A Ten-Inch-Manipulator–Based Fast-Electron Spectrometer with Multiple Viewing Angles

H. Habara,[1] T. Iwawaki,[1] K. A. Tanaka,[1,†] T. Gong,[1,‡] M. S. Wei,[2] S. T. Ivancic,[2] W. Theobald,[2] C. M. Krauland,[3] S. Zhang,[3] and G. Fiksel[4]

[1]Graduate School of Engineering, Osaka University, Japan
[2]Laboratory for Laser Energetics, University of Rochester
[3]Department of Mechanical and Aerospace Engineering, University of California at San Diego
[4]Center for Ultrafast Optical Science, University of Michigan
[†]Currently at Extreme Light Infrastructure: Nuclear Physics, Romania
[‡]Currently at Research Center of Laser Fusion, China Academy of Engineering Physics, People's Republic of China

The measurement of angularly resolved energy distributions of MeV electrons is important for gaining a better understanding of the interaction of ultra-intense laser pulses with plasma, especially for fast-ignition laser-fusion research. It is also crucial when evaluating the production of suprathermal (several tens of keV) electrons through laser–plasma instabilities in conventional hot-spot–ignition and shock-ignition research. For these purposes, we developed a ten-inch-manipulator (TIM)–based multichannel electron spectrometer—the Osaka University electron spectrometer (OU-ESM)—that combines angular resolution with high-energy resolution. The OU-ESM consists of five small electron spectrometers set at every 5°, with an energy range from ~40 keV to ~40 MeV. A low-magnetic-field option provides a higher spectral resolution for an energy range of up to ~5 MeV. This versatile diagnostic with a variable electron energy range can be deployed for experiments on the OMEGA and OMEGA EP Laser Systems.

The spectrometer uses permanent magnets in a Ni-coated yoke to disperse the electrons in energy. Assuming that the magnetic-flux density is constant, the electron motion is determined by the Larmor motion according to the electron's kinetic energy, given by

$$E = mc^2\left[\sqrt{\left(\frac{l^2+h^2}{2h}\right)^2\left(\frac{eB}{mc}\right)^2+1}-1\right], \tag{1}$$

where l is the longitudinal position of the signal on the detector from the magnet entrance, h is the height between the electron incident axis and the detector plane, e is the electric charge, B is the magnetic flux density, m is the electron mass, and c is the speed of light in vacuum, respectively. Because fast electrons created by ultra-intense lasers have considerably large emission angles, a collimator is used to guarantee a parallel electron beam into the magnetic field. Consequently, the number of accelerated electrons, N, per solid angle and per energy is given by

$$\frac{\mathrm{d}N^2}{\mathrm{d}\Omega\mathrm{d}E} = \frac{I_{\mathrm{IP}}}{\Delta l\Delta\Omega}\frac{1}{S(E)\varphi}\frac{h}{ceBl}\sqrt{1+\left(\frac{2h}{l^2+h^2}\right)^2\left(\frac{mc}{eB}\right)^2}, \tag{2}$$

where I_{IP} is the signal intensity on the detector, Δl is the spatial resolution of the detector, $\Delta\Omega$ is the solid angle, $S(E)$ is the detector sensitivity, and φ is the fading rate of the signal.[1]

