Study of Laser-Induced Damage of Borate Crystals

Vlokh R., Dyachok Ya., Krupych O., Burak Ya, Martunyuk-Lototska I., Andrushchak A., Adamiv V.

Institute of Physical Optics, 23 Dragomanov Str., 79005, Lviv, Ukraine,
e-mail: vlokh@ifo.lviv.ua

Received: 02.06.2003

Abstract

The optical damage threshold of β-BaB_2O_4, α-BaB_2O_4, LiB_4O_7 and $CsLiB_6O_{10}$ was experimentally studied. It was observed that the damage dimensions in studied crystals linearly depend on the laser irradiation intensity. The resistance against laser irradiation is highest in LTB crystals and decreases through BBO crystals to ABO crystals and is lowest in CLBO crystals. The appearance of optical anisotropy under powerful light illumination was observed at the power density of two orders smaller than damage threshold. At the powerful beam propagation along the optical axis of studied crystals the observed shape of damages possess the view of stars with the rays parallel to the symmetry elements of the crystals.

Key words: optical damage, borate crystals.

PACS: 42.70.Mp; 61.80.Ba

Introduction

Crystals that belong to borate family are well known as materials for nonlinear optics application [1]. From this point of view the most important performance characteristics that possess these crystals, particularly β-BaB_2O_4, are high efficiency of optical harmonics generation (see e.g.[2-4]), wide spectrum range of transparency [5,6] and resistance of borate crystals against optical radiation with large power density [7]. The literature data testify that these crystals should possess high level of damage threshold, but as we know there are not accurate and unambiguous data of this level. The unique crystals of this family for which the damage threshold was surely determined are β-BaB_2O_4 crystals [7]. For example, according to [7] the damage threshold of these crystals is 50 GW/cm^2 for single pulse for the wavelength 1.06 μm, pulse width 14 ns, beam diameter 0.74 mm and 23 GW/cm^2 for quasi-continuous mode with repetition rate 10 Hz . From one side optical damage threshold depend on a lot of parameters i.e. the beam diameter in focus, beam profile etc.{see for example [8]). From other side we have not find any data concerning damage threshold for other borate crystals, such as α-BaB_2O_4, LiB_4O_7 or $CsLiB_6O_{10}$, that could also be the useful materials for super powerful laser radiation operating.

Present paper is devoted to the study of the damage threshold of BaB_2O_4, LiB_4O_7 and $CsLiB_6O_{10}$ crystals.

Crystal growth

The peculiarities of the borate crystals growth consist in the fact that these crystals contain boric anhydride - B_2O_3. The B_2O_3 has a tendency to polymerization and the melts on its basis have high viscosity, which makes the growth process of single crystals of high optical quality rather difficult. The crystals of $Li_2B_4O_7$ (LTB), $CsLiB_6O_{10}$ (CLBO), α - (ABO) and β - (BBO) phases of BaB_2O_4 are not exception.

The LTB, CLBO and ABO crystals are melted congruently, thus for their growing the classical Czochralsky method was used with the Pt-crucible (dimension ∅40×40×2 mm) in the air atmosphere. The growth batch synthesis of all these borate crystals was conducted by the multi steps method with the carbonate Li_2CO_3, Cs_2CO_3, $BaCO_3$ and boric acid (H_3BO_3) using of the high degree of purity. The optimal growing parameters for these three crystals, which were established experimentally, are the speed of crystal seed withdrawal 0.1-0.4 mm/hour; rotation speed 8-20 rot/min. It was found that growth parameters depend on crystal melting temperature, e.g. the lowest melting temperature possess CLBO crystals (T_m=1123 K) as well as highest – ABO crystals (T_m=1378 K). Such dependence is caused by decreasing of the melt viscosity with temperature increasing that is inherent to B_2O_3.

Another growth peculiarity is that BBO crystals have the phase transition to ABO phase at temperature 1198 K. For BBO crystals growth the modified Czochralsky method is used (seed withdrawal from the melt-solution). The Na_2O plays the role of dissolvent at the optimal rate – 78 moll % of BaB_2O_4 and 22 moll % of Na_2O. For optical quality BBO crystals obtaining the optimal growing parameters are: the speed of crystal seed withdrawal 2mm/day; stable rotation speed 4 rot/min and continuous smooth decreasing of the melt-solution temperature with the rate 2-4°C/day. After temperature decreasing on 30-70°C the single crystal was detached from the melt and cooled with the rate 40-50°C/hour down to the room temperature.

