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# Study of shock waves generation, hot electron production and role of parametric instabilities in an intensity regime relevant for the shock ignition

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**Abstract.** We present experimental results at intensities relevant to Shock Ignition obtained at the sub-ns Prague Asterix Laser System in 2012 . We studied shock waves produced by laser-matter interaction in presence of a pre-plasma. We used a first beam at $1\omega$ (1315 nm) at $7 \times 10^{13}$ W/cm$^2$ to create a pre-plasma on the front side of the target and a second at $3\omega$ (438 nm) at $\sim 10^{16}$ W/cm$^2$ to create the shock wave. Multilayer targets composed of 25 (or 40 $\mu$m) of plastic (doped with Cl), 5 $\mu$m of Cu (for K$\alpha$ diagnostics) and 20 $\mu$m of Al for shock measurement were used. We used X-ray spectroscopy of Cl to evaluate the plasma temperature, K$\alpha$ imaging and spectroscopy to evaluate spatial and spectral properties of the fast electrons and a streak camera for shock breakout measurements. Parametric instabilities (Stimulated Raman Scattering, Stimulated Brillouin Scattering and Two Plasmon Decay) were studied by collecting the back scattered light and analysing its spectrum. Back scattered energy was measured with calorimeters. To evaluate the maximum pressure reached in our experiment we performed hydro simulations with CHIC and DUED codes. The maximum shock pressure generated in our experiment at the front side of the target during laser-interaction is 90 Mbar. The conversion efficiency into hot electrons was estimated to be of the order of $\sim 0.1\%$ and their mean energy in the order $\sim$50 keV.

## 1. Introduction

Shock Ignition is a novel approach to ICF proposed in 2007 [1]. In this approach, the compression phase and the ignition phase are separated. Two different laser pulses are used: the first one in the ns regime to compress the target and the second one in ps regime and more intense to launch a strong convergent shock to achieve the ignition conditions. We performed an experiment at Prague Asterix Laser System [2] to investigate a regime relevant to Shock Ignition [3]. We used two different beams in planar geometry. The first one at $7 \times 10^{13}$ W/cm$^2$ and 1315 nm to create an extended plasma corona in front of the target, and the second one at $\sim 10^{16}$ W/cm$^2$ and 438 nm to lunch strong shock. We changed the delay between the beams from 0 up to 1200 ps to observe the influence of the plasma corona on the shock wave.

## 2. Experimental setup

To characterize the pre-plasma we used optical interferometry [4] at 650 nm obtaining density maps. To measure the electron plasma temperature we used a spherically bent mica crystal spectrometer configured to record the X-ray emission from Cl used as doping in the first plastic layer of the target [5]. Using a streak camera we measured the time required the shock wave to cross the target (shock breakout time). We characterized hot electrons using an X-ray CCD in single photon counting mode [6, 7] recording the K$\alpha$ emission from Cu, and a spherically bent quartz crystal for imaging of the same radiation [8]. The back-scattered light was collected within the cone of the lens used to focus the laser. We analysed this light using a calorimeter and two fiber spectrometers looking at blue frequencies (to detect back scattered laser light and Stimulated Brillouin Scattering) and red frequencies (to record the spectrum due to the Stimulated Raman Scattering). We also recorded inside the chamber signal coming from the Two Plasmon Decay. We used multilayer targets: a first layer of plastic doped with Cl to create an extend plasma corona of low Z material as in a real ICF experiment, a second layer of 5 $\mu$m Cu that we used to trace hot electrons and a third layer of 20 $\mu$m of Al as shock reference. The thickness of the first plastic layer was 0 $\mu$m, 25 $\mu$m and 40 $\mu$m to observe the attenuation of the electrons in plastic. We used on both beams Random Phase Plate (RPP) to homogenise focal spot and to have a stable interaction between laser and plasma. The focal spot diameter of the first beam was 900 $\mu$m, with a flat top energy distribution. The second beam had a gaussian spatial energy distribution with a full width half maximum of 100 $\mu$m.

## 3. Results

We reproduced the experimental shock breakout time with the hydro codes (DUED [9] and CHIC [10]). The comparison with the code CHIC is shown in Figure (1). The maximum pressure inferred is 90 Mbar using RPP on both beams. This is the highest pressure measured until now in this kinds of experiments. Nevertheless even higher values could be obtained if a larger focal spot had been used. Indeed in our setup the main beam had a focal spot of $\sim$100 $\mu$m comparable to the distance between the absorption and the ablation layers. A significant part of the absorbed energy is lost in transverse direction in the conduction (overcritical density) region. Increasing the focal spot size and keeping constant intensity, we would have obtained a pressure of the order of $\sim$120 Mbar. Such value is still low compared to simulation predictions for the nominal incident laser intensity. Probably a large part of the laser energy is lost due to the refraction at very large angles in the plasma plume in front of the target. K$\alpha$ measurements show an electron spot of $\sim$150 $\mu$m not so larger than the laser

