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Research articles

Playback signal distortion in CPP-GMR read heads due to induced electromagnetic interference

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ABSTRACT

Electromagnetic interference (EMI) induced magnetic instabilities are an influential factor which can degrade the performance of magnetic read heads. In this paper, we investigate the influences of EMI on the playback response of the current perpendicular-to-the-plane giant magnetoresistance (CPP-GMR) read heads via micromagnetic simulations. The readback signal and the noise spectral density of the heads when subjected to the EMI were characterized. It was found that the readback signal could be significantly distorted, or become inaccurate, from the EMI through the induced spin transfer torque effect. Also, the incorrect readback signal results in a notable expansion of the noise spectral density which further impacts the head stability. Furthermore, the bit-error-rate of the head signal processing could be markedly increased by multiple EMI occurrences. Hence, the playback response distortion of the CPP-GMR read heads due to the EMI is another concerned factor for the read sensors at higher storage capacities.

1. Introduction

In order to accomplish higher storage capacities of magnetic recording technologies, the current perpendicular-to-the-plane giant magnetoresistance (CPP-GMR) has been proposed extensively as the next generation of magnetic read sensors, since it has extremely low resistance area, therefore wide bandwidth and high data transfer rate [1,2]. Also, Heusler alloy materials for CPP-GMR devices have received massive research attention over the last decade due to their potential for half-metals e.g. 100% spin polarization, large magnetoresistance (MR) ratio, high magnetic moment and high Curie temperature [3–5]. Nevertheless, another influential factor for the CPP-GMR heads which needs earnest consideration is the magnetic noise induced by the spin transfer torque (STT) effect, especially this noise becomes more severe at higher areal densities when the heads are increasingly downsized [1,6–9].

Electromagnetic interference (EMI) has been an unavoidable issue for the magnetic recording heads since several publications claimed that it can impact the performance of the magnetic read head [10–12]. The EMI normally comprises the magnetic field (H-field) and electric field (E-field), it frequently occurs through electrostatic discharge (ESD) which is happened by two different electrical charge objects [13]. The influence of EMI on read sensor applications has been widely studied over the past two decades [12,14,15]. Remarkably, the latest publications indicate that EMI can induce noticeable disturbances to the CPP-GMR heads through STT induced magnetization fluctuations, which degrades the head stability [12]. However, the playback characteristics of the CPP-GMR heads subjected to these fluctuations, which are important factors in the reading process, has not been investigated yet.

In this article, the influence of EMI on the playback characteristics of the CPP-GMR read head, including the readback signal, the magnetic noise spectral density and the bit-error-rate (BER), is evaluated. The magnetic noise is defined as any spectral density induced by the EMI through the STT effect (ST noise). The specific details of the CPP-GMR head based $Co_2FeAl_{0.5}Si_{0.5}$ (CFAS) Heusler alloy for an areal density of 1 Tb/in^2 are assumed. Micromagnetic modelling based on MATLAB code M^3 is performed in the simulations [16].

2. Model and calculation

2.1. Theoretical modelling of the CPP-GMR read head

As illustrated in Fig. 1, the simulation model of the CPP-GMR read head is adopted from our previous publication [12]. The length of the track width (TW) and stripe height (SH) are 30 and 35 nm^2, respectively. The sensing layers consist of a non-magnetic layer sandwiched between the free and the reference layers based on CFAS full-Heusler alloy, the structure(thickness) is indicated as CFAS(2.5 nm)/Ag(5nm)/CFAS(2.5 nm). The magnetization of the free layer is initially aligned along its easy axis in the +y direction whereas the magnetization of the

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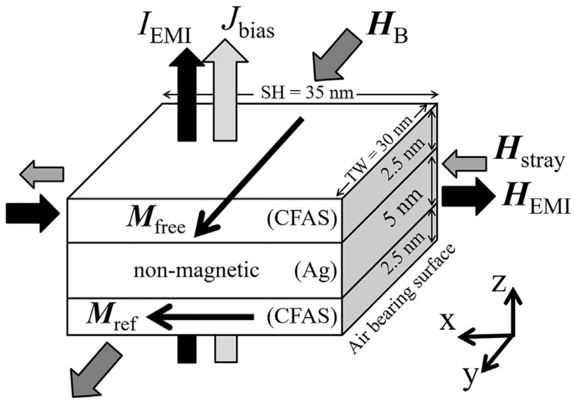

Fig. 1. Simulation model of CPP-GMR read head [12].

reference layer is assumed to be fixed along the +x direction by the exchange bias from the anti-ferromagnetic layer. It is assumed that the head is being operated with 1 Tb/in^2 granular perpendicular medium based on a 10 nm CoCrPt hard layer. The magnitude of a magnetic stray field, $\boldsymbol{H}_{stray}$, generated from this specific medium is 746 Oe [17]. While the head is detecting the information stored in each magnetic bit, it is assumed that a random distribution of continuous $\boldsymbol{H}_{stray}$ with 1 ns pulse width (correlated to an operating frequency of 1 GHz) is applied to the head along SH side (± x axis). A uniform hard bias field, $\boldsymbol{H}_B$, of 1740 Oe (0.138 MA/m) is applied to stabilize the magnetization pattern with 30° tilt angle during the reading process [18].

