Change in Surface Tension and Pin Wear Characteristics of Thin-Film Disks by Heat Treatment and UV Irradiation

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The lubricant on thin-film disks is a key material for disk durability. Bonded lubricant layer remains on disk surfaces after solvent rinsing which removes mobile lubricant. To improve disk durability, lubricant treatments comprising heat treatment and UV irradiation, have been studied. Both of them increase bonded lubricant thickness but the bonded lubricant characteristics are not well understood.

In this study, disks with only the bonded lubricant remaining after rinsing were prepared. Results of pin-on-disk wear tests and surface tension measurements on these disks showed that “bonded lubricant” could be moved by mechanical sliding and that the smaller the surface tension, the lower the pin wear.

Keywords: thin-film disk, hard disk drive, lubricant, ultraviolet irradiation, heat treatment, surface tension, pin wear

1. Introduction

Lubricant performance on thin-film magnetic disks has been improved to increase the recording density of hard disk drives (HDDs). Heat treatment¹ and ultraviolet (UV) light irradiation²⁻⁵ have been used for this purpose. These treatments have been shown to increase the bonded lubricant (that remaining on disk surfaces after solvent rinsing) thickness.

We have been studying head-disk interface durability by transparent pin-on-disk seek wear tests⁶. We showed that on disks with different lubricants, the larger the pin wear, the larger the head pad wear⁷. We considered that head wear in real HDDs could be analyzed by the pin wear characteristics revealed by the test. Using this wear test, we showed that UV light irradiation on lubricated disks increased bonded lubricant ratio and affected pin wear volume⁸. In a recent study, we showed that on disks with both mobile and bonded lubricant pin wear decreased on disks with a medium lubricant bonding ratio but became larger on disks with a high lubricant bonding ratio⁹. It was also found that lubricant droplets on pin surfaces became large even on high bonding ratio disks. Until then, we had thought that the lubricant picked-up onto pin surfaces was mobile lubricant on disk surfaces. If that were true however, the amount of picked-up lubricant should be smaller on high bonding ratio disks. However, since the results contradicted that assumption, we started considering the possibility that so-called “bonded” lubricant could be moved when something slid on it, although the reason for such lubricant behavior was not clear. This led us to study disks with only bonded lubricant.

The results of wear tests on disks with only bonded lubricants showed that pin wear decreased with the increase in bonded lubricant thickness¹⁰. It was also
found that pin wear characteristics varied on disks with the same bonded lubricant thickness treated by different methods. We considered that the reason for this could be due to differences in lubricant distribution or coverage on disk surfaces. To analyze the surface characteristics, critical surface tension is often used; we thus measured contact angles of disks with several low surface energy liquids and analyzed critical surface tensions with Zisman’s plots\(^{11}\).

In this paper, the results of pin-on-disk seek wear tests on disks with only bonded lubricant prepared by heat treatment and UV light irradiation are first described. The relation between the results of wear tests and the measured critical surface tension is then discussed.

2. Experiments

Schematic illustration of our transparent pin-on-disk seek wear test apparatus is shown in Fig. 1. A transparent pin is spring loaded onto rotating test disk surface. The disk is mounted on a spindle fixed on a linear stage and is moved in a radial direction to increase the wear amount simulating head seek motion\(^{12}\).

The test pins were made of transparent quartz glass with a hemispherical sliding surface of 1 mm surface curvature radius. The roughness of the hemispherical sliding surface was about 1.8 nm Ra. The pin was glued under a leaf spring with a hole at the back of the pin contact point. The contact condition between the pin and the test disk was monitored through the hole using an optical microscope. The microscope images were captured by a TV camera and recorded by an HDD recorder. Pin wear amount was calculated by interference rings in the images\(^{13}\). The evolution of lubricant droplet on pin surfaces was also observed.

