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Effect of angle dependent Gilbert damping on magnetization dynamics induced by spin current

W. J. Kim[1]*, T. D. Lee[1], and K. J. Lee[2]
[1]Material Science and Engineering Dept., KAIST, Daejon, Korea
[2]Material Science and Engineering Dept. Korea University, Seoul, Korea

1. Introduction

Spin transfer torque (STT) is induced by spin angular momentum transfer from incident spin-polarized electrons to a local magnetization. It enables magnetization reversal or endless precession [1], [2]. Spin pumping is a counteraction of the spin torque. A moving magnetization pumps spin currents into the neighboring normal metal and loses its spin angular momentum due to spin-flip [3]. The loss of spin angular momentum results in the enhancement of Gilbert damping of the ferromagnet. The enhancement depends on the angle between two magnetizations in spin valve structures [4].

Gilbert damping constant plays an important role in magnetization dynamics induced by STT, because anti-damping effect of spin torque competes with the Gilbert damping. Therefore, in this work, we investigated the effect of the angle-dependent damping on the probability of switching and precession dynamics.

2. Model and method

The magnetization dynamics could be incoherent for a large sample with a small spin polarization [6], [7]. Here, however, we adopted a macrospin model to get the first idea of effect of the angle-dependent damping on the magnetization dynamics. The motion of macrospin is described by Landau-Lifshitz-Gilbert equation including the spin-transfer torque term.

The angle-dependent Gilbert damping is given by

$$\alpha(\theta) = \alpha_o + \alpha'(\theta) \quad (1) \qquad \alpha'(\theta) = \alpha'(0)\left(1 - \nu\sin^2\theta / \left(1 - \nu^2\cos^2\theta\right)\right) \quad (2)$$

where α_0 is the intrinsic Gilbert damping constant, $\alpha'(0)$ is the enhanced damping in the collinear magnetic configuration. The parameter υ varies from 0 to 1 depending on the materials [4].

Gaussian-distributed random thermal fluctuation field $h^{th}(t)$ is dependent on the angle-dependent Gilbert damping, therefore $h^{th}(t)$ is described with correlation function [5]

3. Result and Discussion

We investigated the probability of switching (P_{SW}) as a function of υ. The pulse-width of current is 4 ns. P_{SW} is obtained by counting the number of successful switching out of 100 tries. As shown in Fig. 1(a), the critical current density for switching (J_C) is insensitive to υ. It is because Gilbert damping at the initial angle before switching is important for the switching. The result of Fig. 1(b), where an averaged constant damping(α_{ave}) is used, confirms it. For the large value of υ, i.e., small constant damping, Jc is low.

$$\alpha_{ave} = \langle\alpha(\theta)\rangle = \frac{1}{\pi}\int_0^{\pi}\alpha(\theta)d\theta \quad (3)$$

The result of precession feature is shown in Fig. 2(a), summarized into the power Q-factor (= (precession frequency)/FWHM). The external field is 800 Oe and is applied along the in-plane easy axis. From oscillation data gathered for 1.05 μs, we obtained precession frequency and full-width-half-maximum (FWHM) at the peak frequency as a function of a_J and υ. Dark regions (Lower Q-factor region) in Fig. 2(a) shift to left, i.e., smaller a_J, as υ increases. Similar result is obtained when an averaged constant damping(α_{ave}) is used, in Fig. 2(b). It means that, in the precession motion, the effect of the Gilbert damping varying with angle can be regarded as that of the constant averaged damping equivalent to the angle-dependent damping for each υ. It is because the magnetization rotates over a wide range of the angle during the precession motion.

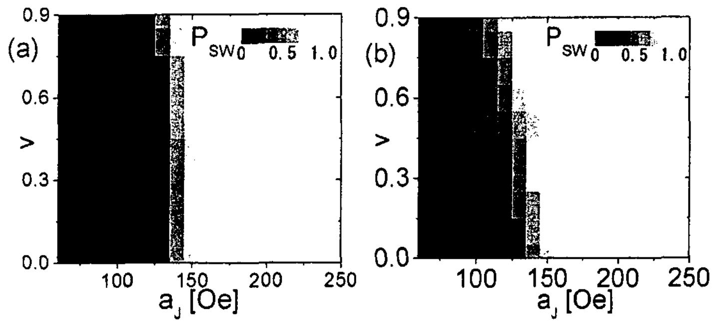

Fig. 1. P_{SW} as a function of a_J, as υ (a) when damping is angle -dependent, (b) when averaged constant damping is used.

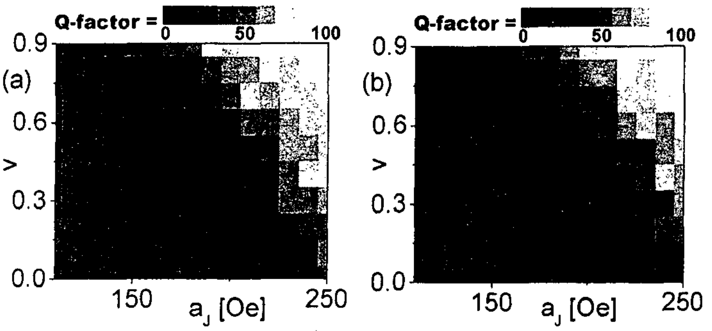

Fig. 2. Q-factor as a function of a_J, as υ (a) when damping is angle -dependent, (b) when averaged constant damping is used.

4. Conclusion

Angle-dependence of Gilbert damping has effect on the current-induced precession motion, although it does not on the current-induced magnetization switching. Because damping at the initial state is decisive for the switching, but different damping over a wide range of angle is effective on the precession. Therefore, from now on, it must be considered in the study of current-induced magnetization dynamics.

5. References

[1] L. Berger, Phys. Rev. B, **54**, 9353 (1996)
[2] J. C. Slonczewski, J. Magn. Magn. Mater., **159**, L1 (1996)
[3] Y. Tserkovnyak et. al., Phys. Rev. Lett., **88**, 117601 (2002)
[4] Y. Tserkovnyak et. al., Phys. Rev. B, **67**, 140404 (2003)
[5] J. Foros et. al., Phys. Rev. Lett., **95**, 016601 (2005)
[6] K. J. Lee et. al., Nature Mat., **3**, 877 (2004)
[7] K. J. Lee et. al., Appl. Phys. Lett. **88**, 132506 (2006)