and parametric oscillations (when the pump wavelength was \( \lambda = 0.532 \mu \)) using a two-crystal optical parametric oscillator made of an LiIO\(_3\) crystal pumped by the second harmonic of the YAG:Nd\(^{3+}\) laser (\( \lambda = 0.532 \mu \)) with passive mode locking and a system for separating a single pulse. The oscillator generated two parametrically coupled waves covering the range 0.7-2.2 \( \mu \). The radiation from this oscillator was directed to a KTP crystal oriented in such a way that the incident radiation traveled in the \( XY \) plane and the polarization of the exciting waves made an angle of 45° with the \( Z \) axis. Measurements were made of the phase-matching angle \( \phi \) (which was the angle between the \( X \) axis and the direction of propagation of the radiation) when the second harmonics of the signal and idler oscillator waves were generated and of the phase-matching angles in the generation of the sum frequency of these two waves when the oscillator was tuned (Fig. 2). The \( Z \) axis of the KTP crystal coincided with the angle of rotation of a goniometric head to within 1° and the angles \( \phi \) within the KTP crystal (Fig. 2) were calculated using the refractive index taken from Ref. 1. The results obtained proved the feasibility of achieving the 90° phase matching in the generation of the second harmonic of radiation of wavelengths 1-1.42 \( \mu \) (by the type II interaction) and for the parametric generation of light tunable in the range 0.85-1.42 \( \mu \).

The considerable width of the frequency and angular phase matching in the KTP crystals makes them suitable for picosecond and femtosecond applications, and for parametric oscillators with synchronous pumping by near infrared radiation of high average power, as well as for intracavity frequency conversion systems.


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Total reflection of light from a corrugated surface of a dielectric waveguide

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It is shown that reflection of a plane monochromatic wave by the surface of a corrugated waveguide structure may excite a guided mode in one of the diffraction orders and thus alter greatly the reflection and transmission coefficients of the incident wave until total reflection or total transmission are achieved.

Interaction of laser radiation with surfaces of condensed media is attracting special attention because the formation of a periodic microrelief on the surface of a medium under the action of one laser beam is a universal effect.\(^1\) A similar relief was found to form on the surface of a dielectric waveguide illuminated by one laser beam.\(^2\) Since the initial stage of formation of a microrelief can be described in terms of the diffraction of light by a specific spatial harmonic of the surface irregularities,\(^1\) it has seemed natural to apply the diffraction approach also to a waveguide. The problem of the diffraction of light by a corrugated boundary of a layer medium was considered earlier,\(^3\) but the case of diffraction of light on excitation of guided modes was not discussed. The diffraction of light under these conditions was observed experimentally\(^4\) and it was found that there were abrupt changes in the behavior of the intensity of the first-order wave when a waveguide was excited. We shall report the results of a detailed investigation of the diffraction of light on the boundary of a corrugated waveguide and we shall allow for the excitation processes.

The diffraction is shown schematically in Fig. 1. A waveguide is assumed to be infinite along the \( X \) axis and a plane monochromatic wave is incident on the waveguide from air (\( n_2 = 1 \)) at an angle close to

\[
\theta = \sin^{-1}(n^* - \lambda / \Lambda),
\]

where \( n^* \) is the effective refractive index of the waveguide, \( \lambda \) is the wavelength of light in vacuum, and \( \Lambda \) is the corrugation period. The problem was solved in the approximation of

FIG. 1. Schematic representation of the process of diffraction by a corrugated surface of a waveguide.
weak corrugations, i.e., \((2\piq/\lambda)^2 < 1\) (\(\sigma\) is the corrugation amplitude), and allowance was made only for waves of the 0, ±1, ±2 diffraction orders. We were interested particularly in the waves of the 0 and ±1 orders. A theoretical analysis was made on the basis of the results of Ref. 5. Figure 2a shows the calculated intensities of the waves of the 0 and ±1 orders obtained for a corrugated diffused waveguide as a function of the angle \(\theta_2\). It is clear from these calculations that in the case of optimal excitation of a loss-free waveguide the intensity of the transmitted wave (i.e., of the wave in the waveguide substrate) vanishes, whereas the intensity of the reflection wave reaches the intensity of the incident wave. A similar result is obtained also in the case of a thin-film waveguide corrugated on the air side \((\sigma_2 \neq 0, \sigma_1 = 0)\). However, if a thin-film waveguide is corrugated on the substrate side \((\sigma_1 \neq 0, \sigma_2 = 0)\), the result is somewhat different: the initial intensity of the zeroth-order wave can be obtained not only in the substrate, but also in air (Fig. 2b). The condition for zero intensity of the reflected wave is as follows:

\[
h = \frac{\lambda}{2n_0 \cos \theta_0} \left[ \pi m \pm \tan^{-1} \left( \frac{n_2 \cos \theta_2}{n_2 \cos \theta_2 - n_1 \cos \theta_1 \cos \theta_2} \right) \right] \times \left( \frac{n_1 \cos \theta_1 - n_2 \cos \theta_2}{n_2 \cos \theta_2 (n_2^2 \cos^2 \theta_2 - n_1 n_2 \cos \theta_1 \cos \theta_2)} \right),
\]

(2)

where

\[m = 0, 1, 2, \ldots;\]

\(h\) is the film thickness; \(n_0, \theta_0, n_1, \theta_1, n_2, \text{ and } \theta_2\) are the refractive indices and the angles at which light travels in the film, substrate, and air, respectively.

Physical interpretation of these results, for example, those obtained for a corrugated diffused waveguide, is quite obvious: the incident light beam excites a guided mode which then propagates along the corrugated waveguide and is emitted into air and into the substrate. The directions of the emitted waves coincide exactly with the directions of the reflected and transmitted waves, whereas the phases of the investigated waves (dependent on the mode excitation conditions) may change. Since the phase of the reflected wave differs by \(180^\circ\) from the phase of the transmitted wave, it follows that by altering the mode excitation conditions (for example, by altering the angle \(\theta_2\), we can achieve interference suppression of the transmitted wave, i.e., we can attain total reflection of the incident wave. We checked experimentally these results by preparing a waveguide from a ZnO film \((h = 0.36 \mu)\) deposited on a corrugated \((\Lambda = 0.6 \mu, \sigma_2 = 0.02 \mu)\) glass substrate. The waveguide was then corrugated both on the air and substrate sides. Therefore, we carried out calculations which showed that in order to attain zero intensity of the reflected wave it was necessary to ensure, for a given film thickness, a specific ratio of the amplitudes of the upper \((\sigma_2)\) and lower \((\sigma_1)\) corrugations. Since this condition was not satisfied in our experiments, we observed only an enhancement (or weakening) of the intensity of the reflected (transmitted) wave for the optimal excitation of the guided mode (Fig. 3).

We thus found that when light is reflected by a corrugated waveguides structure and a guided mode is excited in one of the diffraction orders, it is possible to alter drastically the reflection and transmission coefficients of the incident wave right up to a situation when total reflection or total transmission is achieved. This effect is of resonant nature and, consequently, it can be used to construct narrow-band frequency filters and mirrors reflecting selectively along a given direction. The results of an investigation of the influence of losses in the waveguide on the properties of such devices will be reported later.


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FIG. 3. Far-zone field patterns obtained for the reflected (a) and transmitted (b) waves. The elongation of the transmitted beam spot is due to the wedge shape of the substrate.

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