DESTRUCTION OF RUBY AND LEUCOSAPPHIRE CRYSTALS BY STRONG LASER RADIATION

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The destruction of ruby and leucosapphire crystals under the action of radiation from a Q-switched ruby laser. The stability of the ruby crystals against powerful laser radiation is found to depend on the existence of an additional absorption band in its spectrum. It is shown that multi-phonon ionization of Cr^{+3} ions and stimulated Mandel'shtam–Brillouin scattering are not the determining factors in the destruction mechanism.

DESTRUCTION of transparent dielectrics under the action of powerful laser radiation has been observed in a number of recently published researches.[1-5] Such destruction arises in laser active materials (ruby, neodymium glass) operating in the Q-switched mode.[6] Mechanisms of the destruction of glass were studied in [1,3], and the destruction mechanisms of ruby crystals was investigated in [4]; however, to date, the problems of the destruction mechanisms are not yet sufficiently clarified.

In the present research, the destruction of ruby and leucosapphire crystals under the action of the focused radiation of a Q-switched ruby laser was investigated. The power generated was 30 megawatts, with an energy output of 1 joule. The struction in leucosapphire crystals was observed at the focus of a lens (f = 5 cm) in the form of a spherical cavity with dimensions of the order of 1 mm. Using a lens with a focal length of 15 cm, we succeeded in obtaining damage, in the form of a small crater, only on the rear face of the crystal.

The ruby crystals can be divided into two different groups, depending on the character of the destruction: crystals of the first group are destroyed in a fashion similar to the crystals of leucosapphire; the crystals of the second group are destroyed with the formation of characteristic "tracks," consisting of a series of fine splittings perpendicular to the incident radiation (Fig. 1). Such "tracks" are 2–3 mm in diameter, several centimeters in length, and are observed by using lenses of both f = 5 cm and f = 15 cm. The destruction thresholds in the leucosapphire and ruby crystals of the first group were close to each other and corresponded to a flux of laser radiation at the focus of the 5-cm lens $\sim 10^{10}$ watts/cm^2 (for an estimate of the radiation flux, the generating field

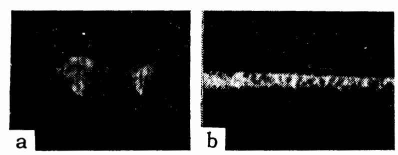

FIG. 1. Internal destruction of crystals: A–ruby of the first group, b–ruby of the second group (lens with f = 5 cm, power 30 MW).

was assumed to be uniformly distributed). The destruction in the ruby crystals of the second group was observed at a threshold of $\sim 10^8$ watts/cm^2. The destruction of crystals both of ruby and leucosapphire is accompanied by an appreciable white glow in the destruction region; in this case the energy of the laser radiation passing through the region of destruction amounts to 10–20% of the radiation energy incident on the sample.

To make clear the reasons for the different resistance of the ruby crystals of the first and second groups to the action of the powerful radiation, their absorption spectra were compared. It was established that the crystals of the second group (less resistant) have an additional intense absorption band with a maximum around 31 400 cm^{-1} (Fig. 2). Such an absorption band was observed in many of our investigations of ruby crystals. Upon irradiation of such crystals by light from a pulsed xenon lamp with wavelength $\lambda < 3000$ Å, the additional absorption band disappears; however, the character of the destruction of the crystals remains as before. Prolonged irradiation of the crystals by the mercury lamp does not lead to a notable decrease in the additional absorption.

The results described allow us to assume that the lower endurance of the ruby crystals of the second group is associated with the presence in them of definite color centers, manifest in the absorption spectrum in the form of an additional

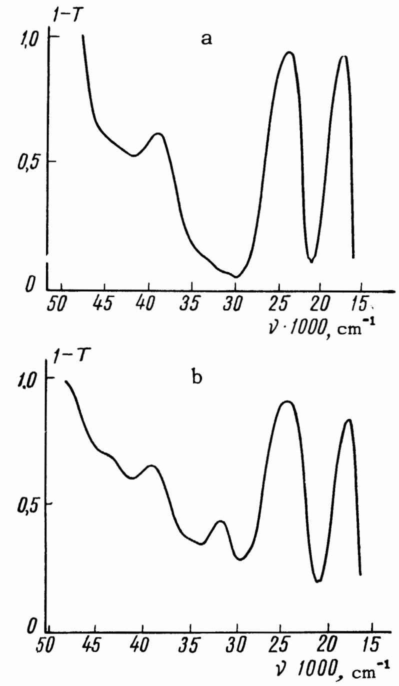

FIG. 2. Characteristic absorption spectra of a ruby crystal: a—first group; b—second group (T—transmission coefficient).

band. Powerful ultraviolet radiation leads to the ionization (evidently stepwise) of these centers. These centers can absorb the laser radiation (by a multistep or multiphoton process) and lead to the destruction of the crystals.

The destruction of the ruby crystals of the first (more resistant) group can be associated with the mechanism of multiphonon ionization of the Cr^{+3} impurity, as is assumed in [4], or by stimulated Mandel'shtam–Brillouin scattering. The latter is also the reason for the destruction of the leucosapphire crystals.

Let us consider the first mechanism. It is known that for the ionization of Cr^{+3} ions in a ruby, the simultaneous absorption of four photons from the $^4A_2$ level and three photons from the ^2E level is necessary. Here the probabilities of three- and four-photon ionization, computed similar to the method of Bunkin and Prokhorov[7] for the power of the incident radiation of 5×10^{10} watts/cm^2, amount to $W^{(3)} \sim 2 \times 10^3$ sec^{-1} and $W^4 \sim 4 \times 10^{-2}$ sec^{-1}, i.e., they differ by five orders of magnitude. Consequently, the threshold of destruction in the ruby should depend strongly on the population of the ^2E level. The cooling of the crystal to a temperature of liquid nitrogen leads to a shift in the ^2E level by 19 cm^{-1} in comparison with its value at room temperature, and the generated radiation does not lead to an appreciable population of this level.

The experimental comparison of the pictures of destruction in ruby crystals at room and liquid nitrogen temperatures (the crystal was placed on a cold finger in a vacuum cryostat) showed the absence of any appreciable temperature dependence of the character of the destruction. Moreover, the ruby crystals of the first group and the leucosapphire crystals have similar destruction thresholds, i.e., there is no dependence of the observed destruction on the chromium content. These results show that the destruction mechanism via multiphoton ionization of the chromium impurity is not the determining factor.

The other assumed destruction mechanism—destruction as a result of stimulated Mandel'shtam–Brillouin scattering—consists in a transfer of part of the energy of the light wave production to a hypersonic wave of lattice oscillations. Here the intensity of the hypersonic wave can be sufficient to destroy the crystal. We made an attempt to observe stimulated Mandel'shtam–Brillouin scattering at an angle of 180° to the direction of the incident laser radiation in ruby and leucosapphire crystals. However, the maximal power which was obtained in the experiments (50 MW) was insufficient to excite stimulated Mandel'shtam–Brillouin scattering.[1)]

Thus, whereas the destruction mechanisms in crystals of ruby of the second group can be connected with the presence of color centers, the destruction mechanisms of ruby crystals of the first group and leucosapphires are still unclear at the present time. It is possible, in the case of these crystals, that stimulated Mandel'shtam–Brillouin scattering at small angles plays a not unimportant role. This has a significantly smaller threshold than forward scattering.[8] Moreover, the reason for the destruction, just as for crystals of the second group, can be connected with defects in the crystal lattice of the ruby and leucosapphire.

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