Alternative efficient methods of dense plasma objects acceleration to high velocities

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Abstract

Numerical modelling of dense plasma objects acceleration was performed. In these investigations a scheme called "cavity pressure acceleration" (CPA) was applied, which allows propelling plasma objects in arbitrary direction in relation to laser beam incident on a target and more efficient absorption of laser pulse energy. Those calculations complement previously performed experiments on the PALS system, in which results of acceleration of dense plasma objects (average speed obtained for 20 μm polystyrene and 10 μm Al targets was ~ $6x10^7$ cm/s) were at the level of the top global results.

Numerical calculations were made for two different laser wavelengths: λ = 1.315 μm (iodine laser) and λ = 0,248 μm (KrF laser). For the "classic" i.e. ablative drive scheme, the advantage of using a short wavelength laser is obvious. Velocities obtained in this variant are two – two and a half times higher than in the case of using a laser with several times longer wave. Numerical calculations, as well as previous experiments on the PALS system, show that the use of "non-classic" drive schemes enables comparable, very good results to be obtained also with lasers of longer wavelength.

Introduction

Recent investigations in the field of laser fusion indicate that the basic problem that determines the success of this method is the possession of an appropriately efficient technically optimized short-wave laser. The use of a laser with a short wavelength guarantees deeper penetration (higher critical density) of the laser radiation inside the driven target, and thus its greater absorption and higher efficiency of the acceleration process. A good candidate for today seems to be, for example, a KrF laser (λ = 0.248 μm). Results achieved in acceleration of foil targets, regarding their use in impact fusion and shock ignition experiments, are today the world's leading [1]. Therefore, it seems reasonable that experimental results obtained in other plasma laboratories, with help of other laser systems, as well as results of numerical modeling of these kinds of experiments, should be compared with those obtained with such laser. The problem that we want to analyze and the question we want to answer can be defined as follows: it is possible to accelerate targets equally efficiently if we apply lasers with significantly longer wavelength, for example an iodine laser and what methods should be used to reduce or even eliminate this short-wave laser advantage? Partial (positive) answer to such question has already yielded the results of

previous experiments on PALS where the so called cavity pressure acceleration (CPA) method was applied [2 - 4]. The CPA method uses targets that are essentially laser energy traps and it allows propelling plasma objects in arbitrary direction in relation to the laser beam incident on a target. Two different ways of acceleration were investigated to obtain superfast and dense plasma objects: forward acceleration scheme (FAS) and reverse acceleration scheme (RAS). CPA method leads to significantly higher velocities of flyer foils than those obtained in traditional way (ablative acceleration scheme) in similar experimental conditions. The best results for BACKWARD acceleration experiment obtained for 20 μm polystyrene (PS) foil gave value of average speed on the level of ~ 6 x 10^7 cm/s [4] i.e. were on the level of the world top velocities (NRL Washington, ILE Osaka) [1, 5].
This work aims to analyze the problem by using the numerical simulation method. In the numerical calculations presented below, modeling experiments performed on the PALS system, the KrF laser was chosen as the reference point, with identical laser pulse parameters (intensity, shape and duration time) as in the case of the iodine laser of PALS.

Dependence of the acceleration process on the wavelength of absorbed laser radiation
Recently, some numerical calculations were performed to check the results of our earlier experiments. These calculations were made using the KAROL program [6]. This hydrodynamic program, taking into account significant physical processes affecting the acceleration process - was used in two versions: one- and two-dimensional. In this work, three variants of acceleration were considered, which are presented in a simple way in Fig. 1.

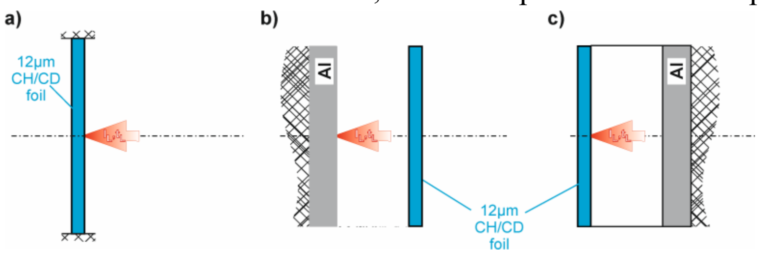

Fig. 1. Geometric variants of simulated cases of thin foil acceleration: a) classic ablative method, b) and c) CPA methods (of *reversed* RAS and *forward* FAS schemes respectively).

