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Blazed holographic grating efficiency-numerical comparison with different profiles

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Abstract

Numerical study of a blazed holographic grating efficiency is made for blazing in low (first) and high (fourth) orders. Comparison with a ruled grating with similar blaze angle is done in order to explain the shift in the observed blazing position for the holographic grating. Consecutively approximating the curved holographic grating profile by increasing the number of segments of the ruled grating, it appears that the largest difference between the holographic grating and the grating with an ideal triangular profile is mainly due to the flatness of the groove top. The deviation from the ideal profile affects much stronger the blazing in higher orders.

1. Introduction

Since the boom in technology of holographic surface relief gratings in the '60s and '70s the chief desire of grating manufacturers and users has been to make it possible to holographically record an equivalence of ruled blaze grazing. Since the interference pattern naturally tends to produce symmetrical sinusoidal grooves, several schemes of groove blazing have been proposed. The first approach [1–3] tries to reach this goal by asymmetrical recording or Fourier profile reconstruction by multiple (or multiple beam) recording. The second way lies in utilizing ion-beam etching to blaze the sinusoidal grating or to increase the asymmetry of the recorded profile [4]. The latter technique plays a great role in increasing the efficiency of concave aberrationally corrected gratings for which there is no additional degree of freedom for optical blazing of the grooves as it is in the case of plane gratings.

However, as it immediately became apparent holographic gratings were far from the performance of ruled blazed gratings [5] – the peak efficiency position was shifted to shorter wavelengths and the peak value was much lower. The latter backdraw is the worst and it becomes better pronounced for higher orders blazing. A straightforward explanation points to the deviation from the ideal triangular profile.

Recent laser-beam and e-beam writing techniques allow better profile control than the holographic recording [6], at least if the period is not too small (2–10 μm). This requires much better detailed quantitative knowledge on the influence of the real profile deformations on the grating performance [7]. To this aim we present a comparative study of the grating efficiency going from ideal triangular groove to the real holographic grating profile with several consecutive deformations – cutting the top of the groove, then the bottom and then deforming the large facet. In order to remove the influence of the grating material, perfect conductiv-

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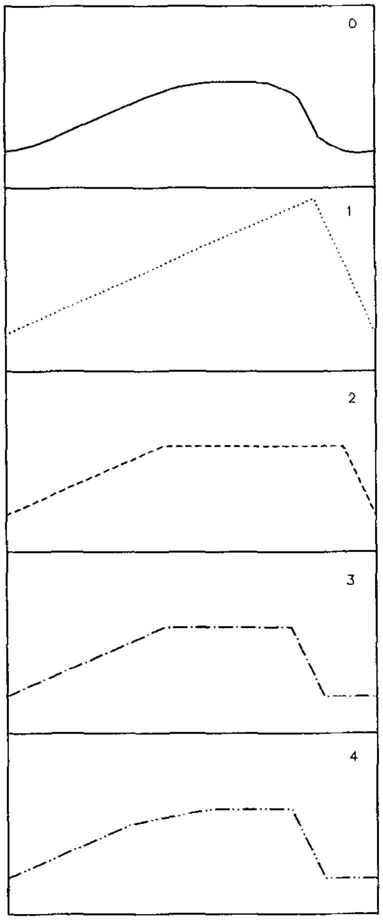

Fig. 1. Several groove profiles: a blazed holographic (0), perfect blazed (1), with the top cut (2), with top and bottom cut (3), and with a deformation of the large facet (4). Period 1 μm.

ity of the substrate is assumed. This is not a limitation of the numerical method used (integral method [8]) but provides an information independent on the particular values of the grating period and wavelength so that

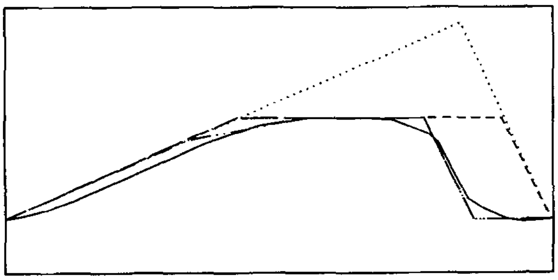

Fig. 2. Scheme of the five profiles from Fig. 1 superimposed.

the scale can be used directly in values of λ/d ratio.

Study of the influence of the deformations on the efficiency behaviour in low and in high orders show that whereas the "cut" of the groove top can sufficiently explain the decrease of efficiency in the blazing diffraction order, the shift of the position of the maximum is due to the deformation of the large groove facet.

2. Groove profiles

In the following it is assumed that the grating period d is equal to 1 μm. Light is incident on the perfectly conducting substrate in a plane perpendicular to the grooves (classical diffraction mount) under the autocollimation angle θ_i (Littrow mount) given by the equation:

$$2\sin\theta_i = -N\lambda/d, \tag{1}$$

where λ is the wavelength and N the number of the diffraction order under consideration (-1 and -4 in the following). Two cases of polarization are considered: TE, with the electric field vector parallel to the grooves and TM, with the magnetic field vector parallel to the grooves.

Several different groove profiles are studied. They are shown in Fig. 1: the initial (numbered 0) corresponds to a holographic blazed grating. It is consecutively approximated by an ideal triangular profile (1) with 24° blaze angle and 90° apex angle, by this profile with top being cut (2), cutting also the bottom (3) but preserving the length of the large facet the same as for profile 2, and finally, slightly deforming the large facet (4). The profiles are superimposed in Fig. 2 for a better comparison.

