Development of High-Durability and High-Sensitivity Glass Disk for Flying Height Measurement Process

Korakoch Phetdee, Alongkorn Pimpin and Werayut Srituravanich*

Department of Mechanical Engineering, Faculty of Engineering, Chulalongkorn University, Pathumwan, Bangkok 10330

*werayut.s@chula.ac.th, Tel: 0-2218-6586, Fax: 0-2252-2889

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 to achieve high-density magnetic storage. Generally, the flying height is characterized in a flying height tester by measuring the interfered light from the head/disk interface whereas a transparent glass disk is employed instead of the magnetic disk. This characterization process easily causes the scratches on the glass disk resulting in a limited lifetime of the glass disk. Therefore, the first objective of this work is to improve the disk durability by employing a hard coating material of diamond-like-carbon (DLC) to increase its wear resistance resulting in lifetime improvement [1]. In the wear test, the wear depth on the disk coated with 3-nm thick silicon and 15-nm thick DLC was reduced by 92% as compared to that on the glass disk. In the disk lifetime measurement, the lifetime of the DLC coated disk can be significantly improved by at least 30 times as compared to that of the glass disk [1]. Furthermore, the sensitivity of the flying height measurement can be significantly improved by optimizing the configuration and the thicknesses of the overcoat layers. We demonstrated that the disk coated with 4 layers (silicon1: 1 nm, DLC1: 55 nm, silicon2: 3 nm and DLC2: 25 nm) has drastically increased the sensitivity in the flying height measurement at near contact (flying height: 0-20 nm) by 85% as compared to the measurement result using a commercial glass disk.

***Keywords**:* Glass Disk, Flying Height, Flying Height Tester, Hard Coating, Diamond-like-Carbon

1. Introduction

In hard disk drives, the flying height or the gap between the read/write head and the 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 [2-8]. Generally, flying height is characterized in a flying height tester using the principle of light interferometry observed through a glass disk [4] as schematically shown in Fig. 1. This specially manufactured glass disk is extremely flat and smooth which makes it very expensive ($300-500 each). Due to the intermittent contact between the head and glass disk, this characterization process easily causes the disk wear and scratches. Here, we aim to improve the durability of the glass disk by utilizing a hard coating material of DLC (Diamond-like-carbon) to extent its lifetime which results in a cost reduction in the flying height measurement process. DLC is a hard coating material which can increase the durability and the wear resistance of glass disks leading to a disk lifetime extension.

Furthermore, the most commonly used intensity-based flying height testers have a sensitivity limitation when the flying height is at near contact, as the measurement sensitivity decreases to zero. Thus, this type of flying height testers is not suitable for the measurement of flying heights below 10 nm. As a result, the flying height measurement requires machine upgrade or capital investment. Here, we propose to increase the sensitivity in flying height measurement by optimizing the configuration and the thicknesses of the overcoat layers of the multi-layered disk. The sensitivity improvement has been performed through the theoretical calculation and verified by an experiment.

This paper consists of 2 main parts which are described in chapter 2 and 3. The

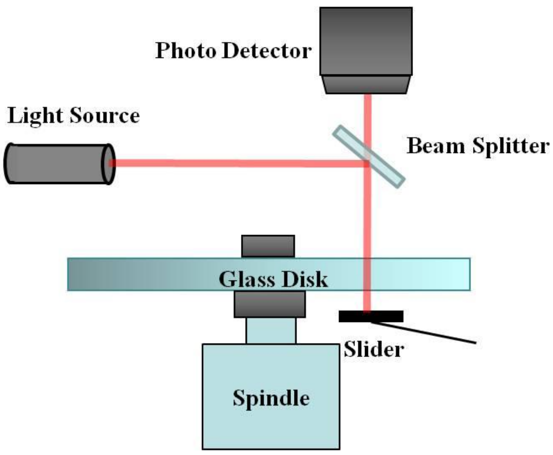

Fig. 1 Schematic diagram of flying height tester

development of high-durability disk for flying height measurement is described in chapter 2. In chapter 3, the development of high-sensitivity disk is described including the theoretical calculation of the measurement sensitivity, disk fabrication and sensitivity measurement. The conclusion of this paper is drawn in chapter 4.

2. The development of high-durability disk

To improve the durability of the glass disk, DLC is employed as protective layer. In the fabrication process, the glass disk was coated by silicon adhesion layer prior to DLC in order to improve the adhesion between the DLC and glass disk. However, it was found that the thickness of silicon degraded the visibility of the pole-tip which used as the reference position in the flying height measurement. Therefore, it is necessary to choose the optimum silicon thickness for the adhesion purpose without degrading the visibility of the pole-tip. To determine the optimum silicon thickness, we carried out wear tests [9-15] to analyze the durability of the DLC coated disks with varied thicknesses of silicon as well as visibility test of the pole-tip image through these disks in the flying height tester. Finally, we investigated the lifetime of the DLC coated disk with the optimum silicon thickness in flying height tester.

2.1 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 The schematic illustration of the glass disk coated with silicon and DLC layers.

