Improvement of Glass Disk Durability and Sensitivity in Flying Height Measurement

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Abstract

In hard disks, flying height or the spacing between the read/write head and the magnetic disk has been greatly decreased to less than 10 nm in order to achieve high-density magnetic storage. Generally, the fly height is measured in a flying height tester using the principle of light interferometry observed through a transparent glass disk. This specially manufactured glass disk is extremely flat and smooth which costs $300-500 each. Due to the intermittent contact between the head and glass disk, this characterization process easily causes the disk wear and scratches. In this paper, we employed a hard coating material of diamond-like-carbon (DLC) layer as a protective layer over the commercial glass disk to increase its wear resistance resulting in disk lifetime improvement. In the fabrication process, silicon adhesion layer and DLC protective layer are deposited on the commercial glass disk by ion beam deposition. According to a wear test performed in a triboindentor, the wear depths measured from the fabricated disks coated with 15-nm thick DLC were 5-7 nm whereas that of a bare glass disk was 62 nm. Furthermore, we investigated the sensitivity of the flying height measurement using the fabricated disks. The analysis results suggested that the sensitivity of flying height measurement using the fabricated disks improved by 341% as compared to that of the measurement using a commercial glass disk. This approach gives a great promise to the disk lifetime extension as well as the significant improvement of the sensitivity in flying height measurement.

Keywords: glass disk, flying height, hard coating materials, diamond-like-carbon, sensitivity

1. Introduction

In hard disk drive, the flying height or the gap between slider and magnetic disk is one of the key parameters. The ability to read/write data strictly depends on this parameter. Currently, the flying height is decreased to less than 10 nm to achieve high-density magnetic storage.[1-7]. Generally, flying height is measured by flying height tester using the principle of light interferometry observed through a glass disk as shown in Fig. 1. This specially manufactured glass disk is extremely flat and smooth which costs $300-500 each. Due to the intermittent gap between the head and glass disk, this characterization process easily causes the disk wear and scratches which costs as much as $80k annually on glass disks (in Western Digital (Thailand)). Furthermore, when the flying height is near contact, the conventional technique using intensity interferometry suffers from the low sensitivity in the flying height measurement. Here, we aim to improve the durability of the glass disk to extend its lifetime as well as improve the sensitivity in the flying height measurement using the disk with hard coating material.

In this paper, a hard coating material of diamond-like-carbon (DLC) is employed as the protective layer to improve the durability of glass disks resulting in the disk lifetime improvement. Wear tests [8-14] were performed to investigate the durability of fabricated disks in comparison to a commercial glass disk. According to wear test results, the wear depth on the fabricated disk (15-nm thick DLC) is approximately one-tenth of that on a glass disk. Furthermore, the sensitivity of flying height measurement using the fabricated disk was investigated. It was found that the sensitivity of flying height measurement can be improved up to 341% as compared with the measurement using a conventional glass disk.

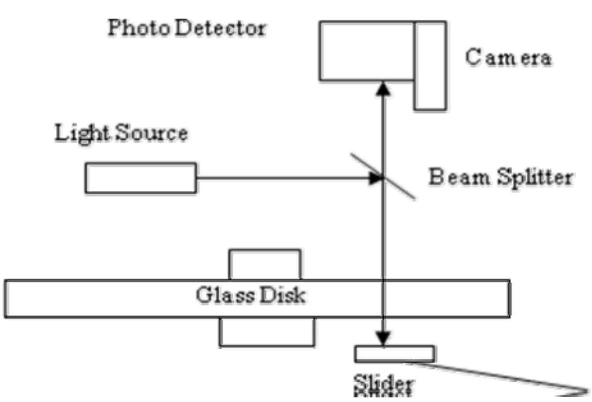

Fig. 1 Schematic diagram of flying height tester

2. Sample preparation

Silicon adhesion layer and DLC protective layer were deposited on one side of a commercial glass disk with ion beam deposition. Prior to silicon and DLC depositions, the glass disk was sputter cleaned with argon ion at RF power of 320 W and beam current of 120 mA for 15 minutes. Then, silicon adhesion layer was deposited using 12-cm ion beam source with discharge voltage of 40 V and beam current of 50 mA. Next, DLC layer was deposited with RF power of 320 W and beam current of 100 mA using methane (CH_4) and ethylene (C_2H_4) as precursors of carbon. The flow rates of CH_4 and C_2H_4 were set at 7 and 5.6 sccm, respectively, and the base pressure was 64.6 mTorr. The schematic diagram of the fabricated disk is shown in Fig. 2.

