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REFLECTION GRATINGS IN CONICAL DIFFRACTION MOUNTING

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SUMMARY : An experimental study of light diffraction from an aluminium holographic grating is carried out in conical diffraction mounting. Angular dependences of the efficiency and ellipticity of the first diffraction order are measured and some peculiar features are pointed out. The results are in good agreement with the calculations based on the rigorous electromagnetic theory. The ellipticity of the diffracted wave changes strongly in the presence of an oxidated layer.

Réseaux de réflexion pour montage de diffraction conique

RÉSUMÉ : Nous étudions la diffraction de la lumière d'un réseau holographique en aluminium pour montage de diffraction conique. Les variations angulaires pour l'efficacité et l'ellipticité du premier ordre de diffraction sont mesurées. Les résultats sont en bon accord avec les calculs basés sur la théorie électromagnétique rigoureuse. L'ellipticité de l'onde diffractée change fortement en présence d'une couche mince d'aluminium oxydé.

I. — *INTRODUCTION*

During the last two decades a great amount of theoretical and experimental works has been devoted to the diffraction properties of relief gratings [1-4]. Most of them are dealing with the classical diffraction case when the incident wavevector lies in the plane perpendicular to the grooves. However, in some particular cases it is important to know the behaviour of the system response in conical diffraction mounting. For example, in that regime the grating efficiency in the x-ray and x-uv region can be improved significantly [5]. Plane gratings in some monochromators and most of the concave gratings operate when the light propagation direction lies out of the plane perpendicular to the grooves. Recently we have discussed the application of the conical diffraction numerical treatment to the mode coupling phenomena in planar corrugated waveguides [6].

Since in the conical diffraction mounting neither the Maxwell's equations nor the boundary conditions can be divided into two independent cases of polarization, a linearly polarized incident wave generates, in general, elliptically polarized diffracted waves. Therefore a special attention has to be devoted to the polarization characteristics of the diffracted light.

The aim of this paper is to present both experimental and theoretical study of the diffraction and polarization properties of an aluminium diffraction grating for an arbitrary angle of incidence with respect to the plane perpendicular to the grooves.

II. — EXPERIMENTAL RESULTS

A grating with a period $d = 0.6635$ µm was prepared interferometrically in a photoresist Shipley AZ 1350 by a technique reported elsewhere [7]. The exposure and the developing processes ensure approximately a sinusoidal grating profile with a groove-depth $h \approx 0.12$-0.14 µm. The grating was coated with an Al layer 0.2 µm thick. Using a theodolite the grating was rotated about two perpendicular axis as shown schematically in *figure 1*. The measurements were carried out for two linear mutually orthogonal polarizations (designated further on with $E_{\parallel}$ and $E_{\perp}$) of the incident from a He-Ne laser light with wavelength $\lambda = 0.6328$ µm. In the classical diffraction case (angle $\varphi = 0$ in *fig. 1*) they coincide with the fundamental TE (or P) and TM (or S) polarizations, respectively. A special precaution has been taken at $\varphi = 0$ to ensure the parallelness of the grating grooves and the vertical theodolite axis with the direction of the incident electric field vector corresponding to $E_{\parallel}$ case (see *fig. 1*). During the measurements the experimental setup was adjusted so that the beam was falling on one and the same point of the grating surface. The diffraction efficiency and the ellipticity of the -1st diffraction order were measured as a function of the angle Θ (*fig. 1*) for different values of φ. The results are presented in *figure 2*. The ellipticity of the diffracted wave is defined as a ratio of the minimum to the maximum values of the efficiency measured with a polarization analyzer, or, in other words, it represents the square of the ratio of the small to the big axis of the ellipse drawn by the diffracted electrical field vector.

