34GB Multilevel-enabled Rewritable System using Blue Laser and High-NA Optics

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Last year, the key optical parameters for blue recording were established in the industry. The optical recording community has agreed to use an NA of 0.85 and laser wavelength of 405 nm as the optical parameters for removable optical storage for the foreseeable future, creating a stable 12cm platform for many applications. Within many laboratories, research will continue on even more efficient modulation schemes than runlength limited codes [1]. One of the candidates is Multi-Level Encoding.

Margin testing of MultiLevel (ML™) technology on a red-laser DVD rewritable base was recently performed using 8 levels [2]; in addition, 12-level feasibility was demonstrated [2,3]. Proof of feasibility has also been demonstrated on a blue-laser tester using a 0.6mm substrate and 0.60NA lens [4] and a blue-laser tester with 0.85NA lens using media with 0.1mm cover [5].

This paper evaluates ML margin-testing results as applied to a blue-laser recording-base with 0.85NA lens and media with 0.1mm cover for an 8-level trellis-coded modulation system that encodes 2.5 user-bits per data-cell. The ML system tested was originally developed on a CD-R/RW base to achieve 2GB [6]. Margin testing results compare favorably to binary system performance on this same tester and produced a 36% increase in capacity above a 25GB base.

The work performed herein was on an experimental optical disc drive with a two-element NA = 0.85 objective and a blue laser. The rewritable phase-change media was of the on-groove design [7] with a track pitch of 320nm, a 0.1mm cover, and optimized for binary blue recording. Recording speed was 2.3m/s (which equals 23 Mb/s) and data cell lengths ranged from 175nm to 190nm. The number of data blocks sampled for each measurement set the lower limit of detectable Byte Error Rate before ECC (BER) at ~ 4 E-5, while the limit of ECC correction was ~ 4 E-3 BER. Fig. 1 shows ML results before the adaptive equalizer process. The ML signal is equalized by an 11-tap fractionally-spaced zero-forcing equalizer. These taps are trained at the beginning of each data block so that in-track inter-symbol interference is removed. The histograms in Figs. 2a & 2b show the effect of the ML write-calibration process, or Pre-compensation Iteration Process (PIP); these histograms are, in effect, quantitative ML eye-patterns. PIP™ is an adaptive ML write strategy designed to remove the majority of nonlinear channel effects. PIP makes data recovery easier by reducing the overlap of the level distributions, accomplished by decreasing their width and centering them.

Table 1 summarizes the physical parameters we used to make the majority of the tests shown, with the exception of those tests that varied the bit cell length (Figs. 3a & 3b). Figs. 4a & b show that ML on a high-NA blue tester has wide radial and tangential tilt margins. In addition to measuring the raw BER as a function of tilt, a new, more descriptive metric was also used to judge ML performance. Level Error Rate (LER) is the relative number of erroneously-detected signal levels measured due to hard-decision decoding for each data-cell. This metric provides a more graded response than does BER. LER is measured after equalization and before the Viterbi, while BER is measured before the ECC.

Figs. 5a & b show ML LER and BER as a function of write- and read-defocus and demonstrate a read-only margin of ~ ±250nm. The more extreme test of write defocus was performed using an ML write strategy developed by our PIP process at nominal focus. Random data was then written at defocus conditions. The narrower write-defocus margin can be significantly improved if PIP is performed at the defocus. As the results show, random data written after PIP under defocus conditions shows performance equivalent to nominal. PIP improves the robustness of ML-writers against static defocus offsets and can also compensate for other drive system static-offsets like write power and tilt.

Fig. 6 shows preliminary ML Direct Overwrite (DOW) performance on standard blue media. Even without ML-media optimization, BER values are reasonable up to 1000 cycles and could still be fully corrected by the ECC under nominal conditions even as it approached 8% LER. Lastly, Fig. 7 illustrates a reasonable write power margin of –10% to over +30% from nominal write power. The work will continue to establish all the margins.

With MultiLevel recording technology, we have demonstrated the feasibility to obtain 34GB on existing high-NA blue laser systems. Preliminary experiments were also done using a 12-level ML code [3] that has the potential to achieve over 40GB on a single-sided, single-layer 12cm disc. Overall, ML is a strong candidate for future use in high-NA blue laser systems.

0-7803-7379-0/02/$17.00©2002 IEEE

Thank you to D. Warland for experimental preparation, Yung-Cheng Lo for coding preparation, and T. Zhou, Y.C. Lu, & M. Erickson for their electronic interfacing expertise.

