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Microwave-assisted shingled magnetic recording simulations on an exchange-coupled composite medium

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ABSTRACT

The potential of microwave-assisted magnetic recording combined with the shingled recording scheme has been studied by simulating read/write processes on exchange-coupled composite media focusing on recording characteristics in the cross-track direction. Microwave fields enhance writability, especially at the track edge, resulting in lower noise and higher signal-to-noise ratio (SNR), which enables higher track density in the shingled recording scheme. Read/write simulations of microwave-assisted shingled recording achieve 1.4 Mtracks/in. while retaining high SNR. Further increases in SNR and track density will require either a narrower reader or track edge noise reduction.

1. Introduction

It is widely known that future advances in the areal density of hard disk drives are essentially limited by the magnetic recording trilemma arising from the conflicting requirements between signal-to-noise ratio, writeability, and stability [1]. Energy-assisted magnetic recording such as heat-assisted magnetic recording [2] and microwave-assisted magnetic recording (MAMR) [3–9] is thought to solve the trilemma by improving writability and enhancing areal recording density. Two-dimensional magnetic recording with shingled writing [10] has also been proposed for increasing track density, which is enabled by partial overlapping of recorded tracks. Energy-assisted magnetic recording combined with shingled writing is a possible candidate for future recording schemes on hard disk drives.

This study investigates read/write characteristics of MAMR combined with shingled writing by micromagnetic simulation. In the micromagnetic simulation, a granular-type exchange-coupled composite (ECC) medium [11] was modeled using discrete Voronoi grains, and an asymmetric single-pole-type (SPT) head with a side shield [12–14] was employed as a recording head model. The ECC-structured media are advantageous in microwave-assisted magnetization switching, because low microwave fields with low frequency enable magnetization switching [15–19]. The ECC media enables signal recording with moderate microwave frequency in the MAMR process [20–22]. In this study, enhancement of the track edge writability by microwave assistance using an asymmetric SPT head was numerically estimated through a signal-to-noise ratio (SNR) and the track density limit was investigated.

2. Simulation model

A 30-nm track-width SPT head with a trailing return yoke and a side shield was employed for the signal recording simulations. Head field distributions were estimated using a finite element method (FEM) calculation with the assumption that a 60-nm-thick soft magnetic backlayer exists under the recording layer. The saturation magnetizations of the main pole and soft magnetic backlayer were 24 kG and 12 kG, respectively. Field rise time was set to 0.1 ns. Magnetic spacing between the SPT head and the recording media was 5 nm. A 10-nm-thick and 30-nm track-width field generation layer (FGL) for a spin torque oscillator [23–25] was also assumed to be located between the main pole and the trailing return yoke, 5-nm distant from the trailing edge of the main pole. The chirality of the ideal magnetization rotation of FGL was assumed to change following the reversal of the head field. Fig. 1 shows a schematic view of the asymmetric SPT head with FGL and the perpendicular component of the head field distributions at the surface of the recording media. The asymmetric profile of the head field in the cross-track direction reflects the asymmetric structure

