

## Elastic and elastooptic properties of $\text{LiB}_3\text{O}_5$

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### Abstract

$\text{LiB}_3\text{O}_5$  (LBO) crystals are of great importance for nonlinear optical applications. In this study a set of elastic coefficients has been determined for LBO by the interference acoustooptical method and a set of elastooptic coefficients has been measured by Dixon's method. © 2004 Elsevier Ltd and Techna Group S.r.l. All rights reserved.

**Keywords:**  $\text{LiB}_3\text{O}_5$  (LBO) crystal; Elastic coefficients; Elastooptic coefficients

### 1. Introduction

Lithium triborate ( $\text{LiB}_3\text{O}_5$  or LBO) is one from the basic crystal materials used for laser beam control in visible and near IR ranges [1–3]. LBO crystals,  $\text{Pn}2_1a$  point group [4] and  $a = 8.441$ ,  $b = 7.379$  and  $c = 5.138 \text{ \AA}$ , are characterized by such valuable properties as appropriate nonlinear optical properties in combination with high optical damage threshold [2,5], electrooptic and piezoelectric effects [6,7], and relative surface chemical stability [8,9]. Recently a method of LBO crystal growth with using molybdate flux has been proposed [10]. The optimization of the growth conditions yields large size,  $\sim 500 \text{ g}$ , LBO crystals with very low defect content [11,12]. As a practical matter, it is desirable to have as more complete set of physical and chemical characteristics of low defect LBO as possible. In the present study the elastic and elastooptic properties of LBO grown by top seeded solution growth (TSSG) method from molybdate flux have been evaluated.

### 2. Experiment

The crystal studied was grown by TSSG method without pulling and rotating. Detailed description of charge preparation and growth conditions has been presented in [13]. Paral-

lelepipiped sample with the dimensions  $10 \text{ mm} \times 8 \text{ mm} \times 6 \text{ mm}$  was cut and polished perpendicular to the three principal crystallographic axes.

In accordance with  $C_{2v}$  symmetry nine independent nonzero elastic constants and 12 independent nonzero elastooptic constants characterize LBO. Elastic constants were calculated with using experimental data on phase velocities of bulk elastic waves in LBO sample. Ultrasonic wave velocities have been measured with original pulse interference acoustooptic method with very high-resolution [14]. The structure of acousto-optical cell is shown in Fig. 1. In this configuration elastic waves are excited by piezoelectric transducer positioned on buffer. The polarization of elastic wave is defined by the transducer used. When a single high frequency electric pulse with duration  $\tau$  is fed on the transducer, a set of ultrasound pulses of the same duration and frequency is excited in the system transducer-buffer-sample due to consecutive reflections at the interfaces. So, in buffer the following pulses will be observed:  $U_1$ -directly from transducer,  $U_2$ -reflected from the interface buffer-sample,  $U_3$ -doubly passed through the sample (passed into sample, then reflected from external face of the sample and returned to buffer), and so on. The high frequency filling of all three pulses in buffer is of the same frequency, wavelength and polarization. The pulse  $U_3$  keeps the information on velocity of ultrasonic wave in the sample and  $U_2$  pulse is a reference. With  $\tau$  increasing, the pulses overlap and the interference is observed. In this case, high frequency variation will induce the variation of the magnitude (beating) of sum pulse in the range from minimum  $A_{23} = A_3 - A_2$  to maximum

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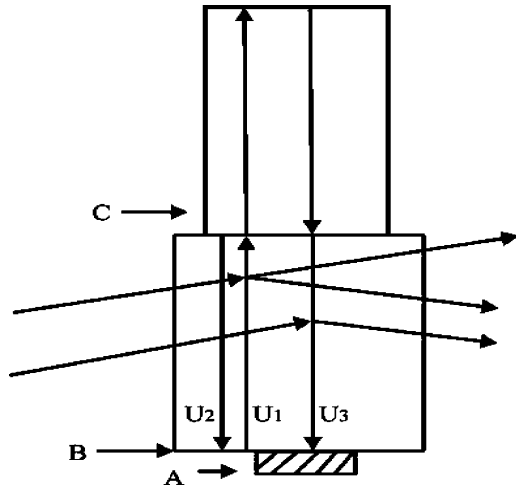


Fig. 1. Acoustooptic cell for elastic constants determination: (A) transducer; (B) buffer and (C) LBO sample.

