SELF-FOCUSING OF LASER BEAMS IN RUBY AND LEUCOSAPPHIRE CRYSTALS

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Submitted 14 March 1967
ZhETF Pis'ma 5, No. 11, 391-393 (1 June 1967)

Self-focusing of intense light beams was observed earlier in a number of liquids [1-4]. In transparent solid dielectrics this phenomenon was observed only in glass damaged by powerful laser emission [5]. We report here observation of self-focusing in ruby and leucosapphire crystals.

We investigated damage produced in ruby and leucosapphire crystals by light pulses at the frequencies of ruby and neodymium-glass lasers and their second harmonics. The lasers operated in the Q-switching mode, and the second harmonics were produced with KDP crystals. The radiation was focused inside the investigated objects with a spherical lens ($f = 45$ mm). A microscopic study of the character of the damage produced in the leucosapphire crystals and in ruby crystals without color centers [8] has revealed the following:

The ruby ($\lambda = 0.69\ \mu$) and neodymium-glass ($\lambda = 1.06\ \mu$) lasers damaged the crystals in the focal region of the lens. The damage consisted of flat cracks crossing along the beam axis (Fig. 1).

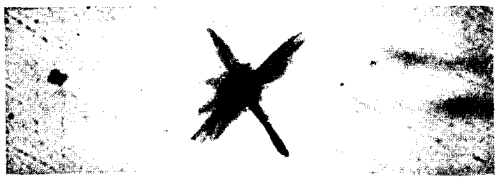

Fig. 1. Typical damage to crystal by laser radiation of wavelength 1.06 and 0.7 micron.

The second harmonics of ruby ($\lambda = 0.35\ \mu$) and neodymium ($\lambda = 0.53\ \mu$) produced damage in the form very thin ($\sim 10\ \mu$) and long (~ 5 mm) filaments, usually emerging from the focus and directed along the laser-beam axis. Cracks measuring several tenths of a millimeter were observed along such a filament (Figs. 2a,b). Several damage filaments converging towards the focus were sometimes observed (Figs. 2c,d). Damage of this kind was observed under the influence of harmonic radiation with considerable field inhomogeneities in the beam cross

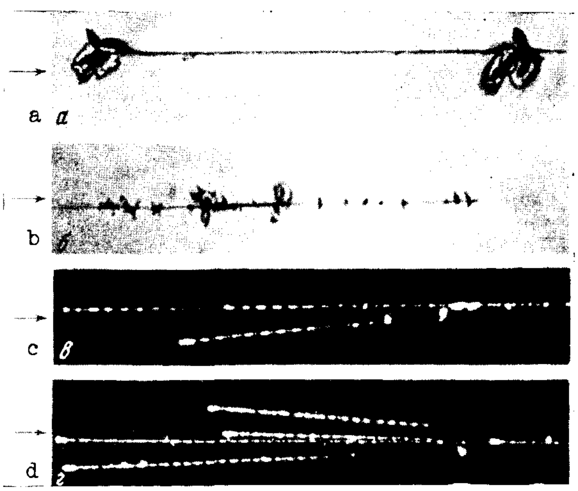

Fig. 2. Damage to crystals by radiation of wavelength 0.53 and 0.35 micron. a and b - photography in scattered light. Magnification: a - 40x, b, c, and d - 20x. The arrows indicate the laser beam direction.

section. For equal radiation power, the filaments were always longer in ruby than in leucosapphire. The filament length increased with increasing power.

Damage in the form of long very thin filaments, with diameter on the order of several wavelengths, can be explained only by assuming self-focusing and self-trapping of the laser beams [6,7]. We measured the damage thresholds in the ruby and leucosapphire, defined as the minimal flaws discernible in the sample when a gas-laser beam is transmitted through the focal region. The dimension of the focal spot at the 50% intensity level was determined by photographing the focal region through a microscope. The absorption of the second-harmonic radiation in the ruby crystal was taken into account. The measurement results are listed in the table.

