High Speed, High Areal-Density Recording with Blu-ray Compatible Optical System

Harukazu Miyamoto, Hiroyuki Minemura, Hiromi Kudo, Junko Ushiyama, Akemi Hirotsune, Koichi Watanabe and Toshimichi Shintani
Central Research Laboratory, Hitachi, Ltd.

Reiji Tamura and Kazuyoshi Adachi
Development & Technology Division, Hitachi Maxell, Ltd.

Keywords: High-density, optical recording, 50GB/layer, Blu-ray, phase-change, write-once, adaptive-type PRML, 3-beam crosstalk cancellation, 12x.

1. INTRUDUCTION

The popularization of DVD recorders has shifted our recording culture from tape to disc. Furthermore the digital broadcasting will rise up the needs for higher quality recording that leads to larger capacity recording. Blu-ray discs, which were put into the market in 2003, have a capacity of 25GB per layer. Dual-layer discs, which have a capacity of 50GB, are also introduced in 2004. In order to satisfy the demand toward higher capacity, increase of the capacity per layer or higher-areal density is the most essential. For the presumption, optical system of the drive should be compatible with current drives in the market, and the cost of the media is also most concerned by general consumers. Therefore, we have targeted to develop the technologies to increase the areal density and also the recording speed with mainly by the signal processing, which shows no large impact on the current DVD or Blu-ray systems.

2. TECHNOLOGIES FOR 50GB/LAYER RECORDING

Table I shows the specifications for 50GB/layer system. High-density recording was achieved mainly by high-linear density recording using adaptive PRML and land and groove recording with cross-talk cancellation. Although both the track pitch and the bit pitch were reduced by 25%, most of the parameters such as wavelength and the numerical apertures are the same as Blu-ray disc. For High-density signal processing technology, an adaptive-PRML (partial-response maximum-likelihood) with compensation bits was adapted[1)]. For narrow track pitch, land and groove recording and 3-beam cross-talk cancellation (CTC) were introduced. The land and groove recording method gives the relatively stable tracking while groove only method can not provide the push-pull tracking signal at the track pitch narrower than 0.24 μm, which corresponds to the optical cutoff frequency of the systems with NA of 0.85. Since the target track pitch is very close to the cutoff limit, we have adopted the land and groove method where the effective physical pitch is double of the track pitch. This large physical feature is also suitable for manufacturing (disc mastering). Cross-erasing, which generally becomes severe problem with a narrow track pitch, was avoided by choosing write-once-type media. We have also developed the high-efficient format for land & groove systems[4].

Table I Specifications for 50GB/layer Recording

Specification	Proposal	BD
Capacity/layer (120 mmφ)	50 GB	25 GB
Data transfer rate	108 Mbps	36 Mbps
Track pitch	0.24 μm	0.32 μm
λ	→	405 nm
NA	→	0.85
Bit pitch	0.085 μm	0.11 μm
Track type	Land & groove	Groove
Format	Wobble Mark Detection	ADIP(MSK+STW)
Code	→	(1,7)RLL
Crosstalk canceller	ORE-CTC	-
Signal processing	Adaptive PRML with pattern comp. bits	Limit EQ, PRML
Head component	3 beams (at intervals of 0.24 μm)	3 beams (at intervals of 0.16 μm)

2.1 HIGH LINEAR DENSITY RECORINDING WITH ADAPTIVE-PRML

Figure 1 shows the experimental set up of the system. Read-out signal from a disc tester (wavelength 405nm, ＮＡ0.85) is digitized and then a series of digital signal processing, such as equalization, timing recovery (PLL) and PRML, is performed to error rates.