$A_{32} = A_3 + A_2$ . Here  $A_i$  is a magnitude of ultrasonic pulse  $U_i$ . Respectively, the beating of intensities appeared for the laser beams  $I_2, I_3$  diffracted on the ultrasonic pulses. Let us suppose that at any frequency  $f_1$  the maximum of intensity of diffracted laser beam is observed under the condition

$$2\pi f_1 \left( \frac{2L}{V} \right) + a_1 + a_2 = 2\pi n, \quad (1)$$

where  $a_1$  and  $a_2$  are phase shifts by reflections,  $L$ —sample thickness in the direction of ultrasonic wave and  $V$ —ultrasonic wave velocity. Then, at frequency  $f_2$  some maximum will be detected with the number  $m = n + N$  under the phase resonance condition

$$2\pi f_2 \left( \frac{2L}{V} \right) + a_1 + a_2 = 2\pi m. \quad (2)$$

So, on frequency variation  $\Delta f = f_2 - f_1$  we will see  $N = m - n$  maximums defined by the condition

$$N = \Delta f \left( \frac{2L}{V} \right). \quad (3)$$

Now, if to measure the value  $\Delta f$  and maximum number  $N$ , the ultrasonic wave velocity is defined by simple Eq.  $V = 2L \Delta f / N$ .

Elastooptic constants were determined by Dixon's method [15]. The structure of the acoustooptic cell used is shown in Fig. 2. In this cell LBO sample and reference sample (silica) are linked in tandem by special bonding layer. Piezoelectric transducer is positioned on external face of reference sample. In this configuration ultrasonic pulse generated by transducer travels through the reference sample and LBO sample, is reflected by free face of LBO sample and returns to reference sample. The ultrasonic wave is probed by laser beam under Bragg's angle. The intensity of diffracted beam is defined by the relation

$$I_1 = I_0 \sin^2 \left( \frac{V}{2} \right), \quad (4)$$

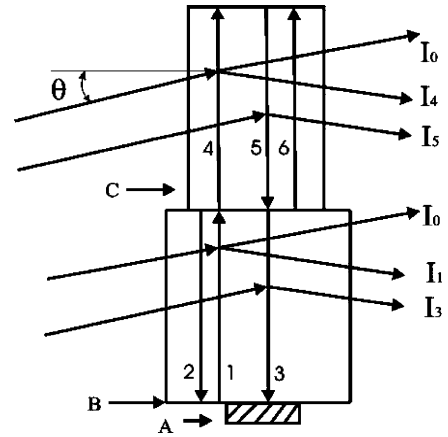


Fig. 2. The cell for elastooptic coefficients measurement: (A) transducer; (B) reference sample (silica) and (C) LBO sample.

where  $I_0$  is an intensity of light transmitted through the sample and  $V$  is governed by the equation

$$V = \frac{\pi L (2M_2 I_a)^{1/2}}{\lambda \cos \theta}. \quad (5)$$

where  $L$  is a length of acoustooptic interaction,  $\lambda$  the light wavelength in vacuum,  $\theta$  an angle between light beam in crystal and wavefront of ultrasonic wave,  $I_a$  the ultrasonic wave intensity and

$$M_2 = \frac{n^6 p^2}{\rho V^3}, \quad (6)$$

where  $M_2$  is a coefficient of acoustooptical figure of merit,  $n$  the refractive index of the crystal,  $\rho$  the density,  $V$  the ultrasonic wave velocity and  $p$  the elastooptic constant. If the sequence of transmittance of ultrasonic waves is designated by indices  $i$ , as it is illustrated in Fig. 2, and  $I_i$  is an intensity of the optical beam diffracted by ultrasonic pulse with number  $i$ , then  $M_2$  for the sample may be resulted as

$$\frac{M_2}{M_2^*} = \left( \frac{I_4 I_5}{I_1 I_3} \right)^{1/2}, \quad (7)$$

where  $M_2^*$  the coefficient of acoustooptical figure of merit of silica reference sample.

