Plasma jet creation by direct and indirect irradiations of conically shaped foils

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Abstract: The paper is aimed at testing the possibility of plasma jet creation by using different constructions of targets with conically shaped thin foils. The cones were irradiated directly or indirectly by a focused pulsed high-power laser beam. The experiment was carried out at the Prague Asterix Laser System. Our investigations have shown that the methods of plasma jet creation based on collapse of a thin conically shaped foil are rather promising, they require, however, careful fitting of the targets to the target irradiation parameters. This is particularly the case of the double target with a pressure cavity.

1. Introduction

The production of jets by collapsing, mostly plate-shaped charges, driven by explosives has been studied very early by Walsh et al. (1953) [1]. The later papers [2, 3] were devoted to analyses of the angle between the plates and the equation of state of the material with the aim to find optimum conditions for jet launching. The method of plasma jet creation by laser beam action on a conically shaped thin metallic foil has been proposed by P. Velarde et al. [4]. This idea is considered as a new fast igniter scheme for realization of inertial confinement fusion. In the shell impact concept the compressed deuterium-tritium fuel is ignited by the jet produced in a conical target placed inside a guiding cone. While the theoretical predictions concerning the plasma jet parameters (jet velocity, collimation and plasma density) were rather promising, maximum velocities of 6×10^7 cm/s only were obtained in numerical simulations carried out for Al and Au jets. In order to validate these results we performed a series of preliminary experiments at the PALS facility.

2. Experimental results

In the investigations the following target irradiation parameters were used: the first harmonic of laser radiation (λ=1.315 μm), laser energies 120 and 600 J, and pulse duration 250 ps (full width at half maximum). The target schemes used for realization of the direct and indirect irradiation of the conically shaped foils are presented in Fig. 1.

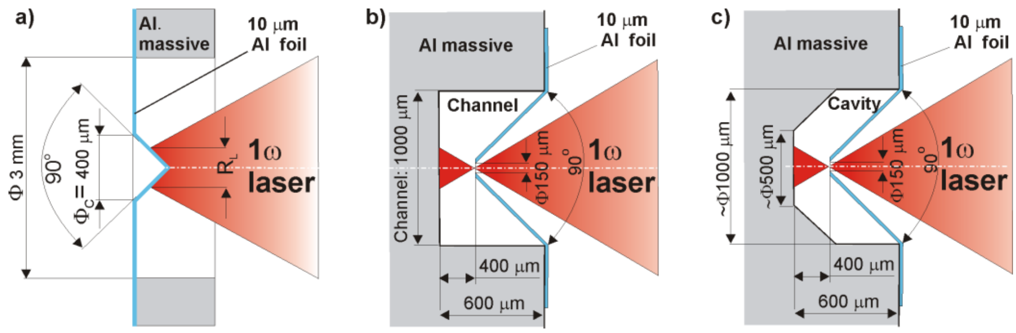

Fig. 1 The target constructions with a conically shaped thin foil: a) – target with direct cone irradiation, b) - double target with free ablative plasma expansion (TF), and c) - double target with pressure cavity (TP).

Our interferometric investigations show that in the case of the direct cone irradiation (Fig. 1a) and the laser energy of 120 J the plasma stream has not a jet shape. Although this laser energy is high enough for plasma creation, it is too low for fast collapse of the shell, which is necessary for production of a cumulative plasma stream. That is likely why the plasma plume has rather a divergent geometry in that case. When increasing the laser energy both the plasma amount and the plasma outflow length grow up considerably (Fig. 2).

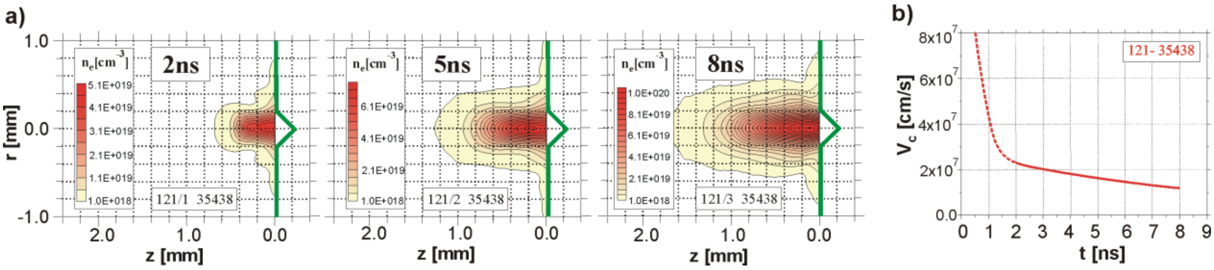

Fig. 2 Sequences of electron densitograms (a) and the axial velocity (b) of plasma streams produced by direct action of laser beam for energy of 600 J.

