Microsyst Technol (2011) 17:1051–1056
DOI 10.1007/s00542-011-1291-1

TECHNICAL PAPER

Humidity effect on head-disk clearance

Yuichi Aoki · Kenichiro Takahashi ·
Jianhua Li · Junguo Xu · Yoshihiko Ooeda

Received: 31 August 2010 / Accepted: 31 March 2011 / Published online: 21 April 2011

Abstract The mechanism of head-disk-clearance change due to a humidity effect was investigated experimentally. The head-disk clearance was measured by moving the head elements towards the disk by thermal flying-height-control technology until the head touched the disk while monitoring them with an acoustic-emission sensor in an environmentally controlled component tester. Measured clearance change from 3% RH to 80% RH reached about −0.6 nm at 25°C and about −1.6 nm at 60°C. Head-disk clearance change caused by humidity was classified as the slider-flying-height change and disk-touch-down-height (TDH) change to clarify the mechanism of the clearance change. Slider FH change was dominated by absolute humidity rather than relative humidity. On the other hand, the humidity effect on disk TDH change was classified as a "water-film effect" and a "lubricant-mogul effect", which both depend on relative humidity. Both effects caused clearance change of about 0.4 nm for lubricant A, which is a lubricant with two hydroxyl functional groups at the end of the main chain. These effects were assumed to be caused by water adsorption onto the surface of lubricant. Reduction of the number of free hydroxyl groups which attract water molecules could suppress the disk TDH change related to the humidity effect.

Y. Aoki (✉) · K. Takahashi · J. Li · J. Xu
Mechanical Engineering Research Laboratory, Hitachi, Ltd, 1 Kirihara, Fujisawa, Kanagawa 252-0888, Japan
e-mail: yuichi.aoki.jb@hitachi.com

Y. Ooeda
Hitachi Global Storage Technologies Japan, Ltd, 1 Kirihara, Fujisawa, Kanagawa 252-0888, Japan

1 Introduction

To increase areal recording density of hard disk drives (HDDs), the magnetic spacing between the head and magnetic disk must be reduced. At the same time, to accommodate the decrease in magnetic spacing, the head-disk clearance must also be reduced. The clearance requirement for a recording density of 1 Tb/in^2 is about 1 nm (Wood 2000). Thermal flying-height-control (TFC) technology has been applied in recent HDDs to move the head elements closer to the disk (Kurita et al. 2005). However, flying-height (FH) must be controlled properly to keep a constant clearance between the head and disk, because head-disk contact results in head degradation due to head wear. Such failures especially occur at high temperature and high humidity because of clearance change (Tyndall 2008; Strom et al. 2007). To ensure stable flying of the slider, the clearance changes under different environmental conditions need to be understood. The authors have therefore focused on studying the effects of humidity on the clearance.

It is understood that clearance drop is largely caused by changes in FH of the slider and disk touch-down-height (TDH) (Sakane et al. 2006). At high humidity, a slider generally loses its FH owing to condensation of water vapor; consequently, the pressure drops in the air bearing (Kirpekar and Ruiz 2009). On the other hand, dependency of disk TDH on humidity has not been clarified yet. Humidity effects on clearance have not been sufficiently evaluated quantitatively nor has the mechanism of the clearance change been sufficiently analyzed. In the experiments performed in the present study, the effects of humidity on clearance were investigated quantitatively by using an environmentally controlled component tester.

