

LETTERS TO THE EDITOR

PACS numbers: 78.20.Fm; 42.70.Mp

Anomalously temperature-independent birefringence in biaxial optical crystals

S G Grechin, V G Dmitriev, V A D'yakov, V I Pryalkin

DOI: 10.1070/QE2000v030n01ABEH001644

Abstract. Temperature-independent birefringence in a biaxial crystal was predicted theoretically and observed experimentally for the first time. The width of the plot against temperature (the range corresponding to the temperature independence of the birefringence) at a fundamental radiation wavelength of 632.8 nm in a KTP crystal 5.9 mm long was more than 160 °C.

In a previous communication [1], we reported implementation of temperature-independent phase matching in second-harmonic generation (SHG) in nonlinear crystals, specifically in a KTP crystal. A tuning curve with a width greater than 200 °C was obtained experimentally. It was shown in the same study that this effect may occur in homogeneous crystals and in crystals with a regular domain structure for all nonlinear optical frequency conversion processes: generation of 3rd, 4th, and higher-order harmonics; generation of the sum and difference frequencies; parametric amplification; parametric oscillation; in other words, in all cases where the first derivative with respect to temperature for the corresponding phase mismatch is zero.

It might be expected that in biaxial crystals there are also directions for which birefringence depends only slightly on temperature. In devices of various types based on anisotropic media — such as amplitude and phase electro-optical modulators, demodulators, switches, *Q*-switches, frequency filters (Lyot and Šolc filters), scanners, etc. [2] — the interaction is determined by the phase difference $\Delta\varphi$ between waves of two different types but with the same frequency, propagating in a medium. The temperature dependence of the refractive indices plays a decisive role in the temperature stability of the process:

$$\Delta\varphi = k_0 L\left[(n_1 - n_2) + \left(\frac{\partial n_1}{\partial T} - \frac{\partial n_2}{\partial T}\right)\Delta T + \frac{1}{2}\left(\frac{\partial^2 n_1}{\partial T^2} - \frac{\partial^2 n_2}{\partial T^2}\right)\Delta T^2 + \ldots\right], \quad (1)$$

S G Grechin Scientific-Research Institute of Radioelectronics and Laser Technology at the N É Bauman Moscow State Technical University, 2-ya Baumanskaya 5, 107005 Moscow, Russia, e-mail: gera@mx.bmstu.ru;
V G Dmitriev 'Polyus' Scientific-Research Institute (Federal State Unitary Enterprise), ul. Vvedenskogo 3, 117342 Moscow, Russia, e-mail: vgdmitr@orc.ru;
V A D'yakov, V I Pryalkin Physics Department, M V Lomonosov Moscow State University, Vorob'evy gory, 119899 Moscow, Russia, e-mail: dva@crystal.ilc.msu.ru, vip@crystal.ilc.msu.ru

Kvantovaya Elektronika **30** (1) 1 – 2 (2000)
Translated by A K Grzybowski

where n_1 and n_2 are the refractive indices of the interacting waves; k_0 is the wave number in free space; L is the length of the medium. When temperature is varied, the difference between the first derivatives of the refractive indices makes the greatest contribution to $\Delta\varphi$ [Eqn (1)]. A decrease in the contribution of the temperature-dependent component in Eqn (1) and the attainment of a temperature-independent regime is possible only in biaxial crystals with a suitable choice of the angle of the crystal cut so that the difference between the first derivatives in Eqn (1) is zero. The possibility of achieving this regime is not difficult to assess with the aid of the ratio of the temperature derivatives of the principal values of the refractive indices. In a KTP (potassium titanyl phosphate) crystal, such a regime occurs in the xz plane, since, according to Kato [3], the following relationships between the temperature derivatives hold for this crystal:

$$\frac{\partial n_x}{\partial T} < \frac{\partial n_y}{\partial T} < \frac{\partial n_z}{\partial T}. \quad (2)$$

For a suitable selection of the angle of cut Θ, it is possible to ensure equality of the first derivatives with respect to temperature for the interacting waves.

Using the program of the LID series (Laser Investigator & Designer, http://www.bmstu.ru/~lid), we carried out a series of calculations for a KTP crystal. The results of the calculations demonstrated that at a radiation wavelength of 632.8 nm a temperature-independent interaction occurs at $\Theta = 36.4 - 46°$ (using the refractive indices and their derivatives with respect to temperature, obtained by different authors). The lack of data on the second and higher-order derivatives with respect to temperature precludes calculations of the temperature range of the interaction.

