Plasma-corona filamentation during the heating and compression of shell targets in the DEL'FIN-1

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Filamentation has been observed in the plasma corona in experiments on the bombardment of thin-walled shell targets in the DEL'FIN-1 laser fusion device. The filamentation was seen in the soft x-ray emission of the plasma.

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Several recent papers have reported the observation of filamentation in the plasma corona during the heating and compression of thin-walled shell targets.[2–5] The phenomenon has been detected primarily by optical methods—through Schlieren pho-

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tography of the corona[2] and through study of the harmonics of the laser beam which are generated in the plasma[3]—and also from the intrinsic x-ray emission of the plasma.[4] The filamentation has been attributed to both the self-focusing of the laser beam and the onset of small-scale instabilities in the plasma corona.[5]

The reason for the interest in the filamentation is that when a hydrodynamic method is used to achieve the high compression of the fuel which is required for fusion ignition the ablation must be kept highly symmetric, and filamentation may be evidence of instabilities in the plasma which would disrupt the symmetry of the compression of the shell.

1. *Experimental apparatus.* The DEL'FIN-1 device[1] is a six-beam laser system with a series-parallel amplification arrangement. The laser beams are focused on the target in a spherically symmetric manner. The focus diameter at the target surface, $d_0 = 250\ \mu$m, is determined by the beam divergence. Experiments with shell targets were carried out with an energy $E_i = 750$–1000 J incident on the target, with a pulse length $\tau_{0.5} = 2.3\times 10^{-9}$ s at half maximum, and with an energy contrast $K_e = 10^6$. Under these experimental conditions, the intensity at the target surface was determined by the dimensions of the target, varying over the range $q \simeq 10^{13}$–10^{14} W/cm^2. The laser radiation was absorbed at an efficiency of 40–50%.

2. *Experimental results.* The x-ray emission from the laser plasma was studied by means of three seven-frame pinhole cameras working in spectral intervals set by attenuating filters with cutoff energies $E_{\text{cut}} = 2.2$–6.2 keV (corresponding to attenuation by a factor of e). The filters were oriented in three mutually perpendicular directions. The spatial resolution of the pinhole cameras was 10–40 μm, depending on the particular pinhole. We used targets of different materials (glass and polystyrene) and with different geometric characteristics (a radius $R = 200$–$250\ \mu$m and an aspect ratio $R/\Delta R = 30$–250).

In the experiments on the heating of the polystyrene shell targets we regularly observed a filamentation in the plasma corona. Figure 1a is a pinhole photograph

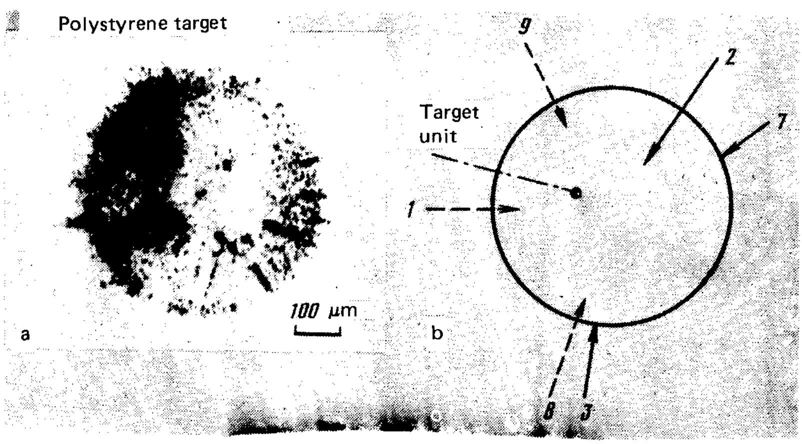

FIG. 1. a—Photomicrograph of a plasma produced in the heating of a polystyrene target (the cutoff energy of the x-ray filters was $E_{\text{cut}} = 3.6$ keV); b—arrangement of the laser beams over the target surface.

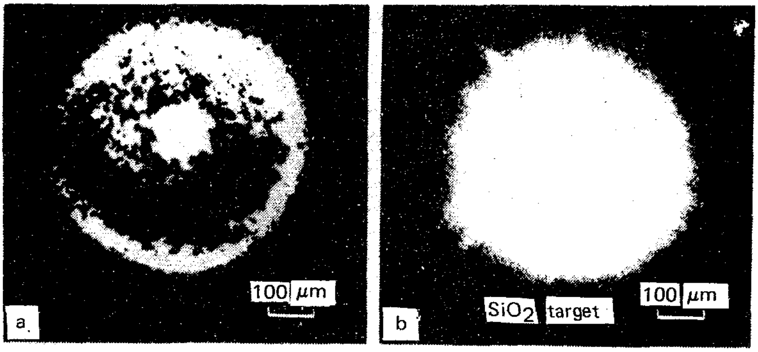

FIG. 2. a—Pinhole photograph of a plasma during the heating of a glass target in the absence of filamentation (the volume compression factor is $V/V_0 = 4\times10^2$); b—pinhole photograph of a plasma in the case of a glass target with filamentation.

