Current induced spin transfer noise in CPP-GMR based Heusler alloy

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***Abstract*—Spin transfer torque (STT) induced magnetic noise is an important role in the current perpendicular to the plane (CPP) read heads since it generates the instability. Thus, this work examines STT noise caused by the sense current in the CPP giant magnetoresistance (GMR) read heads based on the Heusler alloy. The magnetization dynamic due to the sense current is computed by LLGS equation. The power spectral density of magnetization is considered to investigate the noise power. The results show that STT causes the energy pumping into a system affecting to the magnetization dynamic. Also, the maximum noise power occurs when the current reaches a critical value. Hence, STT noise is the main point to develop the future hard disk drive technology since it affects the stability of CPP-GMR heads.**

***Index Terms*—Magnetic noise, Magnetization reversal, Giant magnetoresistance, Magnetic films.**

I. Introduction

To increase an areal density of hard disk drive technology, the bit size and the dimension of magnetic read sensors must be reduced. As smaller read sensors, noise becomes more significant. Magnetic noise, produced by spin transfer torque (STT) effect on the magnetization fluctuations, plays an important role in the current perpendicular to the plane (CPP) read heads since it can generate the instability in the heads [1], which well known as spin transfer noise [2], [3].

In the future, the current perpendicular to the plane giant magnetoresistance (CPP-GMR) read heads are suitable for applying with a higher areal density because the heads have several advantages [4]. Recently, the CPP-GMR read heads using the ferromagnetic Heusler alloy materials as electrode have received an interest in the research for spintronic applications because these structure have many advantages, such as; high spin polarization, large MR ratio, and high Curie temperature [5]. In addition, the $Co_2FeAl_{0.5}Si_{0.5}$ (CFAS), one of the Heusler alloy materials, has a large CPP-GMR ratio for CFAS electrode [6].

In this paper, the spin transfer noise effect on the CPP-GMR due to the sense current was investigated. Simulation is based on macrospin model with using MATLAB code M^3 [7].

II. Simulation Model

Fig. 1 illustrates the simulation model of CPP-GMR. This model assumed at room temperature consists of a reference layer and a free layer, separated by non magnetic layer. The magnetization of a reference layer is fixed along easy axis. Meanwhile, the magnetization of a free layer is aligned parallel to the magnetization of reference layer with an initial angle, θ_0. The model using CFAS as electrode is elliptical geometry with a cross-section area of 250×190 nm^2 and a thickness of 2.5 nm [8]. The magnetization dynamic of free layer is described by the Landau-Lifshitz-Gilbert equation including the spin transfer torque term, which was modified by J. C. Slonczewski and L. Berger [2], [3], given as follow [1]:

$$\frac{d\boldsymbol{M}}{dt} = -\gamma \boldsymbol{M} \times \boldsymbol{H} + \frac{\alpha}{M_s}\boldsymbol{M} \times \frac{d\boldsymbol{M}}{dt} + \gamma \frac{p\hbar J}{eM_s\delta}\boldsymbol{M} \times (\boldsymbol{M}_{RL} \times \boldsymbol{M})$$

where $\boldsymbol{M}$ is the magnetization vector of the free layer, $\boldsymbol{M}_{RL}$ is the unit vector along the magnetization of reference layer, $\boldsymbol{H}$ is the effective magnetic field, γ is the gyromagnetic ratio (2.21×10^5 m/(A·s)), α is the Gilbert damping constant, M_s is the saturation magnetization, p is the spin polarization factor, $\hbar=h/2\pi$ where h is the Planck's constant (6.626×10^{-34} J·s), J is the spin current density, e is the absolute value of electron charge (1.6×10^{-19} C), and δ is the thickness of the free layer.

The free layer based on CFAS material has the following magnetic parameters [8]: M_s of $9.0\text{x}10^5$ A/m, α of 0.01, p of 0.76, exchange stiffness constant, A, of 2.0×10^{-11} J/m, magnetocrystalline anisotropy constant, K_1, of -1.0×10^4 J/m^3, bulk scattering spin asymmetry, β, of 0.77. In order to investigate the magnetization dynamic from parallel state to anti-parallel state, the initial magnetization of a free layer is assumed to be nearly parallel to the magnetization of reference layer with θ_0 of 5°. To calculate the power spectral density (PSD) of the magnetization dynamic in the free layer, the sense current, I_{sense}, is applied perpendicular to the sample from the reference layer to the free layer with its magnitude of 0 to 4 times of a critical current value, I_c, which has a magnitude of 1.8 mA.

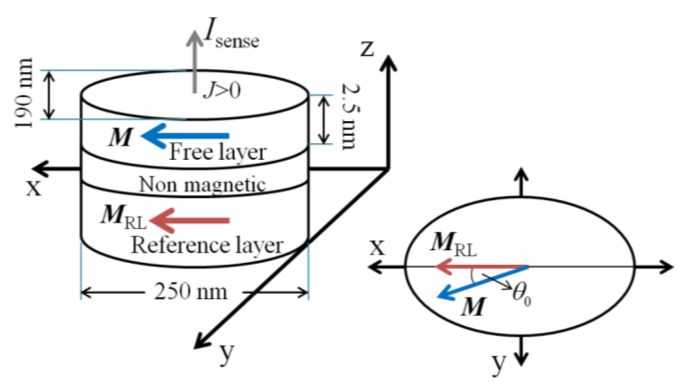

Fig. 1. Simulation model of CPP-GMR using $Co_2FeAl_{0.5}Si_{0.5}$ electrode

III. RESULTS AND DISCUSSIONS

The magnetization dynamic in x, y and z-axis are defined as M_x, M_y and M_z, respectively. The maximum value of power spectral density of M_x, M_y and M_z are defined as $P_{max}(x)$, $P_{max}(y)$ and $P_{max}(z)$, respectively. Also, PSD is calculated by a summation of local power spectral density which is computed by the Discrete Fourier transform of the local magnetization.