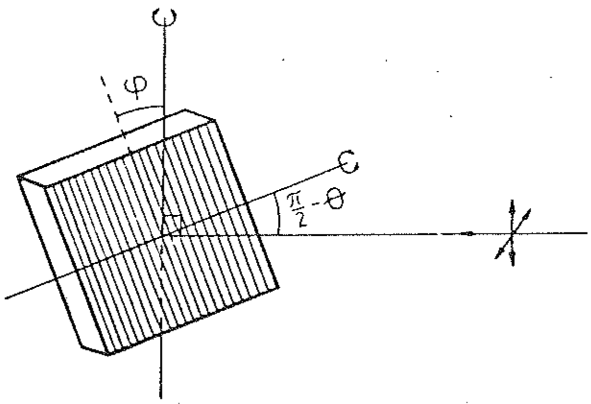


FIG. 1. — *Determination of the angles of incidence for a reflection grating in conical diffraction mounting.*

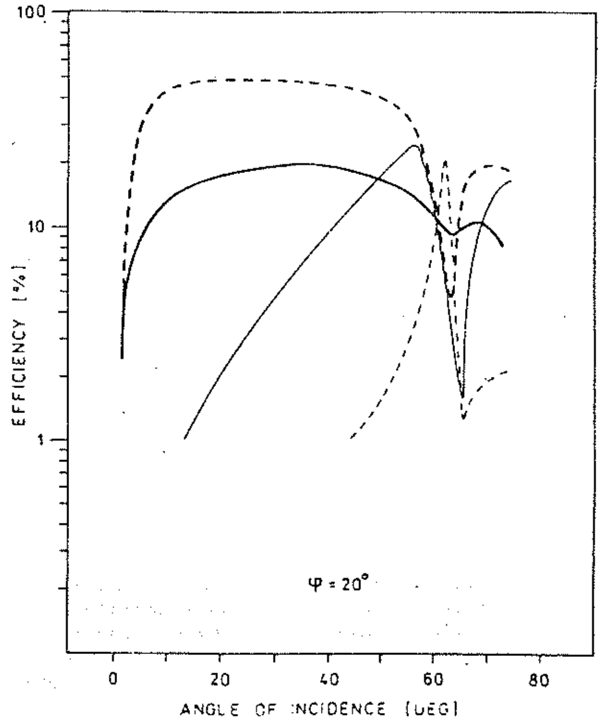


FIG. 2 b.

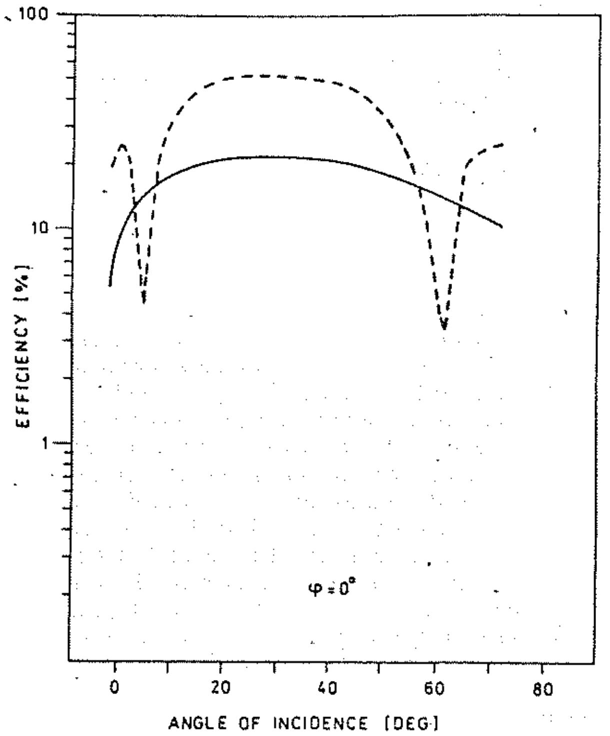


FIG. 2 a.

