Temperature dependence of terahertz optical properties of LBO and perspectives of applications in down-converters

N. A. Nikolaev[1, 2, a], Yu. M. Andreev[3, 4], N. G. Kononova[5], G. V. Lanskii[3, 4], A. A. Mamrashev[1, 2], V. D. Antsygin[2], K. A. Kokh[5], A. E. Kokh[5]

[1]High Current Electronics Institute, SB RAS, 2/3 Akademicheskii Ave., 634055, Tomsk, Russia;
[2]Institute of Automation and Electrometry, SB RAS, 1 Academician Koptyug Ave., 630090, Novosibirsk, Russia;
[3]Institute of Monitoring of Climatic and Ecological Systems, SB RAS, 10/3 Akademicheskii Ave., 634055, Tomsk, Russia;
[4]Siberian Physical Technical Institute of Tomsk State University, 1 Novosobornaya Sq., 634050, Tomsk, Russia;
[5]Institute of Geology and Mineralogy, SB RAS, 3 Academician Koptyug Ave., 630090, Novosibirsk, Russia

[a]Corresponding author's e-mail: nazar@iae.nsk.su

Abstract. Lithium triborate LiB_3O_5 (LBO) crystals are widely used for frequency conversion of the near-IR lasers within main transparency windows. Their optical properties at these wavelengths are well studied. However, very little work has been published on the properties in the terahertz (THz) range. There was a lack of data on the refractive indices, the absorption coefficients spectra and their temperature dispersions. There are no reports of THz applications. Present work reveals all these topics including the prospects for use LBO crystals as down-converters of the near-IR lasers radiation. Optically finished samples of flux-grown LBO crystals were studied by THz-TDS. The refractive index dispersions were recorded and then approximated in the form of Sellmeier equations for the temperatures of 300 and 81 K. The phase-matching curves for the IR-THz and THz-THz frequency conversions were calculated. It was found that the absorption coefficients of LBO decrease significantly with cooling to cryogenic temperatures, but the overall character of optical properties changes is intricated. Experimental results are discussed in detail considering potential characteristics of THz down-converters.

1. Experimental setup and methods

The LBO crystals were grown from MoO_3 flux by modified Kyropoulos method at Institute of Geology and Mineralogy, Siberian Branch of Russian Academy of Science (SB RAS) [1]. LBO samples of thicknesses 2068 ± 5 mkm and faces of $10 \times 10\ \text{mm}^2$ were cut along directions perpendicular to the crystallographic axes **a**, **b**, **c**. The correspondence between the optical and crystallographic axes was determined to be $\boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{Z} \leftrightarrow \mathbf{a}, \mathbf{c}, \mathbf{b}$ [2]. The studies were carried out using Time-Domain Terahertz Spectrometer (THz-TDS) which description and signal processing methods were described elsewhere [3]. The fine-tuning of the spectrometer polarization optics was performed before the studies, which is a prerequisite for measurements of birefringent media [4]. The bath cryostat was used for cooling down the samples to the liquid nitrogen temperature.

2. Results

LBO crystal shows significant changes in their optical properties being cooled down to the liquid nitrogen temperature. The absorption coefficients α_x and α_y decrease vastly to an immeasurably small level (Figure 1a) while α_z remains almost unchanged and keeps the value of about 1.5 cm^{-1} at 1 THz (Figure 1b). The refractive indices n_x and n_y decrease by ~0.37 and ~0.47, respectively, (Figure 2a) whereas n_z increases by ~0.07 (Fig.2 b). Thus, the thermo-optical coefficients in the THz frequency range are $dn_x/dT \approx 1{,}7\cdot10^{-3}$ K^{-1}, $dn_y/dT \approx 2{,}2\cdot10^{-3}$ K^{-1} and $dn_z/dT \approx -3{,}2\cdot10^{-4}$ K^{-1}. They are higher at least by two orders of magnitude than thermo-optical coefficients in the optical range.

