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Anomalous temperature-independent birefringence in a biaxial optical LBO crystal

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Abstract. The existence of temperature-independent birefringence in an LBO crystal was confirmed experimentally for the first time. The considerable role of homogeneous temperature-induced strains was demonstrated. A bandwidth of the temperature phase-matching curve greater than 60 °C was obtained experimentally in a crystal 5.4 mm long at a fundamental radiation wavelength of 632.8 nm.

In a previous communication [1] we reported that the possibility of the occurrence of temperature-independent birefringence in biaxial crystals. A bandwidth of the temperature phase-matching curve in excess of 160 °C was obtained experimentally in a KTP crystal. It was shown in the same study that this effect may occur also in a lithium triborate (LBO) crystal. In most crystals, the thermal stability of the phase difference for the propagating waves is mainly determined by derivatives of the refractive indices with respect to temperature. A distinctive feature of the LBO crystal is high coefficients of the linear expansion tensor. Hence, apart from the temperature-induced changes in the refractive indices examined for a KTP crystal [1], uniform heating results in the appearance of strain-induced changes in an LBO crystal [2]. They are expressed by the rotation of the crystal faces and lead to the rotation of the crystal-optical coordinate system relative to the direction of propagation of the radiation. The angle of rotation depends on the angle of cut of the crystal and may reach 1°. This alters significantly the influence of thermal processes compared with a KTP crystal, which is characterised by an appreciably smaller linear expansion.

A cone of the temperature-independent interaction directions in an LBO crystal has a bisector x axis, i.e. the line intersecting the xy and xz planes. The following relationship between the temperature derivatives of the principal values of the refractive indices is fulfilled in the xy plane:

$$\frac{\partial n_x}{\partial T} > \frac{\partial n_z}{\partial T} > \frac{\partial n_y}{\partial T}.$$

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When a side face of the crystal is clamped, the expression for the phase difference in the xy plane is

$$\Delta\Phi = \frac{2\pi}{\lambda_0} L \cos 2\psi \left\{ \left[\frac{n_z(T)}{\cos\varphi^{\mathrm{i}}_z} - \frac{n_{xy}(\varphi_x, T)}{\cos\varphi^{\mathrm{i}}_{xy}} \right] \times \left[\alpha'_{xx}(\varphi_0)\Delta T + 1 \right] \right\}, \quad (1)$$

where $\psi = -\alpha''_{xy}\Delta T$ is the angle of the thermal-strain rotation of the crystal faces relative to the crystal-optical coordinate system [2]; φ_0 is the angle of cut of the crystal relative to the x axis (in the xy plane); $\alpha'_{xx}(\varphi_0)$ is the coefficient of linear expansion along the direction of propagation of the radiation; α''_{xy} is the coefficient of the thermal-strain-induced change in the crystal; φ_x is the angle between the x axis and the direction of propagation of the radiation;

$$\varphi^{\mathrm{i}}_{z,\,xy} = \psi \frac{n_{z,\,xy} - 2}{n_{z,\,xy}} + \varphi_0 \ .$$

are the angles of refraction for both field components. The remaining designations are generally accepted. Expression (1) shows that the temperature dependence of the angle ψ may make a contribution to the phase difference comparable with the contribution of the temperature dependence of the refractive indices.

A number of calculations were performed for an LBO crystal by using a specially developed program of the LID series (Laser Investigator & Designer, http://www.bmstu.rulid). The model of the crystal took into account the temperature dependence of the refractive indices (cubic polynomial), the temperature dependence of the coefficient of thermal expansion (cubic polynomial), and the contribution of strain-induced changes. The results of the calculations showed that, at a radiation wavelength of 632.8 nm, the temperature independent interaction occurs for the angle of cut $\varphi_0 = 53°$.

