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Analysis of magnetic noises in two-dimensional magnetic recording readers

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A model is introduced in this paper to describe the effects of thermal magnetic noises in the read sensor under off-track reading conditions taking into account the influence of the magnetic field generated by the recorded magnetization patterns on the medium. Our numerical studies show that there exist additional noises in the hard biased reader, depending on recorded patterns on the magnetic media. The influence of the recorded magnetic patterns is not only on the variation in reader resistance but also on the high frequency noises caused primarily by the thermal fluctuations. The theoretical analysis is based on the micromagnetic modeling of the state of magnetization in read sensor taking into account of its external magnetic fields due to both the hard bias and the media magnetization patterns. The effect of the thermal agitation of the gyromagnetical precession of magnetizations is evaluated by considering the angular magnetic noise. *© 2015 Author(s). All article content, except where otherwise noted, is licensed under a Creative Commons Attribution 3.0 Unported License*. [http://dx.doi.org/10.1063/1.4916298]

The read head structure incorporating multiple readers is advantageous for inter-track interference cancellation in Two-Dimensional Magnetic Recording (TDMR).[1] Recent work in TDMR indicated that substantial improvement of bit error rate (BER) and off track capability (OTC) may be achieved [e.g., Refs. 1 and 2]. However, as the hard-biased read heads may be operating near the track center, they are inevitably subject to the influence of the magnetic field of recorded tracks resulting in additional noises as found experimentally.[3] The influence of the recorded magnetic patterns is not only on the variation in reader resistance but also on the high frequency noises caused primarily by the thermal fluctuations. Previous study shows that with the downsizing of the read sensor, the thermal magnetic noises become the key limiting factor in the applicability of the magnetoresistive sensors,[4] according to the analyses of the amplitude distributions of magnetization in the free layer in giant magnetoresistive (GMR) and tunneling magnetoresistive (TMR) heads [e.g., Refs. 5–8]. This paper focuses on the effects of thermal magnetic noises in the read sensor under off-track reading conditions taking into account the influence of the magnetic field generated by the recorded magnetization patterns on the medium. Our numerical studies show that there exist additional noises in the hard biased reader, depending on recorded patterns on the magnetic media. The noise can be markedly strong, several times higher than on track reading under certain conditions. The theoretical analysis is based on the micromagnetic modeling of the state of magnetization in read sensor taking into account of its external magnetic fields due to both the hard bias and the media magnetization patterns. The effect of the thermal agitation of the gyromagnetical precession of magnetizations is evaluated by considering the angular magnetic noise.[8]

In this study, the read sensor used for TDMR has a TMR element which is hard biased with magnets. In the situation of off-track reading, the read sensor experiences external fields due to the hard bias magnets as well as the magnetization patterns recorded on media. The parameters of the reader and media are as follows. The free layer of the read sensor has a width of 40 nm, a height of 30 nm, and a thickness of 3 nm, with saturation magnetization of 800 kA/m, exchange coupling constant of 1.0×10^{-11} J/m, and anisotropy field of 7.5 kA/m. The shield to shield spacing is 23 nm. The saturation magnetization of the hard bias magnet is 590 kA/m. The saturation magnetization of the granular medium, Ms is 500 kA/m. The track width is 65 nm. The head to media spacing is 6 nm.

First, we analyze the influence of the external magnetic field on the read sensor performances. The magnetic field due to the magnetization pattern and the hard bias magnets is analyzed using a finite element method solving the governing Maxwell equations. The magnetic flux vector distributions inside the read sensor element due to hard bias and recorded magnetizations are shown in Fig. 1. In Fig. 1(a), the stray field of the recorded magnetization pattern on the media is, in general, parallel to the magnetization of the read sensor element. In Fig. 1(b), the stray field of the recorded magnetization pattern is opposite to the magnetization of the read sensor element. The variation in the direction and amplitudes of the local magnetic field in the sensor element indicates that the characteristics of the read sensor can be markedly influenced by the magnetization patterns on media.

The magnetization dynamics of the free layer of the read sensor is governed by the Landau–Lifshitz–Gilbert (LLG) equation

$$\frac{d\vec{M}}{dt} = -\gamma'\vec{M} \times \vec{H}_{eff} - \frac{\alpha\gamma'}{M_s}\vec{M} \times \left(\vec{M} \times \vec{H}_{eff}\right), \qquad (1)$$

