THE ROUGHNESS MEASUREMENT OF THE SUPER-SMOOTH SURFACE OF HARD DISKS

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ABSTRACT

Technologies for manufacturing hard disks are driven by the demand to increase magnetic storage capacity. However, the rate of increasing storage capacity is being slowed by the inability to produce ever closer flying heights between the sliders and disk surfaces. One of important requirements for flying height is to control the surface of substrates of hard disks to a super-smooth level to allow the sliders to 'fly' faster and more closely to the disk surfaces. Currently, there are no any assessment standards for super-smooth surfaces. In this paper, the authors attempt to build a measurement and characterisation protocol for the evaluation of hard disk surfaces using a white-light optical instrument CCI (Coherence Correlation Interferometer). The key advantage of this instrument is its exceptionally high vertical resolution which is an order of magnitude better than comparable systems. System factors and measurement factors both influence the experimental results with CCI, this paper focuses on analysing the latter including sampling intervals, the number of measurements, measurement area filter cut-off wavelength etc. Based on the experimental results, an optimised group of parameters for measurement and characterisation are recommended. The authors have successfully measured and compared the surface roughness of six hard disks derived from differing Chemical Mechanical Polishing (CMP) 'abrasives'. It has been found that: (1) the roughness values of the six hard disks surfaces have all reached a sub-nanometre level; (2) there is little difference in the influences of different CMP regimes on the topography of the hard disk surfaces.

Keywords: magnetic storage, hard disk, roughness CCI (Coherence Correlation Interferometer)

1 INTRODUCTION

With the rapid development of precision optics and micro-electronics, requirements on the surface properties of medium substrates including form error, waviness, roughness etc are becoming higher and higher. The magnetic recording process is accomplished by relative motion between a magnetic medium against a stationary or rotating read/write magnetic head, so surfaces are required to be as smooth as possible and the flying height as small as possible due to the need for higher and higher recording densities, which has shown a rapid annual growth rate of 60-100% in recent years [1]. Therefore, one of the critical requirements in the attempt to achieve maximum magnetic storage capacity is to reduce the roughness of the hard disk and the slider down to sub-nanometric root mean-square (RMS) values in order to lower the flying-height with minimum contact. These types of surfaces are called super-smooth surfaces. One typical super-smooth surface is hard disks substrate. The roughness of substrate surface determines the density of data storage, the slide speed and the distance between the slide and the surface. It also has a direct consequence on the reliability of the hard disk interface [2]. Therefore, it is important to measure and describe the surface roughness of the hard disk.

Surface roughness is most commonly measured along a single profile and is usually characterised by one of the two statistical height descriptors [3]. Parameters for areal assessment are still under discussion by ISO and other standards organisations. There already have some parameters used in practical assessment, such as average absolute deviation of the surface (Sa), root mean square deviation of the surface (RMS), skewness of the surface (Ssk), Kurtosis of the surface (Sku) etc. RMS is widely used to discriminate between different surfaces based on height information to monitor manufacturing stability [4] as it is most stable one among the parameters. In this paper, roughness values all refer to RMS values.

An optical instrument, the CCI (Coherence Correlation Interferometer) developed, by Taylor Hobson will be used to measure the roughness of the super-smooth surfaces in this paper. CCI is a non-contact areal measurement system that uses coherence correlation interferometry technology and is the most accurate optical 3D surface profiler available today. It combines the surface imaging quality of a microscope with the accurate measuring capability of a conventional surface profiling instrument. These types of systems are able to get roughness and waviness information as well as complete 2D and 3D analysis. They are able to complete a measurement with over 1 million data points in less than 10 seconds with a resolution of 0.01nm [5].

2 THE FACTORS INFLUENCING THE MEASUREMENT RESULTS USING CCI

A number of factors will influence the accuracy of CCI. They can be divided into two types: system and measurement factors. The former includes vertical resolution of the gauge, light intensity, data points in X and Y (pixel array on CCD) and system noise; the latter includes sampling intervals, the number of measurements, scan size, filter cut-off wavelength etc. The influence of system factors can be reduced only by optimising the environment and working conditions for a customer; while the influence of measurement factors can be reduced by optimising measurement methods. In this paper, only measurement factors are by analyzed.

