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Short Note

34 GB Multilevel-Enabled Rewritable System Using Blue Laser and High-Numeric Aperture Optics

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Multilevel (ML) technology increases storage capacity and data transfer rates of an optical data storage system. ML is shown to be a strong candidate for use with a high numeric aperture (NA) and blue-laser system by demonstrating good margin performance. [DOI: 10.1143/JJAP.42.1074]

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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 a numeric aperture (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 12 cm platform for many applications. Within many laboratories, research will continue on even more efficient modulation schemes than run-length limited codes.[1)] One of the candidates is MultiLevel encoding.

Margin testing of MultiLevel (ML[2)]) technology on a red-laser digital versatile disc (DVD) rewritable base was recently performed using 8 levels;[3)] in addition, 12-level feasibility was demonstrated.[3,4)] Proof of feasibility has also been demonstrated on a blue-laser tester using a 0.6 mm substrate and 0.60 NA lens[5)] and a blue-laser tester with 0.85 NA lens using media with 0.1 mm cover.[6)]

This paper evaluates ML margin-testing results as applied to a blue-laser recording-base with 0.85 NA lens and media with 0.1 mm 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 compact disc writable/rewritable (CD-R/RW) base to achieve 2 GB.[7)] Margin testing results compare favorably to binary system performance on this same tester and produced a 36% increase in capacity above a 25 GB 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[8)] with a track pitch of 320 nm, a 0.1 mm cover, and optimized for binary blue recording. Recording speed was 2.3 m/s (which equals 23 Mb/s) and data cell lengths ranged from 175 nm to 190 nm. The number of data blocks sampled for each measurement set the lower limit of detectable byte error rate (BER) before error correction coding (ECC) at ~4 E-5, while the limit of ECC correction was ~4 E-3 BER.

Figure 1(a) shows ML results before equalization. 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 Fig. 1(b) show the effect of the ML equalization and write-calibration process (pre-compensation iteration process (PIP[9)])); 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 I 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 (Fig. 2). Figures 3 and 4 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.

Figure 5 shows ML BER as a function of write- and read-defocus and demonstrate a read-only margin of $\sim \pm 250$ nm. 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.

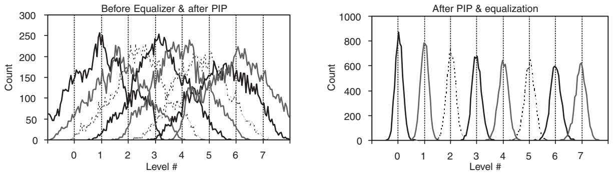
Figure 6 shows preliminary ML direct overwrite (DOW) performance on standard blue media. Even without ML-media optimization, BER values are reasonable up to 1000 cycles and could still be fully corrected by the ECC under nominal. Lastly, Fig. 7 illustrates a reasonable write power margin of -10% to over $+30\%$ from nominal write power. The work will continue to establish all the margins.

With MultiLevel recording technology, we have demonstrated the feasibility to obtain 34 GB on existing high-NA blue laser systems. Preliminary experiments were also done using a 12-level ML code[4)] that has the potential to achieve over 40 GB on a single-sided, single-layer 12 cm disc. Overall, ML is a strong candidate for future use in high-NA blue laser systems.

The work presented here is a product of the joint efforts of the Calimetrics team and the team at Philips. Also, the Calimetrics team would like to thank D. Warland for experimental preparation, Y. C. Lo for coding preparation, and T. Zhou, Y. C. Lu, & M. Erickson for their electronic interfacing expertise.

Table I. ML physical specifications tested.

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	$r = \frac{\text{data bits}}{\text{ch bits}}$	5/6
Channel Bit Length (μm)	$c = r/b \times \text{MML}$	0.058
Density (μm^2/ch bit)	$d = p \times c$	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)	$f \times E$	23
Encoding Efficiency	$E = \frac{\text{User bits}}{\text{ch bits}}$	57%
Total Efficiency	E/r	69%
Program Area (mm^2)	A	8760
User Data Capacity (GB)	$A/d \times E$	34



(a) (b)

Fig. 1. ML results with/without equalization after PIP. 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.

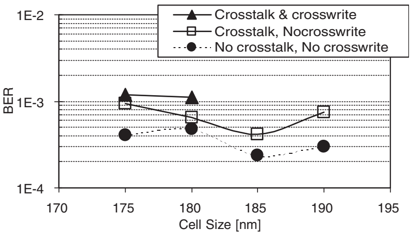


Fig. 2. ML data BER measured before Viterbi decoder as a function of cell size. Measurements include the effects of cross-talk and cross-write.

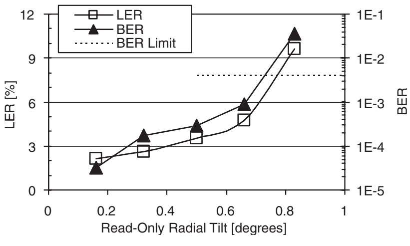


Fig. 3. ML LER and BER vs. Radial Tilt for one side away from nominal. Results infer a margin of ~ ± 0.7° for radial disc tilt.

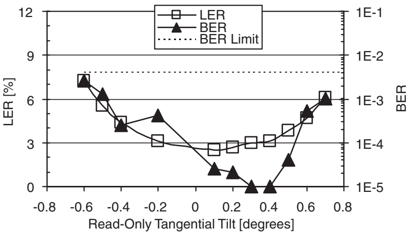


Fig. 4. ML LER and BER vs. Tangential Tilt. Results demonstrate margin of ~ ± 0.7° for tangential disc tilt.

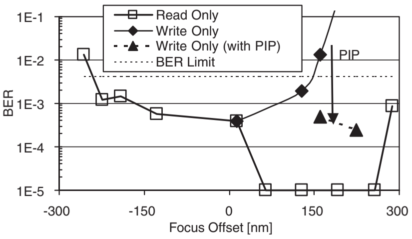


Fig. 5. ML BER vs. defocus for read-only and for write-only conditions with and without PIP process. Notice that the PIP can compensate for static focus-offset errors. Note that in all BER plots shown, data points plotted on the 1.E-5 axis are actually zero errors.

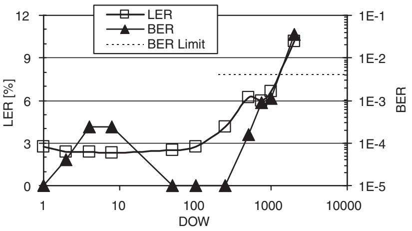


Fig. 6. ML LER and BER vs. DOW showing acceptable performance up to 1000 cycles.

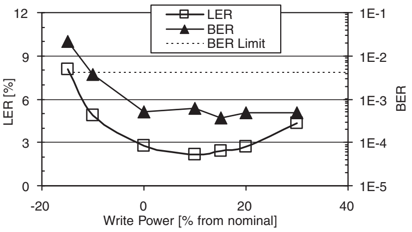


Fig. 7. ML LER and BER vs. write power.

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