Laser-induced damage of Cr: LiSAF crystal at 0.85 μm

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ABSTRACT

An experimental investigation of laser-induced damage of the Cr: LiSAF crystal under pulses from a Cr: LiSAF laser ($\lambda = 0.85$ μm, $\tau \sim 70$ ns) has been made. For comparison, the same measurements were also made with borosilicate glasses BK7 (USA) and K8 (Russia). The experiments were performed with spot sizes from 0.7 to 50 μm. The morphology of the damage area, the spot size dependence, the statistics of the damage thresholds, and the truncation of the transmitted pulse were measured. It was found that for spot sizes of more 10 μm, the damage of LiSAF resulted from the presence of local bulk inhomogeneities. For smaller spot sizes the damage resulted from self-focusing. Finally, for spot sizes of less 1 μm, the damage resulted from the intrinsic laser-induced damage and its threshold was significantly higher than the threshold for BK7 (K8) glass. As a result the spot size dependence for Cr: LiSAF was found to be stronger than for borosilicate glass.

Keywords: laser-induced damage, Cr: LiSAF crystal, spot size dependence, inhomogeneities, self-focusing

1. INTRODUCTION

The Cr: LiSAF crystal is a comparatively new material, finding more and more applications in areas of laser technology due to its large gain bandwidth and high gain cross-section [1]. For its successful application, however, it is necessary to know the mechanisms and absolute values of laser-induced damage (LID) of this crystal under different conditions of exposure. Optical damage of this crystal was measured earlier under 1.064 nm radiation from picosecond pulses (47 ps) from a neodymium laser [2]. These studies indicated that damage in these crystals when operating in laser systems was connected with inclusions in the bulk material. However the authors did not exclude the influence of self-focusing under the focused laser radiation conditions using spot sizes of ~14 μm. Measurements of the damage thresholds performed at the exact emission wavelength of the Cr: LiSAF laser offer more opportunities to study the fundamental processes of LID in this material. Therefore the goals of this paper were:

- to establish the mechanisms possible for LID in Cr: LiSAF crystal;
- to determine the conditions of laser beam focusing under which it is possible to separate different

mechanisms of optical damage;

- to measure the absolute values of the damage thresholds under these conditions at the emission wavelength of the Cr: LiSAF laser.

2. EXPERIMENTAL

LiSAF crystals with 1.5 % Cr doping was used for investigations. The samples were cut from real optical elements, which had been used for a long time as rods for laser oscillators or amplifiers. All the samples were clear of damaged regions in their bulk or on their surfaces. The samples had the form of a parallelepiped with size 5 mm^{x}5 mm^{x}30 mm and all of their sides were polished. A Q-switched, flashlamp-pumped Cr: LiSAF laser was used in these studies. The laser, comprised a 4 mm diameter, 65 mm long laser rod, produced pulsed energies of up to 15 mJ in a 60 ns (FWHM) pulse duration at a frequency of up to 10 Hz. The beam profile of the output of the laser was approximately Gaussian. It is well known that Cr: LiSAF crystal has a very broad gain bandwidth [1]. Due to this the laser oscillated a lot of longitudinal modes and had enough smooth temporal profile. This feature lead to low statistic of instant power of laser pulses and allowed to measure the LID threshold with accuracy of ~ 20 % [3]. Using lenses with different focal lengths, the Gaussian beam was focused to spot sizes of 10, 30, and 50 μm. For investigation with still smaller spot sizes, a special optical system, previously described in [4], was used. It permitted spot sizes of 2 and 0.7 μm to be produced.

Damage was detected by usual methods: by the appearance of a spark, by observing the scattering of a coaxial beam of a green He-Ne laser, and by visual observation of the damage region through a Nomarski microscope. In order to detect the moment of damage during the laser pulse, the temporal shape of transmitted laser pulse was also measured.