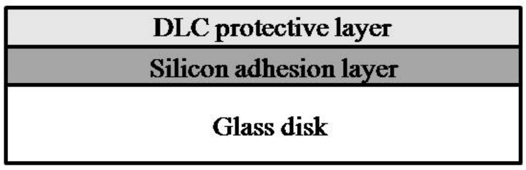

Fig. 2 Schematic diagram of the fabricated disk

The fabricated disks were tested in a flying height tester (DFHT 5, KLA-tencor) to verify that sliders can fly normally on the fabricated disks. The results suggested that the sliders can fly normally on the disks coated with several-nm thick silicon and 10-nm thick DLC. However the disk with thick silicon layer exhibits poor contrast of the pole-tip image. In flying height tester, the position of pole-tip on air bearing surface is used as the reference point for the auto-detection program in order to locate positions on sliders in the flying height measurement as shown in Fig. 3. When the pole-tip contrast is not good, the program is unable to detect the pole-tip position resulting in the measurement failure. Therefore, it is very important to select the optimum silicon thickness which provides good adhesion of the DLC film to the glass disk and also does not deteriorate the pole-tip image in the measurement.

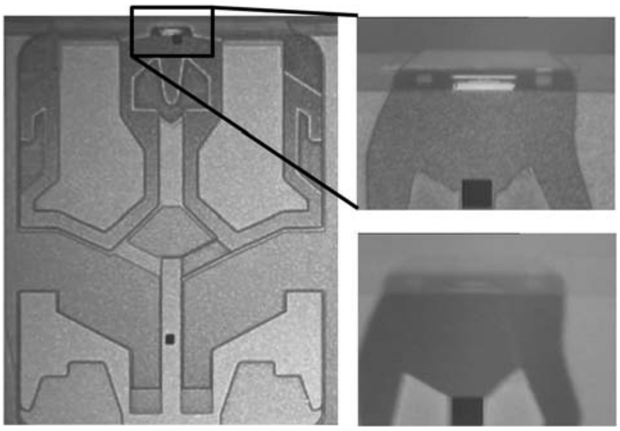

Fig. 3 Position of pole-tip on air-bearing-surface of slider. Pole-tip image captured through a commercial glass disk (Upper right). Pole-tip image captured through a glass disk coated with thick silicon (Lower right).

In order to find the optimum thickness of silicon layer, 5 disks were prepared by coating the glass disks with various silicon thicknesses (1, 3, 5, 7 and 9 nm) while the DLC thickness was fixed at 15 nm for all disks. The durability and pole-tip contrast of all fabricated disks were investigated. Moreover, the sensitivity of flying height measurement in the case of using fabricated disk was also investigated and compared to the case of using a glass disk.

3. Experimental

The contrasts of pole-tip images captured through the fabricated disks were evaluated using the auto-detection program in a flying height tester (DFHT 5, KLA-tencor). The disks through which the program can automatically detect the pole-tip position are desirable.

Disk durability was investigated in wear tests. Wear tests were carried out in a triboindentor (Hysitron, TI-900) using a cube corner diamond tip with the tip radius of 100 nm. The tests were conducted at a scanning size of 3 μm × 3 μm in the reciprocation mode for 1 cycle with the sliding velocity of 7.8 μm/s and the applied load of 60 μN. After the tests were completed, the images of wear profiles were obtained in the AFM mode.