The density of our LBO crystal,  $\rho = 2.4789 \text{ g/cm}^3$ , necessary for calculations, was measured by hydrostatic method.

### 3. Results and discussion

The values of ultrasonic wave velocities measured in LBO are presented in Table 1. It is reasonable to be noted that all velocities were determined for the same LBO sample and possible error is not above 5 m/s. If to compare the absolute values of velocities of ultrasonic waves in LBO with those for some recently studied materials, the highest value detected in LBO exceed that in  $\text{KTiOPO}_4$  (7680 m/c) [16], and is substantially below those found for another borate,

Table 1  
Ultrasonic wave velocities in LBO

Propagation direction	Type	Polarization	Velocity (m/c)
[1 0 0]	L	[1 0 0]	6338
	S	[0 1 0]	4050
	S	[0 0 1]	5846
[0 1 0]	L	[0 1 0]	8612
	S	[0 0 1]	5319
	S	[1 0 0]	4024
[0 0 1]	L	[0 0 1]	6940
	S	[0 1 0]	5324
	S	[1 0 0]	5737

Table 2  
Elastic constants of LBO ( $10^{10}$  N/m<sup>2</sup>)

$C_{ij}$	$C_{11}^E$	$C_{22}^E$	$C_{33}^E$	$C_{33}^D$	$C_{44}^E$	$C_{55}^E$	$C_{66}^E$
This work	9.96	18.38		11.94	7.03	8.16	4.05
Brillouin [6]	10.92	16.22	10.32		7.10	8.66	3.60
Ultrasonic [6]	10.13	14.72	9.04		6.46	8.22	3.56

Table 3  
Elasto-optic constants of LBO

P <sub>11</sub>	0.2
P <sub>22</sub>	0.2
P <sub>33</sub>	0.3
P <sub>12</sub>	0.08
P <sub>23</sub>	0.5
P <sub>31</sub>	0.05
P <sub>13</sub>	0.7
P <sub>21</sub>	0.1
P <sub>32</sub>	0.26

CuB<sub>2</sub>O<sub>4</sub> (9917 m/c) [17], and BeAl<sub>6</sub>O<sub>10</sub> (12,000 m/c) [18]. For the lowest velocity value the distribution of the materials is the same. The elastic constants of LBO in comparison with earlier reported results are given in Table 2. In all cases the constants obtained in present study is few beyond those measured in reference [6] at ultrasonic frequencies. Supposedly this shift to higher values is appeared due to progress in LBO crystal quality. Elasto-optic constants of LBO are listed in Table 3. The possible error in determination of  $p_{ij}$  is defined by the intensity of the lowest  $I_i$  signal and is not above 20%. The coefficients  $p_{44}$ ,  $p_{55}$  and  $p_{66}$  were not evaluated because the constants are manifested in light diffraction on shear ultrasonic waves with change of lightwave polarization. The observation of this diffraction in LBO is possible only at frequencies above ~1 GHz but strong attenuation of ultrasonic waves at the conditions greatly complicates the experiment. As a whole, acoustooptic figure of merit of LBO is in close relation to that of silica.

#### 4. Conclusions

A set of elastic and elasto-optic constants of LBO has been determined at room conditions. LBO possesses middle ultra-

sonic wave velocities for the longitudinal and shear modes and large electromechanical coupling coefficients 28–52% [6]. So, in combination with other physical properties, high optical damage threshold in particular, the crystals may be actively used in acoustoelectronics and acoustooptics.

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