Scanning measurement of step height and freeform surface by using optically trapped microsphere

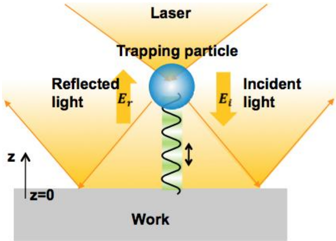
M. Michihata, Y. Takaya, T. Washitani, T. Hayashi
Osaka University, Japan
michihata@mech.eng.osaka-u.ac.jp

Abstract

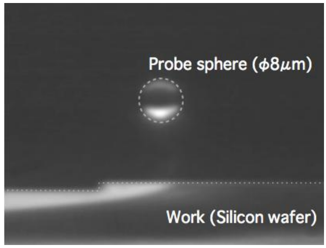
Currently we study the scanning type probe for surface profile by developing the optically trapped microsphere. In this paper, firstly performance of the scanning mode was examined by comparing with the tactile mode. Secondly, the method to measure a step height with scanning mode was proposed. At first, profile measurement of an aspheric lens by both tactile and scanning mode was conducted in order to assess the scanning mode with the standing wave scale. The measured results shows that the measured shape by scanning mode was coincident with the result by the tactile mode well. Besides, it was proposed the method to evaluate a step height with the optically trapped scanning probe with the SWS through measurement of the micro-groove depth. The results of a step height measurement were agreed with one from FE-SEM.

1 Introduction

Needs to measure the dimensions of micro-structures are increased. The micro-coordinate measuring machine (CMM) is the one of the solutions, although there are still issues to be solved. One of which is the micro-probing system. Requirements for the probe system are, for example, resolution of 10 nm and a probe diameter as small as 50 μm. We have been developing the micro-probe system for the micro-CMM [1], which is an optically trapped glass sphere by means of the laser trapping technique. A size of the probe is 8 μm in diameter. The resolution of surface sensing was achieved approximately 30 nm. This probe detects the surface point by point, that is, a tactile probe. As well as measurement resolution and a size of the probe, a measurement speed is one of the most important specifications for the micro-probe system. Therefore, currently we study the scanning type probe for a surface profile by developing the optically trapped microsphere. In this paper, firstly performance of the scanning mode was examined by comparing with the tactile mode. Secondly, the method to measure a step height with scanning mode was proposed.



(a) Conceptual sketch.



(b) CCD image.

Fig.1: Surface measurement using the optically trapped microsphere with the SWS.

2 Principle of measurement

The optically trapped glass microsphere (φ8 μm) is used as the probe. The focused laser generates steep gradient of optical potential that confines the microsphere nearby the laser focus. When a measured surface laid on the optical axis shown in Fig.1, the transmitted laser beyond the microsphere reaches the surface to be measured, and then the retro-reflected light and the incident laser generate a standing wave of optical potential along with the optical axis. A pitch of the standing wave is subjected to the laser wavelength. Thereby, the standing wave performs as a precise length scale, which is the standing wave scale (SWS). The SWS provides spatially periodic weak forces to the optically trapped microsphere. By measuring the displacement of the microsphere, the microsphere acts as a probe to read the SWS [2,3]. Since the SWS origin is rooted on the measured surface, it can measure the surface displacement from the probe along the optical axis by counting the divisions of the SWS. In our measurement system, the probe was scanned over the measured work surface by the precision XYZ stage [1].

3 Validation of scanning mode measurement

Firstly, we conducted to measure an aspheric lens by both tactile and scanning mode, in order to assess the scanning mode with the SWS. In scanning mode, the probe is scaned above the surface horizontally, as the distance between the probe and the surface is varied according to the surface topography. Thus, the surface profile is measured with the SWS. Here a glass aspherical lens (φ9 mm) was used as a work. The probe was scanned around 10 μm above the top surface of the lens with a speed of 4.2 μm/sec. over 1.5 mm along X-axis. The lens form was measured by recording the X-coordinates where the probe gets across the each division of the SWS. On the other hands, in tactile measurement, the transversally vibrated probe was approached vertically to the lens surface at each X-coordinate with interval of 10 µm. The lens surface was detected when the respond amplitude of the probe was damped a half of the initial amplitude. Z-coordinates of the detected points were coordinated by transferred distance of the precise stage motion. Same surface profile was measure for both measurement modes. The measured results are shown in Fig.2. The measured shape by scanning mode was coincident with the result by the tactile mode well.

