Study of Hot Electron production in SI-relevant regime

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Abstract:

In this paper we study the generation and propagation of hot electrons produced by high intensity laser pulses through multiple targets with different thickness in an interaction regime relevant to shock ignition (SI) approach for ICF schemes. The main diagnostic was Cu K-α fluorescence imaging by spherically bent quartz (422) crystal. The average values of hot electron temperature and conversion efficiency are 26.2 ± 1.8 keV and 0.7 ± 0.4 %, respectively. The experiment is in a series of experiments to shock ignition feasibility which performed at PALS lab (Prague Asterix Laser System) in Prague, Czech Republic.

Introduction

At laser intensities up to 10^{16} W/cm^2, envisaged in the SI scheme, laser interaction with the long scale plasma may lead to the generation of hot electrons (**HE**). The experiment aims at investigating of generation of such HE and their role in the generation of the shock wave [3]. We used two types of targets. The thin multilayer targets, CHCl+Ti+Cu, CHCl+Cu+Al, and thick targets, CHCl+Massive Cu with different thickness of CHCl layer. Hot electrons were detected by K-α emission of Cu and Ti layers. The images were recorded with the crystal of quartz (422) spherically bent to a radius of 380 mm. the interaction of hot electrons with Bound atomic structures of tracer layers (Cu or Ti) produce K-α emission which reflected by spherically bent crystal to film plates and produce K-α spot (black circle) with a Gaussian distribution as shown in Fig.1.

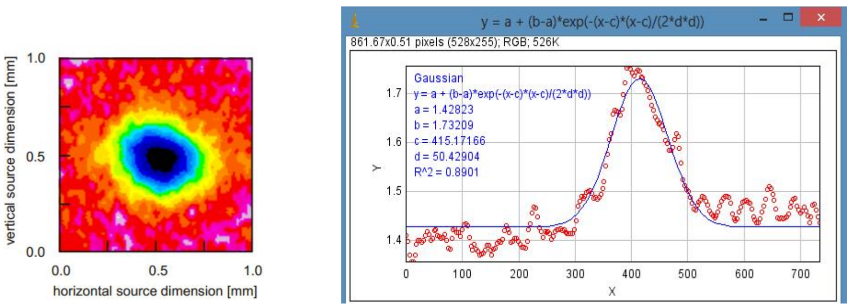

Fig.1: Left: A typical 2D-resolved image of the Cu K-α spot as imprinted on film slice.
Right: Gaussian distribution of hot electrons.

Experimental results:

From the obtained images, we can get two types of quantitative information: K-α spot and Total K-α Number of Photons **(NPhs).** As soon as K-α spot and NPhs determined we can calculate some important parameters as come in following:

1- Spreading angle of hot electrons

The spot size, measured as a function of target thickness, can be used to evaluate the angle of divergence of the fast electron beam. The importance of spreading angle of HE can be seen especially in fast igniting scheme which strongly depends on the generation of HE, their collimation, transport, and energy deposition in the over-dense region of the plasma. Hence the estimation of divergence of HE is, therefore extremely crucial.

For this purpose K-α spot of tracer layers of CHCl+Ti+Cu (Cu and Ti) and CHCl+Cu+Al (Cu) plotted versus total thickness of their targets as presented in Fig.2.

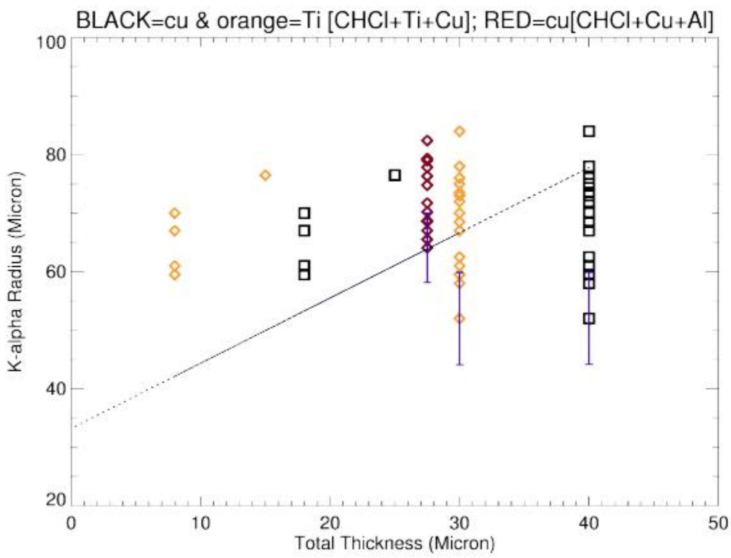

Fig.2: K-α spot of tracer layers of CHCl+Ti+Cu (Cu and Ti) and CHCl+Cu+Al (Cu) plotted versus total thickness of their targets

By interpolation data (Radius R vs. Thickness d) with a straight line R(d) = A +Bd, the tangent of slope (parameters B) will give the spreading angle of HE. In our case the spreading angle estimated to be **θ≈47.5°.**Typical values reported in literature are between 40–50°.

2- HE penetration depth

The penetration depth of HE can be inferred from the measurements of the K-α photon flux versus different thicknesses of the plastic layer as presented in Fig.3. For penetration depth measurement thick targets (CHCl+Massive Cu) must be used to prevent electron refluxing.

