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Rapid step height measurements by polarized dual low coherence scanning interferometry

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Abstract

We demonetrate a polarized dual low coherence scanning interferometer for rapid step height measurements. The polarization multiplexed phase extraction technique and the dual low coherence scheme can alleviate the strict scanning conditions of typical low coherence scanning interferometers and reduce the measurement time. In the proposed interferometer, the sampling interval is not critical because the visibility and the phase are immediately calculated during the scanning procedure, and the whole scanning distance becomes significantly reduced by the dual low coherence principle. To verify the system performance, the surface profiles of a step height specimen was measured, and the whole scanning distance was more than 10 times reduced without the specific sampling conditions.

Keywords : low coherence scanning interferometry, dual low coherence, spatial phase shifting, polarization camera

1. Introduction

Low coherence scanning interferometry (LCSI) is one of the most popular 3D surface metrological tools in various industrial fields such as semiconductor and display. Based on the temporal low coherence of a broadband light source, LCSI enables to measure complex surface textures without the well-known 2π-ambiguity problem.

However, the main disadvantage of LCSI is the measurement speed compared to the other competitive surface measurement tool, confocal scanning microscopy (CSM). By simply detecting the peak intensity position in confocal configuration, CSM can rapidly obtain the best focal positions corresponding to surface profiles because it does not have any specific scanning conditions to obtain the axial intensity response curve. However, the scanning interval needs to be determined to obtain the correlogram by the rigorous sampling theory, which restrict the measuremen speed in LCSI.

In this investigation, we attempt to develop high speed LCSI, so called polarized dual low coherence interferometery (PD-LCSI), using the polarization multiplexed phase extraction as well as the dual low coherence technique without any specific sampling conditions in LCSI. Based on the spatial phase shifting technique to instantly extract the phase and the visibility of the correlogram, the operation of PD-LCSI is as same as CSM as the aspect of rapid scanning, but the measurement result is more precise than those of CSM because of the phase measurement capability. Furthermore, the adoption of dual low coherence characteristics enables the whole scanning distance to be significantly reduced opposed to CSM.

2. Polarized dual low coherence scanning interferometry

Figure 1 shows the optical configuration of the polarized PD-LCSI proposed in this investigation. The system consists of a light source part generating the dual low coherence and a main LCSI with polarized optical components. In the light source part, an LED is used as a broadband light, and a Michelson-type interferometer is configured to have the optical path difference (ΔL) between two mirrors (M_1 and M_2), which can be adjusted and monitored in real time by the spectrally-resolved interferometry (SRI) using a spectrometer.

The beams from the source part are incident to the main interferometer, and they go to a polarizing beam splitter (PBS) after passing through a a 45° rotated linear polarizer (P_{45}) to be separated as a reference and a measurement beams, and the reflected beams go to a polarization camera (PCMOS). Two orthogonally polarized beams pass through a 45° rotated quarter wave plate (QWP_{45}) and generate four phase-shifted interferograms in the PCMOS, in which polarizers are arranged at 0°, 45°, 90°, and 135° inside.

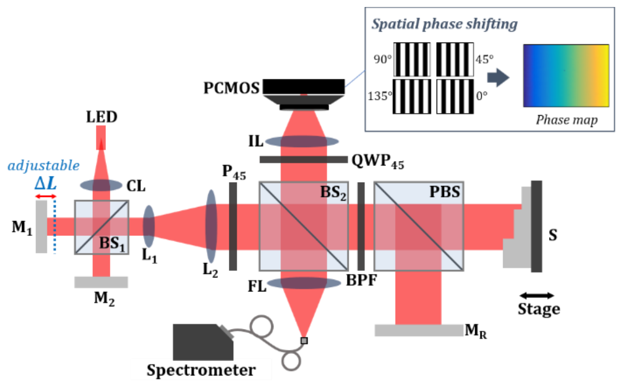

Figure 1. Optical configuration of the polarized dual low coherence scanning interferometry (PD-LCSI); CL, collimating lens; $BS_{1,2}$, beam splitter; $M_{1,2}$, mirror; $L_{1,2}$, lens; P_{45}, 45° rotated linear polarizer; FL, focusing lens; BPF, band pass filter; PBS, polarizing beam splitter; M_R, reference mirror; S, specimen; QWP_{45}, 45° rotated quarter wave plate; IL, imaging lens; PCMOS, polarization camera.

2.1. Low coherence scanning interferometry for high precision

Typically, the correlogram in LCSI is obtained by scanning a reference mirror or a measurement target. By analyzing the correlograms at all pixels of an imaging device, LCSI can reconstruct the 3D surface profile of a specimen. To calculate the surface height, two kinds of approaches have been reported [1], i.e. envelope peak detection and phase detection. In the envelope peak detection, the envelope (visibility) of the correlogram is extracted by Fourier transformation or phase shifting technique, and the peak position of the envelope is calculated as the same way in CSM. Although it can determine the surface height without the 2π-ambiguity opposed to the phase peak detection, the envelope peak position is strongly affected by the intensity fluctuation of the correlogram, which deteriorates the measurement result.