3. RESULTS AND DISCUSSION

Measurements of the bulk LID for BK7 and K8 glasses showed that the values of thresholds increased with decreasing of the spot size and were the same for both glasses for the different spot size similar to previous measurements [3]. However it was found that for spot sizes of 10, 30 and 50 μm, the LID thresholds for Cr: LiSAF crystal had a very large statistical spread in comparison with statistical spread of BK7 (K8) glass thresholds. The latter did not exceed 20 % under the same conditions. For the Cr: LiSAF crystals the difference between maximum pulse energy when the damage was absent and the minimum pulse energy when the damage occurred changed by up to a factor of 10. Moreover, the damage occurred simultaneously in several different sites of the bulk crystal material with distances between sites up to 15 mm. Distinct truncation of the transmitted laser light was not observed in many cases under these conditions (Fig.1b). This resulted because only an insignificant part of the transmitted beam was absorbed when damage occurred in location of small inhomogeneities with sizes much less than spot size of focused beam. On the other hand the same transmitted light signal for BK7 (K8) glasses (Fig.1a) shows a clear truncation of the light at breakdown. All these facts indicate that the breakdown of Cr: LiSAF results from the presence of inhomogeneities in the bulk material. An investigation of damage region morphology also shows a region of many small damage sites, must probably associated with the presence of inhomogeneities.

The appearance of these sites was similar to those shown in reference [5], one of the first paper devoted to LID of material with inhomogeneities.

Distinctly different results were however obtained when the LID thresholds were measured for small spot sizes (0.7 and 2 μm). In these cases the data for the Cr: LiSAF crystal and the borosilicate glasses were very similar:

- there was small statistics of LID thresholds (< 20 %);
- the damage occurred on the same depth of sample from front surface;
- the morphology of damage sites was the same for all damage regions;
- the damage sites had a similar form for Cr: LiSAF crystal and for BK7 (K8) glass for each of spots.

Thus in these cases the LID was connected to the intrinsic interaction of laser radiation with media. There were however significant differences in behavior of the materials in the two focus regions, 0.7 and 2 μm. Firstly, for the 2 μm spot size the transmitted pulses were truncated a few ns after the peak of laser pulse for both materials (Fig.2), and the threshold irradiance at the moment of damage increased when the time of the interaction was decreased. Secondly the central part of the damage site always had a separate direction and appeared cigar-like with the length of the site increasing with pulse energy. A similar investigation performed earlier with K8 glass [6] showed that these types of characteristics are associated with damage resulting from self-focusing.

For a spot size of 0.7 μm, however the truncation of the transmitted pulses for both materials was only observed before or at the maximum of pulse (Fig.3). The threshold irradiance at the moment of damage was constant, within experimental error, as the duration of the interaction was decreased significantly (Fig.3b, curves 1-3). Finally the central part of damage site did not have a separated direction and appeared spherical. These facts indicate that for the 0.7 μm spot size, the intrinsic LID, that was observed, not associated with presence of inhomogeneities or with the process of self-focusing.

The spot size dependencies of the LID threshold for the Cr: LiSAF crystal and the borosilicate glasses are shown in Fig.4. It is seen that the spot size dependence for Cr: LiSAF crystal is considerably stronger than for BK7 (K8) glass. The reason is the following. For large spot sizes (> 10 μm) the LID of Cr: LiSAF crystal occurs due to the presence of inhomogeneities in the bulk material. In the borosilicate glasses, for these spot sizes the LID thresholds are not due to inhomogeneities, but to intrinsic mechanisms. Thus the LID thresholds for these glasses were up to 20 times higher then for the Cr: LiSAF crystals. For small spot sizes (a few microns and less) the LID of Cr: LiSAF crystal resulted from self-focusing or from intrinsic interactions, and the thresholds for these processes were found to be higher for Cr: LiSAF than for BK7 (K8) glass. This last fact is important, because it indicates that with purification and improved crystal growth technology the LID thresholds of Cr: LiSAF crystals for large spot sizes can be increased.

4. CONCLUSIONS

In summary, this investigation of LID thresholds at 850 nm shows that:

- for large spot sizes (> 10 μm) the breakdown of Cr: LiSAF crystal results from the presence of inhomogeneities in the bulk material;
- for spot sizes of a few microns the breakdown of Cr: LiSAF crystal results from self-focusing similar to that which occurs in BK7 (K8) glass;

