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Dependence of current and magnetic field on spin transfer induced noise in CPP-GMR read heads

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Abstract

This paper aims to investigate the magnetic noise dependence on the sense current, I_{sense}, and the hard bias field, $\boldsymbol{H}_{\mathrm{B}}$, of the current perpendicular to the plane giant magnetoresistance read heads. The macrospin modeling was performed in the simulations. The magnetic noise was examined by using power spectral density analysis. The results showed that the magnetic noise was increased with increasing I_{sense} due to an enhancement of STT effect, especially a rapid increase of the noise was found when I_{sense} exceeds a critical value. An asymmetry of I_{sense} indicated that a negative current produces lower noise than a positive current since a ferromagnetic exchange coupling was existed in the model. In addition, the noise could be reduced by increasing $\boldsymbol{H}_{\mathrm{B}}$ which further results in an increase of the ferromagnetic resonance frequency. Hence, an optimization of I_{sense} and $\boldsymbol{H}_{\mathrm{B}}$ strongly influences the magnetic noise and becomes an important factor for acheiving the high performance magnetic read head for higher recording densities.

Keywords: Magnetic noise; Spin transfer torque; Current-perpendicular-to-the-plane giant magnetoresistance; Heusler alloy

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1. Introduction

The magnetic noise (mag-noise) produced by the spin transfer torque (STT) effect has become a significant role in the current perpendicular to the plane (CPP) read heads since it could decline the performance of the heads.[1] Also, the

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sense current, I_{sense}, and hard bias field, $\boldsymbol{H}_{\mathrm{B}}$, of the CPP read heads have been the important factors related to the mag-noise. Recently, the current perpendicular to the plane giant magnetoresistance (CPP-GMR) with using the half-metallic ferromagnetic Heusler alloy material as the electrode is the most candidate for high-density magnetic read heads because of its several outstanding properties.[2,3] Especially, a large CPP-GMR ratio provided by $Co_2FeAl_{0.5}Si_{0.5}$ (CFAS) electrode with Ag spacer was found by T. M. Nakatani *et al.*[3]

The aim of this work was to investigate the dependence of I_{sense} and $\boldsymbol{H}_{\mathrm{B}}$ on the mag-noise in CPP-GMR read head based on CFAS electrode. Particularly, the mag-noise in this work was induced through the STT effect, defined as spin transfer induced noise (ST noise). The macrospin modeling was performed in the simulations.

2. Simulation model

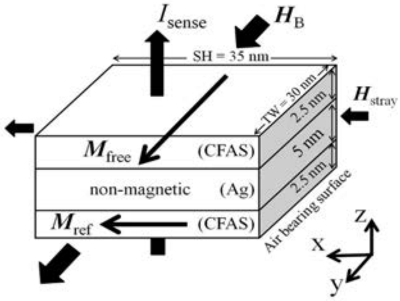

Fig. 1. The model geometry definition of CPP-GMR.

The simulation model of CPP-GMR read head with track width (TW) × stripe height (SH) of 30×35 nm^2 is illustrated in Fig. 1. The model comprises free and reference layers, separated by non magnetic layer which are CFAS(2.5 nm)/Ag(5 nm)/CFAS(2.5 nm). The magnetization of free and reference layers were initially aligned along +y and +x axes, respectively. The magnetic stray field, $\boldsymbol{H}_{\mathrm{stray}}$, produced by a perpendicular magnetic media for an areal density of 1 Tb/in^2 based on 10 nm FePt hard layer with a magnitude of 552 Oe was applied along +x axis while the head is sensing the data bit.[4] The hard bias field, $\boldsymbol{H}_{\mathrm{B}}$, with a magnitude of 1,400 Oe was applied along +y axis in order to stabilize the magnetization of free layer. This magnitude results in 30° tilt of free layer magnetization while the head is detecting data which could provide high linearity of sensor output.[2]

The magnetization dynamic of ferromagnetic materials under the spin polarized current is generally described by Landau-Lifshitz-Gilbert equation including STT term, written as (1).[1]

$$\frac{d\boldsymbol{M}}{dt} = - \boldsymbol{M}\times\boldsymbol{H}_{\mathrm{eff}} - \frac{}{M_{\mathrm{S}}}\boldsymbol{M}\times\frac{d\boldsymbol{M}}{dt} - \frac{p\hbar J}{eM_{\mathrm{S}}}\boldsymbol{M}\times(\boldsymbol{M}_{\mathrm{RL}}\times\boldsymbol{M}) \tag{1}$$

Where $\boldsymbol{M}$ and $\boldsymbol{M}_{\mathrm{RL}}$ are the magnetization vector of the of free and reference layers, respectively. $\boldsymbol{H}_{\mathrm{eff}}$, M_{s}, α, p, J and δ are the unit vector along the effective magnetic field, saturation magnetization, Gilbert damping constant, spin polarization, spin current density and free layer thickness, respectively. The CFAS material has following magnetic parameters[5]: $M_{\mathrm{s}} = 9 \times 10^5$ A/m, $p = 0.76$, $\alpha = 0.01$, exchange stiffness constant, $A = 2 \times 10^{-11}$ J/m, magnetocrystalline anisotropy constant, $K_1 = -1.0 \times 10^5$ J/m^3, bulk scattering spin asymmetry, = 0.77. The magnetoresistance ratio and resistance area product are 34% and 15 m µm^2, respectively.[3]

In order to investigate the ST noise influenced by I_{sense}, the positive and negative I_{sense} was applied to the head with the magnitudes of 0.25 to 5 times of a critical current, I_{c}, of 0.04 mA, while $\boldsymbol{H}_{\mathrm{B}}$ has a constant value of 1,400 Oe. The positive current generally refers to an electron flowing from free to reference layers causing the anti-parallel state between the magnetization of free and reference layers whereas a negative current is inversely defined which yields the parallel state. For an evaluation of $\boldsymbol{H}_{\mathrm{B}}$ effects on ST noise, $\boldsymbol{H}_{\mathrm{B}}$ is varied with using a constant I_{sense} of 0.08 mA. Then, the ST noise was analyzed by using the power spectral density (PSD) analysis. The local noise PSD was firstly computed by discrete Fourier transform of the CPP-GMR output resulting form the time varying magnetization for each point, $\boldsymbol{r}_{\mathrm{i}}$, defined as $\boldsymbol{M}_{\mathrm{x,y,z}}(\boldsymbol{r}_{\mathrm{i}},t_{\mathrm{j}})$, written as following: $S_{x,y,z}(r_i,f) = \left|\sum_j M_{x,y,z}(r_i,t_j)e^{i2\pi f t_j}\right|^2$ where t_{j} is the time