Although it is very important to observe the energy spectrum in different viewing angles, this usually requires multiple electron spectrometers at different port locations around the target chamber. Given that this option is severely restricted because of port availability and interference issues with other diagnostics and laser beams, we maximized the capability of this diagnostic by combining five mini spectrometers at different viewing angles into a module that fits in a single diagnostic shuttle system—the TIM. Figure 1(a) shows a photograph of the OU-ESM. The diagnostic can be inserted into the TIM's on both the OMEGA and the OMEGA EP target chambers. The pointer pin shown at the bottom of Fig. 1(a) is used to align the diagnostic to a given aiming location. Every spectrometer channel is then automatically pointed correctly to the aiming point within the mechanical tolerance. A 20-mm-thick tungsten heavy metal alloy block on the front face with 700-μm-diam holes in front of each magnet serves as a collimator. A large piece of imaging plate (IP) serves as a detector attached to the cover plate of the detector box. Figure 1(b) shows an example of raw data that were taken in a fast-ignition–relevant experiment when a short IR pulse channeled through a preformed, long-scale-length plasma.[2,3] The pre-plasma was formed by a 1-ns, low-intensity UV pulse. A high-intensity, 10-ps pulse (~1×10^{19} W/cm^2) was injected into the long-scale-length plasma. Figure 1(c) shows the inferred electron spectra. An important feature of the system is that the strength of the magnet in each channel can be changed between 0.45 T (high-field operation) and 0.045 T (low-field operation). The detectable energy range in high-field operation is from ~0.6 to ~40 MeV in the inner channels, whereas energy ranges from ~0.6 to ~25 MeV in the side channels. In the low-field operation, the energy range is from ~40 keV to ~5 MeV in the inner channels and from ~40 keV to ~2.5 MeV in the side channels. The five horizontal lines in Fig. 1(b) correspond to the signals from CH1 (bottom) to CH5 (top). In this experiment, CH3 was located on the laser axis. Channel 2 and CH4 were operated in low-field mode, whereas CH1, CH3, and CH5 were in high-field mode.

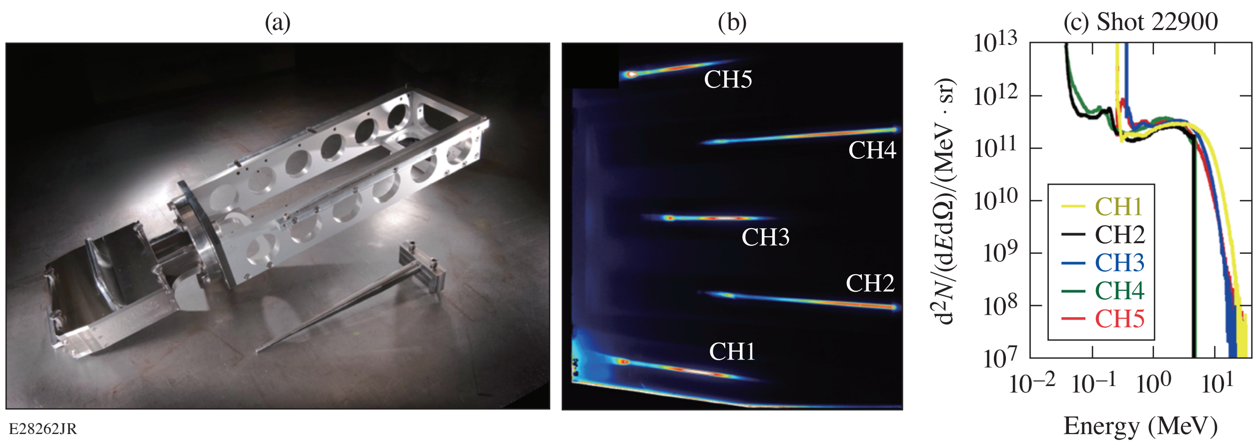

Figure 1
(a) Photograph of the OU-ESM, (b) raw data on an imaging plate, and (c) analyzed fast-electron energy spectra from an OMEGA EP experiment that demonstrated the channeling of an intense 10-ps IR laser pulse through a pre-plasma created by a 2-kJ, 1-ns UV pulse.

This work was fully supported by the Japan/U.S. Cooperation in Fusion Research and Development. Part of this work was also supported by Grant-in-Aid for Scientific Research from the Japanese Society for the Promotion of Science (JSPS) of Japan (Grant No. 15H05751 and 18K03577). This material is also based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856, the University of Rochester, and the New York State Energy Research and Development Authority.

1. K. A. Tanaka *et al*., Rev. Sci. Instrum. **76**, 013507 (2005).
2. L. Ceurvorst *et al*., Phys. Rev. E **97**, 043208 (2018).
3. S. Ivancic *et al*., Phys. Rev. E **91**, 051101(R) (2015).