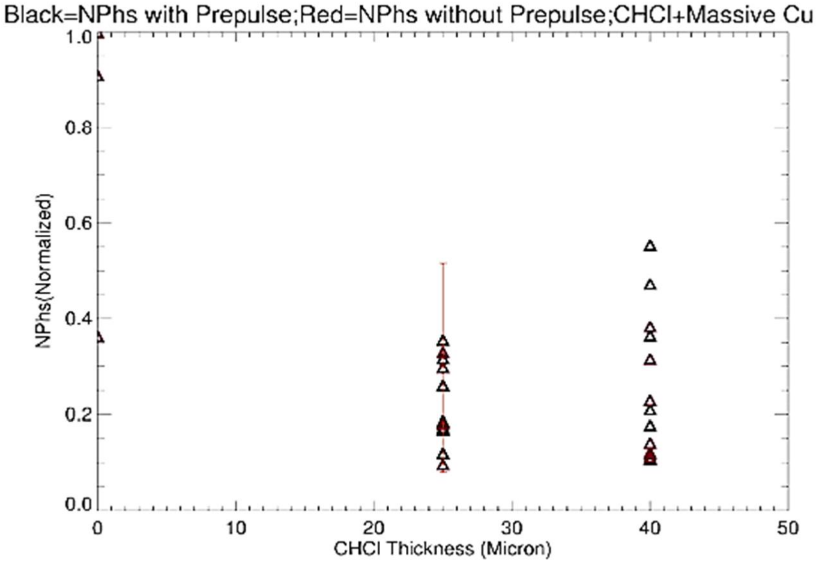

Fig.3: K-α photon flux versus different thicknesses of the plastic layer for penetration depth measurement.

The measured flux as a function of plastic layer thickness fitted with an exponential function, N(x) = a exp (-x/L), where N, x and L indicate the measured photon number, the plastic layer thickness and the penetration depth and a are free fitting parameter. We fitted the function for two data set, first for all data and then for data without prepulse. In first case the penetration depth was found to be **L ≈ 27.4 µm** while for data without prepulse it was **L ≈ 26.9 µm.** As we can see in the presence of prepulse, penetration depth of HE was increased that could be considered as a positive effect of preplasma effect.

3-Hot electron beam temperature

One of key issue in HE experiments is HE Temperature since by determination of T_{HE} we can calculate conversion efficiency. But instead of a more realistic electron energy distribution we assume a mono energetic electron beam. Temperature estimated with different methods:

3-1 Beg's scaling law:

By using Beg's scaling law $\mathbf{T_e}$ **(KeV) = 215(**$\mathbf{I_{18}\,\lambda^2_{\mu m})^{1/3}}$ (ONLY for 3w mode, thin target approximation). According to variation of laser intensity between 2.7 e+15 - 1.07 e+16 (w/cm^2) and $\lambda_{3\omega}$=438nm, T_e ranged **17.3-27.3 (keV)** with the average **Te ≈ 26.2 ±1.8 (KeV).**

3-2 slope of penetration depth diagram

The Experimental slope of penetration depth [N(x) = a exp (-x/L)] enables to infer first the penetration depth of HE (section 2) and second to deduce the corresponding HE temperature.

In the case of CHCl + Massive Cu the penetration depth was found **L ≈ 27.4 µm** that by comparison with the electron stopping range in Mylar the HE energy estimated to be ~50±10 keV. In the case of CHCl+Ti+Cu target, by increasing CHCl layer, the Kα signal was found rather flat so we couldn't fit exponential function to deduce HE temperature.

3-3 Ratio of Kα signals of Ti and Cu versus mean HE energy

Another way to measure T_{hot} is based on the ratio of K-α signals coming from the Ti and Cu layers. In one hand, experimental data are averaged, and error bars are deduced from the standard deviation σ (around 20 % in relative). Then the experimental values was compared with Monte-Carlo GEANT4 simulations. The hot electron temperatures were inferred by fitting experimental data with simulations, as illustrated in Fig. 4 .Depending on the CHCl thickness, the T_{hot} ranges from **18-31.5 keV** which is comparable to ones by Beg's law. [4]

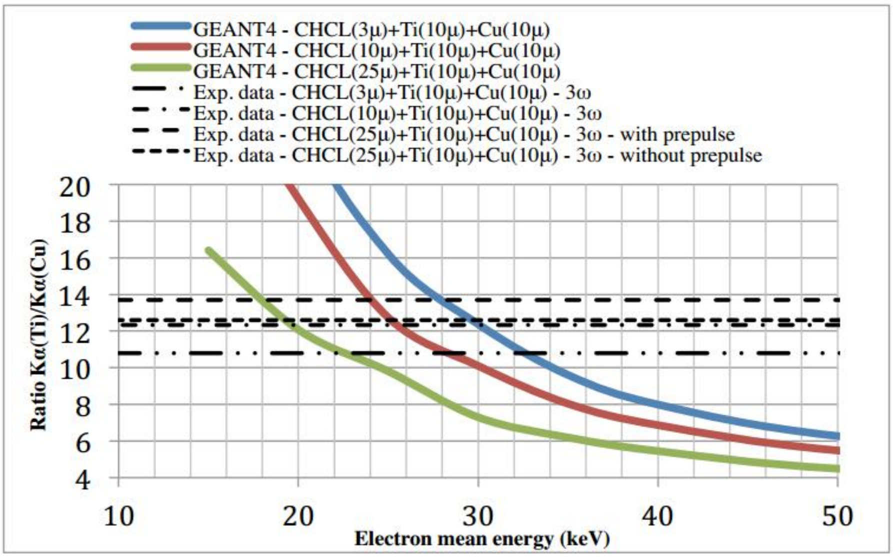

Fig.4: Comparison between GEANT4 simulations and experimental data (for simplicity, error bars are not represented here)

4- Conversion efficiency

By assuming a single-temperature electron distribution function and knowing the energy of the laser E_{laser}, we can infer the laser-to-electrons conversion efficiency (η) by estimating, with GEANT4, the electron total energy E_e needed to reproduce the measured absolute Kα signal. Depending on the CHCl thickness, η ranged from 0.45-1.1 %.

References

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