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High-Density Overwriting on a Magneto-Optical Disk with Exchange-Coupled Triple-Layer Film

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The characteristics of high density recording on an overwritable magneto-optical disk using light intensity modulation were investigated by means of (2, 7)-RLL mark position detection. We examined the overwritable region of optimum high level, (P_H) and low level, (P_L) by varying the recording pulse width and film structure in the overwritable magneto-optical disk, in order to minimize thermal interference between closely recorded marks. A wide margin of ±30% was obtained using low power at a bit length of 0.8 μm.

KEYWORDS: magneto-optic, light intensity modulation, direct overwrite, high-density recording, (2, 7) code modulation, mark position detection

§1. Introduction

In order to perform direct overwriting on a magneto-optical disk, we used light intensity modulation and an exchange-coupled magnetic triple-layer film.[1] Light intensity modulation has the advantage of compatibility with the conventional magneto-optical disk, because we can construct an overwritable drive system by modifying only the initializing field and laser diode circuit.[2] In so doing, we have obtained a sufficient power margin[3] and high reliability even after overwriting one million times.[4]

However, the next-generation overwritable disk must be capable of higher density recording. In order to perform higher density recording, the signal-to-noise ratio must be improved and the influence of thermal interference must be reduced. Another problem with light intensity modulation is that the region of laser power on which overwriting is possible is relatively small.

In this paper, we report an approach to high-density overwriting on an exchange-coupled magnetic triple-layer disk, using mark position recording with (2, 7) code modulation. We researched the distribution of the bit error rate in high-density recording when a recording pulse width is varied and propose a disk suitable for overwritable high density recording.

§2. Bit Error Rate in Higher Density Recording

Random data were written using (2, 7) code modulation on overwritable disks with $H_{rec}=32$ kA/m, $H_{ini}=200$ kA/m and $P_r=2.0$ mW. As shown in Fig. 1, the overwritable disks consisted of exchange-coupled magnetic triple layers with a total thickness of 130 nm, dielectric layers which sandwiched the magnetic layers and a protective layer. We changed the linear velocity from 5.4m/s to 10m/s for higher density recording, using a constant data clock of 68 ns. Optimum high level (P_H) and low level (P_L) recording laser power was used. The dependence of the bit error rate on the bit length is shown in Fig. 2 at recording pulse widths of 40, 50 and 70 ns. At a bit length of 0.8 μm, the narrowest laser pulse proved to be the most effective pulse width for improving the bit error rate.

As is well known, bit error rate is governed by the car-

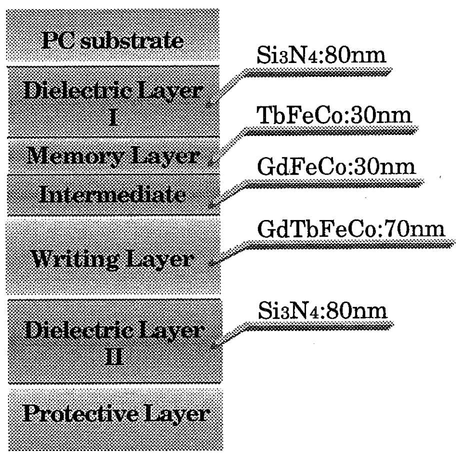

Fig. 1. Film structure of the light intensity modulation overwritable disk.

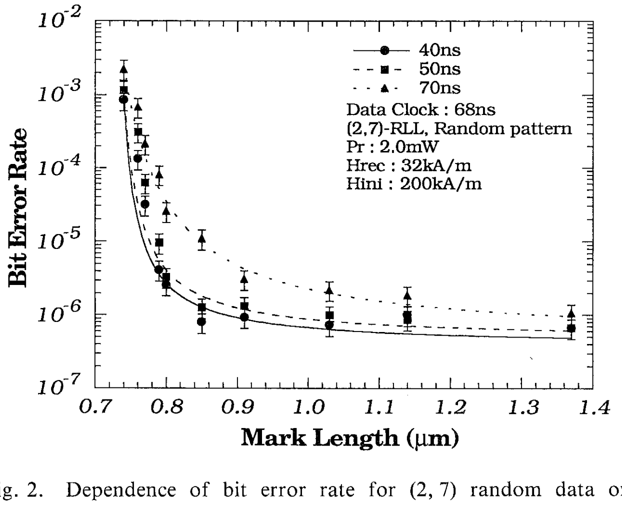

Fig. 2. Dependence of bit error rate for (2, 7) random data on recorded bit length with pulse widths of 70, 50 and 40 ns.