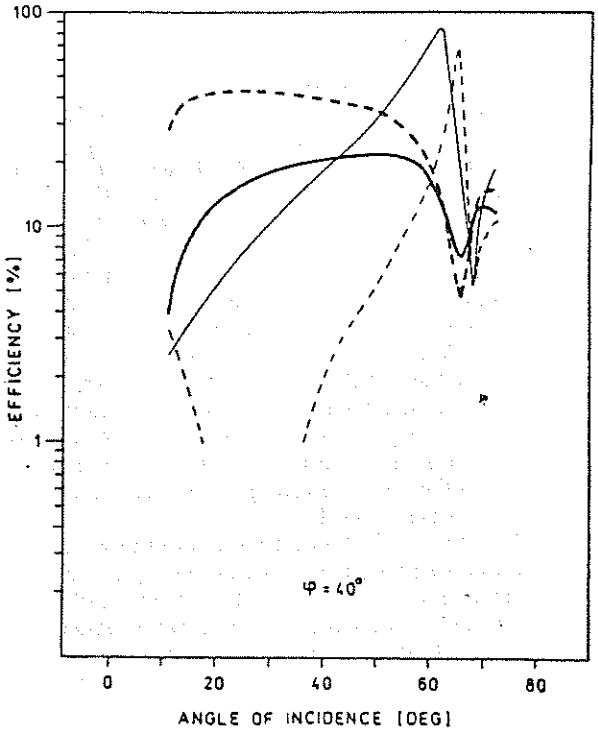
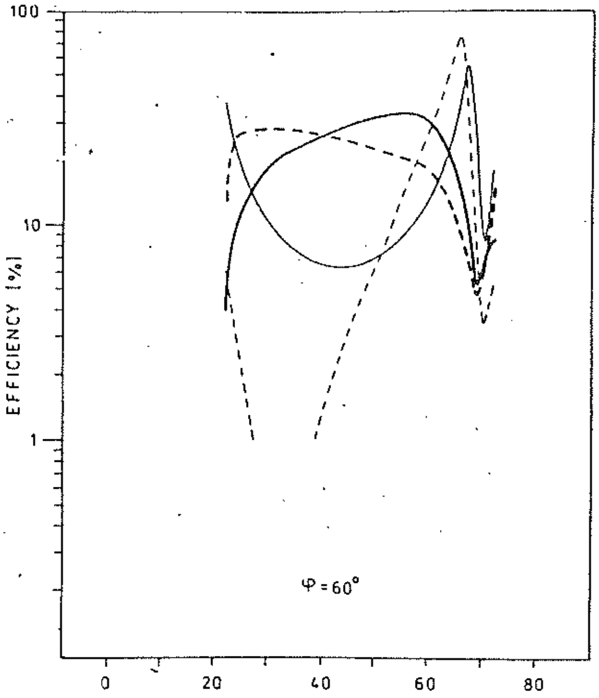


FIG. 2 c.



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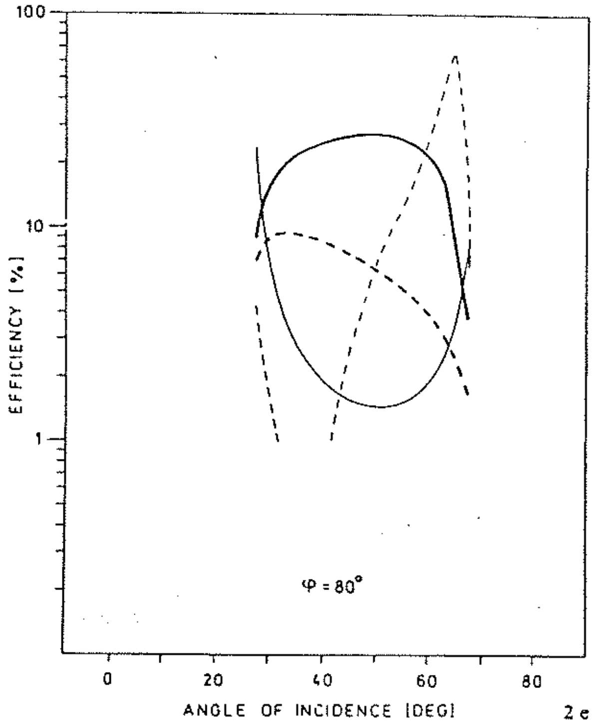

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FIG. 2. — *Angular dependences of the total diffraction efficiency (thick lines) and the ellipticity (thin lines) of the -1st order for different values of the deviation φ from the classical diffraction case.* (a) $\varphi = 0°$, (b) $\varphi = 20°$, (c) $\varphi = 40°$, (d) $\varphi = 60°$, (e) $\varphi = 80°$. *Solid line — $E_{\parallel}$ polarization, dashed line — $E_{\perp}$ polarization. The values bellow 1 % are not shown as they are comparable with the experimental error.*

