lead to overheating and to the appearance of the electronic thermal-conductivity instability [10].

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HEATING AND CONTAINMENT OF PLASMA IN CROSSED LIGHT BEAMS

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Submitted 22 November 1972
ZhETF Pis. Red. 17, No. 1, 52 - 55 (5 January 1972)

Heating of plasma by pulsed-laser radiation for the purpose of obtaining a thermonuclear reaction is the subject of a number of theoretical papers (see, e.g., [1 - 4]). These papers deal with conditions in which the heating time does not exceed the time of the hydrodynamic expansion of the plasma. In the present communication we propose another method of plasma heating by pulsed-laser radiation. In this method, the time of heating can be determined by the duration τ_p of the laser pulse, and by the same token can be much larger than the corresponding time of the hydrodynamic expansion. In addition, unlike the conditions considered in the cited papers, in our method the area of the skin layer (in which the direct conversion of the light energy into thermal energy or into energy of collective plasma oscillations takes place) can be much larger then the surface area bounding the entire volume of the heated plasma.

For such heating, it is necessary to place the substance in the region of intersection of two light beams obtained, for example, from one laser and inclined to each other at a certain angle α. We consider below for concreteness focused beams (with individual focal-region diameters d_{f_1} and d_{f_2}, intersecting in the vicinity of these focal regions. By direct calculation we can verify that under asymmetrical conditions, for example (i) when $d_{f_1} \neq d_{f_2}$ or (ii) when the centers of the focal regions do not coincide and the beams in question have no symmetry plane, etc., three-dimensional "microregions" are produced as a result of the interference of the fields of the crossed beams. At the nodal points of each of the microregions, the values of the optical energy density (and consequently of the electromagnetic-field pressure) are small in comparison with the corresponding values on the boundary. One of the dimensions (Δx) of the microregion is obviously $\Delta x \simeq \lambda/2 \sin(\alpha/2)$ (λ is the laser emission wavelength), i.e., is determined by the distance between the interference bands of two plane waves; the two others (Δy and Δz) can be determined (i) by the dimensions of the focal regions in the directions of the remaining Cartesian axes y and z, (ii) by the dimensions of the region of intersection of the beams in the directions of the same axes, etc. Each of the microregions is a three-dimensional potential well, which keeps the plasma contained in it from expanding, if the pressure p_b of the electromagnetic field in the entire boundary surface of the microregion is larger than the plasma pressure p_{pl}. We assume that the condition

$$p_b > p_{pl} \tag{1}$$

is satisfied during the entire time, starting with a certain instant t_0 corresponding to total ionization of the matter and ending with the instant of time t_1 of interest to us[1].

Let us examine the kinetics of plasma heating under these conditions in a very simple model. We put $d_f = \max(d_{f_1}, d_{f_2})$ and rewrite (1) in the form $p_b = Ap_{pl}$ $(A > 1)$. Since $p_b \sim 2p_L/cd_f^2$ (where $p_L = p_L(t)$ is the laser-beam power), this relation yields

$$p_L = A c d_f^2 nkT, \tag{2}$$

where n and T are averaged (over different microregions) temperature and density of the plasma ions (we assume $T_e = T_i = T$). In addition, we denote by μ the efficiency with which the light energy is converted into thermal energy of the plasma. We then have

$$\frac{d}{dT}(3nkTV) = \mu p_L, \quad (\mu < 1). \tag{3}$$

Here V is the total volume occupied by the plasma in the microregions. The value of μ depends on the total area and on the thickness of the skin layer. By the same token, μ can vary in a wide range when the parameters of our beam are varied. Its value depends in general on the temperature T, owing to the temperature dependence of the coefficient of light absorption in the plasma. Assuming, however, for simplicity μ = const, setting $A = A_0$ = const, and neglecting the time dependence of n and V, we obtain from (2) and (3)

$$p_L(t) = p_L(t_1)\exp\left[\frac{t - t_1}{\tau(A_0)}\right], \tag{4}$$

where

$$\tau(A_0) = \frac{3V}{A_0 c d_f^2 \mu}. \tag{5}$$

Since the time variation of the power p_L is exponential in the remote section of the leading front of a typical laser pulse, the inequality (1) is satisfied for such a pulse when

$$\tau_p < \tau(1) = \frac{3V}{c d_f^2 \mu}. \tag{6}$$

Integrating (3) over the time of the first half of the pulse, we obtain an

[1]We do not consider here the initial stage of ionization of the medium.

expression for the plasma temperature T_1 at the instant of the maximum of the laser power:

$$T_1 = \frac{\mu}{6nkV} E_L , \qquad (7)$$

where E_L is the total energy of the time-symmetrical laser pulse.

Let us consider a numerical example. We put $E_L = 3 \times 10^4$ J, $d_f = 5 \times 10^{-3}$ cm, $n = 5 \times 10^{22}$ cm^{-3}, $\mu = 10^{-1}$, $V = d_f^2 \ell_f$, $\ell_f = 1.4\pi d_f^2/\lambda$, and $\lambda = 10^{-4}$ cm. Then condition (6) yields $\tau_p < 10^{-9}$ sec (we can assume, for example, $\tau_p = 3 \times 10^{-10}$ sec). In accordance with (7) we thus obtain $T_1 \simeq 3 \times 10^7$ deg. We note that at this temperature the speed of sound v_s in a deuterium-tritium plasma is of the order of 0.6×10^8 cm/sec. Therefore the time of its free expansion at $d_f = 5 \times 10^{-3}$ cm would be 4×10^{-11} sec, which is shorter by approximately one order of magnitude than the value $\tau_p = 3 \times 10^{-10}$ sec.

It is easily seen that containment of the plasma under our conditions is possible also if the thickness ℓ of the layer of matter is much smaller than the length of the microregions (then $V \sim \ell d_f^2$). It is necessary in this case to satisfy only the condition $\ell \gg v_s \tau_p$, which means inertial containment in one (longitudinal) direction.

We note also that during the heating process the plasma density n in the microregions can increase with time as a result of the compression by the electromagnetic field. Then the product nV will remain practically constant[2]. According to (5), for larger compression it is better to use shorter laser pulses. If we put in our example $\tau_p = 3 \times 10^{-11}$ sec, then we see from (5) that $A_0 = 30$. The plasma density in the microregions will then be larger by approximately one order of magnitude than the initial value $n = 5 \times 10^{22}$ cm^{-3}.

The authors thank A.A. Samokhin and M.V. Fedorov for useful discussions of the results.

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