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DIFFRACTION EFFICIENCY ANOMALIES OF MULTICOATED DIELECTRIC GRATINGS

L. MASHEV and E. POPOV
Institute of Solid State Physics, Bulgarian Academy of Sciences, BG-1184 Sofia, Bulgaria

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The diffraction efficiency curves of multicoated dielectric gratings are measured as a function of wavelength and angle of incidence for S and P polarization in the visible region. Strong anomalies are observed, due to the excitation of guided waves in the grating.

1. Introduction

Reflection diffraction gratings are coated usually with a metal layer, most frequently aluminium. Despite their wide application in various spectroscopic devices (monochromators, spectrographs), in dye lasers for tuning of the emission spectrum, as well as for optical information processing, such gratings possess some disadvantages:

(i) Most of the metal reflectances are very low in the ultraviolet, which reduces the diffraction grating efficiency.

(ii) High power laser radiation destroys the gratings, due to light absorption by the metal layers.

(iii) Surface plasmons excitation at the metal–air boundary leads to the appearance of grating efficiency anomalies. To avoid these difficulties, usually the aluminium gratings are covered with a thin dielectric layer. The influence of such a layer on the grating efficiency has been studied experimentally in ref. [1].

Maystre et al. [2] proposed to deposite two or four quarter-wavelength dielectric layers on the aluminium grating. Theoretical considerations [3] show that the light absorption is reduced two times for each stack of λ/4 dielectric layers. However, the effects of excitation of surface plasmons and quasi-guided waves are not discussed in [3].

In this paper we report the properties of a new kind of reflection holographic grating, consisting of multilayered dielectric system of $2n$ layers with high and low refractive indices, each one with λ/4 optical thickness, deposited directly on the photoresistive grating.

2. Experimental

The grating with 1200 l/mm was prepared interferometrically in a photoresist Shipley AZ-1350 by the technique, reported elsewhere [4].

After development the grating was coated with a dielectric system $(HL)^4H$ by vacuum evaporation, where H denotes ZnS with $n = 2.3$ and L denotes Na_3AlF_6 (cryolite) with $n = 1.35$. Separately, the same dielectric system was deposited on a plane glass substrate with a photoresist.

Diffraction efficiency of the grating was measured in Littrow mount as a function of wavelength, using the experimental setup, described earlier [5,6].

In our previous measurements, we have been able to obtain the spectral dependance of the relative grating efficiency, i.e. the ratio grating efficiency/Al-mirror reflectance. We shall see further (figs. 5 and 6) that in some cases the grating efficiency can exceed the dielectric mirror reflectance under the same working conditions. Therefore the relative efficiency is not quite convenient to be used.

In order to determine the spectral dependence of

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absolute grating efficiency, we measured first mirror reflectance as a function of wavelength in normal incidence with a Specord UVVIS. The maximum value of 98 ± 1% is located at $\lambda = 632.8$ nm. Taking into account mirror reflectance, the signal from the lock-in amplifier for the grating in Littrow mount is normalized with the signal from the mirror in normal incidence for each wavelength.

Angular dependence of grating efficiency was measured using output from He-Ne ($\lambda = 632.8$ nm) and Ar ($\lambda = 457.9$ nm) lasers. In both cases the experimental setup was adjusted so that the beam fell on one and the same point of the grating. A $\lambda/2$ plate and polarizer were used to change the polarization of the incident beam.

3. Results

The measured Littrow efficiency curves of -1 diffracted order for S and P polarization are shown in fig. 1.

In both polarization curves anomalies are observed, due neither to features in mirror reflectance, nor Wood anomalies including passing-off orders in air and dielectric layers. The corresponding P curve for an aluminium grating is free from any anomalies, while in S curve a Wood anomaly occurs at Rayleigh wavelength $\lambda/\Lambda = 2/3$ [7].

It is interesting to notice that in some cases diffraction efficiency exceeds the mirror reflectance for both polarizations. Maximum value of 70% is located at $\lambda = 610$ nm for S polarization. Quite different behaviour of grating efficiency of Al and multicoated gratings is clearly observed in fig. 2 and fig. 3. For S polarization the Wood anomalies for multicoated grating are shifted and in addition weak resonance anomalies appear. Quite narrow anomalies for P polarization for multicoated grating are due to the excitation of guided waves in the grating. In particular, the anomaly shown with a circle in fig. 2 is attended with an apperance of so-called m-line (fig. 4A). It is well known that the same picture is observed when the modes in a planar waveguide are excited by a prism or a grating coupler [8].