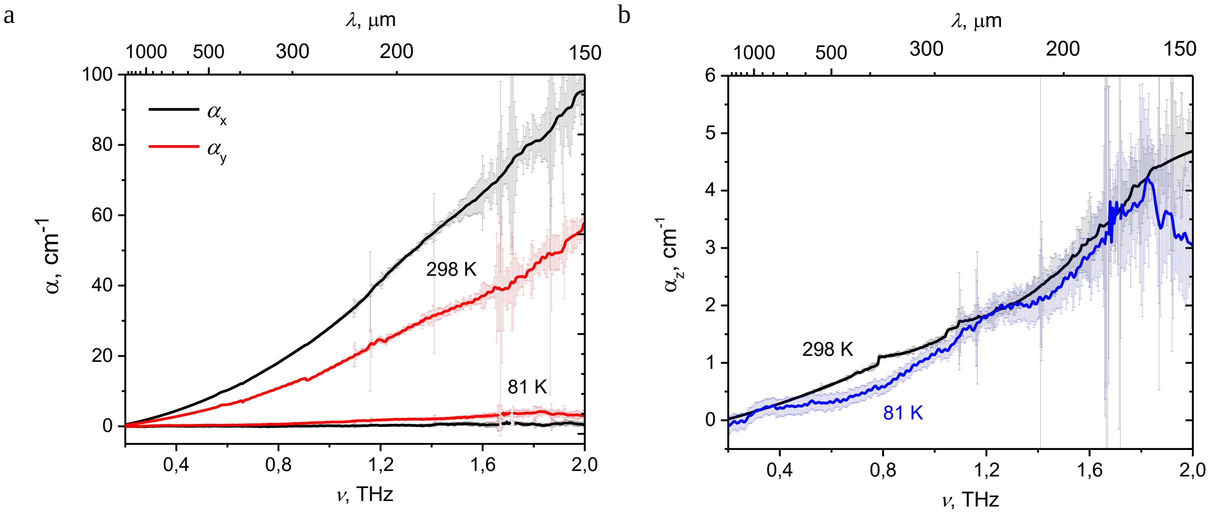

Figure 1. LBO Absorption coefficients α_x, α_y (a) and α_z (b).

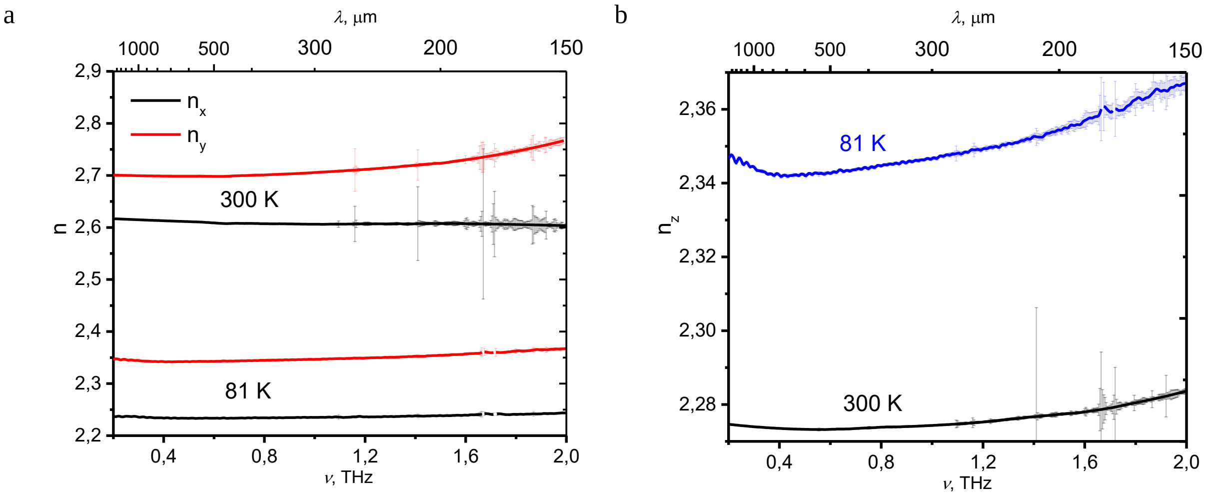

Figure 2. LBO refractive indices n_x, n_y (a) and n_z (b).

