Mechanical Performance Characteristics of 15000 rpm Ultra-high-speed Rotation of an Ultra-thin Disk with a Magneto-optical Recording Film

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We developed a stacked volumetric optical disks (SVOD) system to realize a data capacity of over 1 TB in a cartridge. To increase the read and write speed of the SVOD system, the mechanical performance characteristics of the 92-µm-thick thin optical disk stored in the SVOD cartridge were investigated by combining the magnetic amplifying magneto-optical system (MAMMOS) structure and 15000 rpm ultra-high-speed rotation. The minimum 40 nm mark length has already been reached with MAMMOS recording. This corresponds to 100 GB per disk of CD size. The thin optical disk can be rotated at over 10000 rpm because thin optical disks are flexible, and shatter rarely in comparison with conventional 1.2-mm-thick optical disks. As a result of the study, the mechanical performance characteristics were found to be acceptable for practical use. Therefore, the maximum data transfer rate can be upgraded to more than 2 Gbps by using a combination of thin optical disks, magneto-optical (MO) recording, and 15000 rpm ultrahigh-speed rotation.

Key words: thin disk, magneto-optical recording, stabilizer, high-speed rotation, axial acceleration

1. Introduction

Hard disk drives and computer tapes constitute the main stream of data storage, with a data capacity almost 10 times larger than that of optical disks. We developed a stacked volumetric optical disks (SVOD) system\(^1\) to enhance the data capacity of a cartridge. SVOD systems are in a position to surpass even hard disk drives and computer tapes, because a cartridge capacity of over 1 TB can be realized.

The minimum 40 nm mark length has been already reached with magnetic amplifying magneto-optical system (MAMMOS)\(^2\) recording, as shown in Figure 1. This corresponds to 100 GB per disk of CD size. The 92-µm-thick thin optical disk stored in the SVOD cartridge can be rotated at over 10000 rpm, because thin optical disks are flexible, and shatter rarely in comparison with conventional 1.2-mm-thick optical disks. On the other hand, the maximum rotation speed of 1.2-mm-thick optical disks is restricted because their fracture limit is 10000 rpm. If thin optical disks, MAMMOS recording, and 15000 rpm ultra-high-speed rotation are combined, the maximum data transfer rate can be upgraded to more than 2 Gbps. However, the axial acceleration of thin optical disks varies with disk structure\(^4\).

This paper describes the mechanical performance characteristics of a thin optical disk with MAMMOS structure and 15000 rpm ultra-high-speed rotation.

2. Experimental Conditions

Substrates for thin optical disks were made by converting 92-µm-thick polycarbonate cover sheets typically used in Blu-ray discs. Grooves of a stamper were pressed into the sheets by nanoimprinting. In order to rotate the thin optical disk stably, we developed an aero-dynamic stabilizer (ADS)\(^5\) which consisted of a 0.5-mm-thick transparent glass disk and spacer. Figure 2 shows a schematic diagram of the test setup. The 0.5-mm-thick transparent glass disk contains eight air holes in the central part of the disk. The spacer is 0.1 mm in thickness. The air pressure in the gap between the glass disk with air holes and the thin optical disk rotated together on a spindle motor was analyzed by...
The air pressure from an air hole edge to the outer area was negative, because the air in the gap was drawn from the outer gap by centrifugal forces. Airflow then arises in the gap, because air flows into the gap through the air holes. The airflow was determined by simulation analysis to be stable without turbulent flow. This stable airflow serves as an air damper which controls the axial acceleration of the thin optical disks.

Axial runout and axial acceleration were measured by using a laser Doppler vibrometer to investigate the mechanical characteristics of the thin optical disk rotating at an ultra-high-speed of over 10000 rpm. The measured radii of the inner, middle, and outer areas were 25, 40, and 55 mm, respectively. The axial displacements of the thin optical disk surface of a static condition unaffected by centrifugal force were measured by a laser displacement meter with an adequately low rotation speed (5 rpm).

Fig. 3 Axial displacements of the whole area of a write-once thin optical disk (top view).

Fig. 4 Axial acceleration of a write-once thin optical disk with a reflective film thickness of 50 or 160 nm.

