Mach-Zehnder / Twyman-Green hybrid interferometer for micro-lens testing

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An alternative interferometer design for micro-lens testing is presented. The phase shifting system combines the advantages of a Twyman-Green and a Mach-Zehnder interferometer and allows full characterization of the aberrations of micro-lenses as well as radius of curvature and focal length measurements. The Twyman-Green system is applied to surface testing in reflection whereas the Mach-Zehnder system is used for lens testing in transmission. Both measurements are performed without removing the test part, allowing a combination of the results without confusion of the actual lens and without an azimuthal orientation error.

1 Introduction

Micro-lenses are usually characterized by their geometrical properties such as lens pitch, surface modulation depth, physical thickness, radius of curvature as well by their optical properties such as focal length, wavefront aberration, PSF, and MTF. Because of their high accuracy, the most common tests are based on interferometry.[1,2] It offers rapid full aperture measurements and assess the quality of wavefront produced by the micro-lens, where either surface height errors or wavefront aberrations are measured. For example, using a Twyman-Green interferometer, all important parameters such as radius of curvature, focal length, and reflected and transmitted wavefront shape can be measured. For transmission testing, the use of a single pass interferometer such as the Mach-Zehnder interferometer is often more advantageous.

2 Problems in testing refractive micro-lenses

However, the interferometric testing of micro-lenses incurs certain difficulties due to their small dimensions. Some of these are:

- **Fresnel diffraction artifacts:** Edge diffraction at the lens aperture leads to a superimposed diffraction pattern and prevents a quantitative measurement,
- **Disturbing interferences:** Reflections from other surfaces (front or rear) of the micro-lens may result in multiple beam interferences,
- **Retrace errors:** Systematic aberrations may be introduced when testing in double pass,
- **Non-common path interferometer geometry:** Calibration is required, due to imperfections of optical components,
- **Intrinsic spherical aberration:** If the test situation differs from the working situation (different ray path, different wavelength), systematic aberrations are introduced.

3 The hybrid interferometer system

The interferometer as currently configured is shown schematically in Fig. 1. It consists of a combined phase-shifting Twyman-Green and Mach-Zehnder interferometer. The key element of the proposed interferometer system is the swivelling plane mirror in the reference arm, serving as the switch between the Twyman-Green and the Mach-Zehnder mode of the interferometer and as the phase-shifting element. By the use of polarizing optics, disturbing interferences due to unwanted reflections from optical elements are reduced, the intensities in test and reference arm are adjustable, and light losses at the beamsplitters are avoided.

The software for the interferometric acquisition and analysis was written in modular form in Java. A major advantage of the realized software/hardware concept is that there is no need for expensive frame grabber and D/A converter cards. Piezo transducer and camera can be controlled via standard computer interfaces, which makes the use of a laptop computer possible.

4 Experimental results

Experiments to confirm the capability of the combined interferometer were carried out with a microlens-array, fabricated by glass hot embossing. The test part was a 2 x 6 array of spherical plano-concave micro-lenses with following design parameters: lens diameter $d = 500\ \mu m$, radius of curvature $ROC = -950\ \mu m$ and lens pitch of 1.25 mm. The test piece was set up in the phase-shifting interferometer and the testing procedure was performed for a single micro-lens of the array.

The quantitative result of micro-lens surface figure testing in Twyman-Green mode is depicted in Fig. 2, whereas Fig. 3 shows the result of single pass micro-lens testing in Mach-Zehnder mode. For surface figure, the main part of aberration is spherical aberration. In the transmitted wavefront a strong primary astigmatism is evident.

We also determined other than aberration properties of the lens, such as radius of curvature, front focal length, depth of sagitta, and substrate thickness. The ax-