The coated disk was tested in the flying height tester to verify the disk durability. The results revealed that the visibility of pole-tip get poorer when the thickness of silicon increased. In flying height testers, the position of the pole-tip as shown in Fig. 3 is used as the reference position and is automatically detected at the beginning of the flying height measurement. If

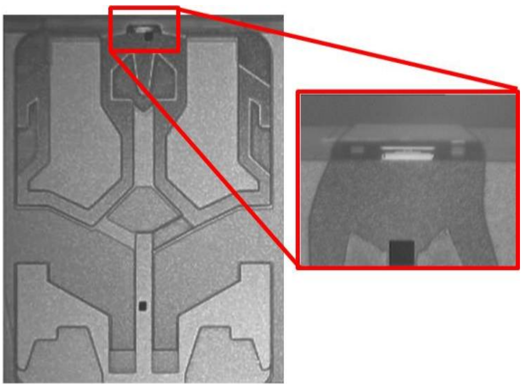

Fig. 3 Position of pole-tip on air-bearing-surface (ABS) of slider.

the disk which is used instead of the glass disk makes the visibility of pole-tip poorer, the auto detection program will not be able to detect the pole-tip position resulting in measurement failure. Therefore, the thickness of silicon has to be selected properly. The thickness should be thick enough to provide a good adhesion but not too thick to cause a problem in finding pole-tip of auto detection program.

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 visibility of all coated disks were investigated. The disk which exhibited the best result from both durability and visibility tests was selected to measure its lifetime compared to the glass disk.

2.2 Experimental

The disks which coated with various silicon thickness (1, 3, 5, 7 and 9 nm) and DLC thickness of 15 nm was investigated in the disk visibility and disk durability aspects. In visibility test, the pole-tip images which captured through the coated disks were evaluated using the auto-detection program in a flying height tester (DFHT 5, KLA-tencor). The disks which yield 100% success rate in the pole-tip detection are qualified. The durability of the disk was characterized by wear test which carried out in triboindentor (Hysistron, 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. Then the test was repeated five times at the difference area of disk surface in order to determine the average wear depth. After the wear test, the images of wear profiles were obtained in the AFM mode.

After the disk visibility test and the disk durability test, the coated disk which exhibited the best wear resistance while providing a clear visibility of pole-tip image was selected and its lifetime was measured in the flying height tester. Generally, wears occur when sliders do not fly properly on the glass disk. These bad sliders can generate a scratch immediately after loading. On the other hand, good sliders can fly without any problems for a long period of time. It is difficult to find identical bad sliders for this measurement. Therefore, good sliders were employed while the flying parameters (i.e. skew angle, linear velocity and z-height) were changed from normal condition to critical condition for accelerating wear on the disks.

The lifetime test was carried out in flying height tester, started with flying slider under normal flying height condition (skew angle: 0°, linear velocity: 14.35 m/s and z-height: 0.7688 mm) for 1 min, then the flying condition was changed to a critical condition (skew angle: -16.44°, linear velocity: 5.31 m/s and z-height: 0.7682 mm) and maintained until scratch or wear appeared on the disk surface. The maximum test duration under the critical flying condition was set at 30 min. The occurrence of scratch or wear on the disk surface was determined from the noticeable debris on the slider surface monitored by an operator via the video monitor. The lifetime of each track was determined from the duration that the slider flies until scratch or wear occurs. The measurements were repeated at new locations using new sliders for 11 runs on the uncoated disk and 5 runs on the coated disk to obtain the average lifetime of both disks.

2.3 Results and discussion

a. Visibility test

Fig. 4a and b show the pole-tip images captured through the disks coated with 3-nm thick silicon and 9-nm thick silicon, respectively. Clearly, the pole-tip image became poorer as the thickness of silicon increased. According to the visibility test results, the auto-detection program in the flying height tester could automatically detect the pole-tip position without any fault detection when the silicon thicknesses were 3 nm or smaller. Hence, the disks coated with the silicon thicknesses of 1 and 3 nm are qualified in this test.

b. Wear test

Fig. 5 shows the comparison of wear depths of the coated disks and glass disk (dotted line). AFM images of wear profiles on the glass disk and the disk coated with 1-nm thick silicon and 15-nm thick DLC are shown in Fig. 6. The wear resistance of DLC coated disks was significantly improved from glass disk. The wear depth decreased drastically from 62.2 nm on glass disk to 6.8 nm on the disk coated with 1-nm thick silicon and 15-nm thick DLC.

The results also suggested that the wear resistance slightly increased with the increment of silicon thickness from 1 to 3 nm while the wear depth decreased from 6.8 to 5.0 nm. However, there is no significant change in the

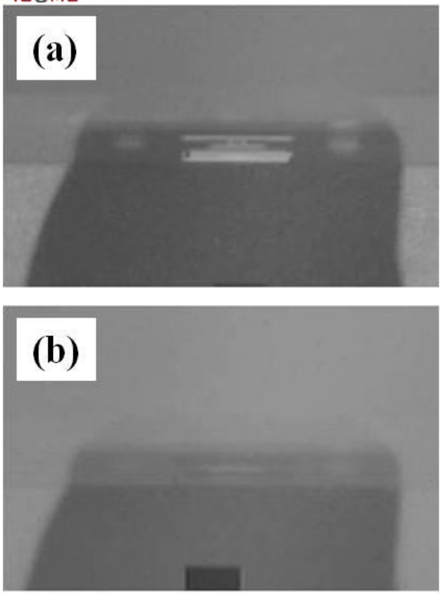

Fig. 4 Pole-tip images captured through the coated disk (a) 3-nm Si/15-nm DLC and (b) 9-nm Si/15-nm DLC

