Roughness Measurements With A Stylus Profiler

KLA-Tencor
P-Series Profiler

Introduction

Roughness measurements via stylus profilometry are an important part of qualifying the output of many processes in the data storage industry. In order to optimize these measurements for throughput[1] and accuracy, it becomes important to understand the various factors that affect a stylus based profiler.

Background

To scan a surface, a Profiler user sets up a 'scan recipe' to specify the 'scan parameters' such as length, speed, sampling rate, and the force to be applied on the sample surface. These parameters must be selected carefully. For example, a slow scan speed will drastically affect throughput, whereas a fast scan speed may cause the stylus to bounce and lose contact with the surface. Apart from the recipe parameters, the user must be aware of environmental noise and must try to minimize its effect through proper isolation techniques.

In the following sections, the effect of some of the aforementioned factors will be explored. Measurements on disk substrates with a nominal roughness of 10Å were used as a basis for this paper. Data was acquired on a KLA-Tencor P-12 disk profiler using submicron (0.1 - 0.2µm tip radius) styli.

Scan Parameters:

Scan Length

Scan length must be selected such that the user can capture enough long term spatial features (waviness[2]). The waviness is removed from the scan trace and the resultant data used to calculate roughness. Figure 1 shows how the waviness (low spatial frequency information) and the roughness (high spatial frequency information) traces can be derived from the scan trace.

It is recommended that the scan length be at least 5 times the waviness of the substrate. If the scan length is too short, then the roughness is influenced by local texture variations and may not provide a true picture of the surface. It will also lead to larger variation in the data when roughness is measured at different locations on the same substrate. Too long a scan will not yield any extra information and will decrease throughput.

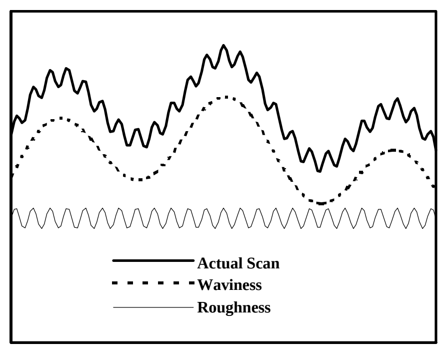

Figure 1 : Actual Scan, Waviness and Roughness

Figure 2 illustrates this fact. For a scan length of 100µm, there is a large variation in the roughness value across the disk. A scan length of 500µm yields good correlation between measurements at different sites on the disk. Longer scan lengths do not improve this correlation. Therefore, one can say that for the given substrate, a scan length of 500μm will result in accurate roughness measurements.

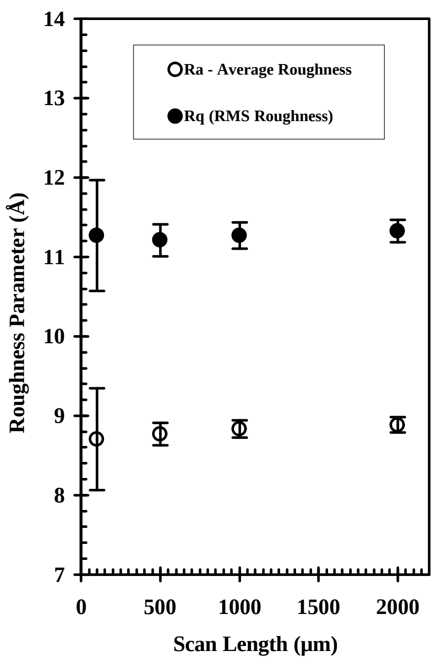

Figure 2 : Effect of Scan Length on Roughness Measured

Scan Speed

As mentioned earlier, the scan speed is an important factor in maintaining constant contact between the stylus and the surface. Scan speed depends indirectly on the stylus force applied also. If the can tolerate higher forces, the scans can be run at higher speeds. As such, 'low' and 'high' speeds and forces are sample specific and there is no definite scan speed that can be specified. For this study, a stylus force of 1mg was maintained while the scan speeds were varied. At lower speeds, the tool will be exposed to external noise for a longer period of time. If the tool is located in a noisy environment, this will lead to a higher value of roughness in the end results. Slow scan speed will also affect the throughput. At a high scan speed, the stylus may bounce, leading to higher values of roughness. Intermediate speeds will yield consistent results. Figure 3 shows the value of roughness measured as a function of scan speed. Scan speeds of 5 - 10μm/sec will be ideal for this surface. Higher or lower scan speed speeds will result in erroneous values of roughness.

