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High-Density Magneto-Optical Disk System Using Magnetically Induced Super Resolution

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Magnetically induced super resolution (MSR) is a new technology developed by us. It more than doubles the readout resolution limit of a conventional optical disk system without shortening the laser wavelength or increasing the numerical aperture (*N.A.*) of the objective lens. We examined the characteristics of the readout signals of an MSR-by-RAD (rear aperture detection) disk and obtained a high *C/N* of more than 49 dB and good stability of the edge position at a mark length of 0.4 μm. We investigated the high-density MO disk system using the MSR-by-RAD disk. Owing to optimization of the writing process and waveform equalization, the system achieved a byte error rate of less than 10^{-4} at a bit length of 0.3 μm. This bit length corresponds to a linear density more than three times higher than that of the conventional 130-mm MO disk system of the ISO standard.

KEYWORDS: magneto-optical disk, magnetically induced super resolution (MSR), rear aperture detection (RAD), superresolution, high density, mark-edge detection, jitter, equalizer

§1. Introduction

Magnetically induced super resolution (MSR) is a new technology developed by us. It more than doubles the readout resolution limit of the conventional optical disk system without shortening the laser wavelength or increasing the numerical aperture (*N.A.*) of the objective lens. Part of the light spot for the readout is optically masked in the MSR disk. Therefore the effective aperture becomes narrower than the conventional light spot, and superresolution is made possible.

MSR can be realized by either of two kinds of detection methods, front aperture detection (FAD) or rear aperture detection (RAD), depending on the mask position.[1-3] Although the RAD disk has a more complex magnetic multilayer thin-film structure than the FAD disk, it has the capability to realize higher track density than the conventional MO disk because the width of the aperture of RAD across the track is smaller than the light spot.

In this paper, we discuss the characteristics of the readout signals of MSR by RAD from the viewpoint of linear density. We also discuss the adaptability of the MSR-by-RAD disk for a high-density MO disk system.

§2. Readout Mechanism of MSR by RAD

2.1 *Basic function of MSR by RAD*

The basic function of the MSR-by-RAD disk is realized through a doublelayer structure of a low-coercive-force readout layer and a high-coercive-force recording layer, as shown in Fig. 1. Prior to readout, an initializing magnet once erases the information in the readout layer. During readout, a readout laser power heats the rear side of a focused spot. The information in the recording layer is copied onto the readout layer in the heated area. Therefore only the heated area inside the focused spot forms an effective aperture by which to read out the information, and the remaining area in the spot functions as an optical mask; thus superresolution is realized.[1,3]

We adopted the quadrilayer structure to actual disks, because it satisfies the condition for forming a clear aperture more easily than does the double-layer structure.[3)]

2.2 *Double-mask structure of MSR by RAD*

With a high readout power, another mask is created in the highest-temperature region, as shown in Fig. 2.* In

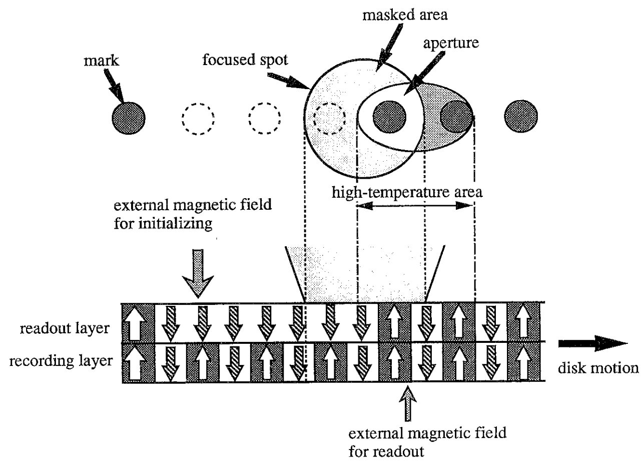


Fig. 1. Basic readout mechanism of MSR by RAD.

