Microcoulomb (0.7±0.4/0.2-μC) Laser-Plamsa Accelerator on OMEGA EP

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Laser-plasma accelerators (LPA's) driven by short-pulse, kilojoule-class lasers provide a path to producing compact sources of high-charge, high-energy electron beams for conversion into x-ray and positron sources. Here, we report on the first LPA driven by a short-pulse, kJ-class laser (OMEGA EP) connected to a multikilojoule high-energy-density science (HEDS) driver (OMEGA).

Experiments were performed on the OMEGA EP Laser System.[1] The laser was run with a central wavelength λ of 1054 nm at best compression (pulse duration of 700±100 fs). To improve the quality of the focal spot and increase the Rayleigh length, the focusing geometry of the short-pulse laser beams was converted from its nominal *f*/2 geometry by using spatially filtered apodizers[2] located at the injection plane before amplification in the Nd:glass beamline to control the beam diameter and generate an *f*/5, *f*/6, *f*/8, or *f*/10 geometry. At focus, the R_{80} spot size of the laser (i.e., radius that contains 80% of the total energy) was between 11.5 and 19.9 μm. The apodized laser energy varied from 10 to 115 J, which produced on-target peak normalized vector potentials $\left[\alpha_0 \cong 8.6 \times 10^{-10} \sqrt{I_0\left(\mathrm{W/cm^2}\right)}\, \lambda(\mu\mathrm{m})\right]$, where I_0 is the vacuum intensity, between 1.8 and 6.7. The apodized laser pulse was focused 500 μm inside a Mach 5 gas jet with nozzle diameters varying between 2 and 10 mm as shown in Fig. 1(c). The gas was 100% He, and the resultant plasma densities in the plateau ranged from 1.5×10^{18} to 4.5×10^{19} cm^{-3}, depending on nozzle diameter and backing pressure.

Figure 2(a) shows that the total charge in the electron beams scales approximately linearly with a_0. The data shown are for a 6-mm-diam nozzle operating at a plasma density of 5×10^{18} cm^{-3}, but plasma densities of 1, 2, and 3×10^{19} cm^{-3} showed the same trend. This trend was also seen for 4-mm-diam nozzles operating at 1×10^{19} cm^{-3} and 10-mm-diam nozzles at densities of 0.2, 0.5, 1, and 3.5×10^{19} cm^{-3}. The charge in the electron beams was calculated using the method described in Ref. 3.

Figure 2(b) shows that the charge in the electron beam scales approximately linearly with plasma density until a density of 1×10^{19} cm^{-3}. The two data sets shown each have a different a_0 value; the rate of increase of charge with plasma density is steeper for the higher a_0 value. The highest-charge electron beam measured in this experiment, which had a charge of 707±429/224 nC, was produced at an a_0 of 6.6 and a plasma density of 7.5×10^{18} cm^{-3}. Using an electron energy of 17.9 MeV, which is the weighted average electron energy of the representative electron spectrum from this experiment [Fig. 1(d)], this charge corresponds to a conversion efficiency from laser energy to electron energy of 11%. The details of this calculation can be found in Ref. 3. Of that total energy, 30%, 50%, and 90% is contained in electrons with energies below 18.5 MeV, 25.6 MeV, and 85.1 MeV, respectively. Figure 2(c) shows that when the charge scaling was extended to higher plasma densities, the maximum charge produced plateaus with density. A similar trend was seen for data taken on a 6-mm-diam nozzle for both a_0 values of 5 and 6.