Large sampling intervals may cause aliasing in the data especially in the case of super-smooth surfaces. Sampling intervals also influence the filtering process and how much of the original information is preserved after data acquisition. Roughness parameters related to the slope, curvature and summit density are known to strongly depend on the sampling interval [6]. Sampling intervals are determined by the object lens and charge coupled device (CCD) array used in the measurement. For CCI, the sampling intervals are only determined by objective lens as CCD is already built into the system, so the way to reduce the influence of sampling intervals is to choose proper objective lens. The lens with 50×magnification is used in this paper in order to achieve the smallest sampling intervals and the highest lateral resolution.

The number of measurements is related directly with measurement efficiency. A single measurement will probably introduce random errors; while too sufficient measurements will influence the measurement efficiency while have little benefit for the accuracy. Although there are already some regulations on it, the number of measurements of a super-smooth surface still needs to be determined by experiment.

For a given sampling interval, the scan size should be sufficiently large to contain the necessary topographical information of the surface to provide statistical significance. In many practical cases, scan size is determined by experiment because the proper dimensions of a specific surface for scanning are open to debate.

The information got from measurements always includes several different components. Filtering can separate certain spatial frequency components of the surface profile. It can reduce the effect of vibrations without losing essential data and can be used to reduce the need for accurate setting-up when using an independent datum. The Gaussian filter is the most widely used surface filter and defined in the ISO16610. The weighting function of a closed profile has the equation of the Gaussian density function. With the cut-off wavelength λ_c, the equation is as follows,

$$s(x) = \frac{1}{\alpha\lambda_c}\exp\left[-\pi\left(\frac{x}{\alpha\lambda_c}\right)^2\right] \tag{1}$$

The transmission characteristic is determined from the weighting function by means of the Fourier transformation. The filter characteristic for the mean line has the following equation,

$$G(\lambda) = \exp\left[-\pi\left(\frac{\alpha\lambda_c}{\lambda}\right)^2\right] \tag{2}$$

Where λ is the wavelength, and $\alpha = \sqrt{\frac{\ln 2}{\pi}} \approx 0.4697$.

The derivative of $G(\lambda)$ in equation (2),

$$\frac{dG}{d\lambda} = \frac{2\pi\alpha^2\lambda_c^2}{\lambda^3}\exp\left[-\pi\left(\frac{\alpha\lambda_c}{\lambda}\right)^2\right] \tag{3}$$

And the second derivative of $G(\lambda)$,

$$\frac{d^2G}{d\lambda^2} = \left(\frac{4\pi^2\alpha^4\lambda_c^4}{\lambda^6} - \frac{6\pi\alpha^2\lambda_c^2}{\lambda^4}\right)\exp\left[-\pi\left(\frac{\alpha\lambda_c}{\lambda}\right)^2\right] \tag{4}$$

Let $\frac{d^2G}{d\lambda^2} = 0$, then,

$$\lambda_c = \sqrt{\frac{3}{2\pi}}\frac{1}{\alpha}\lambda \approx 1.472\lambda \tag{5}$$

When the cut-off wavelength is satisfied in equation (5), $\frac{dG}{d\lambda}$ reaches the maximum value, so $G(\lambda)$ vary most obviously with λ. Correspondingly, the roughness values vary most obviously with λ_c. When the roughness values vary obviously, other components with different wavelength will be included. Therefore, if the cut-off wavelength is satisfy in equation (5), the components different from the roughness will be eliminated or weakened.

Based on the above analysis, the filtering method used in this paper is to apply a series of cut-off wavelengths increasing in small increments repeatedly over the original data in order to directly correlate the effect of filtering on the resulting roughness values. As the cut-off wavelengths increase in small increments, a specific wavelength at which roughness values vary most obviously is chosen as the cut-off wavelength. The reason is that if roughness values vary little, it indicates that all components included in roughness have a similar wavelength at least the wavelengths of most components are mostly the same, which means that most components are roughness. If the values vary more obviously then more non-roughness components are probably included.