The main purpose of these calculations was to obtain confirmation of the sensibility and effectiveness of the CPA methods (Fig.1b and 1c) in comparison with the classic ablative variant of acceleration of thin foil targets (Fig.1a). A numerical modelling experiment was carried out, in which a thin foil made of polystyrene (PS) with a density of 1.18 g/cm^3 and thickness of 12 μm was irradiated with an iodine laser pulse (Gaussian shape, λ_l = 1.315 μm), time duration τ = 300 ps and intensity I_l = 3x10^{15} W/cm^2. An example of numerical simulation (RAS variant) using 2D code is shown in Fig. 2.

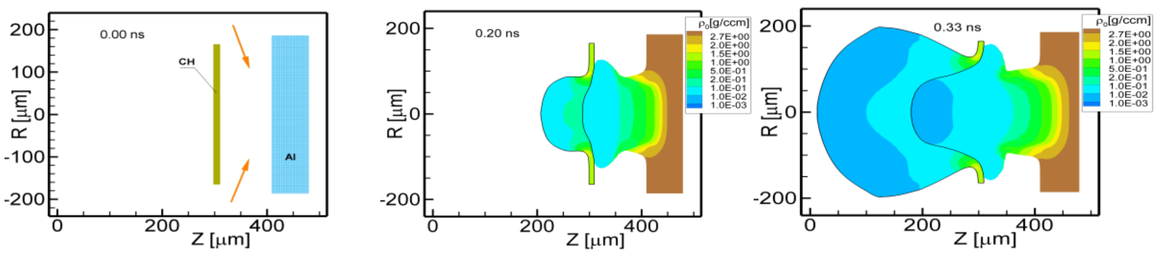

Fig. 2. Results of numerical modelling. Density profiles for three different moments of time.

Laser beam irradiates the massive part of the target. Expanding plasma, as well as a part of the reflected radiation of the laser beam, interacts with the foil and accelerates it.

The main part of the calculations was made using the 1D version of the KAROL program [6]. In order to determine the effect of the wavelength of the laser radiation applied on the course and results of such an experiment, appropriate calculations for another variant were made, using the same initial parameters (same foil, same intensity and pulse shape) but much shorter wavelength λ_l = 0.248 mm (KrF laser). The results for the analyzed variants are summarized in Fig. 3 – Fig. 5. As a criterion, in terms of usefulness and efficiency of driving foil targets, the parameters of the whole fragment of the target driven by the laser in the chosen direction were taken. These are: the kinetic energy of the dense part of the foil driven in the chosen direction E_{kin}, its relative mass m/m_0, average velocity <v> and relative mass density $<\rho/\rho_o>$. In every case (scheme of acceleration) the same parameters of the laser pulse ($I_l = 3x10^{15}$ W/cm^2, τ_l= 300ps, λ_1 = 1.315 µm and λ_2 = 0.248 µm) and accelerated CH foil targets – 12 µm (additionally 20 µm for KrF laser and classic scheme and 6 µm for RAS and iodine laser) were taken. Fig. 3 shows the results for the classic variant.

a) b)

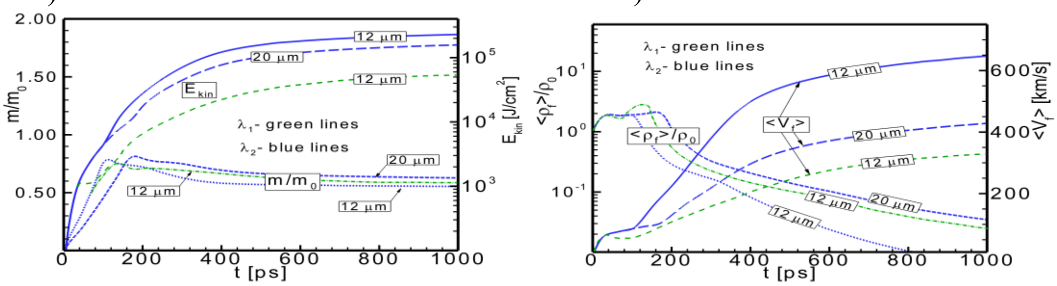

Fig. 3. Results of: a) E_{kin} and m/m_0 for iodine laser (green line) and KrF laser (blue line), b) <v> and $<\rho/\rho_o>$. Classic acceleration scheme applied.

