

Experimental study of Fast electron Propagation with Cone-targets

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Abstract : One of the main issues of the fast ignitor scheme is the role of fast electron transport in the solid fuel heating. Recent experiments used a new target scheme based on the use of cone to guide the PW laser and enhance the electron production. In this context it is fundamental to understand the physics underlying this new target scheme. We report here recent and preliminary results of ultra-intense laser pulse interaction with three layer targets in presence of the cone. Experiments have been performed at LULI with the 100 TW laser, at intensities up to $3 \cdot 10^{19}$ W/cm². Several diagnostics have been implemented (2D K α imaging, K α spectroscopy and rear side imaging, protons emission) to quantify the cone effect.

Introduction

Cone targets have been recently proposed as a new alternative approach to fast ignition. Integrated experiments (R. Kodama *et al.*[1]) have shown an increase in neutron yield in compression of fusion targets in presence of the cone (the CPA beam being directed through the cone). Despite the clear interest of such results, still many points remain obscure. Such integrated experiments do not allow a real understanding of the underlying physics and hence do not allow the study of the scalability of such scheme. With the aim of better understanding the physics at stake, we have performed a simpler experiment totally devoted to studying the early stage of fast electron generation, fast electron propagation in the target, and target heating in the presence of the cone. The experiment was performed at the Laboratoire pour l'Utilisation des Lasers Intenses (LULI) with its 100 TW laser based on the chirped pulse amplification technique. The laser pulse was focused by a f/3 off-axis parabola at normal incidence with a focal spot estimated to be less than 15 μ m FWHM onto a three layer target (Al-Cu-Al) with and without a cone. We have used two configurations of the laser : at the fundamental frequency (1.057 μ m) and at the doubled frequency (0.53 μ m) to test the

influence of the pedestal. In the first case we have measured the extension of the pre-plasma due to the ASE (contrast ratio $\sim 10^8$) in front of the target at around 30-50 μm whereas at 0.53 μm , there is no significant pre-plasma. The incident laser intensities are estimated at $2 \cdot 10^{19}$ W/cm^2 and 10^{19} W/cm^2 for 1.057 μm and 0.53 μm respectively.

The gold cones were manufactured by the target group of ILE at OSAKA and glued at the cone tip on the planar targets. Three kinds of gold cone have been used: 30° and 60° angle with 20 μm tip and 30° angle with 40 μm tip. The planar targets consist of three layers: the first Al layer (at the laser side) varied from 0 to 70 μm thickness (Δx), the second 20 μm Cu fluor layer and the third, (at the rear side) was always 20 μm Al. This last bi-layer Cu/Al was molecularly bonded. The target thickness and surface, the target holder, the ASE, the focalisation point of the laser beam and, of course, the type of cone have been varied in order to study their influence on the electron transport. Several diagnostics were implemented: rear side imaging and HISAC [2], Xray- $K\alpha$ images of buried layers and Xray- $K\alpha$ spectroscopy and at last, protons emission using radiochromic films (RCF). The results are presented and discussed below.

A. Results without cone

By changing the size of the target, i.e. the surface of the target, we have obtained results showing that the behaviour of the fast electrons is influenced by the target geometry. 2D $K\alpha$ images and visible rear side images obtained by a Gated Optical Imager (GOI) 200 ps after the maximum of the laser pulse with two different target dimensions are presented in Fig. 1. With the small target (Fig. 1a), we observe with the GOI diagnostic a very bright emission on the edges of the target, in particular on the corners. This effect, which decrease with the target surface (Fig. 1b), seems to show an accumulation of the electrons on the edges which might correspond to an inhomogeneous heating of the target. This effect is all the more important as the target is isolated from the target mount by an insulator holder (glass wire).

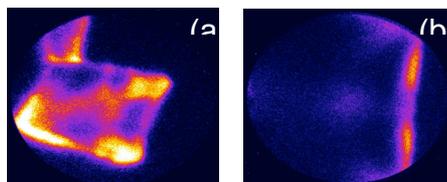


Fig. 1 - GOI images, 2 target (Cu20-Al20 μm) surfaces : (a) 490x 430 μm^2 (b) 900x750 μm^2 .

Concerning the 2D $K\alpha$ images, we observed that the total $K\alpha$ intensity (integrated over all the surface) is constant with the target surface S (Fig.2a). The effect of the ASE has also been

verified by using the laser either at the fundamental frequency (with 2ns ASE) or frequency doubled (with no ASE). The spot diameter increases as a function of Al thickness (the first layer) with an initial spot diameter $55 \mu\text{m}$ for the thinnest targets ($\Delta x = 0$). For thicker targets ($\Delta x > 0$), without ASE, and with the laser right focused on the target surface, we observed a full spreading angle of $\sim \pm 15^\circ$, in agreement with previous results [3]. On the other hand, with ASE, a smaller angle of $\sim \pm 8^\circ$ has been observed (fig. 2b). In this case the laser was slightly defocused, i.e. it was focused before the target surface. This result could indicate an effect of auto-focalisation of the laser in the plasma corona.

