Diffractive Elements for Chromatic Confocal Sensors

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Diffractive elements are increasingly used for white light applications. Two of the most important advantages of diffractive elements are the high dispersion and the design flexibility that computer generated diffractive elements offer. In this paper, we will discuss this on the example of chromatic confocal sensors.

1 Introduction

In chromatic confocal sensors, the height information is mapped into color information, thus eliminating the need for a mechanical z-scan. This allows to develop very fast, one-shot sensor systems that can be miniaturized very well.

The mapping of height into color is realized using an optical system with a well defined longitudinal chromatic aberration (LCA) (see Fig. 1). The LCA can be controlled in optical system design using the dispersive properties of optical materials. The design freedom however can be greatly increased if in addition to refractive elements diffractive surfaces are used.

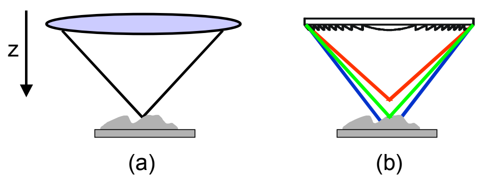

Fig. 1 *Working principle of chromatic confocal sensors. The mechanical z-scan (a) in conventional confocal systems is replaced by a simultaneously generated series of foci at different wavelengths (b).*

Distributing the refraction power between refractive and diffractive components allows to design a system for a given working distance and depth scanning range.

Confocal sensors are intrinsically robust against stray light. However, using diffractive optical elements (DOE) in white light applications leads to unwanted diffraction orders that can produce additional, spurious signals. This is discussed in section 2. Section 3 sketches the fabrication of the diffractive elements used for the applications described in section 4.

2 Efficiency and Diffraction Orders

A standard way to fabricate high efficiency phase-only DOE is to create a saw-tooth-like topography in a homogenous material (e.g. fused silica) corresponding to the desired phase retardation. The maximum depth of the saw-tooth-like structures depends on the design diffraction order m of the element. Deeper structures using a higher design order facilitate to a certain extent the fabrication, since the width of the structures is increased and the number of discontinuities in the topography reduced. However, fabricating the DOE in a higher design order changes its diffractive behavior [1].

For monochromatic applications, there is no difference between elements using different design orders (as long as TEA, the thin elemente approximation holds). This changes for light sources with finite spectral bandwidth. Due to phase mismatching the efficiency of a standard phase-DOE decreases for wavelengths other than the design wavelength (Fig. 2). While for first-order elements the design order is dominant over several hundred nanometers, the usable range is significantly reduced for higher order elements.

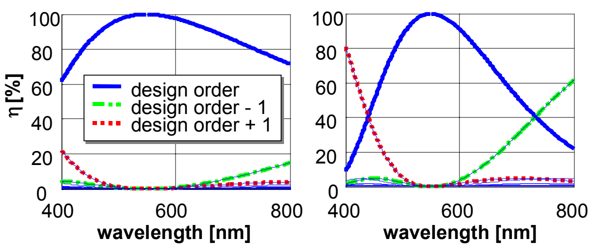

Fig. 2 *Wavelength dependent distribution of incoming intensity into different diffraction orders. Left: design order: 1, right: design order: 2.*

Higher order elements intrinsically allow more diffraction orders, due to the bigger structure widths. For example Fresnel Zone Plates (FZP) realized as second order element create two times more and closer spaced foci than a FZP in first order. Therefore, care must be taken that the desired working range is not overlapped by a parasitic diffraction order, as illustrated in the right graph of Fig. 3.