At higher laser energy the plasma stream geometry is closer to a jet-like structure. It says that conditions for the plasma jet creation become evidently better. The initial axial velocity of plasma contour reaches a value lying in the range of (5-8)x10^7 cm/s, however it drops very fast below 2x10^7 cm/s. In fact, if the plasma moves only in axial direction, the plasma stream velocity should be constant. Therefore, the observed pronounced velocity decrease should result from a lateral plasma escape. The plasma loss occurring at the plasma stream front results in deceleration of the outer electron equidensity line, which was used for determining the axial plasma velocity.

In our opinion, two competitive effects participate here in the plasma jet creation process: (i) the cumulative effect, which leads to plasma concentration at the axis, and (ii) the internal thermal plasma pressure, which acts in the opposite way. Then, the plasma jet parameters (geometry, density and velocity) result from action of these two competing processes. To find the optimum relation between them is crucial for a successful jet launching. Irradiation of a conical shell should ensure only its evaporation, while most of the laser energy should be focused just to the evaporated part of the shell. However, any control of this process is hardly possible. Since the plasma jet quality improves with the growing laser energy, it seems that the maximum laser energy available in our experiment is still too low to achieve the plasma jet quality corresponding to that predicted by numerical modeling.

It is well known from the theoretical analyses that the hydrodynamic efficiency of conversion of the absorbed laser energy into the flyer kinetic energy is lower than 20%. Most of the laser energy is transferred into the ablative plasmas. Recently, we tested the possibility to accelerate the foils by exploiting the ablative plasma pressure. It turned out that it is possible to reach a foil velocity twice higher than that obtained by using a classical method of acceleration (i.e. by direct laser action on a flyer) [5]. It confirms that the laser energy is deposited mainly in the ablative plasma. Considerably better results were obtained by exploiting the so called “cavity pressure acceleration scheme” (CPAS) [6]. The pressure induced by laser action inside the target cavity constitutes here the most important factor of foil acceleration. CPAS enables laser acceleration of very thick foils (e.g. 500 μm) to a velocity of about 10^7 cm/s, which is not achievable by means of a classical method at the same target irradiation conditions. The good results concerning the foil acceleration inclined us to apply the above new methods also for plasma jet launching on conically shaped thin foils. In particular, to exploit the ablative plasma created on a massive target as a heater and accelerator of the cone wall. For this reason two new target constructions were designed: (i) double target with free ablative plasma expansion (TF) and (ii) double target with pressure cavity (TP), as presented in Fig. 1b and Fig. 1c, respectively.

The results of experiments with both the targets types at the laser energy of 120 J are presented in Fig. 3. They show that the plasma jets parameters are considerably better than those obtained with direct cone irradiation at the same laser energy. The average plasma jet velocities in the observation period are higher than 10^7 cm/s, whereas in the direct irradiation case the velocity was decreasing very fast below that value. Moreover, it should be emphasized that the maximum electron density in the jets is twice higher than in the case of the direct cone irradiation. However, the plasma jet propagation starts with a longer delay (several ns), which is characteristic for both TP and TF targets. Although the plasma jet in the case of TP target is faster than that for the TF target, its velocity is still not satisfactory.

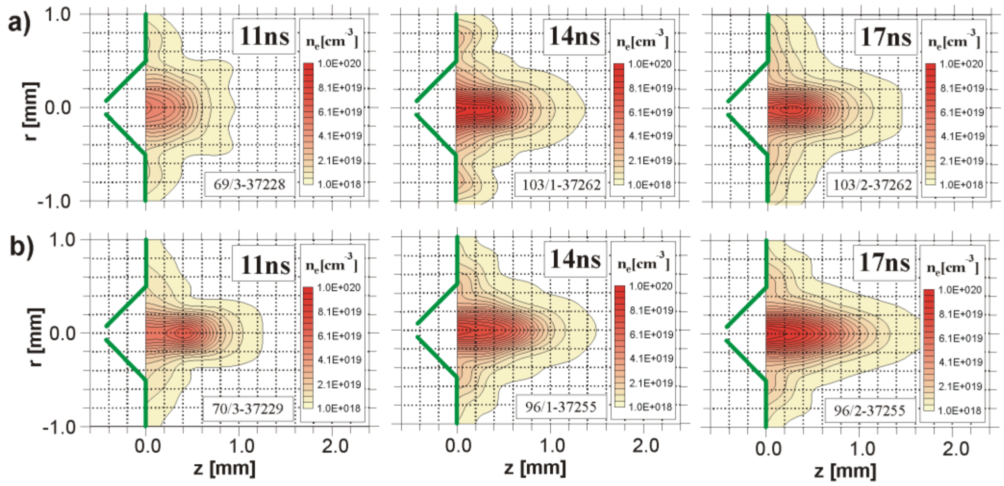

Fig. 3 Sequences of electron equidensitograms of plasma streams at energy of 120 J for: a) - open type target and b) - cavity type target.

Further investigations were performed at the laser energy of 600 J. The sequence of interferograms showing the plasma jet forming for the TF target is presented in Fig. 4a.

