Laser direct writing of diffractive structures on curved surfaces

Matthias Häfner*,**, René Reichle*,**, Christof Pruss*,**, Wolfgang Osten*,**

*Institut für Technische Optik, Universität Suttgart, Pfaffenwaldring 9, 70569 Stuttgart
** Stuttgart Research Center of Photonic Engineering (SCoPE), Pfaffenwaldring 9, 70569 Stuttgart

mailto:haefner@ito.uni-stuttgart.de

We present a laser direct writing system for the fabrication of diffractive structures on rotationally symmetric curved surfaces like spherical and aspherical lenses. The writing system is capable of exposing surfaces at an angle of up to 15°.

1 Introduction

Hybrid optical elements that combine refractive and diffractive functionality are versatile components for all kinds of applications in imaging or metrology. In the past those elements were composed of a flat diffractive and a curved refractive surface. Fusing both functions in a single surface will enhance the capabilities of these optical components further. The fabrication of such precision elements is a challenge since most micro structuring tools are limited to flat surfaces. The growing interest in structuring non-flat surfaces arises in the increasing number of systems designed for this purpose. Radtke et. al. demonstrated a laser writing system designed for structuring surfaces with surface normal deviations of up to 10° [1]. Xie et. al. have demonstrated the fabrication of rotationally symmetric grating structures on curved substrates [2]. In this contribution we present a laser direct writing system that is able to write high resolution arbitrary binary and grey scale structures on rotationally symmetric surfaces with a slope angle of up to 15°.

2 The writing system

The current writing system was designed on the basis of the circular laser writing system CLWS300 [3]. Working with polar coordinates, the writing system is optimized for the fabrication of rotationally symmetric structures e.g. Fresnel Zone Plates. Positioning of the writing spot is realized by a rotating air bearing spindle that holds the substrate and a linear air bearing stage which addresses the radial coordinate on the substrate. Writing on curved surfaces implies that the writing head is able to follow the substrate topography. For this, we integrated a linear air bearing stage with small guiding errors and highly repeatable motion. The stage is mounted collinear to the angular axis, extending the polar coordinates to a cylinder coordinate system. Figure 1 shows a schematic of the writing arrangement. Except for the rotating spindle all positioning is performed by linear stages. Tracking of the substrate topography is accomplished by continuously adjusting the height of the writing head according to the substrate surface sag, thus keeping the surface in the focal plane of the microscope objective. Fast movements that account for surface irregularities in a range of up to 20 µm are performed by a piezo actuator. The vertical linear air bearing stage ensures that the piezo actuator is kept in its optimal working point. That way it is possible to expose the entire substrate in a smooth scan without interruption.

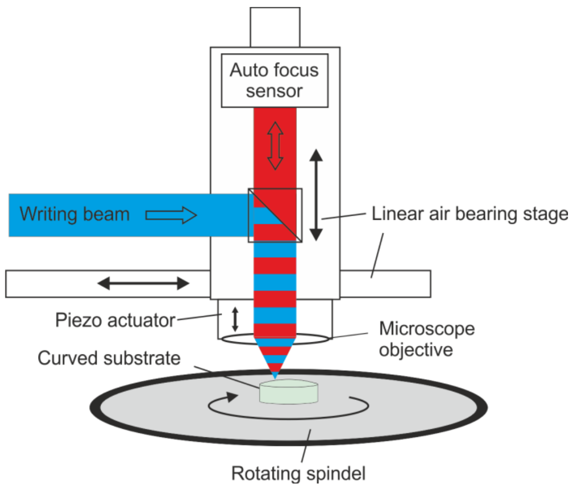

Fig. 1 *Schematic of the writing head*

3 Auto focus

One core development is the new auto focus system. Working in cylinder coordinates implies that the writing and autofocus beams may be not perpendicular to the substrate surface. We therefore developed and integrated a novel auto focus approach that accounts for the challenge of focusing on tilted surfaces. Figure 2 shows a sketch of optical design of the auto focus sensor. The basic functionality is as follows: A collimated laser beam is focused onto the substrate surface with a microscope objective. The reflected beam is recollimated by the objective and then sampled with a small aperture that is placed off the beam axis. The sampled beamlet is directed to a position sensitive detector. Moving the surface out of the focal plane of the microscope objective causes the reflected beam to be diverging or converging beyond the objective. Sampling the beam with an off axis aperture translates that decollimation to an angular deviation of the beamlet. At a certain distance from the aperture the corresponding position change is detected with a position sensitive diode (PSD). The PSD signal serves as the distance signal of the auto focus sensor. A telescope was integrated to increase the sensitivity of the setup.

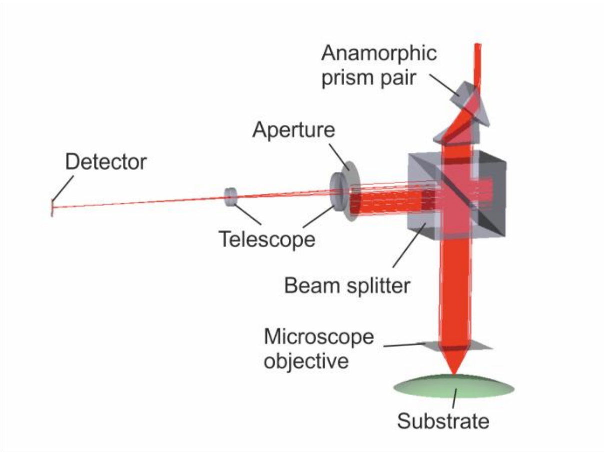

Fig. 2 *Sketch of the novel auto focus approach*

Tilting the substrate surface does not affect the collimation state but only displaces the reflected beam. Thus it is possible to detect the out of focus condition for surfaces with wide range of slope angles.

4 Results

The presented system has proven to be capable of structuring rotational symmetric elements with surface slope angles of up to 15°.

Fig. 3 *Photograph of a spherical lens with binary Fresnel zone plate structure: max. slope angle: 15°, min. structure period: 2.4µm*

So far we fabricated binary structures with periods down to 2.4 µm. The photograph of such an element is shown in figure 3. Furthermore we fabricated continuous grey scale structures with a period of 4 µm and a depth of approx. 1 µm at comparable surface angles. An AFM-Scan of that structure can be seen in figure 4.

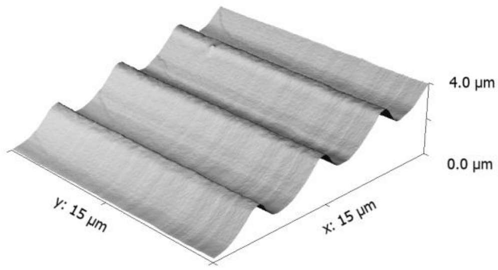

Fig. 4 *AFM-Scan of a grey scale structure at a surface angle of 15°.*

5 Conclusion

We have presented a laser direct writing system that provides structuring of rotational symmetric curved substrates with comparable structure quality as known for flat surfaces. The proposed approach enables future extension and could be combined with advanced writing techniques for the fabrication of high frequency structures [4].

6 Acknowledgements

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