In-Line Setup for the Characterization of Optical Freeform Surfaces

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The in-situ measurement of optical freeform elements is still challenging. We propose an innovative setup for the characterization of transmissive and reflective samples. We found a robust and compact solution which allows an analysis similar to perpendicular illumination in reflection combined with an appropriate optical preprocessing.

1 Introduction

The conventional optical measurement of reflecting surfaces requires setups with tilted illumination or beamsplitter resulting in high efforts on adjustment and calibration [Fig1]. We present an innovative measurement method of illuminating perpendicularly a test sample and analyzing its wavefront directly. The main advantage of this setup is the axial illumination of the samples without conventional beamsplitters.

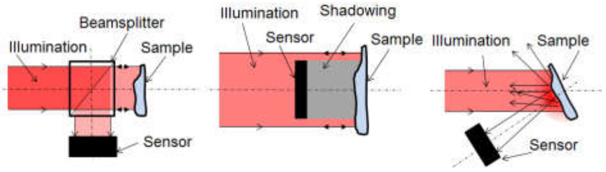

***Fig. 1** Challenge and standard solutions for wavefront evaluation.*

2 Setup

In [Ref3] we developed a method for the wavefront analysis of transmittive samples using two 4f systems and a binary amplitude cross grating. In the second spatial filtering unit the zeroth order is blocked. This offers the possibility to insert an additional light source for the illumination of a reflective test sample.

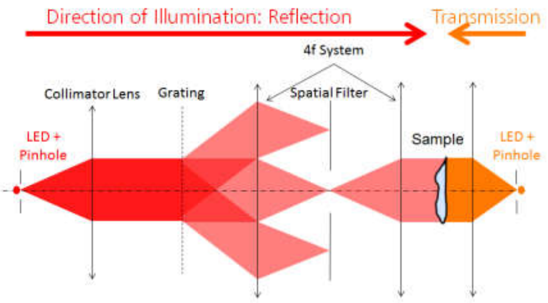

***Fig. 2** Illumination path of the setup.*

The illumination scheme is shown in Fig. 2. The partially coherent light of an LED is collimated. The resulting plane wavefront propagates along the optical axis in left-right direction and passes the diffraction grating where the light is split into numerous diffraction orders. The spatial filter of the following optical processor unit eliminates all unnecessary light components except the 0th order so that the sample is illuminated by a plane wave.

Fig. 3 illustrates the signal path. The wavefront is reflected corresponding to the surface shape and propagates backwards. This light pattern is then imaged onto the grating and is diffracted at the grating. A second optical processor unit ensures the passage of only the ±1st diffraction orders which interfere on the CCD Chip. From this preprocessed captured intensity distribution the wavefront and finally the shape of the test sample are derived. For the expansion to transmittive test objects the illumination unit (LED, pinhole, collimator lens) can be arranged behind the sample. Then the transmitted wavefront can be derived.

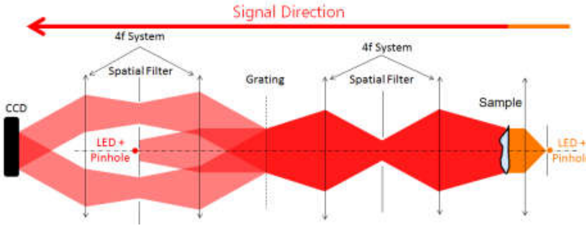

***Fig. 3** Signal path of the setup.*

However the main challenge is the suppression of back reflections at the amplitude grating. These reflections appear exactly at the positions where we expect the signal orders. So we fabricated a highly absorbing amplitude grating based on nanostructured silicon: The opaque grating structures are covered by silicon grass. This nanostructured silicon can be seen as a random arrangement of light scattering needles resulting in an antireflective behavior. It is fabricated by an adapted deep reactive ion etching (DRIE) process which was adopted to glass substrates [3,4].

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3 Experimental Results

We realized a test setup and compared the experimental results to a commercial Shack Hartmann sensor (SHS). We integrated the SHS into the actual setup according to Fig. 4. As test samples we used an ophthalmic lens which was covered by a chromium layer for reflective measurements and a cubic phase plate for the measurements in transmission. Fig. 5 shows the results for both measurement regimes.

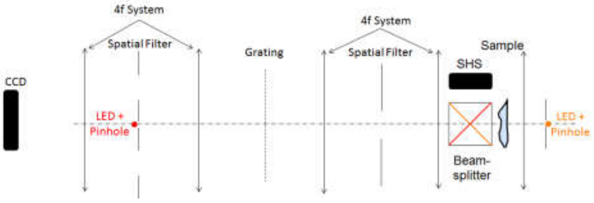

***Fig. 4** Schematic of setup for experimental validation.*

It turned out that the measured wavefront shapes of our proposed method and the SHS are in a good agreement. The peak-to-valley deviation is 0.23 microns in reflection and 0.14 microns in transmission, respectively. The challenge concerning the comparison of the results was the adaptation of the spatial resolution of our measurement to the (12 times) lower resolution of the SHS. Therefore either some artifacts or higher resolved structures might be visible.

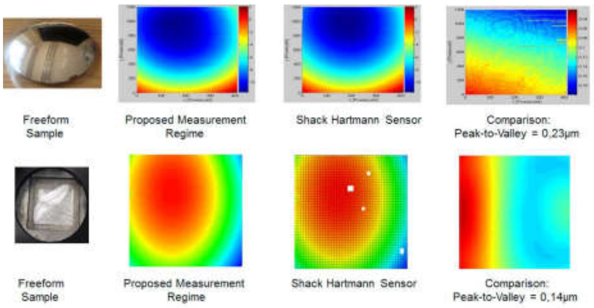

***Fig. 5** Experimental results in reflection (top) and transmittive mode (bottom).*

4 Summary and Conclusions

We presented an innovative method for the measurement of wavefronts in reflection and transmission. The advantages of or proposed setup are: (i) uni-axial compact arrangement of optical components which is well-suited to be implemented into e.g. CNC machines, (ii) measurement in reflective and transmittive regime simultaneously using a single setup, (iii) higher resolution compared to Shack-Hartmann sensor at lower requirement on calibration and (iv) use of partial coherent illumination, e.g. LED.

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