The location of the resonance anomalies is given

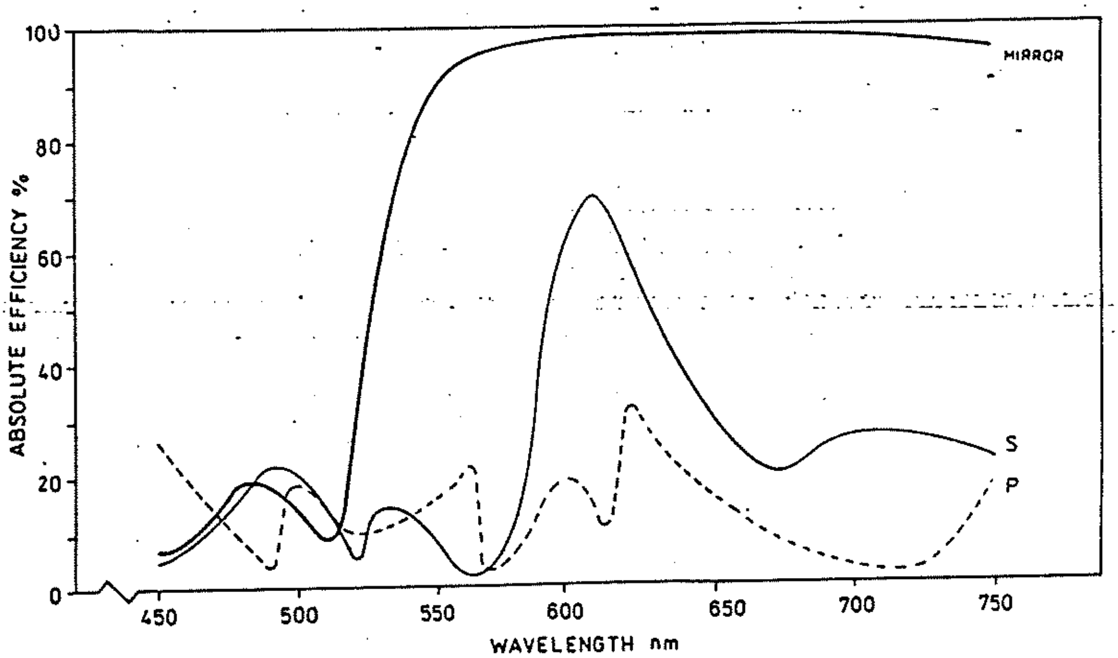


Fig. 1. First-order efficiencies as a function of wavelength: ––– P polarization, — S polarization. Heavy line – mirror reflectance in normal incidence.

