FUSION SCIENCE CENTER RESEARCH ACTIVITY
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RICCARDO BETTI
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Laboratory for Laser Energetics

Entirely/Partially Supported by FSC:
PIs: R. Betti
Students: C. Zhou

High Density and High ρR Fuel Assembly for Fast Ignition. The UR-FSC group is developing a technique to assemble thermonuclear fuel for Fast Ignition inertial confinement fusion. A new method is developed to assemble relatively massive cryogenic shells with a low implosion velocity on a low adiabat using the relaxation laser-pulse technique [K. Anderson and R. Betti, Phys. Plasmas **11**, 5 (2004)]. 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 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 inertial confinement fusion. If fully ignited with a 10kJ petawatt pulse, such targets could yield an energy gain in excess of 30.
Both targets and laser pulse are within the current capabilities of the Omega laser facility.

CHUANG REN
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Particle-In-Cell and Hybrid simulations of Fast Ignition targets. The UR-FSC group is developing a simulation capability to simulate fast electron generation and transport in Fast Ignition targets. The current activity includes

(1) Benchmarking LSP against OSIRIS (with J. Myatt of LLE)
We have run both codes on the problem of an electron beam propagating in a plasma (Lee-Lampe, PRL) with similar resolutions and the preliminary results seems statistically similar. LSP runs used full-particle mode and implicit scheme. The next step is for LSP to increase the grid size and time step to see how the result changes.

(2) Space charge effects on current filamenting (With M. Tzoufras and W. Mori of UCLA). We have developed a kinetic theory for current-driven filaments under the space charge influences and are currently doing OSIRIS runs to verify the theory including the threshold and growth rate.

David D. Meyerhofeer
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Warm, cone-in-shell fuel assembly experiments, in collaboration with GA, are in progress on OMEGA. In particular, experiments are being carried out to determine the conditions of the inner surface of the cone at the time the fuel is assembled. In the near future, experimental work will begin to study the details of the EMP generated by laser-target interactions, including the development of optimized diagnostic shielding techniques. The possibilities of using optical diagnostics for filamentation studies will be explored.

CHIKANG LI RICHARD B. PETRASSO
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Plasma Science Fusion Center

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As its contribution to the Fusion Science Center (FSC), the MIT group is focusing on analytic calculations of the electron transport and energy deposition in dense inertial-confinement-fusion (ICF) plasmas. Initial calculations of penetration, blooming, and straggling were completed only for 1 MeV electrons interacting with a homogeneous plasma of 300 g/cc DT at ~5 keV. At present we are extending these calculations to treat electrons with energies from 0.1 MeV to 10 MeV, again interacting in a dense, uniform plasma. After these calculations are completed, various electron distributions, based on different empirical and theoretical models, will be treated in calculating energy disposition, blooming, and straggling.

In addition to this, we are investigating the effect of different screening cutoffs --Debye, Thomas-Fermi, interparticle distance ----upon the calculations. In a related context, we are investigating the differences between dense cold matter stopping and that in dense plasmas.

RICHARD B. STEPHENS FARHAT BEG

General Atomics UC San Diego

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Entirely/Partially Supported by FSC:

General Atomics: Postdoctoral Fellow J. Pasley
Scientist

UC San Diego: Postdoctoral Fellow (tbd)
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Research: We are setting up experiments (in collaboration with OSU, SNL and UTA) to study the resistive effects in the propagation of laser generated fast electrons along wires. RAL experiments last year showed that electrons propagated along a bare wire much further than one would expect from our buried layer data. We observed there that a 200 μm long, 20 μm diameter Cu wire glowed almost uniformly along its length whereas the previous data suggested the intensity would fall by approximately an order of magnitude in that length. Our experiments will investigate the effect of putting CH plastic at the Cu-Vacuum interface and varying the relative amounts of Cu and plastic. Using K_{α} imaging we would be able to observe collimation of electron beam due to discontinuity in resistivity in radial direction. In addition, built-in cone structure at one end of the wires will be used to study collimation relevant to advance fast ignition geometry. The modeling of the experimental conditions will be performed using LSP code with a capability of laser plasma interactions. We will be using the newly constructed Z-PW at SNL for this experiment. All the major diagnostics (electron spectrometer, x-ray pinhole cameras, Thomson parabola, activation counters, etc) will be funded by SNL; it will be our responsibility to make them functional. Our initial activity has been to meet at SNL to review the tasks necessary—for commissioning the laser system, for developing necessary diagnostics, and for defining the experimental details—to field such an experiment this fall.

