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SEMICONDUCTORS AND DIELECTRICS

Acoustical and Acoustooptical Properties of Lead Tetraborate Single Crystals

K. S. Aleksandrov[1, 2], A. V. Zamkov[1], A. I. Zaĭtsev[1], P. P. Turchin[2], A. M. Sysoev[1], and A. A. Parfenov[2]

[1] Kirensky Institute of Physics, Siberian Division, Russian Academy of Sciences, Akademgorodok, Krasnoyarsk, 660036 Russia

[2] Krasnoyarsk State University, Svobodnyĭ pr. 79, Krasnoyarsk, 660062 Russia

e-mail: az@iph.krasn.ru

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Abstract—The velocities of bulk acoustic waves and the acoustooptical Q factors M_2 are measured. The results of these measurements are used for calculating the photoelastic coefficients of a lead tetraborate single crystal.

1. INTRODUCTION

Although single crystals of lead tetraborate PbB_4O_7 have long been known [1], these materials hold considerable promise for acoustical and acoustooptical applications. Owing to their point symmetry ($mm2$), PbB_4O_7 single crystals can also be used as pyroelectric or piezoelectric materials. To date, the structure, nonlinear optical and electrooptical properties [1–3], and other macro- and microscopic characteristics of lead tetraborate have been investigated. The dependence of the velocity of sound in lead tetraborate crystals on the ratio of the melting temperature to the average atomic weight for oxides, which was reconstructed from the values of the microhardness, deviates from the well-known ("linear") dependence of the velocity of elastic waves [4]. Moreover, this compound is transparent in the ultraviolet range (up to 250 nm) [2], which is not typical of lead compounds. The above properties of PbB_4O_7 single crystals and prospects for their practical application call for more comprehensive study of the acoustic and acoustooptical properties of this material.

2. SAMPLE PREPARATION AND EXPERIMENTAL TECHNIQUE

The initial batch used for growing lead tetraborate crystals was prepared from basic lead carbonate (reagent grade) and boric acid (special-purity grade) according to the reaction

$$Pb(OH)_2 \cdot 2PbCO_3 + 12H_3BO_3$$
$$= 3PbB_4O_7 + 2CO_2\uparrow + 19H_2O\uparrow.$$

Single crystals of lead tetraborate were grown by the Czochralski technique along the b axis at a rate of 2 mm/day. The crystals grown had a length of 20 mm and a diameter of 20 mm. These crystals were used to obtain the oriented samples. Crystallographic setting of the samples was carried out according to the technique described in [2] (space group $Pnm2_1$). The single crystals of lead tetraborate are transparent in the ultraviolet range up to 250 nm. The unit cell parameters of lead tetraborate single crystals are as follows: a = 4.4547(7) Å, b = 10.839(2) Å, c = 4.2437(8) Å, and ρ = 5.852 g/cm^3 [2]. The samples prepared are characterized by a high degree of homogeneity.

The velocities of bulk acoustic waves in the single-crystal samples were measured by a pulsed ultrasonic method at a frequency of 30 MHz in the crystallographic directions [100], [010], and [001].

The acoustooptical measurements were performed using the extended Dixon–Cohen method (Bragg diffraction of light by an ultrasonic wave). The measurement accuracy was no less than 10%. The experimental setup was described earlier in [5]. The measurements were carried out at an ultrasonic frequency of 105 MHz for longitudinal acoustic waves with the use of emissions from a helium–neon laser (λ = 632.8 nm). Fused silica was used as a reference substance.

The measured velocities of propagation of bulk acoustic waves in lead tetraborate single crystals are presented in Table 1. The acoustooptical Q factors M_2 and the photoelastic constants $P_{\lambda\mu}$, which were calculated from the M_2 values and the velocities of bulk acoustic waves, are given in Table 2.

3. RESULTS

The measured velocities of bulk acoustic waves (the highest velocity V_L[001] ~ 8 km/s) are in excellent agreement with the predicted high values. It was found that the material under investigation is characterized by very small values of the acoustooptical Q factors (max-

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Table 1. Velocities of propagation of bulk acoustic waves in the PbB_4O_7 single crystal

No.	*N*	*U*	Mode	*V*, m/s
1	[100]	[100]	*L*	7637.6 ± 0.5
2		[010]	*S*	4684.5 ± 0.5
3		[001]	*S*	4442.6 ± 0.5
4	[010]	[010]	*L*	7070.0 ± 0.5
5		[100]	*S*	4684.3 ± 0.5
6		[001]	*S*	4807.5 ± 0.5
7	[001]	[001]	*L*	7897.9 ± 0.5
8		[100]	*S*	4421.9 ± 0.5
9		[010]	*S*	4776.9 ± 0.5

Note: *N* is the direction of propagation of bulk acoustic waves, and *U* is the direction of oscillations in bulk acoustic waves.

Table 2. Acoustooptical and photoelastic characteristics of the PbB_4O_7 single crystal

Direction of propagation of the longitudinal acoustic wave	Velocity *V*, m/s	Direction of light polarization	*n*	M_2, 10^{-18} s^3/g	$P_{\lambda\mu}$
[100]	7637.6	[100]	1.9325	0.03	0.0387
[010]	7070.0	[100]	1.9325	0.29	0.1073
[001]	7897.9	[100]	1.9325	0.24	0.1152
[100]	7637.6	[010]	1.9183	0.15	0.0885
[010]	7070.0	[010]	1.9183	0.07	0.0177
[100]	7637.6	[001]	1.9269	0.23	0.1082
[010]	7070.0	[001]	1.9269	0.66	0.1632
[001]	7897.9	[001]	1.9269	0.04	0.0474

Note: *n* is the refractive index for the specified direction of light polarization.

imum value $M_2 = 0.66 \times 10^{-18}$ s^3/g) and photoelastic constants. This makes lead tetraborate crystals unsuitable for use in acoustooptical devices.

Such unusual acoustical and acoustooptical characteristics of lead tetraborate single crystals can be explained by the high density, which is unique for borates, and the character of packing of this structural type [6].

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