

# Recent Advances in White-Light Interferometry - Speed Improvement and Transparent Film Profiling -

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**Abstract:** Two major shortcomings in white-light interferometric surface measurement are 1) slow measurement speed, and 2) error caused by a transparent film on the surface. This paper introduces new developments to solve these problems.

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## 1. Introduction

The technique of surface profile measurement utilizing white-light interferometry is widely used in industry as a non-contact and non-destructive method to quickly and accurately measure the profile of microscopic surfaces. However, it has some shortcomings such as (1) slow measurement speed, and (2) error caused by a transparent film on the surface.

To solve these problems, we can now use much more sophisticated algorithms, which would have been impractical ten years ago, thanks to the recent rapid advances in electronics and computer technology. As a result, far more effective commercial products are now possible.

This paper introduces some of such developments in white-light interferometry.

## 2. Speed Improvement by Sub-Nyquist Sampling

We have developed a new signal processing technique, named SEST [1,2]. This algorithm is based upon the fact that the interference fringe waveform can be reconstructed from sub-Nyquist sampled data by using the sampling theorem for band-pass signals [3]. The concept of the SEST algorithm is shown in Figure 1.

For this algorithm, the wavelength of the white light is limited to a narrow range by a band-pass filter in the illumination. When the frequency bandwidth of the interferogram  $f(z)$  is limited to  $\lambda_c \pm \lambda_b$ , the interferogram can be reconstructed from its sampled data  $f(z_m)$  ( $m=1,2,\dots,M$ ) as

$$f(z) = \sum_{m=1}^M y_m \phi_m(z), \quad (1)$$

where  $y_m$  is defined as  $y_m = f(z_m) - f_{average}$  as the AC component obtained by removing the DC component from the measured value  $f(z_m)$ , and  $\phi_m(z)$  is

$$\phi_m(z) = \text{sinc} \left[ \frac{\pi(z - z_m)}{2\Delta} \right] \cos \left[ \frac{4\pi(z - z_m)}{\lambda_c} \right], \quad (2)$$

where  $\Delta$  is the sampling interval, which must satisfy some conditions, and its maximum  $\Delta_{max}$  is expressed as

$$\Delta_{max} = \frac{1}{4} \left[ \frac{\lambda_c + \lambda_b}{2\lambda_b} \right] (\lambda_c - \lambda_b). \quad (3)$$

For example, in case of  $\lambda_c = 600\text{nm}$ ,  $\lambda_b = 20\text{nm}$ ,  $\Delta_{max}$  becomes  $2.175\mu\text{m}$ , which is 15 times wider than the Nyquist interval.

By squaring the envelope of the reconstructed interferogram, we can obtain a smooth function  $r(z)$  (the squared envelope function) to find the peak position.

However, for the purpose of surface profiling, only the peak position of  $r(z)$  is needed and the reconstructed interferogram is unnecessary. Therefore we obtained a formula to calculate the estimated value  $r_b(z)$  of  $r(z)$  directly from the sampled data. For example, when  $z$  is one of the sampled points, namely  $z = z_j$  ( $j=1,2,\dots,M$ ), the formula becomes a simple one that requires only algebraic computation, as

$$r_B(z_j) = (y_j)^2 + (4/\pi^2) \left\{ \sum_{m=1}^M \{y_m/(j-m)\} \right\}^2. \quad (4)$$

The value  $z$  where the squared envelope function  $r(z)$  becomes the maximum can be obtained by calculating  $r_B(z)$  at the sample points by equation (4) and searching the peak in the vicinity of the maximum value.

As a result, the number of sample points required can be reduced to one-tenth of that of the conventional method. The utilization of this algorithm has led to the world's fastest scanning speed of over 50 microns/sec, which is 7-15 times faster than with conventional algorithms.

Figure 2 shows an example of reconstructed waveform and calculated envelope. Figure 3 shows measurement result of IC bumps on a Si wafer obtained with 54 microns/sec scanning speed.

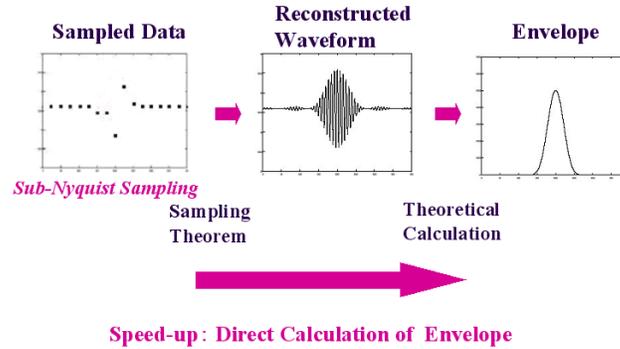


Fig. 1. Concept of the SEST algorithm.

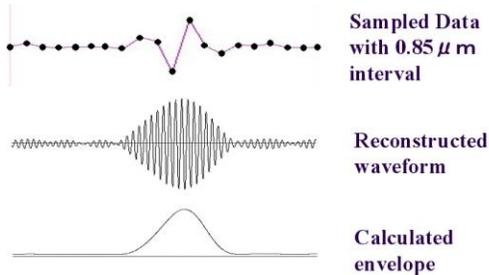


Fig. 2. Sampled data, reconstructed waveform and envelope.

