Nonlocal parametric turbulence of a laser plasma

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We describe the formation of an "opacity zone" appearing in an interferometric investigation of a laser plasma. The observed phenomenon is interpreted in the framework of the theory of a parametrically turbulent plasma.

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We present in this article a discussion of an experimentally observed effect that manifests itself when a high-temperature plasma[1] is investigated by an interferometric method, namely the appearance of an "opacity zone"[1)] near the target surface. This effect is explained within the framework of the theory of a parametrically turbulent plasma[4] and is of interest, since it can be connected with nonlocal parametric turbulence. The latter is manifest in the fact that it subtends over almost the entire plasma corona from the region of the critical density $n_e \sim 10^{21}$ cm^{-3} to the region of a strongly rarefied plasma $n_e \sim 5\times10^{18}$ cm^{-3} with dimension $\Delta x \sim 0.1$ cm.

The interpretation of the previously investigated phenomena which occur when high-power laser radiation interacts with a plasma[5–8] was based on the development of local parametric turbulence in relatively narrow regions of the laser-plasma density plasma in the vicinities of the critical $\omega_0 = \omega_{Le}(x)$ and quarter-critical $[\omega_0 = 2\omega_{Le}(x)]$ densities with dimension $\Delta x \sim 10^{-3}$ cm.

In the experiment discussed here the plasma was produced by focusing high-power radiation from a 9-channel Nd laser[9] on a flat target. The laser radiation parameters on the target surface were the following: energy 250 J, pulse duration at half-power 1.5 nsec, focusing spot diameter ~250 μ. The nonlocality of the plasma turbulence manifested itself in vanishing of the interference fringes on the slit-scanned interference pattern.[10] It is seen from the figure that during the time of action of the laser pulse near the target surface there appears on the interference pattern a rather large (~1 mm) opacity zone (shown shaded in the figure), inside of which no interferometer measurements can be made. The maximum electron density on the edge of the opacity zone at the instant of time 1 nsec (maximum intensity of the heating radiation), obtained from the reduction, reaches $n_e \approx 5\times10^{18}$ cm^{-3}. This density is smaller by almost one order of magnitude than the maximum electron density obtained from the reduction of the interference pattern obtained at 2 nsec, when a rapid decrease of the dimension of the opacity zone takes place.

The vanishing of the interference pattern during the time of action of the heating laser pulse can be attributed to the loss of coherence of the object beam with the reference beam when the object beam of the interferometer passes through the plasma. This is caused by the sufficiently intense (turbu-

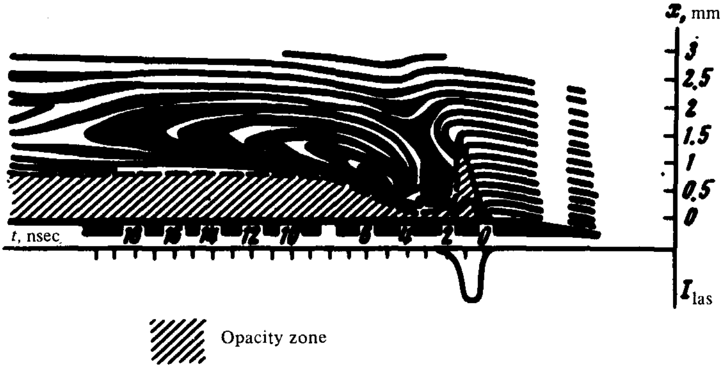

FIG. Slit scan of the interference pattern of a laser plasma.

lent) fluctuations of the plasma density. An analysis of the possible coherence-loss mechanisms shows that the most probable cause is random refraction of the object beam in the turbulent laser plasma. The optical path difference s of the beam over the angle $\sqrt{\langle\theta^2\rangle}$ in a plasma of dimension d is directly connected with the intensity $\langle(\delta n/n^2)\rangle$ and with the characteristic scale l of the turbulence

$$s = \frac{1}{12} d \langle \theta^2 \rangle = \frac{1}{12} \frac{n_c^{-2}}{n_e^{-2}(x)} \frac{d^2}{l} \left\langle\left(\frac{\delta n}{n}\right)^2\right\rangle.$$

Here $n_e(x)$ is the electron density at a distance x from the target, $n_c = 4\times10^{21}$ cm^{-3} is the critical density for the probing radiation (second harmonic of Nd laser, $\lambda = 0.53$ μ). The coherence is lost when the random path difference s becomes comparable with the wavelength λ of the object beam: $s \sim \lambda$. This leads to the following estimate of the required level of the fluctuations of a turbulent laser plasma:

$$\left\langle\left(\frac{\delta n}{n}\right)^2\right\rangle \sim 12\frac{n_c^2}{n_e^2(x)} \frac{\lambda l}{d^2}. \tag{1}$$

Let us dwell now on the possible causes of such a local parametric turbulence. From among the five parametric instabilities discussed in[6], two can initiate nonlocal turbulence: stimulated Raman scattering of the heating laser radiation by the electron plasma oscillations (SRS) and by the ion-sound oscillations (SMBS). According to the results of[11], however, the light fluxes used in the experiment were lower than the threshold for SRS. The loss of coherence of the object beam is therefore due to SMBS. Recognizing that the minimum sound wavelength $l \sim \lambda$ (the characteristic turbulence scale) is obtained for backward scattering of the heating radiation, we find from (1) that the random refraction by the turbulent fluctuations $\langle(\delta n/n)^2\rangle < 1$ determines the loss of coherence of the object beam up to densities $n_e > 6\times10^{18}$ cm^{-3} at a plasma thickness $d \sim 1$ mm. This estimate of the lower limit of the plasma density corresponds to the experimentally observed lower limit of the opacity zone. This interpretation of the experiment (on the basis of SMBS) explains also the experimental fact that the opacity zone vanishes immediately after the heating laser pulse is turned off. The subsequent increase of the dimensions of the opacity zone several nanoseconds after the end of the laser pulse, as well as its appearance at low flux densities $\sim(10^{11}-10^{12})$ W/cm^2 [2,3] is not connected with parametric effects and is due to ejection of the cold mass of target material.

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[1] The term "opacity zone" does not reflect exactly the actual situation and is used for historical reasons (see[2,3]). Probing radiation passes through this plasma region, but interferometric measurements in it are impossible.

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