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Application of the grain flipping probability model to heat assisted magnetic recording

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Heat assisted magnetic recording (HAMR) is often lauded as one of the key technologies poised to replace conventional granular magnetic recording (CGMR). Conventional recording is expected to eventually fail because as the information-bearing grains continue to shrink, they become thermally unstable and will spontaneously flip due to excitations from the ambient temperature. HAMR grains are smaller and have larger anisotropies making them thermally stable, but unwritable at room temperature. Heat from a laser is applied to assist during the writing. The grain flipping probability (GFP) model has been proposed to model and predict the densities achievable in conventional recording systems. In this work we modify the GFP to include a circular hot-spot of a laser as a 2 D Gaussian and predict the expected densities that might be achieved on HAMR media with 4 nm grains. In this work we examine the effect of varying the hot-spot diameter, the hot-spot peak, and the alignment of the hot-spot to the magnetic footprint profile. © 2012 American Institute of Physics. [doi:10.1063/1.3679141]

I. INTRODUCTION

Heat-assisted magnetic recording (HAMR) (Ref. 1) is one of the key contending technologies expected to takeover when conventional granular magnetic recording (CGMR) (Ref. 2) is no longer able to continue along the areal density growth curve. HAMR extends the areal density growth by allowing smaller grains to be used than would be feasible in CGMR. Small grains suffer from the dilemma of being either thermally unstable or having such large anisotropies that they are unwritable using available heads. The third leg of the (in)famous media trilemma³ is to use larger grains, but in this case the signal-to-noise (SNR) cannot be maintained with increasing densities.

In the HAMR paradigm, information is stored on small grains that cannot be written at room temperature, but a laser is used to increase the media temperature at the time of writing, thereby reducing the grains' anisotropy (K_u), making them writable.

The grain flipping probability (GFP) model has been proposed in Ref. 4 and applied to the situation of CGMR, shingled magnetic recording (SMR), and two-dimensional magnetic recording (TDMR).⁵ The GFP is trained through micromagnetic simulations, that are used to populate a look-up table (LUT) of probabilities of grains in different circumstances (defined by the grains' position, H_k , and surrounding bit pattern) flipping. Once the LUT is characterized, grain magnetization profiles are quickly reproduced using a uniform random number generator.

In the current work we modify the existing GFP model by setting K_u to a large value on the media, making the grains unwritable. The laser hot spot is modeled as a 2 D Gaussian region of reduced K_u . With this modification to the

micromagnetic simulations, the GFP LUTs for recharacterization and channel simulations for HAMR were then performed.

II. THE CHANNEL MODEL

The HAMR media used in the micromagnetic simulations consists of a $75 \text{ nm} \times 400 \text{ nm}$ region of 1481 Voroni grains, with thickness of 15 nm. In the channel simulations, a much larger media of dimensions $200 \text{ nm} \times 150\,000 \text{ nm}$ and 1 481 481 grains was needed to accommodate the written bits, as codes of 4 k length are written to the channel. The grains in the simulation have an average size of 4 nm with $\sigma = 19.6\%$ and a grain boundary of 0.5 nm. They were set with a fixed Curie temperature of 700 K. The damping constant used in the simulations was $\alpha = 0.1$ and saturation magnetization $M_s = 500 \times 10^3 \text{ A/m}$. For all the simulations, the thermal stability ratio $K_u V / k_b T$ (where V is the grain volume, k_b is Boltzmann's constant, and T is the absolute temperature) was maintained at 60 with $K_u = 8.18 \times 10^5 \text{ J/K}$. The anisotropy field has a mean value of $H_k = 2.8 \times 10^6 \text{ A/m}$ and $\sigma = 5\%$. Thiele's⁶ equations that describe the temperature dependence of M_s and K , $M_s(T) = M_{so}(1 - T/T_c)^{\beta_m}$ and $K(T) = -0.5K_o \tanh(K_{rate}*(T - 0.5T_c)) - 1.0$, are used in this work and are plotted in Fig. 1. Here, $\beta_m = 0.3$, $M_{so} = 0.6283 \text{ T}$, $K_o = 1.5 \times 10^6 \text{ J/m}^3$, and $K_{rate} = 0.01$ were used.⁷

A head field computed by Mason Williams used during INSIC's initial EHDR program was used in these simulations. It has dimensions of $50 \text{ nm} \times 50 \text{ nm}$ and a peak amplitude of $1.4 \times 10^6 \text{ A/m}$. The magnetic profile of the head is shown in Fig. 2. In the micromagnetic simulations, this head is used in conjunction with a Gaussian hot-spot to write channel bit lengths of 9 nm, corresponding to a channel AD of 2 Tbps, at a nominal track pitch of 32 nm. The outputs

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FIG. 1. (Color online) Variation of crystalline anisotropy K and M_s vs T used in the HAMR simulations.

