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Serguei Y. Kalmykov
University of Nebraska-Lincoln, s.kalmykov.2013@ieee.org

Bradley Allan Shadwick
University of Nebraska-Lincoln, shadwick@unl.edu

Xavier Davoine
CEA, DAM, DIF, 91297 Arpajon Cedex, France

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ALL-OPTICAL CONTROL OF ELECTRON TRAPPING IN TAPERED PLASMAS AND CHANNELS*

S. Y. Kalmykov and B. A. Shadwick
Department of Physics and Astronomy,
University of Nebraska - Lincoln,
Lincoln, NE 68588-0299 USA

Xavier Davoine
CEA, DAM, DIF, 91297 Arpajon Cedex, France

The radiation pressure of a multi-terawatt, sub-100 fs laser pulse propagating in an under-dense plasma causes complete electron cavitation. The resulting electron density "bubble" guides the pulse over many Rayleigh lengths, leaving the background ions unperturbed while maintaining GV/cm-scale accelerating and focusing gradients. The shape of the bubble, and, hence, the wakefield potentials, evolve slowly, in lock-step with the optical driver. This dynamic structure readily traps background electrons.[1] The electron injection process can thus be controlled by purely optical means.[2,3]

Sharp gradients in the nonlinear refractive index produce a large frequency red-shift ($\Delta\omega \sim \omega_0$), localized at the leading edge of the pulse.[2,3] Negative group velocity dispersion associated with the plasma response compresses the pulse into a relativistic optical shock (ROS). ROS formation slows the pulse (and the bubble), reducing the electron dephasing length and limiting energy gain.[4] Furthermore, the ponderomotive force due to the ROS causes the bubble to constantly expand, trapping copious unwanted electrons, polluting the electron spectrum with a high-charge, low-energy tail.[1,2]

Here, we demonstrate a new, all-optical approach to compensating for the increase in pulse bandwidth, thereby delaying ROS formation and thus producing high quality, GeV-scale electron beams with 10-TW-class (rather than PW-class[4]) lasers in mm-scale (rather than cm-scale[4]), high-density plasmas ($n_{e0} > 5 \times 10^{18}$ vs. 10^{17} cm^{-3}). We show that *a negatively chirped drive pulse with an ultra-high (~ 400 nm) bandwidth*: extends the electron dephasing length; prevents ROS formation through dephasing; and almost completely suppresses continuous injection.

Precise compensation of the nonlinear frequency shift can be achieved using a higher-order chirp extracted from reduced simulation models. ROS formation can be further delayed by using a plasma channel to suppress diffraction of the pulse leading edge, minimizing longitudinal variations in the pulse. Plasma density tapering further delays dephasing, providing an additional boost in beam energy.

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