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Optical investigation of flyer disk acceleration and collision with massive target on the PALS laser facility

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1. Introduction

Experiments with the use of flyer-impact configuration can provide information necessary for research work in the domain of complex configuration such as implosion experiments with spherical targets on which the idea of laser fusion is based. The experiments utilizing ablatively accelerated planar target can model large pellet shells in their early implosion phase. The main scientific areas addressed at the thin flyer foil experiments are usually laser radiation absorption, generation of ablation pressure and shock wave, hydrodynamic efficiency, energy transfer, laser pulse uniformity requirements etc. [e.g. 1-3]. Besides, this technique is very useful for generation of extremely high pressure of a few hundreds Gbar in a planar shock [4, 5].

Our paper is devoted interferometric investigation of processes: ablative acceleration of a 6 μm Al flyer disk, its collision with Al massive target, and, finally, crater creation. Relative efficiency of energy transfer from a laser beam into the disk was to be found on the basis of measurement of crater parameters. Discussion of the experimental results on the basis of the 2-D theoretical model [6] was performed.

1. Experimental set-up

The experiment was carried out with the use of the PALS laser facility in Prague. The plasma was generated by the first harmonic of the iodine laser beam (λ=1.315 μm) with energy of 130 J, focal spot diameter of 250 μm, and pulse duration (FWHM) of 400 ps. Intensity distributions in the laser beam cross-section, recorded by the CCD camera, characterized very high homogeneity. In the experiment the double targets made of Al consisting of the flyer disk (6 μm thick), placed before the slab at distances L=200 and 500 μm, were employed. The double targets with the gap of 500 μm were only used for the accelerated disk velocity determination. The disks distant 200 μm were held by 10 μm diameter carbon fibers, whereas the others were attached to a supporting 2.5 μm thick mylar foil.

To study the plasma expansion and disk acceleration, a 3-frame interferometric system with automatic image processing was employed. The delay between the frames was 3 ns, so the interferometric measurement during a single shot covered a period of 6 ns only. To extend our observation period, interferogram sequences from different shots were sewed together. The maximum possible delay of the interferometric measurement related to the heating laser pulse reached 23 ns.

3. Experimental results

One of the most important problems connected with the crater creation by very fast macroparticles is determination of their velocities at the impact moment. The detailed investigation of the disk motion has shown that the disks start moving about 2 ns after the laser action. The average disk velocity is equal to $(6\pm0.2)\cdot10^6$ cm/s.

Taking into account both the disk motion delay and the disk velocity measured, the distance of 200 μm, which was essential in our investigations, should be reached by the disk after about 6 ns from the laser beam action. Thus the sequence of the first three isodensitograms (Δt=2, 5, and 8 ns, Fig. 1) should rather well illustrate the first stage of the investigated phenomena, starting from the laser beam action, and finishing with the disk impact. Because of a strong action of X-ray radiation on the massive target in the case of the 200 μm distance, interferograms in the slit between the disk and the massive target were completely illegible. Therefore the presented electron density distributions start from the disk surface, taken here as z=0. The characteristic property of $n_e(z)$ distributions at Δt=5 and 8 ns is found to be a shift of their maximum out of the initial position of the disk surfaces due to the disk motion contrary to the plasma expansion. Although the disk impact takes place after about 6 ns from the laser action, its consequences are seen after next several ns. The moment of 11 ns corresponds likely to a decay of the ablative plasma. The sequence of subsequent isodensitograms of the electron density shows an evolution of the disk produced plasma. The plasma as a whole consists of two independent parts: (1) the axial stream, with diameter of about 500 μm, as a result of a direct disk action and (2) the lateral plasma, with diameter of about 3 mm, as a by-product of different hydrodynamic and plasma processes. If in the case of the ablative plasma a participation of such the lateral plasma was relatively small due to its low density (electron density on the level of 10^{18} cm^{-3}), here, because of the electron density of the lateral plasma even exceeded 10^{19} cm^{-3}, the participation of this plasma in the whole one reaches 90 %. The other difference, related to the ablative plasma, is connected with generation of the axially directed plasma stream. The velocity of the plasma stream with respect to relatively dense plasma ($n_e > 10^{19}$ cm^{-3}) is equal to about 10^7 cm/s. The maximum electron density in the plasma stream is close to $3{\cdot}10^{19}$ cm^{-3}.