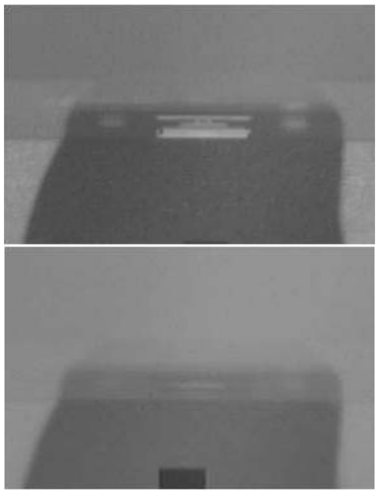

Fig. 4 Pole-tip images captured through the fabricated disk coated with 3-nm thick silicon (Up) and the fabricated disk coated with 9-nm thick silicon (Down).

4. Results and discussion

Fig. 4 shows the pole-tip images captured through the disks coated with 3-nm thick silicon and 9-nm thick silicon, respectively. The disk coated with thinner silicon layer exhibits better contrast. According to the test results, the auto-detection program in the flying height tester can automatically detect the pole-tip position without any fault detection when the silicon thickness is 3 nm or smaller. Hence, the disks coated with the silicon thickness of 1 and 3 nm are qualified in this test.

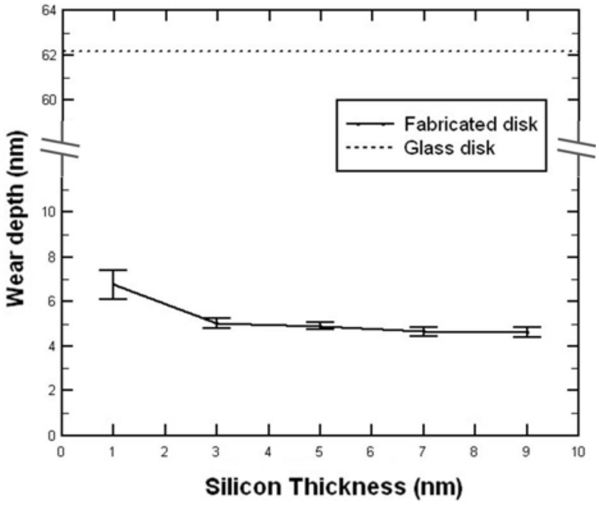

Fig. 5 Wear depths measured on the fabricated disks as a function of silicon thickness. Dot line represents the wear depth of commercial glass disk.

In the wear tests, the wear depths under the applied load of 60 μN on the fabricated disks and the glass disk are compared in Fig. 5. The AFM images of wear profile on the glass disk and the fabricated disk coated with 1-nm thick silicon and 15-nm thick DLC are shown in Fig. 6. The fabricated disk exhibits superior wear resistance to a glass disk. The wear depth decreases considerably from 62.2 nm on the glass disk to 6.76 nm on the disk coated with 1-nm thick silicon and 15-nm thick DLC. The results also suggest that the increment of silicon thickness from 1 to 3 nm can increase the wear resistance whereas the wear depth decreased from 6.8 nm to 5.0 nm. However, there is no significant change in the wear depth when the thickness of silicon is greater than 3 nm. From the above results, 3-nm thick silicon layer is ideal for adhesion purpose while providing clear pole-tip image.