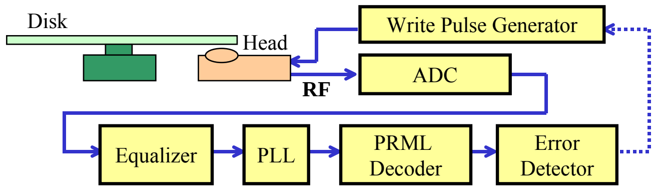
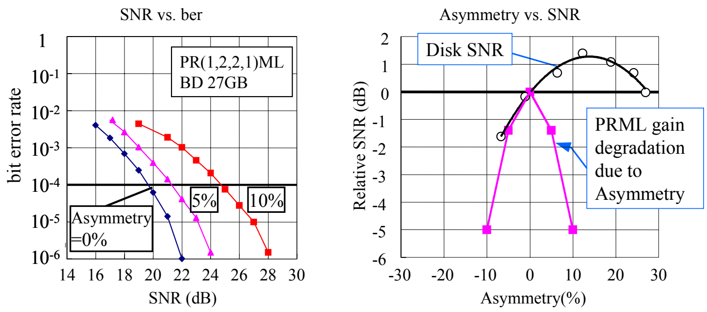


Fig. 1 Schematic Diagram of Tester

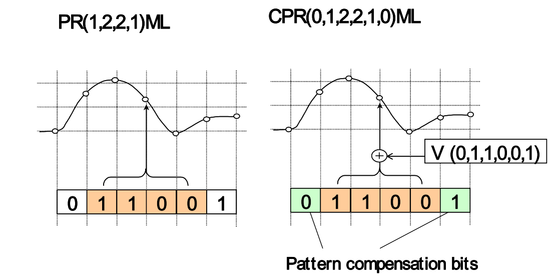
Figure 2 shows the problems when the conventional PRML is applied to the optical disc systems. When asymmetry exists, the effect of PRML decreases. Namely, highly asymmetrical discs require higher SNR for obtaining the same level of error rate. The reduction of PRML effect due to asymmetry is shown in Fig. 2 (b). However, the optimum recording condition of the media at which the maximum SNR is obtained shows non-zero asymmetry. Generally, a little lager marks with asymmetry of about 10% shows relatively good SNR. This is shown as SNR variation of disc in Fig 2 (b). Thus PRML does not always utilize the best performance of the media. Furthermore, when the linear density is high, thermal interaction at the recording can not be precisely compensated by write strategy because the recording mark is much smaller than the light spot itself. This appears as the nonlinear inter symbol interference at reading. The nonlinear interference can be treated by the conventional PRML because the PR system presume the linear summation for inter symbol interference.



(a) S/N v.s bER with asymmetry **(b) Reduction of PRML effect by Asymmetry**

Fig. 2 .Problems of PRML when applied to Optical Disk

Therefore, an adaptive PRML with additional pattern compensation bits was introduced as shown in Fig. 3. An adaptive system varies the PR target adaptively depending on the mark pattern, which can compensate the nonlinear interference and also asymmetry effect. The additional pattern compensation bits are introduced to treat longer interference than the PRML constrain length, by which longer interference can be compensated. In Fig. 3, V(0,1,1,0,0,1) shows the deviation from the normal PR target when the recorded pattern was 0,1,1,0,0,1. The deviation corresponding to each 6-bit pattern is averaged and memorized as a table. Then, the value on the table is added with the fixed to get compensated target for path metric calculation. By using the compensated target value the Viterbi decoding is performed.



(a) Conventional PRML **(b) Adaptive PRML**

Fig. 3 Adaptive-PRML with pattern compensation bits

As shown in Fig. 4, if the value on the table is subtracted from the input signal instead of adding to the target value, compensated waveform is obtained. The compensated waveform is the signal optimally equalized for the fixed target PRML. Therefore, if the compensated waveform is processed by the conventional PRML system, the same result as our system can be obtained. This means our method is equivalent to combination of conventional Viterbi decoder and the non-

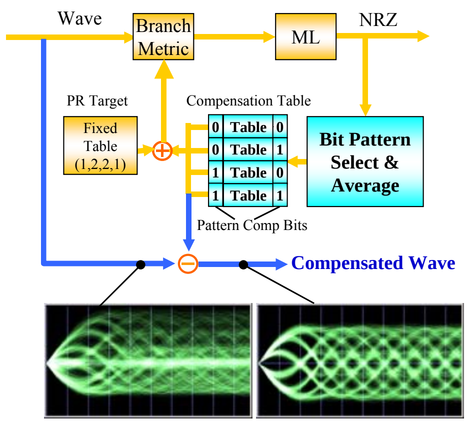


Fig. 4 Adaptive PRML and Compensated waveform

linear equalizer system that compensates the pattern dependent nonlinear deviation.