RICHARD R. FREEMAN
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Principal Investigator

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Research: We have been studying a stopping mechanism of laser generated fast electrons by induced electric fields. These fields arise from the interaction of the return current in the material with the material's resistivity. Since all normal temperature materials have their resistivity increase with temperature until a temperature of approximately 1 keV, the "ohmic" potential that the fast electrons must overcome increases as the temperature of the material begins to climb from its room temperature value. The result is that the fast electrons are stopped in the material in distances much shorter than would be expected from scattering loss. This effect is now understood to depend on a number of parameters, including the number of fast electrons generated, the mean energy of the generated distribution, and the base-line value of the resistivity of the material. We have come to understand that virtually all experiments on electron transport conducted up to this point are providing information that is not really relevant to fast ignition. In fact, the only relevant material condition in which to study electron transport relevant to fast ignition is in material that has a temperature above 1 keV; this is the regime of the so-called "Spitzer Resistivity" where the resistivity of the material drops with increasing temperature. Since virtually all modeling is performed with the "Spitzer" assumption, we now understand why there is such a discrepancy between modeling and our electron transport measurements on room temperature, normal density materials. We have now directed our efforts to producing target conditions where the base-line resistivity is much lower, that is, in shocked matter. These targets will act as surrogates for targets that ultimately will be studied when we have access to facilities that can isochorically heat the targets to the relevant temperatures for fast ignition.

WARREN B. MORI, MICHAIL TZOUFRAS
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Postdoctoral Researcher: J. Tonge

(1) Use of OSIRIS for fast ignition: (with C. Ren U. Rochester)

a. **Determining the region of the target can be modeled using a PIC code:** Using data from hydro simulations provided by U. Rochester, we have plotted density (n), temperature (Te), collisionality (ln(Λ), ν_{ei}/ω_{pe}), and coupling constant (Γ) at maximum compression as a function of distance from the core. This tells us which regions of the target we can simulate assuming non-collisional plasma.

b. **Modifying OSIRIS:** Necessary improvements in the thermal bath boundary conditions of OSIRIS were implemented. We are currently adding an object into OSIRIS which represents the dense (coupled) core of the fast ignition target as a boundary condition. This will improve the efficiency and accuracy of the simulations. It reduces the number of particles that must be followed and uses a boundary condition to represent the collisional regions which can not be accurately represented in OSIRIS.

c. **New diagnostics:** Diagnostics for following individual particles have been implemented in OSIRIS. This will allow the collisionality of the plasma in the simulations to be better understood and ultimately used for simulations of hot collisional plasmas, such as the core of a fast ignitor target.

(3) Space charge effects on current filamentation and Weibel instabilities from arbitrary distribution functions: (with C. Ren U. of Rochester)

a. **Space charge effects:** Previous theories for the Weibel or current filamentation instability neglected the space charge terms that can arise when those particles moving forward to not pinch at the same rate as those going backwards. This can be very important for fast ignition conditions. The space charge terms reduce the growth rate and in some instances they can reduce the growth rate such that the ion motion becomes important. We have developed a kinetic theory for current-driven filaments under the space charge influences and are carrying out 2D and 3D OSIRIS runs to verify the theory including the threshold and growth rate.

b. **Arbitrary distribution functions:** The initial work of Weibel assumed the electron distribution function was current neutral and was a bi-Maxwellian. The instability grew when the temperatures were different in each direction. However, in fast-ignition the distribution functions are probably current neutral but they are not bi-Maxwellian. In particular, they have net heat flux in one direction. We have derived a theory (non-relativistic) for arbitrary current neutral distribution functions. The theory shows that for separable distribution functions the instability condition remains unchanged if one replaces the thermal velocity by the rms velocity in the non-Maxwellian direction. We are currently investigating more complicated distribution functions and carrying out 2D and 3D OSIRIS simulations to verify the theory.

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TOM COWAN
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Research: We are undertaking a study of high intensity laser production of hot electrons in pyramidal cone targets. We are studying the effect that very sharp tipped cones (ie cones with tip comparable to the laser wavelength) have on hot electron acceleration. PIC simulations conducted at UNR by Sentoku et al. suggest that optical guiding of the laser coupled with strong magnetic field generation near the walls of the guiding cone can lead to free-wave-like electron acceleration of electrons toward the cone tip. This has the potential of producing much brighter x-ray sources than simple planar targets. Such sharp tipped targets can be produced easily in Si substrates by taking advantage of the differing etch rates in Si along different lattice planes. We are investigating these kinds of targets by measuring the x-ray source yield and source size for various focal and target conditions. Electron spectra and proton production are also diagnosed in our experiments. The effects of return current are being investigated by using Si supported and free standing metallic pyramids as well. These experiments are presently taking place at the UT THOR laser, though we anticipate that ultimately we will conduct them on the Sandia Petawatt and Texas Petawatt lasers.