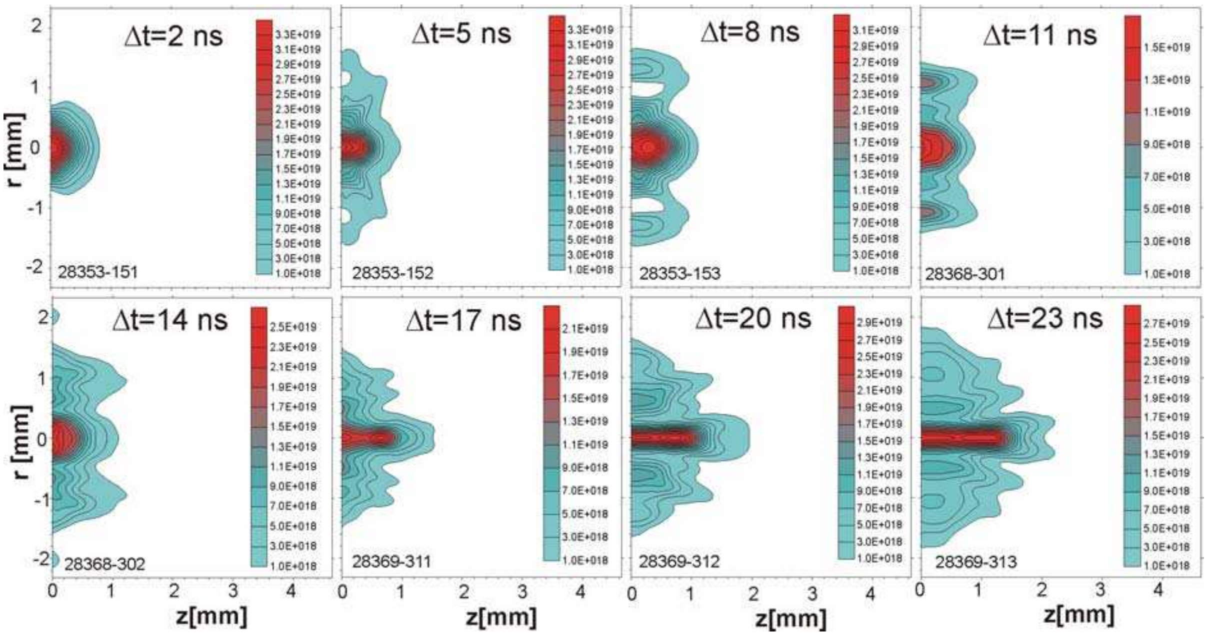

Figure 1: Sequence of the electron density isodensitograms.

Information about crater parameters was obtained by means of crater replica technique. In Fig. 2 the typical profiles of the craters obtained by the impact of the disks and, for comparison, by the direct laser action with the same focal spot diameter, in two perpendicular projections, are shown.

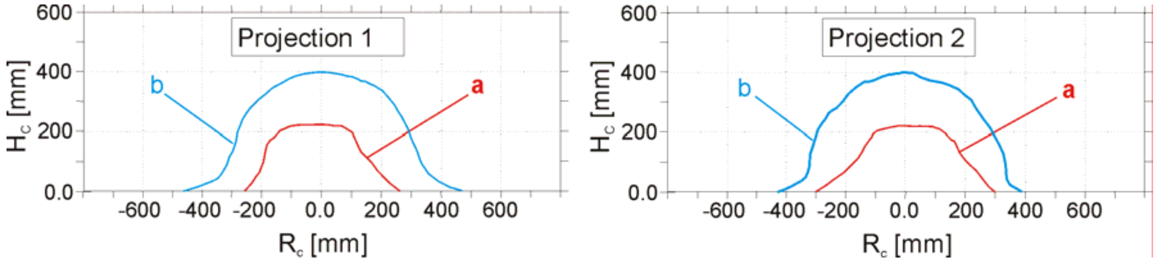

Fig. 2. Crater shapes and dimensions for the disk (a) and direct laser action (b) in two perpendicular projections.

The volumes of the craters presented here amount to: $1.83{\cdot}10^{-5}$ cm^3 for the disk and $1.05{\cdot}10^{-4}$ cm^3 for the direct laser action. The essential differences between the disk produced craters and the craters produced by direct laser action concern both the crater shape and the crater volume. Whereas the direct laser action produced crater has a hemispherical shape, the disk produced crater shape is close to a trapezium, where the shorter side of which constitutes the crater bottom.

2. Theoretical analysis of the experimental results

During the period of the laser pulse duration laser radiation is absorbed in the expanding plasma. For the laser intensities of an order of 10^{15} W/cm^2, used in our experiment, the laser energy is absorbed by electrons mainly due to the inverse bremsstrahlung mechanism. At these intensities a contribution of the resonant and parametric mechanisms into the absorption efficiency is rather small and amounts to several percents. The crater volume depends on the efficiency of the laser energy transfer into a shock wave propagating in the unevaporated part of the solid target. This is characterized by the efficiency of laser-driven loading defined as the ratio of the shock wave energy to the laser energy. In the case of a double target, the disk impact constitutes an additional process of energy transformation, and the crater volume also depends on the energy transfer efficiency during collision of the disk with the massive target. The efficiency of laser-driven loading for both the cases, taking into account a 2D–expanding plasma stream, is equal to 0.0078. The energy transfer efficiency from the disk to the massive target was calculated to be equal to 0.59. Our further calculations allowed to conclude that the theoretical crater volumes will be close to the experimental ones if the laser absorption efficiency equals 0.5.

3. Conclusions

Our investigations have shown the essential differences between processes of plasma expansion and crater creation during the direct and indirect laser action. It was demonstrated, that the disk produced crater efficiency is less a few times as that of the direct laser action.

Literature:

1. B.H. Ripin et al., Phys. Fluids, 23, 1012 (1980).
2. K.Eidmann et al., Phys. Rev., A 30, 2568 (1984).
3. N.G. Basov, S.Yu. Gus'kov, L.P. Feokistov, J. Soviet Laser Research 13, 396 (1992).
4. R. Fabbro, B. Faral, J. Virmont, H. Pepin, F. Cottet, and J.P. Romain, Laser Part. Beams 4, 413 (1983).
5. R. Cauble, D.W. Phillion, T.J. Hoover, N.C. Holmes, J.D. Kilkenny, and R.W. Lee, Physical Review Letters, 70, 2102 (1993).
6. S.Yu. Gus'kov, et al., Quantum Electronics 34, 989(2004).