Development of Non-Contact Micro-Nano Displacement Sensor using Interferometric Phenomena

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Abstract

We developed a non-contact micro-nano displacement sensor based on moiré interference phenomena. This method can detect a relative displacement between a measurement object and a working reference plane using diffraction gratings. Even if you repeatedly attached and removed the measurement object on the stage, the displacement measurement can be done in high accuracy. And it is not influenced from the fixing accuracy of attachment, because of a direct measurement from the gratings on measurement object and reference plane.

1 Introduction

For DNA and cell observations, optical device alignment system for next-generation optical communication and semiconductor production equipment, a high resolution displacement sensor is needed for the development of nanotechnology. Several displacement measurement methods and alignment methods have been proposed by many researchers [1-4]. Some of the studies have been achieved accuracy with the order of sub-nanometers. However, a lot of studies have been satisfactory about repeatability.

In this paper, a micro-nano displacement sensor using interferometric phenomena is proposed and tested under several conditions, theoretically and experimentally reviewed to make effective use of the moiré signals. The moiré signal which passes through two gratings is expressed as a function of displacement between gratings. The moiré signal intensity varies periodically as substantially sinusoidal waveform. Therefore, we use the moiré signal for displacement sensor. In the case of one pair of gratings, the region where sensitivity is particularly low is generated, since there is the region where the variation of the moiré signal intensity is small. Therefore, we use the two pairs of gratings. In this method, the position of the first gating of the second pair is shifted to the position of first pair. As a result, the moiré signals from two pair of gratings have the phase difference corresponding to a shift amount. By using these two moiré signals, it is possible to measure displacement with high resolution.

2 Experimental setup

Schematic of the developed displacement sensor is shown in Fig.1. The sensor consists of a light source (wavelength: λ), two pair of gratings (pitch: P) and two photodetectors. The light beams which are equally divided by beam splitter are normal incidence to the two pair of gratings. Each of first gratings of grating pairs is fixed on the precision motion stage. This stage is movable in perpendicular direction to light axis.

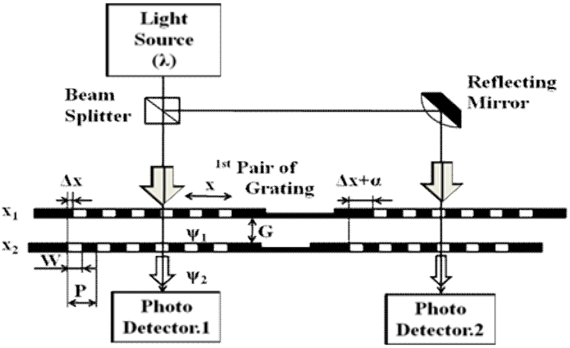

Figure 1: Schematic diagram of displacement sensor

Detected moiré signal intensity I is expressed as a function of the square of the light amplitude [5].

$$I(\Delta x, G) = |\psi_2(\Delta x, G)|^2 \tag{1}$$

Where Δx is the relative displacement of two gratings, G is the gap between the gratings and ψ_2 is the light amplitude of the 0th order beam diffracted from the second grating. Equation (1) indicated that the moiré signal intensity depends on the relative displacement when the gap G is constant. Therefore, the displacement is calculated by the moiré signal intensity. In this sensor, the 1st and 2nd pairs of gratings are used. The position of the first grating of the 2nd pair is fixed with arbitrarily displacement α=nP (n=0-0.5) to the position of first pair. Hence, the moiré signal intensities I_0 and I_α detected from photodetector1 and 2 are expressed by equation (2) and (3), respectively.

$$I_0(\Delta x, G) = |\psi_2(\Delta x, G)|^2 \tag{2}$$

$$I_\alpha(\Delta x + \alpha, G) = |\psi_2(\Delta x + \alpha, G)|^2 \tag{3}$$

By combining these two characteristics, it is possible to expand the range of detection and improve the detection resolution.

3 Results and discussion

The typical characteristic of the moiré signal intensity as a function of relative displacement is shown in Fig.2. The experimental conditions are λ =670nm, P=10μm, G=490μm, n=0.3. Figure 2 shows that the experimental result agrees with the simulation result. The moiré signal intensities I_0 and I_α vary according to the displacement, periodically. The period of the intensity is the same as the pitch of grating. The results also indicated that the moiré signal intensity I_α delayed n period to I_0.

The detection resolution of the displacement is determined from a variation (*dI*/*dx*) of the moiré signal intensity. We effectively utilize the intensity with in a steeper slope region (hatched region in Fig.2) to achieve a high accuracy of the displacement measurement.

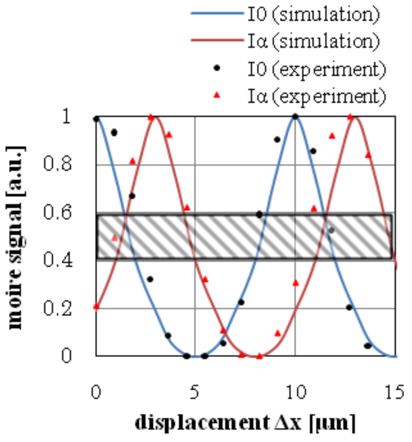

Figure 2: Characteristic of moiré signal intensity

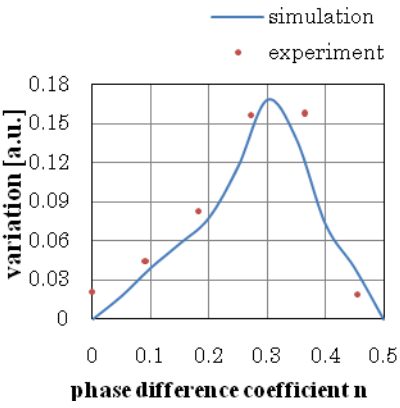

Figure 3: Phase difference coefficient n as a function of minimum variation

To effectively use of the moiré signal, α should be selected properly. Figure 3 shows the phase difference coefficient n as a function of minimum variation. The minimum variation of the moiré signal intensity is obtained by comparison of two variations dI_0/dx and dI_α/dx. The results indicated that the n=0.25-0.3 (approximately 90 degree phase shifted) is optimum condition for wide range displacement measurement. The resolutions obtained by simulation and experimental results are 1.3nm and 1.4nm (σ=13nm) at calculation conditions of P=10μm, n=0.3, detector resolution of 1mV and amplitude of moiré signal intensity 0-4.5V.

For alignment measurement, we only use the steeper slope region. In this case, we observed σ=1.1nm. To negate the gap and the light source fluctuation, the differential moiré signal (I_0 - I_α) at condition of n=0.5 (180 degree phase shifted) can be used.

4 Concluding remarks

A non-contact micro-nano displacement sensor based on moiré interference phenomena is proposed. This sensor has several advantages. The direct measurement from the gratings on the measurement object and the reference plane is possible. And there is no complicated setting. It is neither influenced by gap nor light source fluctuation by using the differential signal. Real time control is possible due to the simple system without image processing. It is easy to apply to present micro-nano device process in industry.

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References:

[1] S. Hattori, et al., Bul. the Japan Society of Precision Eng. 20, 2 (1986)73-78.
[2] H. Zhou, et al., J. Vac. Sci. Technol. B12, 3261(1994)
[3] E. E. Moon, Ph.D. Thesis, MIT (2004)
[4] B. Choi, et. al., J. Opt. A, Pure Appl. Opt.9, 1087-1094 (2007)
[5] Y. Uchida, EUSPEN Conf. Proc., Vol.1, 224-227 (2009)