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OP.Tu_A1

Fast Ignition Realization EXperiment (FIREX) for Inertial Fusion Energy

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Controlled thermonuclear ignition and subsequent burn will be demonstrated in a couple of years on the central ignition scheme. Fast ignition has the high potential to ignite a fuel using only about one tenth of laser energy necessary to the central ignition. This compactness may largely accelerate inertial fusion energy development. One of the most advanced fast ignition programs is the Fast Ignition Realization Experiment (FIREX) [1]. The goal of its first phase is to demonstrate ignition temperature of 5 keV, followed by the second phase to demonstrate ignition-and-burn. The second series experiment of FIREX-I from late 2010 to early 2011 has demonstrated a high (≈10-20%) coupling efficiency from laser to thermal energy of the compressed core, suggesting that one can achieve the ignition temperature at the laser energy below 10 kJ.

Given the ignition temperature demonstration at the FIREX-I together with the ignition-and-burn at the National Ignition Facility [2], the inertial fusion research would then shift from the plasma physics era to power generation era. We anticipate a next step toward inertial fusion energy: a laser fusion experimental reactor that demonstrates electrical power generation. It would take 10 years for technology development and 10 more years for power generation test. The technology includes high rep-rate lasers; target injection, tracking and beam steering; and fusion chamber and blanket. Among these, high-rep lasers, the most critical element, have been demonstrated by using two technology breakthroughs: laser diodes for optical pumping and cooled ceramic crystals for laser materials. Such technology breakthroughs have enabled much higher rep-rates than that required by more than an order of magnitude [3]. The stability of the liquid inner wall has been demonstrated at the same Weber number and the similar Reynolds number as those of liquid LiPb. These technologies would be converged into a laser fusion experimental reactor LIFT with the goal of demonstration of power generation of the order of 10 MW. The experimental reactor would also provide extremely strong neutron sources [4] whose flux level exceed that in supernovae at the target position, accessing nuclear synthesis and potentially nuclear transmutations.

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OP.Tu_A2

The Drive Campaign on the National Ignition Facility*

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The Drive campaign on the National Ignition Facility (NIF) laser [1] has three major goals: to improve hohlraum performance by reducing laser plasma interactions (LPI) and improving laser beam propagation; to improve our understanding of crossbeam energy transfer [2]; and to improve our modeling of hohlraums to give us the tools for designing better hohlraums. Our first sets of experiments are designed to independently change the major components of the hohlraum – hohlraum shape, hohlraum gasfill composition, and hohlraum fill density. A rugby shaped hohlraum [3] is being fielded to test the hohlraum shape. The rugby design has a significantly larger diameter (7 mm) at the waist of the capsule than our standard 5.75 mm diameter cylindrical hohlraum but with approximately the same hohlraum wall area. In the second series of experiments, we vary the hohlraum fill composition in cylindrical hohlraums by using neopentane at room temperature to compare with our standard helium hohlraum fill. A third set of experiments uses higher hohlraum fill density (1.6 mg/cc vs nominal 0.96 mg/cc He fill) to test the effect of fill density. To avoid hydrocoupling in the higher fill density hohlraums, a higher radiation temperature is used in the foot of the pulse. In addition to these integrated experiments, focused experiments will test pieces of the hohlraum physics. These include imaging the laser spots after crossbeam energy transfer using the "viewfactor" target and a target that consists of the laser entrance hole only. Hohlraum NLTE modeling and heat transport are being studied using sphere targets on the Omega laser system. These simpler targets allow us to benchmark and improve our modeling tools. This talk will summarize the results of the Drive campaign and discuss future directions.

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OP.Tu_A3

An Overview of Advances in Shock Timing Experiments on the National Ignition Facility*

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Inertial confinement fusion (ICF) capsule implosions on the National Ignition Facility (NIF) are driven with a carefully tailored sequence of four shock waves that are timed to very high precision in order to assemble a deuterium-tritium (DT) fuel layer with low entropy, a low adiabat, and high areal density (ρR).

The strength and timing of these shocks are adjusted on NIF in specially modified diagnostic hohlraum geometries that are designed to precisely match the performance of ignition hohlraums. These targets (known as "keyhole" hohlraums) employ a re-entrant Au cone to provide optical access to the multiple shocks as they propagate in a liquid deuterium (D2) filled capsule interior. The strength and timing of the shocks is diagnosed with the VISAR (Velocity Interferometer System for Any Reflector) diagnostic. Initial experiments [1] employed only a single diagnostic view, which was successfully used to tune the shock timing at the hohlraum equator. Over the last few years, however, numerous modifications to the target geometry have been made to increase the number of angular views, improve the surrogacy to the ignition target, and extend the temporal range over which the shocks are diagnosed.

Experiments are now routinely conducted in a mirrored keyhole geometry, which allows for simultaneous diagnosis of the shock timing at both the hohlraum pole and equator. This technique has recently been further extended to allow three angular views at polar angles of 0° (pole), 45°, and 90° (equator) to diagnose polar shock symmetry. Additional targets provide three views in the equatorial plane to diagnose azimuthal shock symmetry. Further modifications have been made to improve the surrogacy to ignition hohlraums by replacing the continuous liquid D2 surrogate fuel with a DT ice layer. These experiments quantify differences in shock propagation between D2 and DT as well as incorporate the physics of shock release from an ice layer of finite thickness, which was absent in the liquid-filled targets. Target modifications employing tracer layers and spherical witness plates are currently being explored to extend the measurements to later time and higher convergence.

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OP.Tu_A4

Convergent ablation measurements with gas-filled rugby hohlraum on OMEGA

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The baseline design for implosion experiments with the Laser MegaJoule (LMJ) relies on a rugby-shaped hohlraum, which present significant advantages in terms of LPI mitigation [1], coupling efficiency and symmetry control with a 1/2-1/2 energy balance [2]. The increased x-ray flux on capsule in rugby hohlraum compared to a classical cylindrical hohlraum was moreover confirmed at OMEGA scale by enhanced nuclear performances [3]. It is nevertheless important to acquire convergent ablation measurements [4] to assess the implosion velocity, key metric for implosion performance. Convergent ablation experiments with gas-filled rugby hohlraum were therefore performed for the first time on the OMEGA laser facility.

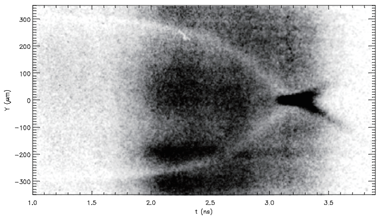

Figure 1: Typical streaked radiography on a capsule implosion in a gas-filled rugby hohlraum.

A time resolved 1D streaked radiography of capsule implosion (see Fig. 1) is acquired in the direction perpendicular to hohlraum axis, whereas a 2D gated radiography is acquired at the same time along the hohlraum axis on a x-ray framing camera. The implosion trajectory has been measured for various kinds of uniformly doped ablators, including germanium-doped and silicon-doped polymers (CH), at two different doping fraction (2 % et 4 % at.). It has in fact been demonstrated that Si-doped ablators are more efficient than Ge-doped ones at NIF scale [4]. Our experiments aimed also at measuring the implosion performance of laminated capsules [5]. A laminated ablator is constituted by thin alternate layers of un-doped and doped CH. It has been previously shown in planar geometry that laminated ablators could mitigate Rayleigh Taylor growth at ablation front [5]. Our results confirm that the implosion of a capsule constituted with a uniform or laminated ablator behaves similarly, in accordance with post-shot simulations performed with the CEA hydrocode FCI2.

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O.Tu_A5

A new symmetry model for hohlraum-driven capsule implosion experiments on the National Ignition Facility[1].

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We have developed a new model for predicting the time-dependent radiation drive asymmetry in laser-heated hohlraums by benchmarking integrated hohlraum-capsule Hydra simulations against the data obtained from a new technique for imaging the inflight shape of an imploding ICF capsule. By fitting our model to time-dependent shape information, we are able to produce a higher fidelity symmetry model than was previously possible. In this new technique (the “2D convergent ablation experiment” or “2DconA”) the imploding shell is radiographed through 800x800 um windows on the waist of the hohlraum using a 10.3 keV Germanium backlighter. A two-strip gated x-ray detector (GXD) produces approximately 20 images of the imploding ablator as it moves from a radius of about 300 um to about 150 um. To develop our new symmetry model we compare the experimental images to simulated images and adjust our model parameters (such as the crossbeam energy transfer saturation level) to match the inflight shape. To determine the surrogacy of the 2DconA experiment to layered implosion experiments we undertook a series of detailed 3D simulations that included diagnostic windows and 3D beam illumination geometry. We predict that the 3D features of the 2DconA geometry cause a small perturbation in the measured P2 and P4 moments of the inflight shape that must be corrected for when using the 2DconA measurements to estimate the symmetry for a layered DT implosion experiment.

Experimental radiographs of 1.3 MJ, 360 TW peak power implosions in standard length (9.43 mm) hohlraums revealed a substantial inflight P4 shape. Integrated Hydra calculations indicated that we could minimize the P4 by lengthening the hohlraum. Subsequent experiments with longer hohlraums have validated the predicted scaling of the inflight P4 shape with hohlraum length.

Further 2D convergent ablation experiments have been performed to establish the sensitivity of the inflight shape to changes in pointing, peak power, and inner/outer cone color separation. Based on these experiments we have changed the crossbeam transfer model parameters. Previous experiments set the amount of color separation to optimize the shape of the self-emission hot-spot image in layered DT implosions. These recent 2DconA experiments have shown that with such setting the inflight shape has a substantial positive P2. This implies that the self-emission shape was not a good indicator of the true shape of the main fuel layer, so that many previous experiments have operated with too much power transfer. The newly benchmarked model has been applied to a number of earlier DT layered implosions to enable us to reassess the performance of those experiments and to design future implosion experiments.

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O.Tu_A6

Onset of Hydrodynamic Mix in High-Velocity, Highly Compressed Cryogenic NIF Implosions

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Deuterium-tritium implosions in hohlraums irradiated with shaped laser pulses of 1.5 – 1.9 MJ energy on the National Ignition Facility have demonstrated a large range of neutron yields ranging from 0.8 - 7×10^{14} [1]. The laser peak power and duration at peak power were varied, as were the capsule ablator dopant concentrations and shell thicknesses. We have found that the variability in yield is correlated to the level of hydrodynamic instability mix of the higher Z ablator into the DT hot spot. To quantify the level of mix, we have developed a simple model that infers the level of contamination using the ratio of the measured x-ray emission to the calculated DT-only x-ray emission based on the ion density and electron temperature inferred from the measured 14.1 MeV neutron yield, core size, burn duration and ion temperature. The presence of excess x-ray emission is an indication of carbon from the ablator mixed into the compressed core [2].

We observe the highest DT neutron yields for shots with mix masses of below 200 ng, and a “mix cliff” where yield and ion temperature drop steeply just beyond, consistent with expected sensitivity to mix mass. The comparison with radiation hydrodynamic modeling indicates that low mode asymmetries and increased ablator surface perturbations may be responsible for the performance. Ongoing experiments are focused on reducing these perturbations to improve implosion performance, and spatially and temporally resolving where and when the hot spot mix occurs for a better understanding of the sources of this mix.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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O.Tu_A7

Hydrodynamic Growth and Mix Experiments at National Ignition Facility

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ABSTRACT

Hydrodynamic growth and its effects on implosion performance and mix are being studied in hohlraum-driven implosions using gas-filled plastic shells at the National Ignition Facility (NIF). These experiments are motivated by observed elevated amounts of plastic mixed into the hot spot, degrading the performance of high-compression cryogenic DT layered implosions on NIF. Spherical shells with pre-imposed 2D modulations are being developed to measure Rayleigh-Taylor (RT) instability growth in the acceleration phase of implosions using in-flight x-ray radiography. Ablation-front RT growth measurements will be carried out for mode numbers ranging from 30 to 80 at drive conditions relevant to high-compression cryogenic implosions. In addition, implosion performance and mix are being studied at peak compression using plastic "Symcap" shells filled with tritium gas and imbedding localized CD diagnostic layer in various locations in the ablator. Neutron yield and ion temperature of the DT fusion reactions are used as a measure of shell-gas mix, while neutron yield of the TT fusion reaction is used as a measure of implosion performance. Experimental results and comparisons with 1D and 2D simulations, including mix models, will be presented.

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Structure and Dynamics of Current Filaments, Plasma Flow and their Spontaneous Fields in Laser-Driven Holhraum Experiments

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A hohlraum is a high-Z enclosure which creates an environment filled with nearly blackbody (Planckian) radiation when irradiated by high-power lasers. Understanding the structure and dynamics of plasmas in the hohlraum, and the electromagnetic fields the plasma generates, is critical to studies of inertial-confinement fusion and high-energy-density physics because hohlraums have been widely used as radiation sources or platforms for a large variety experiments. We have been doing a series of experiments to systematically address various issues in hohlraum dynamics [1,2]. We report in this talk the first time-gated, side-on proton radiography that reveals the structures and dynamics of current filaments, plasma flow and their spontaneous electromagnetic fields occurring at the hohlraum laser-entrance holes [3]. Plasma instabilities are shown to play critical roles in such dynamic structures: in the earlier times with collisionless Weibel-induced current filaments resulting from expansion of low-density plasma into vacuum, and in the later times with resistive magnetohydrodynamic modes resulting from the adiabatic expansion of on-axis, stagnated wall plasma blowoff. Time-resolved observations of spontaneous electromagnetic fields associated with these plasma instabilities have been made. The experiments demonstrate the dominance of magnetic fields over electric fields, consistent with self-emissions of charged fusion products observed from ignition-scale hohlraums in experiments at the National Ignition Facility and energy-scaled hohlraums in experiments at OMEGA laser facility [1]. These experiments advance our understanding of many important phenomena, and provide important insight into the basic physics of the interplay between the magnetic fields and plasma flow, as well as into hohlraum dynamics. This work was supported in part by US DOE and LLE National Laser User's Facility, LLNL, LLE, FSC, and General Atomics.

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O.Tu_B1

Iron ramp compression up to one TPa relevant for Earth-like planetary cores

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Quasi-isentropic laser driven compression on materials relevant to Earth-like planet interiors allows to access thermodynamical parameters directly connected to the extreme conditions (330-1500 GPa, 5000-8000K) of those objects. Here, we report on the measurement of the iron quasi-isentropic compression using a ramp-tailored laser pulse on the LIL (Ligne d'Intégration Laser) facility. Our experiment consists in irradiating a diamond-iron-sapphire sample with a ~20 ns pulse to compress iron up to 1 TPa and 10000 K achieving thermodynamical conditions relevant for Earth-like planetary cores near the melting curve.

We will present the experimental data (VISAR and SOP) showing the difficulty and the limits of such experiments. The analysis of our results leads to assess that we achieved conditions close to the iron melting curve in the whole range 200-1000 GPa on a single shot. This ability opens a new route for planetary science.

O.Tu_B2

Warm Dense Water in 100 GPa pressure range corresponding to Earth-size exoplanetary interior conditions

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We have measured the pressure-volume-temperature and the optical reflectivity of water, which matches with the interior conditions of the water-rich super Earth. Transition of the warm dense fluid water from ionic to electronic fluid, where its physical and chemical properties are changing dramatically (~100 GPa range), has been explored with experiments that can directly measure the temperature and reflectivity as function of pressure of the system. It is done by focusing strong laser onto unprecompsessed or precompressed water target. Investigation of warm dense water is relevant to the understanding of inner structure of such unique super-Earths, resulting in a key constraint on the origin and evolution of exoplanetary systems.

This work was performed under the joint research project of the Institute of Laser Engineering, Osaka University. This work was supported by a Grant-in-Aid for Scientific Research (Grant No. 20654042 and 22224012) and also by grants from the Core-to-Core Program of the JSPS and from the CREST of the JST.

O.Tu_B3

Experimental Measurement of Temperature Relaxation in Solid Density Isochorically Heated Carbon

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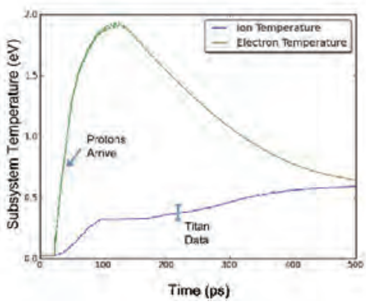
A complete understanding of the ion dynamics in the warm dense matter (WDM) regime is necessary for describing many physical phenomena ranging from phase transitions within the interior of large astrophysical objects to temperature relaxation rates during the internal processes of inertial confinement fusion. However, when creating these exotic states of matter in the laboratory, energy is predominantly deposited into the electron subsystem and the system remains out of equilibrium for many picoseconds.

Recent studies on low-temperature laser-heated graphite suggest a more complex energy exchange than in other materials. We use laser-accelerated protons/electrons to heat macroscopic graphite samples, isochorically and non-radiatively up to temperatures close to the melting threshold. Using time-resolved x-ray diffraction, we show clear evidence of a very small electron-ion energy transfer, yielding approximately three times longer relaxation times [1] than previously reported, see figure. This is indicative of the existence of an energy transfer bottleneck in non-equilibrium warm dense matter [2]. This work was performed at the Titan laser, Jupiter Laser Facility, LLNL, USA and PHELIX laser, GSI, Germany.



Temperature evolution of electron and ions during the creation of warm dense carbon.

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Laser driven shock studies in low density Lead layer on Aluminum target

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Implosion and compression achieved in the direct drive ICF scheme has been shown to have a strong dependence on target structure. Therefore, ICF targets have complex designs consisting of layers of various materials. It is well known that shock pressure enhancement takes place in layered targets with differing shock impedances, laser being incident on the material with lower shock impedance. In our laboratory, we have shown shock enhancement in combinations such as-Al-Au and PolyVinyl Alcohol-Al. We have also studied target combination of Al-Foam for pressure enhancement as well as uniformity of compression.

The aim of the study presented, was twofold- a layered target combination to get pressure enhancement and secondly, to achieve a uniform target motion. Shock measurements and target hydrodynamics were performed using 10 μm thick Aluminum foil with vacuum coated, 3 μm layer of lead (10Al+3Pb). Pb has been chosen for its high density and has not been so widely studied as a material for direct drive ICF. In these experiments, shock pressure was measured using the impedance match technique (Fig.1). Laser (1.06 μm, 500 ps) intensity was varied between 1- 2.4 x10^{14}W/cm^2. Fig.2 shows the SESAME Hugoniot for lead along with our experimental points and of several other laboratories[1]. Experimental values of pressure, especially at higher intensities- 1.25 x10^{14}W/cm^2 and 1.7 x10^{14} W/cm^2, are seen to be much lower as compared to the predicted value. Even then, an average pressure enhancement of about 1.5 is observed at all intensities. We believe this lowering of pressure to be due to the porosity and foam like lead layer which was obtained by vacuum coating. Interestingly, optical shadowgram of Al-Pb target in Fig.3(a) shows uniform target motion, which is not the case in an uncoated Al target, as observed in (b).

