Investigation of interaction of the plasma clouds forming as a result of two laser target irradiation

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ABSTRACT

The results of investigation of two plasma clouds interaction appearing at the laser irradiation of two different targets in background gas atmosphere on the MKV-4 facility of the "Iskra-5" has been described. The experimental data are compared with the results of the theoretical simulation.

Keywords: laser, target, plasma, diagnostics, image converter camera.

1. INTRODUCTION

A laboratory investigation of the plasma clouds interaction dynamics is of interest for solution of some astro- and geophysical problems. In the work [1] we investigated the parameters of the plasma clouds being produced at the laser irradiation of flat and spherical targets in the air at pressure range of (10^{-5}-10^{2}) torr on the MKV-4 facility of the "Iskra-5" [2]. The energy and duration of the laser pulse were 500 J and 0.5 ns, respectively. As a result of "Iskra-5" facility modernization appeared a possibility of double-pulsed irradiation of the targets by different channels of the facility with operated delay between pulses limited by several microseconds that gave the possibility for creation of two plasma clouds interacting with each other. The presence of this instrument allows to study elementary processes determining the interaction of plasma flows and model interaction of supernova explosion remainders with ionized clouds of interstellar gas [3].

In this work the effects accompanying the interaction of two plasma clouds appearing at the laser irradiation of two different targets in background gas atmosphere are investigated. The experimental data are compared with the results of the theoretical simulation.

2. EXPERIMENTAL SETUP

The MKV-4 is a cylindrical vacuum camera (length 1,5m, diameter 1m) provided with pumping and gas filling systems, laser radiation input windows and equipped with a range of optical diagnostics.

The experiments were carried out in the following setup. In the centre of the vacuum camera the hollow thin-walled spherical organic target (CH, $\rho \approx 1.1$ g/cm^3, diameter 4mm, thickness wall 2μm) with 0,8mm diameter hole for laser radiation input into the target was placed. The first laser pulse of the "Iskra-5" facility (energy 350J, duration 0,5ns) was put into the target. On the 5cm distance from this target the plane Al target was placed. Its normal was oriented towards the line of spherical target. The second laser pulse of the "Iskra-5" facility was focused on the target at the spot ≈200 μm diameter. The density flow of laser radiation on the flat target was 4-5×10^{15} W/cm^2. The time between first and second pulses on the target was ≈6.2 μs. The pressure of background air in the camera ≈10^{-2} torr.

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As a result after incoming of the first laser pulse the spherical plasma cloud is formed. The plasma extends in background air atmosphere. The second laser pulse forms a plasma stream from flat target which spreads through spherical plasma cloud.
Figure 1 shows the scheme of the experiment.

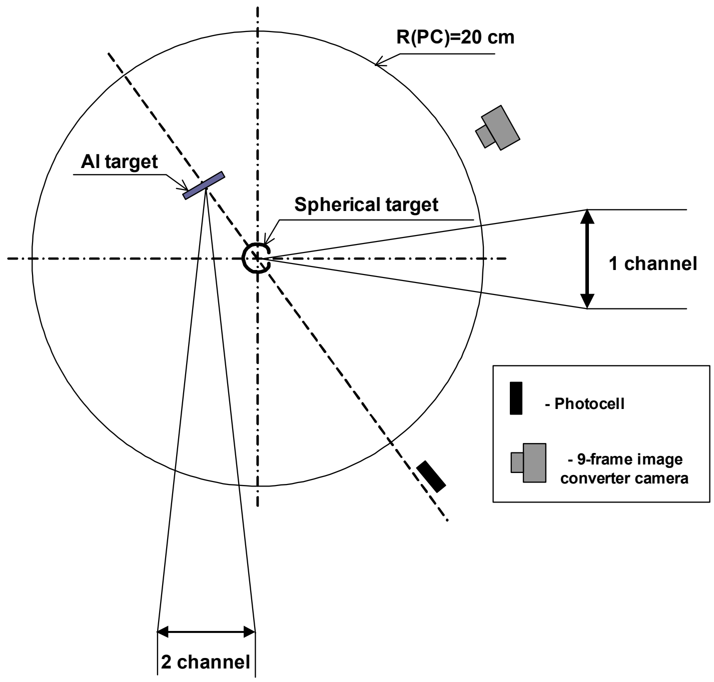

Fig.1 Scheme of the experiment.

During the experiments the record of the dependency of plasma glow intensity in the visible range from time as well as regular shooting of the glow plasma clouds.
1. The dependency of plasma glow intensity in the visible range from time was measured by photocell SDF7 [1].
2. The K011 miniature programmable 9-frame image converter camera [4] was used for optical diagnostics in spectral range 400 – 800 nm. This camera provided independence duration of each frame and each interframe pause from 0.1 up to 102.4 μs with 0.1 μs step. The shooting was recorded towards the line laser radiation input into the spherical target (along of the camera axis).