Merit of our system is that the scale of the hardware can be kept small because the PRML path calculation can be performed without compensation bits even though the table including compensation bit compensates the longer non-linear interference.

Figure 5 shows the effect of proposed system. PRML effect degradation at large asymmetry is reduced and the media performance can be well utilized.

Figure 6 shows the effect of the adaptive PRML with compensation bits (CPR) for high-density recording. All the Adaptive type is based on the PR(1221) and the compensation bits are added to both end. Even an adaptive PRML without compensation bit showed better performance than higher class PR(12221), but the one with two compensation bits on both end showed good performance for 35GB Blu-ray equivalent linear density. In 50GB system, the target linear density corresponds to 32.5GB Blu-ray considering the reasonable operating margin.

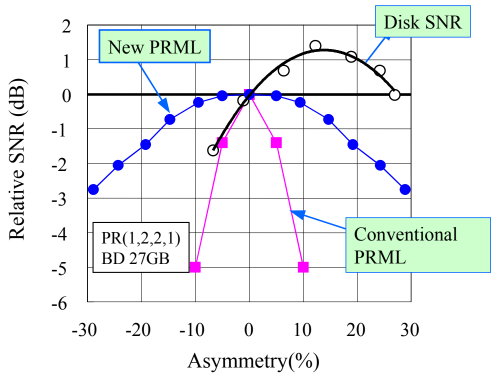


Fig. 5 Effect of adaptive PRML with Compensation bits

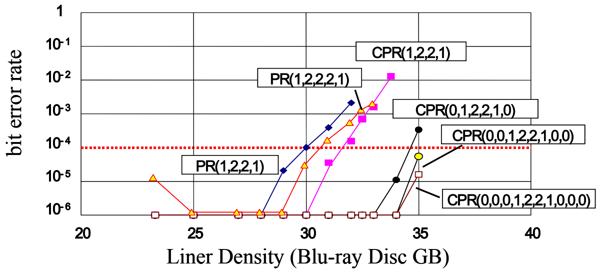


Fig. 6 High linear-density recording with Adaptive PRML

2.2 THREE-BEAM CROSS-TALK CANCERATION WITH OPTICAL RESPONSE EQUALIZATION

Figure 7 shows the basic principle of 3-beam Cross-Talk Canceller (CTC). Optical spots are located at the three adjacent tracks. Since the signals from adjacent tracks contain the crosstalk component from the signals recorded on the adjacent tracks, they are subtracted from the signal from target track with a coefficient α and adequate timing adjustment. In this basic configuration, the spots on adjacent track are used for crosstalk detection. However, since the crosstalk components for the main spot are the signal read by the bottom portion of main spots, effect of the side lobes is relatively large compared with the signal read on the track. Therefore the crosstalk component has different frequency characteristics from the signal from spots on the adjacent track. That is the optical response is different.

Then, the Optical Response Equalized Cross-Talk Canceller (ORE-CTC) was introduced as shown in Fig, 8. FIR type equalizer was applied to each beam for frequency characteristics compensation. Although the concept of response equalization itself is the same as proposed in the reference 2, how the efficient of the equalization is determined is different. In our system, the coefficients of the equalizers are optimized so that the difference between the crosstalk