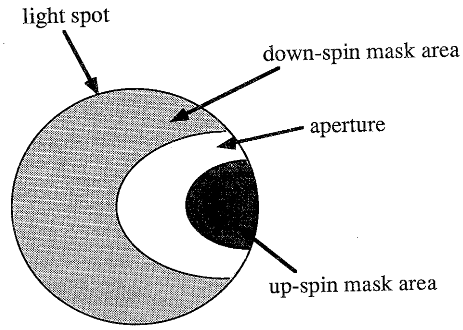


Fig. 2. Double-mask structure of MSR by RAD.

*M. Kaneko, K. Aratani and M. Ohta: appearing in International Symposium on Optical Memory 1991, Sapporo, October, 2D-1.

this "up-spin mask" region, magnetization in the readout layer is aligned in the direction of the external magnetic field during readout. This magnetization is opposite to that in the crescent-shaped "down-spin mask" region.

§3. Readout Signal Characteristics of MSR by RAD

3.1 *Experimental conditions*

The experiments are performed employing the following parameters.

1) The wavelength of the laser diode is 780 nm.
2) The numerical aperture of the objective lens is 0.53.
3) The readout laser source power is 2.8 mW, which is high enough to realize the double-masked structure.
4) The external magnetic field for readout is 400 Oe.
5) The external magnetic field for initialization is 3 kOe.
6) The scanning linear velocity of the disk is 7.5 m/s.

3.2 *C/N of readout signals of MSR by RAD*

Figure 3 shows the mark length (half of the recording wavelength) dependence of C/N. A high C/N of 49 dB is obtained for a mark length of 0.4 μm and 44 dB for a mark length of 0.3 μm.

3.3 *Stability of readout signals*

The fluctuation of aperture may cause the edge shift of readout signals. We measured the time intervals between leading or trailing edges, as shown in Fig. 4, to evaluate

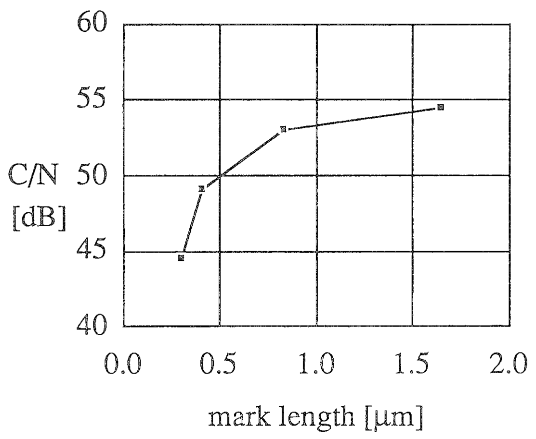


Fig. 3. Mark length dependence of C/N.

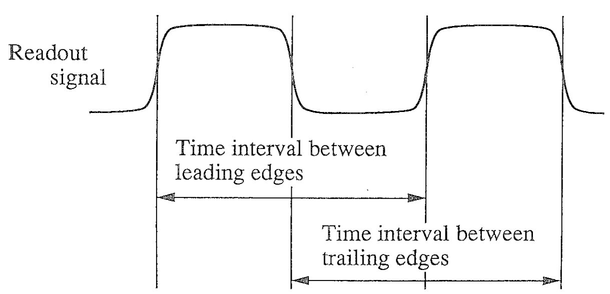


Fig. 4. Schematics of measured time intervals between leading/trailing edges.

