BPM Write Channel Modeling

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Abstract

A write channel model is constructed for bit-patterned-media (BPM) recording. The model takes arbitrary binary data as input and generates the corresponding written magnetization waveform. The model allows investigation of characteristics and impact of bit errors due to imperfections in the lithography process as well as write miss-synchronization. Simulation results successfully demonstrate missing bit and deletion/insertion error characteristics of BPM recording.

Keywords: bit-patterned-media, write channel model

1. Introduction

Bit-patterned-media (BPM) recording is a highly promising next generation magnetic recording technology that can achieve the areal density over 1Tb/in^2. The magnetic disk in BPM recording is patterned to form an array of discrete island domains of magnetic material. One bit of information is typically stored in each island. The remaining area of the disk is non-magnetic. Due to this reason, the island position and size are very important in constructing a write channel model. In this paper, we construct a write channel model for BPM recording. The model takes arbitrary binary data as input and generates the corresponding written magnetization waveform. The model allows investigation of characteristics and impact of bit errors and insertion/deletion, due to imperfections in the lithography process as well as write miss-synchronization. BPM write channel modeling basically amounts to modeling the lithography process and then the magnetization process. The lithography process model generates an array of island domains with their positions and sizes randomly distributed with user-specified probability distribution functions. Our simulation results successfully demonstrate missing bit and deletion/insertion error characteristics of BPM recording.

2. Proposed Method

To model the write magnetization process, a write bubble is assumed to keep overwriting the islands under its influence as it moves in small discrete steps along the track. The head movement across the track is also allowed in the model. The two-dimensional path of the write bubble is obtained via linear interpolation of the discrete positions of the write bubble corresponding to the center positions of the write window, as determined by the external write clock signal. The write-clock-generated bubble positions have both deterministic and random noise components, which are statistically independent of the random position and size parameters of the lithography process. An island is assumed to be completely magnetized in either direction with no partial overwrite possibilities. To determine the direction of the written magnetization of an island, the Zeeman energy is computed by performing a three-dimensional integration over the volume of the island on the product of the user-specified head field gradient function and the medium magnetization function [1]. The Zeeman energy loaded onto the island by head-field H is denoted by

$$E_V \propto \iiint_{V_{island}} \mathbf{H}(\mathbf{x}) \cdot \mathbf{m}(\mathbf{x}) \mathrm{d}\mathbf{x} \qquad (1)$$

where $\mathbf{m}$ is the island magnetization and V_{island} is the volume of the island. The vector **x** represents three orthogonal directions: along the track, across the track and along the vertical direction. We assume $\mathbf{m}(\mathbf{x}) = 0$ off the island and $\mathbf{m}(\mathbf{x}) = m_z(\mathbf{x}) = \pm 1$ on the island (only the vertical-component exists). With these assumptions (1) simplifies to

$$E_A \propto \iint_{A_{island}} H_{eff}(x, y) dxdy \equiv E \qquad (2)$$

where A_{island} is the cross-section of the island in the *xy*-plane and H_{eff} is a scalar representing the effective write-field. The Zeeman energy is then compared with a switching field distribution (SFD) function to determine whether the island will be overwritten.

$$switch = \begin{cases} 1 & if\ E > \eta \\ 0 & elsewhere. \end{cases} \quad (3)$$

The SFD itself is assumed random with certain mean and variance, to reflect local fluctuation of the medium properties.

