A POSSIBLE EXPLANATION OF THE SMALL-SCALE SELF-FOCUSING FILAMENTS

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The so-called small-scale self-focusing filaments were recently observed experimentally [1-3]. The existence of these filaments is presently explained on the basis of the existence of stationary (self-maintaining) solutions of Maxwell's equations in a nonlinear medium [2,4-6]. The difficulties encountered by such an explanation are noted in several papers (see, e.g., [1,3]). It seems to us that another explanation of this phenomenon is possible. This explanation follows from an analysis of a numerical solution obtained in our preceding paper [7] for the problem of self-focusing of an axially-symmetrical beam. According to [7], if the inequality under which the initial power exceeds the critical value, namely $E_0 > N_1[n_2(ka)^2]^{-1/2}$ is satisfied ($N_1 \approx 2$, $n = n_0[1 + (1/2)n_2|E|^2]$ is the refractive index, which depends on the field intensity, a is the initial beam radius, and $k = (2\pi/\lambda)n_0$), then the beam breaks up into annular zones which are focused in succession at different points on the axis (no self-maintaining channels are obtained). The focal points represent small regions (both transversely and longitudinally) with very high energy density. The transverse dimensions of these regions (obtained by numerical solution without allowance for stimulated Raman and Mandel'shtam-Brillouin scattering, etc.) do not exceed in the main 1/500 of the initial width of the beam, and the longitudinal dimensions do not exceed 1/200 of the distance to the initial cross section; their intensity at the center is at least 500 times higher than the initial intensity on the beam axis. From the physical point of view we are dealing here with "bright spots" of very small dimensions. When the initial power is much higher than critical, these spots are located close to one another. The distances in the finite chain that they form are much smaller than the gap between the start of the chain and the entrance plane of the nonlinear medium. In an ideal axially-symmetrical beam, this entire chain is produced on its axis and lies by the same token on one line in space. Of course, in a real beam (even one close to axially-symmetrical), the bright spots have a scatter in the transverse direction. It can only be stated that this scatter will be much smaller than the initial width of the beam.

Such a picture is obtained for a specified initial power. At the same time, an important factor affecting all the experiments performed on self-focusing is the smooth growth (relative to the time of establishment of the Kerr effect) of the beam power in the initial section. It is therefore necessary to analyze the considered solution with allowance for the time variation of the generated power obtained in Q-switched lasers. Inasmuch as the longitudinal arrangement of all the regions of high energy density depends essentially on the beam power in the initial section, we arrive immediately at the conclusion that all these regions will move in a direction along the beam axis, in accordance with the envelope of the laser pulse. The spatial trajectories traced by them will produce a series of filaments directed along the beam axis and having (in the case of real beams) a random transverse scatter near this axis. An investigation of the solutions obtained in [7] for different values of the initial axial-field intensity shows that the number of such filaments will depend on the maximum power of the laser pulse. In the case of a slight excess over the critical power, one filament appears. This is followed by the other filaments, the number of which increases with increasing maximum initial power. The instants t_m at which each bright spot passes through the exit plane of the medium (as well as through any fixed plane inside the medium) will be different, and the corresponding characteristic times Δt_m of this passage will be determined by the formula

$$\Delta t_m = \Delta z_m / v_m,$$

where v_m are the corresponding motion velocities

$$v_m = N_{max} \frac{dz_m}{dN} \frac{d\phi}{dt} \Big|_{t=t_m}, \tag{1}$$

Δz_m are the longitudinal widths of the regions of high energy density;

$$N_{max} = E_{max} \sqrt{n_2 (ka)^2}; \quad N = N_{max} \phi(t);$$

$E(r, 0) = \varphi(t) E_{max} \exp(-r^2/2a^2)$ is the time-variable initial field; the functions $z_m(N)$ are obtained from a plot given in [7] (which gives the dependence of (Nz_m/ka^2) on N). It is of interest to estimate, under typical conditions, the velocities (v_m) of the regions of high energy density and the characteristic times (Δt_m) of their stay at the given point of the medium. This demonstrates simultaneously the validity of the quasistationary approach employed above. We assume that the duration of the laser pulse τ is 20 nsec $(\varphi(t) = \exp(-2t/\tau^2)$; the value of N_{max} is assumed equal to 7.5 (meaning that the maximum initial power exceeds the critical value by about 15 times); the initial beam radius a is assumbed to be 0.25 mm and the longitudinal dimension z_m is assumed equal to $5 \times 10^{-3} z_m \lambda = 0.7 \times 10^{-4}$ cm; $n_0 = 1.5$. We then obtain for a distance of 10 cm from the entrance plane of the medium and for the lowest numbers m = 1, 2, 3, ... the values $v_m \approx 10^9$ cm/sec and $\Delta t_m \approx 0.5 \times 10^{-10}$ sec (the minimal distance from the first bright spot to the entrance plane is 5 cm).

We see from these estimates that the characteristic times Δt_m do not exceed the typical values of the time of establishment of the Kerr effect. It is also important that, for the off-axis regions of the beam, the spatial scale of the longitudinal field inhomogeneity is many times larger than the intervals Δz_m, and consequently the characteristic time of the variation of the field in these regions is much higher than the characteristic times Δt_m. By the same token, we arrive at the conclusion that under the conditions under consideration there is actually established at each instant a quasistationary picture corresponding to a specified value of the time-varying initial power. It must also be noted that the characteristic times Δt_m increase by many times at the "turning points" (determined by the condition $(d\varphi/dt) = 0$).

We can therefore expect processes occurring in the substance at high energy densities but requiring a sufficient development time (for example, breakdown of a liquid), to occur first at the turning points of the high energy density regions. It is also clear that the presence of additional phenomena in the bright spots (SRS, SMBS, breakdown, two-photon absorption, etc.) can influence a number of quantitative characteristics (the really attainable energy density of these points, their dimensions, and their relative arrangement), but introduces no qualitative changes in the obtained picture. For shorter laser pulses it may turn out that the quasistationary picture has time to become established only in the off-axis part of the beam. In this case, the final time of establishment of the Kerr effect can also influence the attainable energy density of the bright spots. For ultrashort laser pulses, all the transient processes will be significant.

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EXPERIMENTAL INVESTIGATIONS OF THE POSSIBILITY OF CONTROLLING TWO-STREAM INSTABILITY WITH THE AID OF MODULATION

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One of the most important problems connected with an experimental investigation of the microinstabilities in a plasma is the study of the possibility of controlling these instabilities.

In this paper we investigate the question of the control of two-stream instabilities by initially modulating the beam and by introducing an initial nonfluctuating disturbance from an external source [1,2]. We show that the intense high-frequency oscillations excited as a result of the development of a two-stream instability with a power on the order of 100 kW can be controlled by applying to the input of the beam-plasma system a very weak regular signal which is smaller by a factor 10^5 - 10^6 than the power of the excited oscillations.

The application of an initial regular disturbance makes it possible to control the character of the excited oscillations and to transform the stochastic (irregular) oscillations into regular ones. Depending on the power of the external signal, the correlation time of the excited intense oscillations during the development of the two-stream instabilities can vary in a wide range (from 2 to 500 nsec and more).

To study the character of the excited oscillations, we investigated a method for directly observing the waveform of the excited oscillations with the aid of a high speed oscilloscope, followed by a Fourier analysis.