ZERO ORDER ANOMALY OF DIELECTRIC COATED GRATINGS

L. MASHEV and E. POPOV

Institute of Solid State Physics, Bulgarian Academy of Sciences, 1184 Sofia, Bulgaria

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The zeroeth order diffraction efficiency of a three-layer dielectric grating is studied theoretically and experimentally. A sharp resonance anomaly due to the excitation of guided waves is observed, which increases significantly the reflectance of the system. The operation of the structure as a tunable narrow-band wavelength filter in a reflection regime is demonstrated.

1. Introduction

In the last twenty years the grating resonance anomalies in the diffraction efficiency have been of continuous interest to both theoreticians and experimentalists [1]. Up to now the anomalies in the grating efficiency due to the excitation of surface waves have been investigated for the first or higher orders. This is not astonishing since the zeroth order is non-dispersive and it is not of interest for most of the spectroscopic purposes. On the other hand, the excitation of surface waves is usually accompanied with a sharp failure of the first order efficiency which is interesting at least as a sensitive test for the grating theories. The excitation of guided waves in a multicoated dielectric grating has been investigated experimentally in our previous paper [2]. In particular, a quite narrow anomaly for P polarization has been observed in the − first diffraction order.

The purpose of this paper is to show that the excitation of guided waves in a three-layer dielectric grating leads to two surprising effects in the zeroth order efficiency: first, the reflectance of the system is increased significantly, and second, wavelength selectivity is achieved.

2. Theoretical study

A grating with a period $d = 0.303$ μm and groove depth $h = 0.12$ μm in a substrate with a refractive index $n_3 = 1.5115$ is coated with a dielectric layer with a thickness $t = 0.7$ μm and a refractive index $n_2 = 1.542$. From the air a P polarized plane monochromatic wave with a wavelength $\lambda = 0.6328$ μm illuminates the structure. The parameters of the system are chosen to correspond to the experimental ones described in the next section. At these conditions only the zeroth reflected and transmitted order are diffracted and, without corrugation, the system can support one TE mode with an effective refractive index $\beta/k = 1.5188$.

The calculations of the diffraction efficiency are performed with a computer code based on the rigorous differential formalism of Chandezon et al. [3] for multicoated gratings. A double precision arithmetics with a single precision computer wordlength of 32 bits is used. The advantages and the restrictions of the method and its comparison with the Rayleigh-Fourier method are presented in ref. [4].

The calculated zero-order efficiency curve, shown in fig. 1, exhibits a sharp anomaly in the vicinity of the mode excitation in the corrugated waveguide. Within a tenth of degree the efficiency is enhanced up to 100% and after that rapidly falls down to about 1.7%. The zero-order reflectance of the same but uncoated grating is quite flat (fig. 1, dashed line).

The same feature occurs at a fixed angle of incidence when the mode of the corrugated waveguide is excited, varying the wavelength (fig. 2), thus the zeroth order

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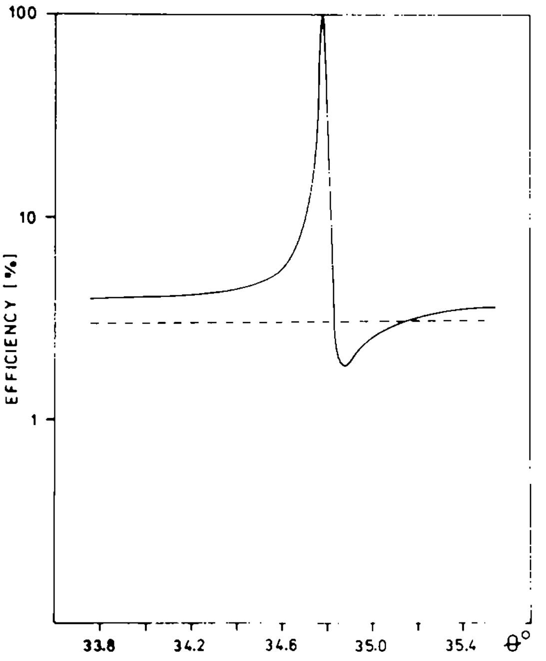

Fig. 1. Calculated reflected zero-order efficiency of sinusoidal grating as a function of the angle of incidence; the parameters are given in the text. Dashed line: bare dielectric grating, solid line: coated grating.

exhibits wavelength selectivity. This curious phenomenon is a consequence of the resonant nature of the anomaly. Moreover, the phase-matching condition for the excitation of guided waves is satisfied for different wavelengths when changing the angle of incidence, which enables the tuning of the wavelength.