3. Write Channel Model

Let $m(x - x_0, y - y_0, d)$ be a cylindrical function of unit-height centered at (x_0, y_0) with diameter d. Let $A(m(x,y))$ be the area of the top portion of $m(x,y)$ and $s(x,y)$ be the continuous write-field. Then, the overwritten portion of two cylinders is described by

$$i(x,y) = m(x - x_0, y - y_0, d)\ \times s(x,y). \quad (4)$$

Therefore,

$$\begin{cases} A\big(i(x,y)\big) > \eta \Rightarrow switch = 1 \\ A\big(i(x,y)\big) < \eta \Rightarrow switch = 0\,. \end{cases} \quad (5)$$

A corresponding pseudo code description of the write process is given as follows:

Algorithm Write process

1. Build the pattern function
$p(x,y) \triangleq \sum_{k,j} m(x - x_{kj}, y - y_{kj}; d_{kj})$
2. Set the medium magnetization initially
$c(x,y) = p(x,y)$
3. Generate the write waveform
$s(x,y)$
4. Generate the SFD
$i(x,y;k,j) \triangleq m\big(x - x_{kj}, y - y_{kj}; d_{kj}\big)s(x,y)$
$switch(k,j) \triangleq \begin{cases} 1 & if\ A\big(i(x,y;k,j)\big) > \eta(k,j) \\ 0 & elsewhere \end{cases}$
5. Write the medium
$c(x,y) \triangleq \sum_{k,j} \Big\{\Big(b_{kj} switch(k,j) + 1 - switch(k,j)\Big) m\big(x - x_{kj}, y - y_{kj}; d_{kj}\big)\Big\}$
6. For overwriting with new data
Go to 3.

4. Simulation Results

Assume that each island stays inside a rectangle of dimension T_x by T_y centered around its nominal position, and let Δx, Δy and Δd be random jitters associated with the island. Fig. 1 shows the particular simulation results representing missing bit error characteristics of BPM recording under different amounts of lithography jitter and SFD fluctuations. The write jitter is assumed fixed in this particular simulation. The figure shows top-down views of magnetized disk regions. The medium is first DC-erased in one direction. Uniform bits are then written onto the medium so as to reverse the magnetized direction. Part (a) represents a recording condition corresponding to low lithography jitter ($\sigma_{\Delta_x}/T_x = 0.05, \sigma_{\Delta_y}/T_y = 0.05, \sigma_{\Delta_d}/d = 0.01$) and low SFD fluctuations ($\sigma_{\Delta_\eta}/\eta = 0.02$). Part (b) corresponds to low lithography jitter (same as above) and high SFD fluctuations ($\sigma_{\Delta_\eta}/\eta = 0.2$). Parts (c) and (d) represent high lithography jitter ($\sigma_{\Delta_x}/T_x = 0.1, \sigma_{\Delta_y}/T_y = 0.1, \sigma_{\Delta_d}/d = 0.1$) /low SFD fluctuations and high lithography jitter/high SFD fluctuations, respectively. In all cases, the normalized write jitter is fixed at 0.05 in both *x* and *y* directions.

The missing bit error effect is shown clearly in parts (b), (c) and (d) with the most errors captured in part (d). The random position jitter and the size fluctuations are evident in parts (c) and (d).

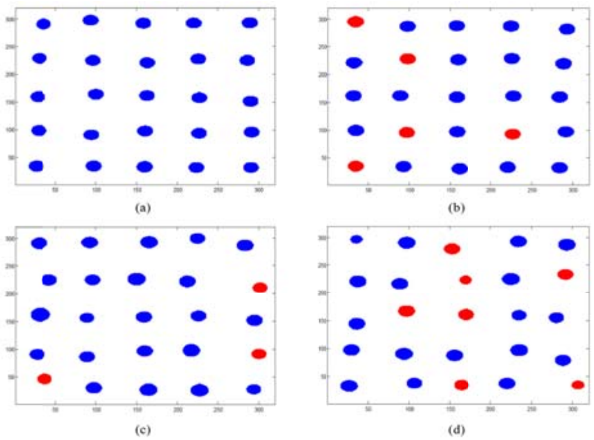

Fig. 1: Sample magnetization waveforms generated under different noise environments: the red dots represent erroneously magnetized islands. Lithography jitter/SFD variation: (a) L/L (b) L/H (c) H/L (d) H/H

References

[1] M. E. Schabes, "Micromagnetic theory of non-uniform magnetization processes in magnetic recording particles," Journal of Magnetism and Magnetic Materials 95 (1991) 249-288.