obtained during the heating of a polystyrene target $2R = 580\,\mu$m in diameter with an aspect ratio $R/\Delta R = 50$ for the pump parameters $E_i = 800$ J and $E_{abs} = 360$ J. This photograph shows the typical pattern of the plasma emission during filamentation. The typical diameter of the jets at the target surface is 20–40 μm. The jets are directed strictly along the normal to the target surface. The diameter of the filaments falls off with increasing distance from the target surface; their total length is 100–200 μm. Diagram 1b shows the arrangement of the pump beams on the target surface. Comparison of Figs. 1a and 1b shows that there is no correlation between the directions of the filaments and the orientation of the laser beams.

We varied the parameters of the laser beams and the targets to determine the changes in the formation of the filaments. The density and number of filaments on the target surface increase with increasing target diameter. Filamentation was observed in all the experiments with polystyrene targets, and in none of these experiments did we detect a compression. In the experiments with the glass targets ($R > 200, R/\Delta R \gtrsim 100$), at an incident energy $E_i < 1$ kJ and a laser pulse length $\tau_{0.5} = 2.3$ ns (the intensity was $q = 10^{13}$–10^{14} W/cm^2), filamentation was not observed, and a high compression, by a factor of 10^3 in terms of the volume, was detected[6] (Fig. 2a). With increasing laser energy ($E_i > 1$–1.3 kJ), and with a different pulse shape (but again with $q = 5\times10^{13}$ W/cm^2), we also observed a filamentation in the case of glass targets, with the same typical jet size as in the case of the polystyrene targets (Fig. 2b). As in the case of the polystyrene targets, we did not detect any compression.

3. *Conclusion.* The filamentation inferred from the intrinsic x-ray emission of the plasma is evidence that the expansion of the plasma involves jets. The absence of a compressed core when filamentation occurs suggests that in this case the acceleration of the shell toward its center becomes unstable, with a consequent sharp decrease in the volume compression. This nature of the plasma extension may be caused by convergence effects which result from a disruption of the spherically symmetric distribution of plasma density near the evaporation boundary. The source of the initial perturbations may be fluctuations in the laser intensity, $\Delta J \cong 1$–5%, which may in turn result from an amplification caused by a self-focusing in the plasma corona of initial coherent

surges in the intensity in the distribution of the light over the target surface. For a substantial change in the intensity distribution in the region of dense plasma, where the energy is released, the decay integral must satisfy the condition[7] $B \geqslant 2\pi$.

In the case of a spherical plasma, the decay integral is given by

$$B = \frac{2\pi}{\lambda} \int_{-\infty}^{R} \gamma(I, r) I(r)\, dr,$$

where γ is an intensity-dependent increment in the refractive index.

In the part of the plasma with $\rho < \rho_c/4$ (ρ_c is the critical density), where the absorption of the laser beam can be ignored, and γ is determined exclusively by ponderomotive forces,[4] we can write

$$B = \text{const } 2\pi\lambda I(R_c) \int_{-\infty}^{R(\rho_c/4)} \frac{1}{R^2} \frac{1}{kT_e} \frac{\rho(r)}{\rho_c} dr .$$

To estimate B we assume that the electron temperature T_e is constant over the region with $\rho_c/10$–$\rho_c/4$, and we approximate the results of the calculations of the density in the corona by the Luch program[8] by the expression

$$\rho(R) = \rho_c \exp \left\{ -\frac{4\pi}{3} R_c^3 \frac{n_c}{z} \frac{\Sigma I + (z+1) kT_{ec}}{\xi E_{\text{abs}}} [(R/R_c)^3 - 1] \right\},$$

where R_c is the radius of the critical-density surface, z is the average charge of the ions, ΣI is the sum of the ionization potentials, E_{abs} is the absorbed energy, T_{ec} is the electron temperature in the ρ_c region, and $\xi = 0.3$. For an SiO_2 target with a radius $R = 225\ \mu m$ we find $B = 1.4\pi$, while a polystyrene target of the same size corresponds to $B = 2.4\pi$.

We see that the conditions are most favorable for self-focusing in an extended plasma corona with a low electron temperature; these are the conditions corresponding to large targets made of a low-z material.

In summary, a self-focusing of the laser beams may occur to an appreciable extent in the plasma corona and be one reason for the experimentally observed filamentation and disruption of the compression symmetry.

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