Long-term evolution of electron-beam-driven plasma wakefields in radially bounded plasma

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In plasma wakefield accelerators, intense laser or particle beams drive strong Langmuir waves with the energy density as high as the rest energy of plasma electrons. A large fraction of this energy remains in the plasma after passage of the accelerated beam and causes rapid expansion of the plasma column boundary. Under conditions of FACET experiment [1] with lithium plasma of density $10^{17}\text{ cm}^{-3}$, the expansion velocity exceeds $10^6\text{ m/s}$ for over 1 ns. The energy initially stored in coherent electron oscillations first transforms into incoherent motion of plasma electrons with multi-keV velocities and, later, into radial motion of plasma ions. The resulting stream of fast ions escapes the initial plasma channel, penetrates the surrounding neutral gas and creates some “seed” plasma there through impact ionization. Once new ions appear at a given location, more electrons come there and further ionize the gas causing near-exponential growth of the plasma density. The energy needed for gas ionization is small compared to the initial wave energy, so the plasma boundary expands with nearly constant velocity corresponding to the velocity of the fast ion front, with the plasma amount growing proportionally. Numerical simulations that include the described effects show quantitative agreement with results of ps-time-resolved optical shadowgraphy that measured evolving plasma density profile at FACET.

References