15 Gbit/in^2 recording on a DWDD disc using a land/groove substrate with a red laser enabled by a side-wall-annealing process

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ABSTRACT

We developed a side-wall-annealing technique for land/groove substrates. By applying this technique to our Domain Wall Displacement Detection (DWDD) Magneto-Optical (MO) recording stack formed on a land/groove substrate, even with an NA of 0.6 and a wavelength of 660 nm, we realized a density of 15 Gbit/in^2 with a sufficiently wide recording tolerance. This density corresponds to a capacity of 4.7 GB on a Φ64 mm disc like MiniDisc.

Keywords: DWDD, side-wall-annealing, magneto-optical recording, MO, red laser, land and groove recording

1. INTRODUCTION

The DWDD technique, which was previously proposed by Shiratori et al. [1], has an exceptional ability for high resolution linear recording in optical storage. Since the invention, many related studies have been reported. Fujita et al. realized a capacity of 2.0 GB on a Φ64 mm disc with land/groove recording [2]. They developed a substrate optimizing deep groove geometry in order to obtain a sufficiently wide recording power tolerance. They showed the interchangeability of the MD system. Birukawa et al. realized 3.0 GB on a Φ2 inch disc with groove recording [3,4]. They used a sampled servo because the groove pitch of 540 nm was too narrow to obtain a conventional push-pull signal for tracking. This time, we developed a technique of side-wall-annealing for land/groove substrates. Using this process, we could utilize conventional land/groove substrates without using a technique of sampled servo or deep groove substrate. In this paper, we report the study of 15 Gbit/inch^2 recording on a DWDD disc using land/groove substrate with a wavelength of 660 nm and NA of 0.6 enabled by the side-wall-annealing process.

2. SIDE-WALL-ANNEALING TECHNIQUES

Figure 1 shows an optical pick-up setup and focused spots on the disc for side-wall-annealing. The side-walls of a land/groove substrate are annealed from the MO film side using a blue laser diode and an objective lens of NA=0.85.

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The incident beam is divided into three beams by a partial diffraction grating through which only the inner portion of the incident beam is diffracted. The 0th order diffracted beam which passes through the entire aperture makes a fine main spot and is used for side-wall-annealing. The ±1st order diffracted beams make side spots and provide a differential push-pull signal for tracking. The ±1st order diffracted beams are broadened in diameter by this special grating in order to suppress the deformation of the differential push-pull signal owing to the harmonic. Figure 2 shows measured sum signal and tracking error signals. The left figure is with tracking off, while the right is tracking on the side-wall in still-mode. The top trace shows the sum signal of the main spot, the middle trace shows a push pull signal from the main spot, and the lower trace shows a differential push pull signal from the side spots. The deformation of the push pull signal due to the harmonic appears in the middle trace, while the lower trace is sinusoidal. Consequently, the differential push pull signal from the side spots enables stable tracking on the side-wall. We also confirmed that these signals agree well with the calculated results as shown in Figure 3.