Test disks were thin-film magnetic disks with 95 mm outer diameter aluminum substrates for longitudinal magnetic recording. The disks were covered with 2.7 nm carbon overcoat film of surface roughness Ra=0.45 nm. Perfluoropolyether (PFPE) lubricants (Fomblin Z-dol 2000 and Z-tetraol 2000, Solvey Solexis Inc.) were dip coated at 1.2 nm thickness on the carbon overcoat film. After lubricant dipping, some of the lubricant coated disks were then heat treated at 130 °C in air or subjected to UV irradiation in nitrogen gas. Heat treatment was performed in a constant temperature oven (CLN-21-DPN from Kato, Co. Ltd.). UV irradiation was performed in a nitrogen-gas-filled chamber with a quartz glass window, using a batch UV cleaning system (OC-2507 from Iwasaki Electric, Co. Ltd.). The residual oxygen content at the beginning of UV irradiation was 50%RH.

Bonded lubricant thickness increased with UV irradiation time until 300 s on Z-dol coated disks and until 30 s on Z-tetraol coated disks. We considered that lubricant was degraded by long UV irradiation time resulting in a decrease in bonded lubricant thickness. In this study, we used data on Z-dol coated disks with 0 to 300 s UV irradiation and Z- tetraol coated disks with 0 to 60 s UV irradiation.

Wear tests load was 0.98 mN, the disk rotation speed was 7200 rpm, and the sliding velocity was 26.3 m/s. Tests were continued for 40 min with seek distance of 1.5 mm and seek speed of 2 mm/s. Tests were performed in a class 100 clean booth at 17 °C and 50%RH.

Surface critical tension was measured by using Zisman’s plot. The test liquids used in the measurements were shown in Table 1. They were all non-polar liquids and the measured surface tensions were the dispersive...
component of the surface tension. The accuracy of the critical surface tension measurement was about 0.2 mN/m.

3. Results and discussions

The variation in pin wear volume on disks with bonded Fomblin Z-dol 2000 lubricant is shown in Fig. 4. Pin wear decreased as the bonded lubricant thickness increased on both UV irradiated and heat treated disks. Pin wear on heat treated Z-dol disks were on the same line of those on UV irradiated disks.

The pin wear volume on disks with bonded Fomblin Z-tetraol 2000 lubricant is shown in Fig. 5. Pin wear also decreased with the increase in bonded lubricant thickness as on disks with Z-dol lubricant in Fig. 4. However, around bonded lubricant thicknesses of 9.5 Å, pin wear on disks after heat treatment (black triangles) were smaller than those on disks after UV irradiation (white triangles). We considered that this difference could be due to chance in lubricant distribution on disks with different treatments. We then started measuring critical surface tension of test disk surfaces to investigate the reason for the difference.

Changes in critical surface tension on disks with Fomblin Z-dol and Z-tetraol lubricants are shown in Figs. 6 and 7. On disks with Z-dol lubricant, critical surface tension gradually decreased with the increase in bonded lubricant thickness. On disks with Z-tetraol lubricant, critical surface tension over 9 Å were smaller than those in Fig. 6. It also became clear that the critical surface tension on disks after heat treatment around 9.5 Å thickness was smaller than that on disks after UV irradiation.

Correlations between the critical surface tension and pin wear volume on disks with Fomblin Z-dol and Z-tetraol disks are shown in Figs. 8 and 9. Pin wear decreased as critical surface tension decreased, reflecting the fact that both decreased with an increase.

<table>
<thead>
<tr>
<th>Test liquids</th>
<th>Surface tension (mN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-Perfluorooctane</td>
<td>14.0</td>
</tr>
<tr>
<td>n-Octane</td>
<td>21.3</td>
</tr>
<tr>
<td>n-Decane</td>
<td>23.4</td>
</tr>
<tr>
<td>n-Hexadecane</td>
<td>27.6</td>
</tr>
</tbody>
</table>

Table 1  Surface tension test liquids

Fig. 4 Pin wear on disks with bonded Fomblin Z-dol 2000 lubricant

Fig. 5 Pin wear on disks with bonded Fomblin Z-tetraol 2000 lubricant

Fig. 6 Critical surface tension on disks with bonded Fomblin Z-dol 2000 lubricant

Fig. 7 Critical surface tension on disks with bonded Fomblin Z-tetraol 2000 lubricant
in bonded lubricant thickness. The pin wear curve in Fig. 9 looks very simple as the critical surface tension on a disk after heat treatment around 9.5 Å was smaller than that on a disk after UV irradiation. We conclude that the lubricant coverage ratio on heat treated Z-tetraol lubricated disks must be larger than that on UV irradiated disk.

