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High Precision Measurement of 3D Profile Using Confocal Differential Heterodyne Interferometer

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The differential heterodyne interferometer (DHI) is suitable for precise measurement of step height and line width, since its differential configuration can significantly reduce disturbances from the environment [1,2]. Like most phase measuring interferometers, however, the DHI is limited, in that it can obtain only the phase from 0 to 2π, because of the sinusoidal nature of the optical interference involved. Thus, the measurable step height is limited to one quarter of the wavelength of the light source. This study describes a confocal differential heterodyne interferometer (CDHI) for measuring step heights of several micrometers, with a high resolution and line width with high repeatability. The CDHI has a simple structure and rapid measurement speed.
OCIS codes : 180.1790, 180.5810, 120.3930

I. INTRODUCTION

The differential heterodyne interferometer (DHI) was developed to evaluate small differences in optical path lengths. Since its differential configuration greatly reduces disturbances from the environment, a depth resolution of higher than 1Å can be obtained [3]. Moreover, unlike mechanical stylus profiling, the DHI is a noncontact and nondestructive device. Therefore, the DHI has many potential applications in future optical microscopy. Like most phase measuring interferometers, however, the DHI is limited, in that it can obtain only the phase from 0 to 2π. This 2π ambiguity in the phase measurement limits measurable step height to less than a quarter of the wavelength of the light source [4]. To overcome this limitation, this paper describes an interferometer based on the differential heterodyne technique and the confocal principle. Using this confocal differential heterodyne interferometer, a step height of several micrometers can be measured with a resolution of 0.5 nm. In addition, this system can measure a line width with high repeatability.

II. STRUCTURE OF CDHI

Fig. 1. schematically presents the structure of the proposed confocal differential heterodyne interferometer (CDHI). The light source is a He-Ne laser, with a frequency of 633 nm. The light from the laser is directed into a Bragg cell. Then, the Bragg cell generates two beams, the frequencies of which are slightly different. The difference between the frequencies corresponds to the modulation frequency from the function generator. Relay optics, composed of two lenses, are located beyond the Bragg cell. Next, the two beams head toward a polarizing beam splitter (PBS). The beams transmitted by the PBS illuminate the specimen through an objective lens. Since the incident angles of the two beams to the objective are slightly different, two focal points are formed on different places of the sample surface. The distance between the focal points can be adjusted by changing the modulation frequency. Since there is a quarter-wave plate between the PBS and the objective, the PBS reflects the light from the specimen. The PBS reflects

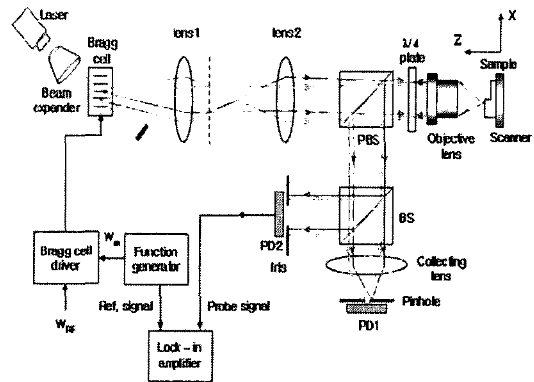

FIG. 1. Schematic diagram of CDHI.

this light toward a beam splitter (BS). The light is then transmitted by the BS toward a collecting lens. As depicted in Fig. 1 a pinhole is located on the focal plane of the collecting lens and causes a confocal effect. Since light beating occurs between the two beams, the signal detected by PD1 becomes sinusoidal. In order to eliminate this AC component, the signal is low pass filtered. Let this filtered signal be a confocal signal. In contrast, PD2 detects the light reflected by the BS, and the signal detected by PD2 is also sinusoidal. Let this sinusoidal signal be a probe signal. The function generator generates a reference signal. A lock-in amplifier can obtain the phase difference between the reference and the probe signal.

By means of this process, most variation caused by vibrations and air turbulence is neutralized, because of the largely common path configuration. So, a high S/N ratio can be obtained.

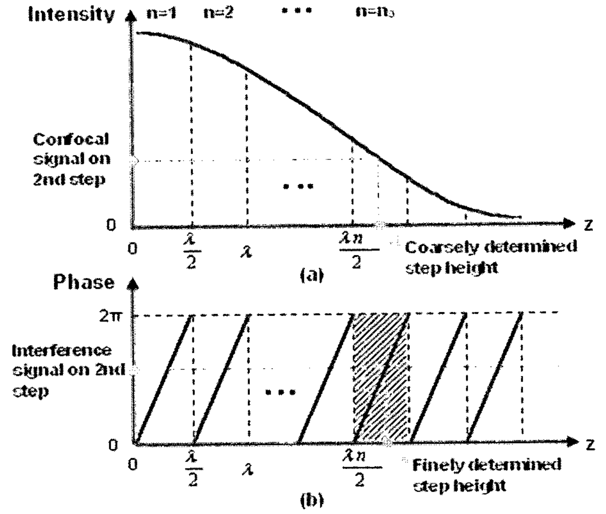

FIG. 2. (a) Coarse measurement using confocal signal (b) Fine measurement using interference signal.