3. NUMERICAL MODEL

The calculations presented in this work had the following goals:
a) To reproduce observed in the experiment dynamics and plasma flows glow for every target in particular.
b) To give the treatment of the optical effects appearing with the influence of radiation on each target from the other target as well as with the collision of plasma flows from different targets.
This led to the range of one- and two-dimensional calculations.
One-dimensional calculations were carried out with SNDP method [5]. The following physical processes were considered: dual-temperature gas dynamics, electron-ion relaxation, spectral x-ray radiation transfer and its interaction with substance, electron and ion heat conductivity. The environment nonequilibrium and laser pulse absorption were calculated according to average ion model [5].
Two-dimensional calculations of the flat target plasma dispersion and its interaction with plasma of the spherical target were carried out by “DMK” numerical method [6]. In that method the gas dynamic equations in the Lagrange’s variables on the irregular meshes are solved. The initial data for these calculations was taken from one-dimensional calculations

carried out by SNDP method for plane problem concerning flat target dispersion. The calculations for dispersion of Al in vacuum were carried out as well as in the plasma cloud of the spherical target. Using plasma motion data and its parameters the brightness of its glowing region was calculated. These calculations were carried out in optically thin body approximation, which emitting possibility was estimated in Kramers' approximation and ionization degree in "effective ion" model by Yu.P.Raizer [7].

4. EXPERIMENTAL AND CALCULATION RESULTS

Fig.2 shows regular shooting of the plasma cloud glow appearing at the double-pulsed irradiation of spherical and flat targets. Time delay of the second pulse relatively to the first pulse was 6.2μs.

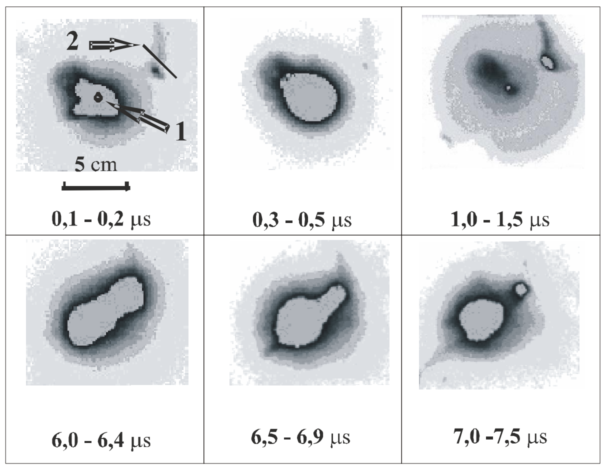

Fig. 2. Plasma clouds glow of spherical and flat targets. 1 – the centre of spherical target, 2 – position of flat target.

On the first frame except the creation process of the spherical target plasma cloud the flat target glow caused by spherical target irradiation is observed. On the second frame the flat target glow stopped. By the time of the third frame the spherical target plasma arrives to the flat one and its glow is observed again. By the time of 6μs the spherical target plasma cloud glow fully stops (not indicated on the figure). The exposition of the fourth frame (fig.2) begins about 0,2μs prior to the second pulse incoming on the flat target. The glowing of both flat target and plasma region of spherical target is observed. On the following two frames the further development process of the flat target plasma clouds as a stream and plasma interaction of flat and spherical targets is observed.

The fig.3 shows r-t diagram of region border movement of the spherical target glow obtained from fig.2 data and one-dimensional calculation with SNDP method.

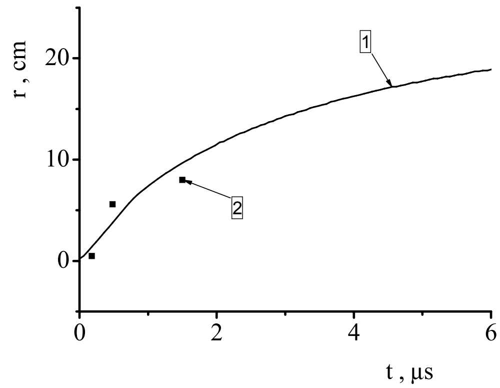

Fig3. r-t diagrams of region border of the spherical target glow. 1 – calculation, 2 – experiment.

On the fig.4-6 the dependencies of intensity of plasma cloud glow from time in the spectral range 0.4μm for different regimes irradiation of the targets are shown.

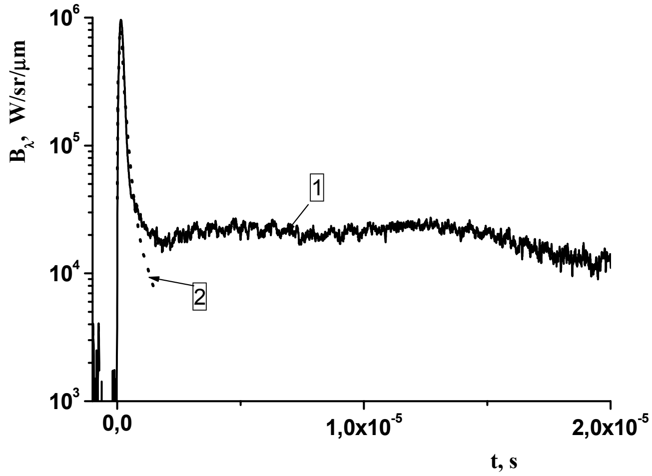

Fig.4 Dependency of radiation intensity of spherical target from time for the 0.4 μm spectral range. 1 – experiment, 2 – one-dimensional calculation.

