Study of Laser-Induced Damage of Improved Strontium-Doped α-BaB_2O_4 Single Crystals

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Received: 01.11.2004

Abstract

The resistance of α-BaB_2O_4 doped with Sr against the laser radiation is experimentally studied. The two criteria, the damage dimensions and probability, are used for characterization of the resistance. It is shown that availability of the substitutive Sr impurity in the crystals under study, combined with the advanced growth technique, leads to a higher optical damage threshold.

Key words: optical damage, α-BaB_2O_4 single crystals.

PACS: 42.70.Mp; 61.80.Ba

Introduction

Single crystals of high-temperature modification of BaB_2O_4 (α-BaB_2O_4 or ABO; space symmetry group $R\bar{3}c$) are promising for the optical instrument engineering, in particular, the acoustooptic cell construction [1]. Nevertheless, the mentioned crystals remain rather "problematic" materials from the viewpoint of technology. In our previous work [2], we have reported on increasing workability of the ABO single crystals obtained by means of substituting Ba with Sr. We have performed the first estimation of optical damage threshold in this paper, too. Unfortunately, the level of the damage threshold for Sr-doped ABO crystals has been found to be lower than that for the pure ABO. Therefore, the aim of the present study is improving the growth technique for the strontium-doped barium borates and upgrading their optical quality, with the purpose of raising the optical damage threshold.

Crystal growth

We have already described the peculiarities of the growth of $Sr_xBa_{1-x}B_2O_4$ (ABO:Sr, x = 0.1) single crystals in the work [2] .

In comparison with the standard growth technology for ABO:Sr (see, e.g., the batch synthesis technique [3] and the growth parameters [2]), we now made the following corrections: (1) while weighting the components before the synthesis, we added some overdose of H_3BO_3 (approximately 1–2%) to the batch, (2) the strontium impurity content was notably decreased (down to x = 0.01), (3) we increased the melt homogenisation time, with continuous mixing by platinum mixer attached to the growth stick, and (4) the speed of the crystal seed withdrawal was decreased to 0.25 mm/h. For the ABO:Sr batch preparation, we used such the agents as $BaCO_3$, $SrCO_3$ and H_3BO_3 of high purity. After grinding and mixing thoroughly, the batch was treated to multi-step thermal synthesis, which was governed by the following chemical reaction:

$$(1-x)BaCO_3 + xSrCO_3 + 2H_3BO_3 \xrightarrow{150°C(-2H_2O)}$$
$$(1-x)BaCO_3 + xSrCO_3 + 2HBO_2 \xrightarrow{250°C(-H_2O)}$$
$$(1-x)BaCO_3 + xSrCO_3 + B_2O_3 \xrightarrow{500-710°C(-2CO_2)}$$
$$Sr_xBa_{1-x}B_2O_4$$

ABO:Sr crystals were grown from the congruent melt by the direct Czochralsky method, using the Pt crucible (the dimension

$\varnothing 40\times 40\times 2$ mm^2) in the resistive-heating setup. The synthesized batch was melted to crucible in the growing chamber in two steps and the melt level was 6–8 mm lower than the crucible top edge. The melt was slightly overheated, and then held for 8–10 hours. After that, the temperature was decreased to the growing one and seeding was performed. Single crystalline seeds oriented along [001] axis were used for growing.

The optimal growing parameters established experimentally were as follows: the temperature gradient over the melt surface 50°C/cm, the rotation speed 17 rpm and the speed of crystal seed withdrawal 0.25 mm/h. As a result, transparent $Sr_{0.01}Ba_{0.99}B_2O_4$ single crystals were obtained, with the diameter 22 mm, the length 10–15 mm and the shape corresponding to trigonal symmetry of the crystal. To avoid cracking of ABO:Sr single crystals after detaching from the melt, we decreased the temperature in the growing chamber down to the room temperature with the rate less than 50°C/h.

All the technological improvements described above allowed us to obtain improved ABO:Sr single crystals of higher optical quality in the whole volume of the boule. Specimens with the dimensions 27(X)×14(Y) ×6.5(Z) mm^3 were grinded with the fine-grained corundum powders and polished with weak solution of SiO_2 in deionised water, till the surfaces of high optical quality were obtained.

