BACK-SIDE DIFFRACTION BY RELIEF GRATINGS

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A comparison is made between the efficiency of bare and aluminum coated dielectric diffraction gratings supporting only two propagating orders utilizing substrate side-light incidence. A large dissimilarity between the two types of gratings is observed and a possibility to achieve a 100% value of the absolute diffraction efficiency in Litrow mount is discussed. An almost constant value of 80% of efficiency is preserved for the aluminum grating nearly in the entire visible region.

1. Introduction

The wishes of grating users are usually connected with the possibility to obtain the maximum diffraction efficiency in a large spectral interval. Blazed gratings can simply be designed with a 100% relative efficiency [1], but the value of the absolute efficiency is restricted by metal coating absorption [2]. On the other hand, it has been shown [3] that a dielectric grating can display a 100% absolute diffraction efficiency in the transmission regime, provided the groove-depth is large enough. However, in a superior amount of spectroscopic devices the gratings are usually used in reflection in order to avoid the necessity of mirrors which can insert additional losses. From that point of view the following question arises naturally: is it possible to propose, at least theoretically, a grating such that a 100% value of the absolute efficiency in a Litrow mount in the visible region is reached? In this paper we are trying to answer partially this question by a drastic reduction of the number of propagating diffraction orders using total internal reflection (TIR) with light incident from the substrate side. This makes it possible to achieve perfect blazin in the case of a bare dielectric grating. For an aluminum grating the back-side diffraction enables us to expand the spectral interval of a maximum efficiency over the entire visible region.

For the sake of clarity and simplicity we have not taken into account the dispersion characteristic neither of the substrate nor of the aluminum reflective indices. The reflectance of the second uncorrugated substrate surface is neglected, too.

2. Dielectric grating

With light incident from the substrate side of a bare dielectric grating (fig. 1), above a given value of the angle of incidence TIR occurs. If the grating period is properly chosen, the number of propagating orders is reduced to two: only the zeroth and the -1st orders are reflected in the dielectric, no orders being allowed to be transmitted in these conditions, according to the grating formula (see the Appendix). In this mount it can be conjectured that the dielectric grating has similar properties as the perfectly conducting grating supporting the same number of diffraction orders: the energy balance is retained.

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taking into account energy flow in the propagation orders only, the scattering matrix \[4\] of the diffraction system is unitary and the phenomenological approach \[3\] can be applied in a similar way for both types of gratings. As a consequence two main results can be expected: sinus square dependence on the modulation depth and an existence of a perfect blaz ing even for sinusoidal groove profiles. The second effect is the most interesting and useful one since we can not expect the existence of a blaze angle for triangular bare dielectric gratings, in contrast to the aluminum coated one (fig. 2).

The calculated diffraction efficiency curves versus the groove depth \(h\) of a sinusoidal grating with a peri

3. **Aluminum grating**

The second set of curves in fig. 4 corresponds to the grating covered with an Al layer \((\beta = 1.33 + 16.95)\). As long as the thickness of the metal exceeds 80–100 nm, it can be considered as infinite, thus the calculations have been performed
assuming that the entire lower semi-space is filled with aluminum. A quasi-periodicity [7] with respect to the groove depth is observed, too (fig. 5), the maximum value for a TM polarization being achieved for ratios \( h/d = 0.4 \), the same value as in the classical mounting [8]. The spectral dependencies (fig. 4) correspond to the case of \( h = 92.6 \) nm. The main advantage is the possibility to obtain a nearly constant value of 80% of absolute diffraction efficiency for TM polarization almost in the entire visible region. When the upper medium is dielectric with refractive index \( n = 1.5 \), the permitted wavelength interval in a Litrow mount is expanded up to three times the grating period rather that \( 2d \) for air-side incidence and the available spectral region is \( 1/3 \) times greater.

It must be pointed out, however, that the reflection on the second substrate boundary should insert a few percent losses for both the dielectric and metal gratings, which must be taken into account in the grating optimization of the working conditions.

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Appendix

If the upper medium is air and the refractive index of the dielectric is denoted with \( n \), the conditions for TIR in the case of plane boundary is

\[
 n \sin \theta' > 1, \quad (1)
\]

where \( \theta' \) is the angle of incidence in the dielectric. Litrow mount is characterized by the equation

\[
 2n \sin \theta = 2d, \quad (2)
\]

where \( \lambda \) is the wavelength in vacuum, and \( d \) is the grating period.

Eqs. (1) and (2) result in the following connection between \( \lambda \) and \( d \):

\[
 \lambda > 2d. \quad (3)
\]

The well-known grating formula gives the angles of propagation of diffraction orders in air (\( \theta_a \)) and in the dielectric (\( \theta_d \)):

\[
 n \sin \theta_d = n \sin \theta' + m/\lambda, \quad (4a)
\]

\[
 \sin \theta_a = n \sin \theta' + m/\lambda, \quad (4b)
\]

where \( m = 0, \pm 1, \pm 2, \ldots \).

If in the Litrow mount only the zeroth and \(-1\)st orders are propagating in the dielectric, then, according to eq. (4a):

\[
 3\lambda > 2nd. \quad (5)
\]

Since \( n > 1 \), from (4b) and (5) it follows that no propagation order can exist in air.
References

[1] See, for example: