An ionic liquid (IL)-based media lube for Hard Disc Drives (HDDs)

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I. Introduction

With the continuous need for higher HDD storage capacity, reduced head-media spacing (HMS) is required. A lubricant nanofilm with lower thickness and/or higher fly clearance can provide valuable space to further reduce HMS. Meanwhile, heat-assisted magnetic recording (HAMR), which uses momentary laser heating to help increase the areal density, has been developed and identified as the next-generation HDD technology.[1] However, current state-of-the-art lubricants, i.e., perfluoropolyether (PFPE), are not thermally stable for HAMR, which is a serious concern for long-term reliability. Moreover, the minimum lubricant thickness of PFPE is limited by their polymeric nature, i.e., the radius of gyration (R_g), and difficult to be further reduced. Notably, ILs, on the other hand, are promising as the next-generation media lubricant due to their high thermal stability, nonvolatility, and small size of ion pairs. Indeed, some ILs have recently been evaluated as the candidates of media lubricant in HDDs.[14-17] However, high surface tension and low bonded ratio have been shown to be the major challenges. Here, we report our design, synthesis, and characterizations of a novel nanometer-thick IL media lubricant that contains abundant fluorinated segments and a hydroxyl functional endgroup. The testing results have demonstrated the advantage of the IL as media lubricant with respect to PFPE lubricant.

II. RESULTS & DISCUSSIONS

A. IL Synthesis & Characterizations

The chemical structure of the novel IL lube, i.e., HFIL-OH, is shown in Figure 1a. HFIL-OH are obtained through a two-step synthesis.[x] The TGA results (Figure 1b) show that the weight loss starts at ~350 °C for HFIL-OH, compared to ~150 °C for PFPE Ztetraol The higher thermal stability of HFIL-OH can be attributed to the strong electrostatic interactions between the IL ions, the aromatic cation, and the highly fluorinated structure. As shown in Figure 1c, the pendant drop testing shows that the surface tension of HFIL-OH is only ~18.2 mN/m, which is significantly lower than the surface tensions of PFPE Ztetraol and the commercially available fluorinated IL [Bmim][FAP]. The lower surface tension of the HFIL-OH can be attributed to the highly fluorinated components in the cation and anion of HFIL-OH since the low polarizability of C–F bonds results in weak intermolecular forces and consequently low surface tension.

HFIL-OH nanofilms with various thicknesses are applied on the COC of the media by dipcoating, widely used in the HDD industry, from solutions of various concentrations, and the average nanofilm thicknesses measured by ellipsometry are shown in Figure 1d. A layer of lubricant with a thickness of ~0.4-0.5 nm stays on COC for each HFIL-OH nanofilm after washing with Vertrel XF, suggesting that HFIL-OH molecules bond to the polar sites on the COC surface via hydrogen bonding, similar to the bonding of PFPEs.

The monolayer (ML) thickness of the lubricant molecules is the key parameter impacting the minimum thickness of the lubricant nanofilm. It has been established previously, when the film thickness exceeds the ML thickness, there is a sharp increase in surface roughness as dewetting occurs. Therefore, the ML thickness can be determined based on the change in the root mean square (RMS) surface roughness with the nanofilm thickness.[14,15] Figure 1e shows the AFM RMS surface roughness results for the HFIL-OH nanofilms with various thicknesses on COC, with the surface roughness results of PFPE Ztetraol as control. The ML thickness of HFIL-OH has been determined to be ~0.75 nm.

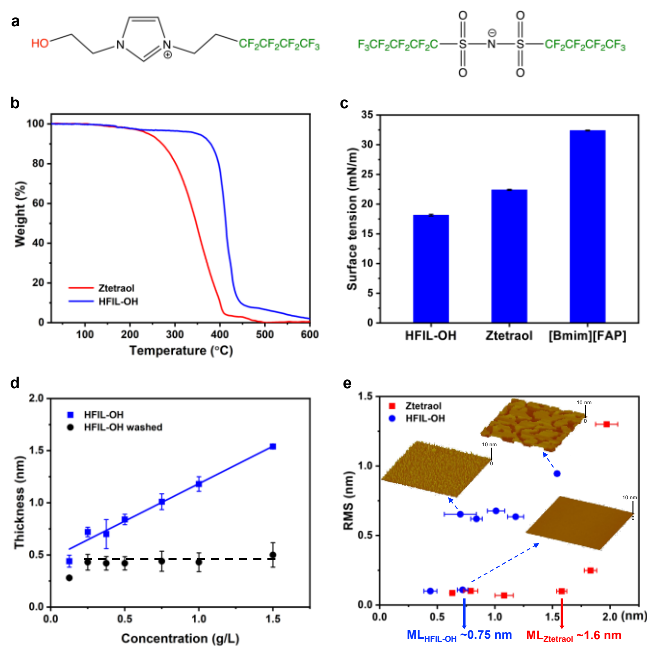

Fig. 1. Characterization of HFIL-OH. (a) Chemical structure of HFIL-OH. (b) TGA results of bulk HFIL-OH with Ztetraol as control. (c) Surface tension of HFIL-OH at RT with Ztetraol and [Bmim][FAP] as control. (d) Average thicknesses of HFIL-OH nanofilms on COC fabricated from various concentrations before and after Vertrel XF washing. (e) Surface roughness results of HFIL-OH nanofilms on COC. The insets are representative AFM images of the HFIL-OH nanofilms at the scan areas of 10 µm by 10 µm.