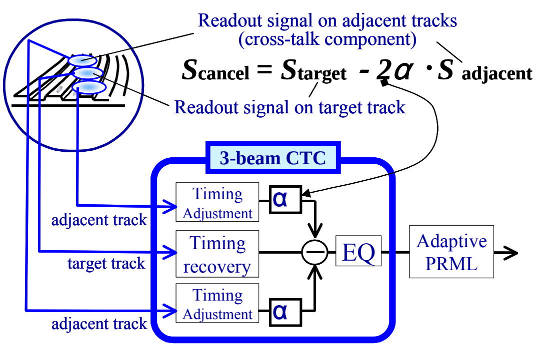


Fig. 7 Principle of 3-beam Cross-talk Canceller

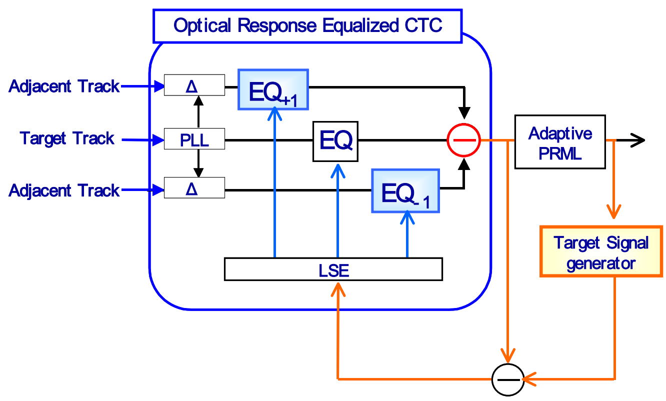


Fig.8 Optical Response Equalized Crosstalk Canceller

cancelled signal and the target levels calculated from the binarized output of the adaptive PRML becomes minimum The merit of this method is that this can be applied to the high density condition where the zero-cross can not be precisely detected due to large interference.

2.3 HIGH-SNR WRITE-ONCE MEDIUM

Figure 9 shows the configuration of the write-once type media. The characteristic of the media is the write-once function was realized with phase change type recording layer, which is suitable for smaller mark formation with high SNR. In order to realize write-once function, an anti-crystallization layer was introduced. This layer reacts with the recording film by the heat during writing, and the crystallization property of phase-change property is changed. That is the crystallization speed is greatly reduced. Of course there is a way to use slow phase change material for write-once function; however, initialization becomes very difficult in this case. There fore the anti-crystallization layer is introduced to suppress the crystallization only after recording. Thus initialization is not affected. The introduction of anti-crystallization layer also suppresses the cross-erase effectively. This gives suitable property for the narrow track pitch recording.

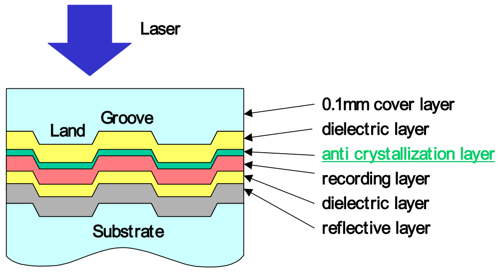


Fig. 9 Disk Structure

2.4 WRITE & READ RESULT AT 50GB/LAYER AND 108MBPS

Figure 10 shows the result of 50GB/layer write and read with the data rate of 108Mbps, which corresponds to the 3x-speed of Blu-ray. Error rates of below 10^{-4} were obtained for both on land and in groove at the nominal condition. However, the cross-talk cancellation effect looks insufficient compared with the isolated track. This is due to the insufficient SNR of side spots especially at high speed. This is consistent with the result at the low transfer rate where the cross talk cancellation is very effective. Therefore for the high transfer rate SNR design including side spots is essential. Anyway effectiveness of adaptive PRML is well proven because the power margin is sufficient for the isolated track recording.

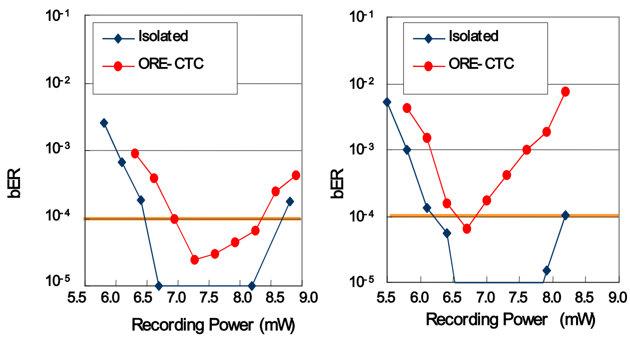


Fig. 10 .Recording power margin at 50GB/layer and 108Mbps

3. HIGH-SPEED WRITE & READ TECHNOLOGIES

The adaptive PRML technology is also effective for high-speed Blu-ray system where the liner density is not very high. We have demonstrated the recording and reading of Blu-ray write-once disc with 12x-speed. The rotation speed for 12x-Blu-ray corresponds to that for 16x DVD, which is said to be the maximum rotation speed for practical use. The medium used for 12x recording was basically the same except for the track pitch. In this experiment, the track pitch was 0.32 µm on groove, which conforms to the Blu-ray specifications. The read system is basically same as depicted in Fig. 8 less the path from the adjacent spots. Namely, adaptive EQ and Adaptive PRML are used.

