DISTRIBUTION-BASED RECORDING MODEL FOR HAMR

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I. BACKGROUND

Landau-Lifshitz-Gilbert (LLG) and Landau-Lifshitz-Bloch (LLB) based recording simulations are the gold standard in judging the performance and the impact of various parameters in Heat Assisted Magnetic Recording (HAMR). While these models include the full dynamics of the recording process, they do not readily allow identification of performance-limiting factors. Furthermore, these simulations are often too time consuming to allow thorough investigation of all input parameters. The standard approach in LLG and LLB recording simulations utilizes a finite number of grains which are chosen based on known recording media distributions. These grains represent only a subset of the entire distribution of grains. For achieving results which are independent of this subset, a sufficiently large number of transitions with different grain configurations has to be simulated. The final result of a recording simulation is then based on averaging over all of the aforementioned simulations.

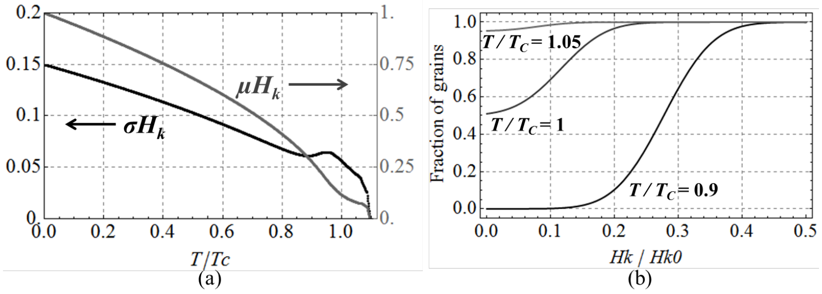

Fig. 1 (a) temperature dependence of the mean and the standard deviation of the normalized H_k distribution, (b) cumulative distribution function for H_k at different normalized temperatures

In HAMR, the impact of grain to grain interactions is reduced by operating around the Curie temperature of the recording medium. At high temperature, the demagnetization field and the exchange coupling are small compared to the applied magnetic field of the recording head. This opens the opportunity to perform all calculations with distributions of grain properties directly, rather than on the basis of single grains and their interactions with their neighbors. The recording-modeling approach presented here has the advantage that no detour via grain subsets is required: the obtained results already represent the average over an infinite number of grains. This allows for short calculation time and a higher resolution of variations among recording impacting parameters, e.g. different thermal distributions in the recording medium.

II. BASICS OF THE DISTRIBUTION-BASED RECORDING MODEL

Most important for determining the recording transition length is the distribution of the anisotropies H_k at the different normalized temperatures $x = T/T_C$. It is defined by the distribution of the anisotropy H_{k0} at 0 K with relative standard deviation σH_{k0}=15%, the distribution of the Curie temperature T_C with relative standard deviation σT_C=3%, and the temperature dependence of the normalized anisotropy field

$$H_k(x)/H_{k0} = (1- x)^{\beta} \tag{1}$$

with the exponent β~0.5 for FePt [1]. Assuming Normal distributions for the anisotropies H_k>0 for every x and taking the accumulation at H_k =0 into account when approaching T_C, a cumulative distribution function $F_x(y)$ for the normalized anisotropy $y = H_k/H_{k0}$ at the normalized temperature x can be derived:

$$\mathrm{F}_x(y) = \Phi(\sigma T_C(x-1)) + (1-\Phi(\sigma T_C(x-1)))\cdot \mathrm{F}_{\mathcal{N}(\mu(x),\sigma(x))}(y) \quad \text{with} \quad \Phi(x) = \frac{1}{2}\left(1+\mathrm{erf}\left(\frac{x}{\sqrt{2}}\right)\right), \tag{2}$$

where erf (x) is the error function and $\mathrm{F}_{\mathcal{N}(\mu,\sigma)}$ denotes the cumulative distribution function of the Normal distribution with mean $\mu(x)$ and standard deviation $\sigma(x)$.

