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Characteristics of the plasma jet generated from a joint of materials with different atomic number

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In the paper investigations of ablative plasma configurations for three different target materials (plastic, Al and Cu) and of plasmas generated from joints of plastic-Cu and Al-Cu are presented. The experiment was carried out at the PALS iodine laser system, with the third harmonic beam of the pulse duration of 250 ps (FWHM). The beam energies varied in the range of 75±2 J, the focal spot radius on the target surface was set to 300 μm with the focal point position inside the target. The experiment has shown that the plasma strongly transforms the laser intensity distribution, which, vice versa, results in changing the plasma characteristics. Depending on the target material different ablative plasma configurations can be created. It has been also confirmed that the ring form of the target irradiation profile resulting from the laser beam-plasma interaction is a necessary condition for the plasma jet creation by a single laser beam. In the case of joint targets, remarkable obliquely propagating jet-like plasma outflows were observed.

1. Introduction

Collimated plasma outflows and jets are a subject of interest in the study of astrophysical phenomena, as well as in the context of new fast ignition concepts [1, 2]. Besides, as shown in recent laboratory experiments with high-power lasers, in the multi-shell target geometry the contact surfaces of different materials may induce formation of multiple shocks and, also, of plasma jets [3, 4]. Production of supersonic plasma jets in laboratory conditions becomes, therefore, a highly attractive issue.

Our experimental results [5, 6] demonstrate that if a massive planar target with relatively high atomic number is irradiated with a defocused laser beam the jet formation is a fundamental process accompanying the expansion of the laser produced plasma. Our later investigations [7, 8] have shown that an annular structure of the focal spot is indispensable for formation of a convergent narrow jet. It should be pointed out that the annular target irradiation is created spontaneously during the laser beam – plasma interaction from an initially flat laser radiation distribution, providing that the focal point of a focusing lens is situated inside the target. Since the plasma parameters (dimensions, density distribution, velocity and the like) depend on the target material, the laser beam-plasma interaction as well as the resulting laser intensity distribution differ for different materials.

The differences in the electron density distributions and in the shapes of the craters produced in plastic, Al and Cu targets demonstrated in the first part of this paper prove well the above thesis. Selected results on the plasma jet generation from joints of materials differing considerably in the atomic number (plastic, Al and Cu) are presented in the second part of the paper. The experiment was carried out at the PALS iodine laser system, with the third harmonic beam of the pulse duration of 250 ps (FWHM). The beam energies varied in the range of 75±2 J, the focal spot radius on the target surface was set to 300 μm with the focal point positioned inside the target. For measurements of the plasma jet characteristics (configuration, electron density distribution, velocity and the like) a three frame interferometric system was employed. In order to obtain information about the actual laser intensity distribution on the target surface a thorough analysis of the shape and dimensions of the laser-produced craters was performed.

2. Influence of laser beam-plasma interaction on plasma configuration for different target materials

In Fig. 1 three sequences of electron isodensitograms for target materials with different an atomic number (N), i.e. plastic (N=3.5), Al (N=13) and Cu (N=29), are presented. One can see that the radial size of the plasma plume decreases with the increasing atomic weight of the

