_q \\ \nu_q - \kappa_q \sin^2\theta_0 & -\alpha\omega\cos\theta_0 \end{pmatrix} \tag{4}$$

where $v_q = v_0 - N_\perp + q^2 + (1/2)\sin^2\theta_q$, $\kappa_q = \kappa - 1 + (3/2)\sin^2\theta_q$. q is the wavevector constant. θ_q is the angle between the direction of the wavevector and the static magnetization, therefore $\sin\theta_q$ is zero for the current perpendicularly magnetized layer model.

When the stable **P**-mode with $\cos\theta_0 \sim 1$ vanishes as h_{az} increases, the fixed point moves to another **P**-mode with $\cos\theta_0 \sim 0.87$. If this **P**-mode is located in the inside of the red line satisfying $\det A_q \leqq 0$, the large amplitude SW is expected to be exited. The $d_{c(SW)}$ can be therefore analytically estimated from the condition, $\det A_q = 0$ after substitution of h_{az}, v_0 and θ_0 satisfying that the line for the Eq. (1) is tangent to one for the Eq. (2) into Eq. (4).

II. LLG SIMULATION AND ANALYTICAL RESULT

Figure 1 shows a schematic illustration of an effective spin model of the single layer used for the LLG numerical simulation where the perpendicularly magnetized each cells with 1 nm thickness are coupled with each other by the exchange stiffness coupling, A_{ex}. H_{dc} is applied along the z-direction and H_{rf} is applied in the xy-plane. As seen in Figure 2, the analytical result for the $d_{c(SW)}$ is good agreement with the result of the LLG simulation. The estimation of the $d_{c(SW)}$ established in this study is expected to be important feature for improving the ultra-high density of the magnetic recording.

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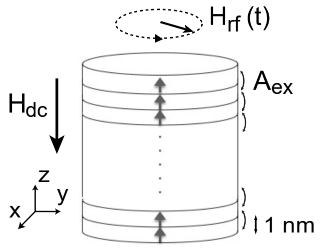

Fig. 1 Effective spin model of perpendicularly magnetized single layer.

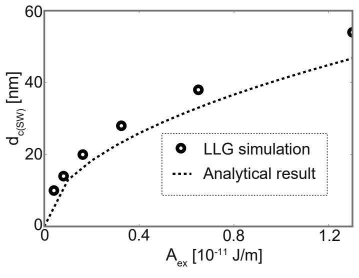

Fig. 2 Results of LLG simulation and SW instability analysis for $d_{c(SW)}$.