3. Experimental results

A grating with a period d = 0.3 μm was recorded in a photoresist Shipley AZ-1350 coated on a glass substrate (n_3 = 1.5115), by a technique reported elsewhere [5]. The grating was transfered into the glass substrate by ion-beam milling. The exposure, the development, and the etching processes ensure a sinusoidal grating profile with a groovedepth h = 0.10 -0.12 μm.

The efficiency of the zeroth reflected order was measured as a function of the angle of incidence with a HeNe laser (λ = 632.8 nm). The experimental values of fig. 3 (dashed line) correspond fairly well to the calculated ones in the previous section.

A monomode waveguide was formed by Ag^+ ion exchange in molten $AgNO_3$ at a temperature T = 217°C for 7 min.

Usually the excitation of guided waves in a corrugated waveguide is accompanied by the appearance in the first or higher orders of the so-called m-line [2], a dark line in the centre of the laser spot. Fig. 4 repre-

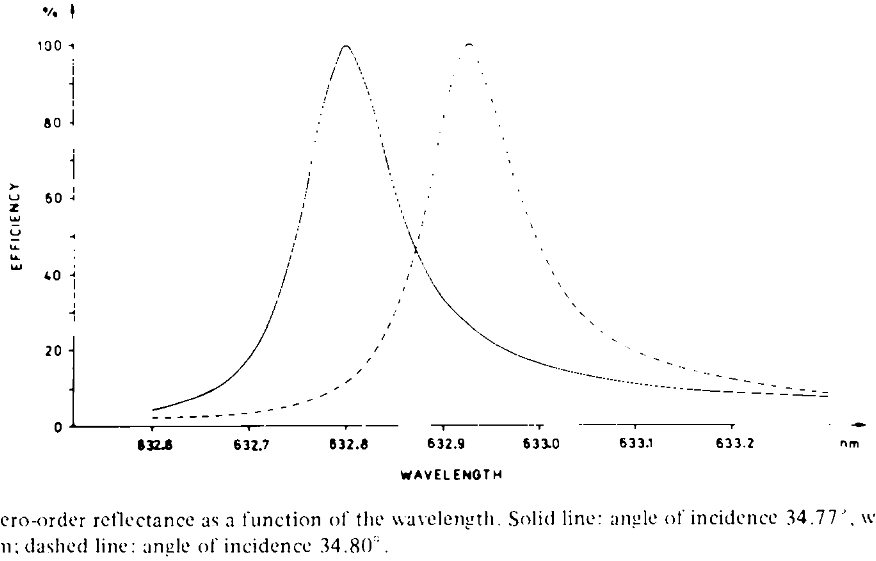

Fig. 2. Theoretical zero-order reflectance as a function of the wavelength. Solid line: angle of incidence 34.77°, with maximum at wavelength 632.8 nm; dashed line: angle of incidence 34.80°.

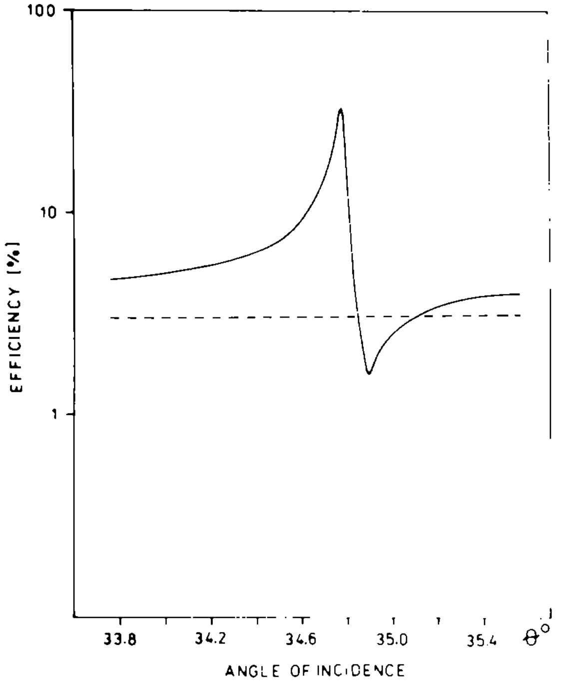

Fig. 3. Measured zero-order reflection efficiency as a function of the angle of incidence; the grating parameters are given in the text. Dashed line: before ion-exchange. Solid line: after formation of the waveguide.

