Properties of Blazed Area-Coded Effective medium Structures (BLACES)

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Blazed area-coded effective medium structures inherently exhibit form birefringence because of their unequal extensions with respect to the two area dimensions. We show that nevertheless, they can be optimized to show nearly no polarization dependence as well as to favor one of the polarizations and explain the polarization behavior.

1 Introduction

Area-coded effective medium structures (ACES) have been recently proposed as a new type of grating design [1]. They consist of dielectric sub-wavelength structures of constant height and thus are able to code an arbitrary phase distribution within a grating period by means of variation of the local transversal fill factor. One of the possible application is the substitution of blazed structures in situations where the binary lithographic technology is available since blazed gratings can be fabricated using blazed ACES (BLACES) by only one etch step. This has been demonstrated in [2] and a good agreement between theoretical and measured efficiencies has been obtained.

2 Optimization of form birefringence

Since in BLACES the structures are subwavelength only with respect to one direction (the y-direction in Fig. 1), they exhibit form birefringence. This has also been observed in [2] where one of the polarizations was 18% points larger than the other. For comparability reasons, in investigating the possibilities of the optimization of form birefringence of BLACES, we use the same material parameters as already used in [1]: The structures consist of TiO_2 (n=2.3), the substrate is quartz (n=1.46), the wavelength is λ = 633nm, the sub-wavelength period is $\lambda/3$, and the grating period is chosen to be g = 5λ = 3.17µm and g = 3λ = 1.9µm, respectively. There are several possibilities to design BLACES: a) for non-polarized light, b) for TE-polarization, c) for TM-polarization. In all considered cases the incidence angle is varied from -60° to +60° and the efficiency of the -1^{st} transmitted order refers to the whole transmitted light since reflection losses can be minimized by AR coatings. First results with g = 5λ for the optimization of non-polarized light are depicted in Fig. 2: The two polarizations are quite similar – the maximal difference is about 10% points. Only for large negative incidence angles, the maximal difference reaches 30% to 40% points. For non-polarized light the optimal profiles are BLACES with linear triangle sides like shown in the top of Fig. 1.

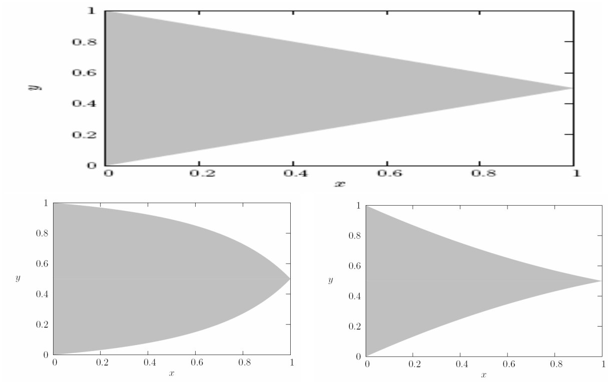

Fig. 1 *Different profiles of blazed area-coded effective medium structures: top: best suited for minimal polarization; left: convex profile improving TE-polarization; right: concave profile improving TM-polarization.*

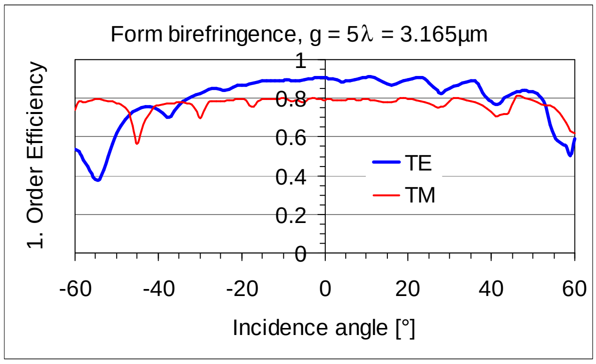

Fig. 2 *Form birefringence of BLACES with g = 5l = 3.17µm and l = 633nm. Polarization optimization for non-polarized light. BLACES consist of n = 2.3 on a quartz substrate.*

The results of polarization optimization for TE-polarization are given in Fig. 3. Here, the form birefringence is quite evident. The efficiency of TM-polarization is smaller by 20% to 30% points for a large area of incidence angles between -30° to +50°. The BLACES-profile improving TE-polarization looks like the convex lower left part of Fig. 1. The results of polarization optimization for TM-polarization are given in Fig. 4. Again, the form birefringence is clearly discernable. The efficiency of both polarizations is quite constant over the whole range of incidence angles and the TE-polarization is smaller by about 20-25% points. The BLACES-profile improving TM-polarization looks like the concave lower right part of Fig. 1. Figures 5 and 6 show the results for g = 3λ. In Fig. 5 the shape is optimized for non-polarized light and in Fig. 6 for TM-polarization.