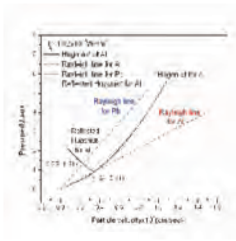

Fig.1

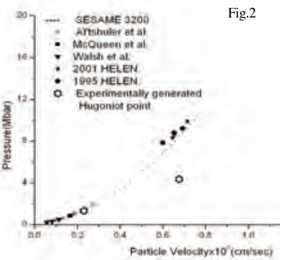

Fig.2

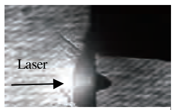

Fig.3(a)Al-Pb

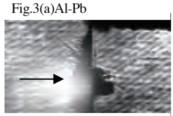

Fig.3(b)Al

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HIF Related Experiments at FAIR

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The Facility for Antiproton and Ion Research in Europe, FAIR, will provide worldwide unique heavy ion accelerator and experimental facilities allowing for research into extreme state of matter physics. Extensive theoretical work has been carried out over the past years to assess the potential of the FAIR ion beams to research this important field. This work shows that one will be able to perform different type of experiments on Heavy Ion Fusion related physics at FAIR. During the past years, significant progress has been achieved in experimental investigation on heavy-ion beam generated high-energy-density (HED) states in matter (warm dense matter, WDM) by using the heavy ion accelerators at GSI and at ITEP-the most powerful and versatile heavy ion accelerators worldwide.

O.Tu_C2

Advanced Target Effects Modeling for Ion Accelerators and other High-Energy-Density Experiments

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We explore the simulation requirements for experiments planned on facilities such as the NDCX-II ion accelerator at LBNL, currently undergoing commissioning. Hydrodynamic modeling of NDCX-II experiments include certain lower temperature effects that are not generally present in extreme high-energy laser facility experiments such as those conducted at the NIF, where targets are completely vaporized in an extremely short period of time. For these lower-energy simulations, we must consider surface tension phenomena as well as potential target fragmentation. Target designs for NDCX-II range from metal foils of order one micron thick (thin targets) to metallic foam targets several tens of microns thick (thick targets). These high-energy-density experiments allow for the study of fracture as well as the process of bubble and droplet formation. We incorporate these physics effects into a code called ALE-AMR that uses a combination of Arbitrary Lagrangian Eulerian hydrodynamics and Adaptive Mesh Refinement. Inclusion of certain of the effects becomes tricky as we must deal with non-orthogonal meshes of various levels of refinement in three dimensions. Modeling of fracture in ALE-AMR is implemented via void insertion/growth, when a zone meets a given failure criteria, followed by fragmentation using interface reconstruction based on volume fractions. We have modeled fragmentation at lower energy laser facilities that used aerogel to capture fragments [1] and for low-energy (~14 kJ) re-emit experiments on NIF where only 1/3 of the target is vaporized [2]. A surface tension model used for droplet dynamics is implemented in ALE-AMR using curvature calculated from volume fractions [3]. We have also studied the removal of numerical parasitic flows [4] in the calculation of surface tension.

Simulation of thin targets on NDCX-II and associated rarefaction waves can be used to infer material properties such as the liquid-vapor critical point. The critical point is poorly known for many of the refractory metals. Thick foam target experiments provide information on how ion beam induced shock waves couple into kinetic energy of fluid flow.

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O.Tu_C3

A Scaled Experiment to Study Energy Dissipation Process during Longitudinal Compression of Charged Particle Beams

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Because of well-defined energy deposition and repetition capability, particle beams are expected to be one of potential drivers for inertial fusion. In the beam driver scheme, the beam power must be increased up to TW level, in which compression technology of a beam bunch in longitudinal direction is essential [1]. However, in this process, degradation of the beam quality may occur through collective motions of particles induced by space-charge field. To investigate the dissipation process, we are conducting an experiment with a compact and flexible bunching simulator device based on electron beams [2]. Figure 1 shows a schematic diagram of experiment. In the experiment, we compress a beam with a pulse duration of 100 ns from continuously extracted with an energy of 2.8 keV. First, the extracted beam was injected to an induction cavity. Next, the beam was applied a modulation voltage with a peak voltage -2.5 kV and a pulse duration of 100 ns for longitudinal compression. The modulation voltage produces a head-to-tail velocity gradient, then, the beam is one-dimensionally compressed in longitudinal direction during a drift in a solenoidal transport line. Up to now, we investigated the compression process in a parameter region with electron densities 10^6-10^7 /cm^3. In addition, to survey required beam parameter regions for discussion of the dissipation process, we numerically extrapolated the current levels of the bunching process with a PIC code. Figure 2 shows a time evolution of particle distribution in phase space when the initial density is 10^8 /cm^3. As shown in Fig.2, in this parameter region, beam particles gradually dilute as the bunching proceeds. The results indicate that our device has a potential as a simulator device to discuss the dissipation process as a function of initial beam current.

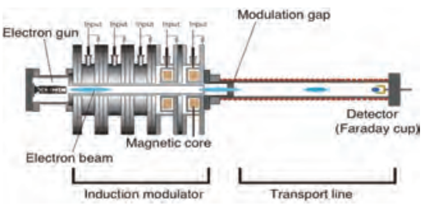

Figure 1: Experimental configuration and schematic diagram of longitudinal compression.

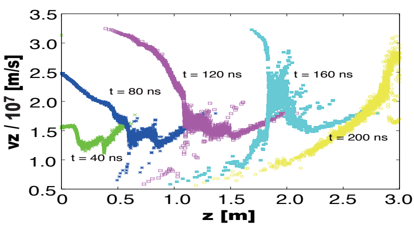

Figure 2: A PIC simulated particle distributions in longitudinal phase space.

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O.Tu_C4

Illumination Non-Uniformity of Spirally Wobbling Beam in Heavy Ion Fusion

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In inertial confinement fusion, the driver beam illumination non-uniformity leads a degradation of fusion energy output. The illumination non-uniformity allowed is less than a few percent in inertial fusion target implosion. Heavy ion beam (HIB) accelerator provides a capability to oscillate a beam axis with a high frequency [1]. The wobbling beams may provide a new method to reduce or smooth the beam illumination non-uniformity [2].

In this paper the illumination scheme was optimized. The HIB irradiation scheme proposed previously [3] is divided into the upper three layers and the lower three layers (see Fig. 1). We change the angle of $\Delta\theta_1, \Delta\theta_2$ and $\Delta\theta_3$. It is found that the non-uniformity is reduced well, when ($\Delta\theta_1$, $\Delta\theta_2$, $\Delta\theta_3$)=(0, 0.2, 0.4)deg or (0.2, 0.2, 0.4)deg (see Fig. 2).

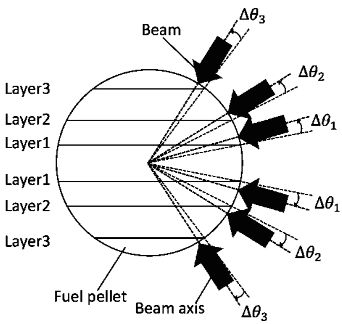

Figure 1: Schematic diagram for the definition of $\Delta\boldsymbol{\theta}$

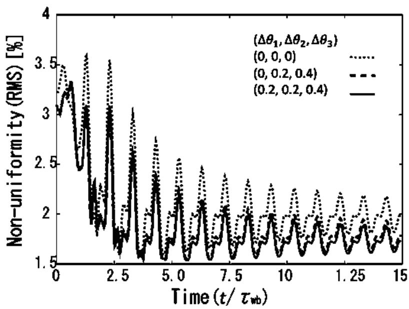

Figure 2: Histories of illumination nonuniformity

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O.Tu_A9

Laser-Plasma Interactions in Drive Campaign Targets on the National Ignition Facility

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The Drive campaign[1] on the National Ignition Facility (NIF) laser[2] has the focused goal of understanding and optimizing the hohlraum for ignition. Both the temperature and symmetry of the radiation drive depend on laser and hohlraum characteristics. The temperature of the drive strongly depends on the coupling of laser energy to the hohlraum, and the symmetry of the drive is critically dependent on beam-to-beam interaction that result in energy transfer[3] within the hohlraum. To this end, hohlraums are being fielded where shape (rugby vs. cylindrical hohlraums), gas fill composition (neopentane at room temperature vs. cryogenic helium), and gas fill density (increase of ~ 150%) are independently changed. Cylindrical hohlraums with higher gas fill density show improved inner beam propagation, as should rugby hohlraums, because of the larger radius over the capsule (7 mm vs. 5.75 mm in a cylindrical hohlraum). Improvement in energy coupling occurs in room temperature neopentane targets, as well as in hohlraums at higher gas fill density. In addition cross-beam energy transfer is being addressed directly by using targets that mock up one end of a hohlraum, but allow observation of the laser beam uniformity after energy transfer. Ideas such as splitting quads into "doublets" by re-pointing the right and left half of quads are also being pursued. LPI results of the Drive campaign will be summarized, and analyses of future directions presented.

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O.Tu_A10

Experimental results on laser-plasma interaction physics in multiple plasmas

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We have designed experiments to address the physics of laser-plasma instabilities (LPI) in the case of multiple plasmas in the context of Inertial Confinement Fusion (ICF). Recent full-scale ignition experiments [1] on National Ignition Facility have shown that LPI are still of great concern for laser driven ICF. In all investigated schemes, LPI physics is of huge complexity compared to the "academic" case of one beam interacting with a single plasma. In many cases, modifications induced by the simultaneous presence of several plasmas (or several beams) must be taken into account, including electromagnetic seeding [2], plasma waves or hydrodynamic coupling. Plasma Induced Incoherence (PII) can also modify the laser coherency [3,4], having major consequences on LPI [5].

We will present results from the experiments in which we have studied several of these complex phenomena under well-controlled conditions. Using a tunable target system and the two kiloJoule beams of the LULI2000 facility, we were able to study LPI in the situations described above. Low density foams were used in order to create hot and homogeneous plasmas. Expanding inhomogeneous plasmas were created from either thick or thin foils. Finally, an adapted combination of the above targets allowed us to investigate plasma hydrodynamic coupling, electromagnetic seeding and PII.

At first, we will provide the context for this study and describe the main diagnostics, including time-resolved Stimulated Brillouin (SBS) and Raman (SRS) Scattering spectra, backscattered energy measurement and full characterization of the transmitted light with time-resolved 1D and time-integrated 2D imaging. We will then expose the results concerning the effect of PII on SBS. It has been observed that SBS is strongly reduced when using a beam that has been smoothed through a short length plasma. We also report the observation of SBS enhancement into the foam when seeded by the backscattered light from a thick foil. Replacing the thick foil by a thin one, SRS signal has been measured in the high $k\lambda_D$ foam plasma region, when seeded by the Raman wave produced in the foil. Finally, an increase of SBS level due to the hydrodynamic interaction between the two plasmas will be reported. To conclude, we discuss the obtained results in light of theoretical predictions and possible consequences for ICF.

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O.Tu_A11

Lessons from LIL's gas-filled hohlraums experiments

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In order to achieve ignition in the indirect drive scheme, high power lasers have to propagate in cm-long and multi-keV hot plasma. All along their path, the lasers undergo many phenomena such as absorption, stimulated scattering on plasma waves, leading to Raman (SRS) or Brillouin (SBS) scattering, or self-focusing. In an ignition hohlraum, linear gains calculations indicate [1] that the inner cones are mainly sensitive to SRS, while outer cones are sensitive to SBS. We use the LIL facility, a well-diagnosed facility and a prototype of one LMJ quad, in order to mimic such behaviors.

We have designed targets where the laser beam propagates into a mm-long under-critical pentane plasma, that fills a gold cylinder, and targets where the laser interacts with a plasma first composed of pentane, then of gold coming from the wall expansion [2]. We will focus on the first target representative of an inner beam's plasma conditions [3]. We shot 4 mm and 1.5 mm long targets with various beam conditioning. The laser pulse is 6 ns long with a maximum energy of 15 kJ.

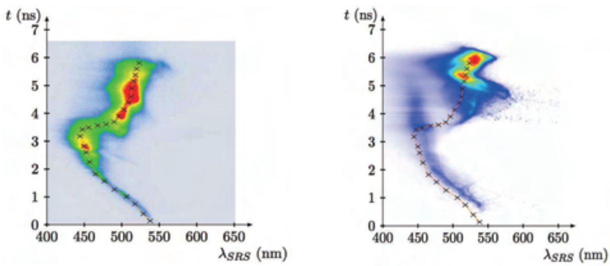

Figure 1: SRS spectra from experiment (left) and simulation (right).

We will present experimental results, see figure 1, confronted with calculated ones from data given by radiative-hydrodynamics and paraxial simulations. We give evidence that the beam conditioning affects the plasma hydrodynamic response to the laser power deposition. Finally, we give insights into how to handle hohlraum's energetics and how it compares to simulations.

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O.Tu_A12

Mitigation of Stimulated Raman Scattering for Inertial Fusion and High Energy Density Physics Research

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Stimulated Raman scattering (SRS) is a concern for laser-driven fusion experiments. High levels of backscatter reduce the coupling of laser energy to the fusion target and place stringent constraints on implosion symmetry and other design parameters. Applying large-scale kinetic plasma simulations to assess SRS risk and to evaluate mitigation strategies are inertial fusion and high energy density physics research thrusts at Los Alamos National Laborotory. Our work centers on a science-based understanding of the essential physics governing the kinetic, nonlinear behavior of SRS in multi-speckled laser beams in the electron trapping regime over a wide range of $k\lambda_D$ values (here k is the wave number of the electron plasma waves and $k\lambda_D$ is the Debye length) in homogeneous and inhomogeneous plasmas [1,2]. We found that hot electrons from intense speckles, both forward and side-loss hot electrons produced during SRS daughter electron plasma wave bowing and filamentation [3,4], seed and enhance the growth of SRS in neighboring speckles by reducing Landau damping. Trapping-enhanced speckle interaction through transport of hot electrons, backscatter, and side-scattered SRS light waves enable the system of speckles to self-organize and exhibit coherent, sub-ps SRS bursts with more than 100% instantaneous reflectivity, resulting in an SRS transverse coherence width much larger than a speckle width and a SRS spectrum that peaks outside the incident laser cone. SRS reflectivity is found to saturate above a threshold laser intensity at a level of reflectivity that depends on $k\lambda_D$: higher $k\lambda_D$ leads to lower SRS and the reflectivity scales as $\sim (k\lambda_D)^{-4}$. As $k\lambda_D$ and Landau damping increase, speckle interaction via side-scattered light and side-loss hot electrons decreases and the occurrence of self-organized events becomes infrequent, leading to the reduction of time-averaged SRS reflectivity. This understanding of speckle interaction and reflectivity scaling with $k\lambda_D$ allows us to assess mitigation strategies, which will be discussed in detail.

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O.Tu_B5

Relativistic intensity laser interactions with low-density plasmas

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We perform relativistic intensity laser experiments using the Omega EP laser facility and the Titan laser at LLNL to investigate channeling phenomena [1,2] and particle acceleration [3] in underdense and near-critical density plasmas. A fundamental understanding of these processes is of importance to the hole boring fast ignition scheme for inertial confinement fusion. Proton probing was used to image the electromagnetic fields formed as the Omega EP laser pulse generated a channel through underdense plasma, which observed filamentation followed by self-correction into a single channel [1]. Also, channel wall modulations were observed, due to surface wave generation, which is a likely injection mechanism for direct laser acceleration of electrons [3]. Recent experiments on the Titan laser investigating near-critical density plasmas through measurements of electron heating and proton acceleration have been performed. Two-dimensional particle-in-cell simulations are performed to understand the dependence on target density of the electron heating and channel depth.

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O.Tu_B6

General Model of Conversion Efficiency in Ultraintense Laser- Overdense Plasma Interactions

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Ultraintense laser interaction with matter is characterized by two modes of the laser ponderomotive force: the steady-state component, which can generate high-fluence, low-emittance ‘hole punching’ ions; and the oscillatory component, which excites a relativistic fast electron current. By controlling and optimizing the modes in which the light is absorbed, one may enable applications such as compact GeV-scale particle accelerators[1], approaches to fast ignition inertial confinement fusion, and medical proton oncology[2]. Yet, to date, a general framework treating both populations on equitable theoretical footing has not been developed. In this presentation, we outline a fully-relativistic absorption model based on conservation of energy and momentum that describes both modes of light coupling on a unified, first-principles basis for the first time. By allowing both the fast electron beam and the hole punching ions to be energetically significant, we derive a strict lower limit on light absorption as a function of laser intensity and target density. Expressions for the laser conversion efficiencies into each kinetic mode are derived. Results from the model are shown to be in good agreement with high resolution one-dimensional particle-in-cell simulations, and high energy density physics applications are highlighted. For instance, relevant to circularly-polarized laser driven fast-ion ignition[3], we simulate simultaneous target irradiation by two ultraintense lasers, examining the partitioning of energy absorbed by the plasma and the stability of the radiation-pressure-driven piston as the phase offset between the lasers is varied.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-630157.

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O.Tu_B7

Laser-matter interaction in cluster medium in the radiation dominated regime: Particle acceleration and radiation

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The interaction between high power laser and matter has opened up various kinds of application such as high energy particle acceleration for both ions and electrons, generation of intense radiations (EUV, x-ray and gamma-ray), and neutron production [1]. Here, the state of material is a key ingredient which determines the characteristics of the interaction, and has to be chosen properly according to the purpose. For instance, besides solid and gas, a cluster and cluster medium are widely interested, which exhibit a prominent feature essentially due to the existence of surface, i.e. a large ratio of the surface to the volume. A cluster mode (slow mode) is one of the examples where the laser can propagate even when the average density of the medium is higher than the critical density [2]. This propagation mode results from the surface polarization of the cluster. Neutron generation for nuclear fusion utilizing the Coulomb explosion of clusters has been intensively studied [3]. Recently, high energy ion acceleration has been realized in the interaction between such a cluster medium and high intensity laser [4]. These phenomena have so far been investigated using laser intensities up to around 10^{21} W/cm^2.

Here, we investigate such interaction between laser and cluster medium extending the intensity higher than 10^{21} W/cm^2 up to 10^{24} W/cm^2. In this regime, electrons are suffered from radiation damping, so that the significant amount of laser energy is transferred to intense x- and gamma-rays. Furthermore, by choosing high-Z material for the cluster, we can expect to realize a high pressure material state which emits strong synchrotron radiation due to electrons trapped by the high-Z cluster core. Positron generation can also be significant in such plasmas leading to electron-positron plasma. More interestingly, ions enter into a relativistic regime, so that a new mechanism of ion acceleration is incorporated with the Coulomb explosion.

In order to study such extreme plasmas, we have explored a comprehensive particle based integral code (EPIC3DR) which includes ionization process simulating high-Z materials, collisional relaxation, radiation damping of electrons, electron-positron pair creation, etc.. Using the code, we study fundamental physical processes of the interaction and their parametric dependences with respect to the cluster species (Z), size, packing fraction, etc. emphasizing particle acceleration and radiation emission.

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O.Tu_B8

The microscale physics of relativistic transparency in the ultra-relativistic regime and it's influence on synchrotron emission

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With 10PW lasers on the near horizon a complete theoretical understanding of ultra-relativistic laser-plasma interactions is necessary. This will require development of models that replace those that are familiar to us at normal intensity regimes with ones that apply in the ultra-relativistic regime, where the electron rest mass is negligible compared to the relativistic mass and novel processes such as synchrotron emission are as important as classical plasma processes. One of the most surprising early results in this regime is that there are still two distinct regimes which correspond to relativistic opacity and transparency[1] despite the fact that direct ponderomotive acceleration of the electrons in the laser direction is the dominant dynamics in both cases. In the opaque regime ion and electron motion is coupled and the laser propagates into the target by hole boring (Figure1 left panel). In the transparent regime electron and ion motion decouple and an electron front propagates into the target with a speed which is only weakly affected by ion motion (Figure 1 right panel). This is true for both linearly and circularly polarized light. The continued existence of these two regimes for ultra-relativistic plasmas is not obvious and the microscale physics which causes it to occur are not those that cause the distinction between the two regimes at lower intensities. Here, this new microscale physics is described and used to explain why synchrotron emission is more efficient in underdense solids than in overdense solids and what this might mean for experiments on next generation lasers.