On the other hand, the surface height can be precisely determined by the phase compared to the envelope peak detection because it is not so sensitive to the intensity fluctuation. As similar to monochromatic interferometry, however, the measured phase experiences 2π phase jumps, and the fringe order should be determined to avoid the phase ambiguity. In LCSI, the fringe order of the phase can be conveniently determined by using the result of the envelope peak detection. Although the surface profile reconstructed by the envelope peak detection has the low precision, it is enough to find out the height jump caused by the fringe order, and the combination of two measurement result can provide the surface profile with the high precision as [1].

2.2. Phase and visibility extraction by a polarization camera

The spatial phase shifting using the polarization multiplexed technique is very attractive to extract the phase and the visibility of the interferogram because it can be immediately operated during the acquisition of interferogram opposed to the temporal phase shifting. Especially, it is beneficial for LCSI, which captures interferogram stack corresponding to the scanning position, where the phase and the visibility of each interferogram is obtained without any sophisticated calculation regardless to the sampling interval [2]. When the PCMOS is used with polarizing optic components in LCSI as shown in Fig. 1, the following four interferograms can be obtained at once, and the phase and the visibility of the interferogram are immediately calculated by 4 bucket phase shifting algorithm.

2.3. Dual low coherence

The whole scanning distance of LCSI is determined by the maximum height of the specimen, and it should be extended when a step height specimen is measured. It's because of the low temporal coherence of the light source, and only the single correlogram can be obtained when the OPD is close to 0. However, three correlograms can be observed if the optical source part is configured as an interferometer as shown in Fig. 1 because there are two more possibilities to obtain the correlograms in the main interferometer to adjust the OPD to be $\pm\Delta L$. When this dual low coherence is applied to measuring a step height specimen by LCSI, the whole scanning distance can be significantly reduced [3]. By adjusting ΔL is similar to the height, the interferograms at upper and lower surfaces can simultaneously appear, which means the nominal scanning distance to obtain the single correlogram is only needed regardless to the surface height. In this case, ΔL is immediately measured by SRI, and the final measurement result is provided as the combination of SRI and LCSI. It is beneficial for LCSI to measure relatively thick step heights and plate thicknesses because of dramatic reduction of the measurement time and the data memory size.

3. Experimental results

To verify the measurement capability of PD-LCSI, three gauge blocks with different thicknesses (1.3 mm, 1.6 mm and 1.9 mm) were attached on another gauge block surface as a practical step height specimen. In this case, the whole scanning distance should be up to 0.65 mm slightly longer than the surface heights of the specimen in typical LCSI.

In PD-LCSI, ΔL was set as 300.84 μm as similar to the nominal height difference of the gauge blocks by using SRI measurement result as shown in Fig. 2(a). In this case, the interferograms simultaneously appeared on all gauge block surfaces during scanning procedure, and only 45 μm scanning distance was enough to obtain whole correlograms. Fig. 2(b) shows the envelope function obtained at each gauge block surface, and the surface profile of the specimen was reconstructed as shown in Fig. 2(c). Then, the final surface profile was obtained with ΔL as shown in Fig. 2(d). As the sampling interval increased, the step heights and each repeatability were also calculated, and all the surface heights were within the reference values by the specification of gauge blocks. In this case, the number of data set was drastically reduced compared to that of the typical LCSI.

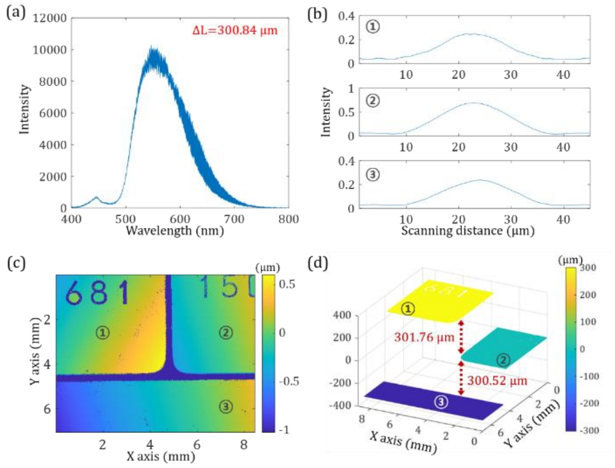

Figure 2. (a) Spectral interferogram with ΔL = 300.84 μm, (b) three envelop functions, (c) the measured surface profile and (d) the final surface profile of the specimen with ΔL.

4. Conclusion

In this investigation, a polarized dual low coherence scanning interferometer, which alleviates the sampling conditions of traditional LCSI using dual low coherence and spatial phase shifting techniques, was described and experimentally verified. The operation of the proposed interferometer is not dependent on the sampling interval because it can calculate the visibility and the phase in real time. In the experiments, it was confirmed that the whole scanning distance was significantly reduced when measuring a step height specimen because of the dual low coherence characteristics. For the verification, the surface profiles of a step height specimen was measured, and it was confirmed that the whole scanning distance was more 10 times reduced without any specific sampling conditions.

References

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