Integrated experiments of Fast Ignition with Gekko-XII and LFEX lasers

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Abstract. Based on the successful result of fast heating of a shell target with a cone for heating beam injection, FIREX-1 project has been started from 2004. Its goal is to demonstrate fuel heating up to 5 keV by using upgraded heating laser beam. For this purpose, LFEX laser, which can deliver, at the full spec, an energy up to10 kJ in a 0.5-20 ps pulse, has been constructed beside Gekko-XII laser system at the Institute of Laser Engineering, Osaka University. It has been activated and became operational since 2009. Upgraded integrated experiments of Fast Ignition have been performed by using LFEX laser. Initial experimental results including implosion of the shell target by Gekko-XII, heating of the imploded fuel core by LFEX laser injection, and enhancement of the neutron generation due to fast heating have been achieved. Results indicate that 5-keV heating can be expected at full output of LFEX laser with improved heating efficiency.

1. Introduction

Fast Ignition is a new scheme for inertial confinement fusion, in which a high-power short-pulse laser is injected to the imploded core for heating the fuel core plasma [1-3]. A shell target with a cone for guiding the heating beam has been proposed for Fast Ignition scheme [4]. Based on the successful result of fast heating of a shell target with a cone for heating beam injection [4], FIREX-1 project [5] has been started since 2004. Its goal is to demonstrate fuel heating up to 5 keV by using upgraded heating laser beam. For this purpose, LFEX laser, which can deliver, at the full spec, an energy up to10 kJ in a 0.5-20 ps pulse, has been constructed beside Gekko-XII laser system at the Institute of Laser Engineering, Osaka University (Fig. 1). It has been activated and became operational since 2009. Instead of the previous experiment with PW laser, upgraded integrated experiments of Fast Ignition have been started by using LFEX laser with an energy up to 1 kJ in a 1-5 ps 1.053-micron pulse. Initial experiment with LFEX laser was performed in June-

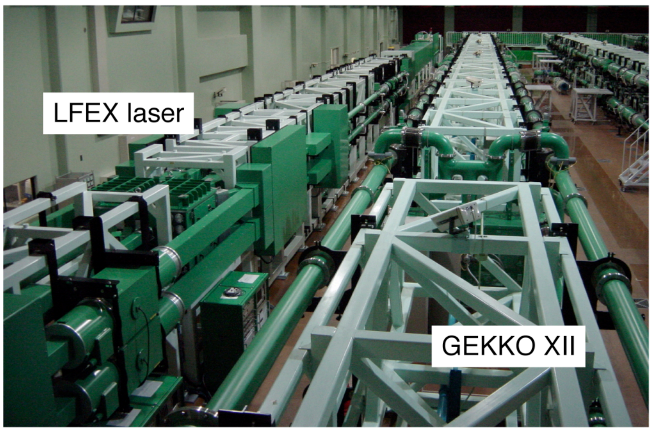

Figure 1. Gekko-XII laser system (right) for implosion of the fuel target, and LFEX laser beam line (left) for Fast Ignition heating.size.

September, 2009 to demonstrate implosion of the shell target by Gekko laser and its heating by LFEX laser.

2. Initial integrated experiments of Fast Ignition with LFEX laser

LFEX has been constructed, and then, fine tuning of the amplification, pulse compression, and focusing of the laser output beam have recently been successfully performed. The full system has four 37x37 cm square beams, although only one of those was used in the present experiment. A pulse from the oscillator was spectrally chirped and was amplified with rod and disk amplifiers. Then the pulse was compressed with large grating compression optical system down to 1.3 ps in the present experiment. The beam was focused with an off-axis parabola mirror down to a focal spot size of 30-60 mm in diameter as shown in Fig. 2, which was nearly twice the diffraction limit, resulting in an irradiation intensity of order of 1×10^{19} W/cm^2. Beam synchronization of LFEX to Gekko-XII was performed optically by using the common oscillator pulse for both lasers.