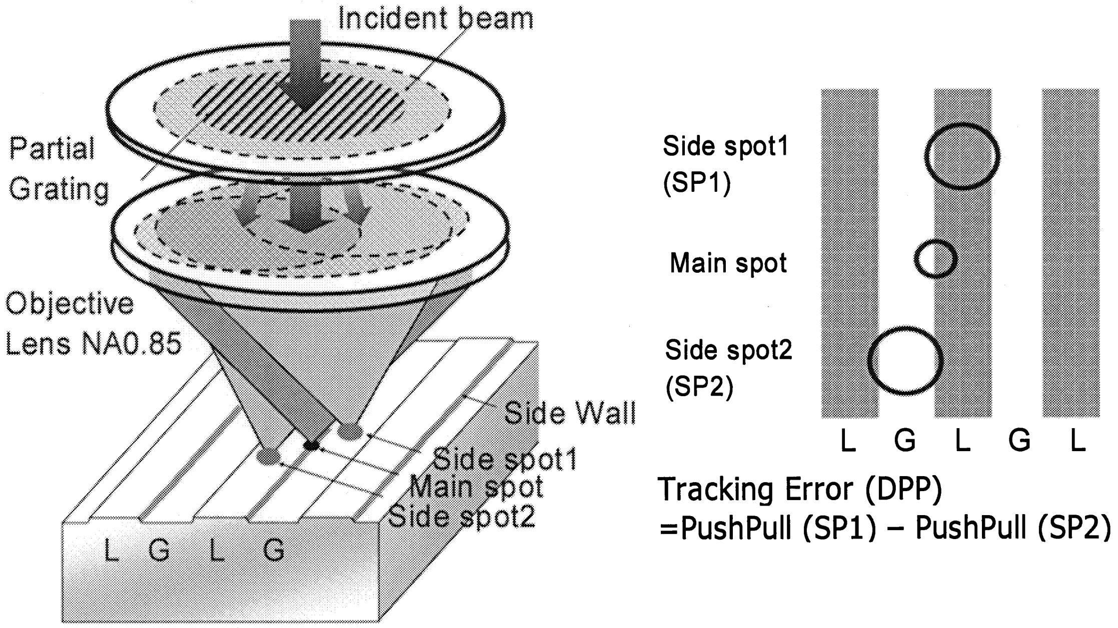


Figure 1: Optical pick-up setup and focused spots on the disc for side-wall-annealing

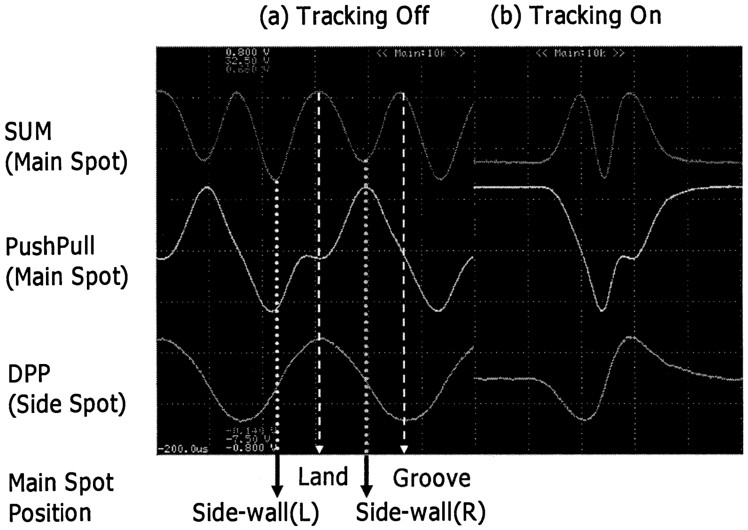


Figure 2: Measured sum signal and tracking error signals.
(a) Tracking Off, (b) Tracking On.

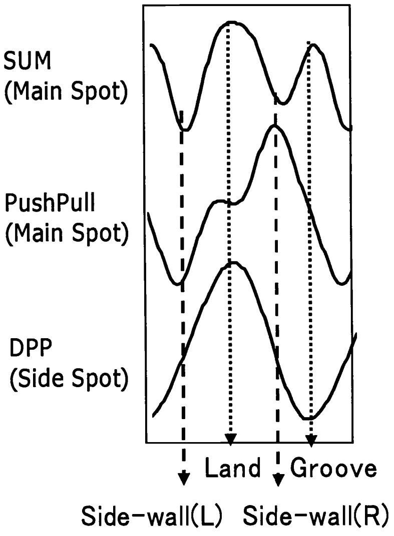


Figure 3: Calculated sum signal and tracking error signals.

3. DISC STRUCTURE

An amorphous poly-olefin (APO) substrate is prepared by using a stamper formed by reactive ion etching (RIE) to obtain a smooth surface in order to improve the domain wall mobility. Figure 4 shows an atomic force microscope (AFM) image of a substrate. The centerline average roughness (Ra) of both groove and land surfaces was less than 0.25 nm.

Figure 5 shows a DWDD film stack. The DWDD MO films were constructed with a memory layer, a switching layer, a control layer, and a readout layer. These exchange-coupled magnetic layers are sandwiched between the SiN protective layers.