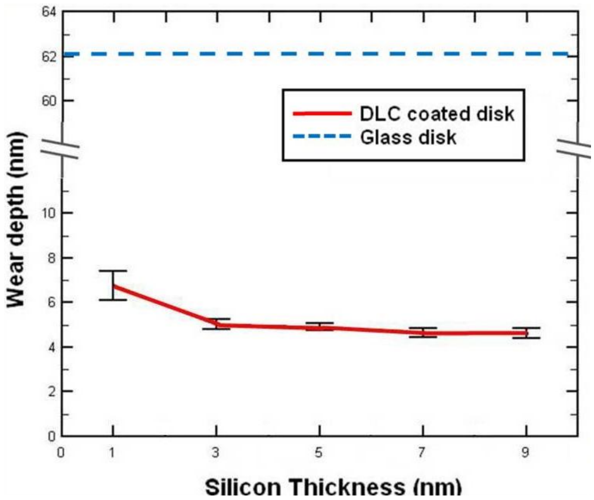

Fig. 5 Average wear depths measured on the DLC coated disks as a function of silicon thickness. The dotted line represents the average wear depth measured on an uncoated disk

wear depth when the thickness of silicon is greater than 3 nm. According to the results from both visibility test and wear test, the disk coated with 3-nm thick silicon and 15-nm thick DLC exhibited the best performance, thus this disk was selected for the disk lifetime measurement.

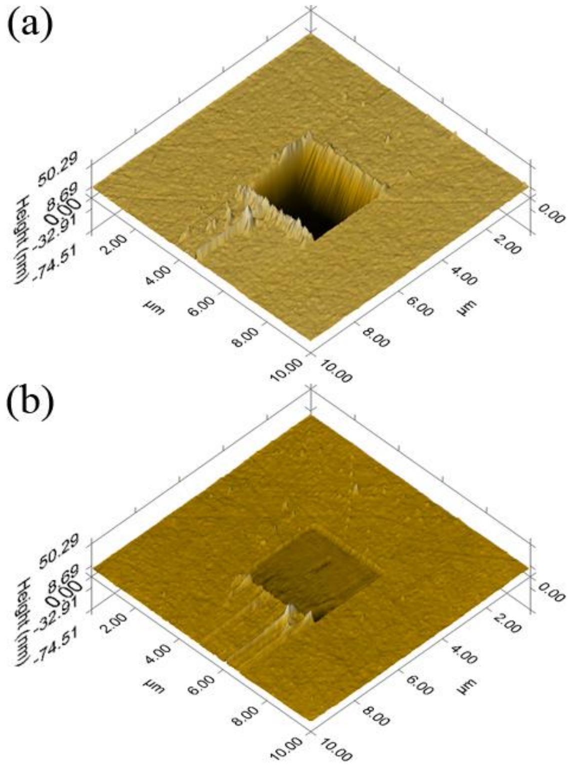

Fig. 6 AFM images of wear profile on (a) the glass disk and (b) the disk coated with 1-nm thick silicon and 15-nm thick DLC.

c. Lifetime measurement

Fig. 7 shows the average lifetime of 1 track of glass disk and the disk coated with 3-nm thick silicon and 15-nm thick DLC. The lifetime of glass disk is 58 s. For the coated disk, only little DLC debris was found on the ABS of slider after 1800 s (30 mins) of the test duration and no obvious wear was found on the disk surface. After the lifetime measurement, the scratch profiles on the glass disk and the coated disk were characterized in a surface profilometer (KLA-tencor, P-16). Fig. 8 shows the images of scratch profile on glass disk (Fig. 8(a)) and coated disk (Fig. 8(c)). From the cross section of scratch profile on both disks, it was found that scratch depth of glass disk was approximately 1 μm (Fig. 8(b)) while the depth of the disk coated with 3-nm thick silicon and 15-nm thick DLC was 10 nm. It should be noted that such scratches on the coated disk do not alter the disk function. Thus, it can be concluded that the lifetime of the coated disk is at least 30 mins.

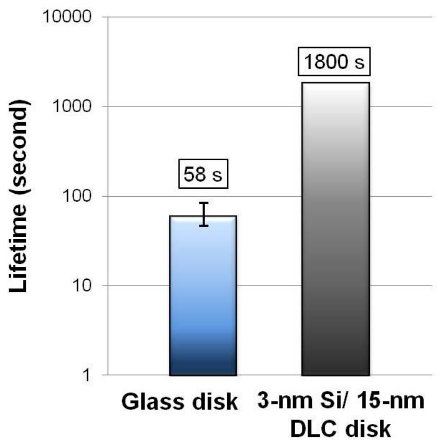

Fig. 7 The comparison of lifetime of glass disk and the 3-nm thick silicon and 15-nm thick DLC coated disk

3. The development of high-sensitivity disk

Besides the issue about the durability of glass disk, the low sensitivity of the flying height measurement at near contact region is also very critical. In fact, the sensitivity in flying height measurement using the intensity-based flying height tester decreased to nearly zero at near contact region. Thus, it is not able to measure the flying height with acceptable accuracy at low flying heights [5]. Nowadays, hard disk companies are replacing the intensity-based flying height testers with alternative types of flying height testers. To circumvent this issue without replacing the equipment, we developed high-sensitivity disks by employing multi-layer configuration with the optimized thickness of each layer to improve the measurement sensitivity especially at near contact region.