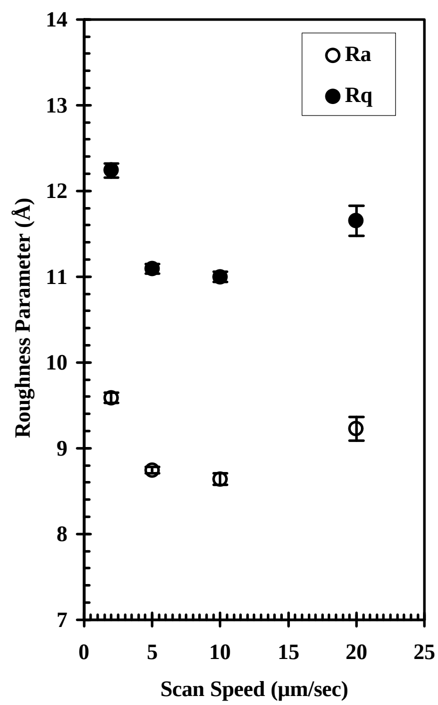

Figure 3 : Effect of scan speed on roughness measured

Stylus Force

The stylus force must be selected judiciously, depending on the substrate being measured. For example, with softer films like Copper or Nickel-Phosphorous films, it is advisable to use forces lower than 1mg. On the other hand, if the applied force is too low, the stylus may lose contact with the surface if it hits a feature with high aspect ratio. Too high a force may cause damage to the sample. In either case, one will see a larger standard deviation of the data. This fact is illustrated in figure 4. From the figure, we can say that a stylus force of 1 - 2mg will be ideal for the given sample.

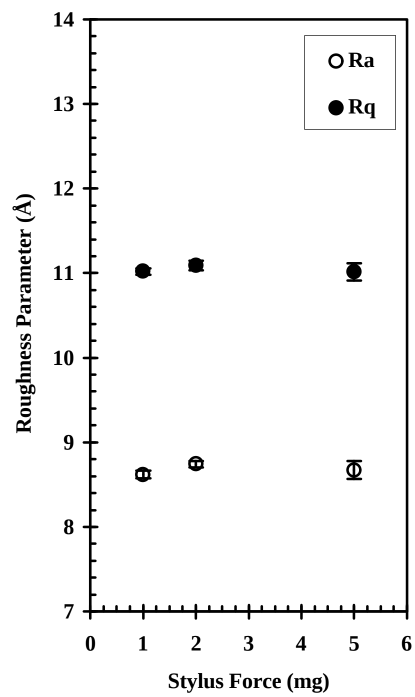

Figure 4 : Effect of stylus force on roughness measurements

Filtering and sampling interval

The Profiler software provides a user the option to select pre-programmed filters to cut out high (spatial) frequency information. This filter must be selected on the basis of the spatial resolution desired and the stylus tip radius. The effect of tip radius will be discussed in the next section. For a given tip radius, the noise filter must be selected such that it is less than the smallest spatial wavelength of interest.

On the same note, the sampling rate must be chosen such that one does not acquire too little or too much data. For example, consider a 2µm tip. A rule of thumb is that a 'unique' data point will be acquired every 2µm. In order to better define the surface, a sampling interval of 1µm would suffice. The profiler calculates the sampling interval as

$$\text{sampling interval} = \frac{\text{scan speed}}{\text{sampling frequency}}$$

For an optimal number of data points, the sampling interval can be chosen such that it is at least half of the tip radius, or a value smaller than the filter applied, whichever is larger.

If no filter is chosen when a recipe is generated, the Profiler software applies a default filter based on the scan speed and sampling rate. The values are tabulated and presented in the Reference manual. The user is advised to check this value to make sure it is suitable for the measurements.

Stylus Tip Radius

The selection of a stylus depends on the degree of spatial resolution desired. For very rough surfaces, where the roughness is of the order of microns, a stylus with a 1µm tip radius would ensure reliable measurements and longer tip life. As the size of the spatial features goes down, the tip radius must be reduced proportionately. Again, the final trace measured by the Profiler would be a function of the filtering also. If the tip radius is much smaller than the filter applied, the user will not gain any additional information.

Figure 5 shows three kinds of surfaces being measured with the same stylus. It is evident that the stylus will be able to resolve surface 1 accurately, but will not be able to define surfaces 2 and 3. But, in the case of surface 3, if the user is not interested in the high frequency information, he can use the same stylus and apply an appropriate noise filter to the scan.

