Development of the compact electron spectrometer for the FIREX-I Project in Gekko XII

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Abstract. The high energetic electron measurement is one of the most important issues to research the ignition mechanism in the Fast Ignition Realization EXperiment Project. It is also important for the energy spectra with angular distribution because the electron spread is different by the target design. Therefore we have been developed the compact Electron SpectroMeter so as to be installed on different angular potions. We have performed the calibration using L-band LINAC in the Institute of Scientific and Industrial Research, Osaka University. The analyzer has been tested to measure energetic electrons from the aluminum and gold plain targets irradiated by LFEX laser (maximum energy of 10 kJ) up to 800 J. The electron measurement has been performed at the integrated experiments using CD-shell with Au cone. The non-Maxwellian spectrum can be observed when the effective core heating by the electron is occurred.

1. Introduction

In the laser fusion, the implosion and the central ignition of the DT shell have been the most popular method to realize the inertial confinement fusion [1]. However in order to achieve the break-even, the compression over 1000 times of the solid density requires huge laser energy over 1 MJ. In Institute of Laser Engineering, Osaka University, the fast ignition concept which is the imploded core heating using the high energetic electron beam produced by the pulse-compressed laser, has been proposed [2]. The high-energy electron is generated by a strong electric field based on the interaction between the high intensity laser and the pre-plasma produced by the laser pre-pulse [3]. The electron beam energy spectrum is strongly depended on the pre-plasma scale length and the main pulse intensity [4]. To obtain suitable electron energy less than several MeV for fast ignition, the pre-plasma scale length should be suppressed enough by choosing target materials, the pre-pulse control and the target area density.

In the Fast Ignition Realization EXperimental (FIREX) Project [5], the electron generated from the guided gold-cone irradiated by the heating laser, is utilized to heat the imploded core to initiate the fusion burning. The high energetic electron measurement is one of the most important issues to research the ignition mechanism. It is also important for the energy spectra with angular distribution because the electron spread is different from the target configuration. Therefore we have been developed the compact Electron SpectroMeter (ESM) so as to be set on different angular potions. The electron spectra obtained by ESM is not reflected directly to the electron profile, which is contributed to the core heating, because the electron is decelerated by electric field due to the virtual cathode which is produced by intensive electron emission. Therefore low energy part less than 0.5
MeV cannot be observed due to the virtual cathode potential. However the electron spectrum included the low energy part can be obtained from the high-energy tail of the electron spectrum if we assume the Maxwellian distribution. Although the result should be compare with the result from the Cherenkov radiation [6], ESM is still an important tool for investigating the heating mechanism in core region.

2. ESM design

Number and size of viewing ports are limited in Gekko XII [7] target chamber I. We use the most popular 6-inches port. The triangle shape of the magnet is chosen due to the compactness and the wide energy range. We can save space since the magnet is hidden in the target chamber. The electron beam enters obliquely into the analyzer in order to obtain the wide observable energy range. A neodymium alloy is used as the permanent magnet. The magnet circuit is determined as to minimize the leakage of the magnetic field. Therefore small leakage of the magnetic field still remains near the top of the triangle. The two-dimensional magnetic field has been measured every 5 mm. The beam orbit has been calculated by using the observed magnetic field. The typical magnetic field strength and the magnet gap are 0.7 T and 8 mm, respectively. Figure 1(a) shows the photograph of the ESM analyzer.

The inexpensive and commercial based imaging plate (IP, Durr Dental Co.) [8], is used as the beam detector. This has merits about no electrical noise and the wide dynamic range for the electron intensity. Two IP folders are installed for measurements in high and low energy regions in order to extend observable energy ranges. The X-ray shield of 10-20 cm thickness covers the IP holder to avoid strong X-ray irradiation from the target. The IP is also shielded from the lights by the shutter in the holder. The holders with the light shield are brought to IP reader (Vista Scan, Durr Dental Co., 12.5 micron/step) after the electron irradiation. The intensity data have 16-bit resolution. The electron irradiates within the 8 mm width on IP. Therefore real signal can be obtained by subtracting signals within 8 mm width from the background in the other area of IP.

3. ESM calibration

The purposes of the calibration are as follows;

(a) comparison of the beam orbit with the calculation, (b) the beam intensity calibration.

We have performed the calibration of the analyzer using L-band LINAC [10] in the Institute of Scientific and Industrial Research, Osaka University. L-band LINAC has an ability of strong and ultra short pulse electron generation of maximum 91 nC and 20 ps. The calibration has been performed using single pulse at two different energy of 9.5 MeV, 27.1 MeV. Main energies and charges in the calibration were 9.5 MeV, 27.1 MeV and from 0.1-10 pC. Electron beam from LINAC passes among air. Own vacuum chamber is prepared because the beam scattering by air should be minimized. The
beam size is 5 mm at the exit of the beam line and 10 mm at 13 cm from the exit in air. The energy spreads are 0.2 MeV at 9.5 MeV and 0.3 MeV at 27.1 MeV, respectively.