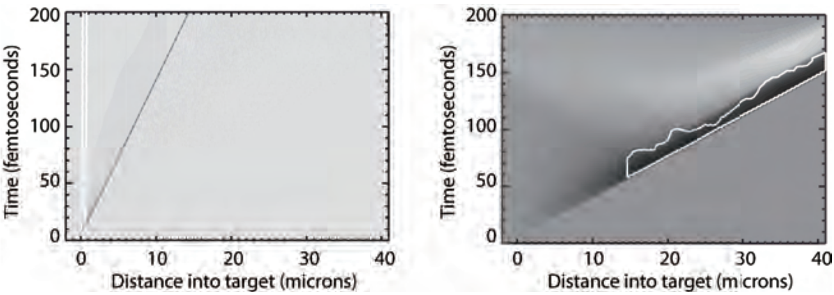

Figure 1: Time distance plots of the space charge field due to the propagation of a 10^{23} W/cm^2 circularly polarized laser into a solid target from 1D PIC simulations. Solid contours show the location of the laser front when ions are considered to be 13+ aluminium ions. White contour lines show the location of the front assuming that ions are infinitely massive. Left panel is for a target density of solid aluminium, right panel is for a target with a density 2% of solid aluminium.

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O.Tu_C5

European efforts towards a kilojoule DPSSL beamline for HiPER

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HiPER (High Power laser Energy Research) is a European scientific consortium dedicated to demonstrate the feasibility of laser driven fusion as a future energy source. In driving the compression phase of the fuel capsule (Shock Ignition scheme), symmetry is a key aspect and 250 kJ distributed over 48 beams (UV) appears to be optimum where each "spot" needs ~13 kJ of fundamental light. Laser engineering considerations (among them efficiency and ASE managements being major ones) impose an energetic unit cell around 1 kJ. Each of the 48 spots on the target will then be illuminated by a bundle of a dozen of laser beams which distribution could be the one illustrated on figure 1. Nine 1.16 kJ beams operating in the nanosecond regime will deliver the compression energy on the DT target whereas the three remaining beams will carry a similar level of energy (~900 J) but in the ps regime to ensure the actual igniting shock.

	Total energy (kJ)	Spots	energy per spot (kJ)	beam per bundle	energy per beam (kJ)
Compression	500	48	10,4	9	1,16
Shock Ignition	130	48	2,7	3	0,90
Total	630	48	13,12	12	-

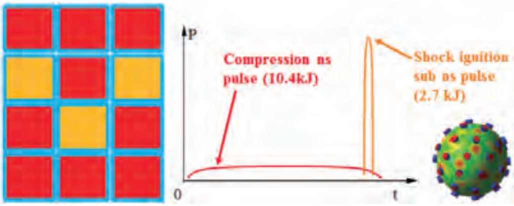

Figure 1. ps and ns ~1kJ beam forming a bundle to be focused on each of the 48 spots distributed over the spherical DT target (green sphere)

During HiPER Preparatory Project Phase (P^3), several approaches were proposed, differing in gain medium or amplifier architectures. The program is now entering a new phase called Technology Development & Risk Reduction Phase (TDR^2) as illustrated of figure 2.

Figure 2. HiPER general roadmap with *Test beds operation* and *13 kJ Bundle* sub phases.

State of the art with already achieved milestones and respective roadmaps for the coming three years period (test beds operation phase, in green on figure 2) will be detailed for Lucia (LULI, Palaiseau, France), Dipole (STFC, Abingdon, UK), Polaris (IOQ, Jena, Germany), HiLASE (Prague, Czeck Republic) and Penelope (HZDR, Dresden, Germany), all of them DPSSL programs with at least a 100J energetic goal.

O.Tu_C6

HiLASE: a scalable option for Laser Inertial Fusion Energy

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Diode-pumped solid-state lasers with high pulse energy, high efficiency, and good beam quality are of increasing interest for Laser Inertial Fusion Energy power plants [1,2]. At present, several high-energy-class diode-pumped solid-state lasers are being constructed worldwide with energies of 100 J or higher. The 100 J HiLASE concept is based on a gas-cooled, cryogenic, end-pumped, multi-slab architecture using Ytterbium-doped Yttrium-Aluminium-Garnet (Yb:YAG) as the gain medium developed at STFC Rutherford Appleton Laboratory [3,4].

We have undertaken extensive energetics, thermal and fluid-mechanical modeling in order to optimize the parameters of various amplifier configurations. Fig. 1 below shows the predicted temperature distribution in the slab (active material, absorbing clad, and invar holder) and in the cooling helium gas within the 100J-class Yb:YAG amplifier.

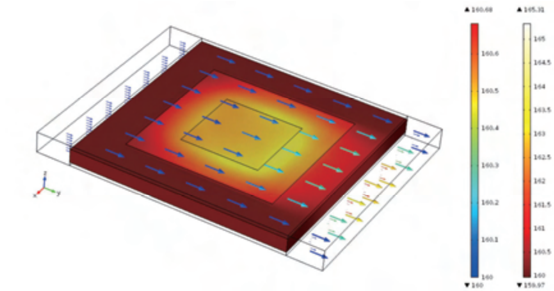

Figure 1: Predicted temperature distribution in a 100J-class HiLASE amplifier slab.

The proposed solution for HiLASE consists of a fibre front end that provides the seed for the main pre-amplifier, a 7-10 J/10Hz/2-10 ns amplifier head. The output of the main pre-amplifier is fed into the 100J amplifier head generating a rectangular laser beam with size of about 66 x 66 mm^2.

This scheme have been numerically investigated and optimized. Detailed results of the slab amplifiers will be presented confirming the viability of cryogenic helium-gas cooling approach to control and drastically reduce thermally-induced distortions.

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O.Tu_C7

Cryogenic cooling for high power laser amplifiers

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The Extreme Light Infrastructure (ELI) will be a new scientific European infrastructure devoted to scientific research in lasers field, dedicated to the investigation and applications of laser-matter interaction at the highest intensity level (more than 6 orders of magnitude higher than today's laser intensity). The ELI project, a collaboration of 13 European countries, will comprise three branches: Ultra High Field Science that will explore laser-matter interaction, attosecond Laser Science designed to conduct temporal investigation of electron dynamics in atoms, molecules, plasmas and solids at attosecond scale, High Energy Beam Science devoted to the development and usage of dedicated beam lines with ultra-short pulses of high energy radiation.

Using DPSSL (Diode Pumped Solid State Lasers) as pumping technology, PW-class lasers with enhanced repetition rates are developed. Each of the Yb:YAG amplifiers will be diode-pumped at a wavelength of 940 nm. This is a prerequisite for achieving high repetition rates (light amplification duration 1 millisecond and repetition rate 10 Hz). The efficiency of DPSSL is inversely proportional to the temperature, for this reason the slab amplifier have to be cooled at a temperature in the range of 100K-170K with a heat flux of 1 MW*m-2. This paper describes the thermo-mechanical analysis for the design of the amplification laser head, presents a preliminary proposal for the required cryogenic cooling system and finally outlines the gain of cryogenic operation for the efficiency of high pulsed laser.

We show also the requirements for a facility as HiPER in term of power supply for the laser cooling system.

O.Tu_C8

Improvement of damage threshold of optics in LFEX compression chamber with heavy oil-contamination

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A very heavy oil-contamination of optical components was found in the pulse compressor of LFEX laser system in 2007 [1]. This contamination was heavy, and optics in the compression chamber showed fogging on the surface after recovery to the atmosphere. Due to this contamination, damage thresholds (DT) of mirrors and gratings at ns region decreased to 1/2 to 1/3 of original value. This reduction of DT is very large, and it was dangerous for the laser system. In ps pulse region, DT was not influenced by the contamination. This difference seems come from the difference of damage mechanism in long and short pulse width.

We have made an intensive study for investigating the contamination material, source of contamination, influence to optics, and the way to prevent this problem [1].

1. Contamination material

   We collected the material from the surface of mirrors, and the material was analyzed by GC-mass spectrometer. Materials are identified as Paraffin oil and Di-butyl phthalate (DBP).

2. Source of contamination

   We seek for the source of contamination in the compression chamber, but no significant oil-source was found. We had 3 different compressor chambers, and almost the same materials were found form these chambers. This means this contamination is a common problem in large-scale chambers. On the other hand, we examined room air where the chamber was located. We found about 50 micro g/m^3 of DBP in the room air. The contamination seems to invading into the chamber through gaskets during the evacuation time. The evacuation was done for several months, and very slow invasion provides a large amount of contamination.

3. Influence to optics

   We investigated the influences of contamination. Some mirrors changes their spectrum characteristic, but other mirrors did not change. So we can only observe the contamination by the DT measurement in ns region.

4. The way to prevent contamination

   For preventing this contamination, we introduced 50 kg of silica-gel into the vacuum chamber to absorb the contamination instead of optics. We observed almost the same DT of sample mirror for 3 months evacuation of compression chamber.

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P.Tu_1

What are the chances / prospects of a proton fast ignition experiment at NIF?

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An interesting alternate route to ignition was triggered by the discovery of intense, short, energetic, directed beams of protons off the rear surface of solid targets irradiated by ultra- intense lasers.
Protons do have several advantages compared with other ion species and electrons. First, because of their highest charge-to-mass ratio, they are accelerated most efficiently up to the highest energies. They can penetrate deeper into a target to reach the high density region, where the hot spot is to be formed, because of the quadratic dependence of the stopping power on the charge state. And finally they do, like all ions, exhibit a characteristic maximum of the energy deposition at the end of their range, which is desirable in order to heat a localized volume efficiently.
So after some years of research, what is the current experimental and theoretical status of the prospects for proton fast ignition (PFI)? Is there a chance using existing facilities like the NIF to test PFI in a real world scenario?
For the potential use of NIF demonstrating the feasibility of PFI the implementation of several kilojoules of short pulse laser capability is mandatory. This coincides with the request for advanced diagnostics to explore the open questions in central spot ignition using the ARC (Advanced Radiograph Capability) Laser. Based on the current design the system consists of multiple beamlines overlapping in the equatorial plane of the NIF target chamber. Due to the final focusing optics f-number a spot size of no less than 100 μm in diameter is planned, largely ruling out the use in electron FI. Also the pulse length of a few ps is rather long, but still matched to the needs of TNSA. In fact, TNSA still works at good conversion efficiency using ps laser systems and the source size and overlap of multiple beams could be beneficial to create a flat initial electron-sheath thereby optimizing the proton focal spot size. ARC could serve as a significant milestone in PFI demonstrating enhanced neutron yield like the Osaka experiment did for electron FI without costly reconstruction of the facility.
The presentation summarizes the recent results and aims at initiating a discussion about a plan to use NIF for an PFI experiment in indirect drive geometry as a proof of principle test.

P.Tu_2

Hot electron spectra on advanced targets in FIREX

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Realization of a fast ignition requires a high coupling efficiency between hot electrons and an imploded core. The coupling efficiency is determined by a transport efficiency of the hot electrons in a guided cone, a geometrical irradiation efficiency of the hot electrons to the core and an energy deposition of the hot electron to the core etc. According to a simulation, the maximum coupling efficiency can be expected at the typical hot electron energy of 2 MeV or less. It is important to suppress a hot electron divergence and to close a generation point of the hot electrons to the core.

We use a DLC (diamond-like carbon) -cone shell target in order to reduce an energy loss in the cone, addition to an Au-cone shell target. The divergence of the hot electrons can expected to be reduced by an external magnetic field, which is induced by a laser irradiation of a capacitor coil. A hot electron flux is observed by an ESM (electron spectrometer)[1)] on a laser axis 1 m far from the core. The flux increases several times when the magnetic field is applied as shown in Fig. 1. The hot electron angular distribution is measured around the core by a HEXS(high-energy x-ray spectrometer)[2)]. The hot electron seems to be converged at the magnetic field application from the X-ray profile obtained by HEXS. However a focus of the hot electrons does not mean a simple bending of the trajectory by the magnetic field. In the magnetic focusing, the hot electrons are expanded remaining the original divergence after they pass through a narrow region around the core. Therefore ESM which is settled 1 m from the core, should observe almost similar flux of the hot electrons. Several reasons are considered: A pre-formed plasma shape, which determines the original divergence of the hot electrons may change due to the strong magnetic field. A Weibel instability, which induces the divergence of the hot electrons may be suppressed by the strong magnetic field.[3)]

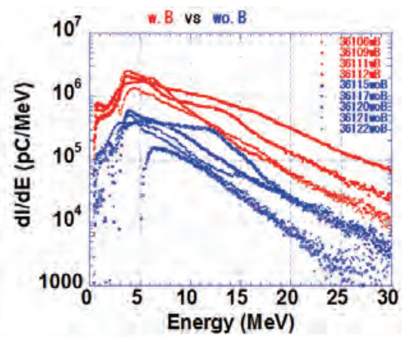

Fig. 1 Hot electrons spectra with and without an external magnetic field.

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P.Tu_3

Imploded Plasma Heating by Irradiation of Heating Laser through a Cone with a Hole for Fast Ignition

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It is of great importance for the fast ignition research to investigate the heating properties of the imploded core plasma by injection of the heating laser. Since the typical size and life of the imploded core plasma are 100 μm and 100 ps, respectively, we used an X-ray streak camera with spatial and temporal resolutions of 10 μm and 10 ps, respectively, for observation of the core plasma dynamics. Fast ignition experiment was performed by using deuterated polystyrene shell with Au cone. The shell target was irradiated with Gekko-XII laser (8 beams, 2240 J / 1.3 ns, 0.53 μm) and the LFEX laser (615 J / 1.5 ps, 1.05 μm) was injected through the cone. The cone was used for keeping the LFEX laser path to be vacuum, while the hole at the tip (diameter = 33.7 μm) allows the LFEX beam to directly irradiate the imploded core plasma.

The image obtained by the X-ray streak camera showed that the core plasma was moving towards the cone. This is reasonable because of the absence of the drive beams near the cone.

The irradiation time of the LFEX laser relative to the X-ray self-emission history was specified with an accuracy of 7 ps by using non-imaged signal of high-energy X-rays emitted by the LFEX irradiation. (Fig. 1(a)) This non-imaged signal is a noise for the self-emission image from the core plasma. By removing this noise signal assuming uniform irradiation on the cathode, we could obtain the net self-emission history of the core plasma (Fig. 1(b)). It was found that the self-emission from the core was increased again when the LFEX laser was injected. This emission started at the irradiation time of the LFEX laser and near the cone tip. Later, the emission gradually expanded over the core plasma with a velocity of about 2.5×10^{8} cm/s. This result indicates that the imploded core plasma was heated by the LFEX laser irradiation, and the heated region expanded to the whole core plasma. Simulation study will be performed for comparison with the experimental result. We will examine the heating property of various cones.

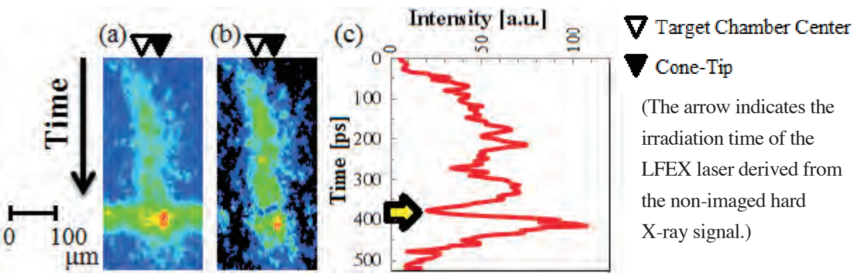

Fig. 1 (a) The self-emission image of the core plasma and the non-imaged signal of high-energy X-rays due to the LFEX laser irradiation. (b) The self-emission image after removal of the non-imaged signal. (c) The history of spatially integrated signal shown in Fig. 1(b). Only signal within full-width-half-maximum of the spatial profile at each time is integrated.

P.Tu_4

Indirect-drive pre-compression of CH coated cone-in-shell target with guiding wire for fast ignition

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Compared with central ignition of laser fusion, fast ignition separates compression and ignition thus it can relax the requirements on the implosion symmetry and the driven energy. Since 2008, the Research Center of Laser Fusion has begun the related experimental researches on fast ignition based on SHENGUANG II laser facility.

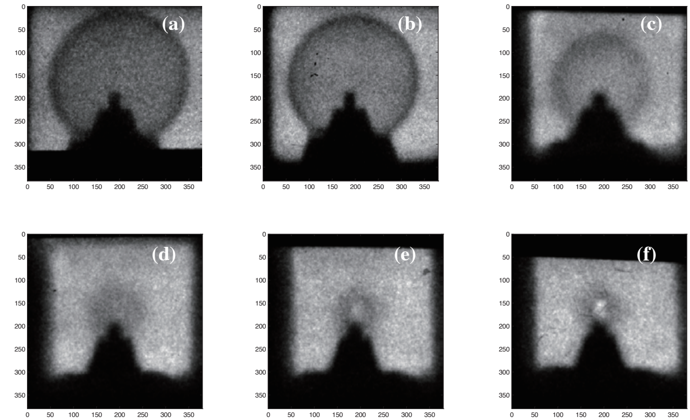

Fig. 1 X-ray framed images of indirect-drive target in shot #209 at (a) 758 ps, (b) 962 ps, (c) 1375 ps, (d) 1558 ps, (e) 1614 ps and (f) 1670 ps

The small scale cone-in-shell target with guiding wire for fast ignition was pre-compressed by the SHENGUANG II eight 260J/2ns/3ω laser beams indirectly since beam smoothing was not available currently. To minimize the mixing of the compressed fuel and high-Z vapor produced by the *M*-line emission from the gold holhraum, a 3μm CH foil was coated on the full outer surface of the cone and guiding wire. The maximum density of the compressed cone-in-shell target 1.3 ns after the lasers' irradiation on the inside wall of hohlraum is about 5.0 g/cm^3, and the implosion velocity is close to 1.9×10^7 cm/s, which are well consistent with the simulation results with two-dimensional radiation hydrodynamic code. Experimental results and simulation results also demonstrated the coated CH foil could minimize the mixing effectively. By the appropriate design, target can remain robust before the maximum compression, that is, the time while the hot electrons produced by ignition laser pulse deposit energy in the compressed fuel.

P.Tu_5

Filamentation and electron transport in intense laser plasma interaction

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The propagation of laser-driven, relativistic electron beams in plasmas is a phenomenon of relevance in fast ignition, particularly concerning the problem of the generation of strong, spatially extended and sustained magnetic fields [1]. We report on experiments where the transport of hot electron currents through foam and wire targets has been studied using the proton imaging technique. Strong filamentation has been observed, possibly due to electromagnetic instabilities of the Weibel type. A multitude of tube like filamentary structures is also observed to form behind the front of a plasma created by irradiating solid-density wire targets with a high-intensity (10^{19} W/cm^2), picosecond-duration laser pulse. These filaments exhibit a remarkable degree of stability, persisting for several tens of picoseconds, and appear to be magnetized over a length corresponding to several filament radii [2].

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P.Tu_6

Fast electron transport in counter-directed resistivity gradients

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In Fast Ignition, the fast electron beam carries the laser energy from the critical surface up to the isochorically assembled Deuterium-Tritium (DT) fuel.

Rapidly changing density and temperature plasma conditions are expected to be found along the fast electron beam path. In particular these variations determine the presence of resistivity gradients, counter-directed with respect to the fast electron beam propagation axis. Very sharp gradients are expected to be found at the cone tip, where a strong shock and a subsequent plasma jet are driven by DT capsule compression. The intrinsic fast electron beam divergence associated with counter-directed resistivity gradients induces magnetic fields which, in turn, can affect the fast electron transport to the compressed fuel, by increasing the fast electron divergence or even preventing the fast electrons in the energy range 1-2 MeV to further propagate in the DT plasma. However, the importance of this effect is directly related to the fast electron current density and fast electron beam divergence.

In this work we expose the study of fast electron transport in counter directed resistivity gradients, constituted by a strong shock driven in solid Al, as function of fast electron current density and fast electron divergence. The simulations are performed using Lsp hybrid code in 2D axis-cylindrical geometry. Scanning over the fast electron beam parameters, it will be determined whether this effect is important for fast electron transport and, in case, which fast electron beam parameters will determine a depletion of fast electron penetration in the range 1-2 MeV. The determination of these parameters will be useful to correct the ignitor beam energy, accounting for the losses related to the presence of resistivity gradient generated magnetic fields.

P.Tu_7

Kinetic Simulation of Electron Transport using Electron Magnetohydrodynamic Structures

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The Electron Magnetohydrodynamic (EMHD) fluid model (simplified fluid depiction of fast electron time scale phenomena for plasmas) supports exact nonlinear solutions in the form of electron vortex currents with associated induced magnetic field in a two-dimensional uniform plasma. Recent simulation studies have shown that such structures can be created as a result of laser-plasma interaction and show stable transport towards high-density plasma region [1,2]. It is considered that these structures can be applicable to the fast ignition. The consideration of immobile ion and zero temperature employed in the EMHD formalism, however, is pretty restrictive. Therefore, the role of kinetic effects due to finite electron temperature on the propagation of these structures has been explored in the present study.

For this purpose, Particle-In-Cell (PIC) simulations that include kinetic effects are conducted. The traveling solution of a combination of two counter-rotating electron vortices by EMHD theory, namely profiles of electron vortex currents and induced magnetic fields are used as initial conditions. Electron velocities are given to satisfy Maxwell velocity distribution with the given electron temperature and then the current-derived drift velocity is added to each electron. Changing the electron temperature, we perform PIC simulations to investigate finite temperature effects.

Simulation results show that the magnetic structure rapidly collapses when the temperature is high. In this case, thermal random velocities of some electrons are faster than current-derived drift velocities, so that Larmor radii of these electrons can be larger compared to the structure size and these electrons run away outside the structure. Most runaway electrons do not return inside the structure because the magnetic fields exist only inside the structure. This results in the decay of the structure. On the other hand, the magnetic structure is found to be robust when the temperature is low enough for the Lamor radius of the electrons to be smaller than the structure size. However, even at the low temperature, if the structure size is smaller than a critical size, it becomes fragile. In this case, the velocity of electrons that drive vortex current is faster than that of the large structure case. Therefore, Larmor radius is larger than the structure size and the structure is collapsed. Furthermore, it is also found that the decay of the magnetic field leads to the decrease of the propagation speed of the structure.

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P.Tu_8

Application of an integrated electron transport framework to a fusion design

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We are interested in being able to model experiments that help us understand the physics of short-pulse generated electrons, both as an energy source for simple geometries on the Orion laser at AWE, and also in the context of inertial ignition schemes. Investigation of ignition schemes combining long-pulse compression with a fast-electron component in computational models is challenging. We have developed a set of tools that allow us to link the explicit PIC code EPOCH through to the hydrodynamics code CORVUS via an efficient hybrid transport code THOR. Although several gaps remain in the self-consistency of the modelling in the current state, it has allowed us to investigate more sophisticated electron sources and the effect on targets of interest in a more integrated manner.

Having developed our integrated framework and demonstrated it on simple designs [1], we consider here a potential new target design that may offer some advantages over existing schemes. We attempt to include the effect of explicit PIC sources in the calculation of such designs, so that we can assess the short-pulse laser characteristics required, and we provide some initial estimates of the impact of the inclusion of realistic density profiles and time varying sources to try to conclude whether the scheme is viable.

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P.Tu_9

Guiding Fast Electrons using Resistivity Gradients for Fast Igntion and HEDP

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Control of ultra-high-current density relativistic electron beams that are generated by ultra-intense laser irradiation of dense plasmas is a matter of critical importance to a range of subjects in laser-plasma physics. These fast electrons are of central importance to Fast Ignition ICF, where well controlled propagation is needed to ensure that FI will be an energetically attractive and economic laser fusion scheme. In the wider context of HEDP in general, fast electron beams may provide a way to rapidly heat dense matter to various ends, ranging from studying the properties of hot dense matter through to laboratory astrophysics.

One route to effective control of these fast electron beams is to exploit the strong growth of magnetic fields at the intersection of fast electron flows and background resistivity gradients [1-3]. Strong resistivity gradients can be engineered into targets through microfabrication of targets composed of various materials with different Z. Not only has this been proposed theoretically, but good experimental evidence has emerged for its effectiveness as well [3,4].

Here we will discuss recent progress we have made in further developing this idea theoretically including an assessment of an elliptical mirror focusing concept [3] for Fast Ignition [6], and our development of using resistive guiding to launch shaped shocks in solid density material, perhaps even achieving a quasi-spherical convergent shock.

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P.Tu_10

Suppression of beam merging and hosing instabilities in the magnetized fast ignition

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Relativistic electron transport in a high density plasma is one of key issues in a fast ignition scheme in an inertial confinement fusion program. When a large electric current produced by a relativistic electron beam flows in a high density plasma, it generates a return current in background electrons. Free energy contained in such two counter drifting electron streams makes the state unstable.

When the free energy is released to longitudinal fluctuations, whose wave number vector is parallel to the beam propagation, the unstable mode is the so-called two stream instability. In this case, electrostatic field is amplified and the free energy is converted into static electric field energy. On the other hand, when the free energy is released to perpendicular fluctuations, the unstable mode is called the Weibel instability. In this case, a static magnetic field is amplified as well as a transverse electric field and the free energy is converted not only into the electric field but also into the magnetic field. The large fluctuated electric and magnetic fields generated by the two kinds of instabilities deflect the injected beam electrons and make an electron angular spread wider and wider. As a result, the number of energetic electrons reaching into a core plasma is reduced and the energy transmission efficiency from the PW laser to the core plasma becomes small.

In order to suppress such beam spread, applying a strong magnetic field parallel to the beam propagation is proposed by the ILE group. When the applied magnetic is strong enough, beam electrons are confined along the field lines and the number of electrons penetrating into the core plasma increases if the electron beams are not scattered by the fluctuations. It is possible that the strong magnetic field suppress those instabilities. In this paper, we will show the detail analysis of the beam instabilities, both electrostatic and electromagnetic, using an analytical calculation, PIC simulation and a hybrid simulation. The final goal of our work is to determine a value of the external magnetic field sufficient for the suppression of the merging and hosing instabilities related to the beam filamentation to achieve the successful fast ignition scheme.

The analysis has two parts. One is the theoretical prediction of the growth rate using kinetic description, which is necessary for the analysis in a low growth rate regime. The other is a hybrid simulation with electron beam injection with a range of external magnetic fields. The simulations show the mixture of electrostatic and electromagnetic instabilities take place in the vicinity of the entrance of the electron beam and electrons are scattered by the excited fluctuating fields, when no external magnetic field is applied. Results show that the sufficiently strong magnetic field is capable of suppressing those instabilities and keeps the electron angular spread narrow for a long distance. The details of the results will be shown in the conference.

P.Tu_11

Effects of the irradiation of a finite number of laser beams on the implosion of a cone-guided target

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In inertial confinement fusion (ICF), the implosion process plays a very important role. However, the irradiation of a finite number of laser beams makes non-uniform distribution on the target surface, which has the possibility to cause non-uniform implosion. Such a problem involved with the finite number of lasers is unavoidable in the case of a direct drive laser ICF. In Fast Ignition Realization EXperiment (FIREX) at Osaka University, the direct drive scheme is adopted, and furthermore a gold cone is inserted into the target for fast ignition [1]. Using a cone-guided target is efficient for heating the fuel core, however, it leads to asymmetric implosion. In order to estimate the effect associated with the irradiation orientation of lasers on the cone-guided implosion, we conducted implosion simulation introducing laser absorption process into a three-dimensional hydrodynamic code IMPACT-2D/3D [2].

In the simulation, the Eular equations are used as governing equations and ray tracing is used to achieve the distribution of laser absorption on the target. The laser beam is divided into multiple beamlets, each of which is treated as a ray defined by the following equation [3]:

$$\ddot{\mathbf{r}} = -\frac{c^2}{2}\nabla\left(\frac{\rho}{\rho_{cr}}\right),$$

where $\mathbf{r}$, c, ρ and ρ_{cr} are the positional vector of ray, light speed, mass density and critical density of plasma. As a preliminary simulation, we performed implosion simulation by adding pressure distribution on the target surface so that the laser absorption distribution is reflected. The laser irradiation orientation is considered as Gekko XII and the target convergence ratio is approximately three in the case of the uniform implosion not to add any perturbation on the pressure distribution. The result says that the maximum density of the fuel region decreased by approximately 30% compared with the uniform case. We will discuss implosion simulations in which the fluid calculation is coupled with the laser absorption calculation. Furthermore, we will introduce a new ray-tracing algorithm.

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P.Tu_12

Plasma-optics of fast electrons for improved coupling in fast ignition*

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Magnetic fields generated at the interface that separates materials with different resistivity can be used to guide the fast electrons towards regions of higher resistivity [1]. Fast electrons can be reflected by these magnetic fields just as photons are by reflective optical elements. In this talk it will be shown that the analogy between classical optics and the "optics" of relativistic electrons can indeed be used to improve the coupling between the ignition laser and the compressed DT core, in a fast ignition scenario.

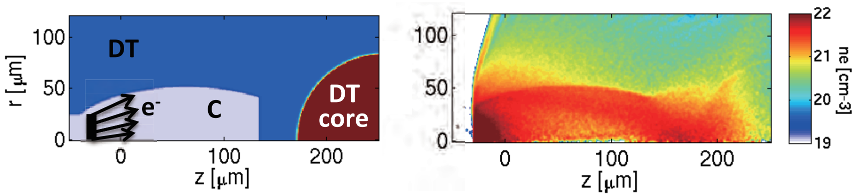

Figure 1: Hybrid-PIC simulation of a fast electron beam injected in a solid-density carbon (partial) ellipsoid embedded in a DT plasma. (Left) Geometry and materials used in the simulation. (Right) Fast electron particle density after 16 ps.

Integrated Hybrid-PIC and radiation-hydrodynamic simulations are carried out for this purpose, with the codes Zuma and Hydra. The properties of the injected fast electron beam accurately represent results from massively-parallel PIC simulations of the laser-plasma interaction. In agreement with preliminary studies [2], these results show that ellipsoidal reflectors can effectively focus the fast electrons towards the compressed DT core, allowing for a significant decrease of the ignition energy with respect to propagation in an all-DT plasma [3].

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. DE-AC52-07NA27344.

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P.Tu_13

Applications of various atomic number plasmas for forming plasma streams of different shapes

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Collimated and supersonic plasma streams (jets) are subject of great interest from the point of view of applications in Inertial Confinement Fusion (ICF) and simulating astrophysical phenomenas. This paper has shown possibilities of creation of desirable plasma configurations using the plasma property saying that its pressure decreases with increasing atomic number (Z) of the target material. It was demonstrated in our earlier papers (e.g. [1]).

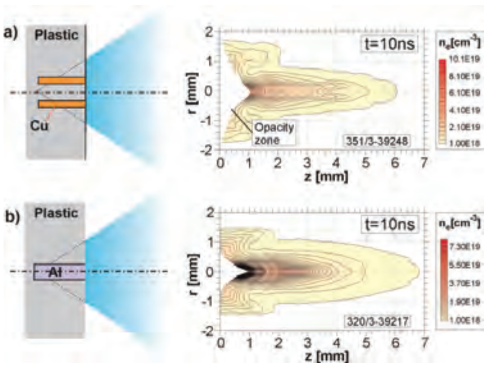

Figure 1: Target constructions (left) and electron density distributions (right) for tubular plasma Cu stream (a) and Al collimated plasma jet (b).

Our experiments have shown that applying axially symetrical inserts, made of various materials, fixed in plastic allows to create different plasma configurations, e.g. high-quality tubular/conical Cu plasma streams being a nozzle for the plastic plasma (Fig. 1a) and collimated jets launched even on targets with low Z, like Al (Fig. 1b).

These possibilities are of benefit to, for example, construction of fuel pellets for ICF, where plasma jets can be used as igniter.

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P.Tu_14

Integrated Simulations for Ion Beam Assisted Fast Ignition

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A fuel target is imploded by long-pulse implosion lasers and its compressed core is heated by a short-pulse ultrahigh-intense laser in the fast ignition scheme. Incorporated fast ignition experiments have started at ILE, Osaka University to demonstrate that the compressed core could be heated up to 5 keV using Au cone-guided targets. First series of the incorporated experiments was performed in 2009, and only 30-fold enhancement in neutron yield, which was ~ 1/30 smaller than that in 2002 experiments, was achieved, and lower energy coupling from the heating laser to the imploded core was suspected.

2D PIC simulations indicate that even the coupling efficiency from the heating laser to fast electrons is generally high (>40 %) but the divergence angle of fast electrons is large (~90 degree), and it results in low coupling efficiency from fast electrons to the core. The Weibel instability, which is induced by a fast electron flow and its counter stream of background electrons, generates quasi-static magnetic fields, and they grow up to more than hundred Megagauss, large enough to scatter several MeV electrons within 1 μm. Furthermore, filamentations of the heating laser induce deformation of the plasma surface, and it enhances the fast electron divergence. To mitigate this critical issue, advanced target designs are proposed and incorporated experiments, in which external-compressed and/or self-generated magnetic fields are expected to guide fast electrons to the core, are scheduled at Osaka University in this year.

On the other hand, high-energetic well-collimated proton beams were observed in many laser-thin foil experiments, and they can be used to additionally heat the core in cooperation with fast electrons. As protons are supposed to come from contaminations on the target surface, it's unclear and uncontrollable. Thus two types of plastic (CH) targets, which generate not only proton (H^+) but also carbon (C^{6+}) beams, are placed close to the cone tip, namely the imploded core. One type is a low-density thin film target where ions are accelerated by the sheath field at the rear surface, and the other is a low-density foam target where ions are accelerated by the Ponderomotive force at the front surface. This design can reduce core-arrival time lags due to different ion energies, and ion beams with wide energy range can be accepted. It can also reduce time lags between fast electrons and ions, and it is easy to introduce into FIREX experiments combining with currently used cone-guided targets. Ion beam characteristics are investigated by 2D PIC simulations and core heating properties are evaluated by integrated simulations.

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P.Tu_15

The effect of laser wavelength on a laser-driven shock produced in a planar target at the conditions relevant to Shock Ignition

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Shock ignition (SI) is a novel concept of ICF in which the target compression is separated from the target ignition and both these processes are driven by a single, properly shaped laser pulse. A multi-ns moderate-intensity part of the laser pulse drives the compression and its short (~ 0.2 – 0.5 ns) high-intensity part (spike) generates a strong convergent shock which ignites the compressed fuel at the stagnation phase. Unfortunately, to produce the shock pressure needed for ignition, the laser spike intensity has to be sufficiently high (~ 10^{16}W/cm^2), comparable to or above the threshold for the nonlinear interaction of the laser pulse with a large scale plasma produced by the multi-ns (compressing) part of the pulse.

The aim of the experiment performed at the PALS laser facility in Prague was to study the effect of the large scale preformed plasma on parameters (total energy and pressure) of laser-driven shock wave produced in a planar target at physical conditions relevant to SI. Characteristics of the preformed plasma were controlled by the delay Δt between the auxiliary beam (1ω, ~7×10^{13}W/cm^2) and the main 1ω or 3ω, 250ps laser pulse of intensity up to 10^{16} W/cm^2 and measured with the use of 3-frame interferometry, ion diagnostics, X-ray spectroscopy and Kα imaging. Parameters of the shock, produced in a CH(Cl) target (25 μm or 40 μm thick) by the intense 1ω or 3ω laser pulse with energy up to 200 J were determined on the basis of volume of craters produced by the shock in the massive Cu target behind the CH(Cl) layer. The measurements indicate that for the 3ω main beam the energy and pressure of the shock do not depend on the preplasma thickness. On the other hand the energy and pressure of the shock induced by the 1ω beam was found to depend strongly on the preplasma thickness: for the 1ω beam at the intensity ~ 10^{16}W/cm^2 the volume of craters produced in the absence of preplasma was by order of magnitude larger than in the presence of preplasma. This suggests that hot electrons produced by the 1ω beam lose their energy in the presence of preplasma before reaching the ablation surface.

P.Tu_16

Gigabar shock wave driven by high energy electron stream

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Hot electron transport and energy deposition are crucial problems in the inertial confinement fusion. In conventional schemes of central ignition the hot electrons are highly undesirable as they may preheat the fuel and spoil the efficiency of shell implosion. However, in the shock ignition scheme the energetic electrons are produced on the late stage of implosion when the shell areal density is sufficiently high to prevent the fuel preheat. Moreover, such hot electrons may contribute significantly to creation of the high ablation pressure, which is one of main challenges of shock ignition. The hot electrons are penetrating much deeper in the dense plasma than optical photons, and thus create a much higher ablation pressure assuming the same energy flux. However, in difference to the laser driven ablation, which is a stationary process, the fast electron driven ablation is a non-stationary phenomenon. The ablation pressure decreases after a specific loading time, that depends on the plasma density and the electron range [1]. This is due to the fact that the fast electron range does not depend on the plasma temperature.

In this paper, we present an analytical model of the shock wave formation by an intense beam of energetic electrons in dense plasma and related numerical simulations. The model is based on the self-similar solution of isothermal expansion of a finite mass of plasma [2]. It provides the expressions for the temporal evolution of the ablation pressure, the characteristic time and the coupling efficiency. The analytical results are confirmed in numerical simulations with the radiation hydrodynamic code CHIC [3] equipped with a kinetic module describing the fast electron transport and the generation of quasi-static magnetic fields [4]. In the case of energy flux of 1 – 10 PW/cm^2 transported by the electrons with the energy 30 – 100 keV, the shock pressure rises to the values of 0.4 – 2 Gbar for a period of 300 – 1000 ps in a deuterium-tritium plasma with the density of 10 g/cm^3. The coupling efficiency of fast electron energy in the shock is about of 10 %.

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P.Tu_17

High efficient ultrahigh acceleration of plasma blocks by PW-ps laser pulses for producing fusion flames in DT and HB11 of solid state density

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Ultrahigh acceleration of plasma blocks in the range of 10^{20} cm/s^2 has been confirmed experimentally after this was long predicted as a non-thermal direct conversion of optical energy into plasma motion due to dominating nonlinear (ponderomotive) forces [1]. The use of laser pulses of more than PW power and ps or shorter duration can ignite a nuclear fusion flame in solid density deuterium tritium because the necessary energy flux of >10^8J/cm^2 according to the theory of Chu [2] is available [3]. For the studies of the necessary velocities of the generated fusion flames above 1000 km/s the detailed processes can be analyzed by using the advanced genuine two-fluid hydrodynamic model [4] where it was surprising that the initiation of the fusion flame by the picosecond interaction needs a comparably long development in the nanosecond range before the thermal processes result in the generation of a general shock front similar to the Rakine-Hugoniot theory but with more details of the thermal broadening of the compression area For the evaluation of power generation the problem of lateral energy losses was studied by using very high pulsed magnetic fields or spherical geometry. An advantage is the increase of the fusion gain by ion stopping processes.

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P.Tu_18

Picosecond laser pulses for ultrahigh plasma acceleration to ignite fusion flames in solid density fuel

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Picosecond high intensity laser pulses convert laser energy directly into mechanical plasma motion by nonlinear (ponderomotive) force driven ultrahigh acceleration in basic contrast to strong energy losses at nanosecond thermal interaction. After this was clarified [1] the generated plasma blocks could be used to ignite fusion flames in sold density fusion fuel following the computations of Chu not only for deuterium-tritium reactions [2] but also for hydrogen-boron [3]. More detailed computations are presented using genuine two-fluid hydrodynamics [4] demonstrating more details of the ignition conditions for hydrogen-boron. A new aspect is to use spherical irradiation of the picoseconds laser pulses instead of plane geometry solving the problems of lateral energy losses and compression with increased fusion gains. Due to the fast processes with directed ultrahigh ion densities, the conditions of the genuine two-fluid model arrive at comparably low electron temperatures which reduce bremsstrahlung losses with power generation avoiding dangerous radioactive radiation from burning hydrogen boron. Laser pulses up to the exawatt range confirm solutions for power generation with prospects of some simplifications by evaluating further effects.

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P.Tu_19

Direct-Driven Target Implosion in Heavy Ion Fusion

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In inertial confinement fusion, the driver beam illumination non-uniformity leads a degradation of fusion energy output. On the other hand, heavy ion beam accelerator provides a capability to oscillate a beam axis with a high frequency [1]. The wobbling beams may provide a new method to reduce or smooth the beam illumination non-uniformity [2].

A fuel target alignment error may happen in a fusion reactor; the target alignment error induces heavy ion beam illumination non-uniformity on a target [3]. Therefore, first we study the effect of driver irradiation non-uniformity induced by the target alignment error (*dz*) on the target implosion. Figure 1 shows that *dz* should be less than about 130 μm for a sufficient fusion energy output. Then we optimize the wobbling beam illumination; spiral wobbling heavy ion beams provide a lower illumination non-uniformity (see Fig. 2).

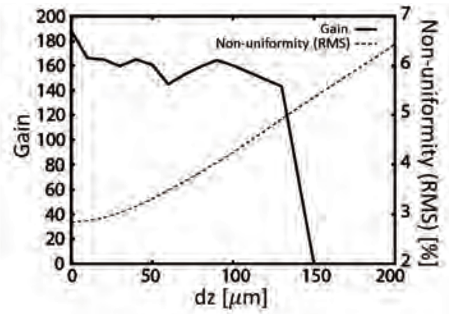

Figure 1: Fusion gain and illumination non-uniformity vs. pellet displacement.

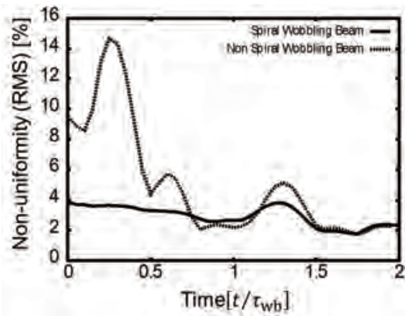

Figure 2: Histories of the illumination non-uniformity.

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P.Tu_20

Simulating and diagnosing mix in NIF capsule implosions

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Sandia National Laboratories

Optimizing the design for the NIF ignition target requires an assessment of the high mode growth of capsule perturbations at the unstable interfaces, and the resulting mix of material into the hot-spot. Mode numbers up to ~ 200 can have significant growth on the outer surface of CH capsules. Mode numbers up to ~ 1000 are important at the DT:CH interface. We have observed evidence of ablator material entering the hot-spot in NIF experiments through measurements of x-ray spectra and images, consistent with simulation predictions. [1]

Sources of high-mode mix into the hot-spot include "isolated defects" on the capsule, such as bumps, "dust", the fill-tube, and the "tent" which supports the capsule in the hohlraum. Depending on the perturbation type, and the relevant growth factors, the penetrating mix can include ablator material (CH), or "payload" (fuel for layered targets or CH for Symcaps). The relative contributions to hot-spot mix can be determined by selectively doping Symcaps with different high-Z materials (Ge in the ablator and Cu in the CH payload), and observing the resulting characteristic x-ray emission.

Through measurements of the x-ray spectrum, with an absolutely calibrated spectrometer, we can estimate the mass of mixed material by inferring plasma conditions from spectral features and assuming a collisional-radiative model. By imaging the K-shell emission from selectively localized dopants, we can isolate the sources of mix and show the distribution of mixed material in the hot-spot. A K-B imager is under development for future experiments.

In addition, radiographic measurements of capsules with both pre-imposed and "nominal" perturbations, with selectively doped high-Z layers (e.g. backlighting above and below the K-edge) provide a means of measuring ρR variation in the imploding and compressed capsule.

Our predictions of high mode mix and its spectroscopic observables are based on highly resolved Hydra simulations that are postprocessed with Cretin [2], a non-LTE radiation transport code. We will present simulations of NIF implosion targets for a range of mix conditions, and the corresponding experimental observables.

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P.Tu_21

Polar and Azimuthal Symmetry Tuning of Defect Induced Mix Experiment Implosions*
LA-UR-12-23046

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The Defect Induced Mix Experiment (DIME) employs the National Ignition Facility's (NIF) and Laboratory for Laser Energetics Omega's Polar Direct Drive (PDD) [1] laser configuration to assess the effects of mix on the thermonuclear burn during a thin-shell capsule implosion. Recent DIME campaigns on NIF and Omega demonstrated the effectiveness of cone power tuning and azimuthal re-pointing technique in reducing polar and azimuthal asymmetry due to the laser drive. Radiographic and self-emission images revealed an improved polar and equatorial low-mode symmetry which was in agreement with 2- and 3-D computer simulations using the 3-D radiation-hydrodynamics code HYDRA [2]. In particular, by reducing the energy in NIF's polar rings (23.5°, 30°, 150°, and 156.5°) by 25%, the P_2 Legendre mode was reduced to near zero around bang time (Fig. 1) from its nominal value of -15%. January 2013 Omega campaign validated code predictions of P_2 tunability with cone powers producing prolate, circular, and oblate capsule implosions.

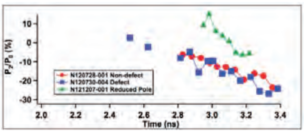

Fig. 1. P_2 around bang time for 3 different NIF shots.

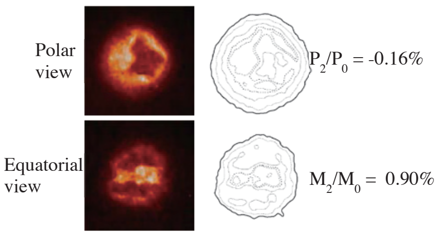

Fig. 2. Self-emission and its contours.

Azimuthal symmetry on NIF was improved by a more radical repointing of NIF's 50° and 135.5° beams (to compensate for removed backlighting beams) which resulted in virtually no M_2 during the implosion (Fig. 2). However, during FY12-13 NIF DIME campaigns, polar and equatorial high resolution self-emission images revealed a complex internal structure around the equator (Fig. 2), which might be attributed to a combination of cross-beam energy transfer and other LPI effects.

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P.Tu_22

Development of a Polar Direct Drive Platform for Mix and Burn Experiments on the National Ignition Facility

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Capsules driven with polar drive [1,2] on the National Ignition Facility [3] are being used [4] to study mix in convergent geometry. The 2.2-mm diameter capsules are mounted on a fill tube, through which a 5 atm deuterium fill is introduced. The inner 2 microns of the capsules are doped with germanium or copper to determine how much ablator material is mixed into the gas and how deeply it mixes. Capsules with two dopant layers, a germanium inner layer and a gallium buried layer, have also been used.

Experiments performed in CY 2012 show that the radius of the imploding capsule varies in time as predicted and that low-mode symmetry is in agreement with simulations. Symmetry control by varying the distribution of laser energy between the beams has been demonstrated. Yields are within the uncertainty of predictions, however the dopant layer temperature is lower than expected. Dual-layer capsules have put limits on the thickness of material that mixes into the fuel from the inner surface of the capsule and on the thickness of material ablated from the outer surface during the laser pulse.

Experiments are being planned to utilize capsules with deuterated plastic inner layers together with a tritium fill gas to measure the effects of mix on the location and rate of nuclear reactions, and compare this to simulations. Simultaneously, mix will be measured by imaging the x-ray emission from a dopant co-located with the deuterated layer with a multiple monochromatic imager [5]. This will allow us to measure burn in the presence of measured mix.

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P.Tu_23

Simulations of Single-mode Ablative Rayleigh-Taylor instability in Indirect-drive Experiments on SGII

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A set of indirect drive experiments to study single mode ablative Rayleigh-Taylor instability at the SGII laser facility has been conducted in 2012. Planar brominated polystyrene foils with a sinusoidal perturbation of 50μm wavelength facing on the x-ray drive are accelerated. Contrast in optical depth was measured as a function of time using face-on radiography. The simulations employed the x-ray drive from the middle part of the gold hohlraum side, in which the foil was mounted. Holding areal density fixed, the concentration of bromine dopant was varied in separate shots with small initial amplitude 0.5μm. Calculations show that preheating effect from the M-band of x-ray drive is reduced with the higher Br-doped concentration and the growth of ablative Richtmyer-Meshkov instability was evidently slowered with the strongly preheating effect. Foils with large initial amplitude 3μm obviously grew into nonlinear regime. The onset of harmonic generation was observed. Coefficient of the fundamental mode, second harmonic and third harmonic from the Fourier transform of experimental datum is compared well with the simulated results. Calculations display the "bubble-spike" shape and self-generated magnetic field up to 0.2Mgauss at the ablative perturbed surface. Self-generated magnetic field is mainly originated from the gradient of electronic thermal pressure and is related with the vorticity of Rayleigh-Taylor instability at ablative front.

P.Tu_24

Deuterated CH Ablators with Tritium Gas Fill as a Diagnostic of Mix[1]

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Abstract. As a part of the National Ignition Campaign, a number of symmetry capsules have been fired at the National Ignition Facility (NIF). Symmetry capsules (or symcaps) look like ignition capsules except that the 60 microns of DT ice has been replaced with an equivalent mass of 20 microns of glow discharge polymer (GDP) plastic. Symcaps are used to assess the symmetry of a NIF implosion. On several symcap shots, the inner 4 microns of CH plastic was replaced with deuterated plastic and the capsules were fired with a pure tritium gas fill. In this configuration, the DT yield of the symcap is a direct measure of the mixing at the atomic level between the tritium gas and the deuterium in the inner plastic. The results from our deuterated mixcap campaign will be presented and the implications for plastic ablator mixing into the gas fuel will be discussed.

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P.Tu_25

Investigating Turbulent Mix in HEDLP Experiments

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We report on initial experiments planned for and performed at the NIF and Omega to investigate turbulent mix on a platform initially developed for the Omega laser facility and scaled up for NIF. We are investigating turbulence-driven mix from two colliding shocks and sheared layers resulting from Richtmyre-Meshkov and Kelvin-Helmholtz instabilities, such as those expected in ICF ignition capsule. Two shocks were generated at either end of cylindrical, CH foams, and the evolution of a Ti or Al tracer layer in the center plane or at one end of the foam was measured using point-projection radiography as it is either shocked twice or sheared. Comparison of this data with simulations using the Besnard-Harlow-Rauenzahn (BHR) model is used. BHR is intended for turbulent transport in fluids with large density variations and has the ability to improve our predictive capability for ICF experiments.

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P.Tu_26

Analytical work on symmetric compression of ICF fuel: Comparison with experimental and simulation results

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Inertial Confinement Fusion (ICF) technology is one of the leading processes to produce fusion energy. There are various instabilities to restrict the success of compression of Deuterium-Tritium (DT) fuel in ICF process. Fluid instabilities are one of the major problems for uniform compression and should be mitigated for success of the ICF. Direct driven ICF with Omega, LMJ, GEKKO XII etc, laser facilities shows that as the high intense laser shocks compress the spherical target the density will increase and Lawson criteria satisfy for ignition. However, in indirect ICF experiment like NIC also shows same results in a pre generated plasma surroundings. In this paper, we represent a model which will describe the physical situation of uniform compression and the increase of density of DT fuel. In this model, we assume that the surroundings of DT fuel are so large that the density and pressure remains constant during the compression of DT fuel by laser. Here, we report that the compression ratio

$$\frac{\Delta \boldsymbol{R}}{\boldsymbol{R_0}} = \mathbf{83}\%$$

Experimental and simulation results show that as the compression occurs then the radius of the interface will decrease which causes the ignition (implosion). However, as ignition start then blow up (explosion) will also occurs and again the radius will increase. The density falls off as the fuel expands. The asymptotic growth rate of the interface is

$$\boldsymbol{V_{assymp}} = \sqrt{\frac{\mathbf{3}\Delta \boldsymbol{P}}{\mathbf{2}\boldsymbol{\rho_2}}}$$

where, $\Delta P, \rho_2$ are the pressure difference at the interface and density of heavier fluid, respectively. However, all results can be controlled by the initial conditions. These types of results have not been reported earlier analytically. Our results show a well agreement with simulation [1] and experimental results also [2,3].

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P.Tu_27

Study of the CH ignition capsule implosion for indirect-driven inertial confinement fusion

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This paper reports some recent progress in the CH ignition capsule implosion. First, we have developed a 0D model for the indirect-driven target design, in which several scale laws have been fitted by a large number of 1d simulations of the RDMG code. Second, we have done many of 1D RDMG simulations to obtain the 1D ignition parameter space. Third, the requirements of the outer surface roughness of the CH ablator, the inner surface roughness the DT ice and the radiation driven asymmetry are obtained according to the simulated growth curves of 2D simulations by the LARED-S code. By changing the CH ablator thickness, the requirements of the high-mode roughness and low-order roughness and driven asymmetry are balanced. The effect of low-mode areal density perturbations on the implosion in the deceleration stage is investigated. Fourth, for reducing growth of hydrodynamic instabilities in the CH capsule implosion, some techniques, for example changing the time shape of radiation drive and dopant position, are explored by 2D simulations.

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P.Tu_28

Mitigation of laser imprinting with diamond ablator for direct-drive inertial confinement fusion targets

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Target imprinting due to non-uniformity of irradiation laser is one of the most important issues on hydrodynamic instability of direct-drive inertial confinement fusion targets. Understandings from previous theoretical studies [1] suggest that the target imprinting is mitigated by thermal smoothing effect. Another important parameter which determines the imprint efficiency is target stiffness (γ) because the target imprint is basically due to the pressure perturbation.

We carried out an experiment with diamond foil as an ablator material. Experiments were done on GEKKO-XII glass laser facility. Diamond is very hard material, and uncompressible under its elastic limit (~ 180 GPa) [2], which means that diamond has a very large effective specific heat ratio γ. The diamond foil was single crystal with (100) orientation on the irradiation surface. The thickness of the diamond foil was 8-10 μm. We also irradiated polystyrene foils as a reference in order to compare the imprint level.

The imprint amplitude was evaluated by measuring areal density perturbation which is amplified by Rayleigh-Taylor instability while the target is accelerated after the target imprinting with a foot pulse. The intensity modulation was imposed for the foot pulse by a slit, where the wavelength on the target was ~ 50 μm. The intensity of the foot pulse was ~ 5×10^{12} W/cm^2. After the foot pulse, the main pulse (~ 1×10^{14} W/cm^2) was irradiated to accelerate the foil. Areal density perturbation was measured with face-on backlighting technique.

The experimental data suggests that the target imprinting for the diamond foil was dramatically mitigated compared with the polystyrene foil. The simple analysis shows the imprint level for the diamond is 1/10 of that for the polystyrene, which is in good agreements with the experimental data.

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P.Tu_30

Rayleigh-Taylor Instability of Intermediate Wavelength in Radiation-Driven Ablation Front

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Rayleigh-Taylor instability (RTI) at ablation front in an accelerated fuel shell is still a critical issue to achieve spherical implosion even though continuous efforts have been devoted to obtain inertial fusion energy. Ablative RTI is well known to be suppressed especially at a short wavelength due to mass flux through the ablation front [1]. In a high-Z doped target, mean-free-path difference between X-rays and thermal electrons results in a double ablation structure, and linear growth rates for RTI are reduced at radiation-driven ablation (RA) front since self-emitted X-rays enhance mass ablation rate [2] while electron-driven ablation (EA) front becomes completely stable. Additionally, a recent theory suggested that the distance of two ablation fronts governs behavior of perturbation growth at the RA front for an intermediate wavelength [3].

We have conducted two-dimensional radiation hydrodynamics simulations for RTI in a high-Z doped planar target. When the acceleration of the RA front is constant and the distance between two ablation fronts is sufficientlly long, the perturbation growth seems to follow the conventional dispersion relation of the ablative RTI. To confirm the theoretical prediction, we should analyze the perturbation growth for the case of a short distance, while two ablation fronts gradually separate with time. In the full paper, we discuss the suppression mechanism for the intermediate wavelength in terms of hydrodynamical response for radiative heat transfer at the RA front.

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P.Tu_31

Influence of the compressibility on the development of hydrodynamic instabilities

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This project is aimed at study of the issues, connected with the influence of effects of compressibility on the development of hydrodynamic instabilities arising on the contact borders of the matter and have a wide range of important applications, including the problem of laser thermonuclear fusion (direct and indirect compression of thermonuclear targets).

There are a number of experimental [1-3], theoretical [4, 5] and numerical [6, 7] works, which deal with various aspects of compressibility. Nevertheless, in most of these are only the straight-line analysis and are determined by the amendments to the classical ratios, determining the development of one or another type of instability. In the given work will be received by the revised values of increments for different equations of state in a wide range of settings, as well as will be determined by the influence of the compressibility parameter $\beta = \frac{g}{kc^2}$ (where is c - the sound velocity, g is the acceleration, k is the wave number) on the evolution of the characteristics of turbulent mixing (such as the width of the of turbulent mixing zone, turbulent energy, introduced mass, etc.). It is important to note that in some cases the compressibility plays an important role in the process of mixing, especially if the environment differ in properties compressibility, since it leads to the change of the number of Atwood.

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Compressibility effect on combined action of Rayleigh-Taylor and Kelvin Helmholtz instability

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In intense laser induced High Energy Density (HED) regime, fluid instabilities are open challenge to the fusion community. Kelvin Helmholtz instabilities (KHI) can be generated due to the laser induced non uniform compression at the interface of two fluids, producing a shear motion which is observed in HED experiment [1,2]. We have extended Layzer's approximation method for studying combined action of Rayleigh Taylor instability (RTI) and KHI. In this model, we report that at intense laser induced interface, combined action of RTI and KHI can enhance the growth of the bubble and velocity of the tip of the bubble and thus producing a destabilization effect in incompressible fluids. Whereas, stabilization and destabilization effect can also be achieved in compressible fluids depending on the compression or decompression of lighter or heavier fluids. The asymptotic growth rate is given by

$$v_{assymp} = \sqrt{\frac{2A_T}{3(1 \pm A_T)} + \frac{5}{16}\left(\frac{1-A_T}{1+A_T}\right)(V_h - V_l)^2 + \frac{3}{2}q_l\left(\frac{1 \mp A_T}{A_T}\right)C_l^2}$$

Where, A_T ,V_h, V_l,C_l are modified Atwood number, relative motion of heavier and lighter fluids and acoustic speed in a lighter fluid, respectively.