In order to consider the EMI effects on the head, the EMI propagating along the +y direction was applied to the head in terms of H-field and E-field. This EMI direction corresponds to the direction of the H-field and E-field along the –x and –z axes, respectively. According to this specific direction of the EMI, the H-field can primarily impact the magnetization alignment patterned by the media $\boldsymbol{H}_{stray}$ along the +x direction, while the E-field can induce a voltage across the head structure which further originates an induced spin polarized current, I_{EMI}, flowing perpendicularly through the head from the reference to free layers. As a result, the I_{EMI} will interact with the magnetization of ferromagnetic layers, yielding the STT effect, which essentially causes the magnetization fluctuation [12]. In this work, we focus on the EMI radiated by the ESD following IEC 61000-4-2 standard, since it can generate higher EMI magnitude than the other ESD types [19]. The characteristics of this specific EMI have already been published in the literature [12]. As illustrated in Fig. 2(a), the maximum EMI amplitude, in terms of the H-field and E-field, were measured with 2, 4, 6 and 8 kV ESD charging voltages at distances of 0.75–3 cm from the discharge point; the EMI waveform is also shown in Fig. 2(b) [12].

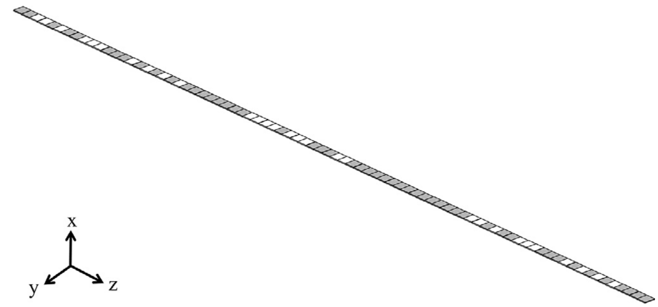

Fig. 3. A model of 80 perfectly written bits along the cross-track direction with the $\boldsymbol{H}_{stray}$ randomly generated along the +x axis (gray-filled bits) and the –x axis (white-filled bits).

The CFAS Heusler alloy has the saturation magnetization (M_s), magnetocrystalline anisotropy constant (K_1), Gilbert damping parameter (α), spin polarization factor (p) and exchange stiffness constant (A) of 9×10^5 A/m, 2×10^{-11} J/m, 0.01, 0.76 and -1.0×10^5 J/m^3, respectively [20]. The structure has specific resistance area (RA) product of 15 mΩμm^2, head capacitance of 10 pF, MR ratio of 34% and shield-to-shield spacing of 30 nm [2,3]. A bias current density, J_{bias}, of 3.15×10^6 A/cm^2 is applied to the head where its magnitude is purposely limited in order to minimize the influence of spin torque induced instabilities from this current. The positive current is generally defined as an electron flowing from the free to reference layers.

The time-varying magnetization under the spin polarized current is generally computed by the Landau-Lifshitz-Gilbert-Slonczewski equation, given as [7]:

$$\frac{dM}{dt} = \gamma M \times H_{eff} - \alpha\frac{\gamma}{M_S} M \times (M \times H_{eff}) - a_j\frac{\gamma}{M_S} M \times (M \times m_p) \quad (1)$$

where $\boldsymbol{M}$, $\boldsymbol{m}_p$, $\boldsymbol{H}_{eff}$ and γare the unit magnetization vector of free layer, unit vector of polarization direction, effective magnetic field and gyromagnetic ratio, respectively. The spin torque factor is given by $a_j = (J\hbar g(\theta))/(2eM_s\delta)$, where J, $\hbar$, e and δare the polarized current density, reduced Planck's constant, electron charge value and free layer thickness, respectively. The scalar function $g(\theta)$ is defined as $g(\theta) = [-4 + (1 + p)^3(3 + \cos\theta)/4p^{3/2}]^{-1}$, where θis the tilted angle of free layer magnetization with respect to the magnetization of the reference layer. A computation cell size of $2 \times 2 \times 2$ nm^3 and a constant time step of 0.1 ps were set in the simulations.

2.2. Analysis of EMI influence on the play back characteristic

In this work, the EMI effects on the playback characteristic of the

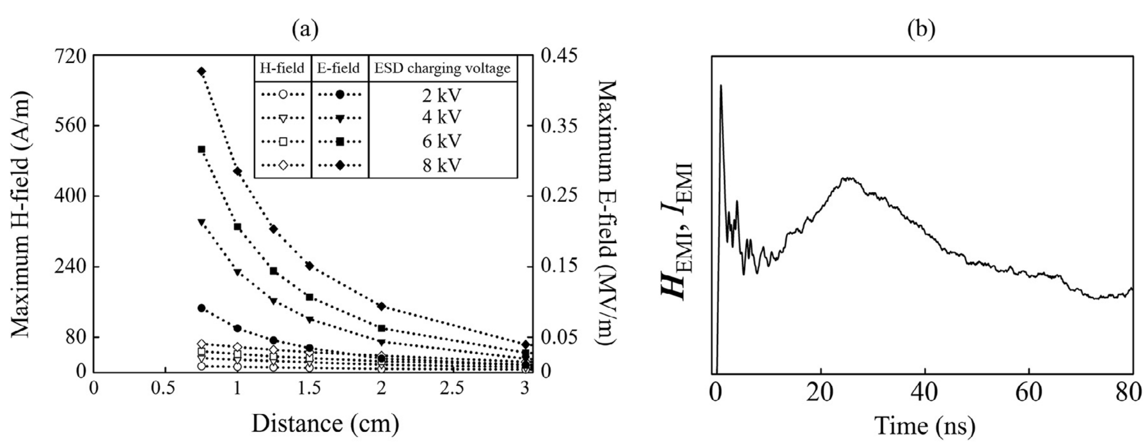

Fig. 2. (a) The maximum magnitude of the H-field and E-field of the EMI radiated by ESD based on IEC 61000-4-2 standard with varying charging voltages and distances and (b) the waveform of the EMI [12].