From the preliminary study, it was found that the sensitivity in flying height measurement using the DLC coated disk is different from that of the uncoated glass disk. The sensitivity in the flying height measurement is the change of the reflected light intensity associated with the change of flying height or the slope of the reflected light intensity vs. flying height curve. Basically, the characteristic of this curve depends on the refractive index and the thicknesses of all overcoat layers. In this paper, to improve the sensitivity in the flying height measurement, the theoretical calculation was performed in order to select the optimum thicknesses of the overcoat layers. Two disk configurations were proposed: the disk coated 2 layers (Si/DLC) and the disk coated with 4 layers (Si1/DLC1/Si2/DLC2) as shown in Fig. 9.

3.1 The calculation of interference light intensity of multilayer coated disk

For decades, optical interferometry has been the common method for measuring slider's flying height in hard disk drive industry [2, 3]. The schematic of optical interferometry used in the 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, interferes at the slider-disk interface and then returns to a photo detector. The intensity of the 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 measured to

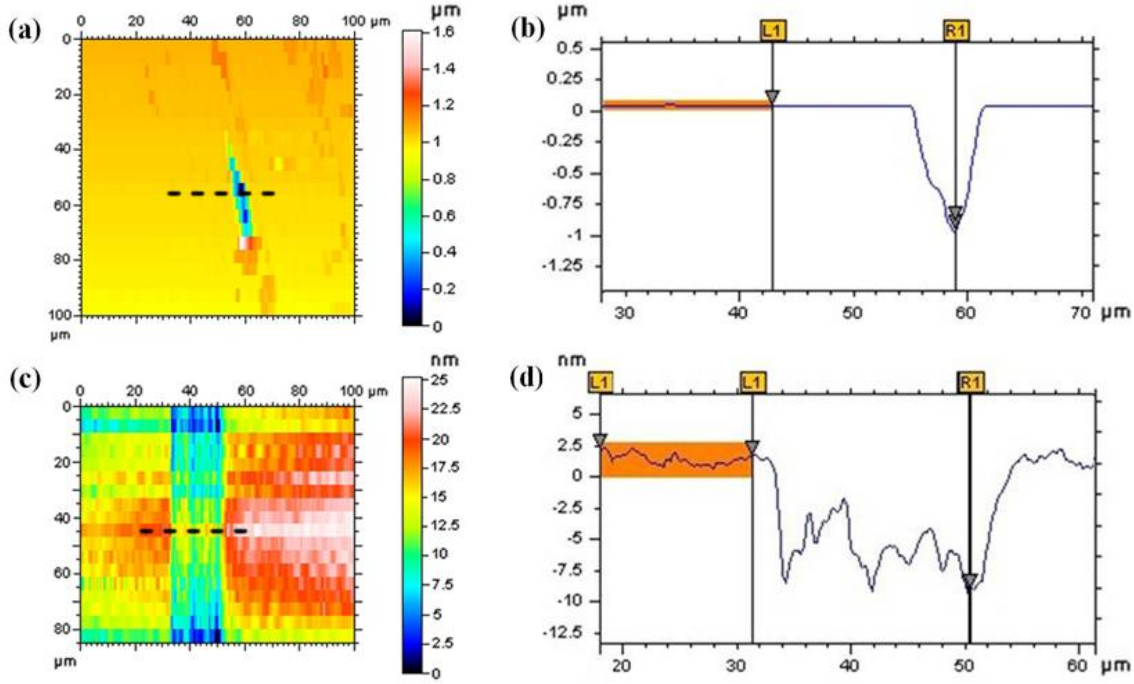

Fig. 8 Scratch profiles measured from surface profilometer. (a), (b) Scratch profile and cross section of scratch of glass disk, the scratch depth on glass disk surface is 1 μm. (c), (d) Scratch profile and cross section of scratch of 3-nm thick silicon and 15-nm thick DLC coated disk, the scratch depth on coated disk surface is 10 nm.

estimate the flying height [3-5, 16]. The flying height tester used in this work is based on the principle of three-wavelength interferometry (wavelengths of 450, 550 and 650 nm) to characterize the flying height. To apply multilayer coated disk as shown in Fig. 9 in the flying

Fig. 9 The disk configurations which are proposed to improve the sensitivity: (a) 2-layer coated disk; (b) 4-layer coated disk

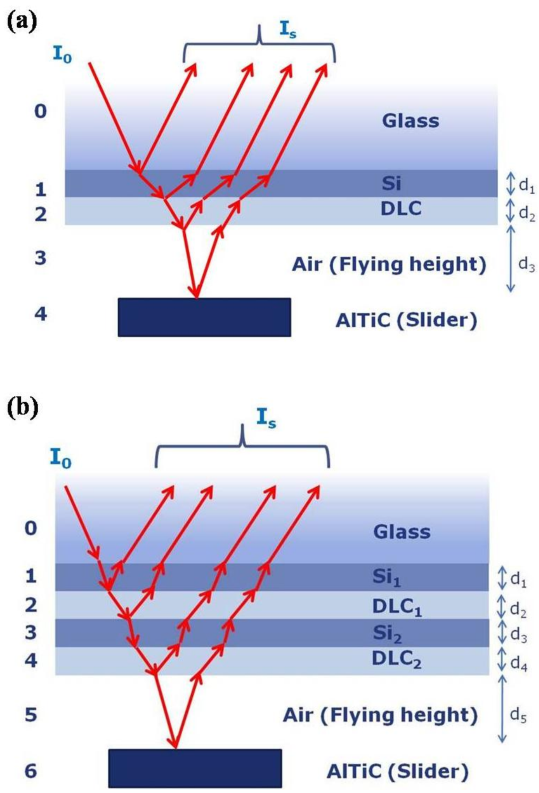

Fig. 10 The schematic illustration of the optical models used in the calculation: (a) 2-layer coated disk; (b) 4-layer coated disk