FIG. 2. (Color online) Head field used in these simulations based on a $50 \text{ nm} \times 50 \text{ nm}$ pole shielded on all four sides.

from these simulations are subsequently used to train various GFP LUTs which are then used for channel simulations. In the channel simulations, we use random low-density parity-check (LDPC) codes with lengths of 4096, corresponding to a long sector size. We are currently not able to run codeword lengths of 32768 due to memory constraints.

The magnetization produced by the GFP is convolved with a 2 D Gaussian representing the read head sensitivity (RHS) response. Electronics noise, modeled by 30 dB additive white Gaussian noise, is then added to the read-back signal. The 2 D inter-symbol interference from the reader is modeled as a Gaussian pulse with parameter T_{50} , defined as the time for the step response of the pulse to go from 25% to 75% of its maximum. To match with conventional recording systems, T_{50} is set to 1.2 T in the downtrack direction. In the cross-track direction, the Gaussian is set such that $6\sigma = TP$, the track pitch. This is to reproduce what happens in today's system where there is no ITI.

As the main difference between HAMR and CGMR in the introduction of the laser hot-spot, this work uses the GFP model to investigate the effect of varying several of the key hot-spot parameters. The hot spot in these simulations is also modeled as a 2 D Gaussian characterized by the peak temperature T_{peak} , and the pulse width σ_T . As the hot-spot cross section is circular, σ_T is the same in both the cross-track and down-track dimensions. Variation in both T_{peak} and σ_T is explored in this work. In addition, we also look at the hot-spot to magnetic footprint alignment.

III. RESULTS

A. Effect of hot-spot amplitude T_{peak}

The peak temperature of the hot-spot in the micromagnetic simulations was varied from 600 K to 700 K in

FIG. 3. Channel simulation results varying T_{peak} from 600 to 700 K. The hot-spot σ_T is held at a nominal value of 14.8 nm.

steps of 25 K. The LDPC coded channel simulations are shown in Fig. 3.

The impact on the channel performance shows that the effect depends on the channel bit length being considered, but in general, the higher T_{peak} , the better the performance. This is reasonable as larger T_{peak} leads to a larger temperature gradient in the model.

B. Effect of the hot-spot σ_T

In the second simulation set, we hold T_{peak} fixed at 600 K and vary σ_T of the Gaussian hot-spot. The micromagnetic output for σ_T 10.6 nm and 24.7 nm, are shown in Fig. 4, while the probability footprints for the same cases from the GFP LUT's are shown in Fig. 5. The channel simulation results are shown in Fig. 6. Changing the hot-spot diameter effectively changes the width of the written tracks (or the track density), as well as the cross-track and down-track gradients. Hence the density and BAR are changing as well. The overall interaction between the various effects is fairly complex, but we see that generally, reducing σ_T has the effect of shifting the FER waterfalls to the left. This can be explained by observing that as σ_T decreases, the track density increases, the SNR drops, and the curves shift leftwards.

C. Effect of head to laser alignment

Up until now, the hot-spot and magnetic footprint profiles have been aligned at their centers. Now we explore the effect of changing this alignment. In Fig. 7, we vary the relative position of the hot-spot to magnetic profile in the down-track direction. We see that the performance improves as we

FIG. 4. (Color online) Micromagnetic outputs for σ_T of 10.6 nm (upper), and 24.7 nm (lower), both at a bit length of 9 nm.

FIG. 5. (Color online) Probability footprint for σ_T of 10.6 nm and 24.7 nm (bit length 9 nm). Each bin is 4.5 nm wide.

FIG. 6. Channel simulation results for varying hot-spot σ_T from 10.6 to 24.7 nm. T_{peak} is held at 600 K.

FIG. 7. Channel simulation results varying the downtrack offset of the hot-spot relative to the magnetic profile. $T_{peak} = 699$ K, $\sigma_T = 14.8$ nm.

increase the offset up to a point, then gets worse again. We attribute this to the alignment of the downtrack optical and magnetic gradients. When the two gradients maximally align, the written transition will have been done with the sharpest combined gradient resulting in the best SNR and best performance. We note that the position of the optimum changes with the written bit-length.

IV. CONCLUSION

In this work we have modified the GFP model to include the effect of a reduced K_u region on the media. We ran channel simulations with this modified model and varied several parameters pertaining to the hot-spot. We find that the interaction is fairly complex involving the hot-spot diameter, as

there are now three fields interacting (reader, writer, and laser) with each other. We also find that the optimization of the alignment of the laser hot-spot to the magnetic profile is needed to maximize the density gains.

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