3. Blazing in the -1st diffraction order

The diffraction efficiency for TE and TM polarization in the wavelength range 0.4–2 μm is presented in Fig. 3. The ideal triangular profile has the "best" performance, with the highest and the smoothest spectral dependence. Following the equivalence rule (although it applies only for profiles with centre of symmetry [9]), the other profiles have similar efficiency curves with much lower saddle part between the two maxima. It is amazing to find that the deepest anomaly near the

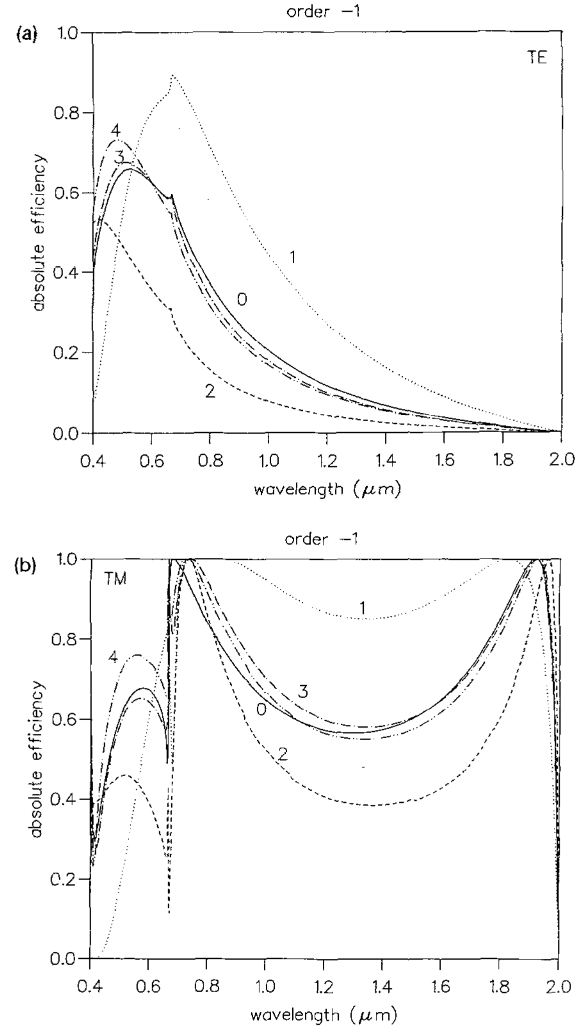

Fig. 3. Spectral dependence of diffraction efficiency of perfectly conducting gratings with profiles given in Fig. 1 in −1st order Littrow mount. (a) TE polarization, (b) TM polarization.

plasmon excitation at 0.66 μm and the lowest saddle value close to 1.4 μm is shown by the profile with slightest deformation (2), but this only points out that in the resonance domain relatively deep gratings efficiency behavior hardly obeys simple reasoning.

4. Blazing in the −4th order

Contrary to the previous case, now the grating supports many diffraction orders to that the equivalence rule does not hold any more. Moreover, as the wavelength is approximately 5 times shorter than the period, the profile deformations affect much more drastically the efficiency behaviour (Fig. 4). Due to the theorem of Marechal and Stroke [10] and the perfect conductivity, TM case and ideal triangular profile provide 100% efficiency at the maximum. Unfortunately, holographic grating (4) maximum values does not exceed 35% in both planes of polarization, which will be even more reduced by the finite conductivity effects.

It appears that the drastical decrease of efficiency is already observed for the simplest deformation (2). Better real profile approximations (3) and (4) does not bring qualitative change, except for that the best fit to

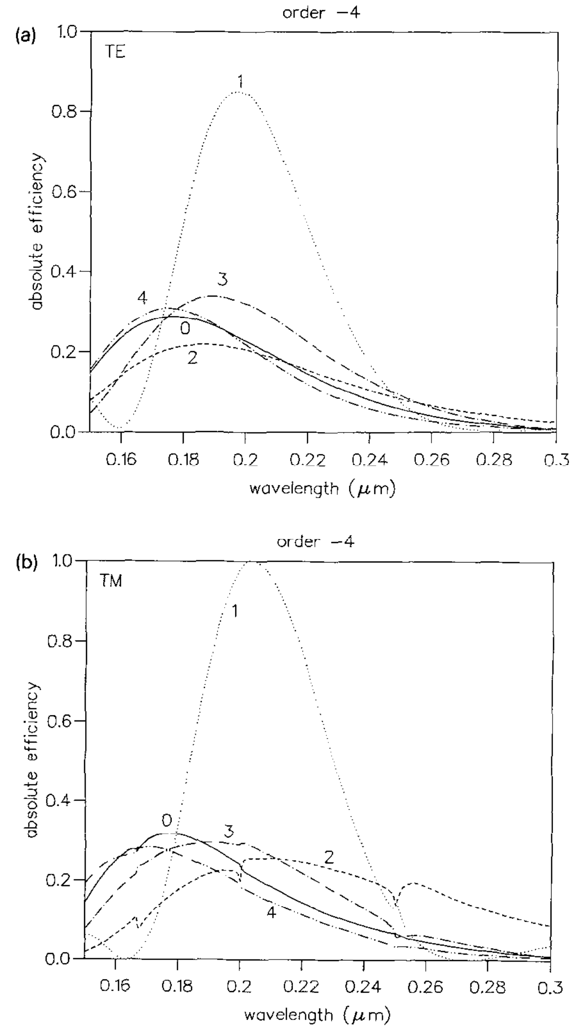

Fig. 4. The same as in Fig. 3 except for −4th order Littrow mount.

the real profile efficiency curves is obtained for the profile (4) which fits better the real profile (0). Moreover, when comparing profiles (3) and (4) which differ only by the slight deformation of the large facet, it appears that this deformations leads to a shift of the position of the maximum to shorter wavelengths, as can be expected from the scalar theory considerations – the effective blaze angle of profile (4) will be smaller than for profile (3).

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