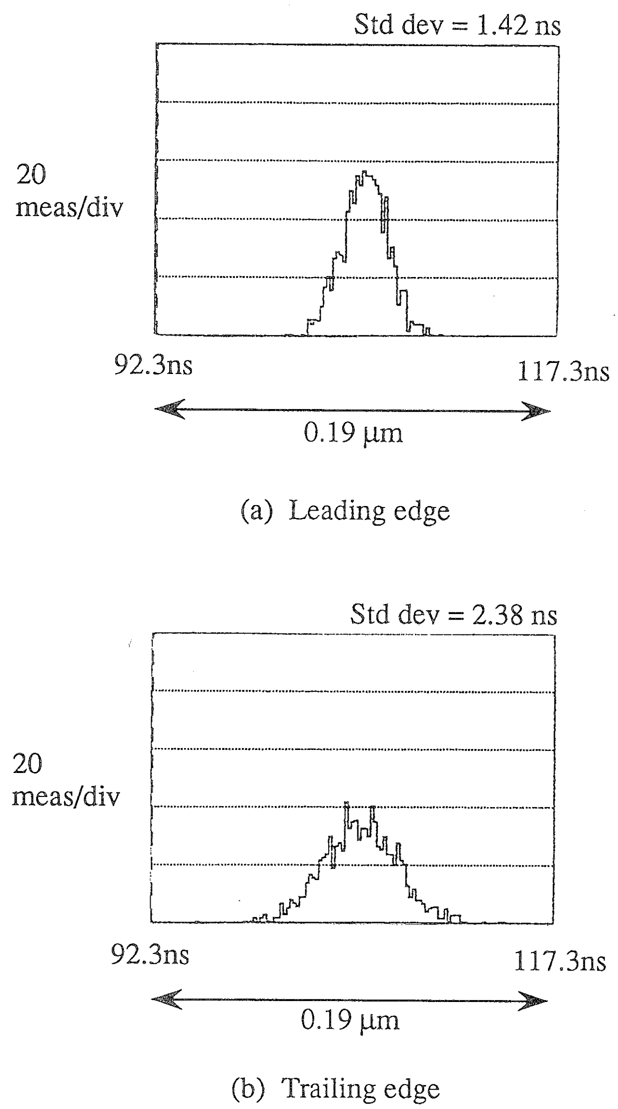


Fig. 5. Distributions of the time intervals between leading/trailing edges at a mark length of 0.4 μm.

the fluctuation of the edge position of the up-spin (front) or down spin (rear) mask. Each edge is detected by the level-slice method.

Figures 5(a) and 5(b) show the distributions of the time intervals at a mark length of 0.4 μm. The standard deviation of the time intervals of the leading edges is less than 1.5 ns, that is, equal to 0.011 μm, and that of the trailing edges is less than 2.4 ns, that is, equal to 0.018 μm. These values are as small as those of a conventional MO disk.

§4. High-Density MO Disk System Using MSR-by-RAD Disk

4.1 *Experimental conditions*

The high-density magneto-optical disk system was investigated using (1,7)-run length limited (RLL) code modulation with the mark-edge detection method. The following investigations are performed using conventional optics, as mentioned in §3.1, and with a 130-mm MSR-by-RAD disk with a 1.6-μm-pitch dc groove. The disk rotates at the speed of 2400 rpm.

4.2 *Optimization of writing conditions and waveform equalizer*

Accurate control of mark size is necessary to realize the mark-edge detection system. Precompensation of the writing process is given to reduce the effect of the thermal history. The detailed explanations of the precompensation method will be given in another paper. We then optimized the laser power and pulse width of the writing process and successfully recorded random data of the (1,7) code by mark-edge recording at the minimum mark length of 0.4 μm, which corresponds to a bit length of 0.3 μm. Figure 6 shows the eye pattern of the readout signals without waveform equalization.

We also examined the waveform equalizer to correct the phase distortion of the readout signals caused by the asymmetric shape of the aperture shown in Fig. 2. The equalizer was constructed by a transversal filter whose tap interval corresponds to a channel clock cycle.

First we simulated the waveform equalization process by a computer to optimize the tap number and tap weight values. Figure 7 shows the block diagram of the simulation system. Readout signals of random data and clock signals generated by the phase locked loop (PLL) are digitized by a 2-channel waveform digitizer. Then these digital signals are transferred to the computer for the simulation. The proper tap weight values of the equalizer for a fixed tap number are given by eq. (4.1) (Wiener-Hopf equation):[4)]

$$W_{\mathrm{LMS}}=\boldsymbol{\Phi}^{-1}(x,x)\boldsymbol{\Phi}(x,d), \qquad (4.1)$$

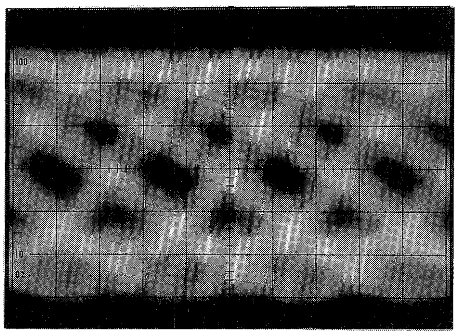


Fig. 6. Eye pattern of readout signals without signal equalization at the minimum mark length of 0.4 μm.

