Methods of backward and forward formation of metallic plasma jets at PALS

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Abstract

In this paper the authors present convenient methods of backward and forward formation of metallic plasma jets. For this reasons a massive Cu target or a combination of Cu and plastic foils were used, respectively. The experiment was carried out with the PALS iodine laser. A three-frame laser interferometer was used for studying the plasma jet creations.

1. Introduction

Supersonic laser-driven plasma jets are a subject of growing interest due to their importance for laboratory astrophysics, as well for inertial confinement fusion [1-3]. Parameters of the jets produced experimentally in laboratories differ considerably from those observed in the Universe. Astrophysical jets are long, narrowly collimated structures emanating from young stellar objects, block holes, and active galactic nuclei. These exclusively astrophysical phenomena can be, however, simulated by artificially produced plasma jets, provided that certain their dimensionless parameters are comparable. High-power lasers can create conditions for studying physical processes taking place in astrophysical objects. The first attempts to generate laboratory jets relevant to astrophysical observations were accomplished at the world most powerful multi-beam laser facilities, such as NOVA or GEKKO XII [4-7], at laser pulse energy levels of hundreds of joules. Jet-like structures were formed there by a cumulative effect of the ablated flows at the axis of conical targets. Our experiments at Prague Asterix Laser System (PALS) have proved that creation of the plasma jets with parameters corresponding to those necessary for simulation of astrophysical phenomena are possible even at laser energies far below 1 kJ.

2. Backward-emitted metallic plasma jet

Hitherto, we have proposed the method of generation of backward-emitted metallic plasma jets using flat massive targets irradiated by the third harmonic of a single partly defocused laser beam [8, 9]. In this case the annular target irradiation plays a decisive role in the plasma jet forming. The gas (iodine) laser PALS tends to generate a small central depression in the transverse beam cross-section. Because in the up-converted third harmonic beam this depression becomes deeper, thus this harmonic is more applicable for the plasma jet creation. In such case a part of the generated plasma collides on the axis creating jet-like plasma configuration. The time evolution of the plasma jet configuration was studied by means of a three-frame interferometric system. The sequences of interferograms and electron density distributions corresponding to the typical plasma jet launched on the Cu massive target are presented on Fig. 1.

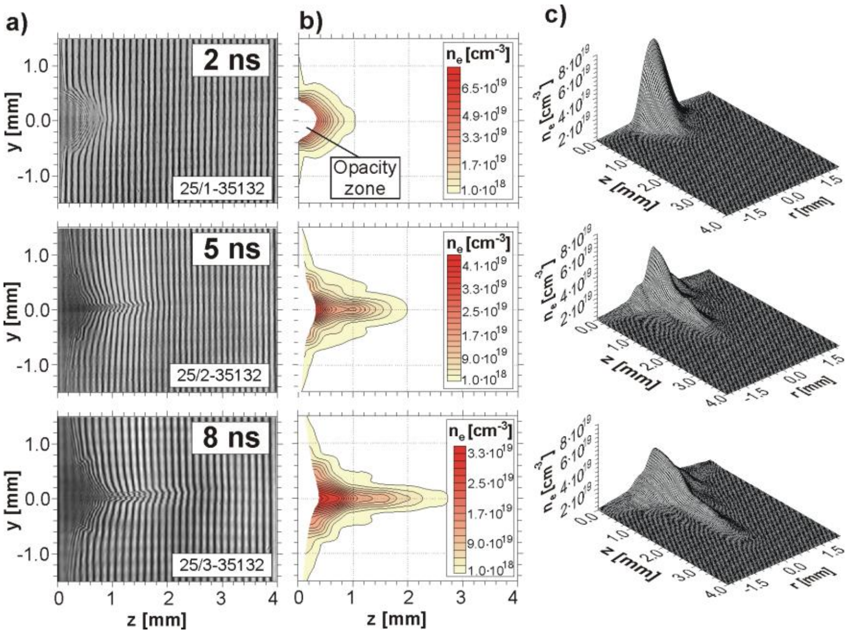

Fig. 1. Sequences of interferograms (a), electron equidensitograms (b) and spatial electron density distributions (c), showing the evolution of Cu-plasma structure.

The Cu plasma jet was here produced at the following laser parameters: laser energy 30 J, focal spot radius 400 μm (the focal point being located inside the target), and the pulse duration 250 ps (FWHM). The plasma jet velocity grows with the laser energy reaching values in the range of (4-7) x10^7 cm/s.

