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Electron self-injection into an evolving plasma bubble: toward a dark current free GeV-scale laser plasma accelerator[1]

SERGUEI KALMYKOV, University of Nebraska - Lincoln

A bubble of electron density created by the radiation pressure of a short laser pulse can travel with the driver over many centimeters and accelerate electrons trapped from the ambient plasma to a few GeV. Nonlinear refraction and depletion of the driving pulse cause variations of the bubble shape and potentials; these, in turn, can either stimulate or extinguish electron self-injection and thus directly affect the process of electron beam formation and determine its final characteristics. The new results [1] show that in low-density plasmas relevant to the next generation of GeV-scale laser- plasma accelerators, expansion of the bubble triggers self- injection. The bucket stabilization and contraction stops injection and thus limits electron beam charge and duration. Laser spot size oscillations caused by nonlinear refraction can induce the desired sequence of bubble expansion and shrinkage. Periodic repetition of the sequence, however, can degrade the beam quality [2]. Using dense plasma slabs in the role of nonlinear lenses helps stabilize the bubble pulsations, achieve phase space rotation, and produce a quasi-monoenergetic bunch well before the de-phasing limit [3]. 3D particle-in-cell simulations complemented with the Hamiltonian diagnostics of electron phase space demonstrate robustness of the concept over a broad range of parameters. Modeling also shows that a single- shot non- collinear optical probing (frequency-domain tomography [4]) can facilitate direct observation of bubble evolution and associate it with the observed electron beam characteristics.

[1] S. Kalmykov et al., PRL 103, 135004 (2009).
[2] S. Y. Kalmykov et al., New J. Phys. 12, 045019 (2010).
[3] S. Y. Kalmykov et al., Plasma Phys. Control. Fusion 52(9) (2010) (in press).
[4] P. Dong et al., New J. Phys. 12, 045016 (2010).

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