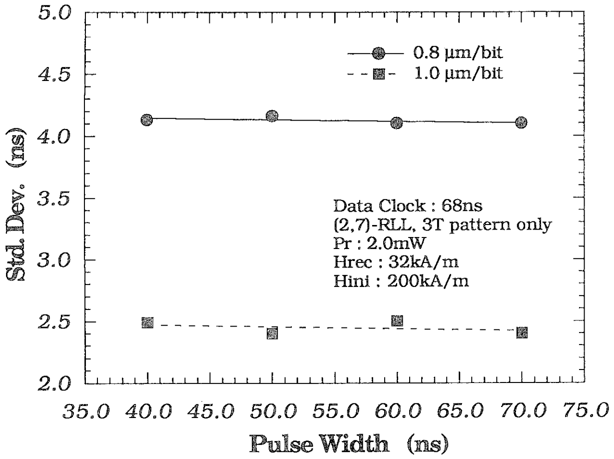

Fig. 3. Pulse width dependence of the standard deviations of interval times between read-out marks. The 3T pattern in (2, 7)-RLL code modulation was recorded at a bit length of 0.8 μm and 1.0 μm.

rier-to-noise ratio, defects in the disk, and thermal interference. In order to determine the exact cause of the errors, the time jitter was investigated. Figure 3 shows the standard deviation of interval times between marks when the 3T pattern in (2, 7) code modulation was recorded by a laser pulse with widths of 40, 50, 60 and 70 ns. Pulse width does not affect jitter even at a bit length of 0.8 μm, which suggests that a short pulse does not contribute to an improvement of C/N, since jitter should be reduced if C/N is improved. Since a shorter pulse improves the bit error rate, it seems that the cause of the errors is not a poor C/N, but thermal interference.

§3. Thermal Effect of Pulse Width on Overwriting

In order to confirm this hypothesis, we investigated the overwritable regions of P_H and P_L at a bit length of 0.8 μm. Figure 4 shows the overwritable regions for recording pulse widths of 70, 60, 50 and 40 ns at a linear velocity of 5.6 m/s, with $H_{rec}=40$ kA/m, $H_{ini}=200$ kA/m and $P_r=2.0$ mW. The dotted area shows the overwritable zone and the dot density corresponds to the bit error rate at a particular laser power. Roughly speaking, a short pulse width expands the overwritable region toward the higher side of P_H. A low power of P_H for pulse width of 70 ns is sufficient to record an excess bit with the help of P_L, as has been shown in previous work.[3]

Figure 5 shows the calculated maximum temperatures obtained by irradiating double laser pulses of 9.0 mW with various pulse widths: 60 ns in Fig. 5(a) and 40 ns in Fig. 5(b). The laser pulses assumed for the calculation have a low level value of zero, '1' widths of 60, 50 and 40 ns, and a total period width from '0' to '1' of 200 ns, as shown in Fig. 6, which corresponds to the 3T pattern of the (2, 7) code. The valley between the double peaks falls as the pulse width is narrowed. Fignre 7 shows the bottom temperatures at the valley for 60, 50 and 40 ns by $P_H=9.0$ mW compared with the higher limit of P_H when $P_L=5.5$ mW in Fig. 4, which is measured with pulse widths of 60, 50 and 40 ns, respectively. The three values for P_H correspond to the same temperature limit at which an excess bit is not written. These calculated results agree well with the experimental results and indicate the validity of our assumption that a shorter pulse width is effective in reducing excess heat and improving the bit error rate at a high density.