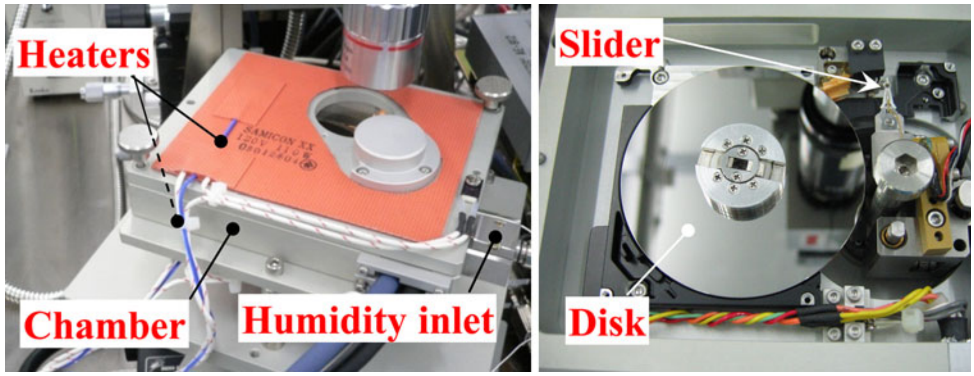

Fig. 1 Environmentally controlled component tester

2 Method for evaluating clearance

The head-disk clearance was measured by moving the head elements towards the disk by TFC technology until the head touched the disk, namely, head-disk touch-down (TD), while monitoring them with an acoustic-emission (AE) sensor. The clearance was determined from the protrusion length of the head elements calculated from the TFC heater power at the TD with the conversion factor estimated by magnetic spacing. The clearance measurements were carried out in an environmentally controlled component tester (shown in Fig. 1).

A component tester is in a chamber which is covered with heaters to control the inside temperature and has a humidity inlet from humid air supply to control the inside humidity. The temperature and humidity were controlled with a sensor inside chamber.

The dependence of clearance on humidity was evaluated by measuring clearance change due to RH change. The relative humidity was varied from 3 to 80% RH at 25 and 60°C. The tested disk lubricants, named lubricant A and lubricant B, consist of a perfluoropolyether (PFPE) main chain structure with two hydroxyl functional groups and four hydroxyl functional groups, respectively. The lubricant thickness, which was measured by FTIR, was about 1.1 nm for lubricant A and from 1.2 to 1.5 nm for lubricant B. Lubricant B was tested to evaluate the effect of free lubricant thickness on the clearance.

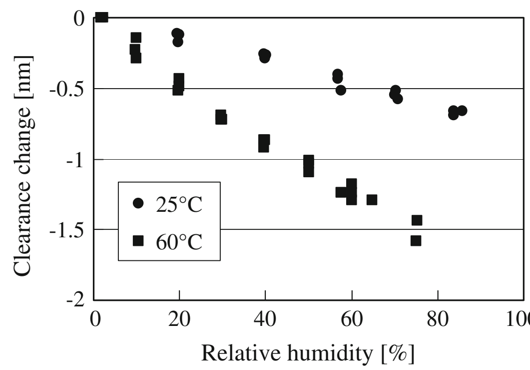

Fig. 2 Results of clearance change as a function of relative humidity

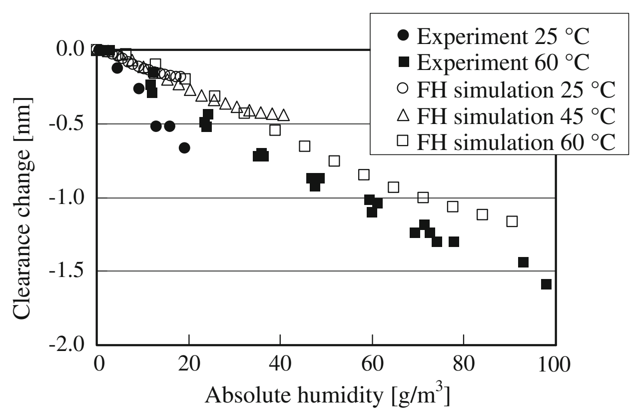

Fig. 3 Results of measured clearance change and simulated flying-height change as a function of absolute humidity

3 Slider-flying-height-change

Figure 2 shows the measurement of clearance change at 25 and 60°C for lubricant A as a function of relative humidity. The clearance was measured from 3% RH to approximately 80% RH. Each clearance changes, or drop, hereafter, represents the difference from the measured clearance at 3% RH. The clearance drop reached about 1.5 nm at 60°C and 0.6 nm at 25°C. The slope of clearance drop at 60°C was approximately 2.5 times larger than that at 25°C.

Figure 3 shows measured clearance change and simulated slider FH change re-plotted as a function of absolute humidity. The FH simulation—based on a water-condensation model (Kirpekar and Ruiz 2009)—took the humidity effect into consideration when RH was varied from 0 to 80% at 25 and 60°C. The measurement and simulation results for both 25 and 60°C can be basically represented as a linear relationship to absolute humidity. This result indicates that the clearance change caused by slider FH change is mainly dominated by absolute humidity rather than relative humidity. However, there is a notable difference between the measurement and simulation results. The measured clearance change is relatively larger than the simulated FH change, especially for 25°C at which FH drop caused by water vapor condensation is small. Accordingly, change in disk touch-down-height as another cause of clearance change was focused on in the rest of this study.