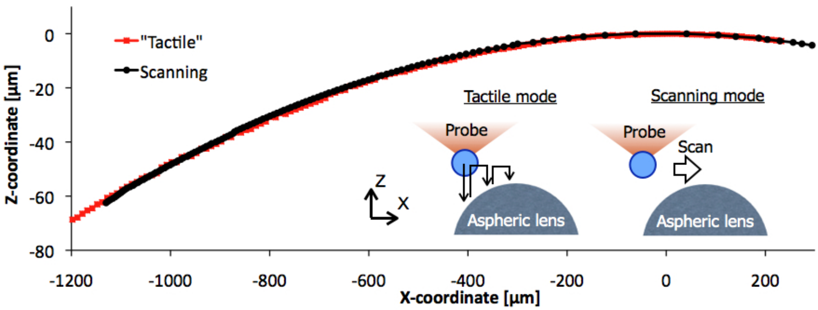


Fig.2: Measured results of an aspheric lens by scanning and tactile mode.

4 Step height measurement

As represented MEMS structures, a step height is an important structure to be evaluated. Because the SWS is based on an interference pattern, phase jumps are occurred at steep surfaces such as a step height. It is proposed, here, the method to evaluate a step height with the optically trapped probe with the SWS.

A cross-correlation calculation was employed to match data before and after a step height, which is so-called the unwrapping process. To unwrap the phase jumps, the probe was scanned vertically just before and after the step height. As different from general interference patterns, the SWS has different optical intensity contrasts at each position of the scale itself. The intensity contrast is strong near surface and weak far from surface (Fig.4(a)). Therefore, by calculating the cross correlation of the vertical scanning data, it is possible to unwrap the disconnected data. In this paper, via depth measurement of a micro groove, feasiblity of this method was confirmed. Fig.3, 4 illustrates the procedure of measuring a micro groove. The probe was scanned vertically at top and bottom surface of the groove.

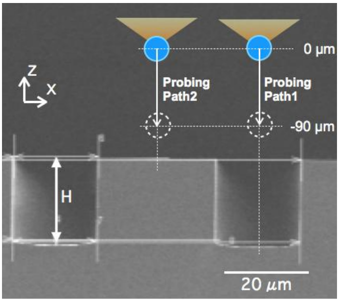
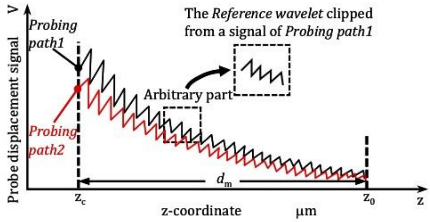
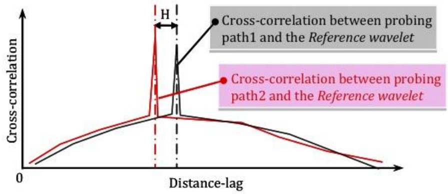


Fig.3: Measurement of step height.



(a) Probe displacement signal for vertical scan.



(b) Cross-correlation.

Fig.4: Measurement procedure of step height.

A reference wavelet was clipped from arbitrary part of the signals obtained from the vertical scan (Fig.4(a)). The cross-correlation between the reference wavelet and the signals at both surfaces were calculated. Because of matching the intensity contrast, the cross-correlations for both signals have a specific peak. Distance between the peaks indicates the groove depth. Here, three works having different depth were measured. The measured results were compared with the result from FE-SEM, which is shown in Table 1. Measurement repeatability was more or less 0.15 μm. The groove depth was largely agreed with ones from FE-SEM. This result validates the feasibility of the proposed method to measure a step height by the optically trapped probe with the SWS.

Table 1: Measured groove depth compearing with results of FE-SEM.

	Groove depth, H [μm]	
	FE-SEM	**Measured results**
Work 1	**2.0**	**1.44 ± 0.13**
Work 2	**12.1**	**10.34 ± 0.19**
Work 3	**21.6**	**20.61 ± 0.14**

5 Conclusion

In this paper, scanninng measurement by the optically trapped probe with the SWS was porposed and examined via measurements of smooth surface and step height.

References:

[1] M.Michihata, et.al., *Annals of CIRP*, 57(1), (2008) pp.493.

[2] Y. Takaya, et.al., *Proc. the 4th CIRP HPC*, Gifu (2010) p. 243.

[3] M. Michihata, et.al,, *Review of Scientific Instruments*, 81(1) (2010) 015107