As it can be expected, at $\varphi = 0$ no polarization effects occur; the anomalies in the *TM* polarization curve are due to the excitation of surface plasmons at the metal — air boundary near to the passing-off of the + 1 and -2 orders. Increasing φ some common features has to be mentioned. First, the maximum value of the total $E_{\parallel}$ efficiency curve is enhanced while the corresponding $E_{\perp}$ efficiency value decreases. The first anomaly disappears because in that angle interval the + 1st order does not exist. The second anomaly is well pronounced for the both polarizations of the incident light. This is not surprizing since the electric field vectors of the incident and diffracted waves are no more orthogonal to the plasmon electric vector, therefore the surface plasmon can be excited even with $E_{\parallel}$ polarized incident wave.

Secondly, the behaviour of the ellipticity for each incident polarization is qualitatively one and the same independent of φ. The maximum value is lying near to the minimum efficiency, while the minimum ellipticity is located at the values of Θ corresponding to Wood's anomaly (passing-off point of the -2nd order). It is interesting to point out that the big axis of the ellipses drawn by the electric field vectors of the diffracted waves for $E_{\parallel}$ and $E_{\perp}$ are not mutually orthogonal. The angle δ between them is not equal to $\pi/2$ and in *figure 3* its deviation $\Delta = \pi/2 - \delta$ from $\pi/2$ is displayed. Again in the vicinity of the anomaly an abrupt change of Δ occurs.

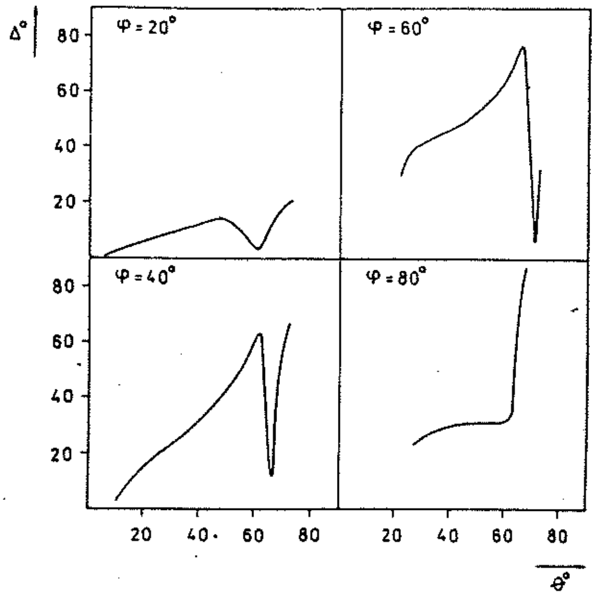

FIG. 3. — *Values of Δ as a function of Θ for* : (a) $\varphi = 20°$, (b) $\varphi = 40°$, (c) $\varphi = 60°$, (d) $\varphi = 80°$.

III. — NUMERICAL RESULTS

In order to perform correctly the calculations of diffracted waves amplitudes one must know the grating groovedepth and the refractive index of the Al layer. The real and imaginary parts of the refractive index $n_2 = 1.09 + i5.31$ have been determined from the reflectivity and polarization characteristics of a plane Al mirror by a least square fit. The groovedepth $h = 0.124$ μm has been obtained by the comparison between the experimental and the theoretical values of the efficiency in a Littrow mount. The numerically calculated ellipticity and efficiency curves corresponding to the experimental conditions of *figure 2 (d)* are presented in *figure 4*. The computer code is based on the rigorous electromagnetic theory for multilayered relief gratings in conical diffraction mounting [8]. The experimental and the calculated efficiencies almost coincide except for in the anomaly region where the theoretical curve is narrower. The ellipticity of the -1st diffraction order exhibits the same features as an experimental curve — a maximum near the anomaly and a sharp minimum at the passing-off of the -2nd order. Although the coincidence is qualitatively good, the calculated ellipticity is much lower than the experimental values.