We have also shown that even if there is no RT instability, due to shearing velocity KHI persists on both the windward and leeward sides. However, we can get also the nonlinear dynamic stabilization depending on the compressibility and relative velocity of both the fluids. These results are shown to be in well agreement with the laboratory based astrophysical experiment in HED. The astrophysical phenomenological situation like the growth of height of the pillar ("elephant trunk") of Eagle Nebula [3] can also be explained.

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P.Tu_33

Nonlinear evolution of a double current-vortex sheet in MHD Richtmyer-Meshkov instability

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Nonlinear motion of a vortex sheet in a homogeneous magnetic field is investigated using the vortex blob method [1, 2]. We show that a double current sheet structure in the neighborhood of the vortex sheet induces a strong magnetic field and current density when the Lorenz force term in the governing equation is sufficiently small. This system is a model of the MHD Richtmyer-Meshkov instability (MHD RMI). When the Lorenz force term is large, an oscillation due to the Alfven wave appears and the nonlinear growth is suppressed. We present various interfacial profiles depending on the magnitude of the Lorenz force and discuss the complicated motion of the non-uniform double current-vortex sheet.

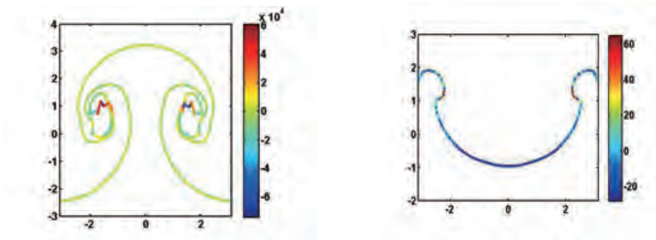

Figure 1: Interfacial profiles with current density in MHD RMI; Left: Atwood number A=0.2 and the Lorenz force term is small; Right: Atwood number A=0.7 and the Lorenz force term is relatively large.

We consider a fluid interface with density and tangential velocity jumps such that a homogeneous (constant) magnetic field is imposed in the whole region including the interface. Then the sharp gradient of the magnetic field between the interface induces current sheets with plus and minus signs in the neighborhood of the interface, and they generate a current-vortex sheet. This can be also a model to explain the extraordinary strong magnetic field amplification in Super Nova Remnants (SNR) [3].

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P.Tu_34

Magnetohydrodynamic Modeling in an Arbitrary Lagrangian Eulerian Framework

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Odin is a two dimensional arbitrary Lagrangian Eulerian (ALE) code being developed jointly between the University of Warwick and Imperial College London. Capable of running in either cylindrical or Cartesian coordinates, Odin will be a multimaterial code with arbitrary equation of state, multigroup diffusive radiation transport and laser ray tracing.

As part of the development the equations of magnetohydrodynamics (MHD) have been added to Odin's core solver. A modified version of the Cauchy solution [1] has been coupled with a constrained transport [2] remap implementation to yield a multidimensional, divergence preserving MHD ALE code. More recent work has centered on the extension to resistive MHD, the inclusion of the Biermann battery mechanism, and its interaction with shock waves.

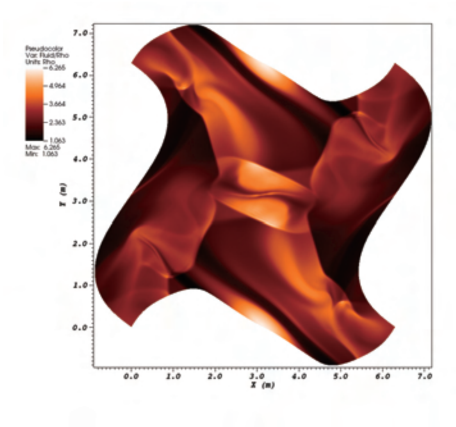

Figure 1: Density plot for ALE calculation of the Orszag-Tang Vortex

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P.Tu_35

Simulation Benchmarking Efforts and Integrated Designs for Magnetized Liner Inertial Fusion Experiments

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Magnetized liner inertial fusion (MagLIF) experiments have begun in earnest at Sandia National Laboratories. Solid beryllium liners containing magnetized and preheated deuterium fuel are imploded using magnetic pressure generated by the Z Accelerator. Reduced heat conduction losses due to flux compression, as well as reduced convergence ratios and implosion velocities due to fuel preheat, may enable interesting fusion yields in the parameter space between traditional inertial and magnetic confinement schemes. Initially, currents of I_{max}~15-18 MA, pre-seeded axial magnetic fields of B_{z0}~7-10 T, and laser preheat energies of E_{laser}~2.5 kJ delivered in 2 ns will be available for MagLIF-relevant experiments, which are designed to separately study the laser preheating of the fuel and flux compression via liner implosion. We report on modeling efforts to benchmark the HYDRA code to these experiments, as well as designs for fully integrated experiments using those initial parameters. Then, we investigate future target designs using the improved parameters I_{max}~27 MA, B_{z0}~30 T, E_{laser}~10 kJ, and deuterium-tritium fuel.

* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

P.Tu_36

Results of the initial Magnetized Liner Inertial Fusion (MagLIF) integration experiments on the Z accelerator*

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The inertial confinement fusion effort on the Z Facility at Sandia National Laboratories is focused on Magnetized Liner Inertial Fusion (MagLIF) [1] experiments. MagLIF utilizes a magnetically-imploded, cylindrical liner to compress magnetized, preheated fusion fuel. Simulations indicate fusion yields on the order of 100 kJ are possible with inputs that may be achievable at the current Z Facility (drive current: 27 MA, 100 ns; laser: 8 kJ, 8 ns; applied B-field: 30 T; fuel: DT). Additionally, a high gain version of the MagLIF concept has been developed [2].

A systematic approach has been adopted to evaluate the MagLIF concept. Several studies of the Magneto-Rayleigh-Taylor instability growth in the liner have been conducted [3,4]. A pre-magnetization capability has been commissioned at the Z Facility, and initial flux compression experiments have been completed. A fuel pre-heat capability has been developed using the Z Beamlet laser, and pre-heat experiments are underway. Upon completion of all individual component testing, the first integrated MagLIF experiments will be conducted.

Initial MagLIF experiments will be conducted at reduced drive current (16 MA), laser preheat (2 kJ, 2 ns), and applied B-field (10 T) with DD fuel. Simulations predict DD neutron yields on the order of 10^{11} for MagLIF experiments with these parameters.

An overview of the MagLIF commissioning experiments completed to date and a description of the applied magnetic field capability will be presented.

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*Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

P.Tu_37

Emission of High Energy Ions in the SHOTGUN III Divergent Gas-Puff Z-Pinch Experiment

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Gas-puff z pinch is a repetitive and efficient system for producing high energy-density plasma. Hard x-ray radiation which has not been observed in the conventional z pinch has been observed in the divergent gas-puff z-pinch experiment, and the generation of high-energy electron was confirmed [1]. It has also been confirmed from the Thomson parabola measurement that the ion acceleration of MeV order has occurred at the same time. As the high-energy ion was also observed in the reversed current experiment, the generation of high-energy ion was believed to be independent of the current direction [2]. In order to understand the mechanism of ion acceleration, the ion pinhole measurement was planned to identify the source and the process of ion emission.

The experiment was carried out on the SHOTGUN-III device at Nihon University. The device is operated with 12 μF capacitor bank, which can be charged positively or negatively. Typical discharge current is about 150 kA at the charging voltage of 25 kV. 10 degrees divergent annular gas nozzle was installed on a center electrode of the device. Argon gas was used for the experiment, and the plenum pressure of the valve was 5 atm. Two ion pinhole cameras were installed in the axial and the radial directions. Track detector (Baryotrak-P) was used for detecting the ions.

When positive voltage was applied to the center conductor, a coaxial structure of ion emission was observed in the axial direction. In the observation using 0.8 μm aluminum foil, some ions on the axis transmitted the foil, and the other ions did not transmit it. When negative voltage was applied to the center conductor, the ions were observed only on the axis in the axial direction. and a flowing pattern toward the cathode was also observed in the radial direction. These observations indicate that high-energy ions about 2 MeV are emitted on the axis regardless of the current direction. Ions were only observed without aluminum foil in the radial direction, so those energies were less than 1 MeV. The ion orbits of both current directions were bent to the cathode direction.

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P.Tu_38

Velocity evolution of electro-magnetically-driven shock wave for beam-dissociated hydrogen interaction experiment

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Ion stopping power depends on target density and temperature [1, 2]. Evaluations of the stopping power are important for heavy ion fusion target design and heavy-ion-driven high energy density physics experiments. Chemical effects in the stopping cross section were studied [3, 4], however, the effects of dissociation up to ionization have not been experimentally investigated. We are interested in dissociation effects on the stopping power of hydrogen targets. In order to produce pure dissociated hydrogen atom without ionization, the electro-magnetically-driven shock was proposed [5, 6]. This method has an advantage to generate a well-defined target condition for the stopping power measurement. Precise shock velocity measurement is required because the target physical condition is sensitive to the velocity. The laser refraction, which needs only simple and compact devices to measure the shock velocity, is suitable for the beam experiment. The velocity measurement showed that the average shock velocity was 10 km/s when the initial pressure was 400 Pa and the discharge voltage was 17 kV. For the beam interaction experiment, duration in the shocked region between the shock front and the discharge plasma as long as microsecond is desired. To estimate the duration, the visible emissions from discharge plasma were measured by photo diodes. The results showed that the duration was up to 8 microseconds with a 400-mm propagation in the shock tube. On the other hand, the shock velocity above was not enough for complete dissociation, which requires 28 km/s. We discuss the evolution of the velocity to understand the electro-magnetically-driven shock physics for the beam interaction experiment.

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P.Tu_39

Study on Pulsed-discharge Devices by using Pulse Forming Network Modules Toward Intense X-ray Source

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For observing interior of dense plasmas, intense and point-spot X-ray source is required. The X-ray source is generated by X-pinch technique [1]. Required parameter of the pulse generator is the rate of current rise of 10^{12} A/s, i. e. 100 kA of current and 100 ns of current rising time [2]. To generate X-ray source by using X-pinch system, Pulse Forming Network (PFN) module [3] was used, having the advantages of holding high peak current, simple fabrication, and so on. The circuit topology of the PFN module through circuit simulations has been optimized, and three-stage LC-ladder of PFN is suitable for the table-top power supply for X-pinch. The inductance component included in the generator is strongly affected to the rate of current rise. In order to reduce the inductance of the X-pinch system, we evaluate the inductance and the rate of current rise, experimentally. We studied high breakdown voltage at the gap switch, the low inductance of the pulsed power supply.

The PFN modules were coaxially arranged in octagon plates, and 48 PFN modules can be connected to drive the X-pinch. The PFN has 73 nH of the inductance and 2700 pF of the capacitance. The discharge device has a coaxial configuration to reduce the inductance. The load current flowing through the inductance measured using a Rogowski coil, contained in the device was determined by comparison between the calculated results with the Alternative Transients Program-Electromagnetic Transients Program (ATP-EMTP) [4] . The rate of current rise obtained was 1.7 x 10^{11} A/s. From these experiments, the electrode inductance of 53 nH was estimated from the results calculated by the ATP-EMTP. The charging voltage to achieve the target rate of current rise is evaluated to be about 60 kV.

To increase the breakdown voltage of gap switch, the gap switch is set into the vacuum chamber due to the dependence of the gap length on the Paschen's law. In short circuit test at vacuum, the charged voltage of capacitor increases at low pressure in the gap switch. The result indicated that the breakdown voltage of gap switch increases due to Paschen's law. However, the charged voltage was 1~2 kV even in the low pressure situation. As a result, using a multi-gap switch and operation at high pressure condition in the gap switch is investigated.

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Target Diagnostics at the Orion laser facility

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ABSTRACT

Orion is a new high power laser interaction facility designed to meet the requirements of AWE's technical programme in high energy density physics

The Orion contract included a substantial inventory of target diagnostics to ensure that the facility is scientifically productive at start-up; these include a broad range of optical, particle and X-ray diagnostics. The configuration of many of the key diagnostics is flexible due to the adoption of Ten Inch Manipulator (TIM) interface first developed for the LLE Omega laser. Commissioning of these diagnostics commenced during laser commissioning activities. We report on the status of these diagnostics and plans to complete their commissioning in parallel with the experimental campaigns scheduled for the first year of operation.

Future developments to meet the experimental programme and enhance the capability of the Orion facility are also discussed.

Keywords: High power lasers, Nd:glass lasers, high energy density physics, plasma diagnostics, X-ray imaging, streak cameras.

P.Tu_41

The development of the current-mode neutron detector for fast ignition experiment

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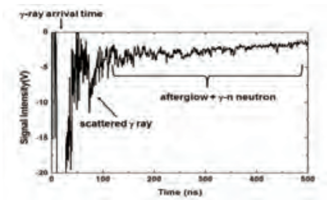
The neutron diagnostics in the fast ignition experiment is one of the key issue for measuring neutron yield and ion temperature of fusion fuel which are essential for coupling efficiency from laser to thermal energy of the compressed core. The bremsstrahlung high energy x rays (defined as γ rays in this paper) generated by ultra-intense laser pulse or neutrons generated from photonuclear reaction (defined as γ-n neutron) make it difficult to measure neutron signals. [1]

In this work, the high sensitivity current-mode neutron detector using liquid scintillator [2] and gated photo-multiplier tube (PMT) was developed for detection of low neutron yield about Yn = 10^6. The scintillation afterglow and PMT saturation caused by intense γ ray flash were successfully suppressed. Furthermore a neutron collimator was installed for reducing γ-n neutrons. Figure 1 shows the comparisons of the neutron TOF signal between conventional detector which is constructed with plastic scintillator (BC-422Q) and ungated PMT and newly-developed detector discussed in this paper. Detail of the neutron detector and experimental result will be presented in the session.

(a)



(b)

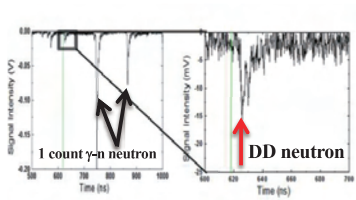


Fig.1. The signal in fast ignition experiment with heating laser energy of about 550 J.
(a)The signal measured by conventional scintillator detector
(b)The signal measured by newly-developed detector. Neutron yield of $(3.8\pm0.7)\times10^6$ were measured.

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P.Tu_42

Development of Multichannel Time-of-flight Neutron Spectrometer for The Fast Ignition Integrated Experiment

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Neutron time-of-flight (nTOF) for determing ion temperature and areal density is an uphill diagnostics in the fast ignition experiment. The multichannel nTOF neutron spectrometer “MANDALA” [1] has critical issues of serious background noises such as photo-neutron signals and the intense afterglow of the scintillation caused by hard X-rays. For the coming 5kJ/ps heating shot, which is the full power shot of the LFEX laser, 80% suppression of the afterglow and 99% suppression of the photo-neutron were required. In this calculation, the bremsstrahlung x-rays generated by the fast electrons from an Au-cone target were simulated. The 20% coupling efficiency of energy from laser to hot electrons and typical divergence angle of 56 degree were assumed [2], and electron spectrum was assumed by using the **J**×**B** ponderomotive scaling model [3]. In the experimental campaign 2012, a 1st neutron collimator as shown in Fig.1 was installed, and 70% of photo-neutrons were suppressed. The 2nd collimator for 99.9% suppression is under construction and will be completed within this year. In addition, the O_2-enriched BBQ liquid scintillator [4] was tested in the experiment and the afterglow was confirmed to be suppressed to 8% compared with the plastic scintillator BC408. We will present the design of the neutron collimator and the modified liquid scintillator and the experimental results in 2012.

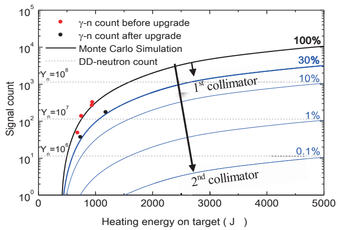

Figure 1: The relation of photo-neutrons versus the heating laser energy

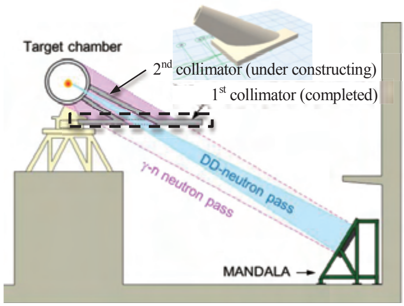

Figure 2: The geometry of the neutron collimator

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P.Tu_43

The neutron imaging diagnostics and unfolding technique for fast ignition experiment

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Neutron or high energy x-ray imaging diagnostics and a new unfolding technique were studied. A multi penumbral apertures with the toroidal inner surface was developed. The unfolding process is essential in the penumbral imaging. In recent studies a novel technique in the unfolding by using Simulated Annealing Heuristic method was proposed [1]. This method solves weakness for noise that is critical issued is the unfolding process. The Heuristic method was tested by using test pattern by adding noise as shown in Fig.1. The clear pattern was successfully unfolded even with adding typical noise obtained in the fast ignition experiment by Heuristic. And about 20μm accuracy length was successfully reconstructed. In the end I make sure that reconstruction by heuristic is strong for noise. The detailed analysis of the Heuristic method and the designs of the detector will be presented in the conference.

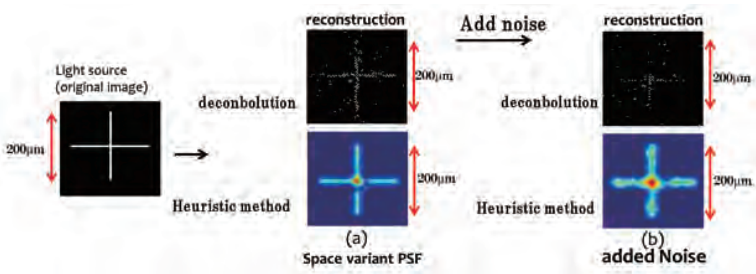

Figure 1 demonstration testing by using test pattern by adding noise. The clear pattern was successfully unfolded even with adding typical noise obtained in the fast ignition experiment by Heuristic.

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P.Tu_44

Characterization of Relativistic Electron Beams Generated by Intense Laser Pulses with High Energy X-ray Spectrometer

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In fast ignition laser fusion, the heating laser energy is converted to a few MeV electron beam, the electron beam heats the imploded fuel core. Efficient heating is established by controlling energy flux, temperature, and divergence of the electron beams.

Electron spectrometer (ESM) utilizing a magnet is often used to measure energy spectrum of relativistic electrons emitted from a laser-irradiated target. Spectral shape of the emitted electrons are strongly modulated by sheath potential generated at the target-vacuum boundary, thus the ESM signal miss especially sub-MeV electrons. High Energy X-ray Spectrometer (HEXS) is developed to characterize the relativistic electrons inside the target through bremsstrahlung x rays emitted from the electrons. Twelve pairs of x-ray filter and imaging plate (IP) are piled in HEXS [1]. The filters are selected to cover x-ray energy range from 10keV to 700keV. Geant4 code, which is a Monte Carlo code to calculate energy deposition and transport of particle through matter, is used to estimate x-ray spectrum from IP signals.

Calibration of the HEXS response for x-ray energy was performed with radioisotope and LINAC. In the calibration, the spectrometer was exposed to a ^{137}Cs radioisotope that emits 661.7 keV γ-ray or bremsstrahlung x rays from a Pb plate irradiated by the electron beams (26 MeV, 18.5 nC/pulse) accelerated by LINAC. Measured signal intensity of each IP signal agree well with the deposit energy in each IP calculated by Geant4 code.

The HEXS was introduced to the Peta-Watt laser interaction experiment. The PW laser irradiates inside of a gold cone attached with a plastic shell and a tantalum block. It is found that the energy conversion efficiency from laser to bremsstrahlung x rays is 3.8%. This conversion efficiency means that the energy conversion efficiency from laser to relativistic electrons is estimated to be 13 - 38% from the theoretical calculation.