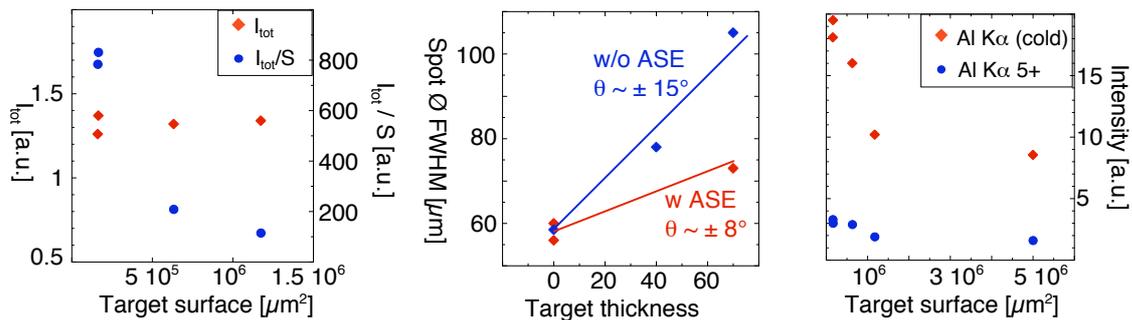


Fig. 2 – Results obtained from the $K\alpha$ diagnostics: (a,b) 2D $K\alpha$ image, (c) $K\alpha$ spectrometer

For the Al- $K\alpha$ spectrometer (conical Bragg crystal), the result is similar with the one obtained from 2D $K\alpha$ images: the cold Al $K\alpha$ line intensity (linked to the electron distribution) decreases with the target surface whereas the decreasing of 5+ ionised Al- $K\alpha$ line (linked to the heating) is weakest (and visible only up to $40 \mu\text{m}$ thickness) (Fig. 2c).

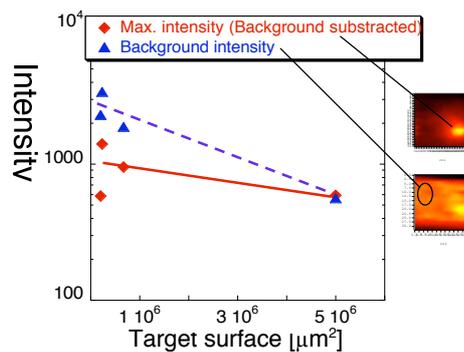


Fig. 3– Results obtained from the HISAC diagnostic: the decreasing of the background (triangle) is more pronounced than this one of the spot corresponding of the maximum intensity (diamond) (Cu20-Al20 μm target)

Results from the HISAC diagnostic are also similar: the spot intensity decreases with the target surface (Fig. 3), but more slowly than the background intensity. This effect might be due to the electrons refluxing inside the target.

B. Results with cone

When the laser first interact with a cone before reaching the planar target, we didn't observed any significant improvement of the heating in our experimental conditions. We used different gold cones (30 or 60° angle and 20 or 40 μm tip) in different interaction conditions: with or without ASE, defocused laser beam yielding a focal spot from 10 to 30 μm . In all cases there was no increase of the $K\alpha$ diagnostics signal, rather it was the or 10-20 % weaker. Nevertheless, the best condition for the cone is without ASE, which indicate the negative effect due to the pre-plasma inside the cone.

This conclusion is also supported by the protons emission diagnostic. The maximum energy of protons accelerated from a 15 μm Al foil is $E_{\text{max}} \sim 6$ MeV without cone and ~ 1 MeV (with ~ 10 times less protons) with cone. The protons are accelerated electrostatically by the hot electrons with a field $E \sim (n_h \cdot T_h)^{1/2}$ and $n_{\text{protons}} \sim n_h$, where n_h and T_h are respectively the hot electrons density and temperature on the target rear-surface. This shows i) n_h is reduced by ~ 10 by using the cone and ii) T_h is either the same or slightly higher.

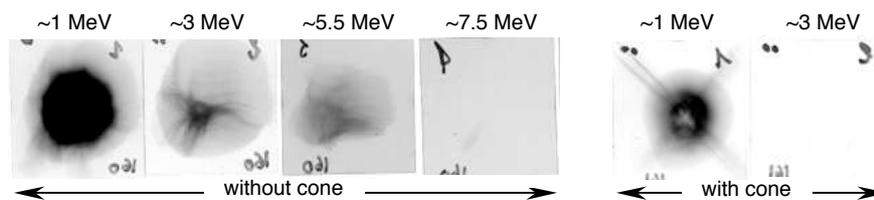


Fig. 4 – Protons emission at 2ω without and with cone

Conclusion

We present recent results of ultra-intense laser pulse interaction with solid targets with or w/o cone, and their preliminary analysis. In our conditions, there is no significant cone effect observed with either the $K\alpha$ or the protons diagnostics. Nevertheless these results seem to indicate that the behaviour of the fast electrons is highly influenced by the target geometry.

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