Asymmetrical trapezoidal grating efficiency

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The diffraction efficiency behavior of reflection gratings with an asymmetrical trapezoidal groove profile has been studied. Theoretical calculations predict that at certain grating parameters superior efficiency compared to the conventional ruled gratings can be achieved.

I. Introduction

In the last two decades the development of rigorous electromagnetic theories, taking into account finite conductivity of the metal coating, has been intensively used for investigation of diffraction efficiency behavior of both ruled and holographic gratings.[1-3] The properties of gratings with various groove shape, such as sinusoidal, triangular, and lamellar ones, generally are well-established now over a wide spectral region.

Moreover, an empirical equivalent rule[4] enables one to compare the efficiencies of these three types of grating. The efficiency of trapezoidal gratings is discussed in Refs. 5 and 6. However, both papers deal with the symmetrical trapezoidal grating groove profile.

The interest of asymmetrical trapezoidal gratings arises for two reasons. First, it was demonstrated experimentally by Mashev and Tonchev[7] that such gratings can be produced interferometrically using the nonlinear part of the photoresist characterization curve. Second, compared to currently used commercial gratings, they have greater flexibility in the choice of the groove shape, since at a fixed grating period the efficiency depends not only on the blaze angle but also on the c/d ratio (Fig. 1). In other words one gains an extra degree of freedom.

The aim of this paper is to present for the first time rigorous calculations of the efficiency behavior of trapezoidal asymmetrical gratings. The influence of the grating parameters is studied in detail, and the corresponding efficiency curves are given. The effect of the departure from the Littrow mount is also considered.

The computer code was constructed on the basis of the recently developed theory[8] applicable for multicoated gratings in the general case of conical diffraction mount. Double precision arithmetic with a single precision computer word length of 32 bits is used. It is worth noticing that the computer code works well for both finite conductivity metal and dielectric gratings with an arbitrary groove profile and high ratios of $h/d > 1$.

II. Influence of the Grating Parameters

In the calculations we chose an aluminum grating with 1200 g/mm because of its widespread use in the visible and UV region. Efficiency behavior as a function of modulation depth is given in Fig. 2 for different c/d ratios. With increasing c/d the efficiency maximum is achieved at progressively lower h/d ratios for both S and P polarization. While the P value remains practically the same, the S-plane efficiency maximum is significantly reduced when $c/d > 0.25$. We may conclude, therefore, that for $\lambda = 632.8$ nm the optimum values for h/d and c/d are between 0.325–0.375 and 0.05–0.25, respectively. Another feature displayed in Fig. 2 is that at certain groove depths the blaze effect occurs simultaneously for both polarizations. S-plane polarization for gratings is defined by the electric vector being perpendicular to the grooves and parallel for the P plane.

The influence of the blaze angle on the efficiency at fixed c/d and h/d ratios or, in other words, the effect of profile asymmetry is displayed in Fig. 3. High efficiency is always observed for highly asymmetrical gratings with an angle β close to 90°. From a practical point of view it is important to notice that the blaze angle of highly asymmetrical gratings tolerates deviation up to 2° without significant variation of the efficiency. As can be seen, an optimum choice represents case (b) in Fig. 3 for $\alpha = 30°$.

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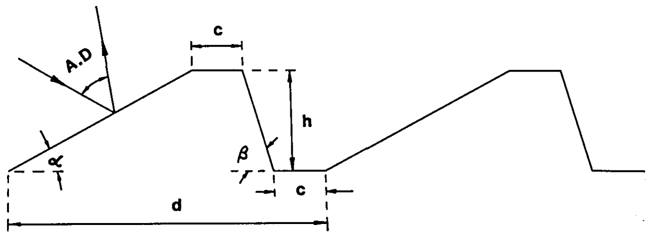

Fig. 1. Grating profile under consideration.

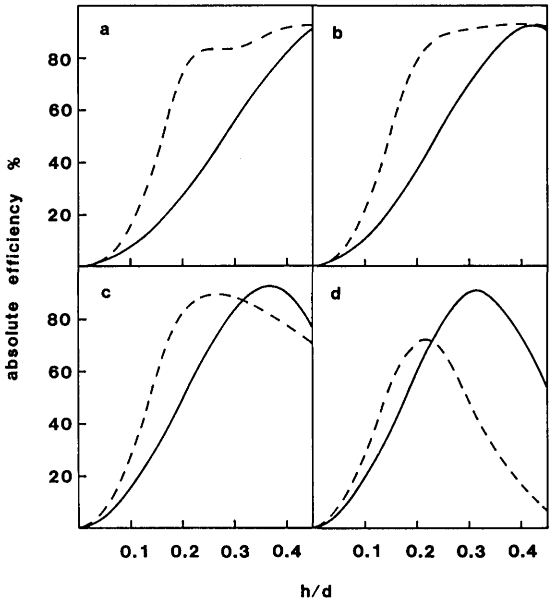

Fig. 2. First-order efficiency as a function of modulation depth h/d for different c/d ratios: (a) $c/d = 0$ (triangular grating); (b) $c/d = 0.1$; (c) $c/d = 0.2$; (d) $c/d = 0.3$. Solid curve, P polarization; dashed curve, S-polarization curve for a grating with 1200 g/mm in Littrow mount. $\lambda = 632.8$ nm.

