Optical Properties of Diffractive Anti-Reflective Gratings on Curved Surfaces: Fabrication and Testing

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Zero-order gratings (ZOGs) show anti-reflective properties. However, in order to replace classical interference thin-film anti-reflex coatings such ZOGs should be applicable to standard optical elements such as e.g. spherical lenses. For most applications in the VIS and NIR duty cycle and etch depth should be in the order of 200 – 300 nm. Fabrication as well as testing and characterisation of such kind of gratings, especially with respect to convex curved surfaces, require new approaches. This article shows the fabrication, testing and characterisation procedure of directly etched ZOGs in standard spherical glass lenses.

1 Introduction

As an alternative to classical thin film anti-reflective coatings, zero-order gratings (ZOGs) offer interesting properties mainly with respect to higher laser damage thresholds and environmental influences [1-3]. However, until now fabrication and testing of such diffractive anti-reflective gratings on curved surfaces are rather difficult. This is mainly due to the small zero-order-grating period, Λ_{ZOG}.

The maximum grating period, where only the zero-th order is transmitted and all higher diffraction orders are suppressed is given by

$$\Lambda \leq \Lambda_{\mathrm{ZOG}} = \frac{\lambda}{n_1 \cdot \sin\theta_1 + n_3} \qquad (1)$$

Hereby, λ is the wavelength, n_1 and n_3 are the refractive indexes of the environment and the grating material, respectively. θ_1 is the incidence angle and $\theta_{3,\mathrm{mT}}$ is the angle of the transmitted m-th diffractive order.Thus, for normal incidence the maximum ZOG period Λ_{ZOG} will be λ / n_3. Depending on the wavelength this results for the VIS-range in approximately 270 - 450 nm.

In this project gratings of different duty cycles, aspect ratios and glass materials are directly etched into plane and spherical surfaces of standard lenses. The reflectivities on different portions of the lens surface are measured and compared to theoretical results.

2 Fabrication

The gratings were fabricated according to a method as previously presented by Schnieper et al.[4].

The convex spherical surface of a meniscus standard lens was spin-coated with photoresist and illuminated in a holographic set-up. After developing the sinusoidal structured photoresist, it was angularly metallised and finally 'opened' in a RIE process (cf. Fig. 1a). In a further process step the so opened gratings were directly etched into the lens surface. Several flat and curved lens surfaces of various glass types such as B270, N-BK7, N-SF15 and fused silica were structured in this way (cf. Fig. 1b – d).

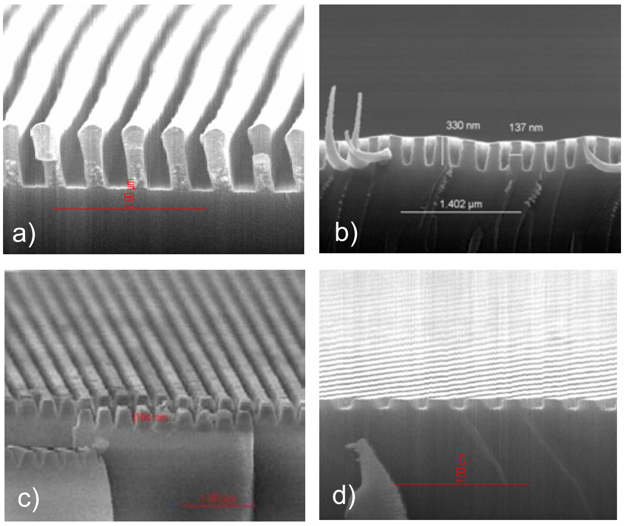

Fig. 1 *Subwavelength structured gratings (Λ = 270 nm) of different duty cycles and aspect ratios etched in different glass types: a) "opened" grating, b) grating etched in borofloat (B270) glass, c) grating etched in SF15 glass, d) grating etched in N-BK7*

3 Testing

The sub-wavelength structured surfaces of N-BK7(n = 1.517), B270 (n = 1,525), fused silca

(n = 1.488) and N-SF15 (n = 1.699) lenses were tested by a set-up allowing the measurement of the local reflectivity in TE- and TM-polarisation at each portion of the lens surface. The lenses laid with its spherical surface on an annular support which allowed exact repositioning and tilting for each lens, independent of its radius.