4 Disk-touch-down-height change

4.1 Water-film effect

Figure 4 shows the detailed measured clearance change at 25°C and simulated FH change of the slider. According to the measurement results, the clearance decreased as relative humidity increased, and it decreased by about 0.5 nm (on average) at 80% RH. However, the numerically simulated FH drop is only about 0.1 nm. A sub-nanometer-thick water-film covering the disk lubricant at high humidity is considered to influence the head-disk interaction and disk TDH (Tagawa et al. 2010). The thickness was estimated to be about 0.3 nm at a relative humidity (RH) of 80% (Karis and Tawakkul 2003). These results indicate that the rest of the clearance change, namely, 0.4 nm, was caused by increase of disk TDH. The reason for the disk TDH increase is believed to be related to the water-film absorbed on the disk surface. Figure 5 shows a schematic of the assumed mechanism of disk TDH change. The dotted line represents the initial head-disk TD level. It is assumed that early head-disk contact could be induced by the head-disk interaction such as a water meniscus generation caused by adsorbed water. Consequently, the disk TDH is raised to the dashed line level. The clearance change is defined as the "water-film effect".

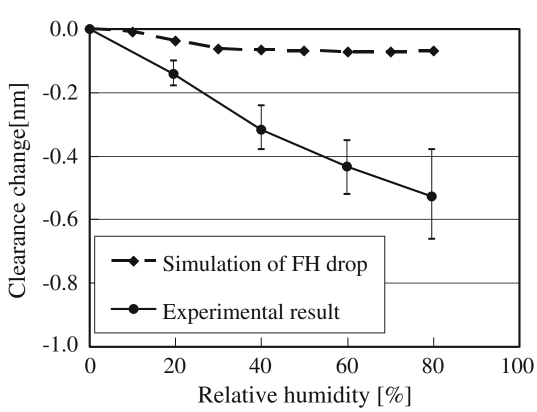

Fig. 4 Comparison with measured and simulated clearance change at 25°C

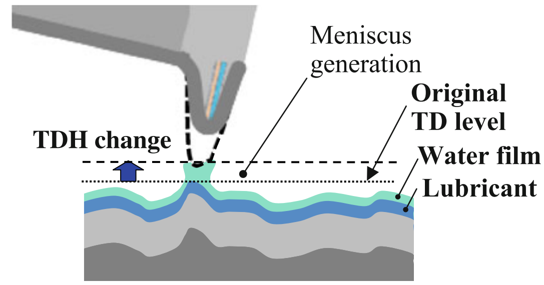

Fig. 5 Schematic of a possible mechanism of disk TDH change caused by water-film effect

4.2 Lubricant-mogul effect

The adsorbed water-film seems to be strongly related to the head-disk interaction. Intermittent interaction between the lubricant and slider is inevitable when clearance is at the regime around 1 nm. It is thus important to understand what is caused by the interaction and how it depends on humidity. Accordingly, a touch-down (TD) cycle test was performed at 3, 40, and 80% RH to simulate intermittent interaction between the head and disk and to determine the effect of humidity on the head-disk clearance. Figure 6a and b show typical results of the TD cycle tests at 80 and 3% RH, respectively. The clearance change represents the difference from the clearance at 3% RH. The clearance change at first TD, in Fig. 6a, thus indicates the summation of the FH change and the water-film effect at 80% RH. (Note that the clearance measured in Fig. 2 represents the clearance at fist TD.)

According to the result, the clearance gradually decreased in accordance with TD counts at 80% RH, while it did not decrease at 3% RH. The decrease at 80% RH was saturated within 30 TDs. After the TD cycle tests, disk lubricant was observed by an optical surface-analyzer (OSA). Figure 7a and b show the observations of disk lubricant after the test at 80 and 3% RH, respectively. The disk after the test at 80% RH clearly had a lubricant-mogul on the track where the repetitive TD was performed. On the other hand, the disk after the test at 3% RH showed no lubricant-mogul. The gradual clearance decrease of about 0.4 nm is considered to be caused by the lubricant-mogul. Figure 8 shows a cross-sectional view of a part of the lubricant-mogul line observed at 80% RH. According to the OSA observation results, the height of mogul is about 0.1–0.2 nm, which is slightly smaller than the clearance decrease. The difference could be caused by the recovery of lubricant after the test. These results indicate that the head-disk interaction under high humidity forms a lubricant-mogul that causes the clearance decrease observed in Fig. 6a. Figure 9 shows a schematic of the assumed mechanism of TDH change caused by the lubricant-mogul. It is assumed that the contact between the slider and the