height tester, the calculation models in the flying height measurement using multilayer coated disks are represented in Fig. 10.Fig. 10(a) shows the calculation model for 2-layer coated disk whereas the intensity of the reflected light can be derived using thin film theory [17] as following:

$$I_s = I_0\left[\frac{r_{01}+r_{1234}e^{2i\beta_1}}{1+r_{01}r_{1234}e^{2i\beta_1}}\right]^2 \qquad \text{--- (1)}$$

where

$$\beta_i = 2\pi(\frac{d_i}{\lambda})n_i \qquad \text{--- (2)}$$

$$r_{ij} = \frac{(n_i+ik_i)-(n_j+ik_j)}{(n_i+ik_i)+(n_j+ik_j)} \qquad \text{--- (3)}$$

$$r_{1234} = \left[\frac{r_{12}+r_{234}e^{2i\beta_2}}{1+r_{12}r_{234}e^{2i\beta_2}}\right],\quad r_{234} = \left[\frac{r_{23}+r_{34}e^{2i\beta_3}}{1+r_{23}r_{34}e^{2i\beta_3}}\right]$$

I_s is the intensity of the reflected light from the slider-disk interface, I_0 is the intensity of the light incident to the slider-disk interface. d_1, d_2 and d_3 are silicon thickness, DLC thickness and air gap (flying height), respectively as shown in Fig. 10(a). 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, *i* and *j* represent the layer which light travels through and layer which light reflects from.

Fig. 10(b) shows the calculation model for 4-layer coated disk whereas the reflected light intensity can be derived using thin film theory as shown in eq. (4) where β_i and r_{ij} can be found in eq. (2) and eq. (3).

$$I_s = I_0\left[\frac{r_{01}+r_{12345}e^{2i\beta_1}}{1+r_{01}r_{12345}e^{2i\beta_1}}\right]^2 \qquad \text{--- (4)}$$

where

$$r_{123456} = \left[\frac{r_{12}+r_{23456}e^{2i\beta_2}}{1+r_{12}r_{23456}e^{2i\beta_2}}\right],\quad r_{23456} = \left[\frac{r_{23}+r_{3456}e^{2i\beta_3}}{1+r_{23}r_{3456}e^{2i\beta_3}}\right]$$

$$r_{3456} = \left[\frac{r_{34}+r_{345}e^{2i\beta_4}}{1+r_{34}r_{345}e^{2i\beta_4}}\right],\quad r_{456} = \left[\frac{r_{45}+r_{56}e^{2i\beta_5}}{1+r_{45}r_{56}e^{2i\beta_5}}\right]$$

Fig. 11 shows an example of the calculation result: the normalized reflected intensity curve in respect to flying height (normalized intensity ranging from 0 to 2) for the case of 4-layer coated disk when the thicknesses of all layers are assumed to be 1 nm. The dotted lines represent the normalized intensity when the glass disk is employed. The refractive indices of all layers used in the calculation are shown in table. 1, the considered flying heights are from 0 to 500 nm.

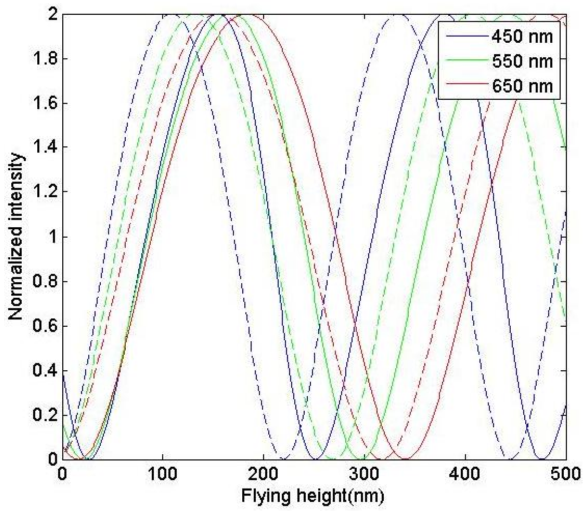

Fig. 11 The reflected intensity curve as a function of flying height using the disk coated with 4 layers (Si1: 1 nm, DLC1: 1nm, Si2: 1nm

and DLC2: 1 nm). The dotted lines represent the intensity curve when the glass disk is employed.

As shown in Fig. 11, for the case of glass disk (dotted lines), when the flying height is lower than 15 nm, the slope of intensity curve or the sensitivity in the flying height measurement will decrease to zero. In fact, the coating altered the reflected light intensity. Thus, it is possible to fabricate high-sensitivity disk for the flying height measurement, if appropriate thickness of each layer is selected.

3.2 Investigation of the optimum film thicknesses

From the theoretical calculation of the reflected light intensity as described in chapter 3.1, the sensitivity in flying height measurement at any flying height can be determined from the slope of the normalized intensity curve at that flying height. Therefore, if all parameters are known, the sensitivity in the flying height measurement can be calculated. On the other hand, this calculation method can be applied to find the optimum thickness of each layer to develop a high-sensitivity disk. This can be done by varying each film thickness used in the calculation in order to find the optimum thickness of each layer which provides the highest sensitivity in the flying height measurement. Subsequently, the disk is fabricated following the optimum thicknesses from the calculation. Currently, the range of measured flying height is from 0 to 70 nm, then in this paper the sensitivity in the flying height measurement is defined as the sum of the slopes of the intensity curve at the flying height of 1, 10, 20, 30, 40 and 50 nm.