3 EXPERIMENTS AND ANALYSIS

Figure 1 shows the relationship between roughness RMS values and the number of measurements. In figure 1, the roughness values decreases as the number of measurements increase. When the number of measurements increases from 1 to 4, the roughness values decrease obviously; they decreases much less as the number of measurements increases from 4. The reason is that experiment repeated for several times can reduce some random errors; however the accuracy will not always increase with the number of repeated measurements. Therefore, the number of measurements is chosen as 4.

If the scan area increased, the information of longer wavelength components will be more included in the roughness. Therefore, it is also necessary to choose a proper scan area. Figure 2 shows the relationship between roughness RMS values and different scan areas. In figure 2, the roughness values decrease more obviously when the scan area decreases from 360 × 360μm² to 90×90μm², but vary gently when the area is smaller than 90×90μm². The possible reason for it is that only single component is included in the results when the scan area is chosen less than 90×90μm². If the scan area is chosen less than 90×90μm², some roughness information can still be achieved, but some roughness information will be lost, so the scan area is chosen 90×90μm².

In this paper, filter cut-off wavelength λ_c is determined in two steps. Firstly, extend the ISO standards in order to find the proper range of λ_c; and then determine the best proper λ_c through experiments. According to the recommended cut-off ISO 4288, if roughness value is from 0.006μm to 0.02μm, λ_c is recommended to choose 0.08mm. For super-smooth surfaces, the roughness reaches sub-nanometre, so λ_c should be chosen less than 0.08mm. Using the methods in section 2, let the filter cut-off wavelength choose the different ISO recommended values from 0.008 to 0.08mm and the values not recommended to find out the relationship between roughness and cut-off wavelength. Figure 3 shows the relationship between roughness values and the ISO recommended λ_c. In figure 3, the roughness values vary more obviously when cut-off wavelength is about 0.008mm. In order to determine the most proper values, the smaller increments of cut-off wavelength near to 0.008mm are used as shown in figure 4. In figure 4, the roughness values vary most obviously between 0.008 and 0.009mm. The possible reason for this is that when the cut-off wavelength is larger than 0.008mm more waviness information will be included in roughness. Therefore, λ_c is chosen 0.008mm.

The system noise of CCI is approximately 0.05nm, which is close to the roughness values of super-smooth surfaces so that it is difficult to be moved out from the roughness information. By choosing a proper λ_s it is possible to solve this problem. λ_s can be determined also by using the method proposed in section 2. Figure 5 shows the relationship between the roughness values and the λ_s, which changes from 0.0008 to 0.0025mm. In the process, λ_c keeps constant 0.008mm. From figure 5, the roughness values vary most obviously when λ_s changes from 0.001 to 0.002mm. In order to remove the noise and keep as much roughness information as possible, λ_s is chosen 0.002mm.

4 MEASUREMENTS AND RESULTS

Six hard disks with different additives were measured. Additive A was added in Disks 1-4 with different concentrations, which are 0.1‰, 0.2‰, 0.3‰ and 0.4‰ respectively. Additive B and C with the same concentrations 0.2‰ were added in disks 5 and 6 respectively. The measurement for every sample testing is repeated 4 times during experiment; the scan area is chosen as $90 \times 90 \mu m^2$; and λ_c and λ_s are chosen as 0.008mm and 0.002mm respectively.

Figures 6-11 show the surfaces of the hard disks measured with CCI. Figure 12 shows the results of the roughness values of the different hard disk surfaces in five experiments at different time (in order to find out the experiment repeatability). According to figure 12, the roughness of the hard disks measured in this paper reaches sub-nanometric levels. The results also indicate the different additives have little influence on the roughness of the hard disk surfaces.

5 CONCLUSION

Roughness is the feature of a surface that defines how it looks, feels and behaves in contact with another surface. In order to precisely quantify and control the roughness of the slider and media during manufacturing, it is necessary to measure and describe the roughness.

In this paper, CCI is used to measure the super-smooth surface of hard disks. The factors influencing the measurement results, including the number of measurements, scan size and filtering cut-off wavelength etc are studied. Based on experiments and analyses, the number of measurement for the same sample was chosen as 4; the filtering area was chosen as $90 \times 90 \mu m^2$; and λ_c and λ_s were chosen as 0.008mm, 0.002mm respectively.