It is clearly visible that the KrF laser is much more efficient. The kinetic energy of the target's fragment is about five times greater than in the case when an iodine laser is used. On the other hand - there are no significant differences for the masses of driven foil fragments. The average velocity of the KrF laser-driven foil fragment is twice as high as in the case of an iodine laser. In turn, for the KrF laser, due to the greater dynamics of the process, density decreases faster. For comparison, the graph also shows a 20µm foil acceleration variant using the KrF laser. For obvious reasons, the speed of the driven foil is now much lower (by 1/3).

a) b)

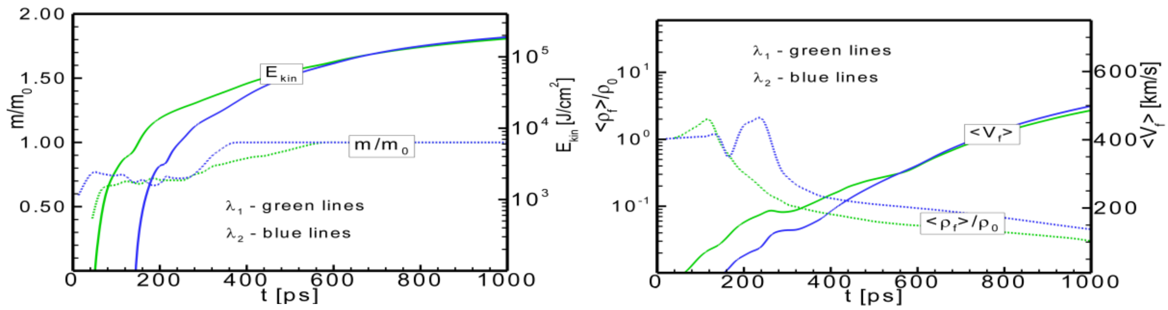

Fig. 4. RAS results of E_{kin} and m/m_0 for iodine laser (green line) and KrF laser (blue line).

The situation changes completely when RAS method is applied, as presented in Fig. 4. Kinetic energy values are very high and close to those obtained earlier for the classic variant and the KrF laser applied. Now, a slightly more efficient RAS variant seems to be the one with use of iodine laser. Velocities are also very similar for both lasers, although they are clearly lower than it was before for the classic variant and the KrF laser used (650 km/s vs. 500 km/s). A positive feature of this method of driving is the clearly slower diminishing density of the foil. In the second part of the observed acceleration process, driven relative masses m/m_0 are identical for both RAS variants, but they are twice as large when compared to the classic case. Very interesting situation occurs, when we change the construction of the target in such a way that the bottom of the cavity is made of light material. Fig. 5. shows the results for the RAS variant and iodine laser which irradiates the massive Al target with a 20 μm PS-layer. Two different accelerated foils (6 μm and 12 μm thick) were applied.

a) b)

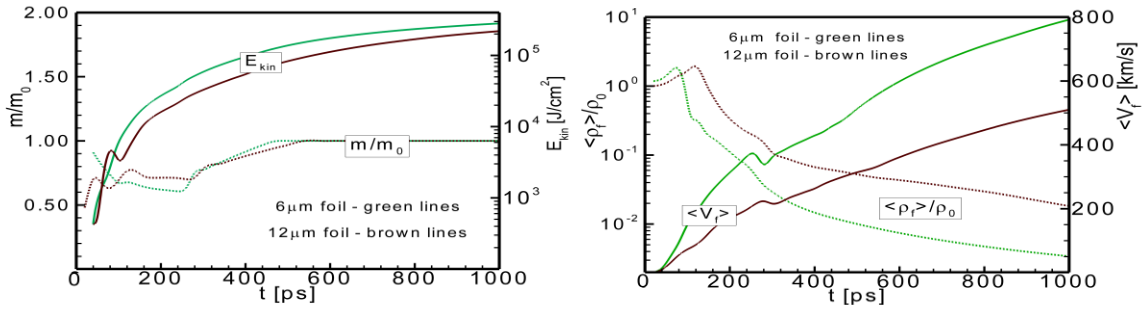

Fig. 5. Results of: a) E_{kin} and m/m_0, b) <v> and <ρ/ρ_0>, for iodine laser. Two "PS - PS" variants: 6 μm thick foil (green lines) and 12 μm thick foil (brown lines). RAS acceleration scheme applied.

It is clearly visible that very high E_{kin} values are obtained for both variants. The average velocity of the driven part of the target is also high, and for the 6 μm foil it is even record-breaking, considering the tested options.

Conclusion

The use of the alternative non-classic acceleration methods (CPA) makes it possible to obtain the speed of accelerated plasma objects, the kinetic energy of the dense part of the foil driven in the chosen direction and the hydrodynamic efficiency of such processes at a high level and the results are not sensitive to the laser light wavelength. What does it mean? Lasers with a longer wavelength (e.g. iodine laser) can also be used to achieve interesting results in acceleration experiments. These results do not differ significantly from those that until now were possible to obtain only for short-wave lasers, for example KrF laser.

References

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