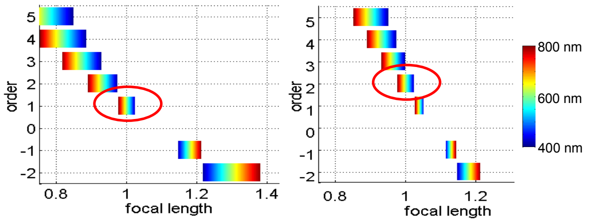

***Fig. 3** Influence of design order on exemplary hybrid chromatic confocal sensor design. The focussing power is split between refractive and diffractive part such that a confocal sensor with working distance 1 mm and working range of 50 µm results. Left: design order 1, no overlap of diffraction orders in the working range. Right: design order 2, overlap would result in faulty signals.*

3 Fabrication

The diffractive elements for this work were fabricated using grayscale direct writing on the polar coordinate laser writer CLWS300. Laser direct writing is a flexible high precision method to produce grayscale computer generated diffractive elements. It replaces the multi-mask binary process with its many alignment and exposure steps with a single exposure and subsequent low contrast developing process. However, it has its limitations due to the finite, Gaussian shaped writing spot. Especially on the edges of the saw-tooth shaped microstructures this fundamental limitation is visible. We chose to fabricate the elements in second design order with an optimized writing strategy on the edges [2].

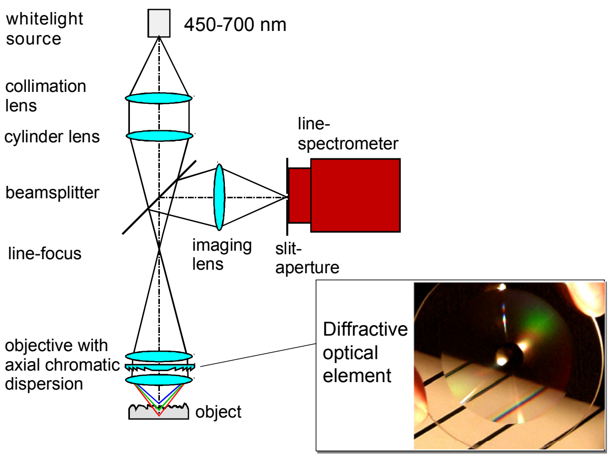

***Fig. 4** Setup for a one-shot chromatic confocal line sensor with 50 mm working distance. A line spectrometer detects the confocal signal created at the slit aperture.*

4 Application examples

One of the major advantages of the chromatic confocal principle is its ability for one-shot-measurements. This was a prerequisite for a line sensor designed for welding inspection. Its optical setup is sketched in Fig. 4. It is capable of measuring a complete line (2.4 mm) in one shot with a depth measuring range of 700 µm.[3]

The second application is a miniaturized point sensor developed and realized for the non-contact measurement of small cavities. In this system the confocal illumination as well as the confocal pinhole is realized by a single mode fiber. The setup is given in Fig. 5. The diffractive optical element not only provides the LCA but also corrects for aberrations introduced by the spherical surface.

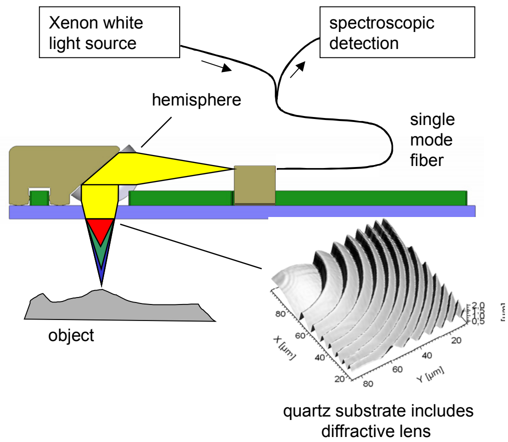

***Fig. 5** Miniaturized chromatic confocal point sensor with a diameter < 2mm. The components are assembled using a LIGA-process based rail system that is fabricated on the quartz wafer carrying the diffractive lenses.*

5 Summary

Computer generated diffractive elements can improve significantly the performance of optical systems. Especially in chromatic confocal systems the effects diffractive elements show in white light applications (diffraction efficiency, parasitic diffraction orders) are not limiting factors. They can be overcome with proper design and calibration.

References

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