- finally, for a 0.7 μm spot size, the breakdown of Cr: LiSAF crystal results from the intrinsic interaction of the radiation with the material;
- purification and improved crystal growth technology will lead to essential increasing of LID damage thresholds for Cr: LiSAF crystal for large spot sizes.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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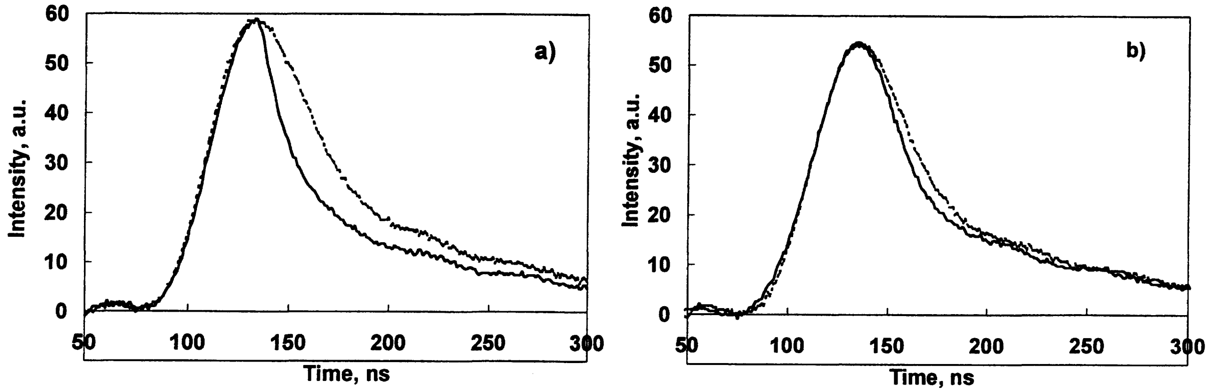

Fig.1. Temporal shape of incident (dotted) and transmitted (solid) through damage region beams for spot sizes more 10 μm: a) BK7 (K8) glass, $D_f = 50$ μm; b) Cr: LiSAF crystal, $D_f = 10$ μm.

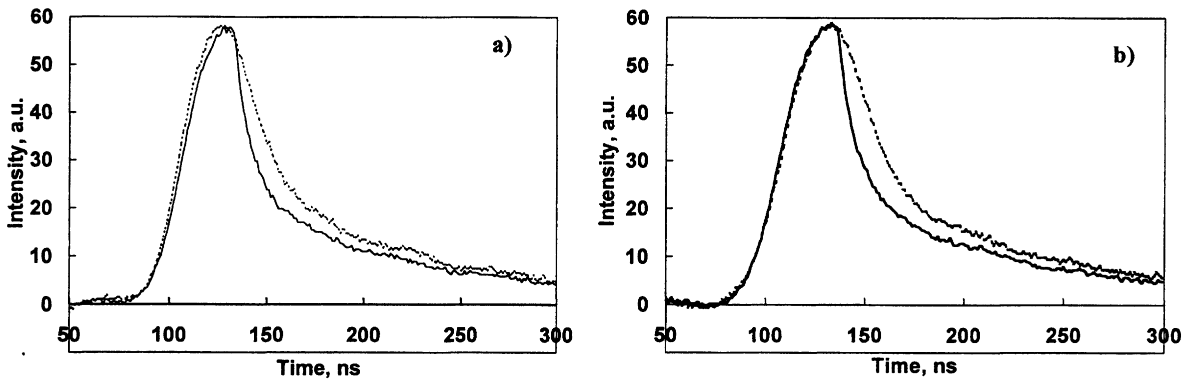

Fig.2. Temporal shape of incident (dotted) and transmitted (solid) through damage region beams for spot size of 2 μm: a) BK7 (K8) glass; b) Cr: LiSAF crystal.