III. MEASUREMENT ALGORITHM

1. Step height measurement algorithm

As depicted in Fig. 1, the scanner can move the sample having a large step height in two directions: x and z. The measurement algorithm can be divided into two steps. In the first step, the scanner scans the specimen along the z-direction. Then, the axial response of the confocal signal can be obtained from PD1. When the surface of the specimen is placed exactly at the focal plane (z=0), the intensity detected by PD1 is at its maximum value. As z increases from zero, the detected intensity decreases. Therefore, the position of the specimen along the z-direction becomes a function of the intensity. In the second step, the scanner scans the specimen along the x-direction. Then, the confocal signal from PD1 and the interference signal from PD2 are obtained simultaneously. Using a lock in amplifier, the phase difference between the interference signal from PD2 and the reference signal from the function generator is obtained. When only the interference signal is used to measure the step height, the same phase difference value is obtained whenever the change in the value is a multiple of 2π. However, an axial response of confocal signal was obtained for the first step of the measurement. Using it and the confocal signal for the second step of the measurement, the step height of the sample can be measured approximately, as depicted in Fig. 2 (a). The approximately measured step height is used to determine the multiplication factor, n. Then, the step height can be measured accurately, using an interference signal for the second step of the measurement as depicted in Fig. 2 (b).

Using this method, the maximum measurable step height depends on the width of the axial response of the confocal signal. In addition, the accuracy of the approximate measurement depends on the sensitivity of the axial response. Moreover, as the width of the axial response is increased, the sensitivity is decreased. Therefore, the width and the sensitivity of axial response must be correlated to obtain both a high height measurement range and a high resolution.

2. Line width measurement algorithm

As depicted in Fig. 3, the phase difference between reference signal and interference signal has maximum value at rising edge and minimum value at falling edge of specimen. Therefore we can obtain the line width of the specimen by measuring the distance between the maximum and the minimum. Since, the interference signal is very stable and has high S/N ratio we can measure the line width with high repeatability.

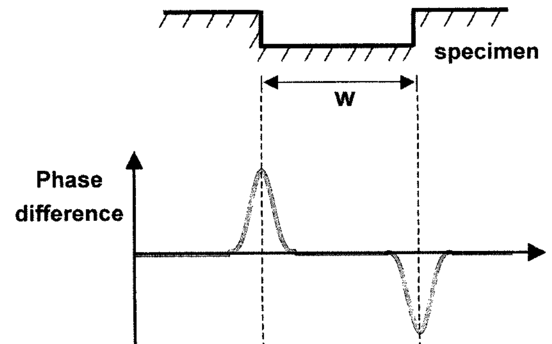

FIG. 3. Line width measurement algorithm.

IV. EXPERIMENTAL RESULTS

Fig. 4 is a profile of the sample obtained by commercial scanning electron microscope. As depicted in Fig. 4, the step height of the sample is 199 nm. Since this value is larger than a quarter of the wavelength of the light source, DHI can't measure it. Fig. 5 is an axial response obtained on the first step. The NA of the objective lens and collecting lens used are 0.65 and 0.25 respectively. And the diameter of the pinhole is 25 um. The axial response is fitted by a polynomial equation of six order. Fig. 6 shows the confocal signal obtained on the second step of measurement. The height information is a function of intensity in Fig. 5. Using this relation, Fig. 6 can be converted to height information as depicted in Fig. 7. The step height obtained in the above process is 224 nm. This means that the step height of the measured sample is between $\lambda/4$ and $\lambda/2$. Fig. 8 shows the interference signal obtained on the second step of measurement. The maximum phase difference is 135°. Since the step height is between $\lambda/4$ and $\lambda/2$, this phase difference corresponds to 198 nm.

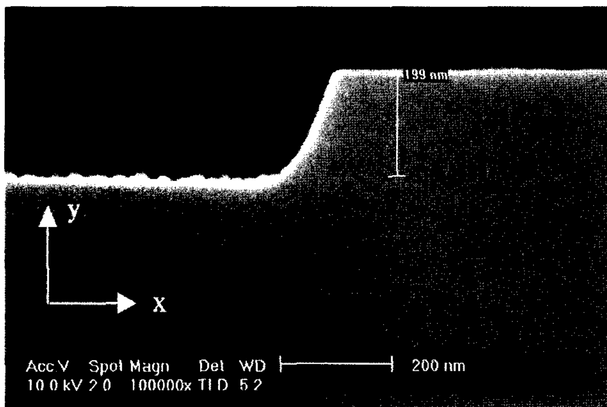

FIG. 4. SEM image of specimen.