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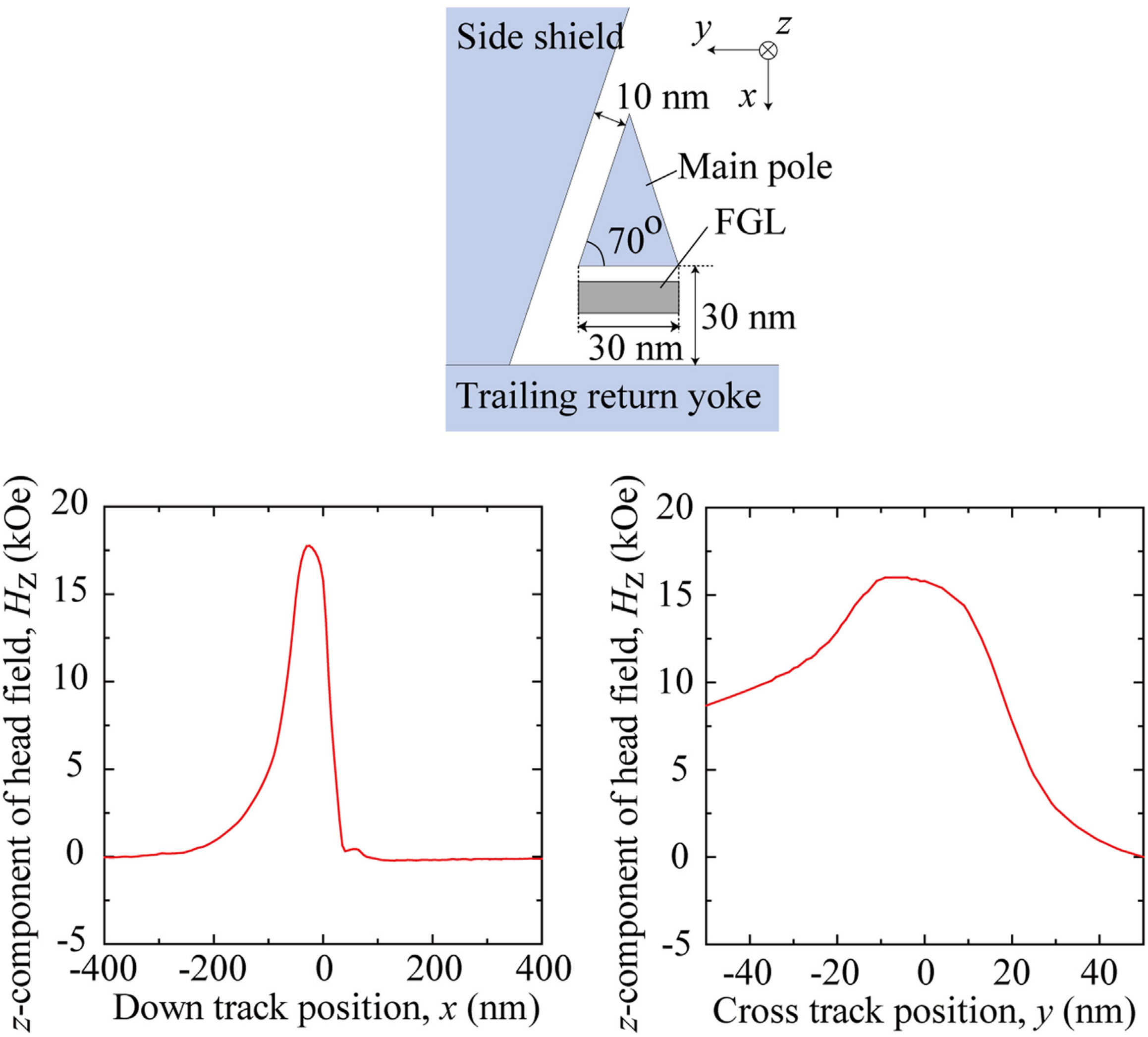

Fig. 1. ABS view of the asymmetric single-pole-type head employed for the recording simulation and the z-components of the head field applied to the medium surface along the down track direction at the track center ($y=0$) and along the cross track direction at the trailing edge ($x=0$) of the main pole. The head field gradients along the down track and cross track directions are 578 Oe/nm at $x=5$ nm and 673 Oe/nm at $y=15$ nm, respectively.

of the recording head; its maximum strength was 17.5 kOe. The head field near the trailing edge was about 15 kOe. A steep gradient field distribution long the cross-track direction was observed at the shielded side. The amplitude of the microwave field provided by the FGL with 1700 emu/cm^3 was 1.3 kOe in the cross-track direction at the medium surface.

Granular ECC media with 7-nm-thick soft and 5-nm-thick hard layers were employed in this study. Uniaxial easy axes were along the perpendicular axis with 5° of standard deviation. The anisotropy fields and saturation magnetizations were, respectively, 13.6 kOe and 780 emu/cm^3 for the soft layer and 73 kOe and 600 emu/cm^3 for the hard layer. Ten percent of the standard deviation of the anisotropy fields was taken into account. The exchange constant for both the layers was 1.0×10^{-6} erg/cm, and their inter-layer exchange constant was 5.0×10^{-7} erg/cm. The dimensionless damping constants for the soft and hard layers were 0.05 and 0.2, respectively. The granular ECC media were modeled using discrete Voronoi grains with an average size of 4.6 nm and an average pitch of 5.5 nm. The standard deviation of the grain diameter was 30% of the average diameter. Numerical unit cell size was 0.9 nm in the x- and y-directions and 1.0 nm in the z(perpendicular)-direction. Energy barrier height for a single grain was estimated using the nudged elastic band method. The estimated barrier height was 3.13×10^{-12} erg, which corresponds to 64.8k_BT at 350 K.

Magnetization dynamics were investigated by solving the Landau–Lifshitz–Gilbert equation. The effective field vector was defined as a vector summation of the external applied field, the exchange interaction field, the anisotropy field, the magnetostatic field, and the stochastic thermal field at 350 K. The reading process was simulated using the reciprocity theorem [26]. Three-dimensional magnetoresistive (MR) head sensitivity was estimated by FEM calculations, assuming an MR head with a 4-nm-thick and 13-nm-wide element and 20-nm-long gap shields.

3. Results and discussion

Fig. 2 shows the bit patterns of the 200 kbpi and 1600 kbpi signals recorded with a microwave frequency of 15 GHz and a weak intergrain interaction, A. Recorded bit patterns are clearly observed for all A, although a few island reversals are observed in the recorded bits on the non-shielded side. The island reversals may result from the poor head field gradient at the non-shielded side of the main pole or from out-of-resonance magnetic grains. A weak intergrain exchange interaction between neighboring grains is thought to increase SNR by suppressing the generation of island reversals, although recorded track width becomes slightly wider as