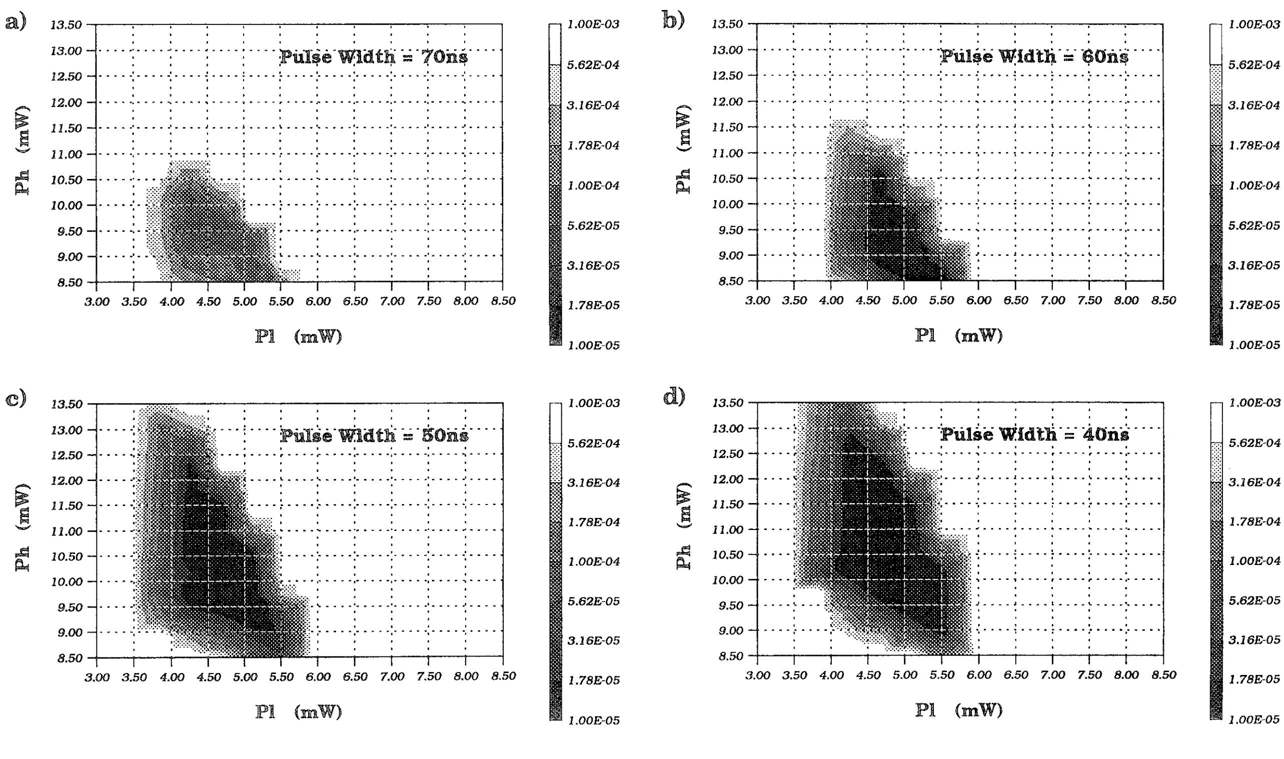

Fig. 4. The overwritable regions of P_H and P_L for random pattern in (2, 7)-RLL code modulation at a bit length of 0.8 μm. The overwritable disk was irradiated with recording pulse widths of (a) 70 ns, (b) 60 ns, (c) 50 ns and (d) 40 ns.