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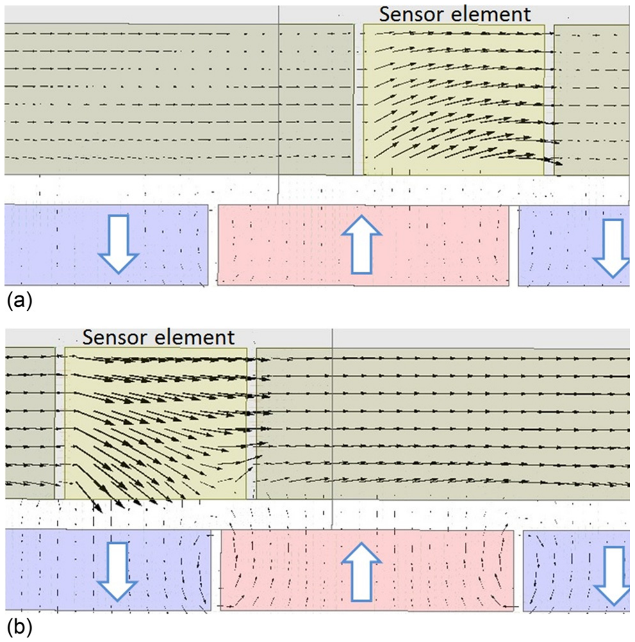

FIG. 1. Schematic view of magnetic field vector distributions in read sensor element due to hard bias and recorded magnetizations, when stray field of recorded magnetization pattern is, in general, parallel to magnetization of read sensor (a) and opposite to magnetization of read sensor (b).

where $\vec{M}$ is the magnetization vector, M_s is the saturation magnetization of the free layer, α is the damping constant, $\gamma' = \gamma/(1+\alpha^2)$, and γ is the gyromagnetic ratio ($\gamma = 2.21 \times 10^{-23}$ m/A s). The effective field vector, $\vec{H}_{eff}$, is augmented with a random thermal field to include the thermal agitation effect for the gyromagnetical precession of magnetizations.[4,5] The random thermal field is of Gaussian distribution having an average of zero and a constant standard deviation of

$$\frac{1}{H_{stiff}}\sqrt{\frac{2\alpha kT}{\gamma V_c \mu_o M_s \Delta t}}, \qquad (2)$$

where k is the Boltzmann constant ($k = 1.38 \times 10^{-23}$ J/k), T is the absolute temperature ($T = 300$ K), μ_o is the permeability of free space, V_c is the volume of the cell element used for the discretization of the sensor element for micromagnetic calculations, and Δt is a time constant ($\Delta t = 10$ ps). The stiffness field, H_{stiff}, can be calculated as the projection of the effective field onto the direction of the local magnetization in each individual cell element.[8]

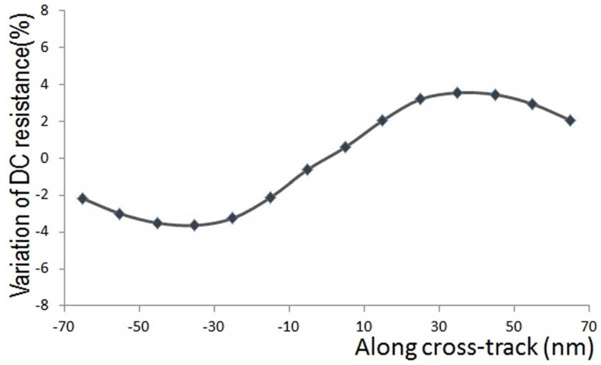

FIG. 2. Variation of DC resistance at track transition when stray field of recorded tracks is parallel to magnetization of read sensor.

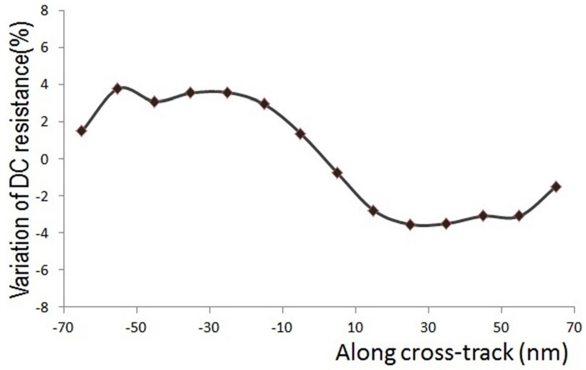

FIG. 3. Variation of DC resistance at track transition when stray field of recorded tracks is opposite to magnetization of read sensor.

