Energy Transport by MeV Hot Electrons in Fast Ignition Plasma Driven with LFEX PW Laser

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INTRODUCTION

Fast ignition is recognized as a promising pathway to efficient thermonuclear fusion in laser-driven inertial confinement fusion. A cone-guided CD-shell has been used as a baseline target for the fast ignition realization [1, 2]. It has long been expected to provide more quantitative information about the hot electron generation and transport in the cone. In this research, we propose an absolute Kα line spectroscopy dedicated for quantitative measurement of hot electron generation and transportation in high-Z targets, such as Au and Ta. With this diagnostic, the local information about the hot electrons propagating through specific materials composing the cone-guided target can be provided, in spite of complicated interaction geometries.

LAUE SPECTROMETER

A Laue spectrometer was developed to cover the high energy Kα lines from Mo (Kα: 17.48 keV) to Au (Kα: 68.80 keV)[3]. Absolute calibrations have been carried out for the crystal and detector separately by using pre-calibrated laser produced Kα sources and radiation isotopes.

HOT ELECTRON PROPAGATION

The hot electron trajectory inside the solid target is tracked with a Monte-Carlo simulation. The electron is treated with a continuous slowing down approximation (CSDA), which means that the electrons change their direction of motion due to elastic scattering, and lose their energy between two scattering points continuously. The number of Kα photons NKα generated from hot electrons with number Nh and temperature Th can be estimated as:

\[ N_{K\alpha} = N_{h} \frac{\sigma_{K\alpha}}{\lambda_{K\alpha}} \int_{E_{1}}^{E_{2}} \int_{x_{1}}^{x_{2}} \frac{dE \sigma_{K\alpha}(E) \times f_{E0}(E_{0}, x) \exp\left(-\frac{x}{\lambda_{K\alpha} \cos(\theta)}\right)}{\lambda_{K\alpha} \cos(\theta)} \]

where \( \sigma_{K\alpha} \), \( \theta_{K\alpha} \), and \( n_{K} \) are, respectively, the cross section for K-shell ionization, the Kα fluorescence yield, and the atomic number density. \( f_{E0}(E_{0}, x) \) describes the energy spectrum for the hot electron propagating inside the Ta cube with a depth x, where the information was derived with the Monte-Carlo simulations. Considering the Kα photon number \( N_{K\alpha} \) measured by the Laue spectrometer, the \( \eta_{TE} \)s were estimated by comparing the experimental measurement and simulation results.

A modified cone target was designed for LFEX fundamental experiments for energy transfer estimation [4], as shown in Fig. 1(a). A cone is attached with a hemi-CH shell, which was irradiated by three beams of Gekko-XII laser. Dense plasma surrounding the tip of the cone was produced to surrogate the condition of the fast ignition Au cone+CD shell target. A Ta cube was attached as the Kα witness tracer after the hemi-CH shell. Four types of cone were used as shown in Fig. 1 (b)-(e): (b) is the standard Au cone with 7-μm thickness; (c) is an open Au cone without tip; (d) is a W-shape Au cone with double Au layers; and (e) is a diamond like carbon (DLC) cone. The \( \eta_{TE} \)s were estimated to be about 20% to 50% for different laser intensities and cone types, as plotted in Fig. 2. Besides the cone geometry, a planar target case was also studied as a reference. Compared with the planar geometry, it was found that the LFEX laser transfer efficiency is significantly enhanced with a guiding cone.

CONCLUSION

A quantitative high energy x-ray spectroscopy was applied for energy transfer estimation in laser plasma interactions. In the fast ignition scheme, the \( \eta_{TE} \)s of
LFEX laser to a guiding-cone was found to be much higher than the planar target case, and was quantified to be 20% to 50%.

Fig. 2. The $\eta_{TE}$ as a function of laser intensity for the planar and cone-guided targets.

REFERENCES

[1] H. Shiraga et. al., 2012 High Energy Density Phys. 8 227