Fig. 5 Axial displacements of the whole area of a thin MAMMOS disk (top view).
3. Results

3.1 Smoothing of the thin optical disk surface

The surface of a thin optical disk is easily deformed by the stress of the films stacked on the thin substrate and the heat of sputtering\(^4\). Before verification of thin MAMMOS disks, we initially considered using existing write-once thin optical disks to achieve surface smoothing of the thin optical disks.

Figures 3(a) and (b) show the surface scanning results obtained using a laser displacement meter for write-once thin optical disks with 160- and 50-nm-thick reflective films, respectively. The disk structure for the write-once thin optical disk is UV resin (5 µm)/Ag alloy (160 or 50 nm)/organic dye (120 nm)/PC substrate (92 µm). Large convex deformations were observed in the middle area of the reference disk with the 160-nm-thick reflective film (Fig. 3(a)). The large convex deformations became smaller when the thickness of the reflective film was reduced to 50 nm (Fig. 3(b)). Surface smoothing is made possible by reducing the thickness of the reflective film. In reflective film sputtering, the maximum temperatures of the thin optical disk surface were low enough (less than 45°C) in both reflective film thickness conditions. Therefore, compressive stress as the film stress of the reflective film is considered to be the cause of the convex deformations, not heat deformation caused by sputtering.

Figure 4 shows the axial accelerations of the write-once thin optical disks with 160- and 50-nm-thick reflective films. The axial accelerations were markedly improved by reducing the thickness of the reflective film. Thus, surface smoothing of the thin optical disk is requisite for stable rotation.

3.2 Mechanical characteristics of the thin MAMMOS disk

The structure of the MAMMOS film stacked on the nanoimprinted sheet is UV resin (5 µm)/Ag alloy (10 nm)/SiN (5 nm)/TbFeCo (50 nm)/TbGdFe (10 nm)/GdFe (20 nm)/SiN (10 nm)/PC substrate (92 µm). Each of the layers was prepared by a magnetron sputtering process. The track pitch and width of the grooves pressed into the thin substrate by nanoimprinting are 0.74 µm and 0.42 µm, respectively.

This thin MAMMOS disk is able to detect an 80 nm mark length\(^7\). The write and read conditions are as follows. The wavelength and numerical aperture of the objective lens are 650 nm and 0.6, respectively. A magnetic flying head for recording is loaded onto the thin MAMMOS disk after rotation. Its flying height is 5 µm at a linear velocity of 5 m/s for default readout. The coil generates a 240 Oe magnetic field on the recording layer under a 300 mA current. Recording is performed by a laser pumped magnetic field modulation method (LP-MFM) with a duty of 35%. The read and write area is only in groove.

Fig. 6 (a) Axial runout and (b) axial acceleration of the thin MAMMOS disk with the ADS.

In addition, the surface of the thin MAMMOS disk shown in Fig. 5 was flat, which is the same as the result shown in Fig. 3(b). Figures 6(a) and 6(b) show the axial runout and the axial acceleration of the thin MAMMOS disk with the ADS. The axial runout decreased with a rise in rotation speed. Consequently, the axial runout at 15000 rpm was less than 10 µm in the whole area. On the other hand, the axial acceleration drastically increased with a rise in rotation speed. However, the maximum axial acceleration of 15000 rpm was smaller than 120 m/s\(^2\). These results are acceptable mechanical characteristics for focusing using a commercialized drive.

4. Conclusion

The mechanical performance characteristics of a thin MAMMOS disk with an ultra-high-speed rotation of 15000 rpm, which is over the fracture limit of 1.2-mm-thick optical disks, were investigated. By using an aerodynamic stabilizer (ADS) and smoothing the thin disk surface, axial runout and axial acceleration were improved to under 10 µm and 120 m/s\(^2\), respectively. These results are acceptable mechanical characteristics...
for focusing using a commercialized drive. If the thin optical disk, MAMMOS recording, and 15000 rpm ultra-high-speed rotation are combined, the maximum data transfer rate is upgraded to more than 2 Gbps.

References

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