B. Component-level testing

The industry-level head-disk interface (HDI) tribology performances of HFIL-OH lubricant on rigid perpendicular recording magnetic disks (Figure 2a) have been tested, and the Seagate production disks with PFPE ($M_n \approx 2000$ g/mol) lubricant are used as references. The thermal stability of the thin-film HFIL-OH lubricant is examined by baking the lubricated disks at 150 °C for 2 hours. As shown in Figure 2b, HFIL-OH has significantly better thermal stability, with a 2.4% thermal loss compared with an 8.0% thermal loss for the reference disk, which is in line with the bulk TGA results. Here, the thickness of the HFIL-OH lubricant film on disk relative to that of the reference disk is determined by dividing the mean bit error rate (BER) difference between the HFIL-OH and the reference disks by the mean clearance sensitivity in the read/write-based spin-stand recording tests. The results in Figure 2c show that the tested HFIL-OH lubricant film is only ~0.35 Å thicker than that of the reference, indicating the thickness of HFIL-OH and PFPE reference are comparable. The fly clearance (i.e., touchdown height) is assessed by the spin-stand clearance tests with an embedded contact sensor to detect the head touchdown, and the results in Figure 3c indicate that HFIL-OH has a 2.0 Å higher clearance than the reference. The HFIL-OH molecules closely pack on the disk surface in ion layers because of the hydrogen bonding between COC's NH_2 groups and cations' OH groups and the strong electrostatic cation-anion association. Since the strong packing in the IL nanofilm is unlikely to be perturbed by the approaching flying head, there is a higher clearance for the head to fly closer to the media surface. In contrast, the PFPE reference lubricant has lower fly clearance, although the relative thickness is comparable to the HFIL-OH lubricant. This is because the polymeric backbone takes the random coil conformation. When the flying head approaches the media and the PFPE lubricant nanofilm, the Van der Waals force between the head and the PFPE backbone deform the flexible polymer towards the flying head, leading to lower clearance.[27] Therefore, HFIL-OH has the fly clearance advantage over PFPE, which provides valuable space to further scale down HMS. Meanwhile, the lower surface tension of HFIL-OH could also contribute to the higher fly clearance since lower surface tension results in lower head-lubricant interaction, i.e., Van der Waals force.

The friction coefficient results obtained from the pin-on-disk tests show that the HFIL-OH lubricant has a 12% higher friction than the PFPE reference, as shown in Figure 3d, indicating a slightly lower but comparable lubricity. The head burnish results (Figure 3d) based on the spin-stand tests show that the HFIL-OH lubricant has a comparable head wear performance to the reference, albeit with somewhat higher variations. Moreover, the HDI wear durability performance is assessed by the spin-stand tests, and the results in Figure 2d show that the durability performance of the HFIL-OH lubricant is slightly, i.e., 12%, worse than that of the PFPE reference. Overall, the HFIL-OH lubricant shows good tribology and durability performance.

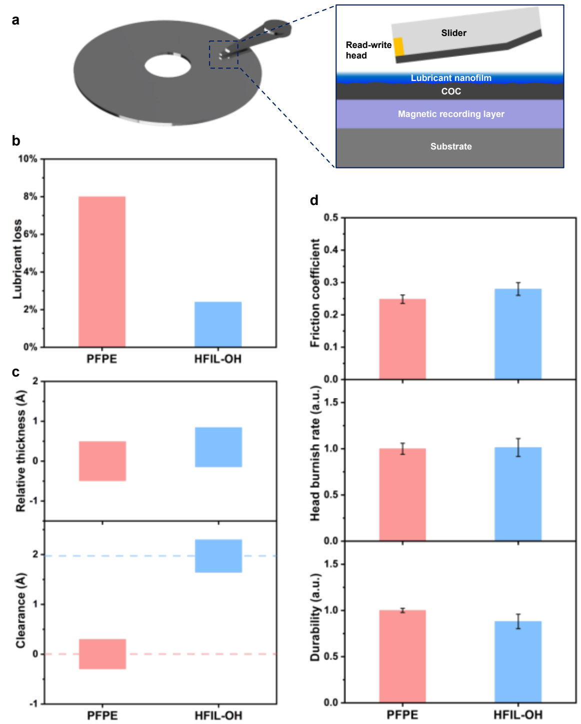

Fig. 2. Component-level testing of the HFIL-OH lubricated disks with the PFPE lubricated production disks as references. (a) HDI components. (b) On-disk lubricant loss after baking at 150 °C for 2 hours. (c) Relative lubricant film thickness measurement based on spin-stand recording tests and clearance performance based on the spin-stand clearance tests. (d) Friction coefficient results based on the pin-on-disk test, head burnish rate results based on the head wear performance tests, and HDI wear durability results based on the spin-stand tests.

C. Conclusion

In summary, a novel IL media lubricant for HDDs has been designed, synthesized, and characterized. Both lab-level and industry-level testing suggest that the IL lubricant has higher thermal stability and higher fly clearance than the state-of-the-art PFPE lubricant. Meanwhile, the IL lubricant also shows good lubricity and durability, which are comparable to the PFPE lubricant. This work has established the novel IL as the next-generation media lubricant for hard disk drives.

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