All the data in Figs. 8 and 9 are summarized in Fig. 10. Data points appear to be in a single curve except for the low wear data on the 300 s UV irradiated Z-dol disk. Differences between lubricants (Z-dol and Z-tetraol), and their treatments appear to be largely explained by the difference in critical surface tension (the sliding condition of the exceptional case will be discussed later). As critical surface tension is affected by the lubricant coverage on disk surfaces, we consider that a lubricant coverage increase is necessary to reduce pin wear.

Next, the contact conditions during wear tests were investigated. Contact conditions at the end of wear tests on disks with UV irradiation are shown in Fig. 11. Flat

wear circles are seen at the contact points in all the photos. Small liquid (lubricant) droplets were also found on some of the disks. They are very small compared to those found on disks with both bonded and mobile
lubricants shown in reference 9; it is considered that the lack of lubricant droplets on pin surfaces reflects the immobility of bonded lubricant. In photos of UV irradiation at 300 s (Fig. 11 (d)) dark debris could be found around contact points. In Fig. 2, we saw that bonded lubricant thickness decreased from 300 s UV irradiation time and that the dark debris may be the result of lubricant degradation due to UV irradiation over a longer-time. This condition corresponded to the low wear condition discussed earlier in Fig. 10. The reason was not clear but the dark wear debris could result in low wear in the disk condition.

Contact conditions at the end of wear tests on disks with heat treatment are shown in Fig. 12. The bonded lubricant thicknesses on HT 0 s disks were larger than those on UV 0 s disks in Fig. 11, because the initial dip-coated thicknesses were larger for HT disks. Flat wear circles were also found in all the photos. In the photos on heat treated Z-tetraol lubricated disks (e - h), large lubricant droplets were clearly identifiable. Lubricant droplet in Fig. 12 (c) indicates that bonded lubricant can also be removed on Z-dol lubricated disks, though the amount was smaller than that on Z-tetraol lubricated disks. As all test disks were prepared with solvent rinsing to remove mobile lubricant, the photos show that so called “bonded lubricant” could be removed by mechanical sliding. “Bonded lubricant” is thus not necessarily fixed on the disk surface while sliding. We consider that the difference in lubricant droplet volume on the slider should be an indicator of differences in lubricant bonding mechanisms on disk surfaces.

The differences in the amount of wear and the critical surface tension between UV irradiated and heat treated Z-tetraol lubricated disks at around 9.5 Å can be found in Fig. 11 (g) and Fig. 12 (e). The amount of lubricant droplets in the latter photo is larger than that of the former. From past head-disk-interface durability studies, it has been argued that mobile lubricants on disk surfaces prevent disk/head damage by replenishing lubricant removed by head/pin sliding 14). The amount of lubricant on pin surfaces should indicate the replenishing characteristics of lubricant film on disk surfaces, and we consider this must be the reason for smaller wear. This shows that tribological characteristics can be different on disks with the same lubricant thickness, but with different after-treatments.

4. Summary

Pin-on-disk wear tests and surface tension measurements were performed on disks with only bonded lubricant. Results are summarized as follows.

(1) Pin-wear and critical surface tension decreased with the increase in bonded lubricant thickness. It was found that the smaller the critical surface tension, the lower the pin wear amount.

(2) On Fomblin Z-tetraol lubricated disks, pin wear was smaller on heat treated disks than that on UV irradiated disks at around 9.5 Å thickness. This corresponded to the lower surface tension on heat treated disks.

(3) Lubricant droplets were found in photos on disks with only bonded lubricant. This shows that bonded lubricant can be removed by mechanical sliding.

(4) The amount of lubricant on sliders tested on disks with heat treated lubricant was larger than those on disks with UV irradiated disks. Lubricant bonding mechanisms would be different in these treatments. Further analyses are necessary to understand the detailed lubricant bonding characteristics under different treatments.

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6. References