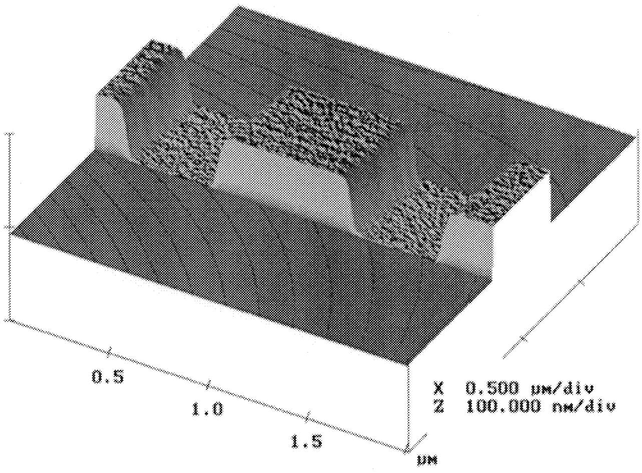


Figure 4: AFM image of land/groove substrate.

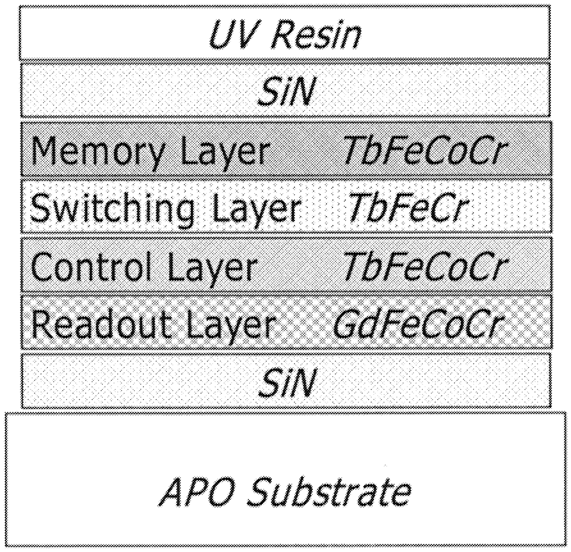


Figure 5: DWDD film stack.

4. EXPERIMENTAL CONDITION

Table 1 shows our experimental conditions. We used a red laser diode of λ=660 nm and an objective lens of NA=0.60. The 0.6 mm-thick substrate, which was prepared by using a stamper formed by RIE, had a groove depth of 55 nm for land/groove recording. The data channel clock was 45 MHz. (1,7)RLL data was recorded by using a laser-pulsed magnetic field modulation (MFM) with pulse duty of 50%, and the bit error rate was measured by PR(1,-1)+Viterbi detection. We studied a disc with areal recording density of 15 Gbit/inch^2, in which the track pitch was 540 nm and the bit length was 80 nm. This density corresponds to a capacity of 4.7 GB on a Φ64 mm disc like MiniDisc. A bit error rate of 5×10^{-4} was the criterion for estimating each tolerance.

Table 1: Experimental condition

Wavelength	660 nm
NA	0.60
Substrate	0.6 mm
Recording track	Land & Groove
Groove depth	55 nm
Track pitch	540 nm
Bit length	80 nm
Recording	Laser-pulsed MFM
Encoding	(1,7) RLL
Decoding	PR (1,-1) + Viterbi
Clock	45 MHz

Table 2 shows our side-wall-annealing conditions. The side-walls of land/groove substrates were annealed from the MO film side using a blue laser diode of λ=405 nm and an objective lens of NA=0.85. The tracking method was side-spot differential push pull servo as shown in Figure 1. The linear velocity was set to 4.5 m/s and the annealing laser power was varied from 5 mW to 6 mW.

Table 2: Side-wall-annealing condition

Wavelength	405 nm
NA	0.85
Direction of incident beam	Film side
Tracking method	Side-spot-DPP
Linear velocity	4.5 m/s
Power	5.0~6.0 mW

5. ANNEALING EFFECT

Magnetic force microscope images of 80 nm/bit random recorded marks on a DWDD disc show an effect of side-wall-annealing as shown in Figure 6. The upper is without annealing, and the lower is with annealing. Without annealing the curvature of domain walls seem slightly different between land and groove, since recorded marks reflect the temperature contour while recording. With annealing a stripe-shaped unrecordable area is formed between land and groove, resulting in recorded marks on land and in groove that are uniformly rectangular in shape. Since an annealing process decreases the magnetic anisotropy constant Ku, the direction of the magnetization-easy axis changes from perpendicular to in-plane at the annealed area [3].

