INVESTIGATION OF SELF-FOCUSING OF NEODYMIUM-LASER RADIATION

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Investigations of self-focusing, which was predicted by Askar'yan in 1962 [1], has been attracting of late the attention of many researchers. A theoretical calculation of the threshold power and of the self-focusing length was made in [2, 3]. Even the first experiment [4] has shown that no self-focusing of the beam as a whole takes place, and that the beam breaks up into individual filaments. This fact was explained by Bespalov and Talanov [5], who showed that a plane electromagnetic wave in a nonlinear dielectric is unstable at a power much in excess of threshold.

Most investigators indicate that a decisive role is played by the Kerr effect in the case of liquids having a large polarizability anisotropy. However, filaments with diameter $\sim$2 μ were observed in [6], and their existence could not be explained by the authors with the aid of this mechanism. It not quite clear at present which mechanism limits the collapse of the beam and what limiting field intensities can be obtained in self-focusing.

In the present investigation, the main results of which were obtained in early 1967 and were reported to the All-union Seminar on Self-focusing in Gor'kii (April, 1967), we studied the self-focusing of radiation of 1.06 μ wavelength at different values of input power. The experiments were performed with a Q-switched neodymium laser with a rotating prism as the modulator. The laser operated in the TEM_{00} mode, this being attained by placing inside the resonator a special diaphragm of 1.5 mm diameter. The maximum laser output power in this mode was 7 MW.

The laser emission passed through a cell 10 cm long, located at a distance 60 cm from the diaphragm, i.e., beyond the Fresnel focus. The distribution of the radiation at the entrance to the cell is shown in Fig. 1a. The radiation has a central maximum with dimension d = 0.5 mm, and subsequent Fresnel rings. The maximum field intensity at the center of the beam was 5.4×10^5 W/cm. The radiation passing through the cell was photographed on film with the aid of a micro-objective. These photographs are shown in Figs. 1b-f for the case of CS_2 at different field intensities in the maximum. In the case of a very weak field (E = 1.5×10^5 W/cm), the distribution is uniform. When the field intensity is raised ot 2×10^5 V/cm, a channel of 30 μ diameter appears in the center (Fig. 1c). With further increase in the field, a filament of 3 μ diameter evolves from the channel (Fig. 1d). Sometimes several such filaments are observed. When the field is increased to 2.7×10^5 W/cm, succeeding channels are produced, located 50 - 100 μ away from the first (Fig. 14). These channels break up in turn into several filaments, with diameter 2 - 3 μ, when the field is increased (Fig. 1f).

The formation of the first channel agrees well with the calculations of Kelley [3], who obtained for the self-focusing length the expression