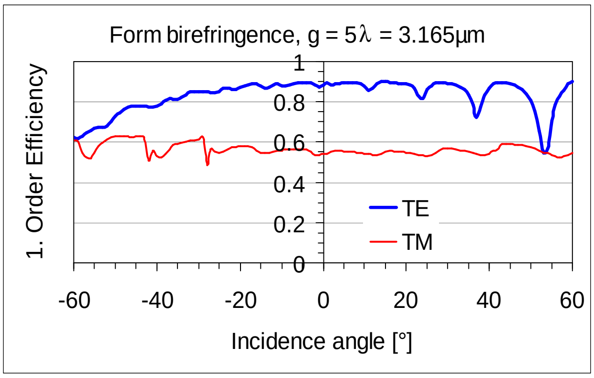

Fig. 3 *Form birefringence of BLACES with g = 5l = 3.17µm and l = 633nm. Polarization optimization for TE-polarization. BLACES consist of n = 2.3 on a quartz substrate.*

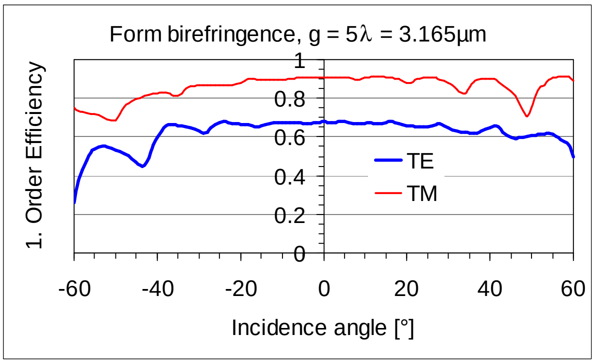

Fig. 4 *Form birefringence of BLACES with g = 5l = 3.17µm and l = 633nm. Polarization optimization for TM-polarization. BLACES consist of n = 2.3 on a quartz substrate.*

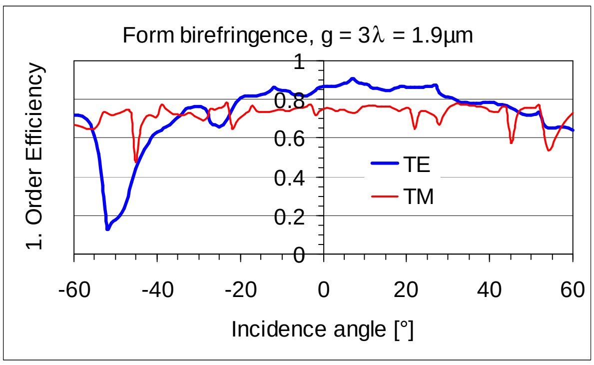

Fig. 5 *Form birefringence of BLACES with g = 3l = 1.9µm and l = 633nm. Polarization optimization for non-polarized light. BLACES consist of n = 2.3 on a quartz substrate.*

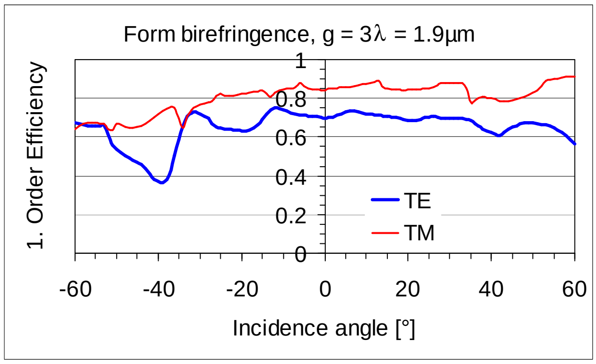

Fig. 6 *Form birefringence of BLACES with g = 3l = 1.9µm and l = 633nm. Polarization optimization for TM-polarization. BLACES consist of n = 2.3 on a quartz substrate.*

3 Explanation of polarization behavior

The effect of the different profiles on the polarization can be explained by effective medium theory. Since it has to be applied to the sub-wavelength period this is the direction perpendicular to the dispersion direction. As well known and repeated in [1], the effective index formulas depend on the two polarizations. The visualisation of these effective index functions over the fill factor shows the difference: for a given fill factor the effective index for TM-polarization is always larger than the effective index for TE-polarization. (Note that this is different from the usual results for binary subwavelength gratings, since there the meaning of TE and TM is just reversed). Conversely, for a given effective index, the fill factor for TM-polarization is always smaller than for TE-polarization. This property directly results in convex BLACES profiles for TE- and in concave profiles for TM-polarization like schematically presented in Fig. 1.

4 Summary

Blazed area-coded effective medium structures inherently exhibit form birefringence. Nevertheless, they can be optimized to show nearly no polarization dependence (cf. Figs. 2 and 5) as well as to favor one of the polarizations (cf. Fig. 3 for TE-polarization and Figs. 4 and 6 for TM-polarization). A simple explanation of the polarization behavior based on effective medium theory is given. All rigorous calculations have been performed using a Fourier Modal Method which has been checked to be sufficiently accurate for this purpose.

References

[1] B. H. Kleemann, J. Ruoff, and R. Arnold, „Area-coded effective medium structures – a new type of grating design“ in *Opt. Lett.* **30**: 1617-1619 (2005)

[2] H. Elfström, M. Kuittinen, T. Vallius, B.H. Kleemann, J. Ruoff, and R. Arnold „Fabrication of blazed gratings by area-coded effective medium structures” accepted for publication in *Opt. Comm.* (2006)