2013

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

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

Plasma Science (ICOPS), 2013 Abstracts IEEE International Conference on
Year: 2013
Pages: 1 - 1, DOI: 10.1109/PLASMA.2013.6633483

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.

1. S. Y. Kalmykov *et al*., Phys. Plasmas **18**, 056704 (2011).
2. S. Y. Kalmykov *et al*., New J. Phys. **14**, 033025 (2012).
3. S. Y. Kalmykov *et al*., AIP Proc. **1507**, 289-294 (2012).
4. W. Lu *et al*., Phys. Rev. ST-AB **10**, 061301 (2007).

---

* Work supported by the U.S. DOE Grant DE-SC0008382 and DOD AFOSR Grant FA9550-11-1-0157.