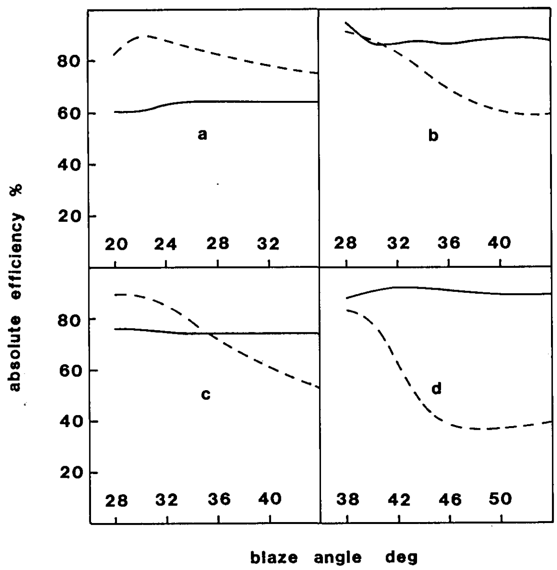

Fig. 3. First-order efficiency in Littrow mount as a function of blaze angle: (a) $c/d = 1.5, h/d = 0.25$; (b) $c/d = 0.15, h/d = 0.35$; (c) $c/d = 0.25$, $h/d = 0.25$; (d) $c/d = 0.25$, $h/d = 0.35$. Solid curve, P polarization; dashed curve, S polarization.

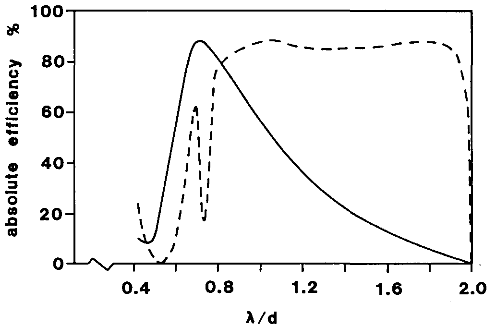

Fig. 4. Littrow mount efficiency curves for $c/d = 0, h/d = 0.43$, and $\alpha = 30°$. Solid curve, P polarization; dashed curve, S polarization.

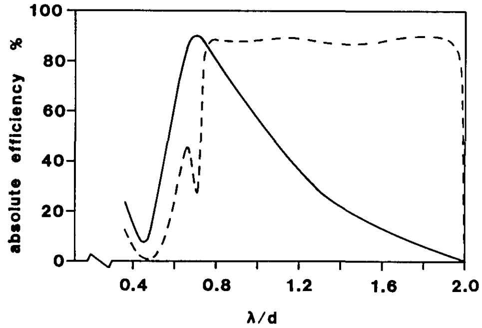

Fig. 5. Same as Fig. 4 except for $c/d = 0.1, h/d = 0.38$, and $\alpha = 29°$.

III. Spectral Characteristics

For reference let us consider first the efficiency curves of triangular aluminum gratings with $\alpha = 30$ and 90° groove apex angle (Fig. 4). Such gratings are characterized by a sharp anomaly in the vicinity of the passing off +1, −2 orders, coinciding with the P-polarization peak, and a relatively broad spectral region with high S-polarization efficiency.[9] It is surprising to observe that the efficiency drop in the anomaly region is highly attenuated by the change to the trapezoidal profile (Fig. 5), and in addition the spectral domain of the high S-plane efficiency is wider. The outstanding characteristics of the S-plane curve are maintained over a c/d ratio band from 0.1 to 0.2 (Figs. 6 and 7). In addition the anomaly is slightly narrower.

For all cases the P-polarization efficiency remains practically the same with a peak value of 90%. That fact may be of particular interest when considering solutions to the inverse scattering problem.[10]

IV. Non-Littrow Mounting

We shall consider only the case of constant angular deviation (AD) between the incident and diffracted beams. This regime describes most monochromators but gives a good qualitative idea of the efficiency behavior in the spectrographic mode as well.