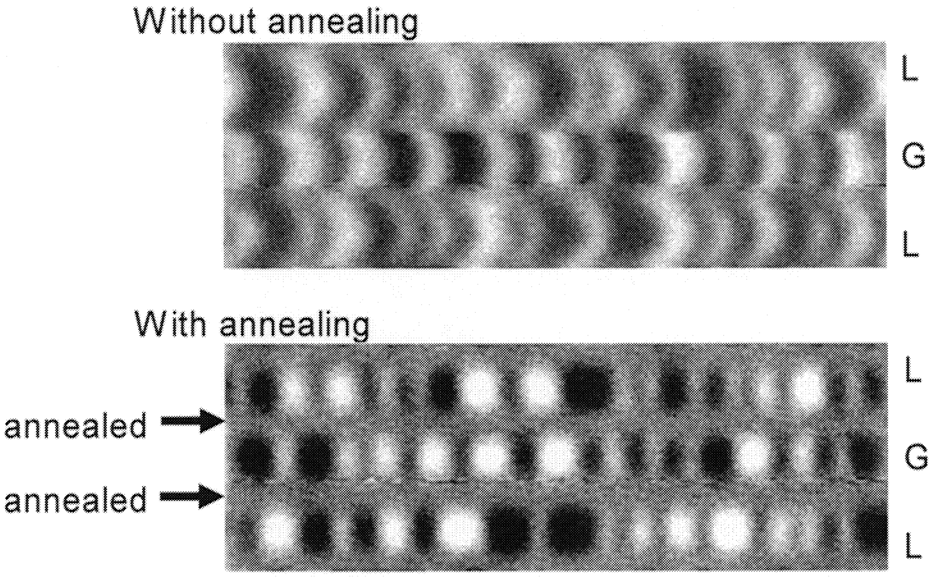


Figure 6: Magnetic force microscope images of 80 nm/bit random recorded marks on a DWDD disc.

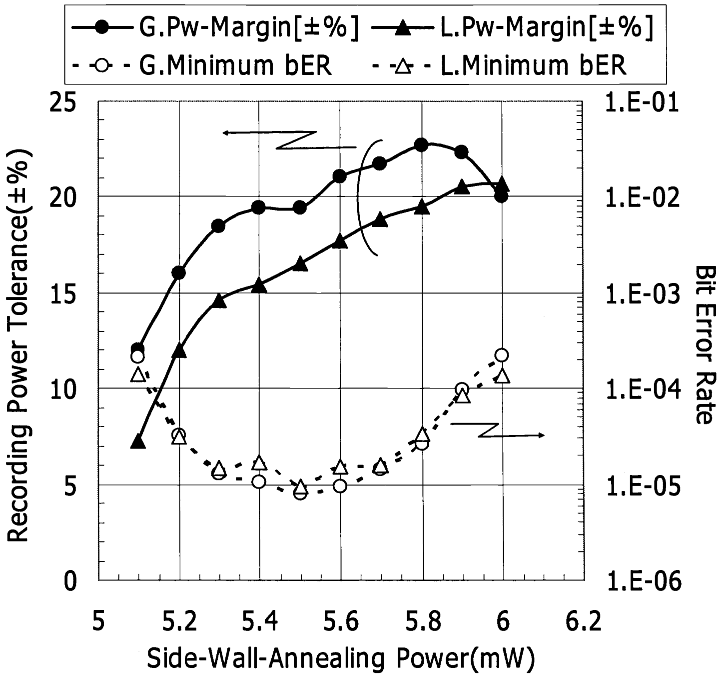


Figure 7: Annealing power dependence of recording power tolerance and that of bit error rate.

Figure 7 shows annealing power dependence of recording power tolerance and that of bit error rate. The recording power tolerance widens as the annealing power increases and we obtained a sufficiently wide recording power tolerance of ±23% in groove and ±21% on land with an annealing power of 5.9 mW, whereas we obtained the minimum bit error rate at a lower annealing power of 5.5 mW. The result clearly shows that the annealing process not only realizes ideal domain wall mobility but also makes a buffer area against cross-writing; on the other hand, it invades the recordable track width. Therefore, the side-wall-annealing power was set to 5.7 mW.

