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Micromagnetic recording field analysis of fast-switching single-pole-type heads for bit-patterned media

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Abstract

A Landau–Lifshitz–Gilbert (LLG) micromagnetic analysis of the recording field of single-pole-type (SPT) heads was carried out. The whole volume comprising the SPT head and the double-layered medium was treated micromagnetically using the finite-difference method with cubic cells as small as 5 nm, giving a total number of cells of more than 10.8 million. A parallelized fast Fourier transform (FFT) method was used to solve this large-scale problem. Dynamic recording fields were calculated for various head structures and head materials. The timing (synchronization) between the dynamic head field and land location in bit-patterned media (BPM) is discussed and the design methodology is discussed for a fast-switching SPT head.

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Keywords: Perpendicular magnetic recording; Single-pole-type (SPT) head; LLG micromagnetic analysis; Bit-patterned media; Parallel computing

1. Introduction

Perpendicular magnetic recording (PMR) has had remarkable success both commercially and technologically, and the areal density has reached 457 Gb/in^2 [1]. However, the so-called tri-lemma of writablity, medium signal-to-noise ratio (SNR), and thermal stability makes it increasingly difficult to achieve higher areal densities. Bit-patterned media (BPM), in which ordered arrays of discrete magnetic elements are used to store data [2], improve the SNR by removing the dominant noise source, jitter, while maintaining writability. The single-pole-type (SPT) head is one of the most important components needed to achieve a high areal density in perpendicular magnetic recording. Recent papers have dealt with write synchronization [3] or write field amplitude [4], however, the switching speed of the write head field was not discussed, while studies of fast-switching SPT heads did not consider the use of BPM [5,6].

While conventional finite-element methods are good tools for analyzing the static head field of complicated head structures [7], the dimensions of an SPT head are too small to treat in a macroscopic manner with Maxwell's equations, especially when dynamic phenomena are considered. In this paper, a Landau–Lifshitz–Gilbert (LLG) micromagnetic analysis of the recording field of an SPT head is carried out. The whole volume, comprising the SPT head and the double-layered medium, was treated micromagnetically using the finite-difference method [8] with cubic cells as small as 5 nm, giving a total number of cells of more than 10.8 million. A fast Fourier transform (FFT) method [9] was used to solve this large-scale problem on a PC cluster system. Dynamic recording fields were calculated for various head structures and head materials and the timing (synchronization) between the dynamic head field and BPM location is discussed. For a typical BPM with an aspect ratio of 1 and a linear velocity of 33.3 m/s, a

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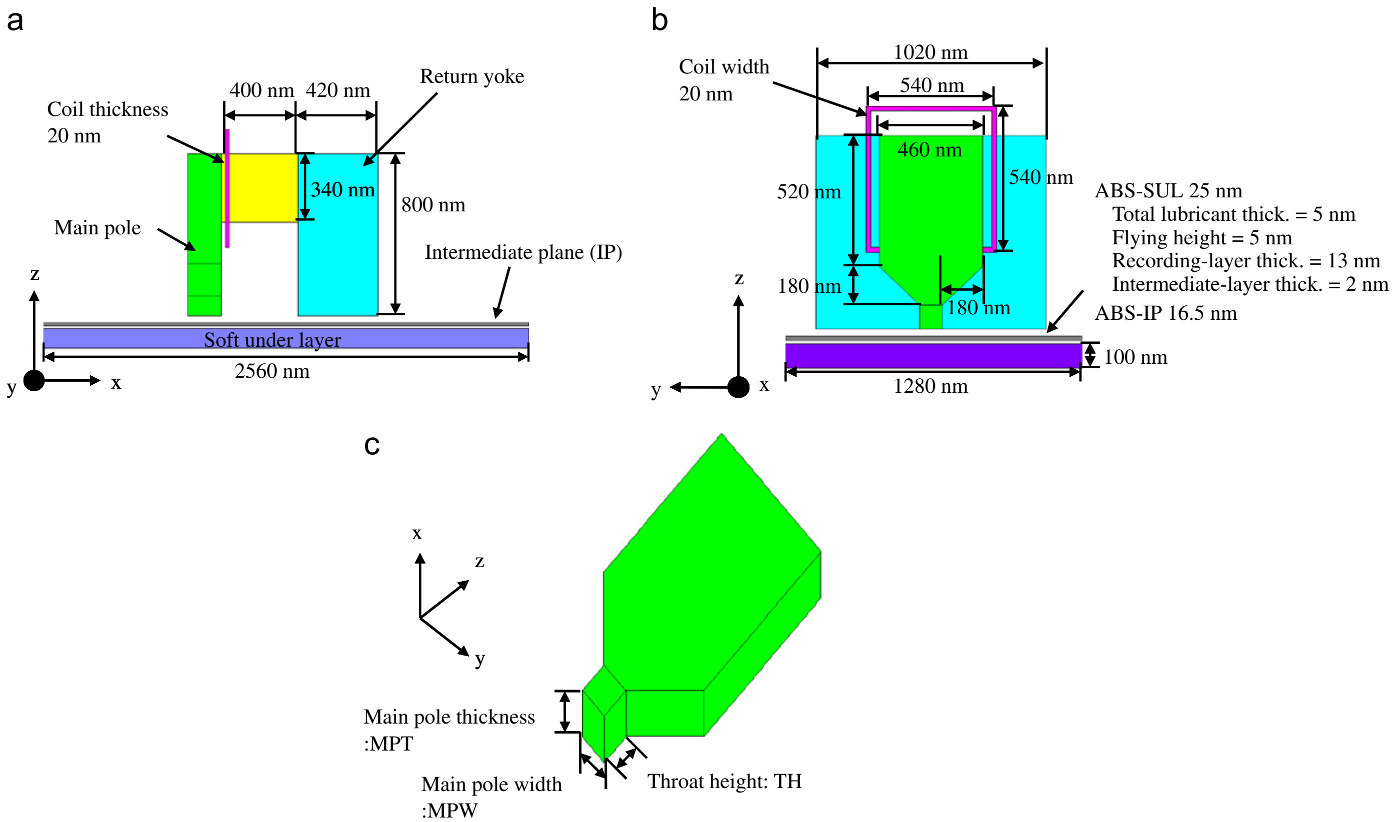