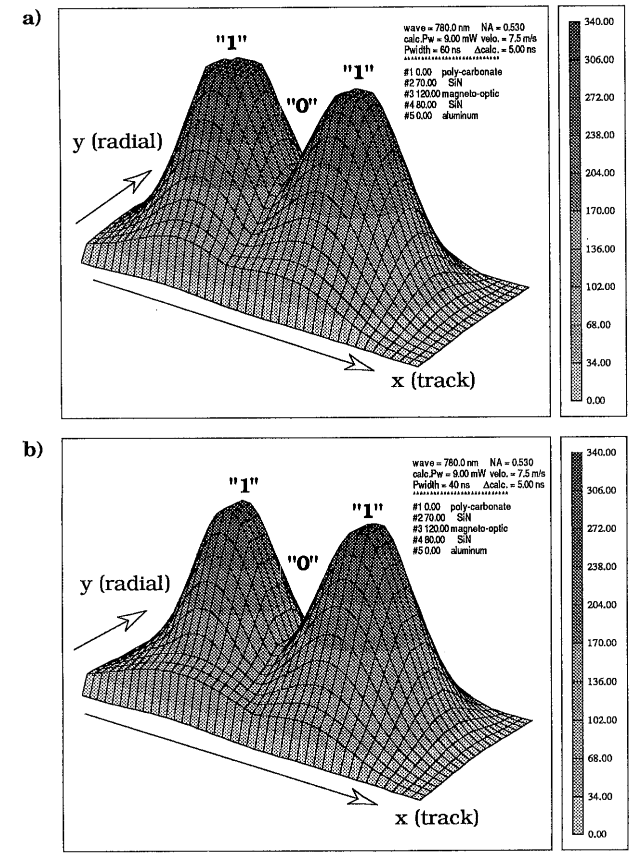

Fig. 5. The calculated maximum temperature of the magnetic layer in the overwritable disk when the 3T pattern in (2, 7) code modulation was recorded with pulse widths of (a) 60 ns and (b) 40 ns at the data clock of 68 ns.

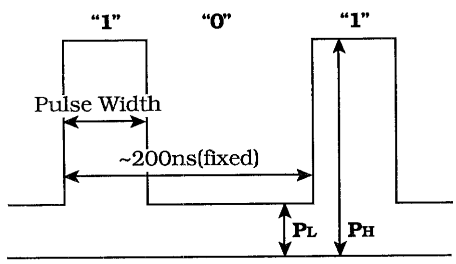

Fig. 6. Schematic drawing of the recording laser pulse.

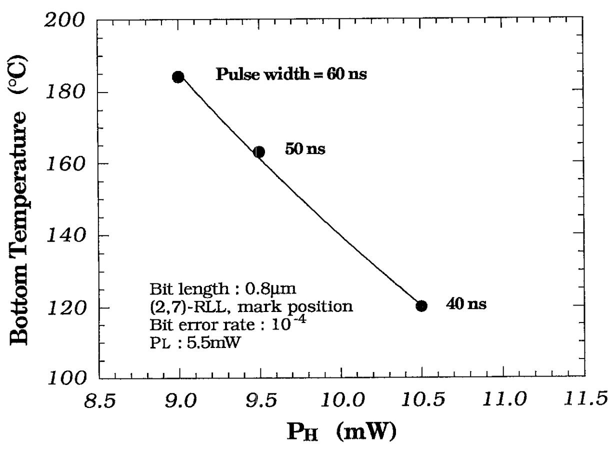

Fig. 7. Dependence of the calculated maximum temperature in the area between two laser pulses of 9.0 mW with widths of 60, 50 and 40 ns on the higher limit of P_H when $P_L = 5.5$ mW in Figs. 4(b), 4(c) and 4(d).

§4. Thermal Effect of a Heat-sink Layer of Aluminum

We have outlined the severest condition for high-density overwriting and now would like to consider how to lessen the influence of excess heat from P_H in the area of "0". We investigated a disk structure with a heat-sink layer,[5] as shown in Fig. 8, in order to find a way to

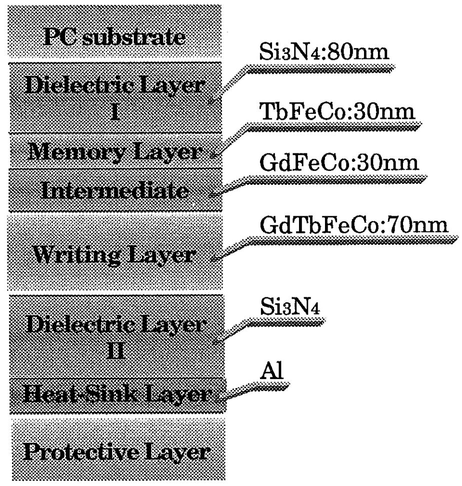

Fig. 8. Film structure of the light intensity modulation overwritable disk with a heat-sink layer of aluminum.

