Studying fabrication induced phase errors in CGHs using RCWA

Sandy Peterhänsel*, Christof Pruss*, Wolfgang Osten*

Institute for Applied Optics and Research Center SCoPE, University of Stuttgart

mailto:peterhaensel@ito.uni-stuttgart.de

Computer generated holograms are a common tool used for null testing of aspheres and free form surfaces. In this set up, undetected phase errors in the CGH will lead to systematic errors. In this paper limits for the scalar theory and effects described by rigorous calculations are presented. Measurement approaches for detection of the phase are described.

1 Introduction

Scalar theory is widely used to design and characterise computer generated holograms (CGH) for the aspheric null test [1, 2]. However, smaller structure sizes are getting more common, as they allow more degrees of freedom for the designer. It is known that scalar theory is becoming unprecise for structure sizes in the range of λ. We studied the generated phase using scalar and rigorous calculations for a binary line grating made of fused silica, with periods of 1 – 6 µm. One can see in Fig. 1, that for periods smaller 2.6 – 2.8 µm (4.5 λ) the phase difference exceeds λ/100 and therefore can no longer be neglected in high precision applications. For the rigorous calculation the rigorous coupled wave analysis (RCWA) was used [3].

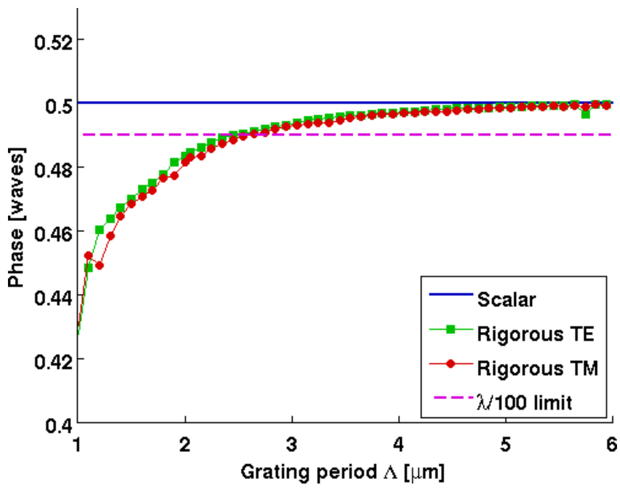

Fig. 1 *Comparison of generates phase calculated with scalar and rigorous methods for a binary line grating (λ=633 nm).*

2 Sensitivity analysis

In this section we study binary line gratings with a period Λ of 1 µm using the RCWA. A sensitivity analysis is done by calculating the phase change introduced by a parameter variation of 1%. As we are only interested in the effects not describable with scalar theory the normalised phase difference ΔW is defined as:

$$\Delta W = \Delta W_{rig} - \Delta W_{scalar} \quad (1)$$

The parameters studied are the line width *b*, the height *h*, the side wall angle α and for gratings in reflection the thickness of the Cr-layer *d*. Also the dependence of the angle of incidence and the polarisation state are investigated. For the evaluation, the first order was used. A more detailed evaluation for all parameters and a wider selection of gratings can be found in [4]. A model of the simulated structures is given in Fig. 2.

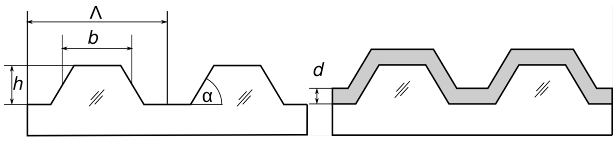

Fig. 2 *Studied gratings for applications in transmission (left) and reflection (right).*

For the transmission grating no significant dependence of the polarisation was found, also the influence of the angle of incidence is quite small (studied *NA* -range: ± 0.5), see Fig. 3.

