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# *THERMAL SELF-FOCUSING OF RADIATION FROM A FREE-RUNNING LASER IN KDP AND ADP CRYSTALS*

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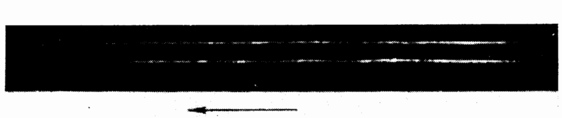
Self-focusing filaments produced in KDP and ADP crystals by radiation from a free-running laser are reported. The self-focusing is the result of heating of the material by the laser beam. Filamentary defects are produced only under the action of e-polarized light on the sample. The self-focusing anisotropy is apparently due to the anisotropy of dn/dt. Self-focusing in KDP and ADP materials with a rated values $dn/dT < 0$ is ascribed to nonuniform pulsed heating. In contrast with free-running operation conditions, self-focusing of a Q-switched laser radiation is of striction origin.

WHEN a laser operating in the single-pulse regime acts on KDP and ADP crystals, filamentary defects are produced in these crystals and are connected with self-focusing[1,2]. We report in this article the observation of filamentary defects produced in these crystals under the influence of a laser operating in the free-running regime.

The investigations were carried out with the aid of a neodymium-glass laser ($\lambda = 1.06\ \mu$) with a power amplifier. To obtain a single transverse mode, a diaphragm of 1.5 mm diameter was placed inside the laser resonator. Radiation with energy up to 0.8 J and pulse duration 400 $\mu$sec (the duration of the individual generation spike was $\sim 1\ \mu$sec, the average distance between spikes was $\sim 10\ \mu$sec) was focused in the interior of specimens measuring $20 \times 20 \times 20$ mm with a lens of $f = 7.5$ cm.

Faults were observed in the KDP and ADP crystals, in the form of filaments up to 8 mm long and 2–4 $\mu$ in diameter (see the figure). The length of the filaments increased with increasing laser-emission energy. The formation of such long and thin filaments can be attributed only to self-focusing of the laser radiation. Indeed, for a light beam with a diameter 1.5 mm, the dimension of the focal spot for a lens of 7.5 cm[3] amounts to $\sim 20\ \mu$, which is larger by one order of magnitude than the diameter of the filaments, and the length of the focal region (2–3 mm) is somewhat smaller than the length of the filaments.

An investigation of the form of the laser pulse passing through the sample has shown that the resultant damage screens the laser radiation. This leads to a change in the shape of the envelope of the laser pulse. At the damage threshold, almost the entire pulse passes through the specimen without distortion, and with increasing energy the damage cuts off an increasing part (in terms of time) of the laser pulse: only the initial part of the pulse passes through the specimen without distortion. Oscillography of the laser radiation scattered by the developing filamentary defect in a direction perpendicular to the primary beam has shown that the defect is generated near the geometrical focus of the lens and develops during the pulse in a direction opposite to the incident radiation. A similar result was obtained by us earlier for filamentary defects in sapphire and in glass, produced under the influence of radiation from a Q-switched laser[4,5].



Self-focusing filaments in ADP crystal. Magnification 7X. The arrow indicates the direction of the incident beam.

The results of these investigations show that during the time of the laser pulse there occurs a monotonic increase of a nonlinear increment $\Delta n$ of the refractive index. This decreases the self-focusing length and causes the region in which the light beam collapses to move in a direction opposite to the incident radiation.

Thus, the nonlinearity mechanism is determined by the energy (and not by the power) of the laser radiation, and consequently the self-focusing is thermal. This conclusion is confirmed by a comparison of the threshold energies of filamentary faults in two specimens of ADP with different linear-absorption coefficients. For a specimen with an absorption coefficient for the extraordinary ray $k^e = 0.12\ \text{cm}^{-1}$, the threshold for the appearance of the filaments was 30–50% higher than for a specimen with $k^e = 0.16\ \text{cm}^{-1}$.

An interesting feature of the observed phenomenon is strong anisotropy: long and thin filaments are observed only under the influence of the extraordinary e-ray. For the ordinary o-ray the damage threshold is much higher, there is strong cracking of the material, and no filamentary defects are observed.

The relative damaged threshold energies for different polarizations of the laser radiation, and also the coefficients of linear absorption $k$ at the wavelength 1.06 $\mu$, are listed in the table.

The strong anisotropy of the damage threshold in KDP and ADP cannot be attributed to dichroism of the absorption. Indeed, we shall assume that the damage process is determined completely by the self-focusing of the radiation[1)], when the threshold damage power $P_{thr}$ is equal to the critical self-focusing power $P_{cr}$.