All mentioned crystals were growth along [001]-axis that was determined by the seed orientation. At the optimal growth conditions we were obtained single crystals with diameter 20-25 mm and length 10-20 mm with the shape that corresponds to the point group of symmetry.

Experimental

The measuring of the damage threshold is usually connected with the forming of superpower beam, i.e. it focusing and energy profile formation. In present studies we use the Nd^{3+} pulse laser with output irradiation energy of 60 mJ, wavelength of 1.06 μm and pulse width of τ=6 ns. The experimental setup is shown on Fig. 1.

The optical radiation from the pulse Q-switched laser LTI-237C (2) is propagated through the glass plates (3) and is focused by the objective lens (4) inside the studied sample (5). The laser light is attenuated by stack of glass plates and neutral-density filter. Each glass plate reduces the laser radiation energy due to Fresnel reflection on the about 8%. The energy of laser irradiation pulse was controlled by laser pulse meter IKT–1N. To determine beam's waist dimension we measured the coordinate profile of intensity by means of single-coordinate moveable shutter. Then we fit the profile data by Gaussian integral using standard approximation procedure. We obtain waist diameter value of 140 μm on the $1/e^2$ intensity level. Having the waist parameters, we calculated maximal intensity value in the central area of the spot using the measured energy of laser irradiation.

The probe, linearly polarized beam of the

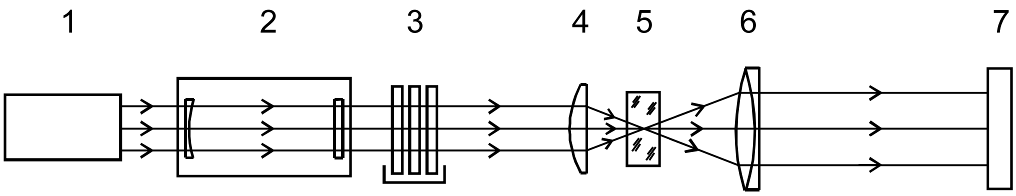


Fig. 1. Experimental setup for the optical damage threshold studying: (1) – He-Ne laser; (2) – LTI-237C laser; (3) – glass plates holder; (4) – focusing lens; (5) – sample; (6) – lens; (7) – screen.

He-Ne laser (1) with wavelength of 0.633 μm is propagated through whole optical system including LTI-237C laser cavity and is scattered by the sample. The scattered light (λ=0.633 μm) creates the speckle structure that is projected on the screen or photo camera (7).

The observation of the speckle structure change was conducted for the determination of the optical anisotropy changes of the studied crystals induced by powerful laser radiation below damage threshold. The optical damages that were finished by failure of samples were analyzed by means of optical polarization microscope. We determined damage diameter as average dimension of dark spot in the failure site at observing in the microscope (see Fig.3b).

Results and discussion

As it is visible from Fig.2, damage diameter linearly depends from the intensity of power laser irradiation. Slope of the linear regression might be a useful characteristic of irradiation fragility of materials (a physical quantity, inversely proportional to irradiation resistance). The resistance against laser irradiation is highest in LTB crystals and decreases through BBO crystals to ABO crystals and is lowest in CLBO crystals. As a rule, the minimal damage diameter, which we observed, was of 90 μm. Intensity of laser irradiation, corresponding this damage value, thus might be considered as damage threshold. Values of damage threshold of borate crystals, calculated in this manner from fitting lines, are presented in the Table 1. Damage threshold is greatest in LTB crystals and lowest in CLBO crystals, that corresponds to irradiation resistance obtained from slope of dependence of damage diameter versus irradiation intensity.

Table 1. Damage thresholds of borate crystals.

Crystal	Damage threshold, GW/cm^2	Slope of the line graph
LTB	32.2	1.41
BBO	30.9	1.82
ABO	14.5	2.20
CLBO	7.5	4.79

The appearance of optical anisotropy under powerful light illumination was observed by speckle structure change at the power density of two orders smaller than damage threshold.

