increasing t is due to the increase in the number of oscillations, and the wavelength changes insignificantly.

The evolution of the discontinuity on the basis of the linearized equation (1) was considered in [5]. The formulas obtained there describe the initial stage of the process at $\eta_0^{3/2}t \ll 1$. The process should subsequently reach the asymptotic solution obtained above, in which the dispersion and nonlinearity effects are of the same order of magnitude. The decay of a small discontinuity in a plasma was experimentally investigated in [6]. The observed picture was qualitatively similar to that in Fig. 2.

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INFLUENCE OF SATURATION EFFECTS ON STIMULATING SCATTERING IN LASER HEATING OF A PLASMA

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We consider the reflection of powerful laser radiation from a plasma produced when laser pulses are focused on a solid target. We show that to calculate the reflection coefficient correctly it is necessary to take the nonlinear effects into account. In particular, saturation effects limit the reflection as a result of stimulated Thomson scattering and stimulating scattering by ions at the $2 \times 10^{11} - 10^{13}$ W/cm^2 level.

Recent papers [1, 2] discuss various stimulated-processes in a dense plasma produced by focusing powerful laser radiation on a solid target. Interest in these processes is connected with the problem of initiating thermonuclear reactions by heating a plasma with a laser [3]. It is feared in [1, 2] that at large fluxes the processes of stimulated scattering in peripheral plasma layers, with electron density $N_e \ll N_{cr} \simeq 10^{21}$ cm^{-3}, where absorption at electron temperatures $kT_e \gtrsim 1$ keV is very small, can lead to a conversion of an appreciable fraction of the incident radiation into scattered waves that leave the plasma, i.e., to reflection of the optical energy.

We wish to call attention in the present communication to a number of important aspects not accounted for in [1, 2]. The most important of them are saturation processes that limit the exponential growth of the scattered waves. The fact that these processes must be taken into account can be seen from the following simple considerations. Let us assume that a plasma of density N is grouped in a lattice $N(x) = N[1 + \alpha\cos(4\pi x/\lambda)]$, where $\lambda = 2\pi c/\omega_L$ is the wavelength and ω_L the frequency of the laser radiation, and α is the depth of modulation. The dielectric constant of the plasma at the frequency ω_L is

$\varepsilon = 1 - N/N_{cr}$, where N_{cr} is the critical density, i.e., the density at which the Langmuir frequency is equal to ω_L. Calculation of the coefficient R of reflection from the lattice yields $R = |\tanh(\pi\alpha NL/2N_{cr}\lambda)|^2$, where L is the thickness of the plasma layer. It is easily seen that when $\lambda = 10^{-4}$ cm, $N_{cr} \simeq 10^{21}$ cm^{-3}, $L \sim 10^{-2} - 10^{-3}$ cm [4], and $N \sim 10^{19} - 10^{20}$ cm^{-3} values $R \sim 1$ are reached at a modulation depth $\alpha \sim 1$. This means that any stimulated scattering mechanism in a plasma with density $N \ll N_{cr}$, leading to a noticeable reflection of the incident flux, should be accompanied by very large perturbations in the state of the plasma. Correct estimates of the gains or of the growth increments should take into account effects that are nonlinear in the amplitudes of these perturbations.

It is convenient to continue the analysis separately for $N < 10^{19}$ and $N > 10^{19}$. At $N < 10^{19}$ and $kT_e > 1$ keV we have $qr_D = q(kT_e/4\pi N_e e^2)^{1/2} \gg 1$, where $q = (2\omega_L/c)\sin(\theta/2)$ is the wave vector transferred in the scattering and θ is the scattering angle. At $qr_D \gg 1$, the scattering in the plasma corresponds to Thomson scattering by free electrons. For the unsaturated gain g (cm^{-1}) we have in this case

$$g = \frac{r_0^2\lambda^2 P_L N_e}{c\,kT_e} f\left(\frac{\Omega}{qv_{Te}}\right); \qquad f(x) = (2\pi)^{-1/2}\exp\left\{-\frac{x^2}{2}\right\}x, \tag{1}$$

where $r_0 = 2.8 \times 10^{13}$ is the classical electron radius, c is the speed of light, k is Boltzmann's constant, P_L is the laser radiation flux density, $v_{Te} = \sqrt{kT_e/m_e}$ is the thermal velocity of the electrons, $\Omega = \omega_L - \omega_S$, and ω_S is the frequency of the scattered light. It is easily seen that the maximum value of g does not depend on the scattering angle θ and is reached at $\Omega = qv_{Te}$, when $f(1) = 0.242$. Thus, the predominant scattering direction is determined only by the geometry of the problem.