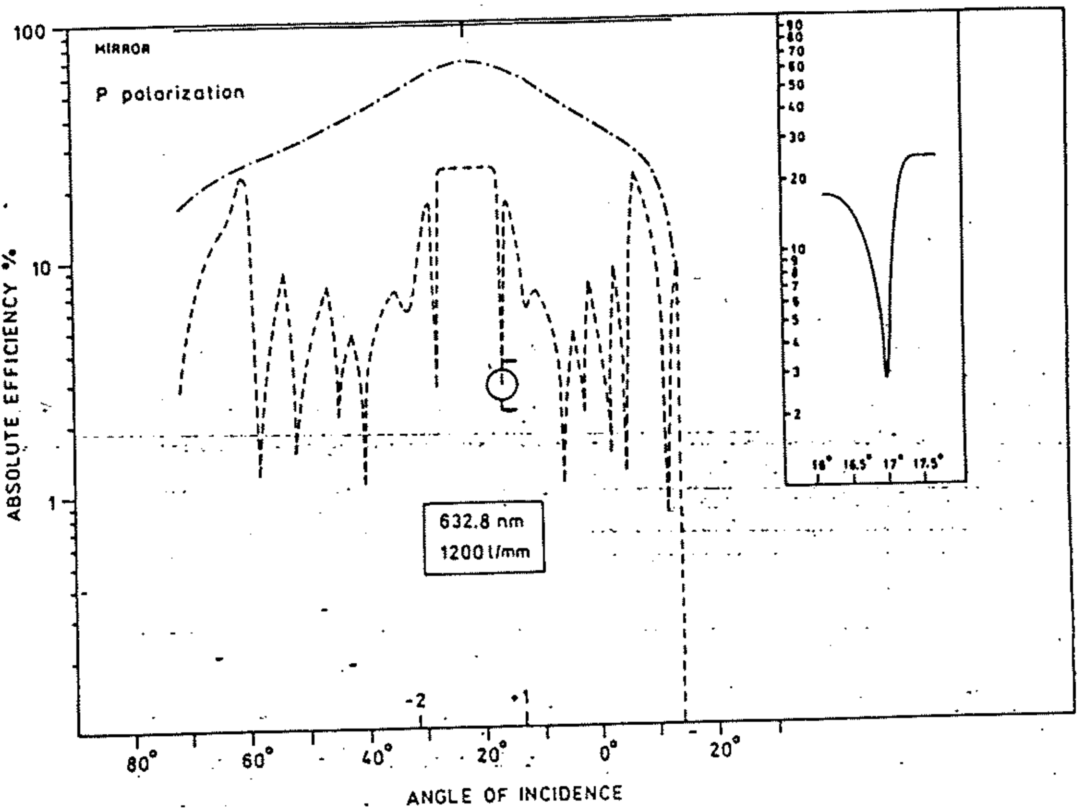


Fig. 2. First-order absolute efficiencies as a function of angle of incidence for P polarization and λ = 632.8 nm. –.–.–· Al coated grating, – – – · multicoated grating. With vertical lines are indicated: in the upper part of the figure – Littrow angle, in the lower part –passing off orders. The shape of the anomaly, marked with a circle, is shown in the right hand side of the figure.

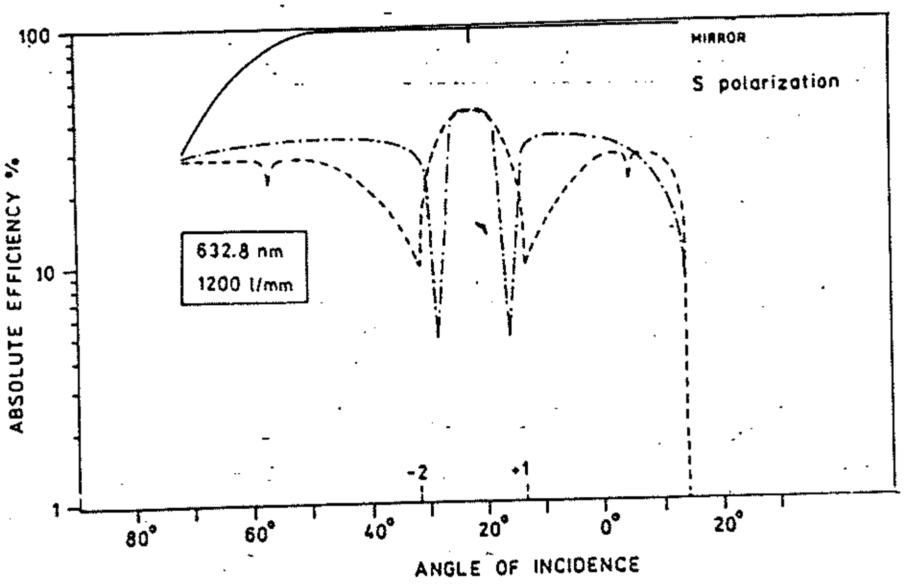
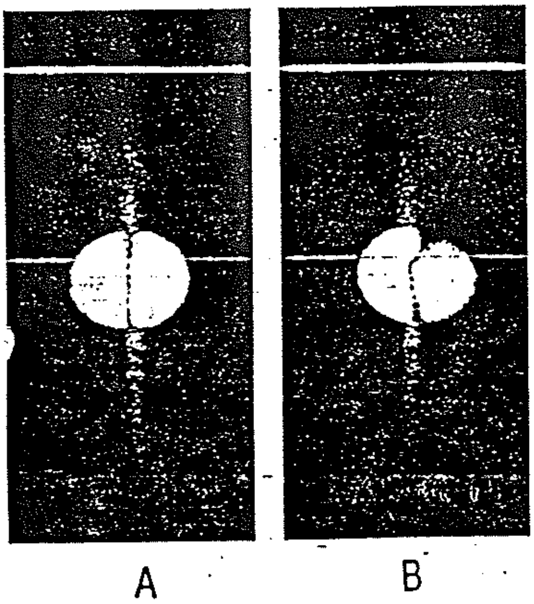