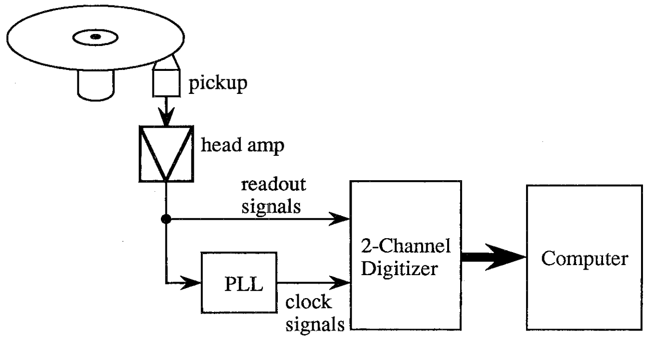


Fig. 7. Simulation system.

where

W_{LMS} optimal tapweight vector

$\boldsymbol{\Phi}(x,x)=\mathrm{E}[\boldsymbol{x}(j)\boldsymbol{x}^T(j)]$

$\boldsymbol{\Phi}(x,d)=\mathrm{E}[d(j)\boldsymbol{x}(j)]$

$\boldsymbol{x}^T(j)=[x(j), x(j-1),\cdots, x(j-N+1)]$

$x(j)$ jth readout signal sampled by channel clock

$d(j)$ jth desired response generated by the computer

N tap number.

We calculated the standard deviation of edge variations of readout signals equalized by the proper equalizer given by eq. (4.1) to estimate jitter characteristics. Figure 8(a) shows calculated results plotted with varying slice levels of edge detection for each tap number. Here the slice level is scaled as shown in Fig. 8(b). For tap numbers of more than 5, standard deviation less than 3.5 ns is guaranteed over a reasonable range of the slice level. On the other hand, for tap numbers of more than 7, there is almost no improvement with the increase of tap number of the equalizer. Considering that an equalizer with a large tap number is difficult and expensive to construct, the optimal tap number is concluded to be 7 from these simulation results.

We constructed the hardware of the optimized 7-tap equalizer using an analog signal processing technique. Figure 9 shows the eye pattern of readout signals equalized by the 7-tap equalizer at the minimum mark length of 0.4 μm. The figure indicates much wider eyes of the readout signals than that in Fig. 6 because of the optimal equalization. Figure 10 shows the distribution of edge variation of those signals. Standard deviation of 3.55 ns, which corresponds to 0.027 μm, was obtained experimentally. These results prove that the effect of the constructed equalizer agrees with that of the simulated equalizing processes.

Owing to optimizations of writing conditions and the waveform equalizer, the byte error rate of less than 10^{-4} is achieved at a bit length of 0.3 μm. This bit length corresponds to a linear density more than three times higher than that of the conventional 130-mm MO disk system of the ISO standard.*

