§48. An Electron/Ion Spectrometer with the Ability of Low Energy Electron Measurement for Fast Ignition Experiments

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An electron energy spectrometer (ESM) is one of the most fundamental diagnostics in the fast ignition experiment. It is necessary to observe the spectra down to a low energy range in order to obtain the accurate deposition efficiency toward the core. Here we realize the suitable ESM by using a ferrite magnet with a moderate magnetic field of 0.3 T and a rectangular magnetic circuit covered with a steel plate in the inlet side.

We used two parallel ferrite magnet plates with the thickness of 22.5 mm as a bending magnet (Central magnetic field of 0.3 T). In FI experiments, a tunnel type pinhole with the length of several cm and 1 mmϕ is used because there are strong X-rays. The low energy electrons cannot penetrate through the pinhole if there is a leakage magnetic field. Therefore, it is important to decrease the leakage magnetic field by using a magnetic shield around this region. We chose a yoke with a rectangular shape of 15 mm-thick from the magnetic circuit calculation result. The inlet was also covered by the magnetic shield. The magnetic leakage could be decreased to almost the terrestrial magnetism level. The analyzer was very compact since the yoke itself worked as a vacuum vessel. The vacuum in the detection region was separated from that in the pinhole/target chamber by using a small gate valve. Therefore, we could quickly set and remove imaging plates (IPs, BAS-SR2025, Fuji Film) in atmosphere without a vacuum break of the target chamber. The lead shields of 3-15 cm-thick for X-rays surrounded the yoke. We could easily add them if necessary because they were in the air. FIG. 1 shows the schematic view of the ESM. The magnetic field including the leakage magnetic field at each 5 mm point has been measured by using a hall-probe in order to calculate the beam orbit, position, and energy resolution on the IPs. Two IPs which contained a magnetized material were attached directly to the side of the magnets. In a calculation, electrons down to 0.1 MeV can be observed. The dose by X-rays could be minimized since IPs were located along the X-ray direction. Maximum observable energy is determined by the lengths of the magnet and the IPs. However the energy resolution decreases because the incident angle of the electron to the IP increases. We chose 249 mm, which was the length of the commercial base product in the IP. As a result, a maximum observable energy of 112 MeV, which was a suitable value for FI experiments, could be obtained. Ions could be measured at the same time by setting another IP on the other side of the magnet. The absolute value of the electrons/ions can be estimated as follows:(1)X-ray noise reduction, (2) Sensitivity in IPs, (3) Calibration in IP-reader, (4) Incident angle correction to IPs, (5) Pinhole loss.

There are three types of X-ray noise. One comes from the target and reflection by the chamber and walls. The second is generated by hitting the front yoke by the low energy electrons. The third is generated by hitting the side yoke by penetrated electrons to the IP. The second type is more affected. By making space between the IP and the side yoke, the effect could be reduced. X-rays and electrons/ions hit the IP and excite the phosphor in the IP. Excited phosphor emits the luminescence light by laser light (PSL: Photo-stimulated luminescence). PSL is read by the IP-reader (Typhoon FLA7000, GE Healthcare) at 40 min. after the experimental shot. A real electron signal can be obtained by subtracting the X-ray signal from the X-ray plus electron signals on the IP. However, a proper procedure is necessary to obtain accurate values. Digitized value C can be converted to PSL by using calibration data estimated by Williams and Kojima for this IP-reader. The correction against the oblique incidence to the IP is considered. A range of electron is much larger than the areal density of the IP. Therefore, the deposited energy in the IP is almost proportional to the traveling length of the electron in the IP l. l is defined as $d/\sin\theta$, where d and θ are a thickness of IP and an incident angle. Then the corrected value can be obtained by dividing by l. The transparent efficiency in the pinhole is estimated by the calculation based on the leakage magnetic field near the pinhole. ESM was calibrated by the L-band LINAC in the Institute of Science and Industrial Research (ISIR), Osaka University. When the electron beam with the monotonic energy of 16.5 MeV was injected to ESM, ESM could observe it within an accuracy of 0.1 MeV.

In ion measurements, the energy-position relation to the IP and the injection angle can be also obtained by orbit calculation. The ion range is much shorter than the electron range, for example, only 20 μm for protons of 2 MeV. Therefore, the incident angle correction is not necessary in a sensitive layer since all energies of ions are deposited in the IP (120 μm-thick). However, the correction is required in a 6 μm-thick polyethylene terephthalate (PET) film region. Minimum detection energy is determined to be 0.86 MeV by the deposition in the PET film. PSL is proportional to the deposited energy in the IP and is almost independent of the particle species. Therefore even if the PSL for the ion is unknown, the absolute flux of the ion can be obtained.

The LFEX laser (three beams, 1.053 μm) energy is from 500 J to 1.6 kJ. The pulse width is 1.5 ps in the experiments. The energy of 82% is focused at the focal spot size (50%) of 40 μmϕ. Gekko XII (9-12 beams, 250 J/beam, 0.53 μm) is used for the implosion of a deuterated polystyrene ball (200 μmϕ) with the Au or diamond-like-carbon (DLC) cone. ESM was set at the opposite side of the LFEX.10. The central stripe of 15 mm is a beam exposure area, and the other attaches to the side of the magnet (beams do not hit the IP). Although two IPs are set on almost the same position with the same X-ray shield, X-ray noise cannot be found on the IP in the ion channel. This means the outer X-ray shield is sufficient but X-rays come from electrons colliding with inside materials. In noise reduction, we divided the central stripe of 15 mm to three areas (7.5 mm-central, 3.775 mm-sides). However, the real trace of electrons/ions are only 2-3 mm because the pinhole diameter is 1 mmϕ. The real electron/ion signal can be obtained by subtracting side signals (X-ray) from the central signal (electron/ion + X-ray). Lower energy electrons cannot be observed due to the imploded core. Protons and deuterons were observed at the same time on the ion side of the IP. The energy of the protons and deuterons are similar (2 MeV) and mono-energetic. This means those ions were accelerated not by laser acceleration but by a potential caused by electron emission. The deuteron was observed little in the Au-cone. It may be that the configuration of the virtual cathode in the Au-cone is different from that in the DLC.

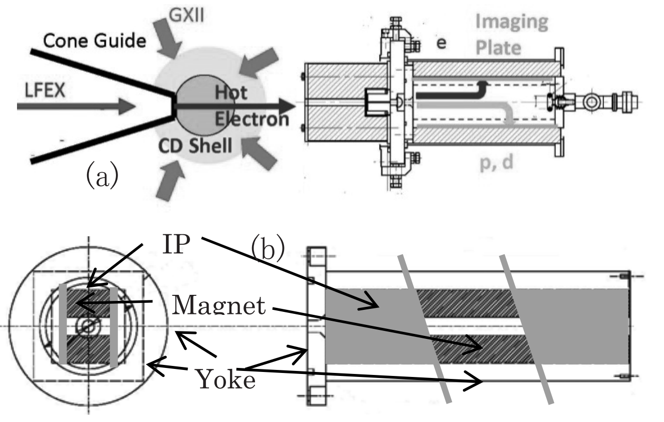

FIG. 1. Schematic diagram of ESM
(a) Experimental arrangement
(b) Schematic diagram of the main part