In the case of 2-layer coated disk, the thickness of each layer was varied as following: silicon thickness (d_1) from 0 to 5 nm, DLC thickness (d_2) from 0 to 400 nm where the refractive index of each layer was obtained from an ellipsometry measurement as shown in table. 1. Fig. 12 shows the percentage of the improved sensitivity in the flying height measurement as a function of the silicon and DLC thicknesses. It should be noted that if the sensitivity is equal or less than that of the glass disk, the sensitivity is displayed as 0%. The highest sensitivity occurs at the silicon thickness of 0 nm and the DLC thickness of 105 nm where the sensitivity is improved by 24.32% as compared to that of the glass disk.

For 4-layer coated disk, the thickness of each layer was varied as following, Si_1 thickness (d_1) from 0 to 5 nm, DLC_1 thickness (d_2) from 0 to 400 nm, Si_2 thickness (d_3) from 0 to 5 nm and DLC_2 thickness (d_4) from 0 to 400 nm

Table. 1 Refractive index of all layers which used in calculation

Material	Refractive index (n+ik)		
	Wavelength 450	Wavelength 550	Wavelength 650
Glass disk	1.54+0.02i	1.51+0.01i	1.52
Air (Flying height)	1	1	1
Silicon	4.419+1.328i	4.232+0.634i	4.014+0.309i
DLC	2.169+0.2087i	2.1699+0.1416i	2.1631+0.0985i
AlTiC (Slider)	2.39+0.432i	2.354+0.363i	2.289+0.344i

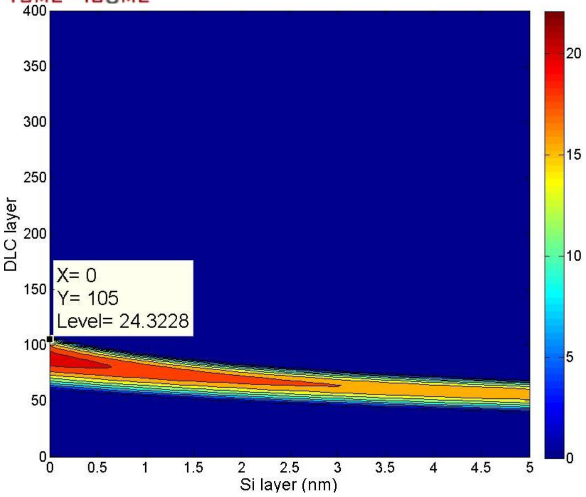

Fig. 12 Percentage of the improved sensitivity as a function of the silicon and DLC thicknesses from the theoretical calculation of 2-layer coated disk

As shows in Fig. 13 the highest sensitivity in flying height measurement occurs at Si_1: 2, DLC_1: 240, Si_2: 5 และ DLC_2: 320 nm where the sensitivity is improved by 29.57% as compare to that of the glass disk.

3.3 Film thickness considerations in the disk fabrication

In the disk fabrication, the film thicknesses might be different from the desired thicknesses. Such variations of the film thicknesses in the deposition process may alter the sensitivity in the flying height measurement. Therefore, the variation of each film thickness should be considered whereas the variation in the film thicknesses should not cause a significant decrease of the sensitivity in the flying height measurement. Moreover, the adhesion between DLC and glass disk should be concerned. If the thickness of DLC is more than 50 nm, silicon layer is needed to improve the adhesion between the DLC and glass disk.

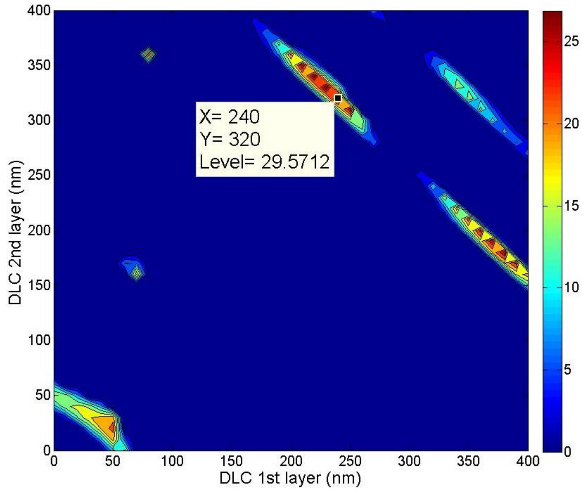

Fig. 13 Percentage of the improved sensitivity of 4-layer coated disk as a function of the DLC_1 and DLC_2 thicknesses where the thicknesses of Si_1 and Si_2 are 2 and 5 nm, respectively

When considering the above practices, the film thicknesses for 2-layer coated disk were redesigned to 1-nm thick silicon and 77-nm thick DLC where the sensitivity in the flying height measurement is improved by 19.42% as shown in Fig. 14. For 4-layer coated disk, the disk was redesigned to consist of Si_1: 1, DLC_1: 55, Si_2: 3 and DLC_2: 25 nm where the measurement sensitivity is improved by 23% as compared to glass disk as shown in Fig. 15. Subsequently, both disks were fabricated using the fabrication process which described in chapter 2.1.

