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Experimental Study on Near-Critical-Density LWFA using a Microcapillary

[1]Michiaki Mori, [2]Ernesto Barraza-Valdez, [1]Hideyuki Kotaki, [1]Yukio Hayashi, [1]Masaki Kando, [1]Kiminori Kondo, [3]Tetsuya Kawachi, [4]Donna Strickland, [2]Toshiki Tajima

[1] Kansai Photon Science Institute, National Institutes for Quantum and Radiological Science and Technology

[2] Department of Physics and Astronomy, University of California, Irvine

[3] National Institutes for Quantum and Radiological Science and Technology

[4] Department of Physics and Astronomy, University of Waterloo

e-mail (speaker): mori.michiaki@qst.go.jp

Laser wake-field acceleration (LWFA) features an acceleration field >1000 times stronger than that of conventional accelerators [1]. Using this technique, it is possible to achieve drastic miniaturization not only for large accelerators but also for small accelerators with lower energy. Especially in the sub-MeV energy range, there is a growing demand for applications such as electron microscopy, sterilization, lithography, and medicine. Roa proposed the potential use of a laser-driven electron beam with sub-MeV energy for high-dose-radiation (HDR) cancer therapy [2]. They compared the cost with the conventional HDR therapy and clarified the advantage of using a laser-driven electron beam. To generate such low-energy electrons, Nicks has theoretically shown that the use of high-density plasma near the critical density is beneficial [3], and the proof of principle was awaited. In this study, we demonstrated the generation of sub-MeV electrons through an interaction between a high-intensity laser and a high-density plasma near critical density.

The experiments were conducted using a terawatt Ti:Sapphire laser, JLITE-X, at the KPSI QST. The terawatt laser beam was focused into a microcapillary array target with a 30 μm spot diameter at 13.5% of the peak intensity by an f/22 off-axis parabola mirror. The microcapillary plate target consists of a two-dimensional microcapillary array with a 27mm effective diameter that is attached to a 30 mm glass plate. The microcapillary hole's diameter and capillary length are 10μm and 410μm, respectively. The energy distribution or the angular distribution of the electron beam was measured by an imaging plate (IP), which is sensitive to electrons, X-rays, and ions. The energy distribution of the electron beam was determined by using an energy analyzer (electro spectrometer), which is placed in front of the IP.

Figure 1 shows the typical energy spectra of generated electrons. The pump laser intensity was varied from 4×10^{16} W/cm^2 to 1×10^{18} W/cm^2 by changing the pump laser pulse duration. We observed the hot tail above 200 keV showed a Maxwell-Boltzmann-like profile at lower laser intensity (< 2.5×10^{17} W/cm^2). This feature was changed by increasing the laser intensity. We observed a two-temperature profile at a higher laser intensity (2.5×10^{17} W/cm^2- 4×10^{17} W/cm^2). At the highest intensity of 1×10^{18} W/cm², it formed a humped structure with a peak at around 300 keV. These electron beams were highly collimated. We observed a beam divergence of approximately 30 milliradians at half-angle. The electron beam has a very weak dependence on the pump laser intensity, and it is close to the field of view angle at the capillary tube (α ~ 25 mrad, where α is the half-angle). From these results, the radiation dose of the electron beam is estimated to be ~500 Gy at 1 cm from the source. Such high absorbed dose and good directivity are expected for medical applications with sharp pinpoint irradiation such as a laser scalpel.

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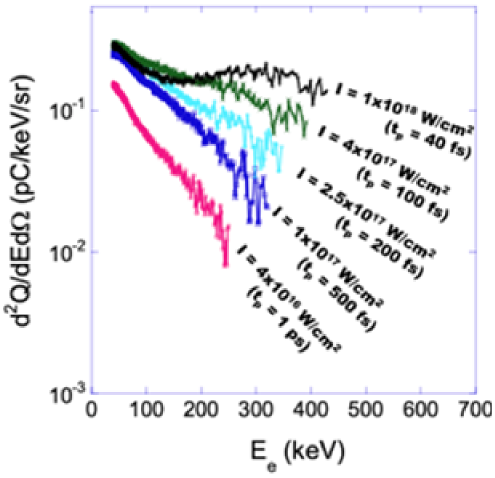

Figure 1 Experimentally obtained electron energy spectra for various laser pump intensities. The effective laser energy incident into the microcapillary was constant (E_{eff} = 27 mJ) [4].

References

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