Plasma jets generation by means of interaction of defocused laser beam with metallic targets of different mass density

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Abstract. The results of investigations are presented which are connected with defocused laser beam-planar target interaction. The experiment was carried out with target materials of different mass densities (Al, Cu, Ag, Ta and Pb) using the PALS iodine laser. The investigations were conduced for a laser radiation energy of 100 J at two wavelengths of 1.315 and 0.438 μm (the first and third harmonics of laser radiation), pulse duration of 0.4 ns and focal spot radius of 300 μm. Plasma dynamics as well as shapes and electron density distributions of plasma streams were obtained by means of a 3-frame interferometric system. The investigations have shown possibility of plasma jet generation in the case of defocused laser beam action on a planar target with relatively high mass density.

1. Introduction

The jets production has been studied for many tens years [1, 2]. Investigations were carried out mostly with the use of colliding plates or cones. One of many interesting and important applications of jets is recently proposed a new fast ignition concept [3]. In this concept the ignition is induced by collision of high velocity matter jet, accelerated inside a conical guide, with compressed DT fuel. As a jet source the conical shell illuminated by laser or X-ray radiation is proposed. The attempts to generate jets relevant to astrophysical observations are presented in the papers [4, 5]. The jet-like structures were formed there by collision of ablated flows at the axis of conical targets. Since the jet diameter increases with decreasing atomic number of the irradiated target, the authors suggested that the jet collimation was due to radiative cooling.

Our paper concerns investigations of a plasma jet generation using planar targets and defocused laser beam. On the basis of our earlier experiments [6] we could conclude that a character of plasma expansion has depended on a laser radiation spatial intensity distribution in the focal area. The great opportunity for realization of this aim could be created by the PALS facility due to the peculiar properties of its radiation intensity distributions. The uniform target irradiation by the PALS laser beam is only possible in the case of the first harmonic of the laser radiation (λ_1=1.315 μm) and relatively low laser energy (below 180 J). For higher energies the intensity distributions become concave. In the case of the first harmonic the flat intensity distribution can be ensured by the use of relatively low laser energy. To have the same laser energy of the third harmonic (λ_3=0.438 μm) as that for the first one, the initial energy of the converted laser radiation should be greater about three times. Thus the intensity distribution in the cross-section of the converted beam, due to its high energy, has usually the minimum in the center.

Because of the above properties of the PALS laser, it seemed to be of interest using both harmonics of this laser for generation of axial plasma jets. In our experiment the following target materials: Al, Cu, Ag, Ta and Pb were used. Here only the results for Al, Ag and Ta , representative for all of them, are presented. Targets were irradiated by the iodine laser beam under the following conditions: the laser energy of 100 J for both the harmonics, the focal spot radius of 300 μm with the focal point located inside the targets, and the pulse duration of 400 ps.

To study the plasma expansion a 3-frame interferometric system with automatic image processing was used. The diagnostic system was illuminated by the third harmonic of the iodine laser. The delay between subsequent frames was set to 3 ns.

2. Results of interferometric measurements

The interferometric measurements are presented in the form of electron density distributions at different instants of plasma stream evolution. The measurements with the use of the first harmonic were aimed at comparison of results corresponding to a flat radiation intensity distribution with those for a concave intensity one. As a matter of fact, we expected great qualitative differences between them assuming that the annular target irradiation would be the only reason of the jet production. Some results of our investigations for the first harmonic are presented in Fig. 1a. These results have shown that generation of the plasma jet is possible under these conditions. As distinct from the Al target, for which the plasma stream is found to be wide with round front, in the case of the other ones at the beginning of plasma expansion the sharp top of the plasma stream is formed. At the later instants (5 and 8 ns) forming the plasma jets is observed. The initial velocities of these jets related to the jet border on the electron density level of 10^{18} cm^{-3} and determined on the basis of the axial jet top position after 5 ns are equal to about $4 \cdot 10^7$ cm/s.