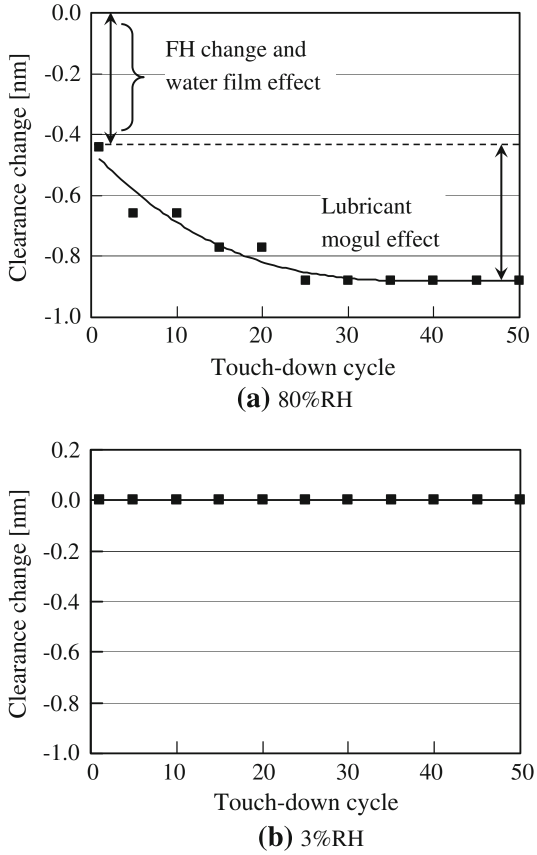

Fig. 6 Typical results of disk touch-down cycle tests at **a** 80%RH and **b** 3%RH

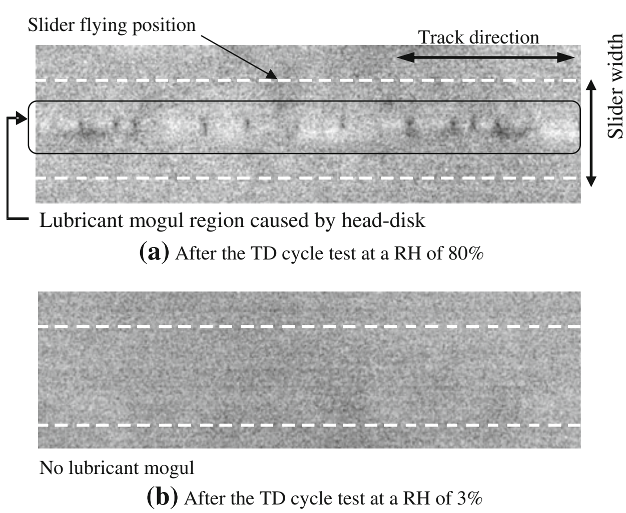

Fig. 7 Optical-surface-analyzer images of disk lubricant after touch-down cycle test at 3% RH and 80% RH

lubricant-mogul causes early head-disk contact. The lubricant-mogul raises the disk TDH to a higher level represented by the dashed line than the original TD level. The gradual clearance decrease in the early stage of the TD cycle is therefore defined as the "lubricant-mogul effect",