The experimental search for this angular direction and determination of the temperature dependence of the birefringence were carried out by the traditional method of crossed polarisers. The measurements were made on four KTP crystal samples 4.35, 5.37, 4.75, and 5.9 mm long, grown at Moscow State University (the crystals had the following cuts, respectively: x cut with $\varphi = 0$, $\Theta = 90°$, y cut with $\varphi = 90°$, $\Theta = 90°$, z cut with $\varphi = 0$, $\Theta = 0$, and a cut for the interaction in the xz plane with $\Theta = 40°$, $\varphi = 0$). The polarisation plane of the He – Ne laser radiation was inclined at an angle of 45° relative to the y axis. An analyser was placed at the crystal exit. On heating the crystal, different changes in the length of the optical path of the two waves led to the formation of an interference pattern. The result of the measurements for the x, y, and z cuts are presented in Fig. 1 (circles — experiment, curve — calculation with initial data from Refs [3, 4]). The half-width of the plot against temperature is 7.1 °C, 9.6 °C, and 21.4 °C, respectively, for the x, y, and z cuts at room temperature. In the range of

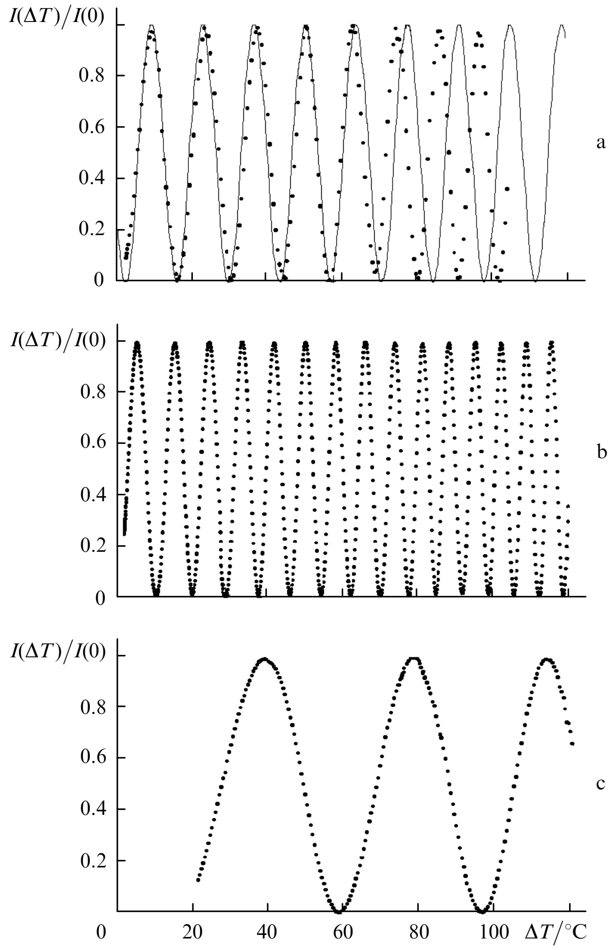

Figure 1. Plots against temperature for the x cut (a), y cut (b), and z cut (c) crystals [circles — experiment, curve (a) — calculation].

crystal temperatures 120 °C – 150 °C, the widths of the plots against temperature for the x, y, and z cuts diminish and amount to 5.6 °C, 6.4 °C, and 21 °C, respectively. It is noteworthy that the results of the calculation agree with the experiment only for the x cut. For the y and z cuts, the difference is very large. This demonstrates the need for a more precise determination of the temperature dependences of the refractive indices and of the linear expansion coefficients of the KTP crystal.

The results of the measurements made for $\Theta = 39.3^{\circ}$ are presented in Fig. 2. The radiation intensity changes by no more than 10% on heating the crystal by 136 °C. The FWHM of the curve is 166 °C. It is seen from the shape of the curve that a temperature-independent regime has been achieved. The nature of the curve shows that, in modelling the temperature-independent birefringence, it is necessary to determine the temperature dependences of the refractive indices up to the 4th or 5th orders. In the direction of the temperature-independent birefringence of a KTP crystal, the angular FWHM is 4′, but the size of the region within which a temperature-independent regime is attained exceeds tens of angular minutes.

Thus the use of the temperature-independent birefringence makes it possible to construct a large number of thermostable devices of different types for controlling laser radiation. Apart from KTP, this effect can be achieved also in an LBO crystal.

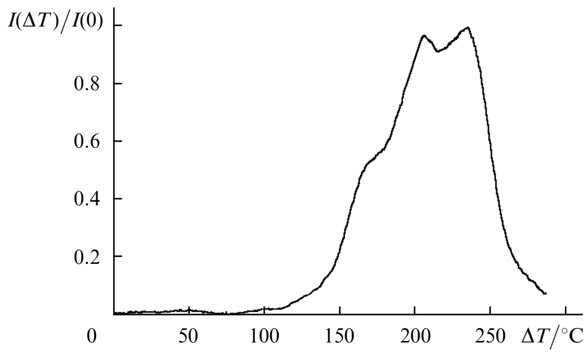

Figure 2. Plot against temperature for $\Theta = 39.3^{\circ}$ in the temperature-independent regime.

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