Figure 11 shows the write strategy for 12x Blu-ray recording.

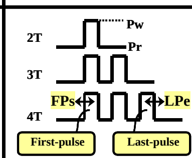
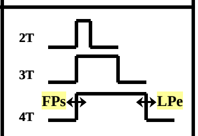
	Multi-Pulse	Mono-Pulse
Pulse-Shapes		
Power Levels	2	
Edge Control	4x4 Tables of FPs and LPe	

Fig. 11 High-speed Recording Strategies

Used strategy was a mono pulse for 12x while multi-pulse strategy showed the good result for the slower speed than 8x. In either case the adaptive type strategy with 4x4 table was used.

Figure 12 shows the result for high-speed recording. Sufficient power margin was obtained at 12x Blu-ray recording. Note that the readout speed is also 12x in this experiment. This was achieved by the adaptive PRML with adaptive equalizer

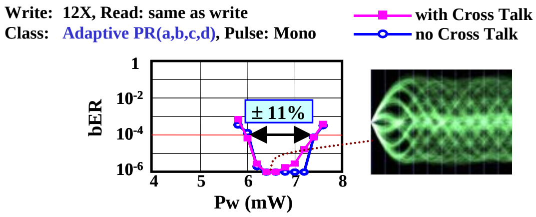


Fig. 12 High-speed Write & Read result: 12X of Blu-ray

4. CHALLENGES BEYOND 100GB

Without introducing new media side technology, 50GB/layer will be the maximum with the Blu-ray compatible system. Beyond that density some resolution enhancement technology will be necessary. For large capacity technology, easy expandability to the multilayer is also essential because current Blu-ray system already support. As a combination multilayer technology and resolution enhancement technology, we have introduced three-dimensional pit selection (3DPS) recording as shown in Fig. 13. The principle is that only the high temperature region of the media shows the high reflectivity while the other portion shows low reflectivity and high transparency.

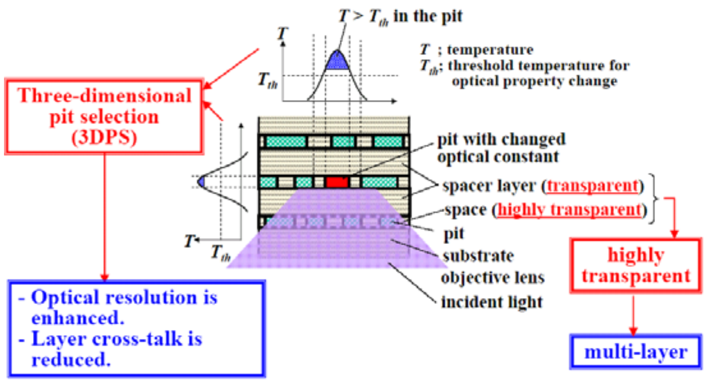


Fig. 13 Concept of Three Dimensional Pit Selection

We have experimentally confirmed the principle of the method and the experimental estimation proved that the method has the potential to achieve 400 to 500GB with 4 to 8 layers, where each layer will have about 100GB.

SUMMARY

By combining adaptive PRML and crosstalk cancellation, high areal-density recording of 50GB/layer was demonstrated on the write-once media with the data transfer rate of 108Mbps. Since this technology uses similar optical system as Blu-ray and the higher density is mainly achieved by signal processing technology. This method will have an advantage from the point of view of the production cost. 12-speed Blu-ray recording and readout was also demonstrated with similar signal processing technology and write-once media. For higher recording density, 3DPS system was introduced. The experimental result showed the potential for sub-terabyte systems.

REFERENCES

1. H. Minemura et al.; ISOM 2003、 [Tu-D-01]
2. F. Yokogawa et al.; JJAP vol.39 (2000) pp.819-823
3. H. Kudo et al.; ISOM 2004 We-G-03
4. H. Miyamoto et al.; ODS 2004、 [PDP1]
5. R. Tamura et al.; ODS 2004、 [WA4]
6. H. Hirotsune et al.; ISOM 2004 Tu-C-02