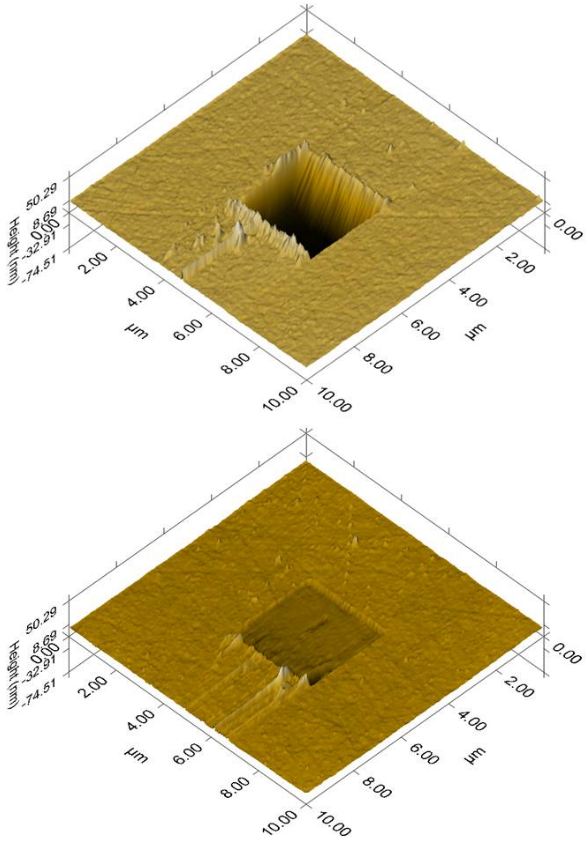

Fig. 6 AFM image of the wear profile on glass disk (Upper) and that on the disk coated with 3-nm thick silicon and 15-nm thick DLC (Lower).

5. Improvement of sensitivity in flying height measurement

The conventional flying height measurement using intensity interferometry faces complexity when the flying height is near contact.[4] This is due to extremely low sensitivity. The sensitivity may be improved by using other measurement techniques [15] or using high sensitivity disks [4]. In this paper, we investigate the sensitivity of flying height measurement using the fabricated disk coated with hard coating materials of silicon and DLC and determine the optimum thicknesses for both layers.

5.1 Principle of flying height measurement

For decades, optical interferometry has been the common method for measuring slider's flying height in hard disk drive industry [1, 2]. The schematic of optical interferometry used in a flying height tester is shown in Fig. 1. These testers simulate the condition in hard disk drive by employing the glass disk instead of magnetic disk. The normal incident beam from light source reflects and interferes at the slider-disk interface then returns to photo detector. The intensity of reflected light varies with the gap between the slider and the disk or flying height. Therefore, the reflected light intensity from the slider-disk interface can be analyzed to estimate the flying height. [2-4, 15]

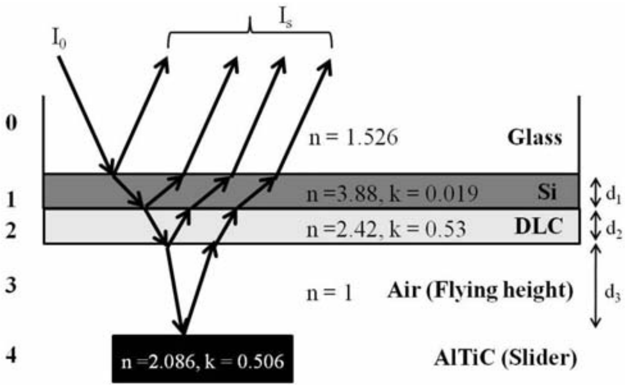

Fig. 7 Model of multi-reflection in flying height measurement using the fabricated disk.

The model of flying height measurement using the disk coated with silicon and DLC is shown in Fig. 7. In this case, the light beam will experience multi-reflection from the slider-disk interface. According to the standard thin-film equation,[16] the intensity of the interfered light reflected from the slider-disk interface can be written as follow:

$$I_s = I_0 \left[\frac{r_{01} + r_{c2} e^{2i\beta_1}}{1 + r_{01} r_{c2} e^{2i\beta_1}} \right]^2 \quad (1)$$

where

$$r_{c2} = \left[\frac{r_{12} + r_{c1} e^{2i\beta_2}}{1 + r_{12} r_{c1} e^{2i\beta_2}} \right], \; r_{c1} = \left[\frac{r_{23} + r_{34} e^{2i\beta_3}}{1 + r_{23} r_{34} e^{2i\beta_3}} \right]$$

$$r_{ij} = \frac{(n_i + ik_i) - (n_j + ik_j)}{(n_i + ik_i) + (n_j + ik_j)}, \qquad \beta_i = 2\pi \left(\frac{d_i}{\lambda}\right) n_i$$

d_1, d_2 and d_3 are silicon thickness, DLC thickness and air gap (flying height), respectively. λ is the light wavelength, r_{ij} is the reflection coefficient of the boundary between medium *i* and medium *j*. *n* and *k* are refractive index and extinction coefficient of each layer, *i* and *j* represent the layer which light travels through and layer which light reflects from. I_0 is the intensity of the light incident to the slider-disk interface.

