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Optical control of electron trapping: Generation of comb-like electron beams for tunable, pulsed, multi-color radiation sources[1]

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All-optical control over the electron phase space in laser-plasma accelerators enables production of “designer” electron beams that can be optimized for specific applications. GeV-scale acceleration with sub-100 TW (rather than PW) laser pulses, at repetition rates orders-of-magnitude higher than permitted by existing PW facilities, in a few-mm (rather than cm) length plasmas, requires maintaining an accelerating gradient as high as 10 GV/cm. This, in turn, dictates acceleration in the blowout regime in a dense plasma ($\sim 10^{19}$ cm^{-3}). These highly dispersive plasmas rapidly transform the drive pulse into a relativistic optical shock, causing the plasma wake bucket (electron density bubble) to constantly expand, trapping background electrons, greatly degrading beam quality. We show that these effects can be overcome using a high-bandwidth driver (over 1/2 the carrier frequency) with a negative frequency chirp. Temporally advancing higher frequencies (thus compensating for the plasma-induced nonlinear frequency red-shift) and propagating the pulse in a plasma channel (to suppress diffraction of its leading edge) delays pulse self-steepening through electron dephasing and extends the dephasing length. As a result, continuous injection is suppressed and electron energy is boosted to the GeV level. In addition, periodic self-injection in the channel produces a sequence of femtosecond-length, quasi-monoenergetic bunches. The number of these spectral components, their charge, energy, and energy separation can be controlled by varying the channel radius and length, whereas accumulation of the noise (viz. continuously injected charge) is prevented by the negative chirp of the driver. This level of control is hard to achieve with conventional accelerator techniques. It is demonstrated that these clean, polychromatic, comb-like beams can drive high-brightness, tunable, multi-color gamma-ray sources.

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