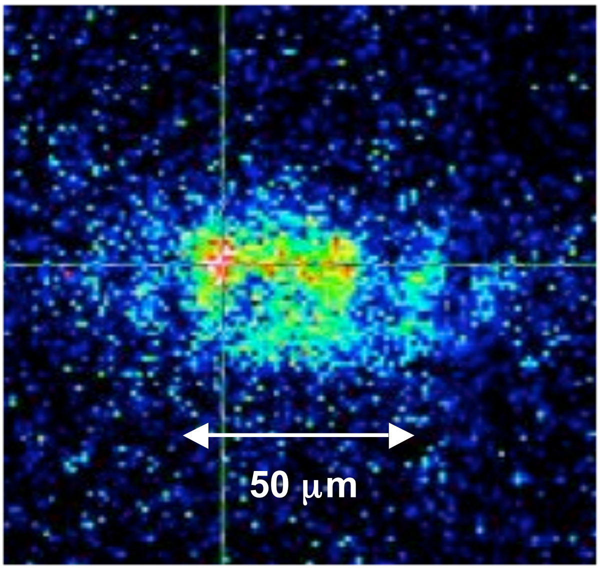

Figure 2. X-ray emission image of a Au plane target irradiated with LFEX beam, showing the LFEX focal spot size.

Implosion and heating experiments of Fast Ignition (FI) targets for FIREX-1 have been performed by operating both Gekko-XII and LFEX lasers. Typical laser and target parameters were as follows. Gekko-XII laser for implosion: 0.53-μm light with an energy of 1.5-4.5 kJ in total/1.5ns pulse, nine beams among twelve. LFEX laser for heating: 1.053-μm light with an energy up to 1kJ in 1.3-5 ps. The beam was focused and injected into a cone attached to a shell target. Shell targets (CD: deuterated polystyrene): 500 μm in diameter and 7 μm in thickness. A 10-20 μm wall-thickness Au cone with an opening angle of 30 or 45 degrees. Outer surface of the Au cone was coated with 10-μm-thick CH layer. Distance from the center of the shell to the cone tip was 50 μm.

Characteristics of the imploded and heated fuel plasma were observed by using variety of plasma diagnostics. Dynamics of the imploded fuel plasma was observed with ultrafast x-ray spectroscopic imaging [6] utilizing x-ray streak cameras [7-9] and x-ray framing cameras [10]. Fusion products were observed with detectors including a multi-channel single-hit neutron spectrometer, ultrafast neutron detectors, filtered CR-39 detectors, and so forth. Hot electrons generated with LFEX beam irradiation were observed with electron spectrometers.

3. Fast heating of the fuel plasma

Figure 3 shows a typical time-integrated x-ray image of a shell target with a cone. The camera observed from the opening side of the cone. Cartoon is overlaid to show the configuration. It is shown that the LFEX beam, injected and focused into the cone, generated plasma right at the interior of tip of the cone. This plasma is expected to create hot electrons to heat the core plasma, a part of which can be seen beyond the cone tip.

Figure 4 shows neutron yield obtained from imploded and heated fuel plasma with heating by 1 ps and 5 ps LFEX beam. Data point with 0.6 ps is of previous experiment with PW laser [4]. Up to 30 times increase of the yield compared with no heating case has been achieved by 1.3-ps heating. Note that 30-degree cone was used for the 5ps data, and 45-degree one for 1.3 ps. Although the result looks as if there is a strong dependence on the pulse width, it is not so clear because other experimental conditions were not the same.