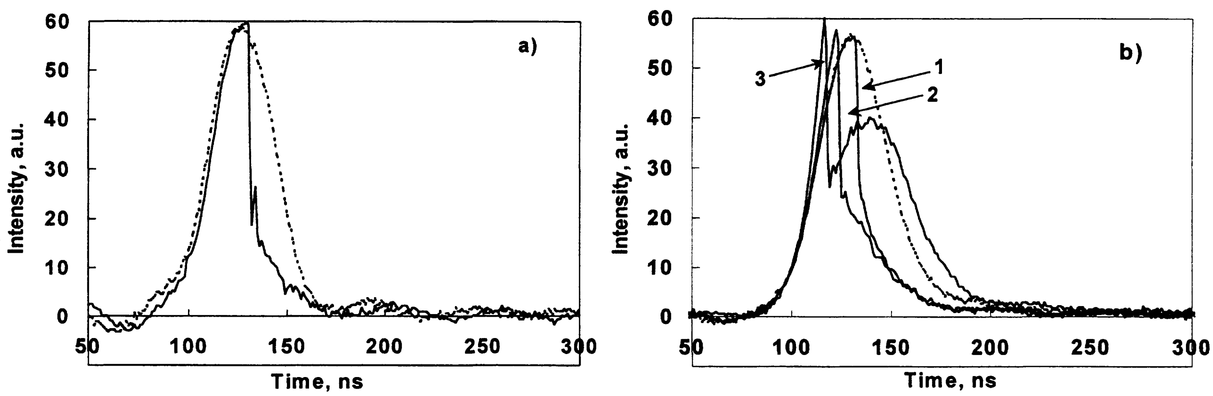

Fig.3. Temporal shape of incident (dotted) and transmitted (solid) beams passing damage region for spot size of 0.7 μm: a) BK7 (K8) glass; b) Cr: LiSAF crystal: 1 – $I = I_{th}$, 2 – $I = 1.5 \cdot I_{th}$, 3 – $I = 5 \cdot I_{th}$.

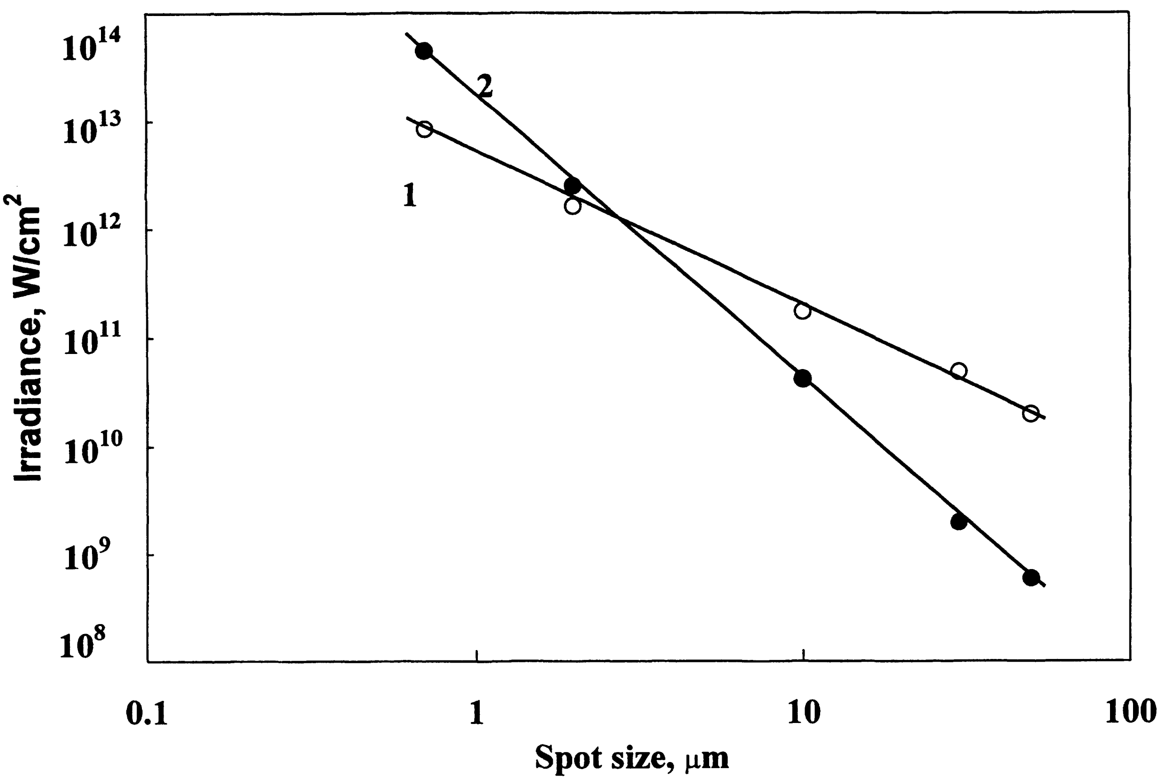

Fig.4. The dependence of LID threshold of BK7 (K8) glass (curve 1) and Cr: LiSAF crystal (curve 2) vs. spot size of laser radiation.