An experimental test of this regime by a method similar to that employed in Ref. [1] was carried out with two specimens of an LBO crystal 5.35 mm long grown in the Division of Wave Processes of the Physics Department of Moscow State University (the crystals had cuts for interaction in the xy plane with $\varphi_0 = 0$ and 45°). The polarisation plane of the He – Ne laser radiation was oriented at an angle of 45° relative to the z axis. An analyser was placed at the exit from the crystal. When the crystal was heated, different changes in the optical path length for two waves led to the formation of an interference pattern (a change in the intensity I). For the cut with $\varphi_0 = 0$, the results of the measurements (circles) and calculation (continuous line) are presented in Fig. 1. The width of the temperature phase-matching curve at FWHM is 6° C. For the angle $\varphi_x = 53°$, the results of

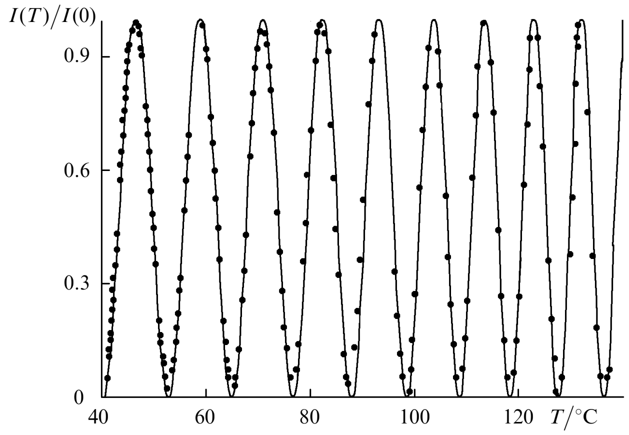

Figure 1. Temperature phase-matching curve for the cut with $\varphi_0 = 0$.

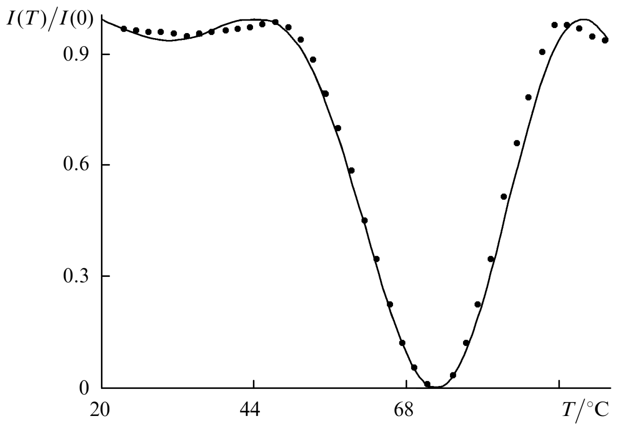

Figure 2. Temperature phase-matching curve for $\varphi_x = 53°$ in the temperature-independent regime.

the measurements (circles) and calculation (continuous line) are presented in Fig. 2. When the crystal is heated to 50°, the radiation intensity changes not more than 10%. The width of the temperature phase-matching curve at FWHM is 62 °C. It is seen from the shape of the curve that a temperature-independent regime has been implemented. The angle of the thermal-strain rotation of the entry face of the crystal on heating to 180 °C was about 2°. This greatly exceeds the angular separation between the interference maxima amounting to 21′. The estimates made demonstrate that, when the optimal angle of cut of the crystal is selected, it is possible to obtain a width of the temperature phase-matching curve greater than 100 °C.

Thus a distinctive characteristic feature of the temperature-independent birefringence achieved in an LBO crystal is the simultaneous operation of three mechanisms: the temperature variation of the refractive index, the linear expansion, and the strain-induced rotations of the entry face of the crystal and of the crystal-optical coordinate system. More detailed theoretical and experimental studies will be presented by the authors at a later date. It is also essential to note that the thermal-strain changes must also be taken into account in measurements of the temperature phase-matching curves for frequency converters in crystals with fairly large linear expansion coefficients in directions other than the principal directions. The existing considerable differences between the widths of the temperature phase-matching curves measured by different investigators can evidently be accounted for by the operation of this mechanism.

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