Fig. 3. Same as fig. 2 except for S polarization.



by the phase-matching condition:

$$\sin \theta_i^n = (\beta/k)_n - m\lambda/\Lambda \,. \qquad (1)$$

where θ_i^n is the angle of incidence, $(\beta/k)_n$ are the mode effective indices ($n = 0, 1, 2, ...$), Λ is the grating period and $m = 0, 1, 2, ...$ is the number of diffracted orders.

The propagation characteristics of the dielectric system have been calculated without corrugation. It is found that for $\lambda = 632.8$ nm the planar multilayered system can support four TE and three TM modes.

The calculated value of the 0th mode $\beta/k = 1.8068$ is in good agreement with the calculated from (1) value $\beta/k = 1.8090$. The dark band in fig. 4 corre-

Fig. 4. m-line picture, observed on the screen, when 0th mode is excited.

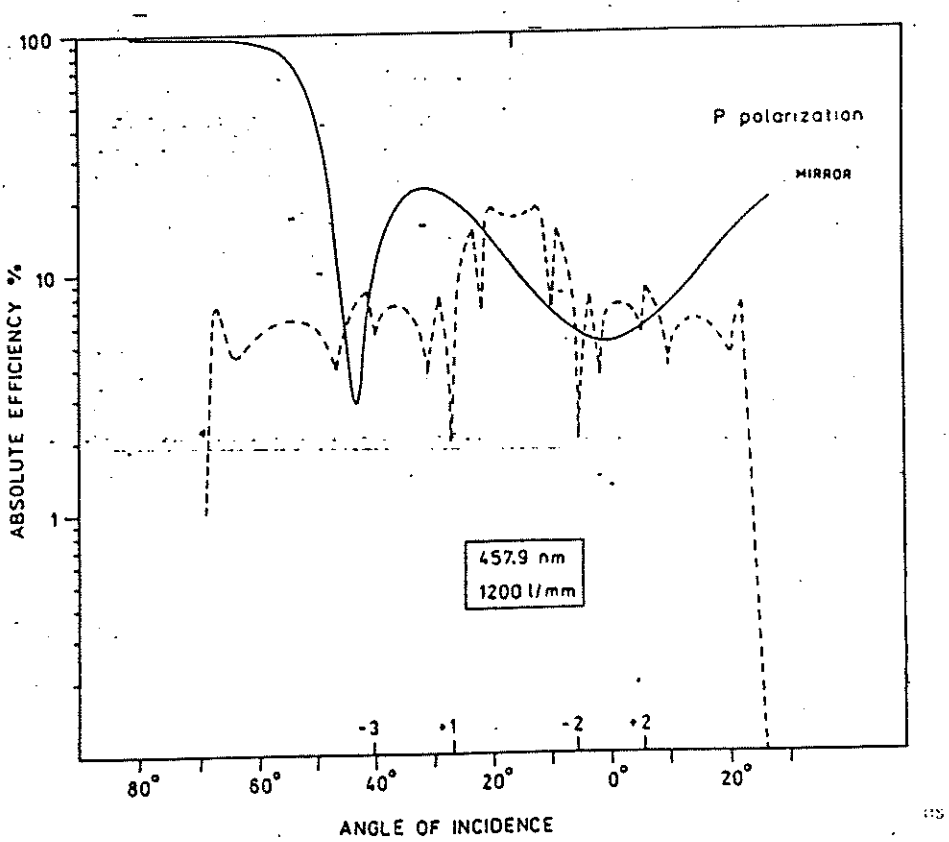


Fig. 5. First-order efficiency as a function of angle of incidence for P polarization and $\lambda = 457.9$ nm.