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P.Tu_45

Development of Compton x-ray spectrometer for the fast ignition experiment

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The single-shot high-energy x-ray spectrometer with the sensitivity from 0.5keV to 9MeV was developed for the fast ignition experiment. The structure of new detector is constructed with a converter, a slit, and an electron spectrometer as shown in Fig1. X-ray energy is measured by energy and recoil angle of recoil electron generated by Compton scattering. In this spectrometer, recoil angle and recoil electron energy are determined by the slit and the electron spectrometer, respectively. By using this we firstly measured γ-rays emitted from ^{60}Co. Figure 2 shows the recoil electrons signal from ^{60}Co, where a red dots shows the experimental data and a black solid line shows the calculated result. Two peaks with the energy of 1.17MeV and 1.33MeV were clearly observed with the about 10% of the FWHM. Furthermore this spectrometer was tested in the fast ignition by using the typical target designed for evaluating the energy slope and the divergence angle of fast electrons from the bremsstrahlung x-rays spectrum. The developed spectrometer and the filter stack spectrometer, which is widely used in the fast ignition, were set at 21° for each relative to the laser axis [1][2]. We successfully measured x-ray spectrum and the signals showed good agreement with each other. The analysis for the estimation of the fast electron energy spectrum and the divergence angle from bremsstrahlung x-rays spectrum is underway. Detailed result of the experiment will be presented.

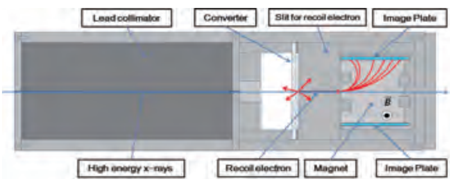

Fig.1 The structure of developed detector

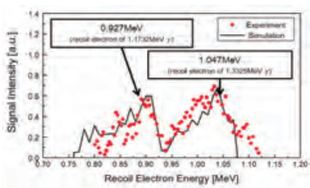

Fig.2 Recoil electron spectrum from ^{60}Co

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P.Tu_46

The high energy X-ray spectrometry by using (γ,n)reaction.

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The bremsstrahlung x-ray spectrometry by using (γ,n) reaction with the energy range from 4MeV to 30MeV has been developed.

High energy bremsstrahlung x-rays spectrum exceeds threshold of photo-nuclear can be measured via photo-nuclear reaction by using various of the material with the different resonant peak of the photo-nuclear reactions.

The high energy X-ray spectrometer was demonstrated by using LINAC facility at Osaka University. The experimental configuration is shown in Fig.1. The bremsstrahlung x-ray was generated by irradiating linear electrons into the lead target with the energy of 26 MeV. Figure 2 shows calculated (black line) and obtained (red point) x-ray spectrum. They shows good agreement even though the error originated from the background neutron is large.

This spectrometer was also tested in the fast-ignition experiment in 2012. The reasonable x-ray spectrum from the fast ignition target was successfully observed. In the presentation, details of this spectrometer and experimental data will be discussed.

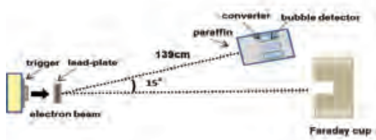

Fig.1 The experimental configuration

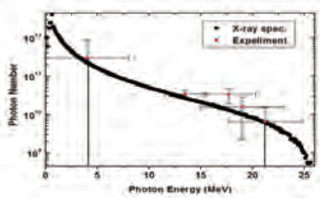

Fig.2 Result of measurement of X-ray spectrum. Black line shows X-ray spectrum calculated using Monte Carlo simulation (MCNP5). Red points shows experimental data.

P.Tu_47

ICF Gamma-Ray measurements on the NIF

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The primary objective of the NIF Gamma Reaction History (GRH) diagnostic is to provide bang time and burn width information in order to constrain implosion simulation parameters such as shell velocity and confinement time. This is accomplished by measuring DT fusion gamma-rays with energy-thresholded Gas Cherenkov detectors that convert MeV gamma-rays into UV/visible photons for high-bandwidth optical detection.

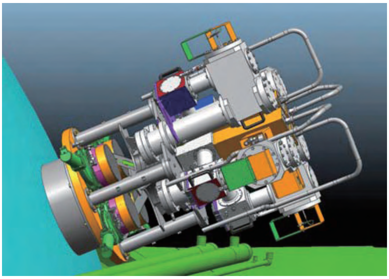

Figure 1: GRH's 4 Gas Cherenkov Detectors.

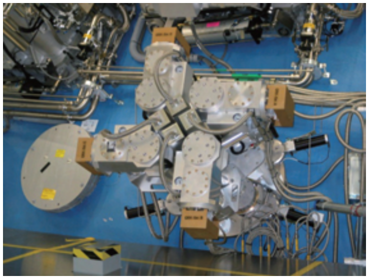

Figure 2: GRH mounted on NIF.

Burn-weighted CH ablator areal density is also inferred based on measurement of the ^{12}C(n,n') gammas emitted at 4.44 MeV from DT neutrons inelastically scattering off carbon nuclei as they pass through the plastic ablator. This requires that the four independent GRH gas cells be set to differing Cherenkov thresholds (e.g., 2.9, 4.5, 8 & 10 MeV) in order to be able to unfold the primary spectral components predicted to be in the gamma ray energy spectrum (i.e., DTγ; ^{27}Al & ^{28}Si (n,n')γ from the thermo-mechanical package (TMP); and ^{12}C(n,n')γ from the ablator). The ^{12}Cγ peak emission timing is found to be delayed tens of ps relative to bang time, implying that the CH ρR continues to increase throughout the burn. Replication of this delay in rad-hydro simulations requires incorporation of ignition failure modes such as shock mistiming, shell/fuel mix and/or implosion asymmetry.

Next generation gamma ray diagnostics are now being considered to provide improved capabilities, including higher sensitivity (DIM-based "Super" GCD), energy resolution (Gamma Compton Spectrometer (GEMS), pixilated "Furlong" detector), higher bandwidth (streaked GRH-15m) and imaging capability (GIS).

P.Tu_48

High-speed x-ray imaging diagnostics compatible with intense hard x-ray background for Fast Ignition experiments

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In Fast Ignition experiment, the target is irradiated with an ultra high-intensity short-pulse laser, which generates plenty of hot electrons. Hard x-rays (γ rays) are generated via Bremsstrahlung ranging in photon energy around and higher than 10 MeV. Intense electromagnetic pulses (EMP) are also generated from such short-pulse laser-irradiated plasmas. Those bring serious difficulties to the plasma diagnostics such as x-ray imaging, neutron detection, and electronic devices by intense background signals and malfunctioning. We have improved our plasma diagnostics to be compatible to such hard-x-ray and EMP harsh environment. High-speed x-ray imaging was successfully performed by introducing x-ray total reflection mirrors, shielding, and imaging Bragg crystals.

Intense non-imaged hard x-ray signals were observed on gated-MCP based x-ray framing cameras coupled with x-ray pinhole cameras. Although this signal can be used as the heating time indicator, it buries the thermal x-ray images of the target at around the time of the heating beam injection. We have developed x-ray framing cameras coupled with total reflection x-ray mirrors, which reflect only thermal x-ray images below 5 keV.

Time-resolved two-dimensional x-ray image of the imploded core plasma was observed with Multi-Imaging X-ray Streak Camera. The cathode disk material (1-mm-thick stainless steel) of the x-ray streak tube is almost transparent to hard x-rays of > 20 keV, and not only the slit area but the whole surface works as a cathode for such hard x-rays, resulting in discharges between the cathode disk and the acceleration mesh due to large amount of the photoelectrons generated by intense hard x-rays. We added a hard-x-ray shielding structure made of tungsten on the photo cathode disk, and the discharge was successfully extinguished.

We also have developed a monochromatic x-ray camera by using Brag crystal imaging mirrors. The cameras were coupled with either an x-ray streak camera or an x-ray framing camera. Direct hard x-rays from the target were stopped with the shielding block inserted between the target and the detector. Time-resolved images were successfully obtained via a separate light path beside the direct line.

These improved instruments worked very well in observation of the imploded core plasmas at the time of the heating laser injection in Fast Ignition integrated experiments at Gekko-XII and LFEX lasers.

P.Tu_49

Control of Imploded Core Plasma by Changing Beam Arrangement of Gekko XII

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Fast ignition is one of the proposed ways to achieve high fusion energy gain in inertial fusion research. The fast ignition realization experiment (FIREX-I) project is going on at Osaka University by using Gekko XII laser system and LFEX laser system. Usually, 3 laser beams of Gekko XII are not used for implosion because they irradiate a cone. However, it was found that this laser unbalance caused an ununiform implosion and made the imploded core plasma move toward the cone. The imploded core plasma may collide with the cone tip and break it. This may disturb the generation of fast electrons from the cone tip and become a serious problem for effective heating. Therefore, we proposed the new laser arrangement to implode a target, 12 beams implosion, and tried it in the fast ignition integration experiment.

The concept of 12 beams implosion is as follows. The 3 laser beams near a cone are shifted not to irradiate a cone as shown in Fig. 1 with the solid line. Long gold cone is used to prevent the irradiation of 3 beams with fundamental frequency (The conventional cone size is shown as broken line in Fig. 1.)

In the experiment, the time-resolved 2 dimensional X-ray images of the imploded core were obtained by using X-ray framing camera (XFC) and multi-imaging X-ray streak camera (MIXS). It is found that the spherical symmetry of the imploded core plasma is improved and the motion of the imploded core plasma towards the cone is suppressed by tuning the beam layout of 12 laser beams. However, the electron temperature and hard X-ray intensity was increased in 12 beams implosion. This suggests that the generation of preformed plasma inside of the cone. 12 beams implosion may become a powerful concept to control the imploded core plasma after we iron out this problem.

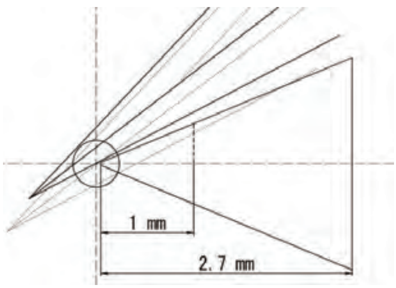

Figure 1: Schematic diagram of a target andconfigurations of 3 laser beams near the cone. The dotted line shows an original configuration of 3 laser beams.

P.Tu_50

A new type of low-pass filter with micro-channel plate optic

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An X-ray transmission model based on square cross section multi-channel plate (MCP) has been developed. This model has the advantages of simplicity and high transmission, and can be the best choice of making band-pass filter device. After the design and technical optimization of this MCP band-pass, the smoothness of the surface was controlled below 2nm and consequently the reflectivity has been greatly improved. By improve the percentage of the doped Pb in the material this filter could greatly prevent the direct passing of medium and high energy X-ray to a very low percentage of 10^{-5}. Several transmission spectra of low-pass filters in the soft X-ray energy range 0.1-1.5 keV have been measured on the Beijing Synchrotron Radiation Facility, as shown in Fig.1. By plus a light tight filter this energy band can be narrowed to be 100 eV.

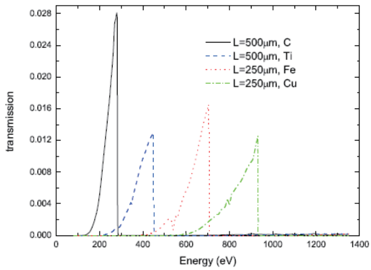

Fig. 1 The band-pass spectra of MCP combined with different filters.

We have developed the angle scanning techniques in the MCP calibrations. The experimental results showed that the positions of the cutting edge of the MCP band pass can be effectively controlled by adjusting the aspect ratio and the grazing incident angle. And the problems of high energy mixing had also been solved. The single reflectivity can be deduced via the experimental transmission data and can be used to validate the method. In the 9th laser grid of Shenguang II facility, the square cross section MCP band pass had been applied in the pin-hole images to choose the energy points. In the experiments 20nm grid images of high quality had been obtained. The experimental results showed that the band-pass can not only to narrow the energy band, but also has the merits of aberration less, high spatial resolution and high signal-to-noise ratio.

We note that this soft X-ray band pass is a novel method which is firstly developed by us in the comparisons with other methods. In contrast to other general methods with reflecting mirrors, our band-pass has the advantages of very high transmission and narrow energy band, and it also has the merit of easy to use. The transmission band-pass method can be used in accurate diagnostics in radiative hydrodynamics. It also can be integrated into the imaging system to perform high quality time-spatial-energy resolved X-ray diagnostics. Therefore this method can be widely used in the researches of ICF, Z-pinch, plasma physics and astrophysics etc.

P.Tu_51

Proton emission imaging by magnetic lens for hot spot measurement in inertial confinement fusion

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Directly imaging of 3.6 MeV protons produced from DD fusion reactions in the implosion region by miniature magnetic quadrupole lenses is proposed for the first time. The magnetic lens, which is widely used in high energy proton radiography, gives a magnified image of DD proton beam with high spatial resolution. The geometrical magnification designed here is about 12. This lens gives a point-to-point imaging when the statistic proton number is large enough. The spatial resolution is better than penumbra emission imaging. The statistical error is also presented. To obtain an ideal resolution, the yield needed must be larger than 10^9.

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P.Tu_53

Measuring X-ray opacities of plasmas relevant to Inertial Laser Fusion: an experimental proposal

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Theoretical values of opacities are employed at present to predict how the background gas in the chamber of an inertial laser fusion reactor absorbs the X-rays produced in the fusion explosions. These values have a strong impact in the design since they determine the required quantity of gas to stop the X-rays before reaching the chamber walls and they play an important role on the thermo-hydrodynamic evolution of the resulting plasma between fusion shots. Thus, their accuracy is of utmost importance not only for the survival of the plasma facing components but also for the successful laser propagation and target injection in the consecutive fusion shots. A wrong evaluation of the opacities may result fatal for the final optics, first wall materials and for a proper irradiation of the fusion pellets.

Thus, there is a pushing need to validate the theoretical values of the opacity of the generated plasmas empirically. However, different experimental limitations have made these measurements difficult to carry out so far. In this contribution, the authors propose an experiment which uses synchrotron radiation X-rays to characterize the absorption of plasmas relevant to inertial laser fusion. Plasma focus devices and GW lasers are plugged to a synchrotron beamline to generate the required plasmas in terms of temperatures and densities (several eV and tens of millibars respectively are the parameters expected in the fusion reaction chamber). A complete experimental set-up with realistic synchrotron X-ray fluxes and plasma parameters will be presented and the range of possible plasma conditions.

This experimental benchmark for theoretical opacities can be applicable not only to fusion needs but also to other fields such as astrophysics, metrology, lithography,.. in which validation is most required.

P.Tu_54

X-ray Thomson Scattering off Warm Dense Carbon on the Shenguang II Facility[1]

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X-ray Thomson scattering off warm dense carbon with a density of 1g/cc is performed on the Shenguang-II laser facility [1]. The sample is produced with a foam carbon that is homogeneously heated with the M-band x-rays of tantalum. The probe for the x-ray scattering is the He-α line of titanium driven by a 1 kJ backlit laser beam [2]. The scattered photons are collected and dispersed with a spectrometer equipped with a slice of highly oriented pyrolitic graphite crystal [3, 4]. Fitting experimental data with theoretical curves, the state parameters of the heated sample are inferred, i.e., the electron temperature is above 35 eV, the electron density is around 1.6×10^{23}/cc, and the averaged ionization state is about 3.5. The results are in good agreement with the averaged atom model.

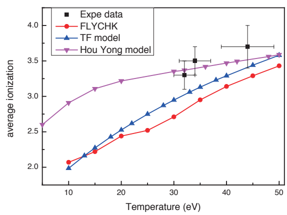

Figure 1: The inferred plasma parameters and the comparison with the predictions of three models.

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P.Tu_55

Experimental Study of Shapping Radiation Temperature

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Abstract: Experimental study of pulse shapping radiation temperature measure technology has been Carried out on the SGIII prototype laser facility. Experiment has resolved out the problem on division and compound of high time resolution high-speed signal and quantifying measure technology with a large-scale range of radiation temperature. The relative standard uncertainty of pulse shapping radiation temperature is smaller than 3%. Shapping radiation temperature time curve with shapping laser pulse has been obtained. With the help of numerical simulation, we have obtained theory curve of shapping radiation temperature. Experimental result was consistent with theory simulation result.

Key words: radiation temperature, shapping laser pulse, uncertainty

P.Tu_56

Ablation loading of solid target through foam absorber on ABC laser at ENEA-Frascati

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The stability of acceleration of targets irradiated by high intensity lasers is a main concern in inertial confinement fusion (ICF) research. A high degree of both irradiation homogeneity and target surface finish will be required in ICF devices to achieve high performance implosions. The uniformity of the pressure exerted by the ablating plasma on the underlying target can be enhanced further by an even absorption of the laser light. Volume structured materials, such as low density foams, have been proposed as random absorbers of the radiation [1,2] mediating the interaction of the laser light with the target. Not to limit the overall energy transfer to the target, optimization of the absorber characteristics is needed. An experimental study of porous absorbers has been performed in the ABC laser facility in Frascati [3,4] with a Nd-glass laser, wavelength 1054 nm, beam energy ~50 J, pulse duration 2.5 ns and intensity $\sim 10^{13\text{-}14}$ W/cm^2. The laser spot size was 500 μm when using ISI plates as flux density profile smoothers and 100 μm when using sharp focalization. Polystyrene foams of various densities (10-40 mg/cm^3) and thickness (200-800 μm) were put on metal substrates (Al, Sn), which absorbed the energy of the shock wave produced by the laser. The plasma produced on the foam was characterized by 2nd harmonic interferometry and imaging, time resolved soft X ray emission and ion-collectors measurements [4]. The dimensions and shapes of the craters produced by the shock wave on the metal substrate were measured with a precision $\sim 10^{-3}$ μm^3 on a confocal microscope. The experimental dependence of crater characteristics vs. foam thickness, the physical properties of the substrate material and on interaction parameters are compared with simulations. On the base of the measurements of the crater volumes and knowledge of the properties of the substrate material, the conclusion on the energy transmitted through the foams was done.

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P.Tu_57

High Energy Density Physics Research Using Intense Heavy Ion Beams at FAIR: the HEDgeHOB Scientific Program

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Abstract: High intensity, strongly bunched and well focused beams of energetic heavy ions have emerged as a novel, very efficient tool for generating High Energy Density (HED) matter including Warm Dense Matter (WDM) and strongly coupled plasmas, in the laboratory. **F**acility for **A**ntiprotons and **I**on **R**esearch (**FAIR**) at Darmstadt has already entered into construction phase that includes building of a huge heavy ion synchrotron, SIS100 (100 Tm magnetic rigidity) that will deliver high intensity beams of all stable particle species from protons up to uranium. HED physics research is an important part of the FAIR research program. Since the heaviest particles (uranium) deposit the highest amount of specific power in the target material, mostly, the HED research will be done using a uranium beam. According to the design parameters, the SIS100 is expected to generate a uranium beam having an intensity of 5.10^{11} ions delivered in a 50 ns long bunch. A wide range of particle energy (400 MeV/u – 2.7 GeV/u) will be available while the beam can be focused to a circular spot with a radius of around 1 mm. Provisions have also been made to generate a hollow beam with an annular focal spot to perform cylindrical compression experiments. These beam parameters lead to a specific power deposition of 15 TW/g in solid lead which will allow one to access those parts of the HED matter phase diagram that have never been accessed before.