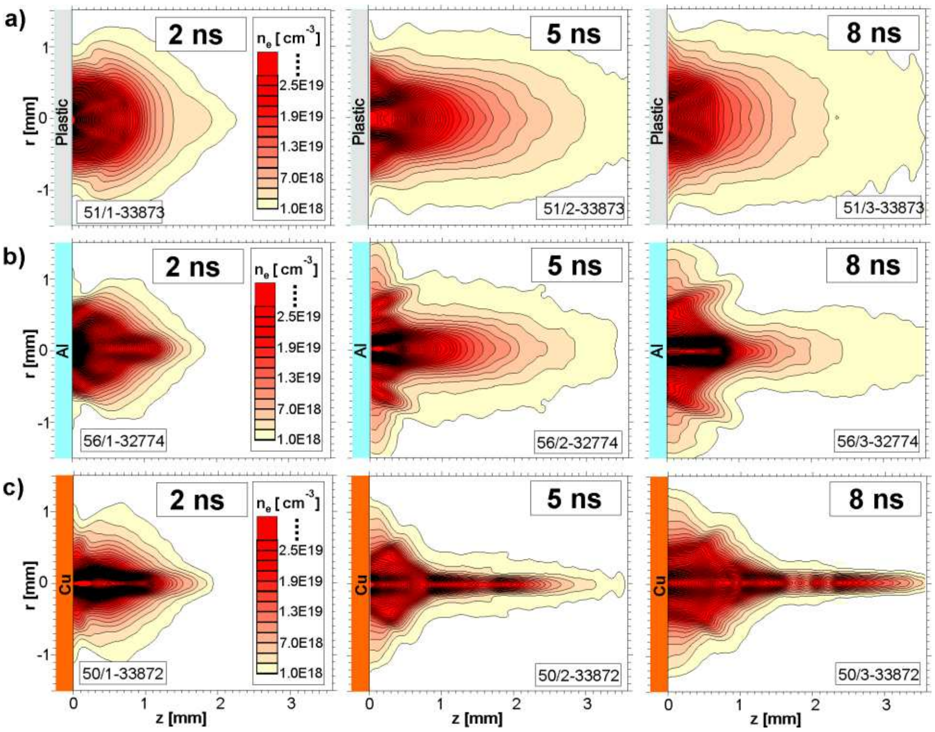

Fig. 1. Sequences of electron equidensitograms of plasma outflow for: a-plastic, b-Al and c-Cu.

target. In the case of Cu target a very narrow plasma structure (plasma jet) is observed. In our opinion, the radial size of the plasma beam in the target vicinity at 2 ns after the laser action corresponds to the radial reach of the laser beam. The main reason of the laser beam intensity transformation is the deflection of laser rays due to gradients of the electron density, which is different for different materials.

The fast plasma of plastics deflects the laser beam farther from the axis than the heavier metallic plasmas. Certain information about the laser intensity distribution can be obtained from the shape of the craters (see Fig. 2). In the case of plastic the crater has a flat shape with a single depth maximum at the axis, whereas the Cu crater is almost semi-toroidal. The shape of Al crater is more complicated. The Al crater depth maximum at the axis results here from a cumulative effect of the semi-toroidal shock wave collapsing at the axis. Without that effect the Al crater should have, in fact, a minimum in the centre. On the basis of the craters shape analysis we can conclude that the plasma strongly transforms the laser intensity, which, vice versa, changes simultaneously the plasma characteristics. We also confirmed that a ring form of the target irradiation is necessary for the plasma jet creation.

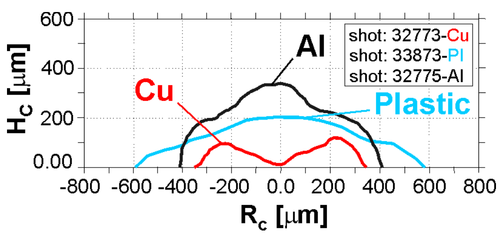

Fig. 2. The crater shapes for different target materials.

3. Plasma jets produced from a joint of different materials

The laser beam action on a joint of materials with different atomic numbers can deliver some interesting information concerning: (i) configuration of the plasma outflow and its properties, (ii) mutual interaction of two different plasma streams, (iii) shock wave propagation and crater creation at the border of two different materials and the like.

The investigations were carried out for the joints of plastic-Cu and Al-Cu. In Fig. 3 two photographs of the craters top views as well as the crater shapes for both the joints are presented. One can see that the craters consist of two independent parts, the dimensions of

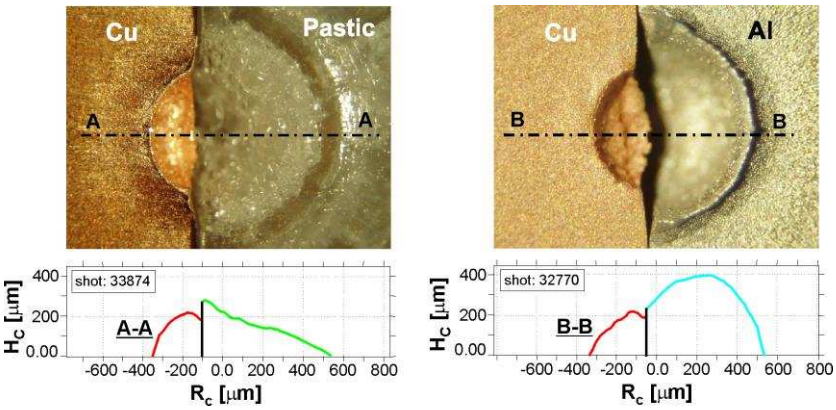

Fig. 3. Photographs of the craters top view and crater shapes for the plastic-Cu and Al-Cu joints.

which correspond to those for each material alone. The forms of plasma outflows for both the joints are illustrated by the sequences of interferograms in Fig. 4.