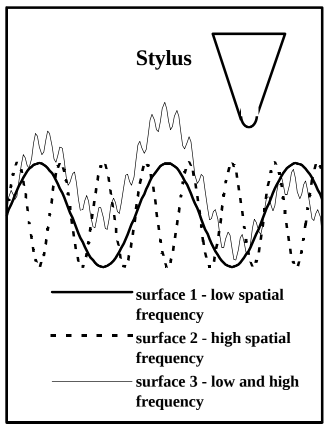

Figure 5 : Stylus traversing over high and low spatial frequency surfaces

Roughness measurements on a 10Å (nominal average roughness) disk were performed with a number of different styli with the following scan parameters:

Scan length	200 µm
Scan Speed	5 µm/sec
Sampling Rate	50 Hz
Stylus Force	0.5 mg
Vertical Range	6.5 µm
Noise Filter	0.25 µm
Long Wave Cut-off	25 µm
Measurement cursors	@ 5, 195 µm with delta = 0µm
Leveling Cursors	@ 0, 175 µm with delta = 25µm

The resulting Ra (average roughness) values are shown in Table 1 :

Stylus	**Tip Rad (µm)**	**Cone Angle (deg)**	**Ra (Avg Roughness) (Å) Mean**	**Std. Dev.**
S1	**0.10**	**84**	11.7	0.1
S2	**0.10**	**88**	12.3	0.2
S3	**0.10**	**95**	11.4	0.2
S4	**0.20**	**90**	11.6	0.2
S5	**0.25**	**90**	11.5	0.2
S6	**0.25**	**90**	10.7	0.2
S7	**5.00**	**60**	6.6	0.4
S8	**2.00**	**45**	9.5	0.2

Table 1 : Effect of stylus tip radius on roughness measured

From the above data, one can see that measurements with styli of radius 0.2µm or less yield the same information about the surface. This is because a spatial filter of 0.25µm is being applied to the trace.

Another way of deciding on the optimal tip and sampling rate is to look at the PSD (power spectral density)[3] of the surface. Any random trace (in this case roughness) can be reconstructed by adding sine waves of varying amplitudes and frequencies. A PSD plot shows us these frequencies and the relative magnitude of their contribution to the surface. For example, if the PSD shows a sharp spike at a certain frequency, that means that the surface has repetitive features at that spatial frequency.

The PSD corresponding to the scan from stylus S2 is illustrated in Figure 6. The horizontal axis of the PSD is in terms of spatial frequency (inverse of spatial wavelength) which has the units of 1/µm. A tip radius can be selected on the basis of the maximum frequency contributing to the PSD. For example, in this case spatial frequencies up to 2µm^{-1} are present in the PSD. That implies, the lowest spatial wavelength contributing to the surface is 0.5µm. In such a case, a stylus with a tip radius of 0.25µm or less must be selected to scan the surface. This also provides a validation for the trends observed in the data.

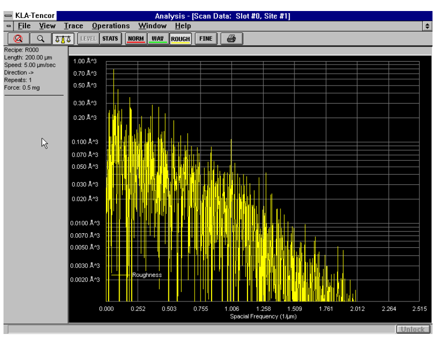

Figure 6 : PSD of roughness trace generated with stylus S2

Therefore, in order to select an appropriate stylus, the user must be aware of three factors:

- spatial resolution desired
- filters applied
- spatial wavelengths that make up the surface

Conclusions

The accuracy and repeatability of roughness measurements can be improved by choosing the proper scan parameters. An ideal scan would be (spatially) long enough to contain enough waviness and roughness information, without taking a long time or damaging the surface. The tip radius should be chosen such that it can resolve all the spatial features of interest. An appropriate noise filter must be applied to the data, depending on the spatial resolution desired.

References

1. " *High-Speed Roughness Measurements Increase Throughput*", Applications Note Prof #2, V1, Metrology Division, KLA-Tencor

2. "*Surface Texture (Surface Roughness, Waviness and Lay)*", ANSI/ASME B46.1-1985

3. "*BASIC Program for Power Spectrum Estimation*", E. L. Church and P. Z. Takacs, BNL #49035, rev. 5/94

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