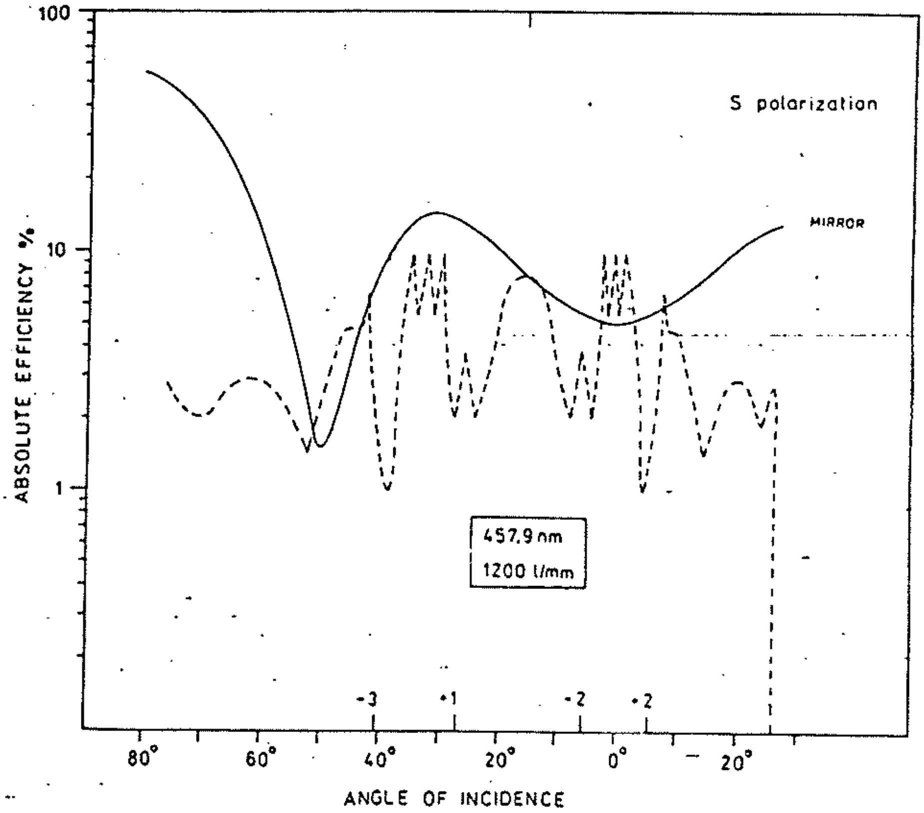


Fig. 6. Same as fig. 5, except for S polarization.

sponds to the power loss, "carried away" by the waveguide mode. The interference between the incident and the guided wave gives the possibility to estimate the quality of the grating. Fig. 4B shows the excited m-line in the presence of a local defect in the grating.

The measurements of the angular dependence of the diffraction efficiency for λ = 457.9 nm are shown in fig. 5 and fig. 6. The number of anomalies in S polarization curve is increased. Shape and locations of the anomalies are not connected with the mirror reflectance peculiarities. Near Littrow angle the grating efficiency exceeds the mirror reflectance. The enlargement of the anomalies width at λ = 457.9 nm is probably due to higher losses of the waveguide modes.

An important feature in figs. 1, 2, 5 and 6 is that the positions of the anomalies are not symmetrical about Littrow angle, unlike Wood anomalies. On the other hand, the position of the anomalies is symmetrical in terms of eq. (1), i.e. the values of $(\beta/k)_n$ evaluated from (1) for one set of anomalies located on the left hand side of Littrow mount corresponds fairly well with $(\beta/k)_n$ of the set of anomalies on the right hand side of Littrow mount. Similar behaviour has been observed earlier by Hutley and Bird [9] due to the excitation of surface plasmons on metal coated gratings. To our knowledge, however, such a strong asymmetry has not been observed up to now in gratings.

4. Conclusion

We have proposed and studied the properties of a new kind of holographic diffraction grating. The diffraction efficiency behaviour is completely different from the most commonly used aluminium gratings. The excitation of guided waves in the dielectric gratings in general reduces their efficiency. Nevertheless, the maximum value of 70% can be considered encouraging. Further experimental and theoretical works are required to improve the performance of such gratings for applications.

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