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Coherent control of plasma dynamics[1]

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The concept of coherent control - precise measurement or determination of a process through control of the phase of an applied oscillating field - has been applied to numerous systems with great success. Here, we demonstrate the use of coherent control on plasma dynamics in a laser wakefield electron acceleration experiment. A tightly focused femtosecond laser pulse (10 mJ, 35 fs) was used to generate electron beams by plasma wakefield acceleration in the density down ramp. The technique is based on optimization of the electron beam using a deformable mirror adaptive optical system with an iterative evolutionary genetic algorithm. The image of the electrons on a scintillator screen was processed and used in a fitness function as direct feedback for the optimization algorithm. This coherent manipulation of the laser wavefront leads to orders of magnitude improvement to the electron beam properties such as the peak charge and beam divergence. The laser beam optimized to generate the best electron beam was not the one with the "best" focal spot. When a particular wavefront of laser light interacts with plasma, it can affect the plasma wave structures and trapping conditions of the electrons in a complex way. For example, Raman forward scattering, envelope self-modulation, relativistic self-focusing, and relativistic self-phase modulation and many other nonlinear interactions modify both the pulse envelope and phase as the pulse propagates, in a way that cannot be easily predicted and that subsequently dictates the formation of plasma waves. The optimal wavefront could be successfully determined via the heuristic search under laser-plasma conditions that were not known *a priori*. Control and shaping of the electron energy distribution was found to be less effective, but was still possible. Particle-in-cell simulations were performed to show that the mode structure of the laser beam can affect the plasma wave structure and trapping conditions of electrons, which subsequently produces electron beams with a different divergence. The proof-of-principle demonstration of coherent control for plasmas opens new possibilities for future laser-based accelerators and their applications. This study should also enable a significantly improved understanding of the complex dynamics of laser plasma interactions.

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