Performance of PRML Channels with Mark Edge Jitter and Signal Non-linearities in High-Density Phase Change Recording

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In phase change recording, higher linear densities can be achieved with materials in which crystallization is dominated by growth. This is due to the fact that marks can be written with sharper edges which give rise to lower jitter [1]. However, higher write powers are required in growth-dominated media compared to nucleation-dominated media to compensate for the recrystallization that occurs while recording a mark. The higher write powers result in significant cross talk between tracks due to partial erasure of amorphous marks written in one track while writing in the adjacent track. This has been investigated and methods have been proposed to overcome this issue: for instance, the use of a higher thermal conductivity for the Al alloy reflective layer [2] or suitable multipulse strategies [3]. In this paper, we address, through the use of simulations, the issue of thermal interference at high linear densities. PRML equalization and detection is then applied to the simulated read-back signals to estimate bit error rate (BER) degradation due to channel amplitude non-linearities and mark-edge jitter.

To simulate mark formation, the thermal diffusion equation was numerically solved in three special dimensions and time. We consider the material Ge($Sb_{70}Te_{30}$)+Sb which is a "more pure growth dominant material" [4] as the phase change medium. The thermal parameters of this material were not available and hence we used the same values as that of AgInSbTe which is also a growth dominant material. The laser wavelength was chosen to be 660nm. We assumed that the probability of nucleation was very low and that crystallization occurs via growth. The velocity of growth is highly temperature dependent and is given by [5]

$$v_g = fa\alpha\left[1-\exp(-\Delta G/kT)\right]\exp(-E_{ag}/kT) \tag{1}$$

where f is a factor related to growth mode, a is the atomic distance, α is a frequency factor, ΔG is the free energy between the amorphous and crystalline phases, k is Boltzmann's constant and T is the absolute temperature. Since the values of these parameters for the growth dominant materials were also not available in the literature, we assume all but E_{a2} to be the same as nucleation dominated media [5]. E_{a2} was assumed to be much lower than in the nucleation-dominated case to account for the fact that the material is growth dominant [3]. After the mark was written, a Gaussian read back beam was convolved with the reflectivity of the medium to obtain the read-back signal. From these signals, we estimated the signal modulation as well as the full width at half maximum (FWHM) and jitter.

Three different linear densities were considered by varying the clock period. A pattern of 3T mark, T space, 3T mark was recorded and the read-back signal obtained. 3T marks were then written individually (without the neighboring 3T mark) and the read-back signal from the single 3T mark was obtained. For purposes of channel modeling, we tested for linearity by comparing a linear superposition of the individual 3T waveforms spaced T apart to the waveform obtained from the 3T, T, 3T pattern. As the marks are brought closer together, we notice amplitude variations as well as an increase in the mark-edge jitter.

In the idealized case, the read-back signal $r(t)$ can be modeled as a linear superposition of step responses [6] as follows:

$$r(t) = \sum_{k=-\infty}^{\infty} c_k u(t - kT) + n(t) \tag{2}$$

where, $u(t)$ is the step response obtained by moving the focused spot across a transition, $n(t)$ is the additive Gaussian noise with double sided power spectral density $N_0/2$, T is the bit interval, and c_k is used to mark transitions in the bit stream i.e., $c_k = -1$ for a transition from mark to space and $c_k=1$ for a transition from space to mark, while $c_k=0$ indicates the absence of a transition.

A more intuitive signal model employs a linear superposition of pulse responses as given below

$$r(t) = \sum_{k=-\infty}^{\infty} x_k h(t - kT) + n(t) \tag{3}$$

where, $h(t) = [u(t) - u(t-T)]/2$ denotes the channel pulse response from an isolated 3T mark, $x_k = 1$ for a positive going pulse (a space between marks) and -1 for a negative going pulse (a mark between spaces), and $c_k = (x_k - x_{k-1})/2$.

The linear superposition as assumed above does not necessarily hold at high densities due to thermal interference between adjacent bits leading to non-linear amplitude fluctuations and timing errors. The signal non-linearities as well as mark-edge jitter estimated at high densities from our simulations are therefore incorporated into the read-back signal model using the non-linear error signal $e_{nl}(t)$ and the jitter parameter Δt_k to obtain a close approximation of the actual read-back signal. We model this imperfect signal as,

$$r(t) = \sum_{k=-\infty}^{\infty} x_k h(t - kT + \Delta t_k) + e_{nl}(t) + n(t) \tag{4}$$

The objective of this paper is to simulate the impaired signals at high densities and evaluate the performance of PRML detection. We will present BER results at different densities, for realistic values of jitter and non-linearity.

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