Technical Note No.3

High-speed non-contact 3-dimensional microscopic-surface-profiling using a new signal processing algorithm

1. Introduction

The need for highly accurate measurement of unevenness of 3-dimensional microscopic-surface of submicron to several tens microns has been increasing in semiconductor, liquid crystal and other industrial fields. Although many methods have been proposed so far, optical interferometry is deemed most suitable for FA applications because it has virtually unlimited measurement range while keeping high resolution and high repeatability.

The surface unevenness measurement using optical interference utilizes the phenomenon that dark and bright fringes are observed for the distance of optical paths for every 1/2 wavelength when interference is caused between the reflected light from the observation surface and the reflected light from the reference surface. In recent years, with the progress of digital image processing, it became possible to automatically measure surface profiles with high speed and high accuracy using automated interference fringe analysis. One of the most popular techniques is vertical scanning interferometry.

Toray Engineering Co., in cooperation with Ogawa Research Laboratory in the Graduate School of Information Science and Engineering of Tokyo Institute of Technology, has devised a new signal processing algorithm (named SB algorithm) that increases the scanning speed in the vertical scanning interferometry 10 times or more than that of conventional methods. The world's highest speed non-contact surface profiler SP-500 incorporating this algorithm is introduced here.

2. Principle of measurement

The interference microscope to be used in this measurement system (Mirau type) is shown in Figure 1.

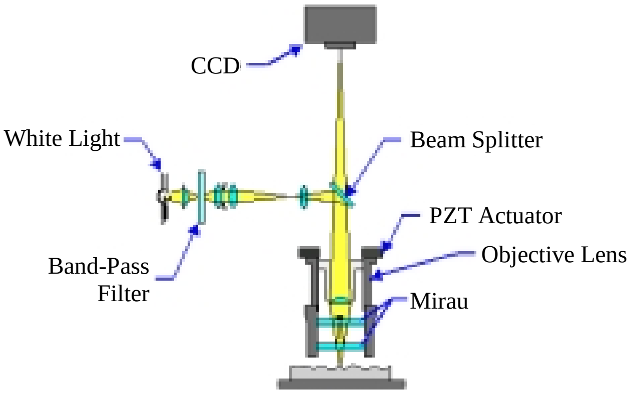

Figure 1 Optics of the interference microscope (Mirau type)

If the objective lens is scanned in the direction of the Z-axis and white light is used as the light source, interference fringes with the maximum contrast are observed where the distance of light paths between the surface of the specimen and the reference surface becomes zero as shown in Figure 2. Such an interferogram as shown in Figure 3 is obtained if the intensity of each point of these images is observed. As this peak position corresponds to the height of the surface of the specimen, the height at each pixel in the frame, namely 3-dimensional surface profiles can be obtained en bloc.

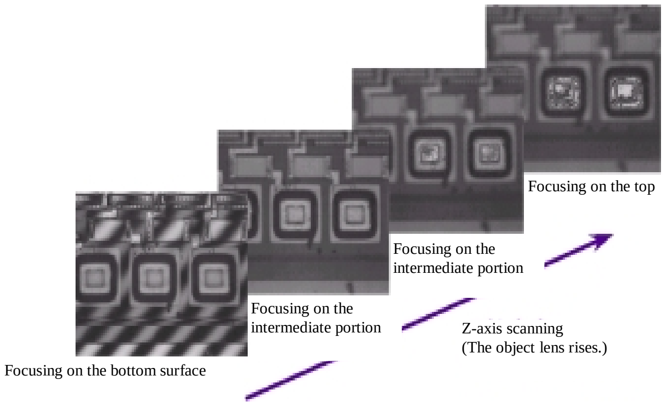

Figure 2 Interference images by scanning in the direction of the Z-axis

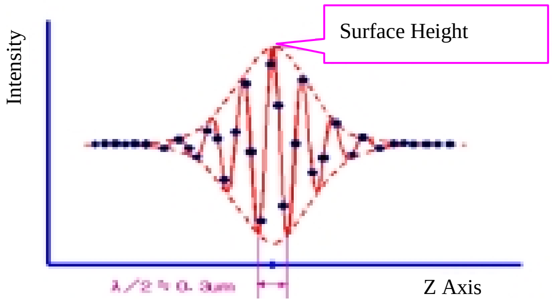

Figure 3 Interferogram

Data obtained in the actual measurement is not continuous as shown in Figure 3, however, and is discrete as shown by • in the chart. There are several proposed methods for obtaining the maximum position of the interferogram from such discrete data. For example, in one method, the maximum position of the envelope waveform is obtained by squaring the AC components of the interferogram and passing the obtained results to the low-pass filter. In such a method, there is a problem of slow measurement speed as the sample point interval must be sufficiently small.

