ANOMALOUS REFLECTION WITH NONCOLINEAR EXCITATION
OF A CORRUGATED WAVEGUIDE

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It is shown that when there is simultaneous excitation of two waveguide it is possible to increase the maximal value of the anomalous reflection as compared to the case of excitation of a single mode. This is the basis for creation of a narrow band optical filter operating on reflection with a maximal reflection coefficient of $R_{\text{max}} \approx 0.8$.

Reflection of light is observed with excitation of a corrugated waveguide by a planar electromagnetic wave [1,2]. The amplitude of the reflected wave may rise to the amplitude of the incident wave, while the phase is monotonically changed from zero to $2\pi$ [3]. Anomalies are localized in a quite narrow range of light incidence angles (at a fixed wavelength) or in a narrow range of the spectrum (at a fixed incidence angle). Investigation of anomalous reflection is associated with the potential for using it in different spectral instruments.

The presence of dissipative losses $\alpha_d$ in the waveguide leads to a reduction in the maximal reflection coefficient $R_{\text{max}}$. The relation between the dissipative and radiational $\alpha_r$ losses in the waveguide is the parameter which determines $R_{\text{max}}$, $R_{\text{max}} = \left( r_p \alpha_d - \alpha_d \right) / ( \alpha_d + \alpha_d)^2$ is the case for a thin film waveguide with low reflection on the waveguide layer - substrate boundary, where $r_p$ is the amplitude of the coefficient of Fresnel reflection. Therefore, the condition $\alpha_r > \alpha_d$ must be satisfied to produce anomalous reflection.

In seeking ways to increase the maximal reflection coefficient attention has been focused on the fact that at low incidence angles and excitation of two waveguide modes, which are propagated in opposite directions, there are two characteristic peaks in the reflection spectrum. Waveguide modes propagated in opposite directions interact with each other in the second order of diffraction in a corrugation. This leads to asymmetry in the peaks of reflection. More precisely, as perpendicular is approached the spectral width of the longwave peak is greatly reduced, while that of the shortwave peak is approximately doubled.

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[4]. When there are dissipative losses the maximal value of the reflection coefficient is reduced, where the narrower the spectral width of the reflection peak, the greater the influence of the dissipative losses. Thus, with perpendicular incidence the reflection spectrum contains a single shortwave peak and its spectral width and the maximal reflection coefficient are greater than the corresponding values with excitation of a single mode. The maximal reflection coefficient with perpendicular incidence is determined by the formula \( R'_{\text{max}} = \frac{(r_0 a_d - 2 a_d)}{(a_d + 2a_d)^2} \). When the Fresnel reflection \((|r_0| < 1)\) is ignored, then the increase in the reflection coefficient is

\[
\frac{R'_{\text{max}}}{R_{\text{max}}} = \frac{12(a_x + a_d)}{(2a_x + a_d)^2}.
\]

Simultaneous excitation of two waveguide modes associated in a second order of diffraction is also observed with noncolinear excitation of a waveguide.

When the projection of the wave vector of the incident wave is parallel to the lines of the lattice, then at an incidence angle of \( \xi \), which satisfies the condition \( \sin^2 \xi + (\lambda/\Lambda)^2 = n^2 \), where \( n^* \) is the effective refraction index of the waveguide, and \( \Lambda \) is the period of the corrugation, it is possible to achieve simultaneous excitation of two waveguide modes. In order to realize excitation of only a single mode, it is possible to detune the system, turning the waveguide by a small angle \( \theta \) with respect to the axis parallel to the lines of the lattice (Fig. 1a). If the angle \( \xi \) is measured in the plane which is parallel to the lines of the lattice and which contains the wave vector of the incident wave, then the excitation condition acquires the following appearance:

\[ \sin^2 \xi + (\cos \xi \sin \theta \pm \lambda/\Lambda)^2 = n^2. \]

Thus, at \( \theta = 0 \) the system is in resonance (two modes are excited), while at \( \theta \neq 0 \) the modes are alternately excited (as \( \xi \) is changed). The condition for excitation of the waveguide is schematically illustrated in the diagram (Fig. 1b).

Unlike the case of perpendicular incidence of light, noncolinear excitation of a waveguide makes it possible in the same sample to realize simultaneous excitation of two modes in a quite wide spectral range through adjustment of the angle of incidence \( \xi \). In this case there is no need to precisely select the period of the lattice or to use a tunable laser.

The experiment was performed with a waveguide made in the following manner. A precorrugated glass substrate (\( \lambda = 0.842 \) micron and a corrugation half-depth of 0.12 micron) was submerged in a melt of \( \text{AgNO}_3 \) (2% by weight) and \( \text{NaNO}_3 \) salts at a temperature of 320°C for 2.5 min. A thin \( (h = 200 \text{ Å}) \) silicon film was then sprayed onto the surface of the formed diffusion waveguide. This film does not form the waveguide layer by itself, but deforms the field of the mode in such a
Fig. 1. Noncolinear excitation of a corrugated waveguide: a) general appearance; b) diagram of the wave vectors.

Fig. 2. Angular relations of the reflection coefficient with noncolinear excitation of a waveguide by a transverse magnetic (TM) polarization wave (the parameters of the waveguide are given in the text).

Fig. 3. Angular relations of the reflection coefficient with colinear excitation of a waveguide in the case of transverse magnetic (a) and transverse electromagnetic (b) polarizations of the incident radiation.
way that its value is increased on the surface, which leads to an increase in the radiative losses in the lattice. The field of the waveguide is localized basically in the region of diffusion of the Ag ions and, therefore, as with the diffusion waveguide, the combined waveguide has low dissipative losses.

The experiment showed that with simultaneous excitation of two modes ($\theta = 0$) the maximal reflection coefficient is somewhat greater than with excitation of a single mode ($\theta \neq 0$) (Fig. 2). For the best samples it was about 80 and 60%, respectively, with TM polarization of the incident radiation and a light wavelength of $\lambda = 1.15$ microns.

With colinear excitation such waveguides also display quite high anomalous reflection (0.70 for transverse electromagnetic and 0.48 for transverse magnetic polarizations of the incident radiation) (Fig. 3).

Thus, noncolinear excitation of a waveguide makes it possible to simultaneously excite two modes and in the same way to increase the maximal reflection coefficient with anomalous reflection of light.

REFERENCES


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