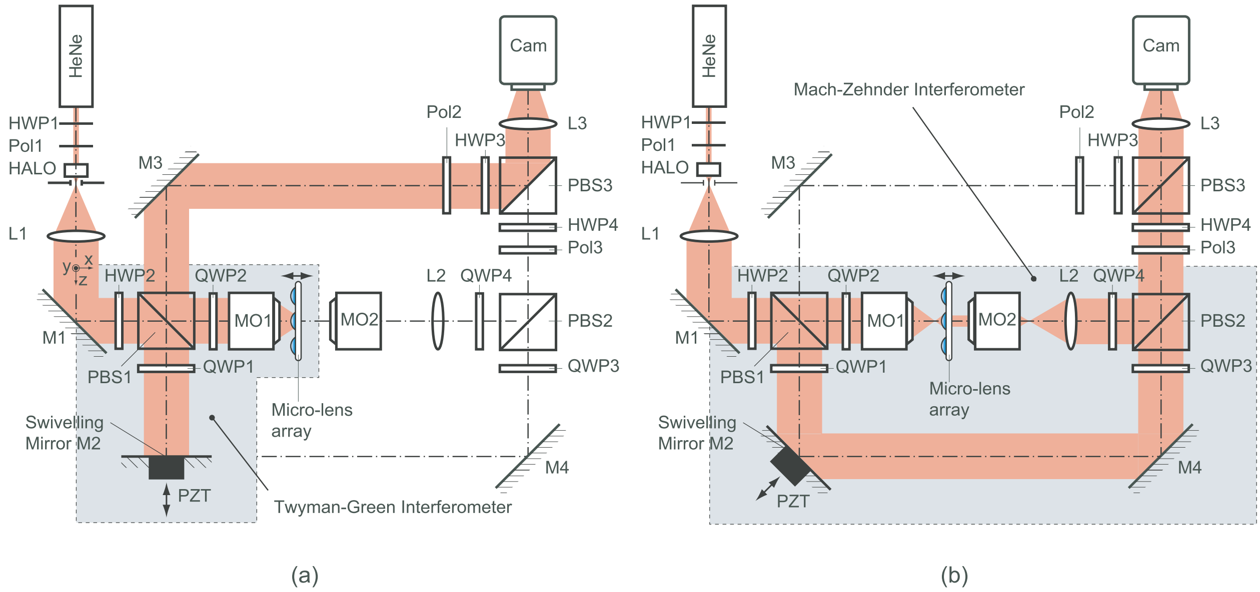

***Fig. 1:** Setup of the combined phase-shifting interferometer. (a) Twyman-Green system and (b) Mach-Zehnder system. HeNe, Helium-Neon laser (633 nm); MO, microscope objective; PBS, polarizing beamsplitter; HWP, half-wave plate; QWP, quarter-wave plate; Pol, linear polarizer; HALO, high aperture laser objective; L, positive lens; M, mirror; Cam, camera; PZT, piezo transducer*

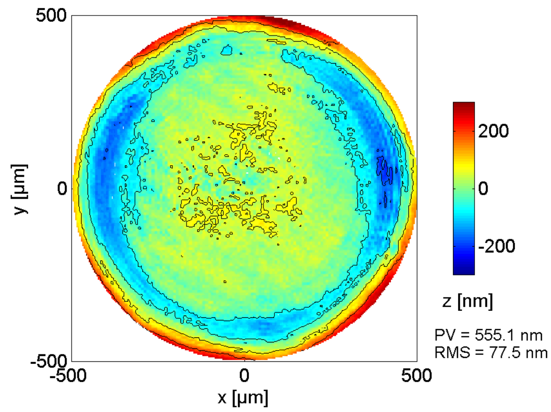

***Fig. 2:** Wave aberrations of surface figure testing.*

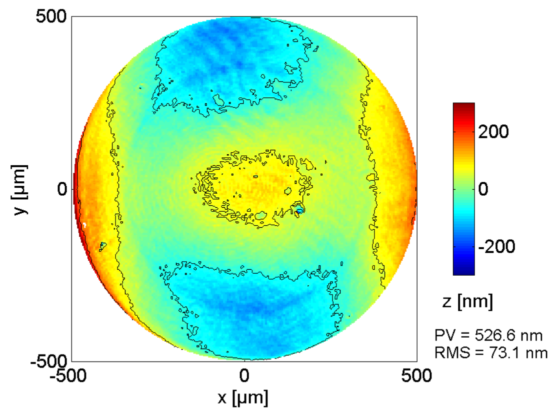

***Fig. 3:** Wave aberrations of single pass lens testing.*

ial shifts of the test part between the different null positions were measured by a length gauge. The measured physical parameters of the lens differs about 7.5-8.5% from their nominal values. Shrinkage during glass cooling process could be a reason for these discrepancies.

5 Conclusion

A versatile phase-shifting interferometer for micro-lens testing has been presented. The system combines the advantages of a Twyman-Green and a Mach-Zehnder interferometer, thus enabling accurate determination of both optical and physical properties of micro-lenses. For most micro-lenses, all measurements can be performed without removing the test part, whereby the results can be related to each other without confusion of the actual lens and without an azimuthal error. For high-NA micro-lenses, we have to accept the disadvantage that the micro-lens has to be reversed for transmission testing.

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