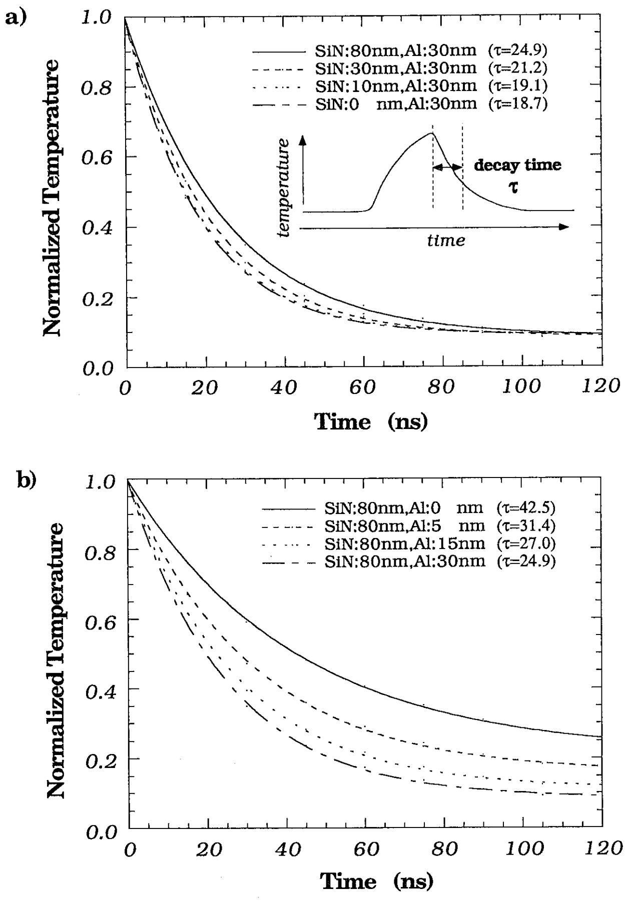

Fig. 9. Calculated decay in the normalized temperature at which a laser pulse is terminated. The dependence on a thickness of dielectric layer II of SiN is shown in (a) and the dependence of a thickness on a heat-sink layer of aluminum is shown in (b).

reduce thermal interference. We adopted aluminum as the material for the heat-sink layer. Since the thermal conductivity of aluminum is different from that of magneto-optical materials or SiN, we speculate that the thickness of dielectric layer II of SiN or the heat-sink layer of aluminum is very important.

We calculated the speed with which the temperature was cooled after it reached the maximum, when a light pulse with a height of 9.0 mW and width of 40 ns was irradiated. The results, which are normalized by the maximum temperature, are shown in Fig. 9(a) for various thicknesses of SiN dielectric layer II and Fig. 9(b) for various thicknesses of the Al heat-sink layer. In general, the temperature distribution obeys the following equation of thermal conduction:

$$\partial T/\partial t=\chi\, \partial^2 T/\partial x^2, \tag{1}$$

after the light pulse is terminated. The general solution at a fixed position can be roughly expressed by eq. (2) as a function of time:

$$T(t) \propto e^{-t/\tau} \tag{2}$$

In eqs. (1) and (2), χ is the thermal conductivity, and τ is the decay time. We obtained the value of τ by fitting eq. (2) to our simulated results in Fig. 9. The calculated results are also shown in Fig. 9. A thick aluminum layer is very effective from the standpoint of fast decay while a thick SiN layer is not, although aluminum becomes saturated at a thickness of 15 nm.