3.4 Measurement of the sensitivity in flying height measurement

In this chapter, the sensitivity in flying height measurement of the coated disks and the glass disk were measured and compared to the sensitivity from the theoretical calculation. The sensitivity in flying height measurement can be measured from the reflected light intensity at various flying height and this data is used to

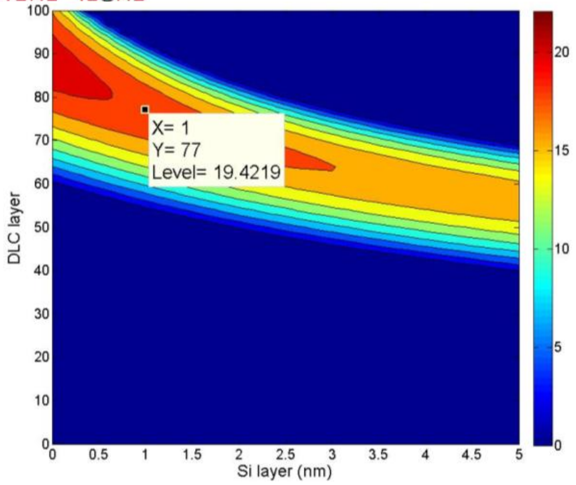

Fig. 14 Percentage of the improved sensitivity at designed thickness (silicon 1 nm and DLC 77 nm) as a function of silicon and DLC thickness of 2-layer coated disk

compare with the reflected light intensity vs. flying height curve from the theoretical calculation as shown in Fig. 11. The sensitivity in flying height measurement at any flying height can be determined from the slope of the curve at that flying height.

The measurement of sensitivity started with specifying the measurement point on ABS of slider as shown in Fig. 16, then the reflected light intensities and the flying heights from these 4 specific points were measured in order to compare with the calculation results. The reflected light intensity data was measured using the coated disks whereas the flying height data was measured using a glass disk. Actually, the flying height data should be measured from the coated disk too, but because the complication in the measurement using the coated disks may result in inaccurate flying height data. Thus, the flying heights were measured using a glass disk instead. Since the coated disks were coated with the total thickness less than 100 nm, thus the coated disks and the glass disk are comparable

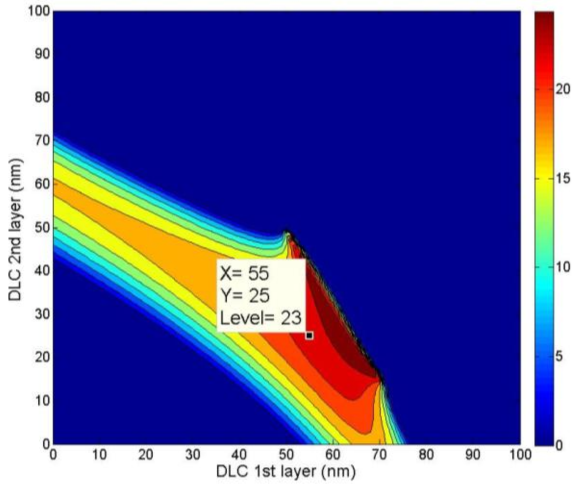

Fig. 15 Percentage of the improved sensitivity at designed thickness (Si_1: 1, DLC_1: 55, Si_2: 3 and DLC_2: 25 nm) of 4-layer coated disk as a function of DLC_1 and DLC_2 thickness where the thickness of Si_1 and Si_2 are 1 and 3 nm.

in term of physical property. Therefore, the slider should fly at the same flying height on both disks. In this measurement, the light intensities and the flying heights of these 4 specific points were repeatedly measured for 5 times in order to determine the average of both data. Then, the data of the reflected light intensities and the corresponding flying heights from the 4 measurement points were plotted on the reflected light vs. flying height curve that obtained from the theoretical calculation.

3.5 Results and discussion of the sensitivity measurement

In the case of 2-layer coated disk, as shown in Fig. 17, the results revealed that the measurement data was resemble to the calculation curve that assumed the silicon thickness of 1 nm and the DLC thickness of 77 nm. However, these data do not fit very well on the calculation curve. This may be due to the

Fig. 16 The measurement points on ABS

variation of the film thicknesses from the fabrication process. Since the ion beam deposition machine used in the fabrication was not equipped with a film thickness monitoring system, thus the thickness of each film was controlled by controlling the deposition time calculated from the desired thickness divided by the deposition rate. Hence, the variation of film thickness may be a result from the errors in the deposition rates. The deposition rate of DLC was directly measured, but the deposition rate of silicon was from the company data. We believed that the discrepancy between the measurement data and the calculation curve may be a result from the film thickness errors between the real disk and the ones used in the calculation. To confirm this assumption, the thickness of each film used in the calculation was adjusted to fit the measurement data. As a result, the thicknesses which give the best fit were 0.57 nm and 71 nm for silicon and DLC, respectively. As shown in Fig 18, the calculated curve using the adjusted thicknesses fits very well with the measurement data, so it is reasonable that the exact film thicknesses of silicon and DLC were 0.57 nm and 71 nm, respectively. This corresponds to the thickness errors of 43% and 7.7% for silicon and DLC, respectively. It should be noted that the silicon film has a very large error because the deposition rate of silicon was not directly measured but the data from company was used instead. This is because the desired silicon thickness is very thin (1 nm) and the variation of silicon thickness does not significantly affect the sensitivity in the flying height measurement as shown in Fig. 14. For the silicon thickness of 0.57 nm and the DLC thickness of 71 nm, the sensitivity in the flying height measurement at the specified flying heights, was improved by 16.64% as compared to that of the glass disk. For low flying heights (1, 10 and 20 nm), the sensitivity was improved as much as 55.44%.

