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***O-3.001**, Wednesday June 29, 2005*

High Density and High ρR Fuel Assembly for Fast Ignition Inertial Confinement Fusion

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A method to assemble thermonuclear fuel at high densities, high ρR and low temperature is presented. Massive cryogenic shells can be imploded with a low implosion velocity on a low adiabat using the relaxation laser-pulse technique.[1] While the low implosion velocity yields a low temperature hot spot, the low adiabat of the fuel leads to large peak values of the density and areal density. The low velocity and the shaped adiabat[1] have also mitigating effects on the growth of hydrodynamic instabilities that should not significantly impact the fuel assembly of such massive shells. One dimensional simulations show that a 25kJ driver can assemble a 0.07mg, 860μm in diameter, cryogenic wetted-foam shell with a low implosion velocity of about $2.5 \bullet 10^7$cm/s reaching peak ρR of 0.7-0.9g/cm^2, peak densities of 700-950g/cc and relatively low central temperatures of about 3keV. The hot spot volume at time of peak ρR is only 20% of the high density volume above 300g/cc. This cold and dense fuel assembly is optimal for Fast Ignition[2] inertial confinement fusion.

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1. K. Anderson and R. Betti, Phys. Plasmas 11, 5 (2004)
2. M. Tabak *et al.*, Phys. Plasmas 1, 1626 (1994).

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Observation of Ion Temperatures Exceeding Electron Temperatures in PetaWatt Laser-Solid Experiments

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Neutron time of flight signals have been observed with a high resolution neutron spectrometer using the PetaWatt arm of the Vulcan laser facility at Rutherford Appleton Laboratory from plastic sandwich targets containing a deuterated layer. The neutron spectra have two elements: a high-energy component generated by beam-fusion reactions and a component around 2.45 MeV, most likely to be thermonuclear in origin. The ion temperatures calculated from the neutron signal width clearly demonstrate a dependence on the front layer thickness and are significantly higher than electron temperatures measured under similar conditions. The ion heating process is intensity dependent and is not observed with laser intensities on target below 10^{20} W cm^{-2}. It is shown that process is also strongly dependent upon the intensity pre-pulse level. The measurements are consistent with a coupled two-step plasma instability process that cascades the laser energy directly to the ions. The implications for fast ignition will be discussed.

Application of laser-accelerated high-energy protons for isochoric heating of matter

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We have evaluated the interest of using laser-accelerated protons to heat matter isochorically and compared it to heating by fast electrons. The experiment was performed using the two intense short pulses of the LULI 100 TW facility with 15-20 J energy and > 10^19 W.cm^-2 intensity each. One beam, focused on a 10 micron thick Au foil, generated forward a laminar proton beam with a maximum energy of 16 MeV. This proton beam irradiated and heated a secondary target positioned after a vacuum gap. The heating was diagnosed in three different ways: (i) by 1D and 2D time-resolved measurement of the optical self-emission of the heated target rear-surface, (ii) by time-resolved interferometry of a chirped probe beam reflecting on the heated target rear-surface, (iii) by x-ray absorption spectroscopy of the secondary target using a laser-produced backlighter. Detailed results as a function of the Z and the thickness of the secondary target as well as analysis, including a full modeling of the target heating with a hydro-code (MULTI) coupled to a proton energy deposition code, will be presented. We have also studied the efficiency of heating as a function of the primary target topology, i.e. either flat, which results in a diverging proton beam, or curved, which has the ability of focusing partly the proton beam.

Charge dynamics and proton acceleration in ultrashort laser-solid interactions

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A series of recent experiments carried out at the Rutherford Appleton Laboratory (RAL) and at the LULI laboratory have investigated the e.m. fields generated by the flow of energetic electrons driven by the laser pulse in solid target interactions, at intensities in the range 10^{18-19} W/cm^2. Deatiled information on global target charge-up and on impulsive fields at the rear surface leading to the acceleration of multi-MeV ion beams has been obtained by using proton probing diagnostics. The evolution of the electric field during the subsequent beam expansion has been resolved with ps temporal resolution, revealing the presence of a peak at the ion front, followed by a constant field. Particle probing from different lines of sight allowed the reconstruction of the 3-dimensional structure of the electric and magnetic fields present near the target surface. The dependence of the field structure on target material and thickness, and the effect of target geometry (wires, cylindrical targets) on the ion front evolution have also been studied. The experimental data are compared with Particle in Cell and Lagrangian simulations, by using 3-D particle tracers to reconstruct the probe particle deflections in field configurations derived from the codes. Good agreement has been obtained between theoretical predictions and experimental findings, particularly for what concerns field structure, front evolution and final ion energy.