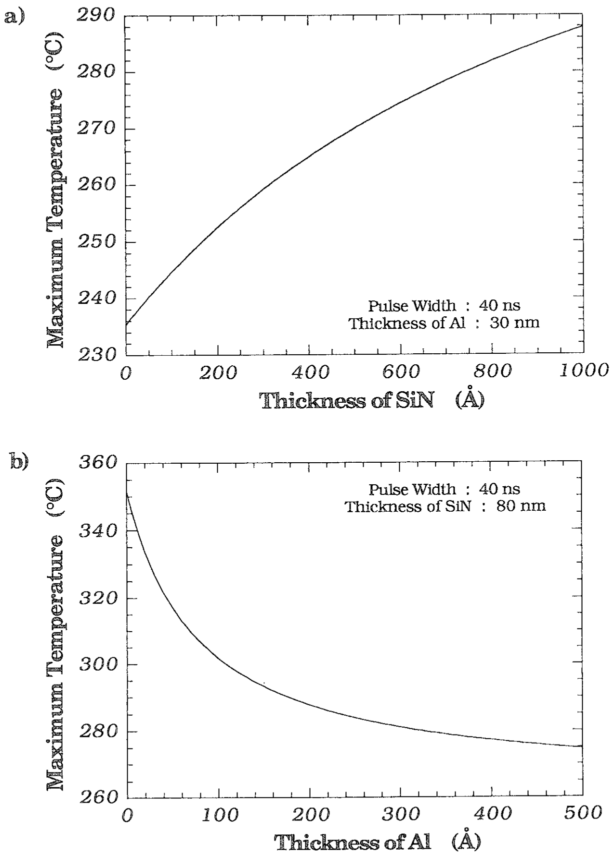

Fig. 10. Dependence of the calculated maximum temperature on the thickness of (a) a SiN dielectric layer and (b) an aluminum layer at a constant laser power of 9.0 mW.

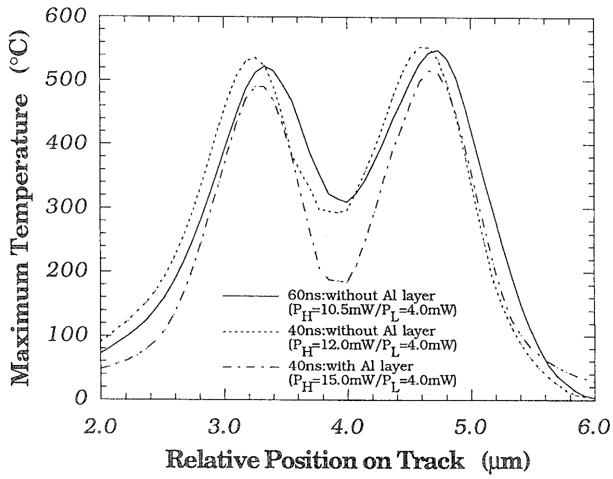

Fig. 11. Calculated temperatures with double laser pulses as shown in Fig. 6, in comparison with temperatures at the valley between double peaks.

On the other hand, the maximum temperature decreases as the thickness of dielectric layer II of SiN decreases, as shown in Fig. 10 (a). If the SiN layer is very thin, a higher value of P_H is necessary to enable the recording of data because heat is removed by the heat-sink layer.[5] Of course the thicker aluminum layer requires higher P_H, as shown in Fig. 10(b). The thicknesses of the Al layer and SiN layers should be selected such that the influence of any excess heat from P_H is minimized and the required P_H is within an available range of values. We adopted a thickness of 80 nm for the dielectric SiN layer to obtain reasonable P_H power required for overwriting.

In Fig. 11, we compare the three calculated maximum temperatures. The horizontal axis shows relative position on a disk. Double laser pulses, as shown in Fig. 6, were used and the laser power of P_H was controlled so that the first peak temperature would reach a constant value of 500°C. The laser power of P_L was fixed at a constant value of 4.0 mW. We obtain the lowest bottom temperature of 200°C when the disk with a heat-sink layer is irradiated with double laser pulses with a pulse width of 40 ns. We expect that the wider power margin for P_L will be obtained with the short laser pulse and the heat-sink layer; because the bottom temperature of 200°C is sufficiently lower than 350°C, at which a recording is expected to occur.

