DP-28

CRITICAL FREQUENCY OF MICROWAVE ASSISTED MAGNETIZATION SWITCHING

H. ARAI[1], and H. IMAMURA[2]
1) AIST, Spintronics R. C., Tsukuba, Japan, and PRESTO, JST, Kawaguchi, Japan, arai-h@aist.go.jp
2) AIST, Spintronics R. C., Tsukuba, Japan, h-imamura@aist.go.jp

I. INTRODUCTION

The microwave-assisted switching (MAS) of magnetization is a promising method for reducing the switching field of ultrahigh-density magnetic recording media [1]. The most important feature of MAS is that the switching field decreases with increasing frequency f of the radio frequency (rf) field H_{rf}, and it takes a minimum value at a certain critical frequency f_{c}. Although past studies based on the macrospin model in a rotating frame revealed the physics behind f_{c}, an analytical expression for f_{c} has not been obtained; i.e., f_{c} was obtained only by numerical calculation. In this paper, we theoretically analyzed MAS in a perpendicularly magnetized circular disk and derived an analytical expression for f_{c} by analyzing the presence of a quasi- periodic mode by calculating the energy change over one precession period in the rotating frame [2].

II. MODEL AND THEORY

Schematic illustration of the system we studied is shown in Fig. 1(a). We assumed a perpendicularly magnetized circular disk. A static magnetic field $\boldsymbol{H}_{\mathrm{dc}}$ is applied in the negative z-direction. A circularly polarized rf field $\boldsymbol{H}_{\mathrm{rf}}(t)$ is also applied in the x-y plane, where the amplitude is H_{rf} and the angular frequency is ω. We adopt a rotating frame where X- and Y- axes rotate around the z-axis, which keeps the X-axis follows the rf field as shown in Fig. 1(b). The dimensionless Landau-Lifshitz-Girbert (LLG) equation in the rotating frame is given by,

$$d\boldsymbol{m}/d\tau = -\mathrm{m}\times\boldsymbol{h}_{\mathrm{eff}}^{\mathrm{rot}} - \alpha\, \boldsymbol{m}\times(\boldsymbol{m}\times\boldsymbol{h}_{\mathrm{eff}}^{\mathrm{rot}}) - \alpha\omega_{\mathrm{d}}\, \boldsymbol{m}\times(\boldsymbol{m}\times\boldsymbol{e}_{\mathrm{z}}), \tag{1}$$

where $\boldsymbol{h}_{\mathrm{eff}}^{\mathrm{rot}} = [\, H_{\mathrm{rf}}\boldsymbol{e}_{\mathrm{X}} + (-H_{\mathrm{dc}}+H_{\mathrm{k}}^{\mathrm{eff}}m_{\mathrm{z}})\, \boldsymbol{e}_{\mathrm{z}}\,]/M_{\mathrm{s}}$, $\omega_{\mathrm{d}} = \omega/\gamma M_{\mathrm{s}}$, $\tau = \gamma M_{\mathrm{s}}t$, and $\boldsymbol{e}_{\mathrm{i}}$ is the unit vector along i-axis. We assume $\alpha \ll 1$. The effective anisotropy field is defined as, $H_{\mathrm{k}}^{\mathrm{eff}} = 2K_{\mathrm{u}}/(\mu_0 M_{\mathrm{s}})\text{-}M_{\mathrm{s}}$, where K_{u} is the uniaxial anisotropy constant, μ_0 is the magnetic permeability of vacuum, M_{s} is the saturation magnetization.

The fixed points of Eq. (1) are obtained by setting $d\boldsymbol{m}/d\tau = 0$. They are called periodic (P) modes, because the fixed points in the rotating frame represent the state rotating with ω in the laboratory frame [3]. The stability of the P mode is analyzed by a linearized equation of motion for a small deviation of $\boldsymbol{\delta m}$ from the fixed point, $d\boldsymbol{\delta m}/d\tau = A\boldsymbol{\delta m}$, where A is the matrix. In the simple analysis, f_{c} is obtained $\det A = \mathrm{Tr}A$ and is larger than that obtained by numerical simulations [4].

The discrepancy is solved by considering quasiperiodic (Q) modes, which represent limit cycles in the rotating frame [3]. The magnetization switching is the transition from the initial P mode to the final P mode. If an attractive Q mode exists between them, the switching is interrupted. Such Q mode appears in the lower frequency than f_{c} given by the simple analysis [5]. The presence of the Q mode is analyzed by calculating the change over one precession period at the saddle point of the magnetic energy density, $d\varepsilon/d\tau = w_{\mathrm{dis}} + w_{\mathrm{rf}}$, where w_{dis} represents the work of dissipation and w_{rf} represents the work of the rf field. By integrating over one precession period, one obtain the energy loss (gain) due to dissipation (rf field). The value of f_{c} is obtained by solving the equation where energy loss and energy gain are balanced,