Table

Threshold power of unfocused beam (P_{thr}, W) and power flux averaged over the section of the focal spot (S_{thr}, W/cm^2)

Radiation wavelength, μ		0.53	0.35
Pulse duration, nsec		20	15
Leucosapphire	P_{thr}	4.2×10^5	5×10^5
	S_{thr}	1.5×10^{10}	2.0×10^{10}
Ruby	P_{thr}	1.1×10^5	2.5×10^5
	S_{thr}	4×10^{10}	1×10^{10}

The self-focusing phenomenon is connected with an increase of the refractive index of the medium in the field of the light wave:

$$n = n_0 + n_2E^2.$$

The increase in the refractive index may be due to the Kerr effect, to electrostriction, or to cubic electron polarizability [7]. In addition, for media with $\partial n/\partial T > 0$, where T is the temperature, an increase of n may be due to heating of the medium by the light beam [6,9]. In our case the self-focusing may indeed be due to thermal effects ($\partial n/\partial T > 0$ for sapphire [10]). This is corroborated by the following results:

1. Self-focusing filaments are observed at the second-harmonic frequencies of the ruby and neodymium lasers, corresponding to the absorption bands of the Cr^{+++} ions in ruby. The leucosapphire crystals used in our experiments contained also small amounts of chromium ($C \sim 10^{-3}$ %). The thresholds for damage with self-focusing are lower for ruby than for leucosapphire (see the table). The experiments revealed no great difference in the breakdown thresholds of ruby and leucosapphire, although their absorption coefficients differ noticeably. This may be due to saturation of the absorption coefficient connected with the chromium under the influence of the intense radiation.

2. No self-focusing filaments are observed at the ruby and neodymium laser frequencies. This may be due to the higher self-focusing threshold at longer emission wavelength and to the absence of sufficient absorption to produce heating in the crystals.

The damage produced in the crystals at these frequencies may be due to impact ionization and to development of an electron cascade. Experiments confirming this mechanism will be described in a separate article.

We note in conclusion that self-focusing cannot be observed in ruby crystals with color centers. The type of damage produced in these crystals at all four frequencies was the same and took the form of characteristic "tracks" consisting of microcracks. The breakdown thresholds were close to 10^9 W/cm^2 at all frequencies, which is apparently lower than the self-focusing thresholds.

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OSCILLATIONS OF THE PHOTOMAGNETIC EFFECT IN INDIUM ARSENIDE

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Submitted 23 March 1967
ZhETF Pis'ma 5, No. 11, 393-396 (1 June 1967)

We have previously reported [1] oscillations of the photomagnetic effect in InSb. Continuing this research program, we have measured the photomagnetic emf in indium-arsenide single crystals at low temperatures. The first sample, of n-type, had an impurity concentration 10^{16} at/cm^3 and an electron mobility 2.5×10^4 cm^2/sec-V. Figure 1 shows the results of measurements of the photomagnetic effect at T = 4.2°K. They show that the oscillations have

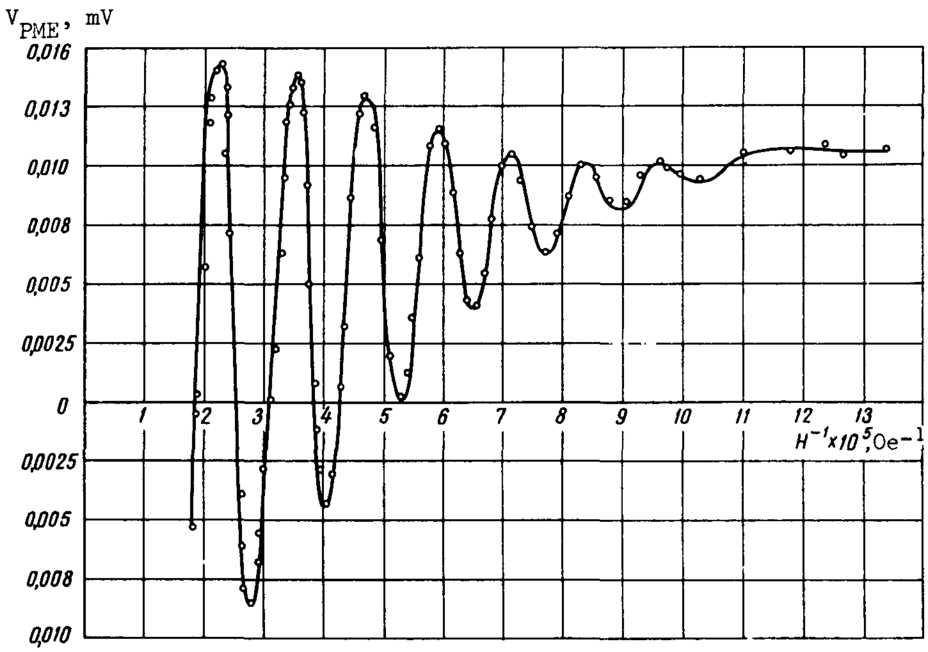

Fig. 1. Odd photomagnetic effect in InAs, $n = 9.2\times10^{16}$ cm^{-3}, $\mu_n = 2.5\times10$ cm^2/sec-V, T = 4.2°K