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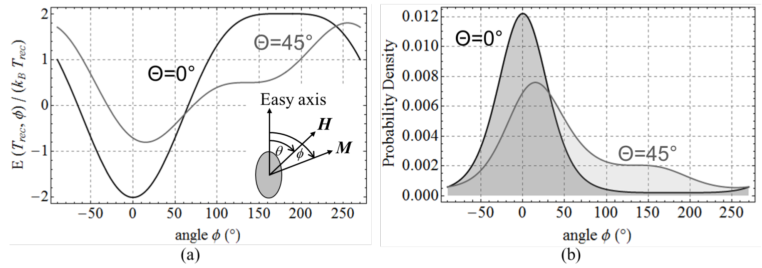

Fig. 2 (a) To the thermal energy $k_B T_{rec}$ normalized Stoner-Wohlfarth energy at the recording point for T_{rec}/T_C=0.997 and a weak head field with H_{eff}/H_{k0}=0.04, (b) corresponding probability density

Fig. 1a shows the temperature dependence of the mean μH_k and the standard deviation σH_k of the normalized anisotropy y, which can be numerically derived by a random number simulation based on (1) assuming a $\mathcal{N}$ (1, σT_C) distribution for x and a $\mathcal{N}$ (1, σH_{k0}) distribution for y itself, which multiplies the right hand side of (1). Fig. 1b shows the cumulative distribution function $F_x(y)$ according to (2) based on the μH_k and σH_k curves shown in Fig. 1a.

Applying (2) to the spatial temperature distribution in the middle of the recording layer gives the H_k distribution at every point in the layer. According to the Stoner-Wohlfarth model [2], switching of a grain occurs if its H_k is smaller than the effective head field given by

$$H_{eff}(T) = |H(T)| \frac{\sqrt{1-\tan^{\frac{2}{3}}\theta + \tan^{\frac{4}{3}}\theta}}{1+\tan^{\frac{2}{3}}\theta} \cdot \mathrm{sign}(H_{perp}), \qquad (3)$$

where H_{perp} denotes the component of the head field perpendicular to the recording layer and θ is the angle between the easy axis of the grain and the head field. Therefore, if the spatial H_{eff} distribution in the recording layer is known, $F_x(y)$ with y= H_{eff} /H_{k0} gives at every point in the layer the percentage of switchable grains, i.e. the percentage of grains for which $H_k < H_{eff}$.

Although the $H_k < H_{eff}$ map obtained according to the procedure outlined above can be used to evaluate the quality, i.e. thermal gradient and curvature, of thermal distributions and their interplay with the media distributions and read-back width, this approach does not include thermal fluctuations. Therefore, this model delivers reliable results if the head field is assumed to be sufficiently high, such that the impact of thermal fluctuations on the recording can be ignored. Extension of the model to incorporate thermal erasure can be achieved by estimating the probability of stable switching for switchable grains in the recording layer with the Stoner-Wohlfarth energy

$$E(T,\phi) = \mu_0 M_s(T) V\left[\tfrac{1}{2} H_k(T)\sin^2(\phi) - H\cos(\theta-\phi)\right], \qquad (4)$$

where M_s is the saturation magnetization, V is the grain volume, H is the head field magnitude, and ϕ is the angle between the magnetization and the grain's easy axis, which can also be understood as the grain's state.

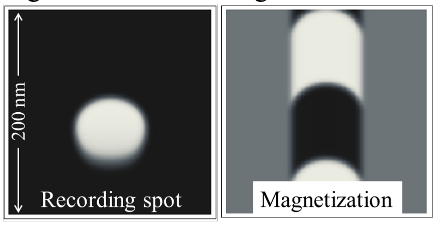

Fig. 3 Recording spot and track-map based on distributions with max. T/T_C=1.14 and max. H_{eff}/H_{k0}=0.04

Assuming that the explicit time dependence of the switching process is less dominant than the change of the energy barrier between the two stable states at room temperature, a stationary switching model can be formulated. Inserting the energy (4) at the recording point (Fig. 2a), i.e. $H_{eff}=H_k$, in a Boltzmann factor and normalizing by the integral of this factor over all grain states, gives the probability density function of the grain states ϕ (Fig. 2b). For a sufficiently long bit-length and assuming the worst case, all switchable grains freeze at the ($H_{eff}=H_k$, $T=T_{rec}$) pair determined by (1) with the highest temperature T and therefore with the lowest H_k. Weighting all grains with this switching probability results in an approximation for the fraction of stable switched grains that are not thermally randomized. Fig. 3 shows a recording spot and a resulting magnetization probability track-map derived by the model presented here using a representative thermal spot with a thermal gradient of ~7 K/nm.

REFERENCES

1) J.-U. Thiele et al., *J. Appl. Phys.*, **91**, NO. 10, 6595 (2002)
2) E.C. Stoner and E. P. Wohlfarth, *Philos. Trans. R. Soc. London*, Ser. A **240**, 599 (1948)