6. READING AND RECORDING PERFORMANCE

Figure 8 shows the bit density dependence of bit error rate. A bit error rate of 1 x 10^{-5} on land and in groove is obtained at 80 nm/bit, which is the areal density of 15 Gbit/inch^2. Figure 9 shows the dependence of bit error rate on recording magnetic field. We obtained sufficiently low bit error rate with a magnetic field of 20 kA/m. We also studied various margins of a side-wall-annealed disc. We could obtain sufficiently wide recording power tolerances of 5.9 mW ±22% in groove and 5.7 mW ±19% on land, as shown in Figure 10. Figure 11 shows the readout power dependence of bit error rate. We found that the readout power tolerance was 2.0 mW ±20% on land and in groove. The track offset dependence of bit error rate is shown in Figure 12. When data was recorded without track offset, the detrack margins were ±73 nm in groove and ±78 nm on land. But the detrack margins were decreased to ±34 nm in groove and ±36 nm on land when the same offset was added during both reading and writing. We believe that the recorded domain shape by the track offset is responsible for the detrack margins. Bit error rate as a function of disk tilt at optimum readout power was measured, as shown in Figure 13 and Figure 14. The readout power increases in order to compensate the corresponding degradation of Strehl intensity of light spot under the tilt condition. For readout, we obtained both tangential tilt margins and radial tilt margins of more than ±1 degree in groove and on land. When tilt occurred during both reading and writing, the disc tilt margins were ±0.78 degrees in groove and ±0.73 degrees on land in the tangential direction, ±0.48 degrees in groove and ±0.71 degrees on land in the radial direction. During this measurement, no tracking offset was added, while radial tilt causes some detrack in push-pull tracking. Table 3 summarizes the result of various margins. All of these margins prove to be acceptable for practical use.

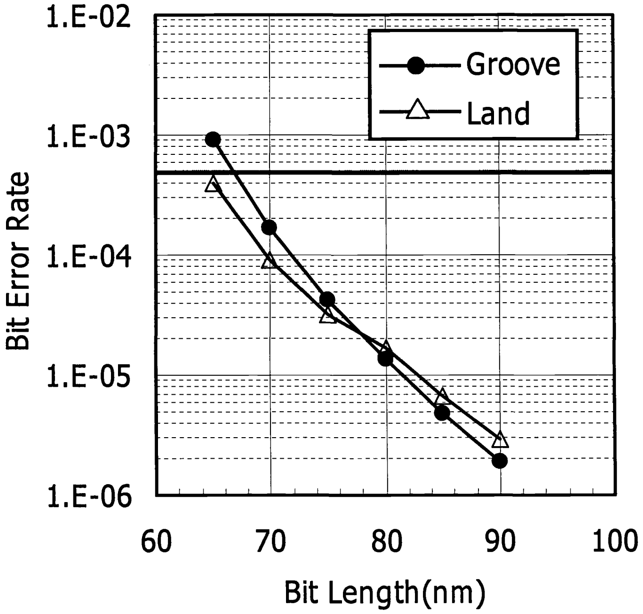


Figure 8: Bit density dependence of bit error rate.

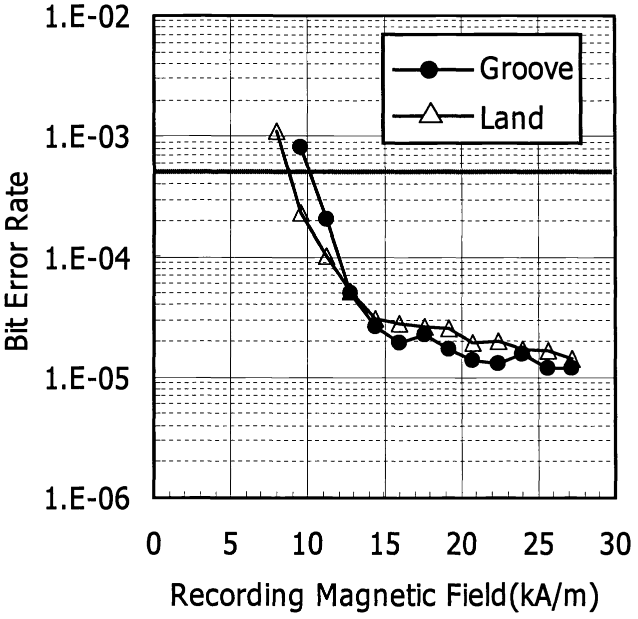


Figure 9: Dependence of bit error rate on recording magnetic field.