The dispersion equations based on measured data were approximated for the range of 0.2 – 2 THz (Table 1). Overall results show that the LBO becomes quasi isotropic at the temperature of liquid nitrogen. It means that the phase-matching conditions for Difference-Frequency Generation (DFG) cannot be fulfilled at 81 K. The phase-matching curves in ***XZ*** plane were calculated for the room temperature by using approximated dispersion equations (Figure 3).

Table 1. LBO refractive indices dispersion equations approximation for the range of 0.2 – 2 THz.

Room temperature	81 K
$n_x^2 = 6.82232 + \frac{0.03648\,\lambda^2}{\lambda^2 - 11676}$	$n_x^2 = 4.86951 + \frac{0.11663\,\lambda^2}{\lambda^2 - 6516}$
$n_y^2 = 6.84070 + \frac{0.45596\,\lambda^2}{\lambda^2 - 9418}$	$n_y^2 = 4.79318 + \frac{0.68735\,\lambda^2}{\lambda^2 - 3316}$
$n_z^2 = 5.06773 + \frac{0.10363\,\lambda^2}{\lambda^2 - 7012}$	$n_z^2 = 4.81255 + \frac{0.66883\,\lambda^2}{\lambda^2 - 3329}$

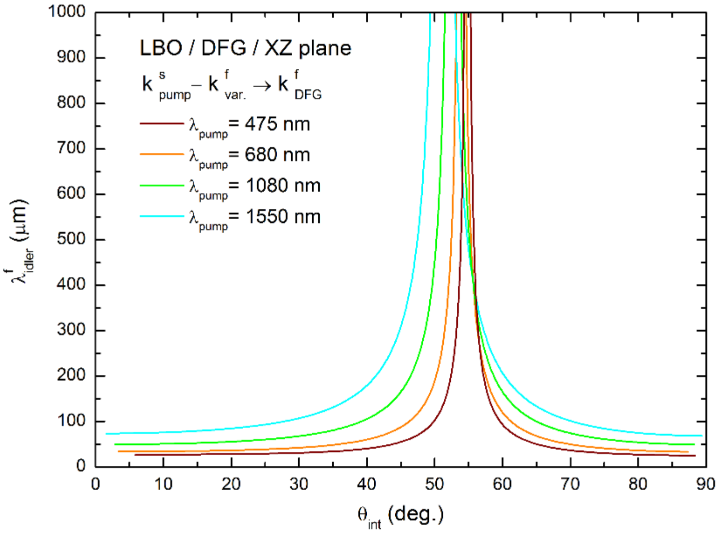

Figure 3. THz-DFG phase-matching curves for the typical wavelengths of telecom lasers (1550 nm), Ti:Sa lasers (680 – 1080 nm) and multi-terawatt system based on XeF(C-A) amplifier (475 nm) [5].

3. Conclusion

Despite having very low absorption coefficients in the terahertz range LBO can't be used for the down-conversion of visible and IR lasers radiation due to unfulfillment of phase-matching conditions. However, LBO could be perspective for the THz generation via optical rectification of femtosecond laser pulses. Moreover, the small changes of α_z and n_z with the cooling makes LBO perspective material for the manufacturing of temperature insensitive optical elements.

Acknowledgements

The work has been supported by the Russian Science Fund, Project 15-19-10021. The THz-TDS spectrometer provided by "Spectroscopy and Optics" Shared Equipment Center of the Institute of Automation and Electrometry, SB RAS.

References

[1] Kokh A, Vlezko V, Kokh K, Kononova N, Villeval P and Lupinski D 2012 *J. Cryst. Growth* **360** 158-161
[2] Nikogosyan D 2006 *Nonlinear optical crystals: a complete survey* Springer Science & Business Media
[3] Antsygin V, Kaplun A, Mamrashev A, Nikolaev N and Potaturkin 2014 *Optics express* **22**(21) 25436-25443
[4] Antsygin V, Losev V, Mamrashev A, Nikolaev N and Potaturkin O 2016 *Optoelectronics, Instrumentation and Data Processing* **52**(4) 374-380
[5] Alekseev S, Aristov A, Ivanov N et al. 2013 *Laser and Particle Beams* **31**(1) 17-21