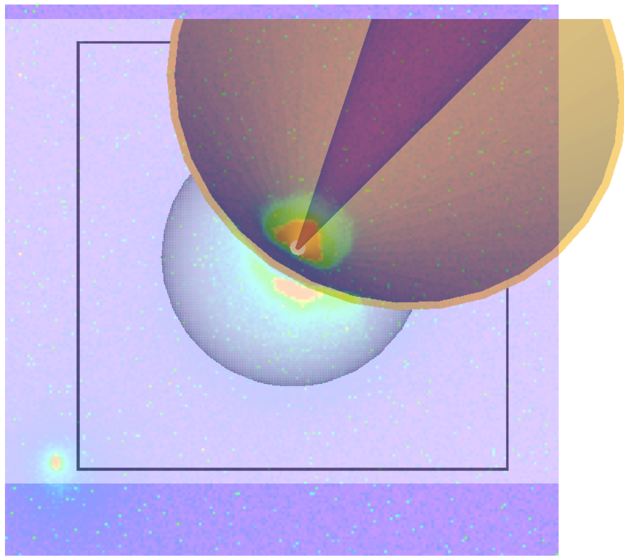

Figure 3. Time-integrated x-ray image of shell target with cone irradiated with Gekko-XII and LFEX lasers. Cartoon of the initial target is overlaid. Initial diameter of the shell s 500 μm. The left bottom spot is a noise.

The ion temperature estimated from 1.3 ps and 5 ps data shows that heating efficiency is only 3-5%, which is much lower than 20-30% in the previous 0.6 ps data. Observed hot electrons had higher energy spectrum of about 10 MeV than expected value, a few MeV to cause efficient energy deposition in the present level of the expected fuel ρR, 100-300 mg/cm^2. According to a separate measurement of preformed plasma and simulation analyses, it can be attributed to the preformed long-scalelength plasma created with a prepulse in the LFEX beam and confined in the cone. This is also inferred from the fact that the size of the x-ray emission region inside the cone shown in Fig.3 is larger than the spot size shown in Fig.2. It is of great importance to understand the condition of the preformed plasma at the time of the heating pulse injection. Further investigation will be essential in the coming next experiment.

It is expected to reduce such prepulse to increase the heating efficiency and to enhance neutron yield. Heating up to 2-3 keV is expected with 3 kJ heating, and 5 keV with 10 kJ with

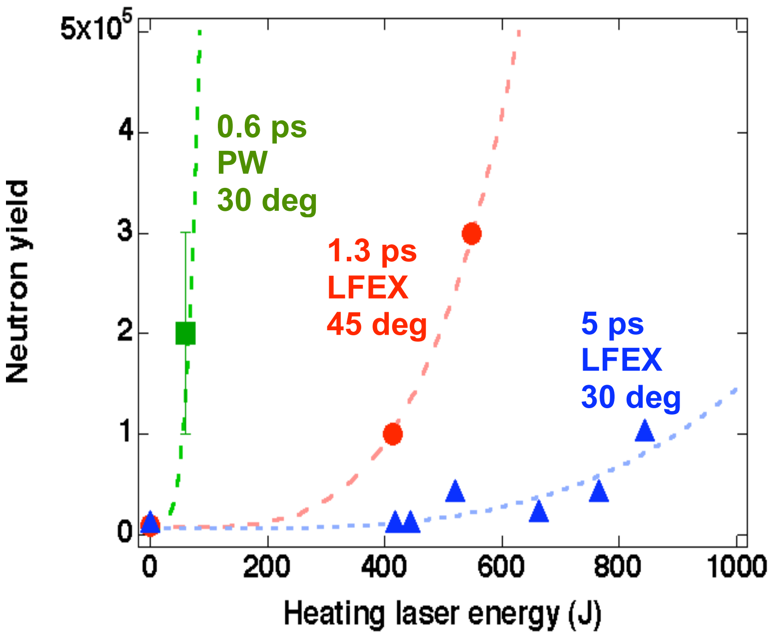

Figure 4. Neutron yield as functions of heating laser energy. Indicated are heating pulse width and opening angle of the used cone.

previously demonstrated heating efficiency of 20-30%.

4. Conclusions and future prospect

Enhancement of the neutron generation due to heating has been achieved in the initial integrated experiment of Fast Ignition with LFEX. Further tuning of LFEX is underway to extend the FI integrated experiments. 5-keV heating is expected with full output of LFEX when the heating efficiency is improved by reducing the preformed plasma.

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