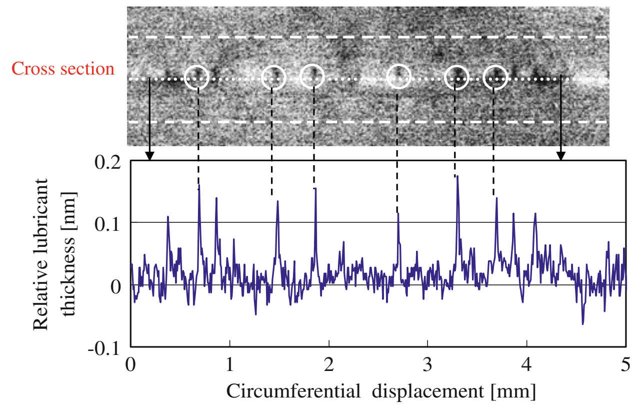

Fig. 8 Cross-sectional view on lubricant-mogul line

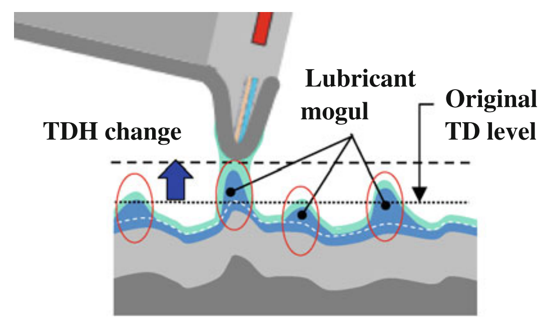

Fig. 9 Schematic of a possible mechanism of disk TDH change caused by lubricant-mogul effect

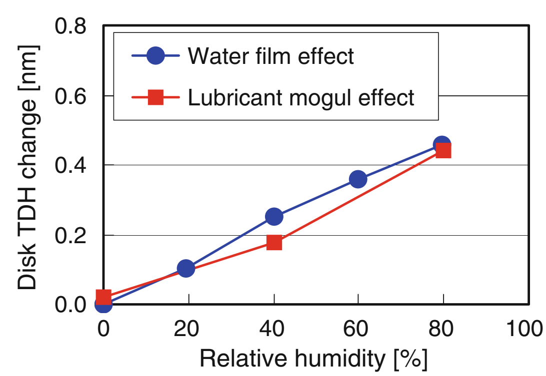

Fig. 10 Summary of disk TDH change at each relative humidity in TD cycle test

which is strongly related to the relative humidity. The mogul may be caused by an increase of mobile fraction of lubricant due to the interaction of hydroxyl functional groups with the water molecules absorbed on the lubricant.

Figure 10 summarizes the dependency of disk TDH on humidity, named water-film effect and lubricant-mogul effect as the function of RH. Both effects seem to increase linearly as RH increases. In other words, the amount of the absorbed water molecular, which is nearly proportional to RH (Karis and Tawakkul 2003), influences the interaction between head and disk lubricant.

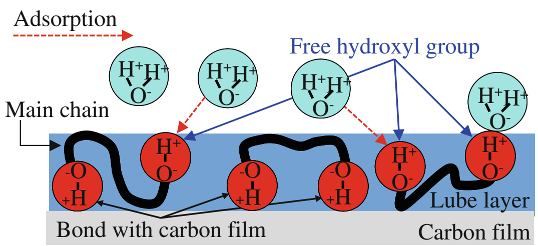

Fig. 11 Mechanism of adsorption of water molecules on lubricant

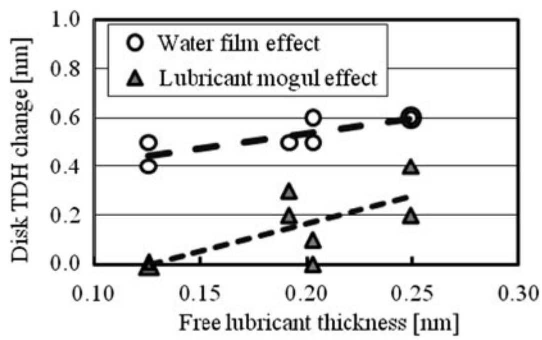

Fig. 12 Effect of free lubricant thickness on disk TDH change in TD cycle test at 80%RH

Figure 11 shows a possible mechanism of adsorption of water molecules on the disk lubricant. A magnetic disk is basically coated with a carbon film and lubricant. When a water molecule is adsorbed on the disk lubricant, the free OH functional groups of the lubricant that do not bond with the carbon film attract the molecule because of its strong polarity. In the rest of this study, the effects of free OH functional groups on the disk TDH change due to humidity were thus investigated.