The local conductance of each cell of the read sensor can be calculated based on the state of magnetization obtained from micromagnetic analyses with the effect of non-coherent movement of the local magnetization taken into consideration, as follows:

$$g_{ij} = g_{oij}/(1+\delta_{oij}\cos\Phi_{i,j}), \qquad (3)$$

where $\Phi_{i,j}$ is the angle between the local magnetization with respect to the magnetization of the reference layer, $\delta_{oij} = \Delta r/(r_{max}+r_{min})$, $\Delta r = (r_{max}-r_{min})$, $g_{oij} = 1/r_{oij}$, $r_{oij} = (r_{max}+r_{min})/2$, and r_{max} and r_{min} are the maximum and minimum resistances of the read sensor, respectively. The total reader conductance can then be obtained using such a discretized model given by

$$G = \sum_i \sum_j g_{oij}/(1+\delta_{oij}\cos\Phi_{ij}). \qquad (4)$$

In the following analysis, the damping constant α is assumed to be 0.02. The cell size for discretization, l_c, is

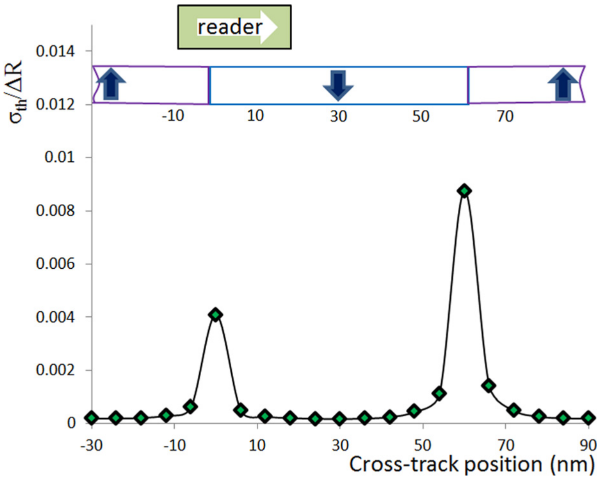

FIG. 4. Thermal magnetic noise compared with resistance variations at different cross-track positions. Inset figure indicates track transitions and hard-biased reader schematically.

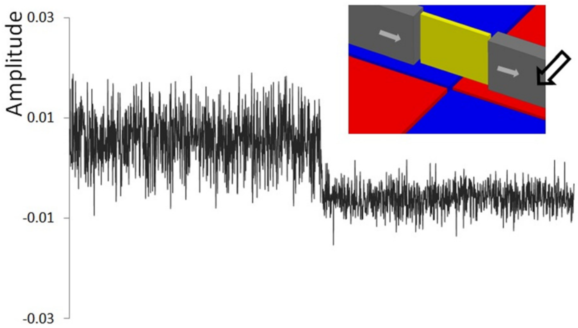

FIG. 5. Thermal magnetic noise when the reader scans over a transition in down track direction as shown schematically by the inset figure.

chosen to be approximately equal to the exchange length of the sensor element.

Figs. 2 and 3 show the variation of the reader resistance when it is under the influence of recorded magnetization patterns. The variation of the sensor DC resistance is obtained by finding the equilibrium of the time averaged magnetic states in each cell using micromagnetic analysis. Fig. 2 plots the variation of DC resistance at the track transition when the stray field of recorded tracks is parallel to the magnetization of the read sensor element. Fig. 3 shows the variation of DC resistance at the track transition when the stray field of the recorded tracks is opposite to the read sensor magnetization. It shows that the reader resistance changes depending on the conditions of the recorded magnetization patterns on the media. It can also be observed that the peak value of the resistance variation for the latter case is relatively larger. Fig. 4 shows the magnitude of thermal magnetic noise at different cross-track locations under the condition of alternating polarization of the tracks as indicated in the inset figure. The non-coherence of the local magnetization inside the read sensor due to the media magnetization patterns can also affect its response to the high frequency variations of the magnetic field and its performance associated with other noise conditions such as the low frequency thermal magnetic fluctuation noise.[4,8]

Fig. 5 shows thermal magnetic noise when the reader scans over a transition in the down-track direction. The rms value of the thermal magnetic noise, σth, is calculated, and the ratio of σth over the change in the mean value of the sensor resistance due to the field of the recorded magnetizations on media, ΔR, is plotted against the cross-track positions in this figure. It can be seen that when the longitudinal component of the magnetic field due to the recorded magnetizations on media is, in general, in the opposite direction of the hard bias field, leading to greater degree of stiffness field weakening. As a result, the magnitude of the thermal noise is comparatively larger, as shown in the figure.

It will be noted that the variation in resistance is also sensitive to the head and media spacing. It is also worth mentioning that the magnetic field external to the read sensor is dependent on various head media parameters.

The performance of hard-biased read sensor at off-track reading has been studied. A model is introduced for calculation of reader resistance to account for effect of non-coherent rotation of the local magnetic moment. The effect of the thermal agitation of the gyromagnetical precession of magnetizations is evaluated by considering the angular magnetic noise. Our numerical studies show that there exist additional noises in the hard biased reader, depending on recorded patterns on the magnetic media. The model is effective for studying the reader performance at off-track reading which appears to be unavoidable in the TDMR.

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