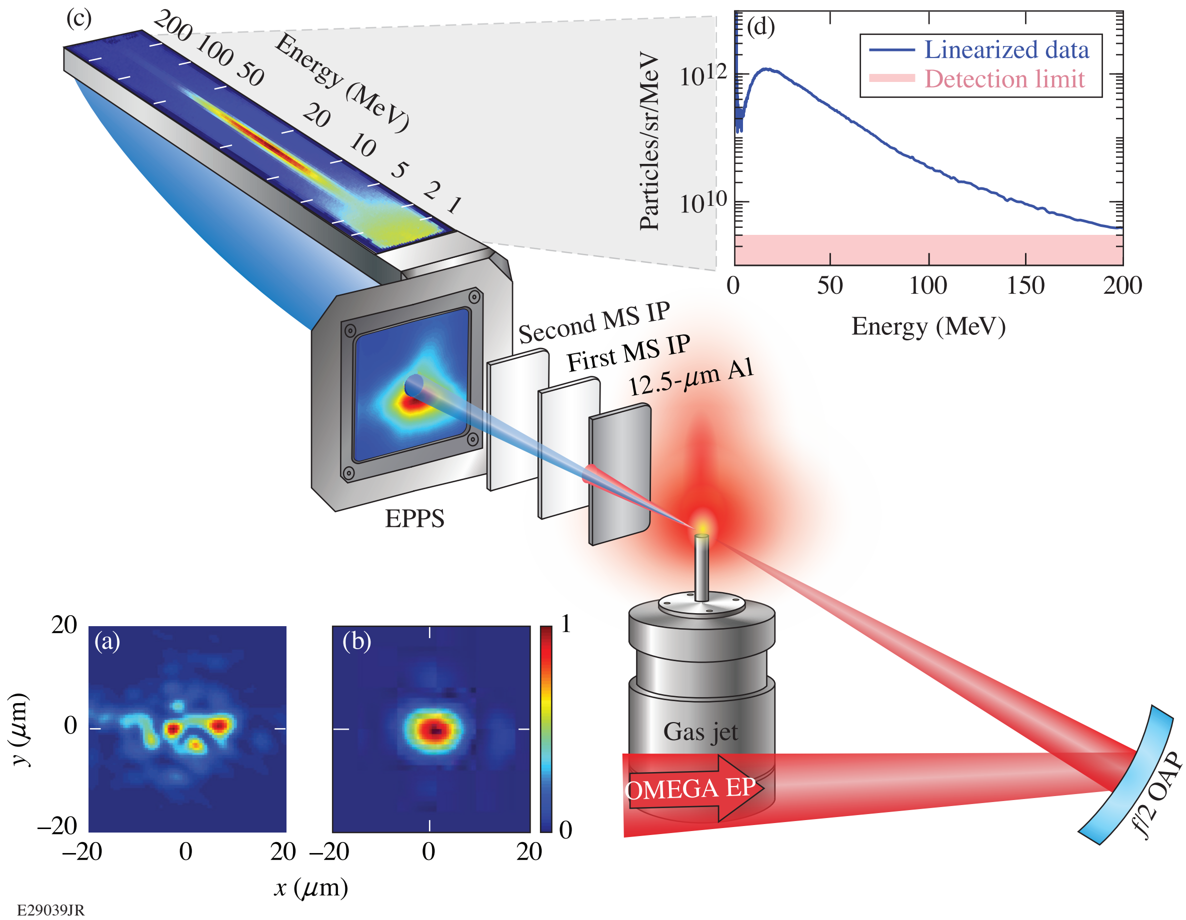

Figure 1
[(a),(b)] Examples of a target spot at the focal plane for the standard *f*/2 focus and the *f*/6 apodized focus, respectively. The peak fluence per energy for (a) and (b) is 7.9 and 11.8×10^5 cm^{-2}, respectively. (c) Relative layout of the laser, target, and diagnostics. (d) Electron spectrum from an $a_0 = 5.1$ laser shot propagating through a plasma density of 5.4×10^{18} cm^{-3} generated by a 6-mm-diam nozzle. The shaded region marks the detection limit of the electron–positron–proton spectrometer (EPPS). OAP: off-axis parabola.

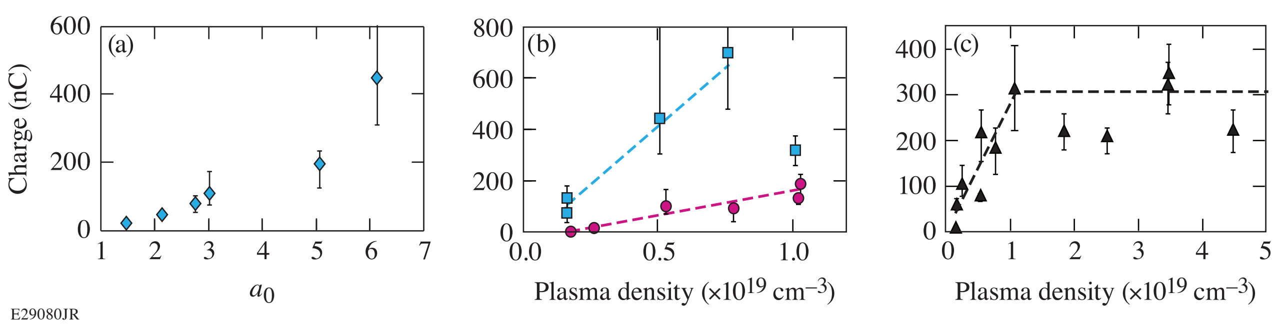

Figure 2
(a) Electron-beam charge versus a_0 for a 6-mm-diam nozzle operating at a plasma density of 5×10^{18} cm^{-3}. Electron-beam charge as a function of plasma density (b) up to $\sim 1 \times 10^{19}$ cm^{-3} for $a_0 \sim 3$ (magenta circles) and $a_0 \propto 6$ (blue squares) for a 6-mm-diam nozzle and (c) over the entire sampled plasma density range for $a_0 \sim 5$ and a 10-mm-diam nozzle. The dashed lines are added to guide the eye.

A microcoulomb-class, high-conversion-efficiency laser-plasma accelerator was demonstrated, providing the first laser-plasma accelerator driven by a short-pulse, kJ-class laser (OMEGA EP) connected to a multi-kJ HEDS driver (OMEGA). The produced electron beams have maximum energies that exceed 200 MeV, divergences as low as 32 mrad, record-setting charges that exceed 700 nC, and laser-to-electron conversion efficiencies up to 11%. The total charge in the electron beam is found to scale with both a_0 and plasma density. Based on these empirical scalings, higher-charge electron beams may be possible using laser systems that can deliver a_0 values larger than the maximum a_0 of 6.7 produced in this configuration while still maintaining longer *f* numbers and near-Gaussian, single-moded laser spots on target.

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