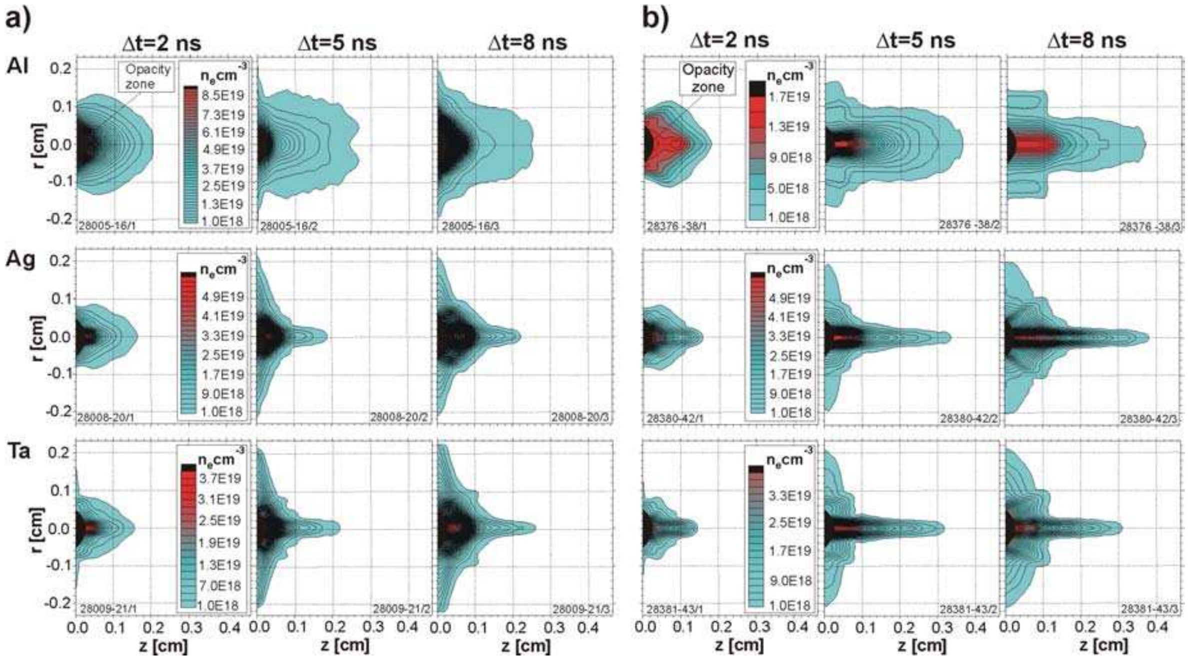

Fig.1. Sequences of electron isodensitograms for different target materials correspond to: a) the first and b) third harmonic of laser radiation.

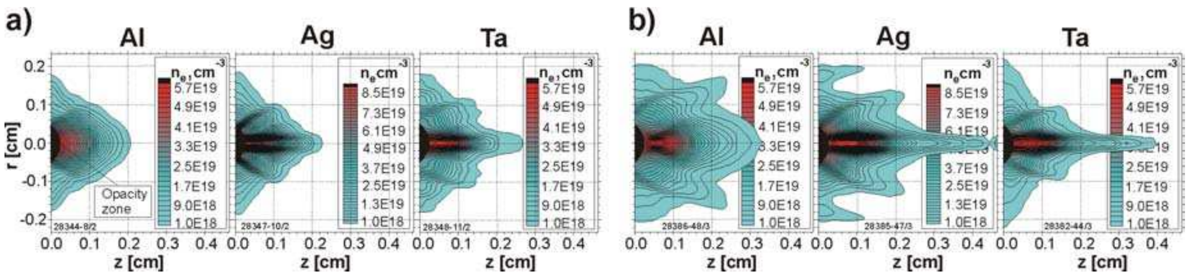

Fig. 2. Electron isodensitograms at Δt=17 ns for different target materials correspond to: a) the first and b) third harmonic of the laser radiation.

Their length and diameter amount approximately to 1 mm and 0.4 mm, respectively.

The use of the third harmonic of iodine laser radiation for plasma generation changes the form of the plasma streams but these modifications have only quantitative character. Generally, the strong elongation of the plasma stream in all the cases is observed (see Fig. 1b). This result is, among other, connected with higher dynamics of the plasma. The initial axial jet velocity, related to the same jet border as that in the former case, for all the targets reaches the maximum value of $7 \cdot 10^7$ cm/s. The length of the jets is approximately equal to 2 mm, i.e. they are twice longer as those for the first harmonic, whereas the jet diameter for both the harmonics proves to be roughly the same (~0.4 mm).

At the later time an increase of the jet length is stopped and process of the plasma jet forming has stationary character. The jet creation lasts longer than our observation period (Δt=17 ns). It can be seen in Fig. 2, where the jets are still very well defined.

3. Conclusions

First of all, we would like to point out, that our intention to produce the plasma jet using target materials with mass density greater as that of Al was realized successfully. The plasma jet parameters in the case of the third harmonic seem to be very promising. The great surprise for us constituted possibility of the jet generation by interaction of the laser beam with a flat distribution of radiation intensity with planar target, as it took place in the case of the first harmonic of the iodine laser beam and target materials with relatively high mass density. It has shown, that the jet production has not geometrical character connected with the annular target irradiation. The more detailed descriptions of the experimental investigations of the jet formation will be presented in the papers [7].

Recently, numerical simulations of plasma dynamics related to the presented experimental results were performed [8]. Preliminary results of their theoretical analysis show that the fast radiative cooling of plasma, which starts before the expansion process, plays a crucial role in the launching and collimation of the jet. In the contrary, it seems that the self-generated magnetic fields play a relatively minor role in these processes.

The work was supported in part by the Association EURATOM-IPPLM (contract No FU06-CT-2004-00081), by the Ministry of Scientific Research and Information Technology in Poland (project No 3 T10B 024 273), and by the Ministry of Schools, Youth and Sports of the Czech Republic (project No LC528).

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