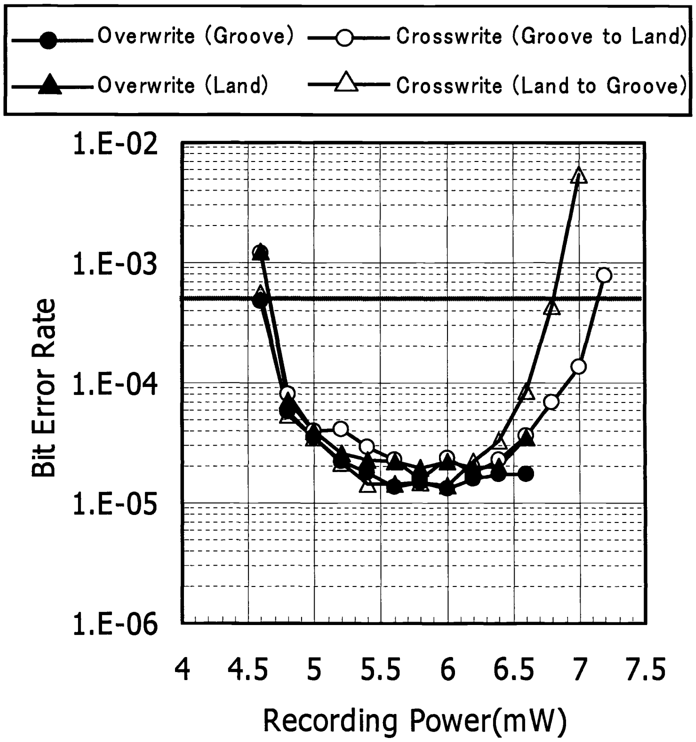


Figure 10: Recording power tolerance with an annealing power of 5.7 mW.

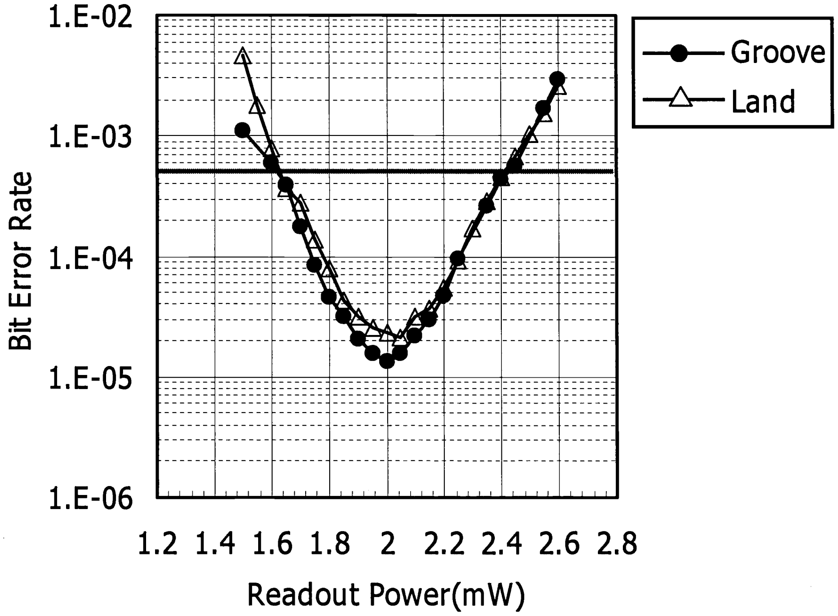
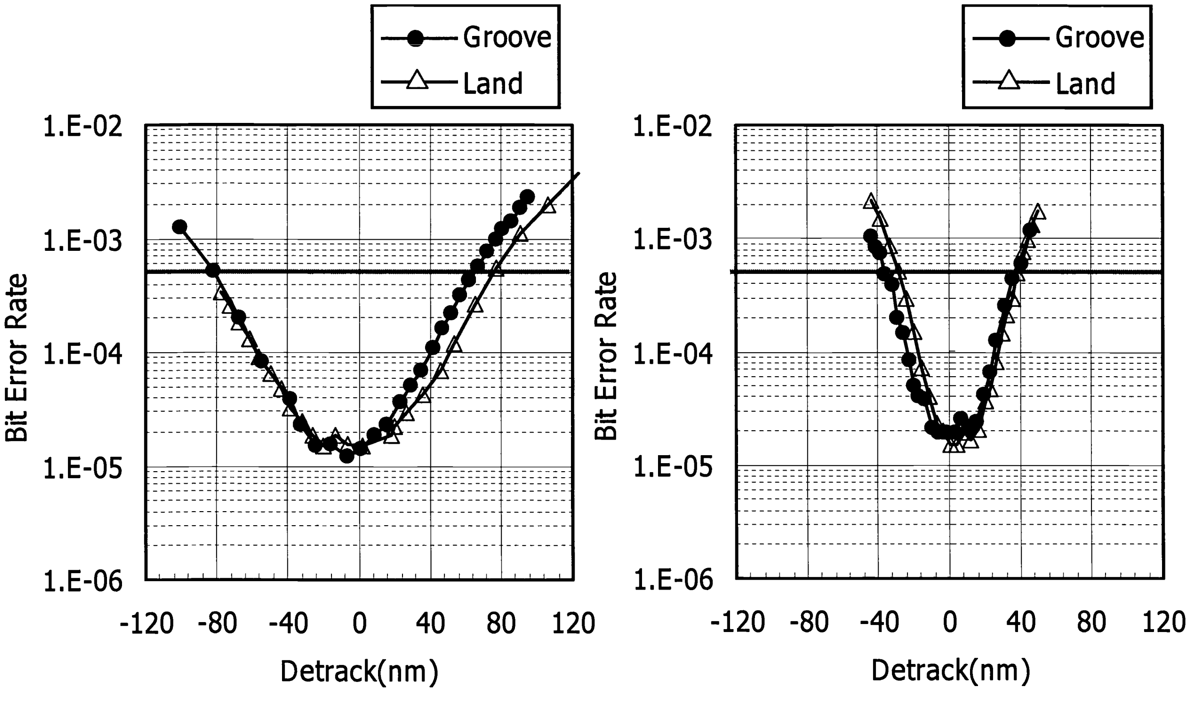