The measurements of six hard disk surfaces with different additives and different concentrations were completed using the above measurement method. The assessment results using the filtering method indicate that the roughness values of hard disk surfaces reaches sub-nanometric levels. The results also indicate the different additives have little influence on the roughness of the hard disk surfaces.

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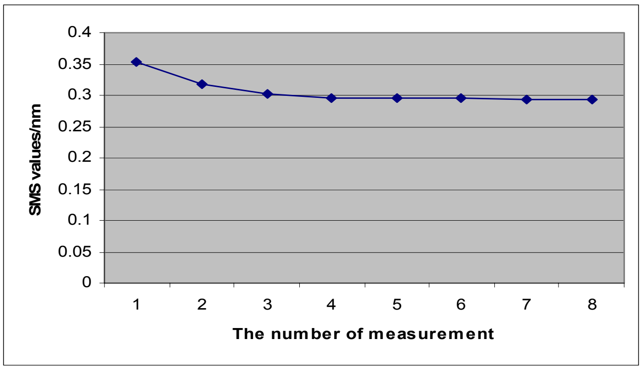

Figure 1: The relationship between roughness RMS values and the number of measurements

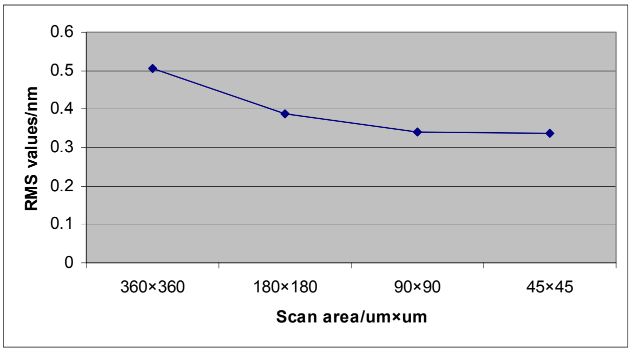

Figure 2: The relationship between roughness RMS values and scan area

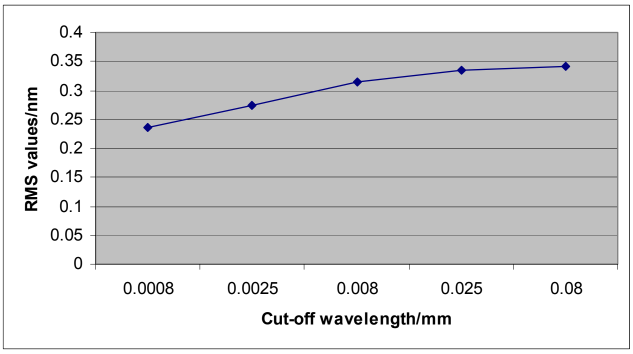

