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Numerical modelling of strong shock waves and craters for the experiments using single and double solid targets irradiated by high power iodine laser (PALS)

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1. Introduction

Thin foil targets ablatively accelerated by laser provide a unique and very useful method for obtaining very fast (> 10^7cm/s) macroparticles [1]. It is the reason to treat this method as a fundamental one on the way of achieving laser fusion. This method may be also used to investigate many problems of laser plasma physics such as the energy transfer, the generation of very strong pressures and shock waves, crater production and so on. Some of them can also be applied for practical purposes (e.g. for modifications of physical properties of materials, diamond production and others).

In this paper we analyze some investigation results of efficiency of macroparticle acceleration and crater creation processes that correspond to our experiments [2-4] performed on PALS (Prague Asterix Laser System). These experiments were carried out for two laser wavelengths of 0.438 and 1.313 μm respectively. Two types of planar Al solid targets were applied: the single massive target and the double target consisting of the foil (thickness of 6 μm) placed before the massive target at the distances of 200 or 500 μm. Targets were irradiated by the iodine laser beam: E_L=130 J, the focal spot diameter of 250 μm, and the pulse duration of 0.4 ns. Velocities of the accelerated macroparticles were determined by means of a 3-frame interferometry. Shape and volume of craters were obtained employing the crater replica technology and microscopy measurement.

In the experiments performed on PALS it was found (as one could expect) that the dynamics of the foil acceleration and crater creation process strongly depended on the laser light wavelength (the accelerated foil velocity and the crater volume grow for the shorter wavelength). For the experimental conditions mentioned above it was measured that the same foil irradiated by 3ω iodine laser light reached velocity two and a half times higher comparing to the first harmonic where as the crater volume was even five times bigger for 3ω case.

We used two-dimensional Lagrangian hydrodynamic code ATLANT-HE [5] to analyse and interpret the results of PALS experiments. These simulations confirmed a strong dependence of the acceleration process dynamics and crater creation on the laser light wavelength observed in the real experiment and gave us the possibility of watching some other processes (laser light absorption, heat conduction, ablation pressure and shock wave generation) for different laser light wavelengths applied in such experiment. Having in mind the main goal of these simulations i.e. to obtain a good agreement with experimental measurements we have to say that the numerical results (acceleration foil velocities and crater volumes) showed rather big discrepancies (up to 50%) comparing to the experimental ones. It was the reason of introducing of a flux inhibition mechanism in the electron heat conduction module of the 2D hydrodynamic code used in our simulations.

2. Flux-limited heat flow influence on the foil acceleration and crater formation process

Assuming "classical" (Spitzer's) non-limited form of heat conduction [6] in plasma we have got some inaccuracies in comparison with data obtained in our experiment. It was the reason of introducing a flux limitation for the electrons, which is important for an electron temperature gradient length comparable with the electron mean free path. The maximum electron heat flux q_{max} is usually written as $q_{max} = fn_e kT_e[kT_e/m_e]^{1/2}$, where f is a free parameter introduced to obtain a better accordance between the experimental and numerical results. Such mechanism reduces the values of the essential plasma parameters characterizing the foil acceleration process (ablation depth and pressure, velocity of the accelerated foil, hydrodynamic efficiency of the energy transfer to the accelerated foil).

Fig. 1a illustrates the f influence on the chosen plasma parameters for 3ω case at t = 0 (maximum of the laser pulse intensity). In the range of f decreasing from 1.0 to 0.01 $T_{e,max}$ increases from 2.9 keV to 5.1 keV but m, which is the fraction of mass ablated from the target, decreases from 0.43 to 0.09 and u (velocity of the accelerated foil) decreases from $1.5\cdot10^7$ to $0.3\cdot10^7$ cm/s. From our simulations and from the comparison with the experimental data we came to conclusion that the "good value" of f factor should be equal 0.03 and this value was taken in our calculations. Some results of our numerical simulations performed for the experimental conditions mentioned above (for f = 0.03) are presented in Figs 1a, 1b and

Fig. 2. In Fig. 1b and Fig.1c we compare the maximum and averaged velocities and the kinetic energy of the accelerated foil fragment for the first and third harmonics of the iodine laser. These velocities were calculated in the absence of the massive part of the double target and could be compared with those obtained in the experiment.