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2. K. Balasubramanian et al, "Multilevel-Enabled Double-Density DVD (Re)writable", *Technical Digest ISOM/ODS '02.*
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5. M. Horie et al, "Material Characterization and Application of Eutectic SbTe-based Phase-change Optical Recording Media", *Proc. SPIE* **4342**, 76-87, 2001.
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Parameter	Formula	8-level ML Blue
Cover Thickness (mm)	t	0.1
Laser Diode λ (nm)	λ	405
Objective Lens	NA	0.85
Track Pitch (µm)*	p	0.32
Min. Mark Length or ML Data Cell Length (µm)	MML	0.175
Code Rate	r = data bits / ch bits	5/6
Channel Bit Length (µm)	c = r/b x MML	0.058
Density (µm²/ch bit)	d = p x c	0.019
Data Bits per Min. Mark	b	2.50
Linear Velocity (m/s)	v	2.3
Channel Bit Rate (MHz)	f = v/c	39
User Data Rate (Mbps)	f x E	23
Encoding Efficiency	E = User bits / ch bits	57%
Total Efficiency	E/r	69%
Program Area (mm²)	A	8760
User Data Capacity (GB)	A/d x E	34

Table 1: ML Physical Specifications Tested

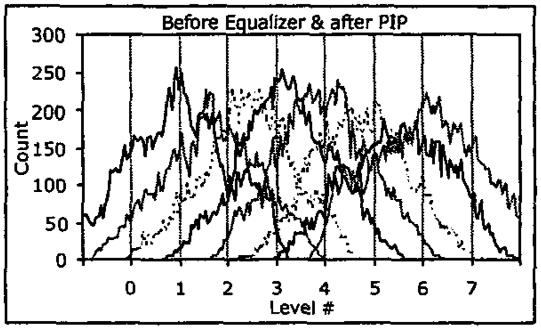

Fig. 1: ML results without equalization and after PIP. Histograms are individual reflectivity-levels measured (counted) per data cell for the total number of random data-cells sampled (~8x10^4).

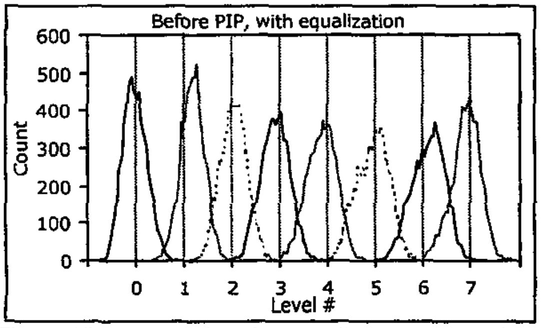

Fig. 2a: Histograms before the ML write pre-compensation iteration process (PIP) and with equalization.

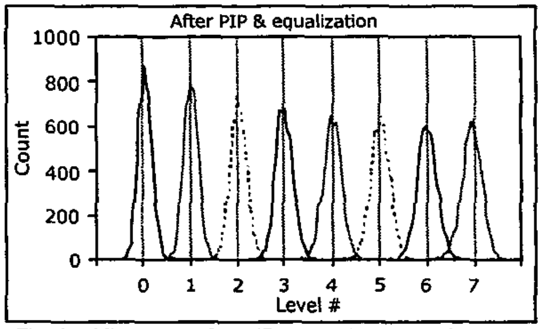

Fig. 2b: ML results after PIP and with equalization. These histograms are, in effect, quantitative ML eye-patterns. Notice that PIP decreases the width of the distributions and also centers them, thereby reducing the overlap.

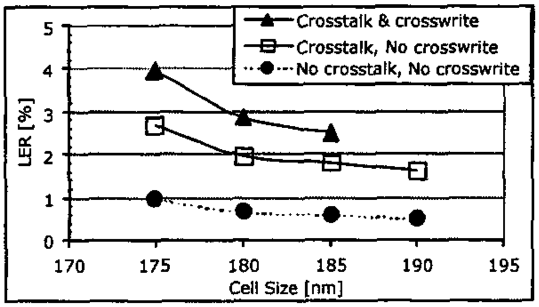

Fig. 3a: ML data Level Error Rate (LER) measured before Viterbi decoder as a function of cell size. Measurements include the effects of cross-talk and cross-write.