$$f_{\mathrm{c}} = \gamma H_{\mathrm{k}}^{\mathrm{eff}} F^{2/3}\{6\text{-}5F^{2/3}\} \,/\, (6\pi\,\{1\text{-}F^{2/3}\}^{1/2}) \tag{2}$$

in SI unit. Here F is $H_{\mathrm{rf}}/H_{\mathrm{k}}^{\mathrm{eff}}$. For a small rf field satisfying $H_{\mathrm{rf}} \ll H_{\mathrm{k}}^{\mathrm{eff}}$, the critical frequency is approximated as $f_{\mathrm{c}} \sim \gamma/\pi\{H_{\mathrm{k}}^{\mathrm{eff}}H_{\mathrm{rf}}^{2}\}^{2/3}$.

Hiroko Arai
E-mail: arai-h@aist.go.jp
tel: +81-29-862-6639

III. RESULTS

Figure 1(c) shows switching field as a function of rf frequency numerically obtained from magnetization dynamics solved by LLG equation. We set initial state as $m_z = 1$. Applying H_{dc} and $H_{rf}(t)$ at $t = 0$, magnetization dynamics is calculated for 100 ns. Then if $m_z < 0$, we clarified the magnetization is switched. The dots in Fig. 1(c) indicate that the magnetization is switched. Material parameters are assumed as $M_s = 1.0$ MA/m, $K_u = 0.85$ MJ/m^3, and $\alpha = 0.01$. The value of f_c is found at 4.6 GHz for $H_{rf} = 0.4$ kOe (31.8 kA/m). Figure 1(d) shows H_{rf} dependence of f_c. The dots indicate the numerical results, and dashed line indicates the analytical result calculated by Eq. (2). Our analytical expression agrees well with the numerical results.

IV. SUMMARY

We analyzed the presence of a quasiperiodic mode for magnetization dynamics in the rotating frame, and obtained the analytical expression for the critical frequency in magnetization switching assisted by rf field. The value of f_c is expressed as a function of H_{rf} and H_k^{eff}. The validity of the analytical formula is confirmed by comparing with the numerical simulations.

REFERENCES

1) J. G. Zhu, X. Zhu and Y. Tang, "Microwave Assisted Magnetic Recording," IEEE Trans. Magn., 44(1), 125-131, (2008).
2) H. Arai and H. Imamura, "Analytical expression for critical frequency of microwave assisted magnetization switching", Jpn. J. Appl. Phys., 55, 028002, (2016).
3) G. Bertotti, I. D. Mayergoyz, and C. Serpico, "*Nonlinear Magnetization Dynamics in Nanosystems*", Chap. 7, Elsevier, 2009.
4) S. Okamoto, N. Kikuchi, M. Furuta, O. Kitakami, and T. Shimatsu, "Microwave assisted magnetic recording technologies and related physics", J. Phys. D, 48 (35), 353001, (2015).
5) H. Suto, K. Kudo, T. Nagasawa, T. Kanao, K. Mizushima, R. Sato, S. Okamoto, N. Kikuchi, and O. Kitakami, "Theoretical study of thermally activated magnetization switching under microwave assistance: Switching paths and barrier heigh", Phys. Rev. B, 91, 094401, (2015).
6)
7)

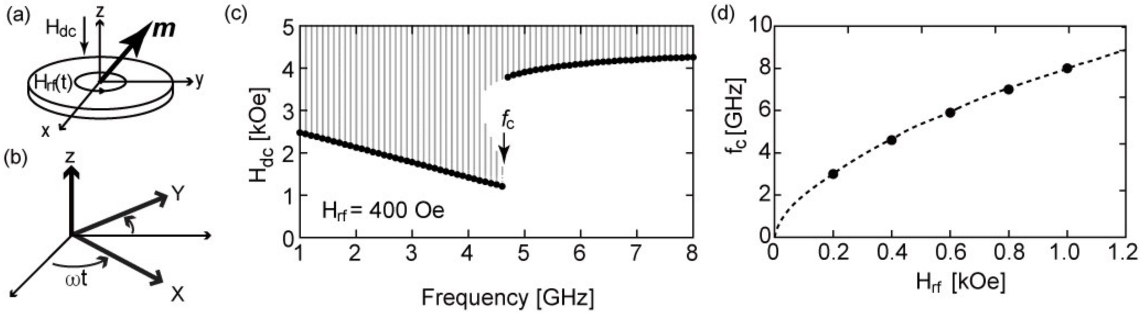

Fig. 1 (a) Schematic illustration of the circular disk and laboratory frame. (b) Definition of the rotating frame. (c) Numerically obtained switching condition. In the colored area, ***m*** is switched. Critical frequency (f_c) is indicated by the arrow. (d) H_{rf} dependence of f_c. Circles represent numerically obtained f_c. Dashed line represents f_c given by Eq. (2).