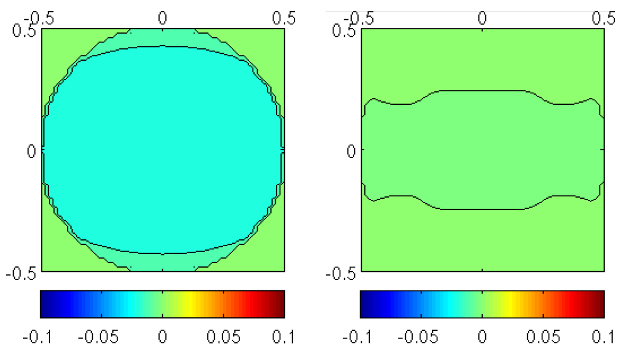

Fig. 3 *Phase change ΔW for a transmission grating using TE polarised incident light with 1% variations in height (left) and side wall angle (right).*

A different result is found for reflective gratings with a Cr-layer on top. Here a strong dependence on the polarisation and angle of incidence is found. Also the side wall angle, that had next to no influence in transmission, shows a quite large sensitivity, see Fig. 4.

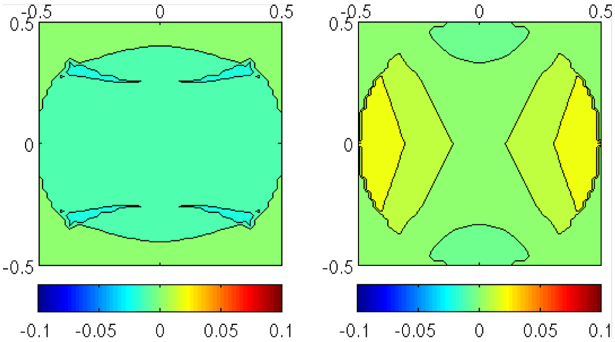

Fig. 4 *Reflective grating with TE (left) and TM (right) polarised incident light and 1% variation in side wall angle.*

Given these few examples, it becomes quite clear that a general prediction, which parameter is especially sensitive to the phase, can not be made. However the phase difference introduced by a very small variation of only 1% dictates, that an accurate measurement technique has to be found, to characterise the phase to the needed accuracy. One idea is described in the following section.

3 Phase measurement

The problem in measuring an arbitrary CGH is that the reconstructed phase typically can not be measured directly. Hence one has to solve the inverse problem of reconstructing the phase from accessible measurands. One way to do that, is to use the well established method of ellipsometry. To study the possibilities, simulations have been done for a binary line grating. The set up is in reflection mode with an illumination and detection angle of 75° and a wavelength range of $\lambda = 280 - 800$ nm. The measured values are the ellipsometric angles Ψ and cos(Δ) and the wanted value is the transmitted phase of the first order. Variations in height and line width were studied. The results indicate that especially the cos(Δ) value can be used to differentiate between variations in height and line width, but also to define a certain variation in the signal that corresponds to phase changes smaller than the tolerance regime. Figure 5 shows the simulated behaviour of cos(Δ) in a selected wavelength range for changes in height and line width and the corresponding phase.

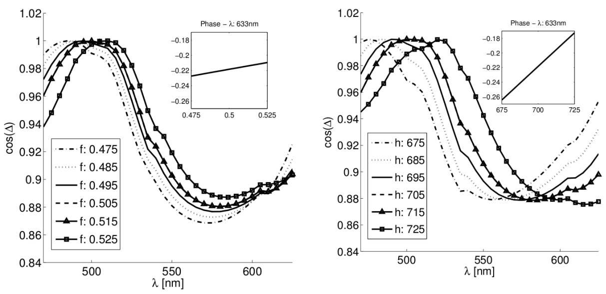

Fig. 5 *Behaviour of* $\cos(\Delta)$ *and the generated phase for changes in line width (left) and height (right).*

4 Conclusion

It has been shown that for an accurate description of the phase generated by a CGH rigorous methods have to be used for grating periods smaller than 4.5λ. As for the sensitivity of grating and illumination parameters on the generated phase, no general prediction can be stated. Instead gratings in this regime have to be characterised carefully on their behaviour. In order to get a fast and reliable characterisation method, ellipsometric measurements were studied and showed a good performance, allowing to differentiate between defects in line width and height. One goal of the investigation is to define allowable tolerances concerning the phase for structure parameters.

The authors would like to thank the German Research Society (DFG) for the financial support of this work within the project (OS111/32-1).

References

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