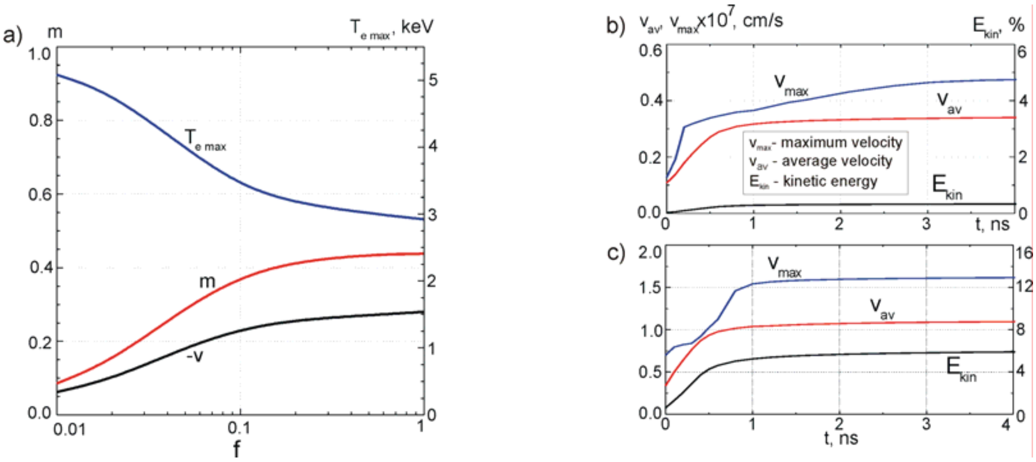

Figure: 1 The results of the simulation: a) the f factor influence on the plasma parameters, b) v_{max}, v_{av} and E_{kin} of accelerated foil fragment calculated for 1-harmonic, c) v_{max}, v_{av} and E_{kin} of accelerated foil fragment calculated for 3-harmonic.

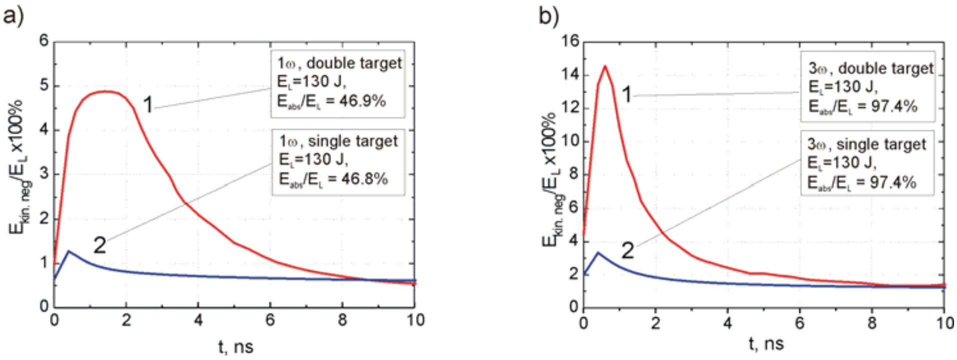

Fig. 2 The efficiency of the energy transfer of the absorbed laser light for the double target (1) and the single massive target (2) relatively to the incident energy of the laser pulse; a) - results calculated for the first harmonic, b) – for the third harmonic.

In Fig. 2a we show efficiency of the energy transfer of the total absorbed laser light (λ_1) for the double target (1) and the single massive target (2) relatively to the incident energy of the laser pulse. For both cases we have practically the same absorption (~47%). In the case of the double target we have a maximum of this transfer on the level of 1.3%. It characterises the kinetic energy of the accelerated (moving in the direction of the massive target) part of foil. After collision with the massive part of the double target it decreases to 0.6% level and it determines the energy behind the front of the shock wave propagating in the massive target. In the case of the single massive target (2) the efficiency of the direct transfer of the absorbed laser energy to the shock wave is on the similar (a little higher) level. The same comparison we also made for 3 ω laser light (Fig. 2b). The energy transfer of the laser light to the target is much more efficient in this case.

3. Comparison with experimental results

The comparison of the experimental velocity ($v_{\lambda 1} \cong 0.6 \cdot 10^7$ cm/s and $v_{\lambda 3} \cong 1.5 \cdot 10^7$cm/s) with these obtained in our simulations (see Figs 1b, 1c) shows that they are very close.

Table 1: The set of average crater volumes for double target and two wavelengths.

	Crater volume [cm^3]	
	Experiment	Simulation
First harmonic (1ω)	$0{,}64 \cdot 10^{-4}$	$0.66 \cdot 10^{-4}$
Third harmonic (3ω)	$3.31 \cdot 10^{-4}$	$2.82 \cdot 10^{-4}$

In Table 1 we compare crater volumes for the double targets and two wavelengths that were calculated in 2D numerical simulation with those obtained from the experiment on PALS. The above table clearly shows that there is a very strong dependence of the crater volume on the laser wavelength (the efficiency of crater creation grows very strongly with a decrease of the wavelength of the laser beam). The craters obtained experimentally for the double target and the same laser parameters as those taken in numerically modelled experiments show a quite good overlapping of the crater contours obtained experimentally and numerically in our experiment. The diameters of the craters were almost the same. Some differences were observed for the crater depths. The crater volume discrepancy can be explained by the simple equation of state (perfect gas) used in 2D code ATLANT-HE. Nevertheless within the framework of these crude assumptions the calculated crater volumes were turned out to be close enough to the experimental ones.

4. Summary and conclusions

In this work we presented some results of numerical modelling of the dynamics of the shock wave generation and crater formation process in the ablatively accelerated planar double targets. We observed much more dynamical behaviour of the plasma produced in the experiment with the third harmonic of the iodine laser applied (the higher velocities of accelerated foil fragments, the bigger craters) as well as the strong influence of the form of heat conduction on the results of simulation. The value of flux limiting factor can strongly modify plasma parameters and properly chosen allows obtaining much better agreement with experimental results.

References:

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