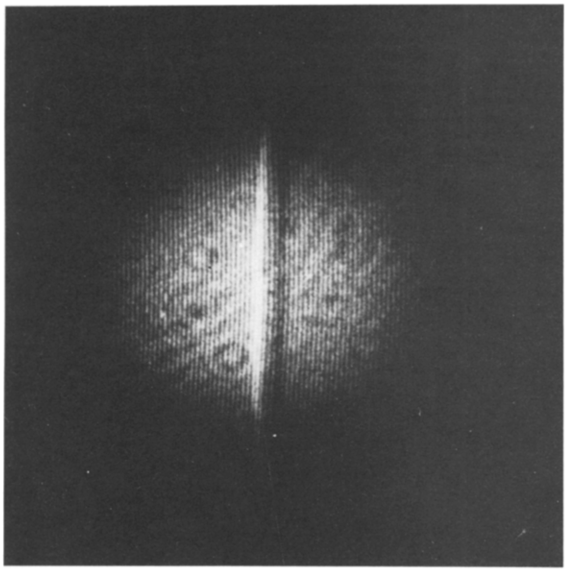

Fig. 4. The m-line picture in the zero-order reflectance, observed on a screen.

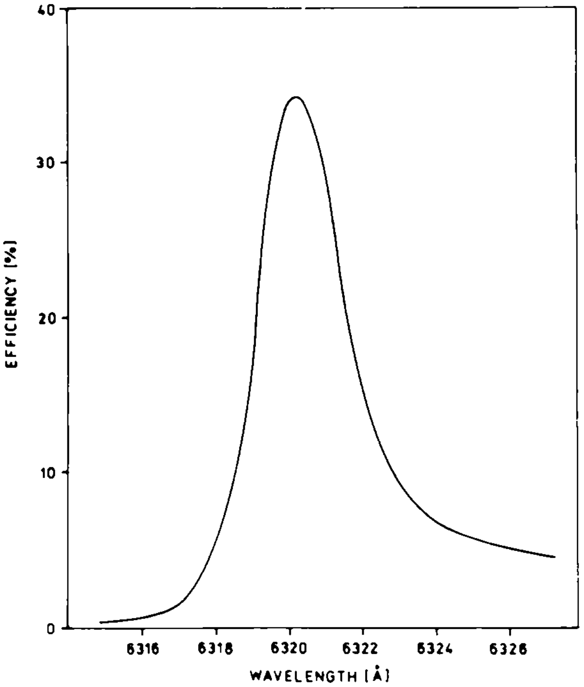

Fig. 5. Experimental wavelength dependence of the zeroth reflected order efficiency.

sents the excited m-line in the zeroth reflected order. The bright and the dark lines corresponded to the maximum and the minimum value of the curve in fig. 1 respectively. The interference fringes are due to the multiple interference between the two substrate surfaces.

The measured angular dependence of the zeroth-order reflectance is presented in fig. 3 with a solid line. The position of the maximum and minimum and the width of the anomaly are in good agreement with the calculated values. The lower value of the maximum in fig. 3 in comparison with fig. 1 can be explained taking into account that: (i) the real system is lossy, (ii) the grating is not perfect, and (iii) the incident beam in limited and a great amount of energy is carried away by the propagating mode. Our opinion is that this type of losses is of the greatest importance.

The zero-order efficiency was measured as a function of the wavelength using a dye laser pumped by N_2 laser. The results are shown in fig. 5. The halfwidth of the curve is about 3 Å. To our knowledge this is the first demonstration of a narrow-band tunable optical filter in a reflection regime.

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