Experimental results and discussion

We used the technique described earlier [4] for determining the damage threshold, with the application of pulsed Nd^{3+} laser (τ = 6 ns; the output radiation energy 60 mJ). This technique, based on a linear dependence of damage diameter upon the intensity of powerful laser irradiation, was applied in our previous works [2,4]. In the present case, we used the additional technique involving the studies for the damage probability. For a fixed high laser light intensity, we determined the damage rate as a ratio of number of the damaged sites to the total number of irradiated sites. Then we obtained the dependence of the damage rate versus the laser intensity. The intensity that corresponds to the damage rate value of 0.5 is commonly used [5,6] as a single-shot damage threshold.

The results of the radiation resistance studies in the improved ABO:Sr, obtained with this technique, are compared in Fig.1 with the previous results for the pure ABO and ABO:Sr.

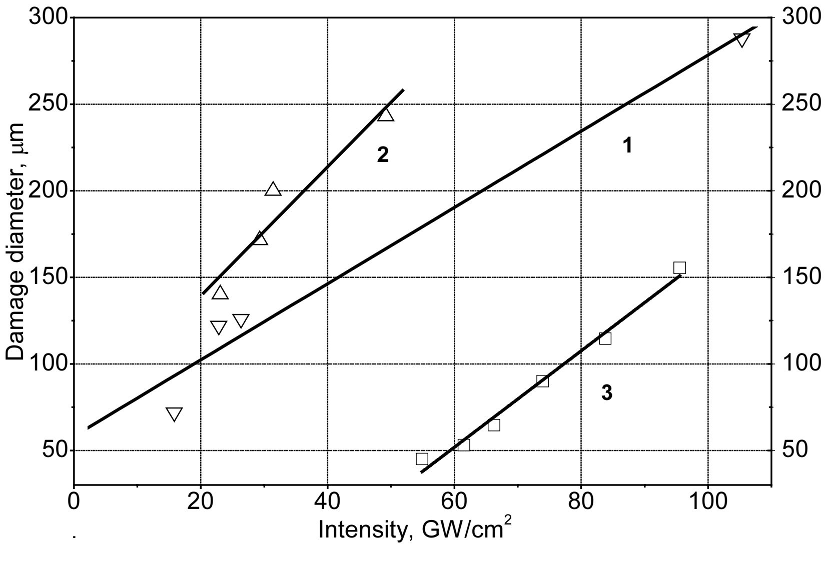

Figure 1. Damage diameter dependence on light intensity:
1 – pure ABO [4], 2 – ABO:Sr [2], 3 – advanced ABO:Sr.

As seen from Fig. 1, the resistance against the laser radiation characteristic of the earlier obtained ABO:Sr single crystals is insignificantly lower than that of the pure ABO. At the same time, the improved ABO:Sr demonstrates quite good radiation resistance, which is even better than in case of the other borate crystals ($Li_2B_4O_7$ and β-BaB_2O_4). It is interesting to notice that the minimal damage dimensions in the improved ABO:Sr are also far smaller, when compare to the other borates. One can see that determination of the damage threshold in the last case differs from that used in the comparative study of borates [4]. In the mentioned work, the intensity of the laser radiation, corresponding to the damage diameter of 90 μm, has been chosen as a damage threshold. This has been caused by the experimental fact that, in the most of cases, the minimal observed damage diameter was just 90 μm. However, the minimal damage diameter appears to be 45 μm for ABO:Sr.

The dependence of the damage rate on the laser light intensity is shown in Fig.2. The damage threshold calculated as the intersection of the fitting line with the damage rate value of 0.5, is equal to 59 GW/cm^2. This threshold value corresponds to the damage diameter of 49.7 μm.

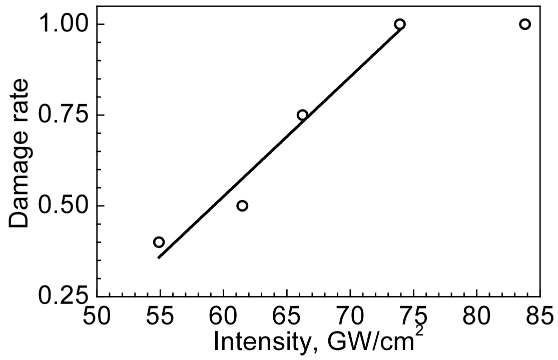

Fig. 2. Dependence of the damage rate on the light intensity.

Conclusion

Basing on the presented results, one can conclude that introduction of the substitutive impurity of Sr and improvement of the growth technique, when employed together, give rise to higher optical damage threshold for the ABO family crystals. This promises a prospect for using the improved ABO:Sr single crystals in acoustooptic cells for controlling powerful laser radiation.

Acknowledgement

The authors are grateful to the Ministry of Education and Science of Ukraine (the Projects N0103U000699 and N0104U000460) for financial support of this study.

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