5.2 Sensitivity in flying height measurement using the fabricated disk

The sensitivity in flying height measurement depends on various parameters such as refractive index of each layer, film thickness of each layer and so on. In this paper, thickness of each film layer was optimized in order to improve the sensitivity in flying height measurement. The sensitivity can be determined as the change of the reflected light intensity associated with the change in flying height.

For example, the sensitivity in flying height measurement can be calculated from the difference of Eq.(1) at flying height (d_3) of 8 nm and 9 nm assuming the real flying height is in this range. Other parameters are given as following: both silicon thickness (d_1) and DLC thickness (d_2) vary from 1 to 100 nm, light wavelength 632.8 nm. As taken from ref.[17], the refractive index of glass, silicon, DLC, air and slider are n_0+ik_0 = 1.526+0i, n_1+ik_1 = 3.88+0.019i, n_2+ik_2 = 2.42+0.53i, n_3+ik_3 = 1+0i and n_4+ik_4 = 2.086+0.506i, respectively.

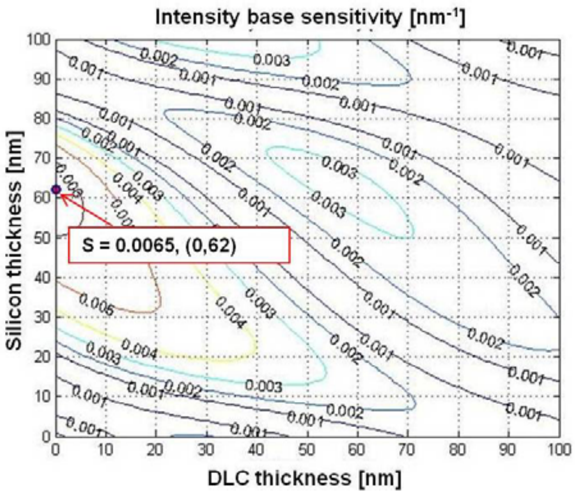

Fig. 8 Intensity based sensitivity as a function of silicon and DLC thickness. The maximum sensitivity (0.0065 nm^{-1}) is at the silicon thickness of 62 nm and the DLC thickness of 0 nm.

Fig. 8 shows the sensitivity in flying height measurement as a function of silicon thickness and DLC thickness from calculation when flying height changes from 8 nm to 9 nm. The results suggested that the measurement using the disk coated with silicon and DLC can significantly improve the sensitivity in flying height measurement as compared to that using a typical glass disk. The highest sensitivity occurs when the silicon thickness is 62 nm and the DLC thickness is 0 nm, where the sensitivity improves from 0.0015 nm^{-1} (a bare glass disk) to 0.0065 nm^{-1} or 341%. In the flying height measurement, the disks are preferred to have high sensitivity as well as high durability. Thus, the disk sensitivity may be slightly sacrificed by adding 10-15 nm of DLC layer in order to improve the durability. It should be noted that the calculation result may vary depending on the real refractive indices of silicon and DLC layers which are subjected to different fabrication process.

6. Conclusions

In this paper, an approach to improve the durability of the glass disk used in flying height tester was proposed. We also show that the fabricated disks can significantly improve the sensitivity of flying height measurement. From the wear test results, the glass disk coated with 3-nm thick silicon and 15-nm thick DLC can reduce the wear depth by 12 times as compared to a bare glass disk. From the sensitivity analysis, it is found that the glass disk coated with silicon and DLC layers can improve the sensitivity of flying height measurement up to 341% in a comparison to a glass disk. This approach gives a great promise to the disk lifetime extension as well as the significant improvement of the sensitivity in flying height measurement.

7. Acknowledgements

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