$$z_f = \frac{a}{2}\sqrt{\frac{n_0}{n'_2}}\,\frac{1}{E - E_{cr}}\,.$$

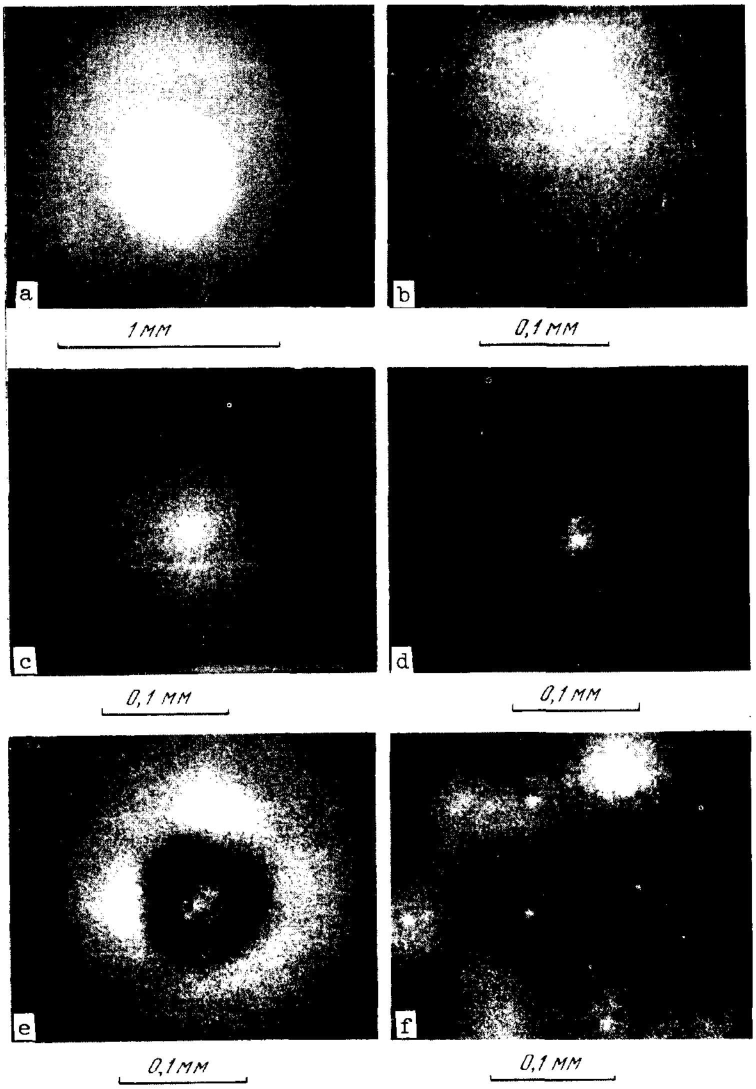

Fig. 1

For $Z_a = 0.5$ mm, $E = 1.5 \times 10^5$ W/cm, and $n'_2 = 1.8 \times 10^{-11}$ we get $Z_f = 9$ cm.

When the field is increased to 2.8×10^5 V/cm, the input radiation becomes unstable to amplitude perturbations, and division into several channels is observed. Indeed, according to [5], the characteristic transverse dimension of the instability

$$\Lambda_\perp = \frac{\lambda}{n_0 E \sqrt{8 n'_2}}$$

is equal to 100 μ when $E = 2.8 \times 10^5$ W/cm; this is one-fifth the diameter of the incoming radiation.

The division of the channel into individual filaments is apparently also the result of instability. It follows from (2) that a power on the order of critical is localized in each channel. Therefore further division should be connected with a decrease of the critical power. This can be attributed to the addition of one more mechanism that changes the refractive index. Such a mechanism may be striction, which should play an important role for thin channels (since its time of establishment for a diameter ∿2 μ is on the order of 10^{-9} sec), or nonlinear electronic polarizability.

At an input field intensity 2.3×10^5 V/cm, breakdown and plasma formation are observed in the channel. A side photograph of the cell is shown in Fig. 2. We see that the breakdown has a discrete character, the average distance between sparks being ∿ 3 - 5 mm. One of the

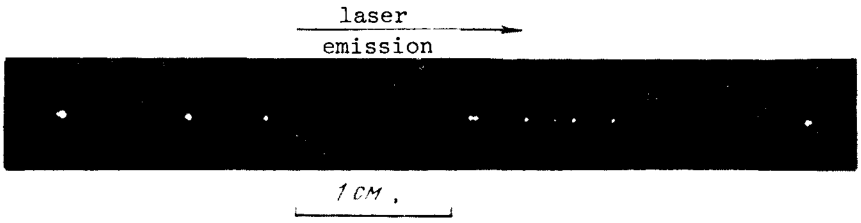

Fig. 2

possible mechanisms of discrete spark production is the longitudinal self-focusing channel instability described in [6]. Another mechanism may be the spatial beats between the different frequency components of the laser emission, or spatial beats between the laser emission and the Mandel'shtam-Brillouin scattering components, similar to the beats observed in [7] between the laser emission and the Stokes component of Raman scattering.

The production of the sparks indicates that in some cases the increase of the power in the channel is indeed limited by ionization.

Breakdown was observed in carbon disulfide and nitrobenzene, but not in toluene.

Observation of breakdown in an unfocused beam is reported also in [8], which became known to the authors after this paper was written.

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NONLINEAR OPTICS OF GYROTROPIC MEDIA

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1. The subject of this letter is a discussion of the singularities of propagation of intense light waves in gyrotropic media. Recent success in the construction of powerful sources of visible and ultraviolet radiation make it possible to set up suitable experiments in media having natural optical activity. In nonlinear optics of gyrotropic media one deals with at least two types of problem. On the one hand, effects connected with spatial dispersion appear anew in strong light fields. This set of problems, which we shall call "nonlinear gyrotropy" for short, includes such phenomena as nonlinear rotation of the plane of polarization, nonlinear circular dichroism, etc. Their study can yield new information on the physical properties of the medium. On the other hand, ordinary, linear gyrotropy can change the behavior of already known nonlinear effects. This pertains, in particular, to coherent processes (such as harmonic generation, anti-Stokes Raman scattering, etc.) for which the gyrotropic properties of the medium can change the conditions for optimal interaction. Finally, interest attaches to the study of coherent nonlinear effects under conditions when the "nonlinear gyrotropy" is significant. We develop below a procedure for solving problems in nonlinear optics of gyrotropic media, and discuss effects pertaining to both of the above classes; the calculations were made with optically active media as examples.

2. Equations of nonlinear optics of gyrotropic media. The electromagnetic properties of a medium will be described by material equations in the form