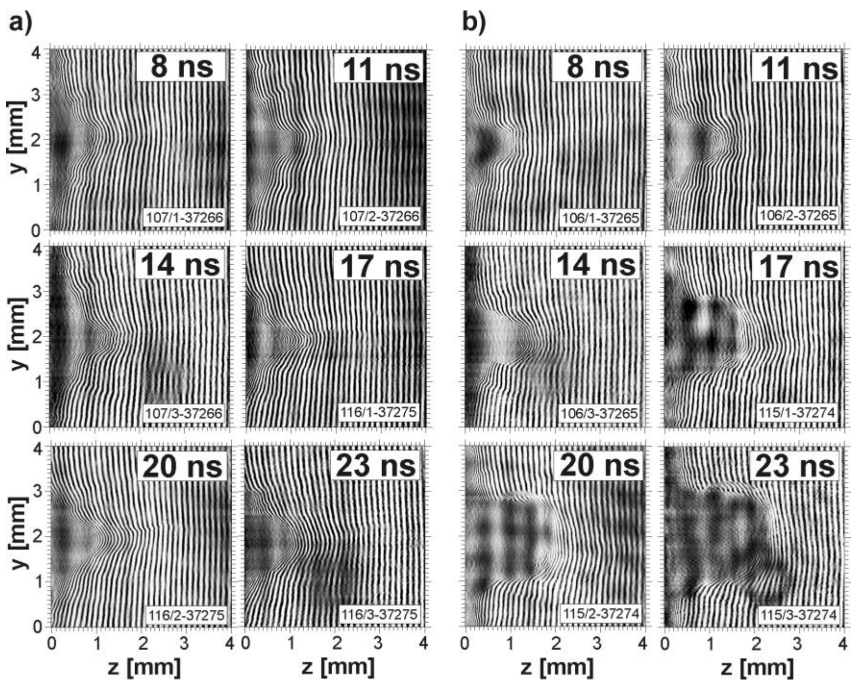

Fig. 4 Sequence of interferograms of plasma stream for: a) the open and b) cavity type target.

The plasma jet starts relatively early (3-5 ns after the laser pulse), persisting for a long time. Its initial velocity falls in the range of (5-8)x10^7 cm/s. The great advantage of that plasma jet type consists in its high electron density, particularly in the cone vicinity, where it considerably exceeds 10^{20} cm^{-3}. This is well seen in the opacity zone in Fig. 5. Such a dense plasma is not transparent for the diagnostic laser beam. The best results were expected for the TP target. First of all, the velocity of the plasma jet was expected to be close to 10^8 cm/s. It turned out, however, that the cone was at first inverted by the plasma created inside the cavity (see Fig. 4b at 8-14 ns) and then it was completely destroyed.

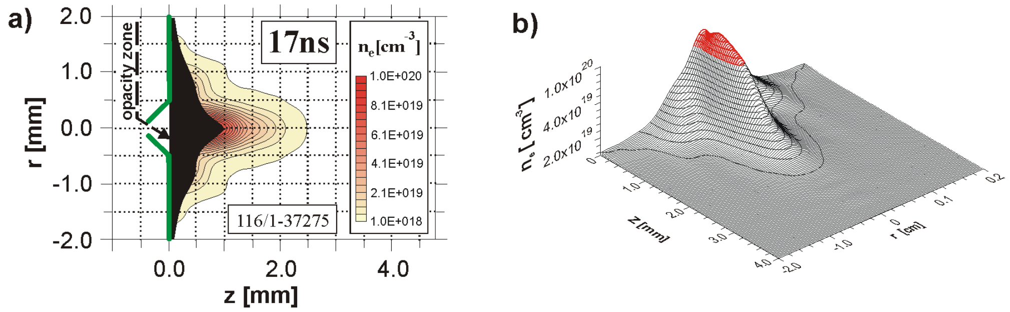

Fig. 5. Electron density distribution inside the plasma jet for the open type target at 17 ns in forms: a) - equidensitograms and b) - spatial distribution.

No plasma is seen in the interferograms. It means that the pressure inside the cavity was too high and acted before the cone evapored. This observation clearly demonstrates that proper correlation between the heating and impact of the cone shell is critical for the plasma jet creation.

3. Conclusions

The investigations of plasma stream parameters for the three target constructions used allowed us to come to the conclusion that a proper ratio of the laser energy part used for heating to that exploited for acceleration of the cone wall is very important for launching a good-quality jet. If a majority of laser energy is used for the cone wall heating, the collapse of the cone is not effective, whereas in the opposite case the too fast acceleration of the cone wall results in conservation of its steady state and in subsequent cone reversal and destruction. However, in the case of TP target there is a certain possibility to control the above energy ratio by means of fitting the cavity volume to target irradiation parameters. It would allow us to avoid situation like that seen in Fig. 4b, where the cavity volume was too small in relation to the laser energy. For that reason some additional numerical modeling will be very useful. In the case of indirect methods of plasma jet generation a certain disadvantage may consist in some delay of the plasma jet creation. Combination of the direct cone irradiation with the pressure cavity technique may allow us to remove drawbacks of application of the direct and indirect methods alone.

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