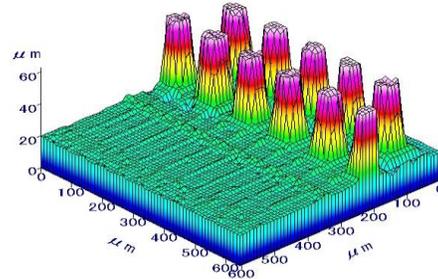


Fig. 3. Measurement of IC bumps using the SEST algorithm with 54 μm/sec speed.

#### 4. Profiling of a Thick Transparent Film

We have developed an algorithm, named KF, which can automatically detect the positions of two contrast peaks in an interferogram generated by vertical scanning interferometry [4]. From sampled data of interferogram as shown in Figure 4, this algorithm at first calculates the contrast, which is shown as a bar graph in Figure 5. Then the optimal threshold for peak separation is obtained using Otsu's automatic threshold selection method in the field of image processing. The solid line in Figure 5 shows the Otsu's objective function, and its minimum position is the optimum threshold point.

From the peak positions determined for each of the separated peak regions and the known refractive index of the film, the surface height, the back surface height and the film thickness are obtained. Using this algorithm, we have developed a non-contact Film Profiler SP-500F.

Figure 6 shows the measurement result of an oxide film step formed on a Si wafer. The measured surface step was 2.9 microns, and the film thickness was 4.0 microns in the thicker area and 1.1 microns in the thinner area. These thickness values completely agreed with the measurement by ellipsometry. It is also shown that the back surface was correctly measured as a flat surface, with the supposed refractive index of 1.46.

This development enables the following measurements, which would have been difficult using conventional methods: 1) Profiling of a surface covered with a transparent film; 2) Profiling of a bottom surface through a transparent film; and 3) 2D measurement of film thickness distribution.

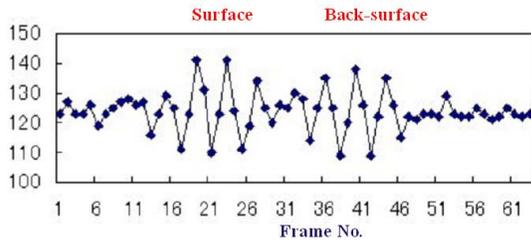


Fig. 4. Interferogram used for algorithm test.

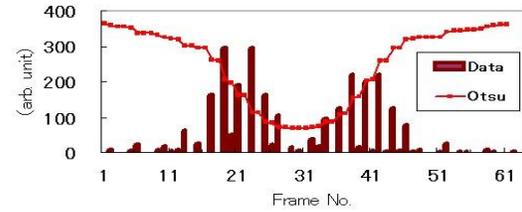


Fig. 5. Contrast data and Otsu's objective function for automatic threshold selection.

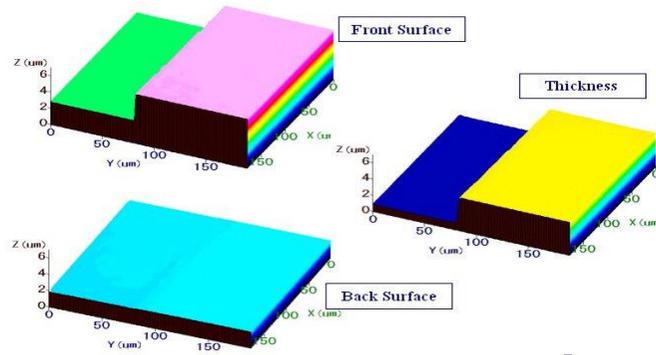


Fig. 6. Thick film measurement result.

## 5. Profiling of a Thin Transparent Film

When the film becomes very thin, the KF algorithm cannot be applied any more due to the overlap of two interference peaks. To solve this problem, we have developed an algorithm, named NF, which is robust enough to be practically used in industry. Using this algorithm, we have developed a non-contact Surface Profiler SP-700 for thin-film covered surfaces.

Figure 7 shows the measurement result of an oxide film with 100 and 300 nm thickness on a Si wafer. The repeatability (1 sigma) of the film thickness measurement is within 0.5nm.

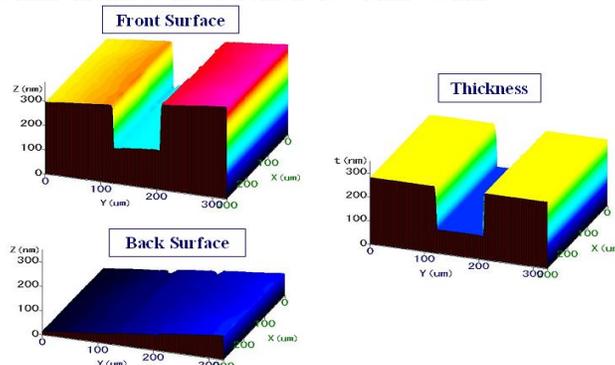


Fig. 7. Thin film measurement result.

## 6. Conclusions

Thanks to the recent rapid advances in electronics and computer technology, we can incorporate newly developed, sophisticated algorithms in the interferometric profiler, with dramatic results. The future is bright. I'd like to say that 'the 2nd generation of interferometry' has begun.

## 7. References

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