Putting $N(x) \propto \exp\{-x/L\}$ and integrating from the point with $qr_D \sim 1$ to ∞, we obtain for $L \sim 10^{-2}$ cm

$$\int g(x)\,dx = 3\frac{P_L L r_0 \lambda}{mc^3} = (3\cdot 10^{15}\ \mathrm{W/cm^2})^{-1} P_L \quad . \tag{2}$$

To convert an appreciable fraction of the laser radiation into scattered waves it is necessary to satisfy the condition $\int g(x)dx \gtrsim \ln(P_L/P_n) \simeq 25 - 30$, where P_n is the power of the residual spontaneous scattering. This yields $P_L \gg 10^{16}$ W/cm^2.

We now determine the saturation effect, i.e., the deformation of the electron velocity distribution function F(v) as a result of scattering. Including in the equation for F(v) the term responsible for the transfer of the energy to the electron in the scattering process, and determining with the aid of the obtained function[1)] F(v) the increment of the intensity of the scattered waves, we can show that at sufficiently large scattered fluxes, $P_S \gg P_S^{sat}$, the exponential growth of the scattered waves gives way to a linear growth. The

[1)]The calculations here are analogous to those used in quasilinear theory of the damping of plasma waves (see, e.g., [5]).

characteristic saturating flux is equal to

$$P_S^{sat} \approx \frac{\nu m_e c^2 k T_e \Delta\omega}{4\pi r_0^2 \lambda^2 P_L} \qquad (3)$$

where ν is the frequency of the electron-electron collisions, and $\Delta\omega$ is the spectral interval in which the scattering is effective enough. In accordance with [6], we can put $\Delta\omega \sim qv_{Te}/5$. At $N = 10^{19}$ and $\nu = 6 \times 10^9$ sec^{-1} we have $P_S^{sat} = 2.5 \times 10^{27}$ (W/cm^2)$^2 P_L^{-1}$. Since we are interested in fluxes $P_L \gg 10^{16}$ W/cm^2, we obtain $P_S^{sat} \ll 2.5 \times 10^{11}$ W/cm^2. Thus, in accordance with the example considered above, that of reflection from a lattice, scattering in a layer of plasma with $N \leq 10^{19}$ and $L \leq 10^{-2}$ cm cannot lead to a reflection of a noticeable fraction of the incident flux.

In plasma layers with higher density, $N_e > 10^{19}$, when $qr_D < 1$, the scattering spectrum contains terms due to plasma oscillations and ion motion. At $T_e = T_i$, the latter represents the ordinary ion Doppler shift. Repeating all the above steps, we find that the gain for this type of scattering is maximal at $\Omega \sim qv_{Ti}$, and at $N \sim 10^{20}$ and $L \lesssim 10^{-2}$ cm it follows from the condition of appreciable reflection that $P_L \gg 10^{15}$ W/cm^2, and saturation limits the scattered flux to $P_S^{sat} \ll 2 \times 10^{13}$ W/cm^2. There is consequently no significant reflection in this case, too.

At $T_e \gg T_i$, the ionic part of the spectrum corresponds to Mandel'shtam-Brillouin scattering by ion sound. The presence of such scattering was experimentally demonstrated in [7] and was discussed theoretically in [8]. With respect to the possible reflection coefficients R due to such scattering, as well as to scattering by plasma oscillations, there are no grounds at present to make any definite statements. In fact, it is seen from the foregoing that, regardless of the scattering mechanism, very strong plasma-density modulation, $\alpha \sim 0.1 - 1$, is needed to obtain $R \sim 1$ at $N \lesssim 2 \times 10^{20}$ cm^{-3} and $L \lesssim 10^{-2}$ cm. The final answer concerning the possible values of R can be obtained only in a theory that takes the nonlinearity of the ion sound or of the plasma oscillations into account.

We note in conclusion that it is seen from the foregoing example with reflection from a sinusoidal lattice that the modulation depth α needed to obtain appreciable reflection is inversely proportional to the thickness L of the scattering plasma layer and is therefore very sensitive to the form of the laser pulse (duration, steepness of the leading front, contrast, etc.). Obviously, at larger L the values $R \sim 1$ can be reached at smaller perturbations of the plasma parameters.

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