3. New algorithm – SB method –(1)-(3)

The authors developed a new algorithm (named the SB algorithm) in which the peak position of the interferogram is calculated from the measured values which are sampled with a far wider interval than the sampling interval satisfying the Nyquist theorem (hereafter referred to as the “Nyquist interval”). For this algorithm, it is necessary that the wavelength of the white light is limited to the narrow range, but this can be achieved by inserting a band-pass filter in the illumination unit of the microscope. An outline of the SB algorithm is described below.

When the bandwidth of the frequency of the interferogram f(h) is limited to $\omega_c \pm \omega_a$, the band-pass type sampling theorem can be applied, and f(h) can be reconstructed as

$$f(h) = \sum_{m=-\infty}^{\infty} f(h_m)\,\phi_m(h) \qquad (1)$$

using its sample value $f(h_m)$ ($m = -\infty$ to $+\infty$).

$f(h_m)$ is the intensity at the sampled point $h_m = (m-1)\,\Delta B$; the sample point interval $\Delta B = \pi/(2\omega_a')$ where ω_c' and ω_a' are positive real numbers which satisfy $\omega_c' - \omega_a' \le \omega_c - \omega_a$; $\omega_c + \omega_a \le \omega_c' + \omega_a'$; $\omega_c' = (2I + 1)\omega_a'$ (I is a positive integer).

$\phi_m(h)$ is ;

$$\phi_m(h) = \mathrm{sinc}[\omega_a'(h-h_m)/\pi]\cdot\cos[\omega_c'(h-h_m)] \qquad (2)$$

Since the number of sample values is finite in the actual system, the infinite series of the formula (1) is aborted at the number M, and y_m is defined as $y_m = z_m - z_{average}$ as the AC component obtained by removing the DC component from the measured value $z_{m.}$. Then, the reconstructed function $f_B(h)$ of the interferogram is represented by

$$f_B(h) = \sum_{m=1}^{M} y_m\,\phi_m(h) \qquad (3)$$

By squaring the envelope of this reconstructed interferogram, we can obtain a smooth function r(h) (hereafter referred to as the squared envelope function) to find the peak position.

Only the peak position of r(h) is needed, and the reconstructed interferogram is practically unnecessary. Therefore we obtained a formula to calculate the estimated value $r_B(h_J)$ of r(h) directly from the sampled values. For example, when h is one of the sampled points, namely $h = h_J$ (J is an integer defined as $1 \le J \le M$), the formula becomes a simple one that requires only algebraic computation, as

$$r_B(h_J) = (y_J)^2 + (4/\pi^2)\{\Sigma(y_m/(J-m)\}^2 \qquad (4)$$

where, with respect m, Σ represents the sum of all sample points of odd order if J is an even number and the sum of all sample points of even order if J is an odd number.

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

The concept of the SB algorithm is shown in Figure 4.

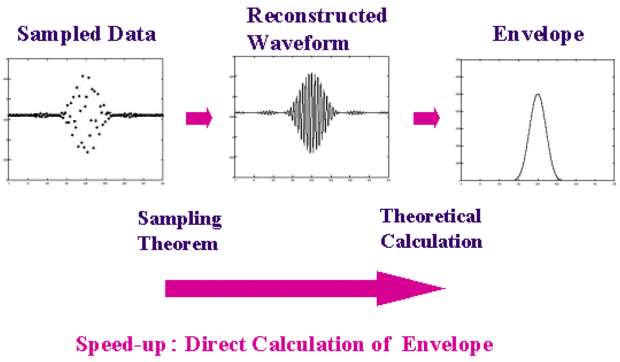

Figure 4 Concept of the SB algorithm

4. System configuration

The developed system is shown in Figure 5 and its configuration in Figure 6.

Figure 5 Surface Profiler SP-500

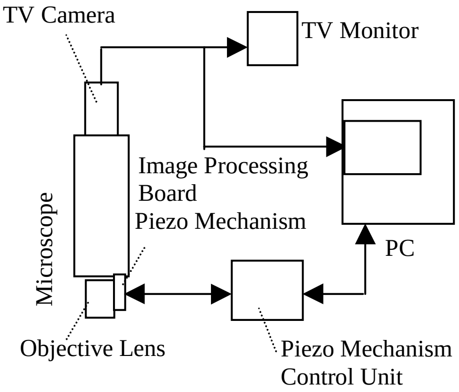

Figure 6 System configuration

The interference optics consists of a combination of a microscope and a Mirau interference objective lens. The Z-axis scanning system is of a structure in which the objective lens is moved by a piezo mechanism. A halogen lamp is used as the illumination light source and an interference filter with a center wavelength of 600 nm and a half-width of 40 nm is used as the narrow-band filter.

The image signal from the TV camera is converted into a digital signal and taken into the memory as the data of 512 × 480 pixels × 8 bits for each frame. Image processing computation is conducted by a Pentium processor.

5. Features

Features of SP-500 are as follows:

(1) High accuracy: Height measurement resolution of nm order.

(2) High-speed scanning: Z-axis scanning speed of 50 µm/second is possible (the fastest in the world).
(3) High-speed 3D measurement by a 2-D camera: Measurement time is within several seconds/Field-of-view.
(4) Wide measurement range: Maximum height measurement range of 350 µm.
(5) Variable field size: Maximum field size of several mm × several mm.

