Phase retrieval of optical gratings in transparent media

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Methods for phase retrieval are usually applied to problems related to the design of holographic beam shapers, where a certain output intensity distribution has to be met using a phase-only holographic device. The same methods can also be applied for the identification of already-manufactured optical gratings in transparent media, e.g. in order to elucidate the underlying process and to find suitable process parameters. Here, we demonstrate the application of a method based on iterative calculation of the beam shaping pattern and the resulting diffraction pattern.

1 Introduction

Phase retrieval is a common tool for example for the design of holographic beam shaping devices with a given target intensity distribution or for the identification of diffracting structures in crystallography. As shown by [1], it is possible to employ the commonly used Gerchberg-Saxton [2] algorithm for phase retrieval to identify phase gratings in transparent media, as, for example, manufactured by femtosecond-laser radiation [3] or hot-embossing [4]. As this approach for phase retrieval is limited by ambiguities in the solution space for the one-dimensional case [5] which can increase the computation time, we investigate the suitability of a different approach based on the work of Farn [6] for the identification of phase-only gratings, using a known grating that was manufactured by hot-embossing beforehand.

2 Experimental setup

In the experiment, the grating under test was illuminated using a 4mW HeNe-Laser at a wavelength of 633nm. The resulting diffraction pattern was then monitored using a Thorlabs PM200 laser-powermeter with a Thorlabs S120C photodiode sensor, as sketched in Figure 1.

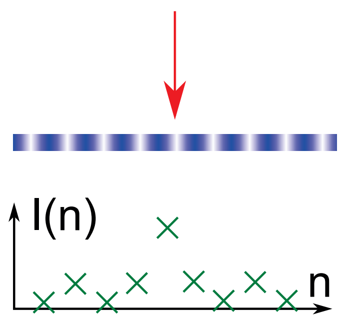

Figure 1 *Sketch of the experimental setup.*

The grating itself was embossed into a polymethylmethacrylate substrate using an aluminum stamp which exhibits a sawtooth surface profile in a process similar to [4]. The resulting surface structure in the transparent substrate was then measured with a confocal microscope to determine the profile height and grating period. With knowledge of the measured profile and the refractive index of the substrate material of $n = 1.49$ we calculated the expected phase function (see Figure 2) which was later used to verify the results of the phase reconstruction algorithm.

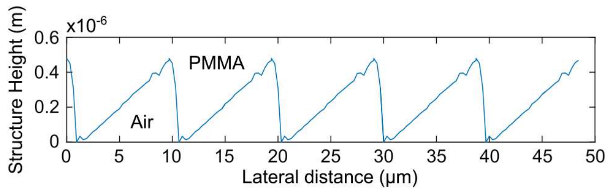

Figure 2 *Surface profile of the manufactured grating. The refractive indices where $n = 1.49$ for the PMMA subtrate and $n = 1.00$ for air, the wavelength $\lambda = 633nm$.*

3 Phase reconstruction algorithm

The phase reconstruction algorithm applied is based on iterative calculation of the phase $\varphi(k)$ of the diffracting structure and the phase $\alpha(n)$ of the diffraction pattern. Note, that both phase functions feature different resolutions. While n in this case ranges from $n = -8$ to $n = +8$, indicating the measured diffraction orders, k ranges from 0 to 100, typically, therefore allowing for a smooth representation of the desired phase function.

Figure 3 shows the sequential function chart of the utilized algorithm. Starting from a random phase distribution $\alpha_1(k)$, a phase function $\varphi(k)$ is calculated and from that result a new phase distribution $\alpha_2(n)$ and also an intensity distribution $I'(n)$. An outer loop is generating a set of weights $w(n)$ from the dif-

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ference between the measured intensity distribution $I(n)$ and the computed intensity distribution $I'(n)$. This negative feedback allows to control the direction of convergence of the algorithm towards a solution (i.e. a phase function $\varphi(k)$) that generates an intensity distribution as measured beforehand in the experiment, thus, enabling a nondestructive testing of the produced grating.

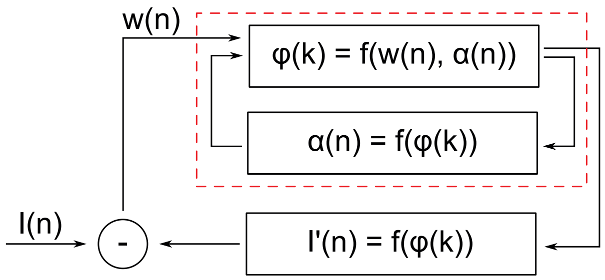

Figure 3 *Sequential function chart of the utilized phase retrieval algorithm.*

4 Results and discussion

After measuring the intensities in the diffraction pattern (see Figure 4), the algorithm was started several times with a random starting phase $\alpha(n)$ while the measured intensity $I(n)$ was added with noise to test the stability of the procedure towards measurement errors. Due to the sawtooth-like phase function, an asymmetric intensity distribution was expected and also measured.

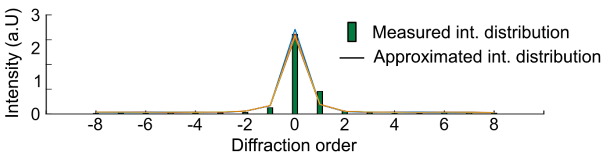

Figure 4 *Measured intensity distribution (green bars) and approximated intensity distribution from several runs of the iterative algorithm.*

Although the algorithm does not produce an approximated intensity profile as asymmetric as the measured one (see colored lines in Figure 4), the resulting phase function is in good agreement with the measured function, as can be seen in Figure 5. We account the differences in measured and approximated intensity profiles to effects which can not be reproduced by the utilized algorithm, as, e.g. absorption effects in the sharp edges of the produced sawtooth profile. Because the algorithm relies solely on a phase-modifying grating, any additional change in intensity would lead to false results.

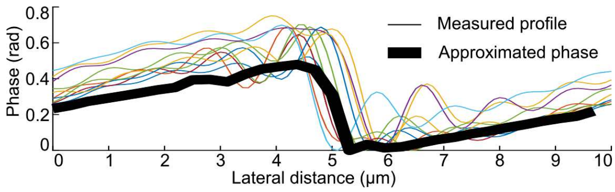

Figure 5 *Measured phase function (black) and phase function as approximated by the algorithm after several runs (colored thin lines).*

5 Conclusion

In this work, we were able to show that it is possible to characterize a hot-embossed grating using an alternative phase retrieval approach that is especially suited for application to one-dimensional problems. For the near future we plan to use the approach for an extensive study on femtosecond laser direct written gratings in transparent polymers.

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