Fig. 1. SPT head model used for LLG and FEM calculations: (a) *zx*-plane, (b) *yz*-plane, and (c) main pole.

Table 1
Major specifications for head materials

	SPT head	Soft underlayer
M_s (emu/cc)	1910	955
$4\pi M_s$ (kG)	24	12
K_u (erg/cc)	3×10^4	3×10^4
A (erg/cm)	1×10^{-6}	1×10^{-6}

K_u, the anisotropy energy; A, exchange constant.

head switching speed (positive peak to negative peak) of less than 0.38 ns is necessary. To achieve such fast switching, an optimum damping factor, a short yoke and fast switching of the current in the SPT write head are necessary.

2. Calculation model

We consider the SPT head model shown in Fig. 1 with material characteristics shown in Table 1, for which a throat height (TH) of 100 nm, main pole tip width (MPW) of 100 nm, and main pole tip thickness (MPT) of 180 nm were assumed, unless stated otherwise. The recording layer was assumed to be air. In the micromagnetic analysis the LLG equation:

$$(1+\alpha^2)\dot{\boldsymbol{M}} = -|v|\boldsymbol{M}\times\boldsymbol{H} - \frac{|v|\alpha}{M_s}\boldsymbol{M}\times(\boldsymbol{M}\times\boldsymbol{H}) \quad (1)$$

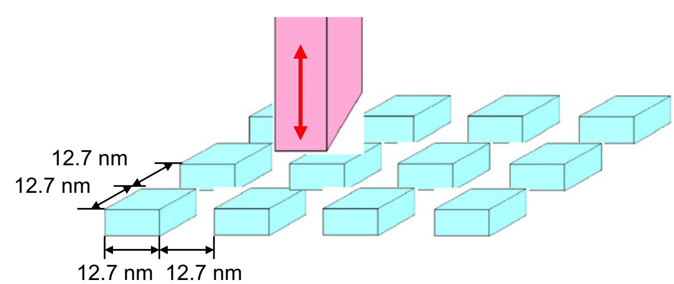

Fig. 2. A schematic of a bit-patterned medium with an areal density of 1 Tb/in^2.

was solved using the finite-difference method, where $\boldsymbol{M}$ is the magnetization vector, M_s the saturation magnetization, $\boldsymbol{H}$ the effective field vector, v the gyro-magnetic constant, and α the damping factor. The recording field distributions were observed on an intermediate plane [8], 16.5 nm from the ABS.

3. Results and discussion

Consider the BPM shown in Fig. 2. The bits have an aspect ratio of 1, land width, L, and groove width, G, of 12.7 nm in both the down- and cross-track directions and an areal density of 1 terabits per square inch (Tb/in^2). If the medium velocity is 33.3 m/s, the head field should be switched from negative peak to positive peak in less than 0.38 ns (= (25.4/2)/33.3). The pole tip dimensions of the