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Direct Diagnostic of Multi-Temperature Fast Electrons Beams on UHI Laser-Solid Interactions by Optical Transition Radiation Diagnostics

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Within the context of fast electron transport in dense matter, we report on results from high repetition rate-type ultra-intense laser (up to 9 10^{19} W/cm^2) interaction with Aluminium foil targets. In such extreme interaction conditions, an intense and collimated supra-thermal electron current is injected from the plasma created on the laser focal spot into the cold interior of the target. A detailed characterisation of the accelerated hot electrons is fundamental for the global understanding of the highly complex physics involved in its generation and transport through dense matter, ruled by both collisions and self-induced field effects, and of crucial importance for several applications like the laser-produced proton and heavy ion beam sources and the inertial fusion fast ignitor.

The geometry and dynamics of the fast electron propagation in the conducting targets has been directly investigated by means of the Optical Transition Radiation (OTR) emitted when the fast electrons cross the target-into-vacuum boundary. We estimate a fast-electron population with a temperature of 1 MeV and a total kinetic energy of about 50% of the on-target laser energy. A simultaneous coherent and incoherent character of the emitted radiation allowed to conclude on both the micro-bunching and the small radial spreading of the relativistic electron flux through solid targets with up to 200 μm thicknesses. A highly relativistic component on the electron distribution is pointed out. We discuss on if it corresponds to a higher temperature (between 5 and 10 MeV) or just to the tail of the 1 MeV bulk population. The OTR-based diagnostics reveal to be the only capable to characterize in detail the form of the electron distribution at high energies.

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Experiment vs. Theory on Electric Inhibition of Fast Electron Penetration of Targets

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There has been considerable discussion of stopping mechanisms of laser generated fast electrons in materials. Of special note is the effect of electric fields under the conditions in which the density of the fast electrons is far less than the density of the background electrons, but the material has a finite resistivity. Under such conditions, the fast electron penetration is expected to be a function of not only the mean energy of the laser generated electron distribution, but of their relative density to background electrons, as well as the magnitude and temperature dependence of the material resistivity. *In this paper we present new experimental results of penetration images of fast electrons in normal density materials using a high resolution crystal imaging system transverse to the electron flow. Our results show striking images that provide obvious evidence of the electric inhibition, as well as the lateral spreading of the fast electrons.* By analyzing the images, and correcting for aberrations and distortions introduced in the imaging system, we are able to extract the penetration depth of the electrons into the material, and an excellent measure of the transverse spreading of the electron beam as a function of its penetration depth. We compare the observed penetration depth to stopping models built upon electrostatic potential development due to the return current interaction with the material resistivity. We find good agreement between theories based upon this physical concept and our experiments results. and we relate the conclusions derived from these measurements and calculations to various fast fusion schemes. One conclusion we have reached is that that all measurements of fast electron penetration in materials with normal densities, and temperatures less than approximately a 1 keV, will be overwhelmingly dominated by electric field inhibition. This is because ALL materials increase their resistivity with increasing temperature until they reach a temperature on the order of 1 keV. Only for temperatures greater than 1 keV do materials enter the so-called “Spitzer” regime, where increasing temperatures result in decreasing resistance (the condition required for high conductivity channels with little or no electric inhibition). Until facilities are available to conduct charge transport measurements on materials heated to temperatures greater than 1 keV, it may be feasible to use lower temperature targets shock-compressed to higher densities, with decreased resistivity, thus providing the opportunity to explore the development of high conductivity channels.