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HOT ELECTRON GENERATION FOR FAST IGNITION

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R.B. STEPHENS, K.U. AKLI, T. BARTAL,[1] F.N. BEG,[1] S. CHAWLA,[1] C.D. CHEN,[2] H. CHEN,[3] E.A. CHOWDHURY,[4] R. FEDOSEJEVS,[5] R.R. FREEMAN,[1,2,6] E.M. GIRALDEZ, D.S. HEY,[3] D. HIGGINSON,[1] M.H. KEY,[3] A.J. LINK,[4] T. MA,[1] A.G. MacPHEE,[3] H.S. McLEAN,[3] D. OFFERMANN,[4] V.M. OVCHINNIKOV,[4] P.K PATEL,[3] Y. PING,[3] D.W. SCHUMACHER,[4] Y.Y. TSUI,[5] L.D. van WOERKOM,[4] M.S. WEI,[1] B. WESTOVER[1] and T. YABUUCHI[1]

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[1]Department of Mechanical and Aerospace Engineering, University of California San Diego, La Jolla, California
[2]Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts
[3]Lawrence Livermore National Laboratory, Livermore, California
[4]Department of Physics, The Ohio State University, Columbus, Ohio
[5]Department of Electrical & Computer Engineering, University of Alberta, Edmonton, Alberta Canada
[6]Department of Applied Science, University of California-Davis, Livermore, California

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The basic idea for the Fast Ignition (FI) approach to Inertial Confinement Fusion (ICF) is straightforward in concept: The fuel capsule is imploded onto the outer tip of a hollow cone; a short pulse laser is focused through the cone to relativistic electrons; these electrons travel through the cone tip and into the assembled DT [1]. However, the actual realization of the technique, and particularly the injection of the hot electrons, requires laser-plasma interactions at an extreme of intensity and resulting currents only recently accessible, and their complexities not completely understood. Early analysis [2] of the process using laser-generated hot electrons concluded that one must deposit hot electron energy, E_{ign} ~ 10-20 kJ, within τ_{ign}~ 30 ps. More recent, detailed simulations [3] show the strong sensitivity of the energy requirement on details of the laser-generated electrons: Conversion efficiency, energy spectrum, and divergence. Those parameters depend sensitively on details of the laser-plasma interface (LPI), but the connection between interface and the resulting electrons, let alone control of their parameters, is not well understood because of both the influence of the laser pulse on the interface, and difficulty of making electron measurements inside dense plasmas.

Experimental campaigns to rectify this situation have been carried out at the Titan laser facility at Lawrence Livermore National Laboratory (LLNL) that take advantage of the improved laser pulse diagnostics [4] allowing characterization of the (vacuum) laser focus and prepulse on every shot. Experiments have been performed to study: 1) *in situ* electron spectrum, 2) laser-to-electron coupling dependence on pre-plasma, 3) cone geometry affecting electron divergence.

In-situ electron spectrum. Electron energies are related to incident laser intensity by scaling relations that vary with the scale-length of the plasma gradient at the critical plasma density [5]. Simulations suggest a short scale-length plasma at the LPI allows higher laser intensity (~10^{20} W/cm^2) to produce the 1-3 MeV electrons that are optimum for core heating [3]. Measurement of the coupling efficiency into this energy range has been indirect (vacuum electron spectrometers [6], Cu-K_α spectrometery [7]). Bremsstrahlung radiation from a series of experiments on flat foils has been used to determine *in situ* electron conversion efficiency [8]. Results indicate I = $10^{19\text{-}20}$ W cm^{-2} as a useful intensity, higher than previously expected, but still, because of the Titan prepulse (~10 mJ), not as high as predicted for a sharp interface.

Laser-to-electron coupling dependence on pre-plasma. Conversion in gold cones of photon energy to useful electrons has been characterized using 1 mm long, 40 μm ϕ copper wires to extract the forward-going electrons for analysis [7]. Results show their number substantially decreasing with increasing pre-plasma in the cone. The effect already noticeable at Titan intrinsic <10 mJ prepulse, and numbers decreasing by 10× with prepulse increasing to ~ 1 J. This is consistent with PIC simulations showing the laser-plasma interface becoming increasingly more stochastic, resulting in increasing divergence, with added prepulse, and that this effect is much more severe in a narrow cone than on a flat surface [9]. This data will define contrast required of the ignition beam in integrated experiments.

Cone geometry affecting electron divergence. Experimental characterization of the electron divergence from inside a cone tip requires removal of extraneous barriers. Unlike the cone-wire targets described above, electrons created by the ignition pulse at the tip of a reentrant cone FI target can escape the cone into the surrounding plasma blown off from compressing the capsule. A "buried cone" target (conical hole in a block of Al) was designed to simulate that condition. Fluorescing layers buried in the aluminum block beyond the cone tip show the electron divergence in this case to be the same as previously observed for flat foils (~40°) only if the cone tip is 90 μm ϕ; it is much larger for 30 μm ϕ. Refining that data, and determining its sensitivity to pre-existing plasma (~10 mJ for this experiment), will put constraints on the point design cone geometry.

In conclusion, we have developed techniques for more direct, *in situ*, characterization of laser-produced electron parameters and are using them to understand their sensitivity to the laser-plasma interface, particularly as affected by the laser-prepulse. We find that the ignition-laser-prepulse-induced modification of the laser plasma interface has a strong influence on the parameters of laser-produced hot electrons. Even small amounts (of order 10 mJ) cause the electron spectrum to be hotter and more divergent than otherwise. And the geometry of a narrow cone tip increases those effects.

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