6. Measurement results of actual samples

Examples of measurement of actual samples with the surface profiler SP-500 are shown below.

6.1 Standard step height

The results of measurement of the standard step height(9.947 µm) with the scanning speed 25.5 µm/sec (the sample point interval 0.85 µm) are shown in Figure 7. Although the sample point interval is approximately 6 times the Nyquist interval, an accurate surface profile was measured. The average value of the step was 10.031 µm.

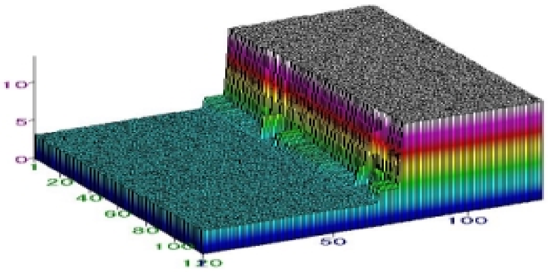

Figure 7 Measurement example: Standard step height

The intensity data, reconstructed waveform, and squared envelope function on a point are shown in Figure 8. The latter two waveforms were calculated with a sufficiently narrow interval for the demonstration purpose.

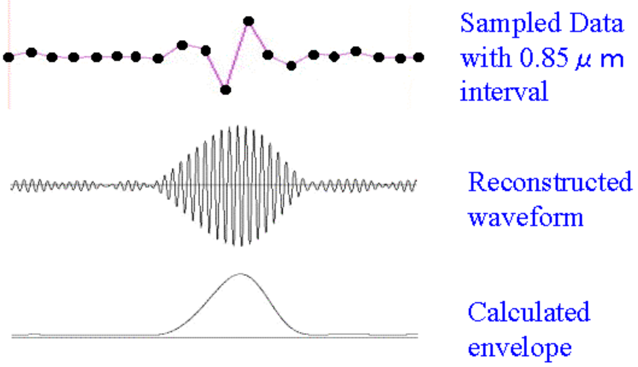

Figure 8 Sampled data, its reconstructed waveform and square envelope function

6.2 Surface of a coin

Figure 10 and 11 shows the surface profile of the coin in Figure 9 obtained at a speed of 51 μm/sec that is equal to the sample point interval approximately 12 times the Nyquist interval. The surface profile was measured within 2 seconds with a measurement range of 55 μm.

Figure 9　Measured coin

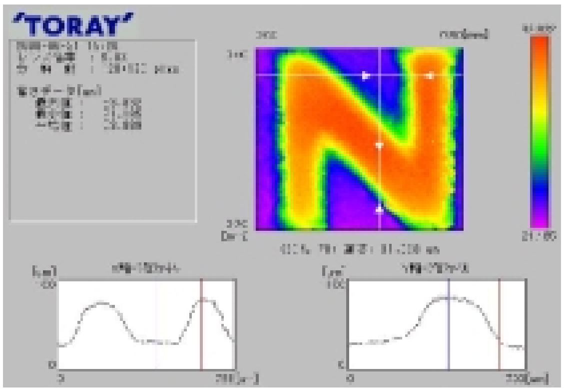

Figure 10　Measurement result
(Scanning speed: 51 μm/sec)

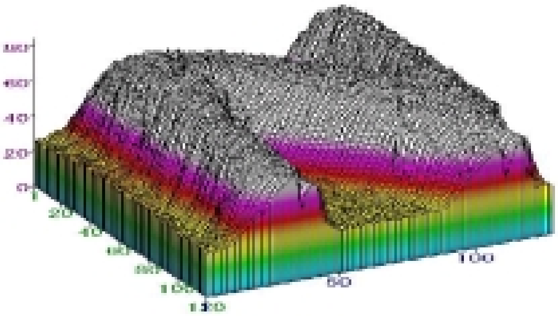

Figure 11　3-dimensional view of the measurement result

7. Conclusion

The authors have devised a new signal processing algorithm utilizing the band-pass type sampling theorem in the vertical scanning white light interferometry, and developed the surface profiler SP-500 that achieved the world's fastest scanning speed of 50um/sec. The heights in one field of the camera (15,000 to 250,000 points) can be measured within several seconds. Furthermore, measurement by the phase shift algorithm is also possible with the same system.

The applications include semiconductors, displays, electronic parts, optical elements, and high-precision machine components.

References:

(1) "Fast Surface Profiler by White-Light Interferometry Using a New Algorithm, the SEST Algorithm", Proc. of SPIE Annual Meeting 2001, vol.4451,356/367(2001.8)

(2) "Fast surface profiler by white-light interferometry by use of a new algorithm based on sampling theory", Appiled Optics, vol.41, no.23, 4876/4883 (2002.8)

(3) Patent pending

■ TOPICS:

The SP-500 surface profiler was introduced in the NHK TV news program "Close-up Gendai" on July 25, 2000.

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