4.3 Effect of free hydroxyl of lubricant

To determine the effect of a free OH functional group on the disk TDH change caused by humidity, lubricant B was tested. The amount of free OH functional groups was estimated from the bond ratio and film thickness of the lubricant as free lubricant thickness, which was calculated from the following equation.

$$\text{Free lubricant thickness} = (100\% - \text{Bond ratio}) \times \text{Disk lubricant thickness}$$

The film thickness was from 1.5 to 1.2 nm and the bond ratio, which was controlled in baking process, was from approximately 83–89%. The free lubricant thickness was calculated to be from 0.12 to 0.25 nm. Figure 12 shows the results of the TD cycle test at 80% RH; that is, it represents disk TDH changes caused by the water-film and lubricant-mogul effects as a function of free lubricant thickness. The lubricant with smaller free lubricant thickness showed less disk TDH change for both effects. The results could be considered to be less influenced by total lubricant thickness in terms of TDH change, while it influences TDH itself. Figure 13a and b show the OSA observation results of disk lubricant in the case of free lubricant thickness of 0.12 and 0.25 nm, respectively. The disk with 0.25-nm free lubricant thickness clearly showed a lot of lubricant-moguls after the test. On the other hand, the disk with 0.12-nm free lubricant thickness has no lubricant-moguls after the test. These results show that reducing the number of free hydroxyl groups suppresses the disk TDH change caused by humidity.

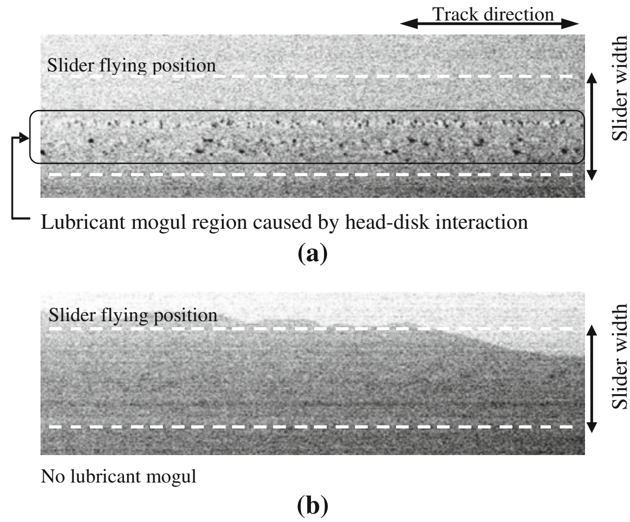

Fig. 13 Optical-surface-analyzer images of disk lubricant after touch-down cycle test at 80% RH for free lubricant thickness of **a** 0.25 and **b** 0.12 nm

5 Conclusion

The effects of humidity on head-disk clearance were investigated quantitatively with an environmentally controlled component tester. Environmental humidity is strongly related to the clearance change caused by FH change of a slider and disk TDH change. Slider FH change was mainly dominated by absolute humidity rather than relative humidity. On the other hand, the humidity effect on disk TDH change was classified as a "water-film effect" and a "lubricant-mogul effect", which both likely depend on relative humidity. Both effects caused clearance changes of about 0.4 nm for lubricant A. Reduction of the number of free hydroxyl groups that attract water molecules could suppress the disk TDH change related to humidity.

Acknowledgments The authors would like to thank Dr. Hidekazu Kohira, Mr. Kenji Kuroki, and Mr. Akira Kato of Hitachi Global Storage Technologies Japan, Ltd for generous support.

References

Karis TE, Tawakkul MA (2003) Water adsorption and friction on thin film magnetic recording disks. Tribol Trans 46(3):469–478

Kirpekar S, Ruiz O (2009) Computing the performance of an air bearing in humid conditions. Appl Phys Lett 94:234103

Kurita M, Xu J, Tokuyama M, Saegusa S, Maruyama Y, Fukui H (2005) Simulation of thermal protrusions on magnetic head elements. JSME Int J C 48(3):359–362

Sakane Y, Wakabayashi A, Li L, Kasai PH (2006) Effect of molecular structure of PFPE lubricant on interaction at HDI in near-contact operation. IEEE Trans Magn 42(10):2501–2503

Strom BD, Lee SC, Tyndall GW, Khurshudov A (2007) Hard disk drive reliability modeling and failure prediction. IEEE Trans Magn 43(9):3676–3684

Tagawa N, Hatakeyama J, Mori A (2010) Effect of humidity on the interactions between probes and ultra-thin liquid lubricant films in an environmentally controlled atomic force microscope. Microsyst Technol 16(1–2):287–292

Tyndall GW (2008) Role of the head disk interface in HDD. Reliability IDEMA Technical Symposium, Tokyo

Wood R (2000) The feasibility of magnetic recording at 1 terabit per square inch. IEEE Trans Magn 36(1):36–42