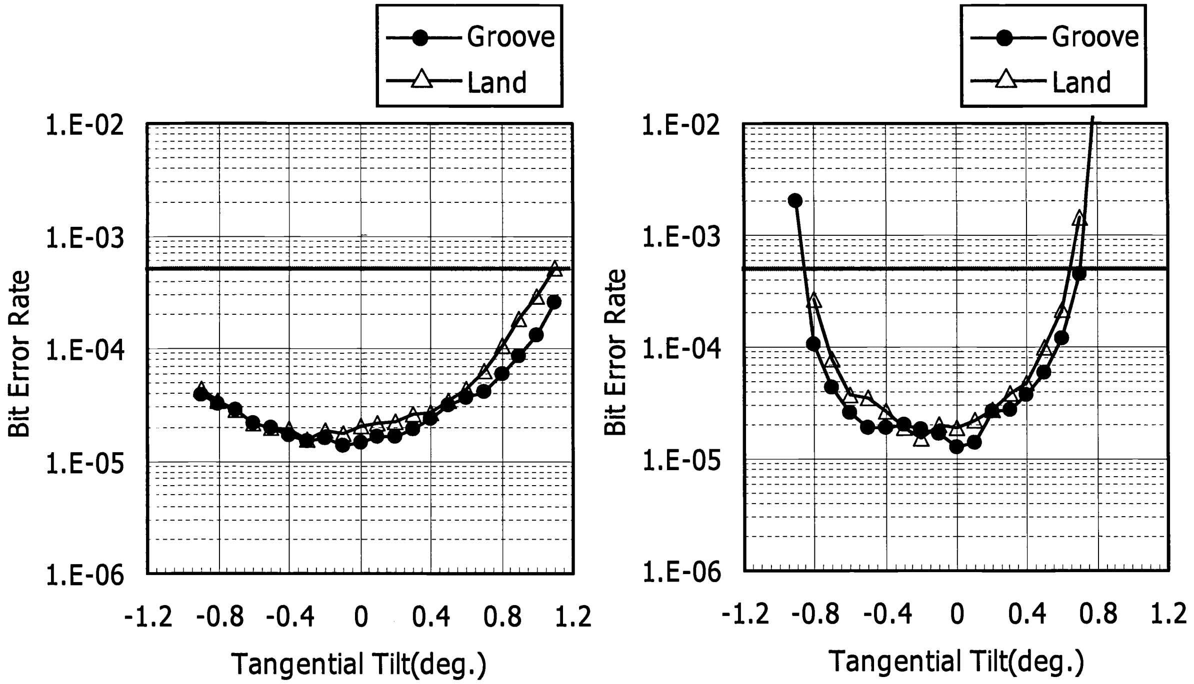
Figure 11: Readout power dependence of bit error rate.