Fig. 2(a), 2(b) and 2(c) show the magnetization dynamic due to the sense current applied to sample with a magnitude of 0.5, 1 and 2 times of I_c, respectively. The results indicate that when $I_{sense}/I_c<1$, M_x is still not reversed. After that, when $I_{sense}/I_c=1$, M_x is nearly reversed and it brings about the largest oscillation amplitude of the magnetization precession. Then, the complete switching of M_x is occurred when $I_{sense}/I_c>1$.

Fig. 3 illustrates a magnitude of $P_{max}(x)$, $P_{max}(y)$ and $P_{max}(z)$ with the varying I_{sense}/I_c. Below I_{sense}/I_c of 0.75, $P_{max}(x)$, $P_{max}(y)$ and $P_{max}(z)$ are insignificant changed with increasing the sense current. $P_{max}(x)$ is dramatically decreased when I_{sense} is in the range between 1 to 1.1 times of I_c. On the other hand, $P_{max}(y)$ and $P_{max}(z)$ are reached the maximum value at I_{sense}/I_c of 1.1 and 1, respectively, and are suddenly decreased when I_{sense} exceeds 1.1 times of I_c. After that, when I_{sense}/I_c surpasses 1.25, the noise power becomes slightly change with increasing the sense current. Also, the results show that the magnitude of $P_{max}(x)$ alway exceeds the magnitude of $P_{max}(y)$ and $P_{max}(z)$ according to the amplitude of M_x, M_y and M_z, respectively.

Fig. 2 and Fig. 3 show that the change of PSD is related to the magnetization dynamic. Below I_{sense}/I_c of 1, PSD normally depends on the amplitude of the magnetization. Then, the maximum PSD is occurred when $I_{sense}/I_c=1$ due to the largest oscillation. In addition, the magnetization reversal causes the reduction of PSD.

From the results, the change of PSD can be explained by the energy analysis of spin system [1], [9]. I_{sense} causes the energy pumping into the system by STT effect exiting the magnetization precession. During a magnetization precession, the energy change of system is caused by the change of the magnetization alignment. This leads to the change of PSD. Also, the immediate decrease of PSD is due to the magnetization reversal in the free layer resulting in a complete suppression of spin transfer induced magnetic noise.

IV. CONCLUSIONS

The spin transfer noise in CPP-GMR read heads due to the sense current was investigated by macrospin model. In general, the results indicate that the STT term affects to the magnetization dynamic. Also, the extremely different oscillation amplitude of the magnetization dynamics results from the sense current magnitude nearby a critical value. This leads to a rapid change of PSD around the critical current value. Furthermore, the change of noise power depends on a magnitude of the sense current. The noise power has a maximum value when the sense current reaches a critical value because the effect of the maximum STT term. Hence, this shows that the noise power has a significant effect on the stability of CPP-GMR read heads during the read process and becomes the important factor for a development of the future read sensors technology.

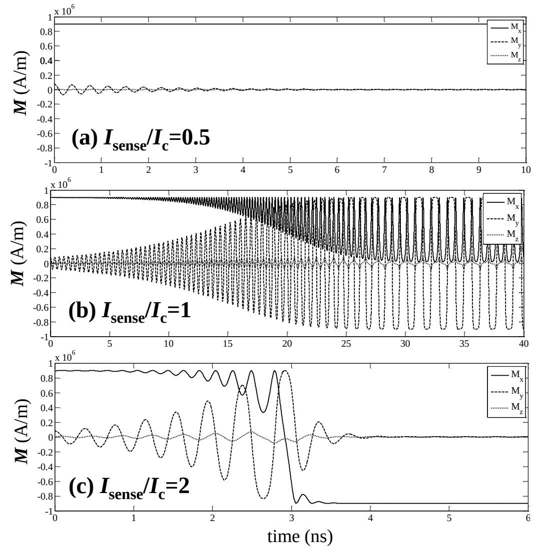

Fig. 2. Projection of the magnetization dynamic as a function of time

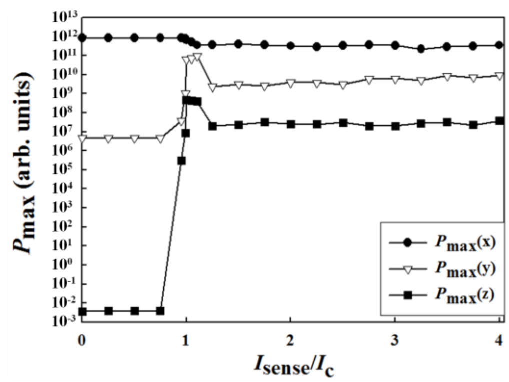

Fig. 3. Dependence of The maximum PSD on I_{sense}/I_c

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