At the powerful beam propagation along the optical axis of studied crystals the observed shape of damages possess the view of stars with

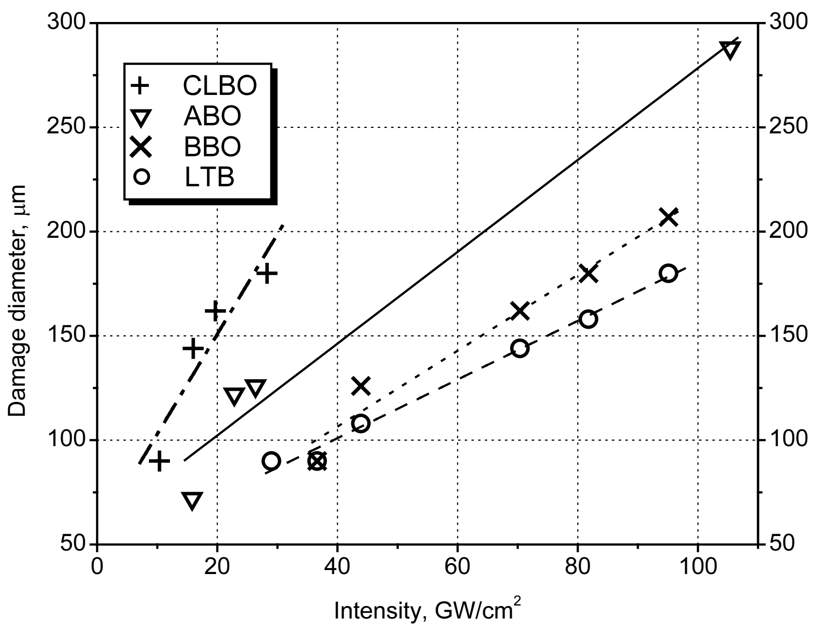
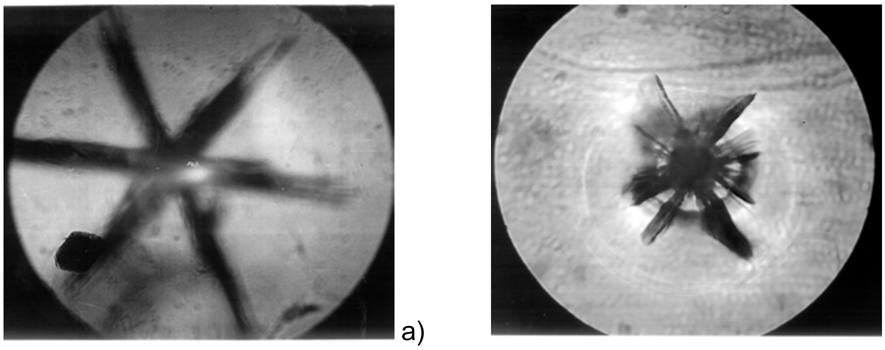


Fig. 2. Damage diameter dependence on light intensity.



a) b)

Fig. 3. Damage stars in BBO crystals (a) and LTB crystals (b).

the rays parallel to the symmetry elements of the crystals (Fig.3). This fact is connected with the anisotropy of elasticity of crystals.

Conclusions

As the result one can conclude that the highest value of damage threshold corresponds to LTB crystals as well as lowest corresponds to the CLBO crystals. It was observed that the damage dimensions in all studied borate crystals linearly depend on the laser irradiation intensity. The appearance of optical anisotropy under powerful light illumination was observed at the power density of two orders smaller than damage threshold. At the powerful beam propagation along the optical axis of studied crystals the observed shape of damages possess the view of stars with the rays parallel to the symmetry elements of the crystals that is connected with the anisotropy of elasticity of crystals.

Acknowledgement

Authors gratitude the Science and Technology Center in Ukraine (Project N1712) for the financial supporting of this studying.

References

1. Nikogosyan D.N. Electr.Techn. Laser Techn. and Optoelectron. Issue. **54** (1990) 3 (in Russian).
2. Kato K. IEEE J. Quantum electronics **22** (1986) 1013.
3. Ishida Y., Yajima T. Optics Comm. **62** (1987) 197.
4. Cheng L.K., Bosenberg W., Tang C.L. Appl.Phys.Lett. **53** (1988) 175.
5. Chen C., Wu B., Jiang A., You G. Appl.Opt. **28** (1985) 235.
6. Bhar G.C., Das S., Chatterjee U. Appl.Opt. **28** (1989) 202.
7. Nakatani H., Bosenberg W., Cheng L.K., Tang C.L. Appl.Phys.Lett. **53** (1988) 2587.
8. Manenkov A., Prokhorov A. Usp.Phys.Nauk **148** (1986) 179 (in Russian).