The energy calibration is different from that in calculation. The main reason may be due to the magnetic field leakage near the top of the triangle. We can obtain the calibration curve from those results as shown in Fig 1(b). In this fitting, a magnetic field strength added parabola-like modification is assumed. The calibration of the intensity was also obtained by comparison between the incident electrons and the counts on IP. The real signal is obtained by the elimination of the background from the irradiated signal. The intensity calibration factor is found to be $1.35 \times 10^{-8}$ pC/counts.

4. Target irradiation by LFEX laser and the implosion-heating experiments using CD-shells with Au-cone

The analyzer is tested to measure energetic electrons from the aluminum plain target with 10 µm thickness irradiated by LFEX laser (maximum energy 10 kJ, the wave length of 1.05 mm, 4 beamlets) [11] with the pulse duration of 4 ps. The analyzer is installed on the Gekko XII Target chamber I at 20.9 degrees against the laser injection direction where is at the rear side of the target. This shot has been done by compression of one beam let LFEX laser. The maximum electron energy of 3 MeV can be observed when the LFEX laser is collimated up to 75 x 110 mm and the laser intensity of $3.5 \times 10^{17}$ W/cm$^2$. The electron spectrometer only detects the escaped electrons over 0.5 MeV into and the amount of the electrons observed are strongly limited by the high electrostatic potential formation by the electrons.

LFEX laser irradiates the CD shells (deuterium polystyrene) with Au cone imploded by the Gekko XII laser. CD-shells specification is 500 µm diameter and 7 µm thickness with gold cone of 30-60 degrees. Mainly 9 laser beams of Gekko XII with 200–400 J/beam are used to compress the CD-shell. The injection timing of LFEX laser is adjusted so as to irradiate the imploed core of CD-shell using the optical delay system between LFEX and Gekko XII. The imploding time is determined by the shell specification and Gekko XII laser intensity. Until now the laser timing does not match each other accurately, we are finding the best timing for heating in the combination of the shell and laser energy.

Figure 2(a) and (b) show the electron exposure signal on IP and the typical energy spectra in three different cases of irradiated CD-Au shells. The real signal can be obtained by the subtracting the x-ray noise because much X-ray still remains on IP in spite of thick metal shielding. The calibration data in Sec. 2 are used to obtain the absolute spectra. In the figure, the uniform spatial distribution is assumed. The spectra in the effective heating cases are different from that in ineffective heating case.

Figure 3(a) shows the LFEX laser energy dependence of the electron flux. The electron flux on Au target is larger than on Al target because the there are more electrons in Au. The electron flux in the simple Au-cone is compared with that in CD-shell with Au cone. In CD-shell with Au cone, the LFEX laser should be injected at the final phase of the shell implosion ideally. However the implosion duration and the life-time of the imploded core are nano-seconds and several tens
pico-seconds, respectively, which are larger than the LFEX laser pulse duration. Therefore the shell implosion process is independent on the energetic electron production mechanism by LFEX laser if the Au cone is not destroyed during the implosion. The electron flux in the Au cone should be equal to that in the CD-shell with Au cone. However the flux in CD-shell is obviously larger than that in Au cone. Two reasons are considerable. One is that the Au cone may be broken during implosion. Another possibility is that the ablation plasma makes short circuit so as to prevent the virtual cathode production. Figure 3(b) shows the injection timing dependence of the electron flux. At 200 ps in advance of the imploding, the Au cone is expected to remain without destroy. However the electron flux on CD-shell with Au cone is ten times larger than that on the simple Au cone. This means that the electron flux is enhanced by the ablation plasma.

In the electron measurement using ESM, we can find whether the heating is successful or not by the spectrum shape rather than the electron flux. At the successful heating, the low energy part in the spectrum is disappeared due to the electron absorption in the imploded core. For example, the intensity of the non-effective heating decreases at 2.3 MeV. However the intensity of the effective heating decreases at 3 MeV as shown in Fig.2(b). The spectra in the effective heating is the non-Maxwellian distribution because the electron may be absorbed by the imploded core. We find the spectrum has strong angular dependence from another detector, which is positioned just in front of the LFEX laser direction. [12]

5. Summary

The high energetic electron measurement is one of the most important issues to research the ignition mechanism. We have been developed the compact electron spectrometer so as to be set on different angular potions. ESM is calibrated by using L-band LINAC in the Institute of Scientific and Industrial Research, Osaka University. The analyzer was tested to measure energetic electrons from the plain target and Au cone irradiated by LFEX laser. The combination experiments between the Gekko XII and LFEX laser starts using CD-shell with Au cone. We can obtain the energy spectra when the hot electron produced by the LFEX laser heats the imploded core of CD-shell produced by the Gekko XII.

6. References

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