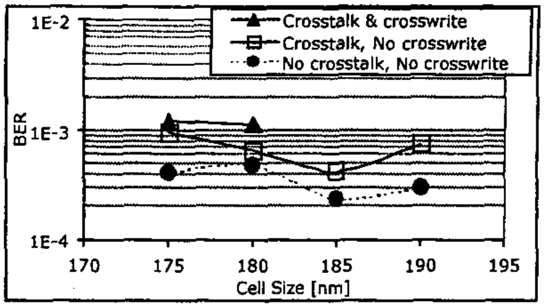

Fig. 3b: ML Byte Error Rate (BER) measured before ECC as a function of cell size under conditions of Fig. 3a.

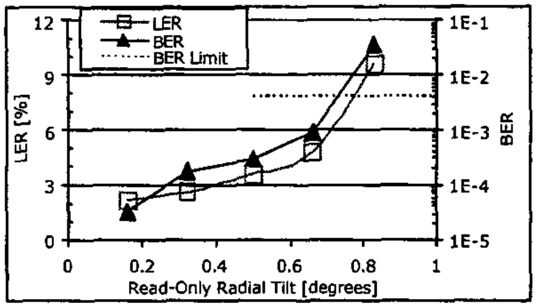

Fig. 4a: ML LER and BER vs. Radial Tilt for one side away from nominal. Results infer a margin of ~±0.7° for radial disc tilt.

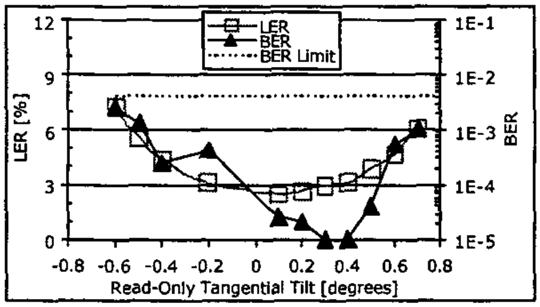

Fig. 4b: ML LER and BER vs. Tangential Tilt. Results demonstrate margin of ~±0.7° for tangential disc tilt.

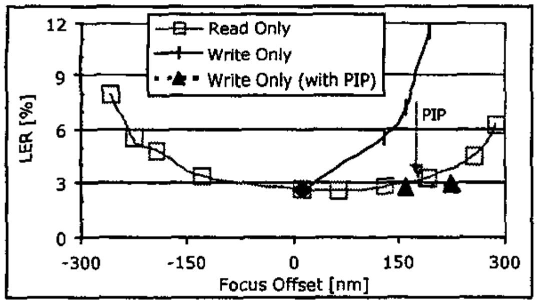

Fig. 5a: ML LER vs. defocus for read-only and for write-only conditions with and without PIP process. Notice that the PIP can compensate for static focus-offset errors.

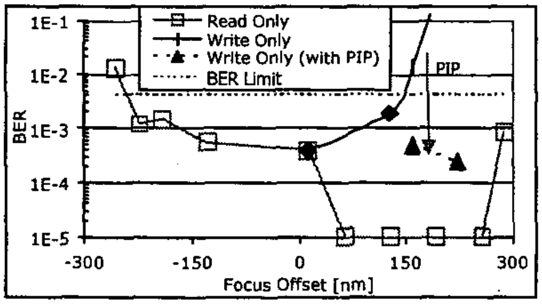

Fig. 5b: ML BER corresponding to conditions of Fig. 5a. Note that in all BER plots shown, data points plotted on the 1.E-5 axis are actually zero errors.

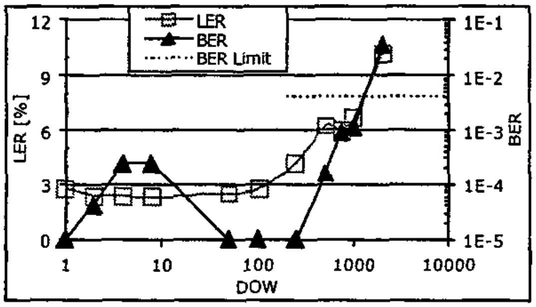

Fig. 6: ML LER and BER vs. direct overwrite (DOW) showing acceptable performance up to 1000 cycles.

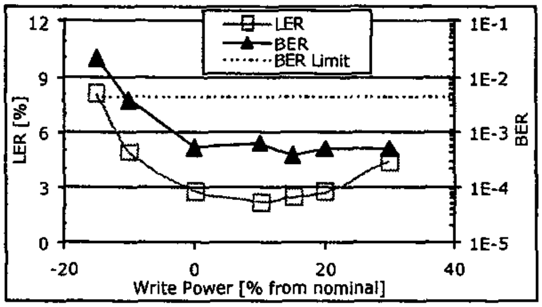

Fig. 7: ML LER and BER vs. write power.