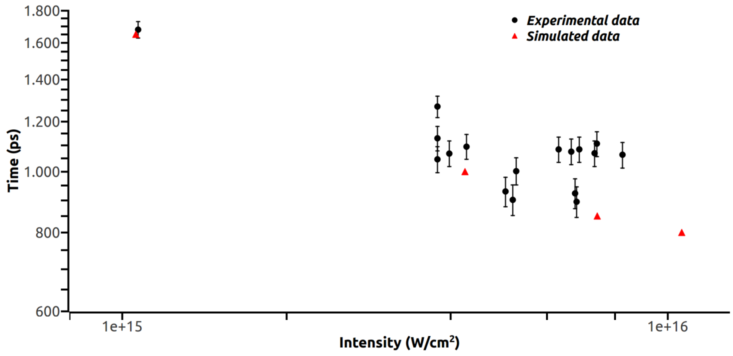


**Figure 1.** Experimental and simulated (using CHIC code) shock breakout time vs. laser intensity.

focal spot. Measuring signal coming at different depth we studied the attenuation of the K$\alpha$ signal. Considering K$\alpha$ signal proportional to the number of hot electrons generated, it is possible to estimate the hot electron range as shown in figure (2). We found a range of ∼27

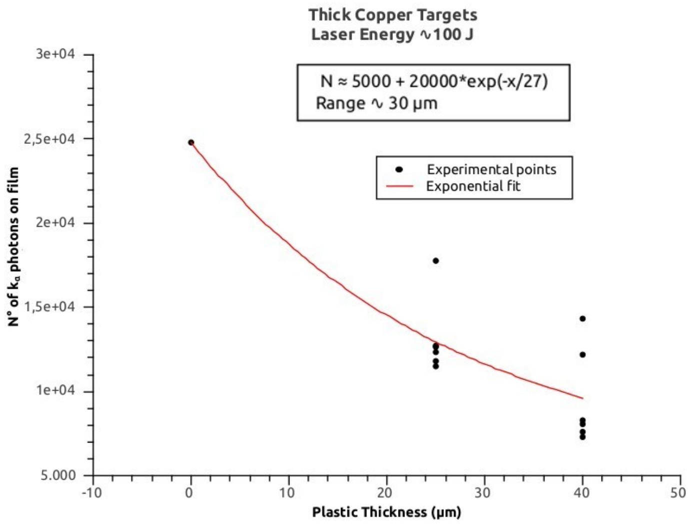


**Figure 2.** K$\alpha$ signal versus thickness of plastic over layer. Assuming an exponential penetration of hot electrons, we obtain an estimation of their range and of the associated average energy.

$\mu$m corresponding to an energy [11] of ∼ 45 keV with an error of 10 keV in accordance with values measured in previous experimental campain in PALS [12]. From crystal measurements we evaluate the total amount of K$\alpha$ emitted. Using the same assumption to find the range we estimated a conversion efficiency of laser energy into hot electrons in the order of 0.1 %. Back scattering measurements show an amount of back-scattered energy of ∼ 5-6% [13]. The energy back-scattered by Raman process was in the order of 0.1%

## 4. Conclusion

We studied laser-matter interaction in an intensity regime relevant for Shock Ignition. The experiments were performed at the Prague Asterix Laser System. We characterized our conditions using different diagnostics, in particular Shock Chronometry, K$\alpha$ measurements, and back scattering measurements. The maximum pressure produced by the laser on the target front during interaction was inferred by reproducing the shock breakout time on target rear side. The obtained value of the order of 90 Mbar is the maximum measured until now in this kind of experiments. Hydro simulations show that, if larger focal spots were used at given intensity, pressures of about 120 Mbar could have been reached; The difference is due to lateral losses due to thermal conduction in the overcritical region, due to the distance between the absorption and ablation region being comparable to the focal spot size. Simulations also show that only about 50% of laser light is absorbed. We observed a low amount of back-scattered light within the cone of the lens (~5-6%) and we characterized the hot electrons using a spherically bent crystal, obtaining images of the K$\alpha$ emission from a Cu-tracer layer. From these images we measured the diameter of the electron beam which was compatible with our focal spot. We also measured the flux at different depths to calculate the hot electron range. From our measurements we obtained an average energy of 50 keV compatible with the assumption of hot electrons generation from Raman scattering [14] (non local effects have not,insted, been taken into account since they appear not to play a major role [15]). The total energy of the hot electrons was less than 1% laser energy.

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