It is well known [9] that the oxydation of the aluminium layer in air results in the formation of Al_2O_3 film 1-5 nm thick. The presence of such a dielectric layer, however, can change significantly the polarization characteristics of the grating. To illustrate that fact an aluminium grating coated with a 5 nm thick layer with a refractive index 1.538 is considered *(fig. 5)*. In order to retain the same efficiency value in a Littrow mount a slightly greater groovedepth $h = 136$ nm has to be taken. In this case the agreement between the theoretical and the experimental curves is better — the halfwidth of the anomaly gap in the efficiency curve is enlarged and, in addition, the ellipticity increases about 1.5-2 times in comparison with the uncoated case.

Therefore the comparison between the experimental and the theoretical results in conical diffraction mounting has to be performed most carefully. Even a slight change of the parameters of the system can result in a significant change of the grating polarization characteristics, keeping the diffraction efficiency curves practically unchanged.

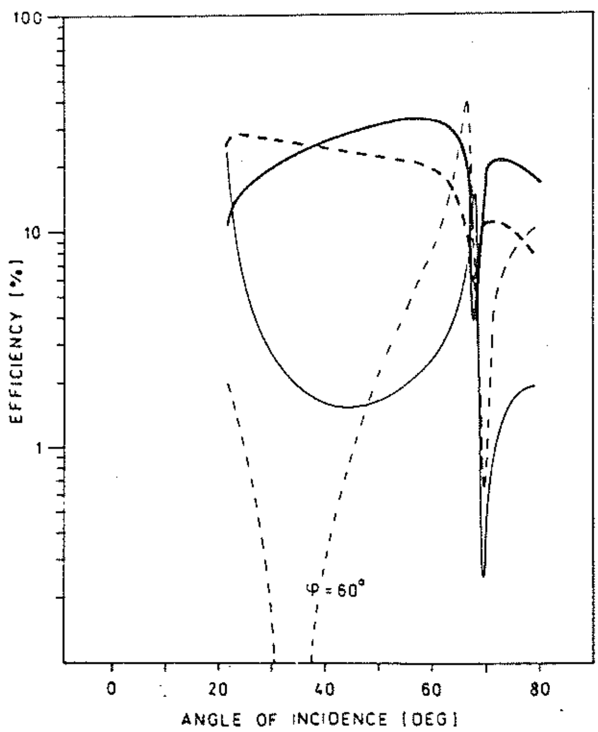

FIG. 4. — *Theoretical -1st order diffraction efficiency (thick lines) and ellipticity (thin lines) of a bare aluminium grating for* $\varphi = 60°$. *Solid line* — $E_{\parallel}$ *polarization, dashed line* — $E_{\perp}$ *polarization.*

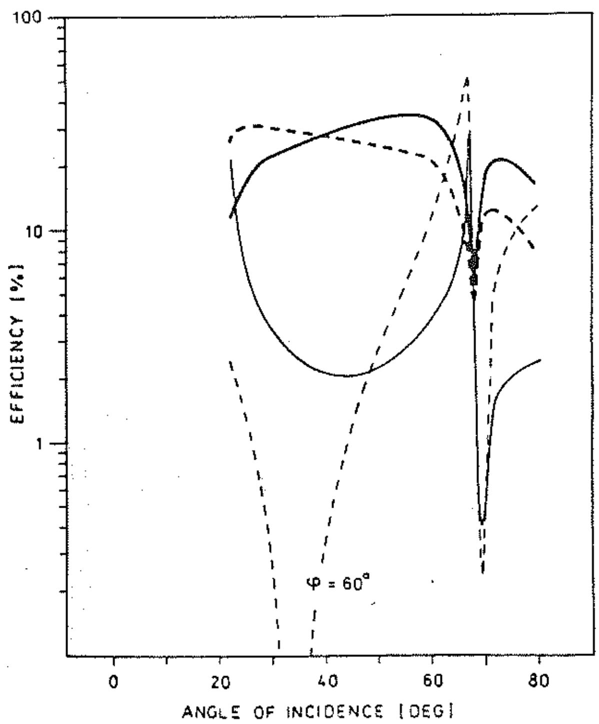

FIG. 5. — *The same as figure 4 except for a dielectric coating.*

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