Multiplexing of transmission holograms in photopolymer

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Theoretical and experimental investigations of multiplexing of thick transmission holograms in photopolymer are shown. The objective is the expansion of the angular and spectral acceptance of thick gratings. One of the problems is the non-linear response of the photopolymer to exposure. The characteristics are measured and accounted for in multiplexing experiments.

1 Introduction

Holographic sunlight redirection [1,2] has been addressed in the past more than once. Economic success, however, was hindered by some obstacles: Diffractive optics in principle are spectrally and angularly narrow. The spectral acceptance can be stretched to application relevant levels by using materials with high refractive index modulation and thickness as low as possible. In silver halide and dichromate 3 micron film thicknesses and an index modulation of 0.1 are typical values for this purpose. The angular narrow acceptance of the holograms is usually overcome by mechanical tracking of the position of the sun along at least one dimension. In the past this led to prohibitive expensive systems. Today there is a new class of holographic materials being developed by Bayer MaterialScience. It is based on photopolymers and has a close relationship to materials, which have been used for holographic data storage. This suggests to explore the photopolymer's capabilities with respect to angular multiplexing, heading for a tracking-free sunlight redirection system.

2 Fundamental concept

The material used in this work has a functional film of 16 micron thickness and is able to produce an index modulation Δn of 0.032 [3]. The idea is to multiplex several gratings, in this case four, into the film, whereas the diffraction angle of each gratings is 35 degrees but the slant angle is tilted about 5 degrees. In an ideal situation this should lead to an angular acceptance of about 20 degrees. Simulations based on Kogelnik theory [4] for multiplexing were made. At this stage any interdependency between the gratings was neglected. In figure 1 the diffraction efficiency for different levels of multiplexing are shown: The blue dashed graph represents a single grating with a Δn of 0.016. The green graph two gratings with 5 degrees tilt in between with Δn of 0.016. The orange and red lines show three- and fourfold multiplexing with assumed Δn of 0.0106 and 0.008 respectively.

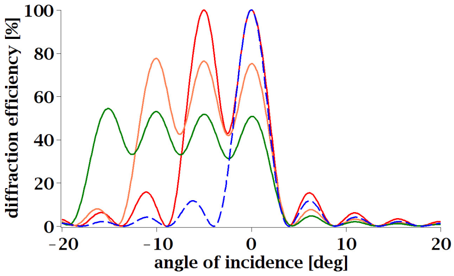

Fig. 1 *Simulated diffraction efficiency of multiplexed holograms with respect to the angle of incidence*

In figure 2 the efficiency of the described systems is shown in dependence of incident wavelength. All holograms were assumed to be written at 532 nm.

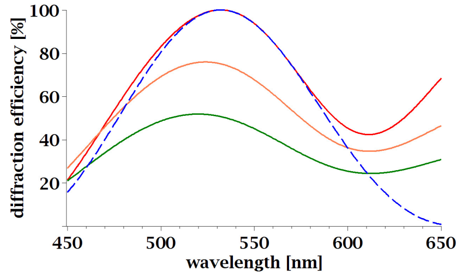

Fig. 2 *Simulated diffraction efficiency of multiplexed holograms with respect to the wavelength*

The graphs show clearly the possibility of angular and spectral broadening. The reduced efficiency in the multiplexed holograms, however, is a consequence of reduced Δn assumed. At this point it is not clear, what index modulations can be achieved practically in the gratings under multiplexing conditions.

3 Transient Monitoring

Diffusion processes play an essential role in the photopolymer during exposure and explain its non-linear gradation. This non-linearity has to be taken into account explicitly, when several gratings with well defined characteristics have to be multiplexed into one film subsequently. Therefore a setup was designed, which allowed a simultaneous recording and reading of gratings. Writing was done at 532 nm whereas reading was done at 632 nm with much less intensity compared to the writing beams. In figure 3 the monitoring of 2 subsequentially written gratings is shown. The diffraction efficiency is expressed as $\eta = I_1/(I_1 + I_0)$, where I_1 and I_0 are the intensities of the first and zeroth diffraction order. The nonlinear gradation of the film is clearly visible. It is evident that this behavior calls for precise and individual choice of exposure time for each grating in a multiplexed hologram.