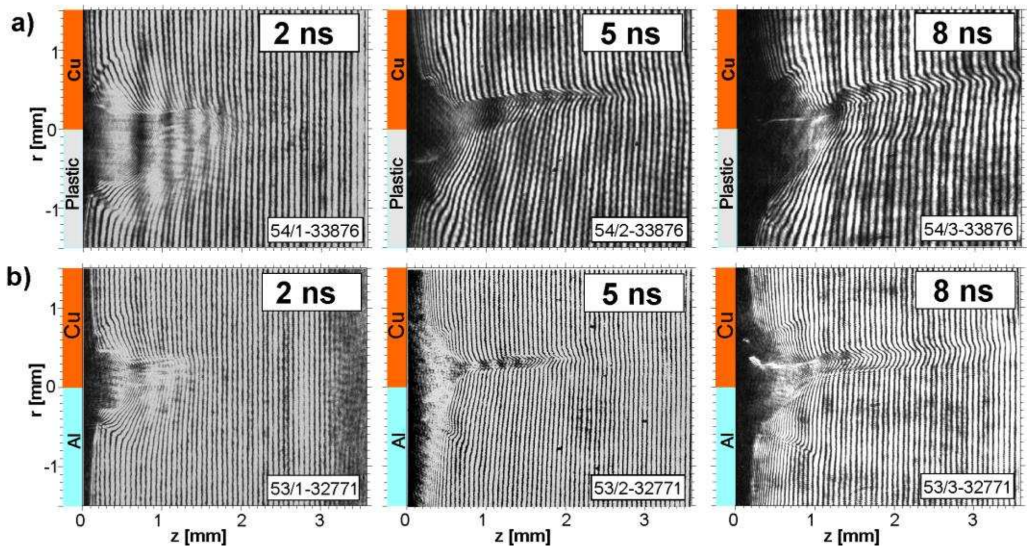

Fig. 4. Sequences of interferograms illustrative of the forms of plasma outflows for the plastic-Cu (a) and Al-Cu (b) joints.

At the beginning of the plasma expansion (t≤5 ns) a difference between both plasmas is clearly seen. Although the Cu plasma constitutes just a part of the whole plasma volume, that plasma amount is sufficient for the plasma jet creation. The other plasma creates a relatively wide structure. Later on, due to mixing of the plasmas, a distinct border of the plastic plasma appears (see the lower part of interferograms at t=8 ns). A very interesting property of the jet-like structure consisting of two plasmas is its oblique propagation. The plasma jets do not propagate normally to the target surface but they are deflected to the side of the heavier material. The angle of deflection is greater for plastic (~10^o) than for Al (~5^o). It means that the lighter is the plasma the higher is the plasma pressure.

4. Discussion of the experimental results and conclusions

Let us discuss the results of the joint-target experiment on the basis of the theoretical analysis of the crater creation in the planar target made of different metals, including Al and Cu, presented in paper [9]. The volumes of Al and Cu crater components of the joint target are, respectively, $1.7 \cdot 10^{-4}$ cm^3 and $3.2 \cdot 10^{-5}$ cm^3. The main reason why the Al crater volume exceeds the Cu crater volume is the fact that the specific melting energy ε for Al is smaller in comparison with that for Cu (ε_{Al}=2686 J/cm^3, ε_{Cu}=5527 J/cm^3), whereas the efficiency of plasma corona energy transformation into the energy of shock wave is, on the contrary, higher (being inversely proportional to the square root of the metal density). The ablation pressure of plasma corona can be expressed as follows [9]: $P \propto \rho_{cr}^{1/3}(K_p I_L)^{2/3}$ ($K_p = E_c/E_L$ is a coefficient of the laser energy transformation into the corona energy and ρ_{cr} is the critical plasma density: $\rho_{cr}=1.83\ 10^{-3}\ A/Z\lambda^2$ g/cm^3, where A and Z are the atomic weight and the charge of ions, respectively). Taking into account the data from the paper [9], i.e. $K_{p(Al)} = 0.47$, $K_{p(Cu)} = 0.31$, and $Z_{Cu}=20$, $Z_{Al}=10$, the pressure of the Al plasma component is a bit larger than the pressure of Cu plasma component: $P_{Al}/P_{Cu} \approx 1.14$. It results in a small (sound) perturbation of lateral velocity in the plasma corona of the joint target directed to the Cu component: $\Delta V/V_{Cu} \approx P_{Al}/P_{Cu} - 1 \approx 0.14$. This evaluation is in a good agreement with interferometric measurements of the non-symmetrical lateral motion of plasma corona in the case of the joint targets which indicate the lateral component of the velocity of Cu plasma, approximately, 0.1 of longitudinal one.

The joint target experiments demonstrate that if the laser pulse is short enough the plasma coronas of the components of joint target conserve their properties due to the differences of laser interaction with different metals, as well as that the shock waves in both the components conserve memory of the properties of their generation and propagation in different materials. The presented here investigations have a preliminary character. It is expected that subsequent experiments with the use of compositions of other materials should allow to launch plasma jets with parameters and propagation directions desirable for various applications.

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