Hereby, light from a white light source is focussed normally onto the spherically curved surface of the lens test sample. The reflected light is collimated and finally guided to a fibre spectrometer, which measures the reflectivity in TE- and TM-polarisation for wavelengths from 350 – 1050 nm (cf. Fig. 2).

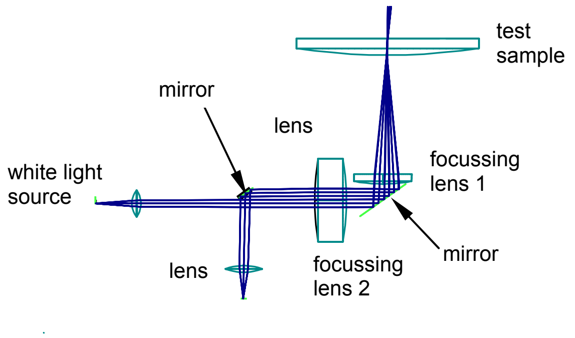

Fig. 2 *Experimental set-up of the local reflectivity measurement.*

4 Results and Discussion

The results from these measurements are shown in Fig. 3 and 4.

Fig 3 shows the TM- and TE reflectivity near the apex of an N-SF15 lens. TE-reflectivties vary between 4% at 950 nm to 1,7 % at 540nm, whereas for TM-reflectivities values of 4% at 950 and only 0,8% are obtained at 450nm. Compared to an uncoated lens with reflectivities beween 7,6% at 350nm and 6,3% at 950nm, in the VIS-range a clear anti-reflective effect is shown.

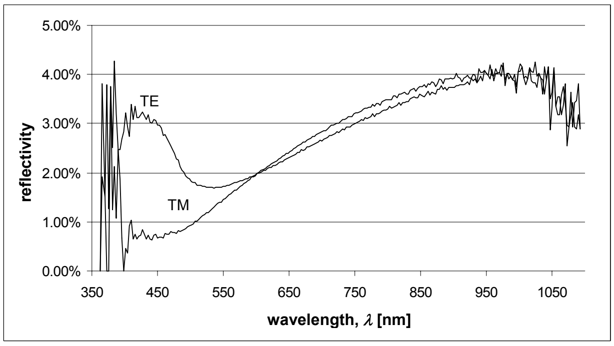

Fig. 3 *Results from the reflectivity measurement of the both, TE- and TM polarisation, near the apex of a typical N-SF15 lens as depicted in Fig.1c).*

Fig 4. depicts the distribution of the local TE-reflectivities at various locations on the spherical lens surface. The values vary from 2.1% towards the lower edge to 4.2% towards the upper edge. A radial gradient over the lens surface with its center outside the lens can be recognised. A possible reason may be a slightly tilted lens sample during the spin-coating process or other asymetries during the angular metallization process. With respect to the spherical lens topography, almost no radial-symmetric distribution of the reflectivities can be seen.

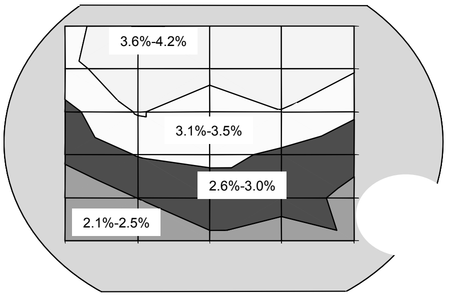

Fig. 4 *Distribution of the local TE- reflectivity at λ = 441 nm over the spherical lens surface. The shape (outer contour) was given by the industrial application of lens.*

5 Conclusion and Outlook

We have shown a method to fabricate sub-wavelength structured AR-gratings on spherical surfaces. The results show typical reflectivities of the of 3% (TE-polarisation) and 0,8% (TM-polarisation), which clearly show the AR-effect of these grating structures. However, due to fabrication related reasons a radial gradient of the reflectivities, which is not related to the spherical lens topography was noted. This shows that in principle sub-wavelength AR-structures do work on spherical surfaces, however more research especially with respect to fabrication errors and straylight reduction has to be done.

References

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