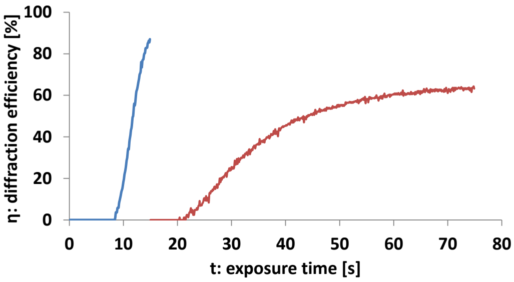

Fig. 3 *Nonlinear gradation of the photopolymer. Two gratings are written sequentially.*

4 Analysis of Mulitplexed Holograms

The analysis of the multiplexed holograms was made with a self made, fully automated photogoniometric measurement system. In figure 4 the red line shows the measurement of a fourfold multiplexed hologram. Only the highest diffracted intensity of one grating is considered at a time. The simultaneous contribution of two or more gratings, which are found in different directions when multiplexing is done in our angle variation scheme, is neglected. The black curve is a Kogelink simulation of four interaction-free gratings with a best fit of Δn.

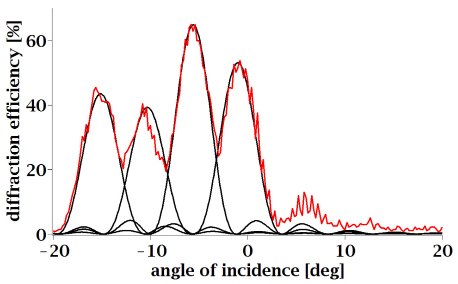

Fig. 4 *Measurement (red) of a fourfold multiplexed grating and best-fit simulation of four independent gratings (black). The fitted Δn are 0.0083, 0.0094, 0.0067 and 0.007 respectively.*

For the application, however, a modified definition of efficiency is relevant. The contribution of all gratings at the same time has to be considered and not the strongest contribution of one grating. This system efficiency can be calculated easily, when the efficiency of the individual gratings is known. It is given by:

$$\eta_{sys} = 1 - (1 - \eta_1)(1 - \eta_2)...(1 - \eta_n)$$

In the following graph the system efficiency is added as a black line to the measured single grating efficiencies.

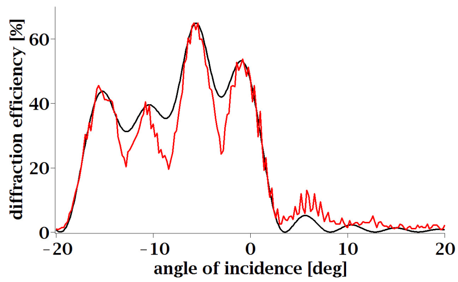

Fig. 5 *Single grating diffraction efficiencies (red) and system efficiency (black) of fourfold multiplexed gratings.*

With the multiplexing scheme applied here and with the given photopolymer the angular acceptance has been stretched by a factor of 4 to about 20 degrees at the cost of efficiency, which is just below 50 $\%$ when averaged over the region of angular acceptance.

5 Conclusion

According to our findings multiplexing of transmission holograms in photopolymer seems to be a promising approach for tracking-free sunlight redirecting devices. The non-linear characteristics of the photopolymer necessitates an individual tuning of each multiplexed hologram. In the future the overall performance will depend on the achievable Δn in the photopolymers and its buffering capabilities under multiplexing. Theoretical modeling already allows precise predictions regarding single grating efficiencies and regarding system efficiency in multiplexed systems.

6 Bibliography

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