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Study on fast electron transport in plasma-surrounded cone-wire targets for cone-guided fast ignition

コーン付き高速点火に向けたプラズマ内コーンワイヤターゲットを用いた高速電子輸送研究

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Cone-wire targets surrounded with imploded dense plasma have been used to study the fast electron transport in FI-relevant environment. The yield of Kα x-rays from the wire is clearly reduced when the cone-wire is surrounded with plasma, which can be explained with a divergence of the fast electrons after the cone. The results will be an important database to benchmark simulation codes for the study of fast electron generation and transport in the full-scale fast ignition.

1. Introduction

Transport efficiency of fast electrons from the source to the fuel plasma core is important in the fast ignition (FI) laser fusion. The core heating after the fast electron transport through the cone tip has been studied by the measurements of the thermal fusion neutrons in integrated experiments of FI[1].

Cone-wire targets have been studied to study the fast electron energy spectrum and the coupling efficiency after the electrons propagate through the cone tip[2]. Past studies have been performed using the cone-wire target in vacuum, namely stand-alone targets, so that the fast electrons are guided along the cone-wall and the wire due to the self-excited electrostatic and magnetic fields[3]. This guiding effect can increase the efficiency of fast electrons traveling in the wire, however, the significant guiding of the electrons along the cone-surface may not be expected in the FI situation. In addition, there is a separation between the cone tip and the plasma core, which may result less coupling to the core because of the electron beam divergence angle. Therefore, the estimated efficiency based on the stand-alone cone-wire experiments could be higher than the one expected to heat the plasma core in FI. In order to estimate the efficiencies of fast electrons reaching to the core, the cone-wire target is placed inside the imploded plasma in this study.

2. Experiments

In the presented experiments, the cone-wire target was surrounded with high-density plasma, which is produced by a plastic shell implosion with the GXII laser pulses at the Institute of Laser Engineering, Osaka University. An intense laser pulse from the LFEX laser was focused into the cone at various timings. The cone was made of 7 μm thick gold with an opening angle of 45° and an inner tip of 30 μm in diameter. A 50-μm-diameter copper wire was glued on the cone tip and its length was 250 μm, which is equivalent to the radius of the shell with a thickness of 7 μm. The shell implosion was performed with 9 beams of GXII with an energy of ~250 J/beam in 2ω with a pulse duration and a focused spot of 1.3 ns and 500 μm, respectively. The LFEX laser energy was changed from 0.5 to 0.9 kJ in a duration of 2 ps. The fast electrons interact with the wire and produce the Cu Kα x-rays (8.05 keV). The spatial profile of the Kα x-rays along the wire was measured with a Bragg crystal imager. The x-ray energy spectrum was also measured with a spectrometer using a HOPG crystal. The energy spectra of fast electrons were measured on and off the wire axis, as well as various x-ray diagnostics including streak cameras, which were used to monitor the LFEX injection timing. Since the fast electron transport in the wire could be affected by the shock compression and/or heating of the wire due to the imploded plasma, the LFEX injection timing was carefully adjusted.

3. Results and Discussion

Figure 1 shows the intensity of Kα x-rays observed under various conditions. In the case when the LFEX was injected at the maximum compression timing (t = 0), the observed results and the hydrodynamics simulation results indicate; 1) the coupling efficiency into the wire was clearly reduced (down to ~20%) compared to the case without the surrounding plasma, 2) the wire was partially heated and could be disturbed because of the shock compression.

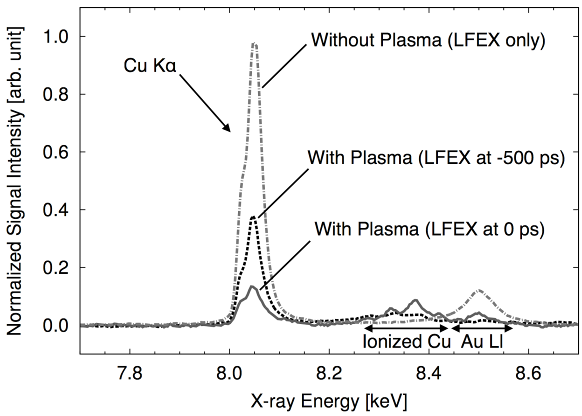

Fig. 1. X-ray spectra emitted from cone-wire targets.

To avoid the shock effects, the LFEX was injected at –500 ps since hydrodynamics simulation results show that the most part of wire remains cold with its solid density in the original shape but the cone-wire is surrounded by plasmas at ~500 ps prior to the maximum compression timing (i.e.–500 ps). In this case, the signal is increased compared to the case of 0 ps. However, signal reduction down to ~30% is still clearly seen. This signal reduction can be explained with the electron beam divergence at the source. Results of hybrid particle-in-cell simulation shows that a significant number of fast electrons escape from the wire quickly when the wire is surrounded by plasma. In contrast, the simulation confirms that the fast electrons are confined within the wire if it is in vacuum or if the divergence is quite narrow.

4. Summary

The fast electron transport in cone-wire targets in plasmas has been investigated using an intense laser pulse with the energy up to sub kJ in order to estimate the effect of imploded plasmas on the electron transport to the fuel core in the cone-guided FI laser fusion. The fast electrons appear widely spread into the plasma resulting less coupling to the wire.

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