Figure 8 shows the efficiency curves for the grating of Fig. 4 at 25° AD. The anomaly in the Rayleigh passing off wavelength is still pronounced for S polarization. The P-polarization peak is reduced and is slightly shifted toward longer wavelengths.

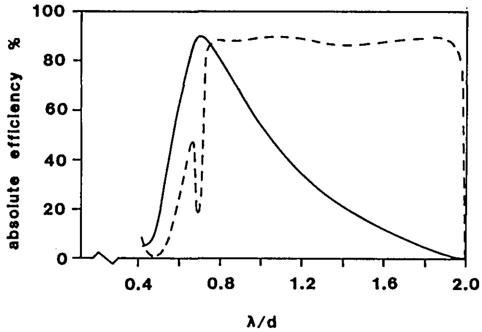

Fig. 6. Same as Fig. 4 except for $c/d = 0.15$, $h/d = 0.35$, $\alpha = 30°$.

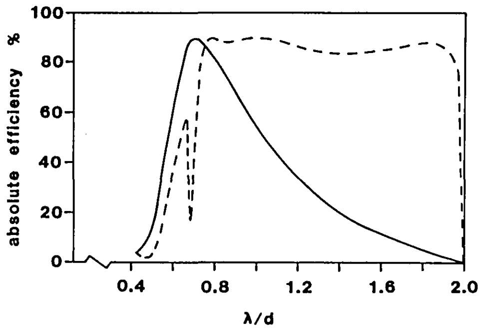

Fig. 7. Same as Fig. 4 except for $c/d = 0.2$, $h/d = 0.32$, $\alpha = 31°$.

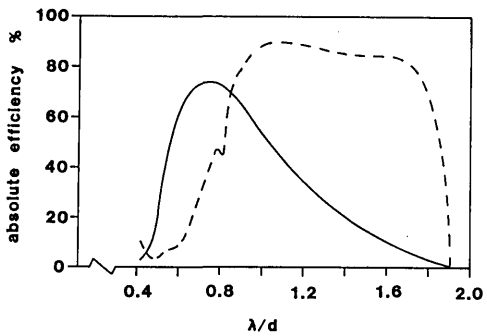

Fig. 8. First-order efficiency curves for triangular grating with $\alpha = 30°$ and 90° apex angle used in 25° angular deviation between the incident and diffracted beams. Solid curve, P plane; dashed curve, S plane.

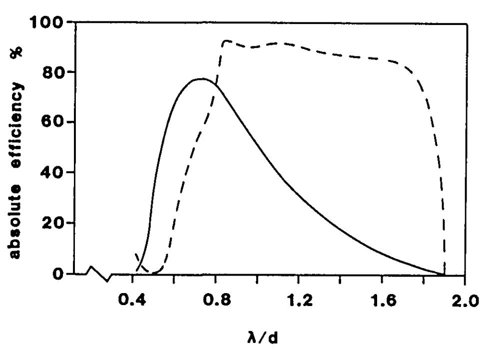

Fig. 9. First-order efficiency curves for asymmetrical trapezoidal grating with $c/d = 0.1$, $h/d = 0.38$, $\alpha = 29°$, and AD = 25°. Solid curve, S plane; dashed curve, P plane.

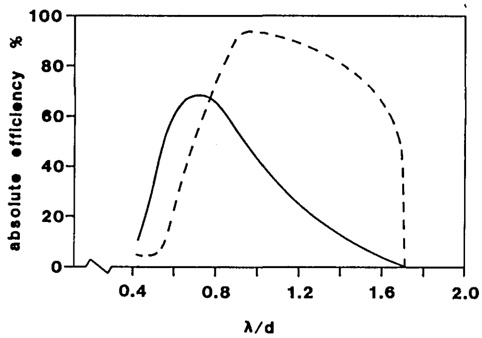

Fig. 10. Same as Fig. 9 except for AD = 45°.

The corresponding S-plane curve for a trapezoidal gratings (Fig. 9) is free from anomalies, and the spectral domain of high S-polarization efficiency is again larger. Even for 45° AD it is still possible to attain high efficiency in the S plane (Fig. 10). However, the P-polarization efficiency is reduced.

V. Conclusion

We have demonstrated that asymmetrical trapezoidal gratings have comparable and in some cases even higher efficiency than the gratings with triangular groove shape. The anomaly in the vicinity of passing off orders can be suppressed, and an efficiency of ~90% in the S plane can be achieved over 1.5 octaves.

This work was undertaken while one of us (L.M.) was with Milton Roy Co., Analytical Products Division, as a postdoctoral fellow.

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