(a) Recording without track offset

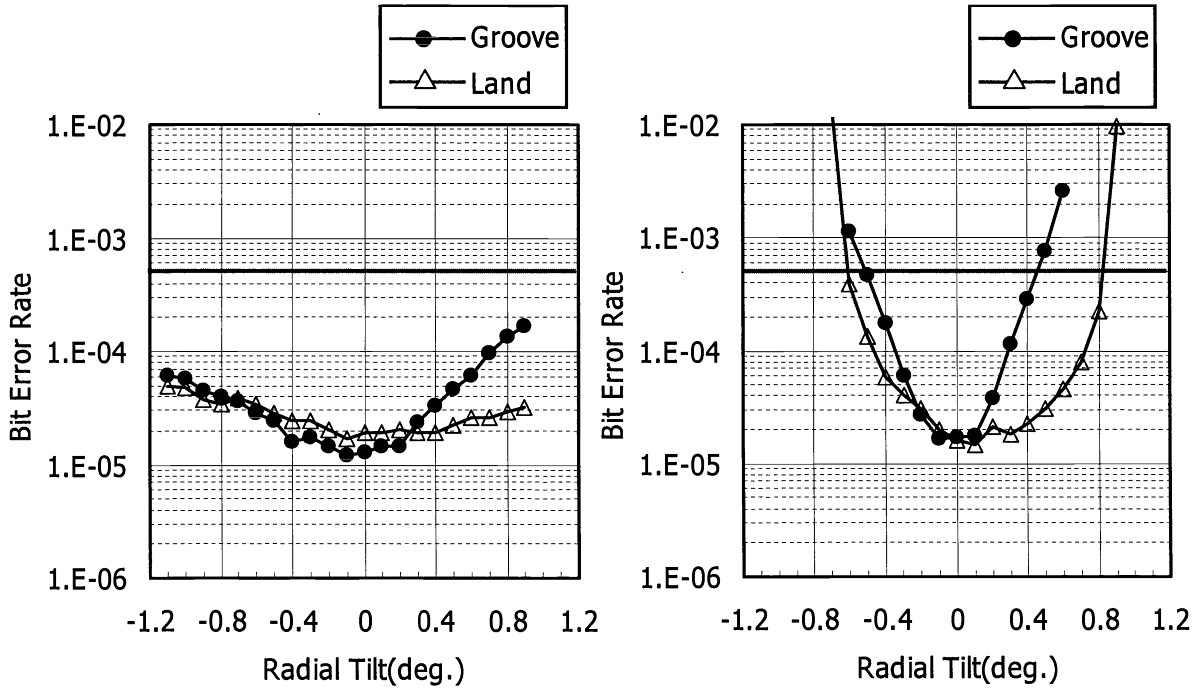
(b) Recording with track offset

Figure 12: Track offset dependence of bit error rate. (a) Data is recorded without track offset. (b) Same track offset is added during both reading and writing.



(a) Readout Only (b) Reading and Writing

Figure 13: Tangential tilt margin. (a) Data is recorded without disc tilt. (b) Tangential tilt occurred during both reading and writing.



(a) Readout Only (b) Reading and Writing

Figure 14: Radial tilt margin. (a) Data is recorded without disc tilt. (b) Radial tilt occurred during both reading and writing.

Table 3: Result of various margins

		Land / Groove
Write Power		±19% / ±22%
Read Power		±20% / ±20%
Detrack	Read	±78nm / ±73nm
	Read/Write	±36nm / ±34nm
Tangential Tilt	Read	>±1.0° / >±1.0°
	Read/Write	±0.73° / ±0.78°
Radial Tilt	Read	>±1.0° / >±1.0°
	Read/Write	±0.71° / ±0.48°

7. CONCLUSION

We developed a side-wall-annealing technique for land/groove substrates. By applying this technique to our DWDD MO recording stack formed on a conventional land/groove substrate, even with an NA of 0.6 and a wavelength of 660 nm, we realized a density of 15 Gbit/in^2, in which the track pitch was 540 nm and the bit length was 80 nm, with a sufficiently wide recording tolerance and readout performance. This density corresponds to a capacity of 4.7 GB on a Φ64 mm disc like MiniDisc.

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