Figure 3: The relationship between roughness RMS values and recommended λ_c

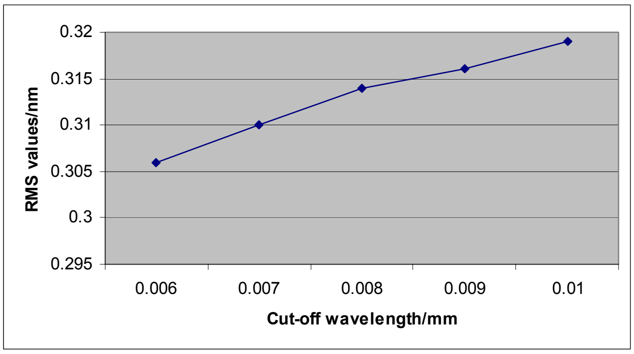

Figure 4: The relationship between roughness RMS values and non-recommended λ_c

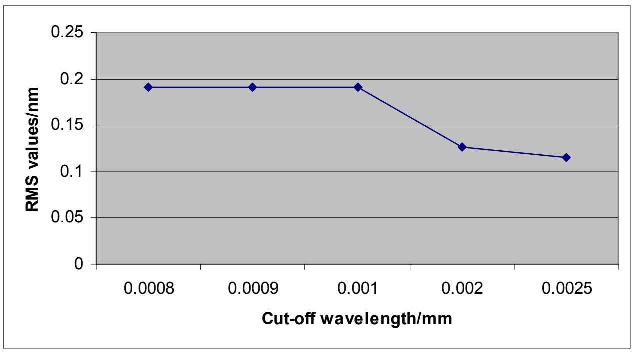

Figure 5: The relationship between roughness RMS values and λ_s

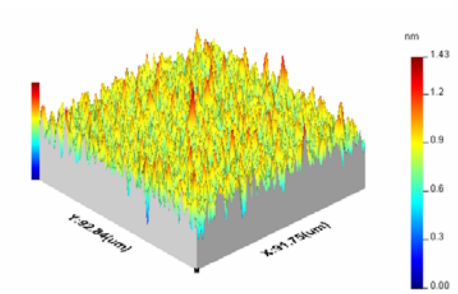

Figure 6: Disk 1

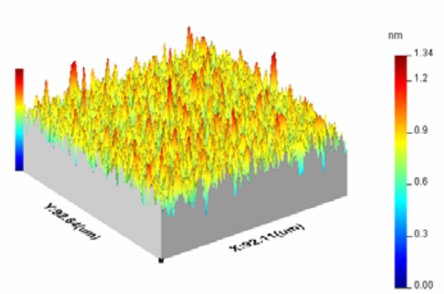

Figure 7: Disk 2

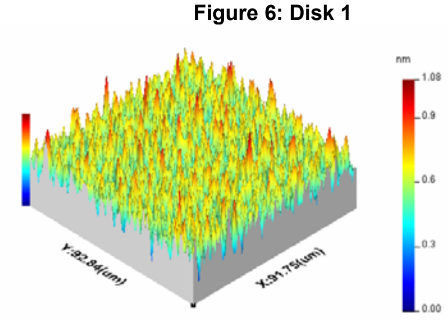

Figure 8: Disk 3

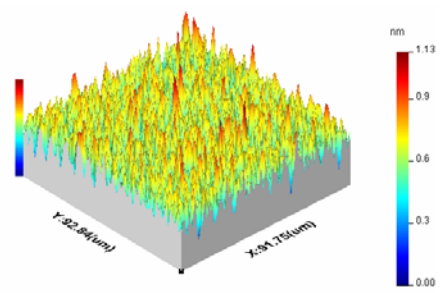

Figure 9: Disk 4

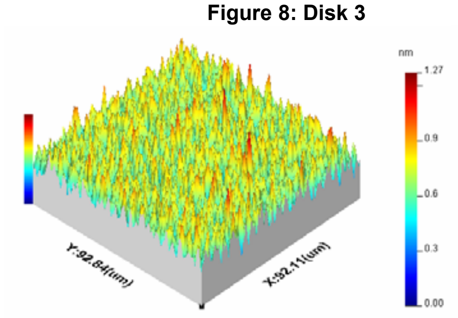

Figure 10: Disk 5

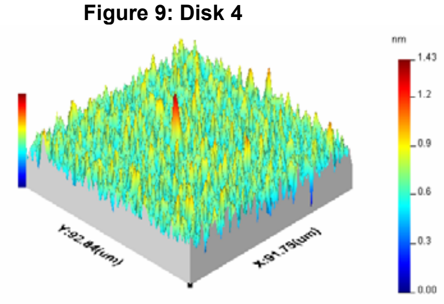

Figure 11: Disk 6

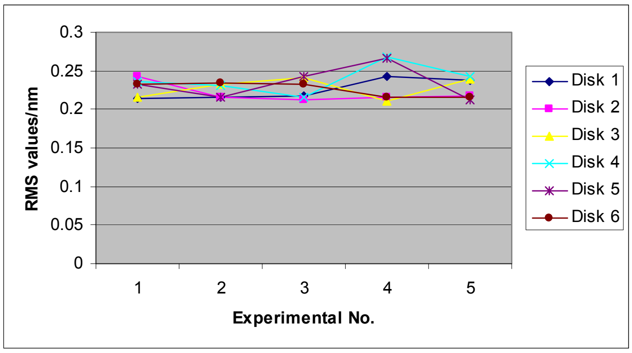

Figure 12: Roughness RMS values of six hard disks in five experiments