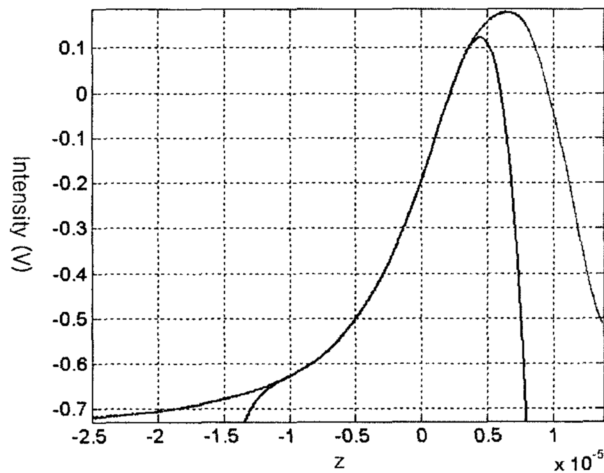

FIG. 5. Axial response of confocal signal.

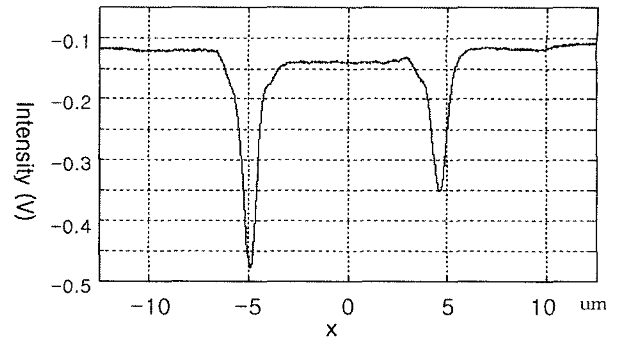

FIG. 6. Confocal signal obtained for the first step.

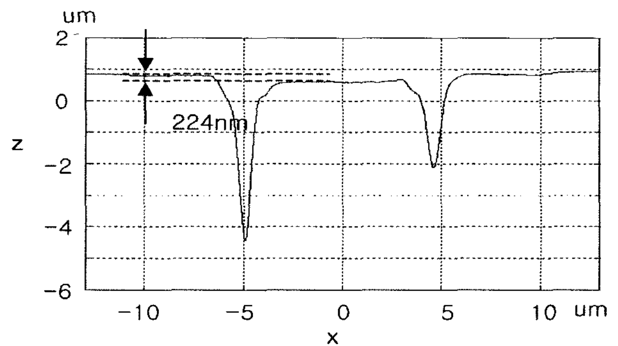

FIG. 7. Height information from axial response and confocal signal.

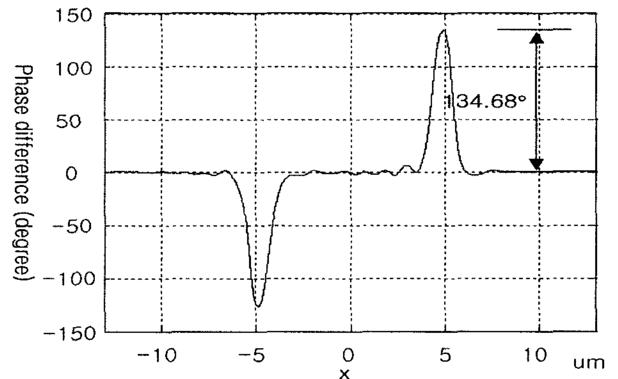

FIG. 8. Interference signal obtained for the second step.

Fig. 9 depicts the line width measurement result. The distance between maximum and minimum is 9.98 um. The line width obtained by conventional SEM is 9.84um. In order to check repeatability, we measured the same specimen twenty times. The standard deviation was 71 nm. These results show our measurement algorithm is reasonable and repeatable.

V. CONCLUSION

This paper describes the use of an interferometer to measure large step height and line width. The proposed

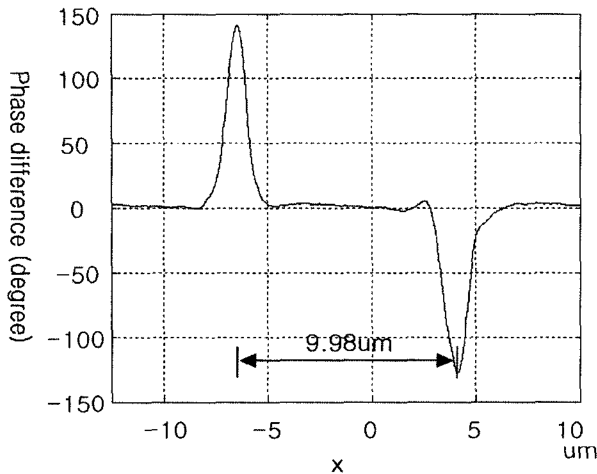

FIG. 9. Line width measurement.

confocal differential heterodyne interferometer is composed of a differential heterodyne interferometer, combined with a confocal scanning microscope. Using the CDHI, a step height larger than a quarter of the wavelength can be measured with high resolution. Furthermore, the measurement time is short, since only one scan, in both the z and x directions, is required to measure the step height. Also the CDHI can measure a line width with high repeatability. To verify the performance of the CDHI, a sample having a step height larger than a quarter of the wavelength was used. The experiment demonstrates that the CDHI produces a similar result as that of a commercial scanning electron microscope. The expected use of the proposed CDHI is to test the pattern on a semiconductor wafer, or an LCD panel, containing a step height of several micrometers.

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