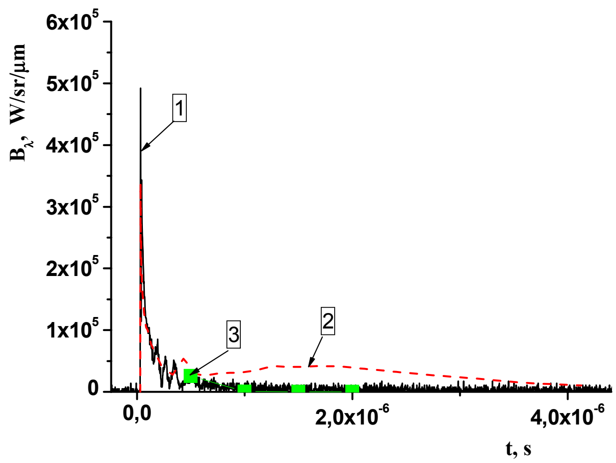

Fig.5 Dependency of radiation intensity of flat target from time for 0.4 µm spectral range. 1 – experiment, 2 – one-dimensional calculation, 3 – two-dimensional calculation.

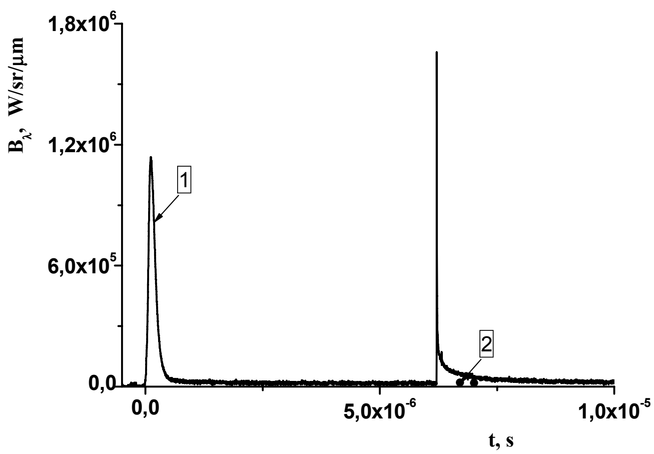

Fig.6 Dependency of radiation intensity of flat and spherical targets from time for 0.4 µm spectral range at double-pulsed irradiation mode. 1 – experiment, 2 – two-dimensional calculation.

The fig.7 shows the result of two-dimensional calculation of flat target luminosity when it disperses into plasma formed at the irradiation of spherical target in 0,5µs time. The radiation stream was calculated for spectral range 0,3 - 0,7µm. On the bitmap there is a color intensity scale. In the optically thick body approximation the bitmap area integral gives full power of the plasma stream radiation in the concerned spectral range.

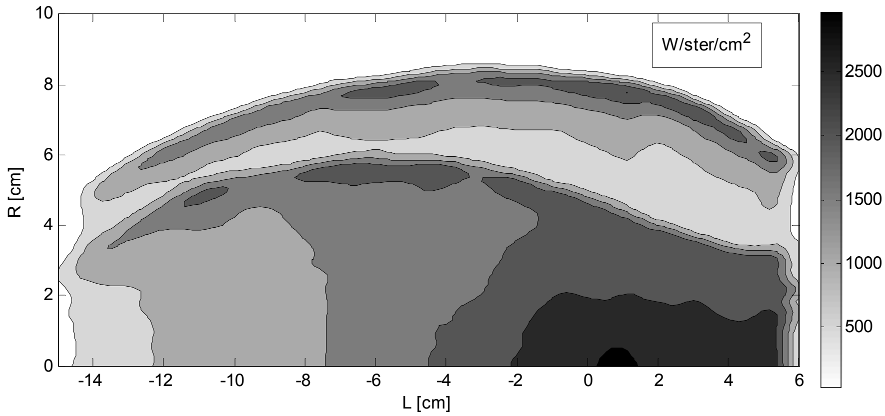

Fig.7 The two-dimensional calculation of flat target luminosity at its dispersion into background plasma of spherical target (at 0.5µs).

The quantitative characteristics of sizes and their comparison with experimental data (fig.2) are shown in the table.

Parameter	Theory	Experiment
R cm	8	7,5
L cm	12	10

Here: R – maximum cross size of the glowing region, L – region length.

5. CONCLUSIONS

As a result of investigation of two plasma clouds interaction appearing at the laser irradiation of two different targets in background gas atmosphere we found out:

The interaction of plasma clouds of flat and spherical targets conclude in following: at plasma dispersion of flat target in the presence of spherical target background plasma in spite of its smaller density significant increase of glowing region and more slow dimming in comparison with dispersion into vacuum is observed.

The optical observation data for spherical target is in the quantitative agreement with corresponding one-dimensional calculation. The observation data of flat target dispersion both in the mono- and in the double-pulse irradiation regime in qualitative manner agree with two-dimensional results.

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