In the case of 4-layer coated disk, the disk consists of 4 layers as following: Si_1 1, DLC_1: 55, Si_2: 3 and DLC_2: 25 nm. It should be noted that the deposition rates used in the fabrication of this disk were adapted from the

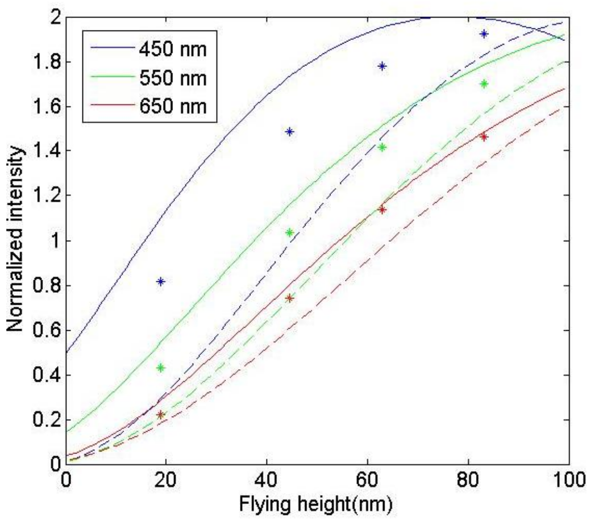

Fig. 17 The intensity as a function of flying height curve of the disk which coated with 1-nm thick silicon and 77-nm thick DLC. The stars

represent the measurement data and the dotted lines represent the intensity curve of glass disk.

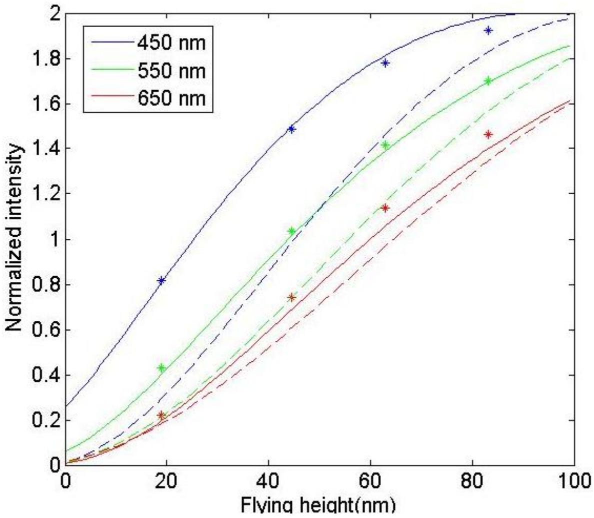

Fig. 18 The intensity as a function of flying height curve of the disk which coated with 0.57-nm thick silicon and 71-nm thick DLC. The stars represent the measurement data and the dotted lines represent the intensity curve of glass disk.

deposition rates obtained in the fabrication of 2-layer coated disk. As shown in Fig.19, the result showed that the measurement data fit very well with the calculation curve. This result suggested that the film thicknesses from the disk fabrication process were very close to the designed thicknesses. This result also confirmed our previous assumption. Furthermore, the sensitivity in the flying height measurement at the specified flying heights was improved by 23% as compared to that of the glass disk. For low flying height (1, 10 and 20 nm), the sensitivity was improved as much as 85.16%.

4. Conclusion

This paper proposed the method to improve the durability of the glass disk used in the flying height tester. Furthermore, the developed disk also showed a significant improvement of the sensitivity in the flying height measurement. According to the results, the glass

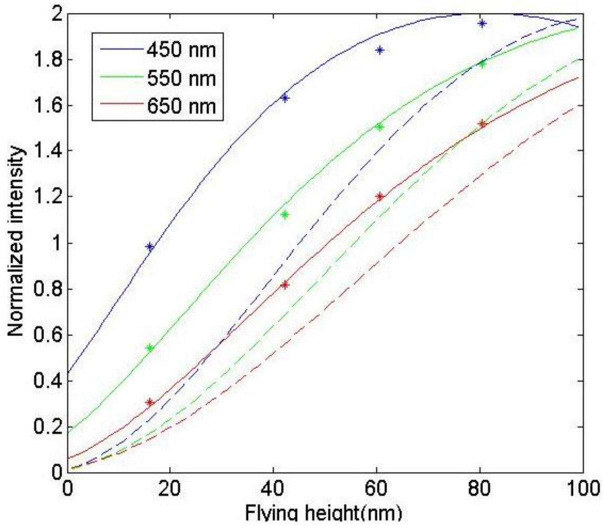

Fig. 19 The intensity as a function of flying height curve of the disk coated with Si_1 1, DLC_1: 55, Si_2: 3 and DLC_2: 25 nm. The stars represent the measurement data and the dotted lines represent the intensity curve of glass disk.

disk coated with 3-nm thick silicon and 15-nm thick DLC reduced the wear depth by 92% and the disk lifetime was improved by at least 30 times as compared to the glass disk. In the improvement of high-sensitivity disk, the results revealed that the developed disk significantly improved the sensitivity in the flying height measurement at low flying heights as much as 85.16% as compared to the measurement using the glass disk. The proposed approach can greatly reduce the cost of glass disk in the flying height measurement process, as well as offer alternative route for the high-sensitivity measurement of the flying height especially at low flying heights.

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