3. Forward-emitted metallic plasma jet

A new method proposed by us allows to get a metallic plasma jet directed forward. This method bases on difference in pressures of plastic and copper plasmas, which was demonstrated by us in Refs. [10] and [11], where experimental investigations and theoretical analysis of the dynamics of plasmas produced by laser from a joint of light and heavy target materials (CH-Cu) are presented. This analysis allowed us to evaluate the average pressures in plastic and copper plasmas near the critical densities during the period of laser action. They are equal to 14.3 Mbar and 10.6 Mbar, respectively. The ratio of plastic and copper plasma pressures amounts to 1.35. In a method of forward formation of Cu plasma jet proposed by us we took advantage of the fact that the lighter is the plasma, the higher is its pressure. For this reason combinations of Cu and plastic foils with thicknesses of 1μm (Cu) and 2 or 6 μm (plastic) were used. The experiment was carried out at the Prague Asterix Laser System (PALS) iodine laser. The first harmonic of laser radiation (λ=1.315) with an energy of 490 J and a pulse duration of 250 ps irradiated the Cu foil. A focal spot radius was changed in the range of 40 – 120 μm. The interaction of plastic and Cu plasmas was studied by means of a three-frame interferometric system. Interesting results were obtained for the 2 μm plastic foil and the smaller focal spot radii. At the 6 μm plastic foil used the Cu plasma was completely blocked by the plastic plasma and any Cu plasma jet was not observed. Mechanism of the forward Cu plasma jet formation is rather complex. It is shown in Fig. 2. Despite the fact that the minimum focal spot radius was used due to the lateral thermal conductivity a region of foils heating was considerably larger (about 0.6 mm in radius). Nevertheless the central foils region, i.e. the region of direct laser beam action, reached the highest temperature. Initially, the Cu plasma expansion is blocked by the plastic plasma because of its higher pressure until a window in the central plastic plasma is opened. It occurs due to a faster expansion of the central plastic plasma (because of its higher temperature) compared with the other. As a result, the released Cu plasma can flow only through the narrow channel in the plastic plasma (which plays a role of a nozzle), reaching a velocity of about $4\text{x}10^{7}$ cm/s and an electron density in the range of 10^{18} – 10^{19} cm^{-3}. Of course, this result is not yet fully satisfactory. Too high laser energy is still necessary for this plasma jet creation as compared with that used for the backward jet production. In our opinion a proper choice of the foils thicknesses is able to reduce the laser energy to a level of a hundred Joules and also to improve the plasma jet parameters.

4. Conclusions

The methods of the metallic plasma jets creation presented here differ essentially each other not only in their propagation directions, but also from point of view of conditions necessary for their initiation. The backward produced metallic jets require the annular irradiation of massive metallic target. This is fulfilled at the PALS experiment by defocusing of laser beam on the target surface. Besides, the third harmonic of laser radiation proved to be better for this reason in comparison with the first one. Requirements necessary for creation of the forward metallic plasma jets are more complex. The first harmonic of laser radiation as well as the minimum focal spot radius create proper conditions for generation of these jets. It should be pointed out that in this case the targets are composition of two foils. So, to obtain a good jet quality thicknesses of both foils should be chosen very carefully. It seems that in our experiment these thicknesses were not optimum. However, the result presented here has a preliminary character. It only shows a potential of this method which seems to be very promising.

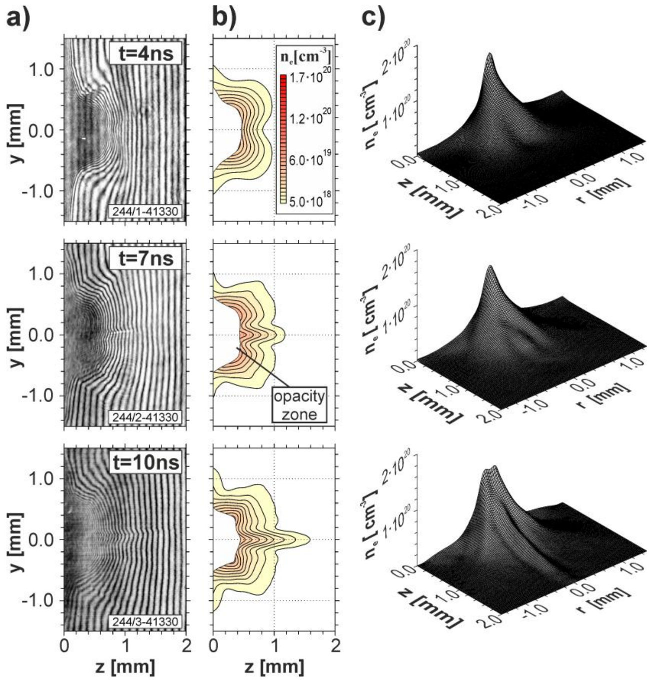

Fig. 2. Sequences of interferograms (a), electron equidensitograms (b) and spatial electron density distributions (c), showing the Cu-plasma jet emission.

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