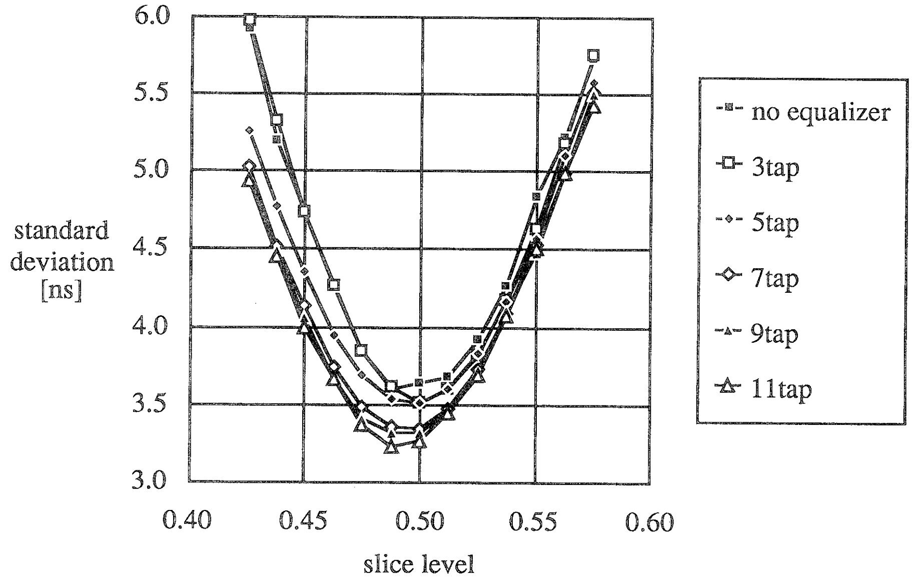
The analog signal processing technique may be replaced by a digital signal processing technique, and the optimization process of the equalizer by computer simulation may be replaced by the adaptive filter technique when an actual system is considered in the future.

§5. Conclusions

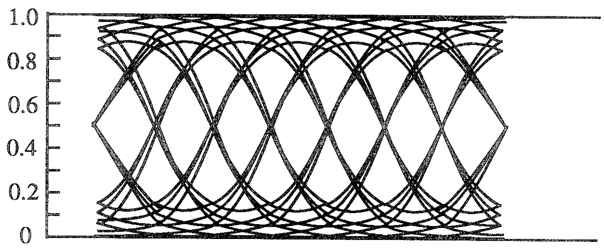
We examined the characteristics of the readout signals of an MSR-by-RAD disk. A high C/N of more than 49 dB and good stability of the edge position were obtained at a mark length of 0.4 μm.

We investigated the high-density MO disk system using an MSR-by-RAD disk. Accurate control of the mark size was realized through the optimization of the laser power and pulse width of the writing process. We also optimized the waveform equalizer by computer simulation, and

*ISO JTC/SC23/WG1 N321, July 1990.

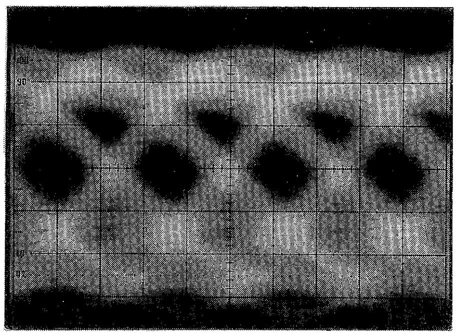


(a) Standard deviation vs slice level



(b) Scaling of slice level

Fig. 8. Standard deviation of edge variations vs slice level.



10 ns / div.

Fig. 9. Eye pattern of readout signals equalized by the 7-tap equalizer at the minimum mark length of 0.4 μm.

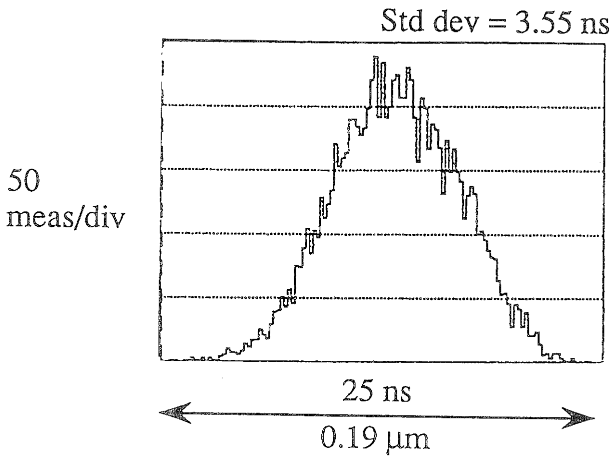


Fig. 10. Distribution of the edge variations of the equalized signals.

constructed the hardware for the optimized equalizer. Owing to these optimizations, the system realized a byte error rate of less than 10^{-4} at a bit length of 0.3 μm.

We believe that MSR by RAD will contribute to the development of next-generation high-density optical storage of digital images and computer data.

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