§5. The Overwritable Regions of a Heat-sink Layer Disk at 0.8 μm/bit

In order to reveal the effect of thickness of the heat-sink layer, the overwritable regions for a disk with a heat-sink layer with thicknesses of 10, 20 and 30 nm were investigated under the same conditions as in Fig. 4. The results are shown in Fig. 12. It is clear from these results that the heat-sink layer expands the overwritable region toward the higher P_L side, compared to a disk without a heat-sink layer, as can be seen in Fig. 4(d), in spite of the absence of change in the lower limit. We also observed that the higher limit of P_H moves toward higher power as the thickness of the heat-sink layer increases. We speculate that the heat-sink layer exerts an influence on the overwritable region similar to that of irradiation with

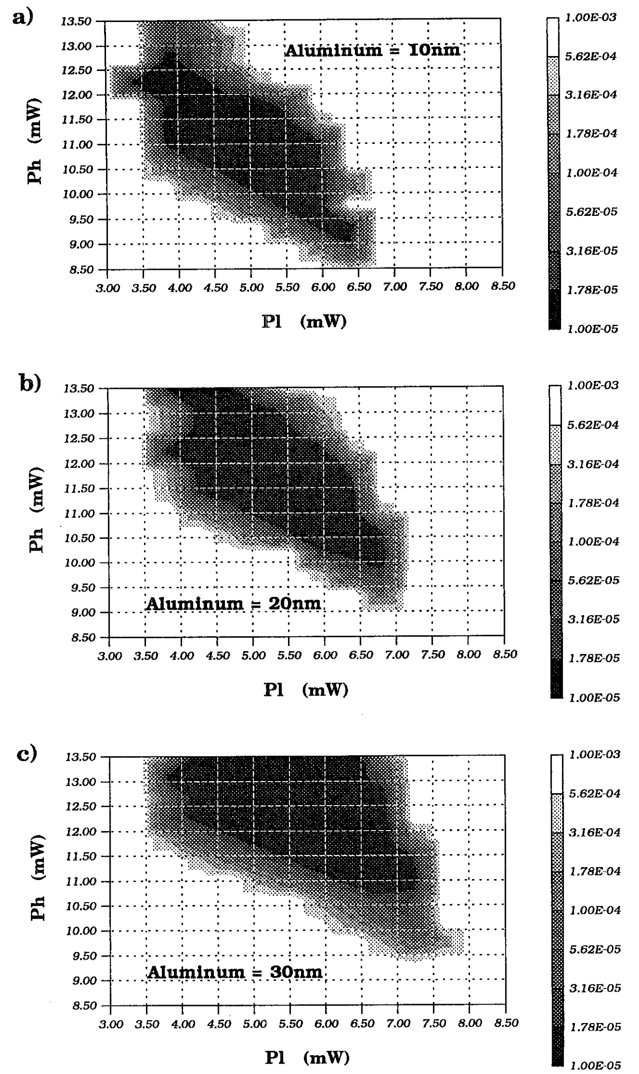

Fig. 12. The overwritable regions of P_H and P_L on an overwritable disk with a heat-sink layer for random pattern in (2, 7)-RLL code at a bit length of 0.8 μm. The overwritable disk had a heat-sink layer with thicknesses of (a) 10 nm, (b) 20 nm and (c) 30 nm.

a short-width pulse. The widest power margin of $\pm 30\%$ on P_L is consequently obtained by adopting a 30 nm thickness for the heat-sink layer and a pulse width of 40 ns.

§6. Conclusions

The possibility of high-density overwriting with light intensity modulation was investigated on a disk with exchange-coupled magnetic triple-layer film. In mark-position recording with (2, 7)-RLL code and for a low bit error rate, it is necessary to control thermal interference in the area of '0' with methods such as recording '1's with a short laser pulse of 40 ns, or adopting a disk structure with a heat-sink layer of aluminum. We determined the most appropriate disk structure for high-density overwriting. A wide P_L margin of $\pm 30\%$ was obtained at a bit length of 0.8 μm with a pulse width of 40 ns for P_H on a disk which has a dielectric layer 80 nm thick and heat-sink layer 30 nm thick.

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