[1)]We disregard the concrete mechanism of damage of the material in the zone where the light beam collapses.

| | ADP | | KDP | |
|---|---|---|---|---|
| | e | o | e | o |
| Relative threshold damage energies | 1 | 19* | 5 | 20* |
| k, cm$^{-1}$ | 0.12 | 0.11 | 0.01 | 0.04 |
| (dn/dT) × 10$^5$ deg$^{-1}$ | −0.1±0.1 | −4.0±0.1 | −2.4±0.1 | −4.0±0.1 |

*The damage thresholds for the o-ray were reached by increasing the diameter of the diaphragm in the resonator to 2.5 mm.

As is well known, $P_{cr} \sim \lambda^2/n_2$. In the case of thermal self-focusing[6]

$$n_2 = \frac{dn}{dT}\frac{k\tau nc}{4\pi c_p \rho},$$

where n is the refractive index, $\tau$ the pulse duration, c the velocity of light, $c_p$ the specific heat, $\rho$ the density, and T the temperature. Then

$$P_{\text{thr}} = P_{\text{cr}} \sim \lambda^2 c_p \rho \Big/ \frac{dn}{dT} k\tau nc \quad \text{or} \quad P_{\text{thr}}\tau \sim (kdn/dT)^{-1}$$

The data in the table show that for ADP the strong anisotropy of the damage thresholds is observed at practically identical absorption for the o- and e-rays. For KDP, the anisotropy of the absorption coefficients is inverse to the anisotropy of the damaged thresholds.

A possible explanation of the strong self-focusing anisotropy is connected with the anisotropy of dn/dT. The published data on the equilibrium values of dn/dT for the crystals KDP and ADP[7,8] for the visible region of the spectrum are listed in the table. A control experiment performed by us at a wavelength 1.06 $\mu$ has shown that under equilibrium conditions for KDP we have $dn/dT < 0$ and approximately coincides in magnitude with dn/dT for a 0.63-$\mu$ wave.

It follows from the foregoing data that the thermal self-focusing in the KDP and ADP crystals is impossible. However, the fact that the threshold for the formation of filamentary defect is determined by the energy and not by the power indicates a thermal nature of this phenomenon[2)]. An explanation of this contradiction, in our opinion, lies in the following. The tabulated values of dn/dT pertain to the case of homogeneous heating of the substance, when there are no thermoelastic stresses in its volume. Stresses are produced in the medium as the result of the presence of temperature gradients. Owing to these stresses, the medium in the focal region expands less and the resultant value of the density turns out to be higher than in the case of uniform heating. This effect can lead to a change in the sign of dn/dT compared with the case of homogeneous heating[3)].

[2)]Estimates show that $P_{thr}$ = 1.3 × 10$^3$ W (for the KDP crystal at a pulse duration 400 $\mu$sec) we should have in the medium $n_2$ = 3 × 10$^{-10}$ cgs esu. We can then expect $dn/dT \approx 1 \times 10^{-6}$ deg$^{-1}$.

[3)]The question of the possibility of thermal self-focusing in a medium with $dn/dT < 0$ is considered in greater detail in a separate article [10].

It should be noted that filamentary defects connected with self-focusing were observed in KDP and ADP crystals also after application of short laser pulses ($\sim 10^{-8}$ sec)[2]. In this case, however, unlike the free-generation regime, there is no damage-threshold anisotropy, and the ADP crystals are more resistant to the laser radiation than the KDP crystals. A comparison of the damage thresholds of the ADP crystals has shown that in the case of the single-pulse regime the damage appears at energies smaller by 20 times and intensities higher by 500 times than for the free-generation regime. All this indicates that the self-focusing mechanism in the single-pulse regime differs from the case of free generation. The most probable self-focusing mechanism for the single-pulse regime is electrostriction. Assuming, as before, that $P_{thr} \approx P_{cr}$ at the damaged threshold, we find that $n_2 \sim 2-3 \times 10^{-18}$ cgs esu for the ADP crystal. An estimate of the value of $n_2$ due to the electrostriction, in accordance with[9], leads to a value $n_2 \sim 3.5 \times 10^{-13}$ cgs esu, which is close to the experimental value, whereas the $n_2$ connected with the thermal self-focusing and calculated under the assumption that $dn/dT \sim 10^{-6}$ deg$^{-1}$ turns out to be lower by a factor of 100. This shows that a decisive role in the formation of the nonlinearity of the refractive index in the single-pulse regime is played by striction phenomena, whereas in the free-generation regime the self-focusing is thermal.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