Imploded Plasma Heating by Irradiation of Heating Laser through a Cone with a Hole for Fast Ignition

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Abstract
It is of great importance for the fast ignition research to investigate the heating properties of the imploded core plasma by injection of the heating laser. The open-end cone was introduced recently. An expanding self-emission of x-ray from the core plasma near the cone tip was observed after the heating laser irradiation through the cone. It indicates that the core plasma was heated by the heating laser.

1. Introduction
The process of the proposed fast ignition scheme is to create an imploded core plasma by Gekko-XII laser having twelve beams which were symmetrically arranged and to heat it by LFEX high intensity peta watt laser. We are conducting experiment using a deuterated polystyrene shell target with an Au cone for guiding LFEX laser. The fast electrons generated at the cone tip irradiated by the LFEX laser are expected to heat the core plasma. [1-4] So far, a closed-tip cone was used. Recently, we introduced an open-end cone, and x-ray self-emission from the heated core plasma was observed.

2. X-ray imaging diagnostics
Since the typical size and life of the imploded core plasma are typically of order of 100 µm and 100 ps, respectively, we used an x-ray streak camera (XSC) with spatial and temporal resolutions of 10 µm and 10 ps, respectively, for observation of the core plasma dynamics (Fig. 1). The data were taken as a part of multi-imaging x-ray streak camera (MIXS). [5-7]

The time of the LFEX laser irradiation relative to the x-ray self-emission history from the core plasma was specified with an accuracy of 7 ps by using the non-imaged hard x-ray signal caused by hot electron generation with LFEX laser irradiation of the target as shown in Fig. 2. Yellow arrow in Fig. 2 indicates the arrival time of the LFEX laser. This non-imaged signal acts as a noise for the self-emission image from the core plasma. By removing this noise signal assuming uniform irradiation on the cathode, we could obtain the net self-emission history of the core plasma.
3. Experiments

Fast ignition experiment was performed by using a deuterated polystyrene shell (diameter = 505 µm, thickness = 7.5 µm) with an open-end Au cone (opening angle = 45 degree, diameter of the hole = 33.7 µm, distance between shell center and cone tip = 47µm). The shell target was irradiated with Gekko-XII laser (8 beams, 2240 J / 1.3 ns, 0.53 µm) and the LFEX laser (615 J / 1.5 ps, 1.05 µm) was injected through the cone. We needed 9 beams to make an uniform core plasma, but one beam was missing due to a failure in the laser system. The cone was used to keep the LFEX laser path to be vacuum, while the hole at the tip allows the LFEX beam to directly irradiate the imploded core plasma. Because the diameter of the hole is approximately the same as the diameter of heating laser spot, the electrons around the hole are expected to be heated and to heat the core plasma without being blocked at the tip.

4. Experimental Results

The image obtained by the X-ray streak camera (Fig. 4 (b)) shows that the imploded core plasma was moving towards the cone. (The white triangle indicates the initial target shell center and the black triangle points the cone tip in Fig. 4.) This is reasonable due to the absence of the drive beams near the cone. Furthermore, because one beam was missing, the core plasma became nonuniform. The self-emission from the core plasma fell down from about 350 ps (Fig. 4 (c)). After LFEX laser irradiated at about 390 ps, the emission restarted, especially near the cone tip. This emission went up
until 420 ps, well after the LFEX beam irradiation, which indicates that it is a self-emission from the core.

The region of this restarted emission was found to be gradually expanding over the core plasma from the cone tip with a velocity of about $2.5 \times 10^8$ cm/s. This result indicates that the imploded core plasma was heated by the LFEX laser irradiation, and the heated region expanded to the whole core plasma.

![Fig. 4](image_url) (a) The self-emission image of the core plasma and the non-imaged signal of high-energy X-rays due to the LFEX laser irradiation. (b) The self-emission image after removal of the non-imaged signal. (c) The history of spatially integrated net signal in Fig. 4(b). Only signal within full-width-half-maximum of the spatial profile at each time is integrated. (d) The enlarged view of the restarted self-emission region after smoothing processing of the image. (0 ps indicates the starting time of the self-emission of the core plasma.)

The similar x-ray self-emissions near the tip of the cone without the hole were obtained in a separate experiment. However, those occurred in both cases with and without heating laser as shown in Fig. 5. These emissions started before the time of the peak x-ray emission from the core, continued for more than 100 ps and did not expand. Thus it can be concluded that these were effect by the imploding laser or the imploded plasma hitting the closed tip of the core. The image shown in Fig. 4 is different from those.

![Fig. 5](image_url) (a) The obtained emission without LFEX laser in 2010. (b) The obtained emission with LFEX laser in 2012.
Clear difference between open-end cone and standard cone in x-ray self-emission feature from the core plasma near the core tip may indicate effectiveness of the open-end cone in the core plasma heating. Details of the core and cone dynamics will be investigated by using various types of the cone, for example, diameter of the open-end, core material, and so forth. A cone made of 10 µm-thick diamond-like carbon (DLC) is such a candidate, and is ready to use for our experiment. X-rays emitted inside a DLC cone can be easily observed from outside since this DLC cone is almost transparent to 3-5 keV x-rays. It is expected that we can observe the plasma heating features inside the cone by using such a DLC cone.

5. Conclusions
Temporally resolved x-ray self-emission images around the heating beam injection time were obtained for a fast ignition target with an open-end cone. It is indicated that the core plasma was directly heated by the heating laser injection. We will continue the experiment to confirm utility of the open-end cone and examine the heating mechanism of the core plasma by LFEX laser.

References
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