It is important to note that ion beams provide unparalleled flexibility as they can be used to generate HED matter not only by isochoric heating but also by shock compression. Over the past decade, extensive theoretical work that is based on sophisticated 2D and 3D numerical simulations and analytic modeling, has been done to design different HED physics experiments for the FAIR. This work has resulted in a nice and very wide range scientific program named, **HEDgeHOB** (**H**igh **E**nergy **D**ensity matter **ge**nerated by **H**eavy **IO**n **B**eams). This program includes several HED physics experiments that are suitable to study for example, Equation-of-State of HED matter [1], planetary physics [2,3], hydrodynamic instabilities [4,5,6] and others. Work is in progress to design more experiments in other areas of HED physics. An overview of this wide range scientific program on HED physics is presented.

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P.Tu_58

Numerical Simulation on Measurement of Optical and Thermal Properties for Warm Dense Matter Generated by Isochoric Heating with Pulsed Power Discharge Device

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Property data in warm dense matter (WDM) are important to optimize implosion dynamics in a fuel pellet of inertial confinement fusion (ICF) and to understand interiors of giant planets, and so on. However, the condition is in an extreme high pressure, it is difficult to create with measurable setup. As a result, the properties in WDM are unclear.

A table-top pulsed power discharge device with isochoric heating using a sapphire hollow capillary was proposed [1], and was used to generate the extreme state of matter with a well-defined condition. In the apparatus, the emission from the heated sample is observable due to the transparent sapphire capillary.

For these reasons, it will be easy to confirm the experimental data with the numerical simulation. We investigate numerically to generate the WDM by using the pulsed power discharge device [2-3]. The numerical simulation of time-dependent one-dimensional thermal diffusion with radiative transfer was carried out in the experimental result. The achieved temperature of the numerical simulation result was confirmed by the previous experimental results. Also, the radiation energy density calculated was confirmed qualitatively by the corresponding experimental result. Consequently, the numerical simulation was useful to understand the thermodynamic properties during the discharge in comparison with the experimental results. To improve the opacity model and so on, the radiative transfer calculation will be quantitatively confirmed with the experimental results.

To investigate the properties of WDM in the timescale of ICF implosion process, we are planning the experiment by the intense pulsed power generator "ETIGO-II" [4]. The numerical simulation developed in this study will be effective tool to support the solution of the phenomena.

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P.Tu_59

Concept for Generation of Warm Dense Matter of Insulator due to Flyer Impact Accelerated by Electron Beam Irradiation using Intense Pulsed Power Generator

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A table-top pulsed power discharge device with isochoric heating using a sapphire hollow capillary was proposed, and was used to generate the extreme state of matter such as warm dense matter (WDM) with a well-defined condition [1]. The apparatus could generate the WDM of conductor due to the Joule heating by the direct electrifying of the sample. On the other hand, property data in WDM of insulator are important to optimize the fast ignition of inertial confinement fusion (ICF) [2] and to understand interiors of giant planets [3], and so on. However, the condition is in an extreme high pressure, it is difficult to create with measurable setup. As a result, the properties in WDM are unclear.

A solid target irradiated by an intense laser is ablated, and becomes plasma. The generated ablation plasma expands, and the remnant of the target is accelerated by the counteraction from the high pressure of the expanding ablation plasma. The flyer impacts another target material, and creates high pressure at the interaction surface.

Instead of intense laser, the intense light ion beam could generate the accelerated flyer [4] using the intense pulsed power generator "ETIGO-II" [5]. In this study, we propose the generation of accelerated flyer irradiated by an electron beam for WDM of insulator. The use of electron beam has advantage from the viewpoint of the focusability due to the self-induced magnetic field, because of the mass in comparisons with the ions. The concept and estimation will be introduced in this conference.

This work was supported from MEXT Grant-in-Aid for Scientific Research, and by Program for High Reliable Materials Design and Manufacturing in Nagaoka University of Technology, and by JSPS Grant-in-Aid for Challenging Exploratory Research No.25630418.

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P.Tu_60

Dynamics of structural phase transition in ploycrystals under laser-induced shock compression studied via nanosecond time-resolved X-ray diffraction

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Dynamics of structural phase transition in polycrystals (3Y-TPZ (3 mol% Y_2O_3 stabilized tetragonal phase zirconia) ceramics and bismuth) under laser-induced shock compression has been studied using nanosecond time-resolved shingle-shot X-ray diffraction. The time-resolved shingle-shot X-ray diffraction was performed using a laser pump and X-ray probe technique with a 100-ps X-ray pulse from the synchrotron radiation facility (Photon Factory Advanced Ring, KEK) in Japan [1,2]. The energy of X-rays was 15.6 keV and their bandwidth was set to be 4.4%. The laser used wad a 10-ns pulsed YAG laser (a wavelength of 1064 nm, and maximum energy of 1J per pulse) operated with synchronizing the synchrotron radiation. In order to increase pressure and duration, we used a plasma-confined target, which consists of a polymer film (25 μm), an Al foil (1 or 3 μm), and a sample (50 or 20 μm). The Debye-Scherrer diffraction pattern was recorded on an integrating charge coupled devise detector (Mar-CCD 165) of diameter 165 mm with the pixel size of 79 x 79 μm^2.

The 3Y-TPZ ceramics showed that the tetragonal phase transfers to the monoclinic phase within 20 ns during shock compression at 9 GPa without any intermediates and reverts back to the tetragonal phase during pressure release [3].

Bismuth shows more complex phase transition [4]. The Bi-I structure, which is the stable structure at ambient pressure and temperature, transfers to the high-pressure Bi-V structure within under shock compression at 11 GPa. The Bi-V structure transfers sequentially to the Bi-III and Bi-II structures and finally reverts to the Bi-I structure during pressure release within 30 ns. The phase boundaries between (Bi-I, Bi-II), (Bi-II, Bi-III) and (Bi-III, Bi-V) are reported at pressures of 2.6, 3.0, and 7.7 GPa, respectively [5]. In contrast to the pressure release, the Bi-III and Bi-II structures have not been observed under the pressure increase within 4ns.

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P.Tu_61

Hydrodynamic description of matter passing through the liquid-vapor metastable states

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In many warm dense matter experiments the heated and expanded material crosses the binodal, the boundary to the two-phase liquid-vapor region of the phase diagram. The area between the binodal and the spinodal, which delimits the region of absolute thermodynamic instability, corresponds to metastable states, where the equation of state is double-valued. In hydrodynamic calculations one can either use the metastable branch of the superheated liquid (supercooled vapor), or the fully equilibrium EOS obtained by the Maxwell construction. A proposed solution to this dilemma, which stays within the pure hydrodynamic approach, allows to simulate the dynamic of matter passing through metastable states without additional kinetic equations for description of the phase transitions. The model is based on the local criterion of explosive boiling [1], derived by applying the theory of homogeneous bubble nucleation in superheated liquids [2]. This approach is illustrated by hydrodynamic simulations of a quasi-static thermal expansion of a planar layer of fused silica SiO_2. The results demonstrate that adequate modeling of the transition from the metastable to the equilibrium state can be crucial for correct interpretation of experimental data.

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P.Tu_62

Ab Initio Simulation Beryllium in Solid Molecular Hydrogen

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In systems of inertial confinement fusion targets Deuterium-Tritium are manufactured with a solid layer, it must have specific properties to increase the efficiency of ignition. Currently there have been some proposals to model the phases of hydrogen isotopes and hence their high pressure [1], but these works do not allow to explain some of the structures present at the solid phase change effect of increased pressure.

In this work we address the problem of change in the solid phase to the solid molecular hydrogen at pressures greater than 200 GPa to 300 K, by means of simulation with first principles methods. With this methodology [2] we compare the structural difference of solid molecular hydrogen pure and solid molecular hydrogen with beryllium, watching from quantum molecular dynamics Beryllium segregation in solid hydrogen matrix, obtaining several differences in points where transitions are observed experimentally solid phase. We use the hydrogen as a first approximation for a point of comparison with recent experiments, however the method is being used to model the isotopes deuterium and tritium, and mixtures thereof.

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P.Tu_63

Measurement of the preheating in aluminum target driven with radiation fields[1]

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A velocity interferometer system for any reflector (VISAR) is applied to study the preheating of aluminum samples driven with radiation fields. The rear surface motion prior to the arrival of shock front is observed and compared with hydrodynamic simulations [1]. By properly adjusting the portion of hard x-rays in the radiation field in accordance with the diagnostics [2, 3], the simulated rear surface motions can agree well with the experimental results, which gives us confidence to predict the preheated temperature of the sample. The simulations indicate that the x-rays around 1.5keV (below M-band) from gold plasmas could also be a potential source of preheat for aluminum samples, which is normally referred to as a standard material during the equation of state (EOS) measurement.

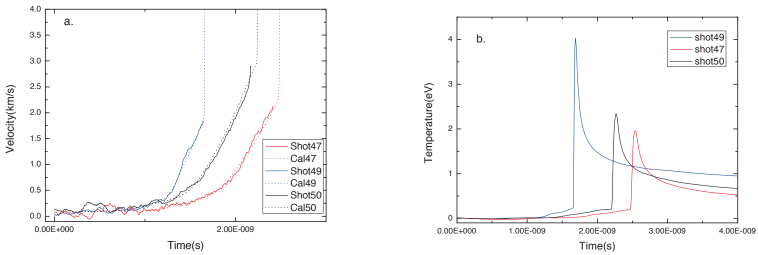

Figure 1: a) The measured and calculated rear surface motion; b) The predicted preheat temperature of the sample.

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P.Tu_64

Shock compression of materials in the range up to 100 Mbar.

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Research in isentropic compression and expansion of materials has been conducted on laser facilities "Luch" and "Iskra-5". Schemes of direct and indirect target irradiation have been applied both. High stability of the shock front spatial distribution is ensured – its delay makes less than 10 ps on the output from the plane targets. Experiments on shock compression of lead, iron and gold, and on expansion of cuprum are fulfilled. In order to reach 100 Mbar pressure the multilayered target's structures have been applied as well as special hammer targets.

Results on the materials testing accord the results shown on hydrodynamic stands. Inaccuracy of shock velocity measuring in tested materials reaches <2%, and of pressure and mass velocity determining <6%.

P.Tu_65

Observations of silicon lattice deformation under uniaxial shock-compression

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Understanding material response under extremely high strain rate compression is of importance in the study of high energy density physics. Direct observation is essential to determination the crystal structure and deformation of material during the shock loading process.

We have performed X-ray diffraction observation of the crystalline structural deformation of a single crystal [100] silicon using laser-shock compression along the orientation. We simultaneously observed multiple wave structure in silicon with line-imaging velocity interferometers(VISAR). The VISAR interferometry image shows characteristic rear-surface motions indicating a multiple pressure wave propagation in the silicon target. The first velocity change occurs due to the elastic wave arrival to the rear surface. Then, the following waves, corresponding to the plastic waves, reach the free surface resulting in the remaining surface velocity changes. Two characteristic diffraction lines from the laser-shock compressed Si were found in the XRD image. The first and second likely correspond to the Hugoniot elastic limit point and elastic-plastic phase transition(ELPT) point, respectively. Here we discuss the consistency between the observed lattice deformation and rear-surface motion.

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P.Tu_66

Laser-shock compression experiments on methane in Mbar pressure range

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Under strong shock compression, chemical bonds of hydrocarbon compound break and/or form to a new state depending on the shock pressures and temperatures.[1] A new matter state is possibly created through such chemical reactions occurring only in the extreme conditions.[2] Hydrocarbon also plays important role as major constituent of giant planets. Therefore, studies on hydrocarbon compound under ultra-high pressures are related strongly to material science and planetary science.

We have performed experiments to measure the physical properties of methane (CH_4) under the extreme conditions. Methane is a hydrogen-rich molecular material that is expected to dissociate at high pressures and temperatures into an electrically conductive fluid. In our experiments, methane was precompressed statically to ~0.4GPa by diamond anvil cell (DAC) and then was shock compressed dynamically to pressures of more than 100GPa. We simultaneously measured pressure, density, temperature, and optical reflectivity for highly compressed methane with velocity interferometers (VISAR) and an optical pyrometer (SOP).[3] These data imply the ionization reaction or dissociation of methane at over 40GPa. We here discuss the mechanical properties of methane.

This work was performed under the joint research project of the Institute of Laser Engineering, Osaka University. This work was partially supported by a Grant-in-Aid for Scientific Research (Grant No. 20654042) and also by grants from the Core-to-Core Program of the JSPS and from the CREST of the JST.

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P.Tu_67

Sound velocities of $Fe_{75}Ni_{15}Si_{10}$ alloys up to 800GPa by laser-shock compression

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The Earth's outer core is considered to be composed of iron (Fe) with few percent of nickel (Ni) and light elements (such as silicon (Si), sulfur (S), oxygen (O), hydrogen, and carbon etc.) The sound velocity of Fe alloy is important to consider the composition of Earth's outer core because it can be directly compared with seismic data. The sound velocity measurement of liquid Fe-S-O using gas gun has been reported [1]. As a result, the effect of O for the sound velocity is stronger than that of S. Although Si and Ni are very important elements in Earth's outer core, the effect of Si and Ni for liquid Fe on the outer core conditions has never been reported. In this study, we have measured the sound velocity of laser-shocked $Fe_{75}Ni_{15}Si_{10}$ up to 800 GPa. Comparing to the sound velocity of liquid Fe at same density, the sound velocity of $Fe_{75}Ni_{15}Si_{10}$ is higher about 20%.

We performed laser-shock experiments at the GEKKO-HIPER Laser system in Institute of Laser Engineering, Osaka University. The laser-shock compression can generate pressures of 400-800 GPa which are much higher pressures than previous works by gas guns [1, 2].

The sound velocity of the alloys was measured by side-on radiography [3]. In this technique the time variation of the X-ray shadow of target is recorded on X-ray streak camera by using x ray irradiated from the side of target. The sound velocity is obtained from the time variation of the X-ray shadow because the rarefaction wave propagates target material with the sound velocity (See experimental details [3]).

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Sound velocity and density measurements of FeSi alloy by laser-shock compression

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It is well known that the earth's core consists of mainly iron alloyed with a few percent of light elements. Several light elements (hydrogen, carbon, oxygen, silicon, sulphur, etc.) have been considered as the candidate of the light elements, but its composition is still unclear. In order to constrain the earth's core composition, it is important to measure the sound velocity of iron alloys because it can be directly compared with the seismic wave. Silicon has been proposed as a major light element in the earth's inner core [Mao et al.2012]. So we measured the sound velocity of laser-shocked FeSi alloys in order to investigate the effect of silicon for sound velocity of liquid Fe in the outer core.

The starting sample was prepared by synthesizing from mixture of Fe (99.98% purity) and Si (99.9% purity) slugs at arc furnace. The compositions of Fe and Si are about 66.5 wt. % and 33.5 wt. %, respectively. We measured sound velocities and densities of FeSi at high pressure and high temperature conditions at the large laser facility in Institute of Laser Engineering, Osaka University. The sound velocities were measured by the X-ray radiography [Shigemori et al.2012]. We obtained the sound velocity of FeSi in pressures around 700 GPa. It is seen that silicon has the effect of increasing the sound velocity of liquid iron. Comparing our results and PREM model, silicon may be contained up to 17 wt.% at 135 GPa, and up to 6.4 wt.% at 330 GPa in the outer core.

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P.Tu_69

Investigations of shock-compressed, warm dense iron near melting via in-situ X-ray diffraction and optical reflectometry

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The knowledge of warm dense iron near melting is of particular importance because of its geophysical abundance and central role in earth's core chemistry and dynamics.[1] Despite its geophysical importance, the characterization of such iron states is still in the focus of current researches.

We here report two experiments in order to investigate warm dense at near melting temperatures under laser-driven shock compression. First, we have observed a crystal structure of iron under laser-driven shock compression via picosecond time-resolved x-ray diffraction technique because microscopic studies are essential to investigate finely the structure changes. Phase transition from body-centered-cubic (bcc) α phase to hexagonally–close-packed (hcp) ε phase was observed at a dynamic high pressure of ~180 GPa. Second, we have observed optical reflectivity and interface velocity of shock-compressed iron using decaying shock technique and VISAR velocity interferometry. Reflectivity change under a solid-liquid transformation will be discussed.

This work was performed under the joint research project of the Institute of Laser Engineering, Osaka University and the LULI, Ecole Polytechnique. This work was partially supported by a Grant-in-Aid for Scientific Research (Grant No. 22684032) and also by grants from the Core-to-Core Program of the JSPS and from the CREST of the JST.

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P.Tu_70

Development of recovery technique of laser-shocked earth and planetary interior materials

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It is important to recover the shock-compressed samples for understanding the synthetic mechanism of high-pressure phase, shock metamorphism and shock-melt vein in meteorites. In the past, many impact experiments have conducted by using explosive or gas guns. In fact, although high-pressure phase in meteorites is recovered by the impact experiments (impact velocity is 1.5 km/s and shock pressure is 26 GPa) [1], the impact velocity in these methods is limited below 10km/s less than second escape velocity on the Earth. Recently, impact experiments at the velocity over 10 km/s were conducted by using projectiles which were accelerated by high-power laser [2].

We developed the recovery technique of the laser-shocked materials at higher pressures (130-460 GPa) in high-power laser system and estimated the pressure range of the production conditions from analyzing the structure of the shock metamorphism. We used the single crystal olivine (from San Carlos, USA) which is a major mineral of meteorites and of the Earth. We used the aluminum recovery cell. On this cell, titanium plate was located in the front of olivine to prevent the sample from being blow off. We used GXII/HIPER laser system at Institute of Laser Engineering (ILE), Osaka University [3]. The deformation, fracture and phase identification of the recovered olivine were observed comprehensively by optical microscopy, field emission-scanning electron microscopy (FE-SEM), electron backscatter diffraction (EBSD) and micro-Raman spectroscopy.

We recovered about 100 wt.% of the sample. There were some distinctive structures in the recovered sample. We estimated the shock wave attenuation rate from the distribution of these structures.

Part of this work was performed under the Joint Research of Institute of Laser Engineering, Osaka University.

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P.Tu_71

A modified VISAR on "SG-II" laser facility and platinum equation of state measurement

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A modified line-imaging optically recording velocity interferometer was established on "SG-II" laser facility. A new illumination method which can increase threefold the luminosity of such a diagnostic was put forward. The modified VISAR is applied to laser-driven shock wave experiments and platinum Hugoniots were obtained in the range from 300GPa to 3000Gpa.

P.Tu_72

Integrated modelling framework for short-pulse High Energy Density Physics experiments

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Modelling experimental campaigns on the Orion laser at AWE, and developing a viable point-design for Fast Ignition (FI), calls for a multi-scale approach; a complete description of the problem would require an extensive range of physics which can not realistically be included in a single code. For modelling the laser–plasma interaction (LPI) we need a fine mesh which can capture the dispersion of electromagnetic waves, and a kinetic model for each plasma species. In the dense material of the bulk target, away from the LPI region, collisional physics dominates. The transport of hot particles generated by the action of the laser is dependent on their slowing and stopping in the dense material and their need to draw a return current. These effects will heat the target, which in turn influences transport. On longer timescales, the hydrodynamic response of the target will begin to play a role as the pressure generated from isochoric heating begins to take effect.

Recent effort at AWE [1] has focussed on the development of an integrated code suite based on: the particle in cell code EPOCH, to model LPI; the Monte-Carlo electron transport code THOR, to model the onward transport of hot electrons; and the radiation hydrodynamics code CORVUS, to model the hydrodynamic response of the target.

We outline the methodology adopted, elucidate on the advantages of a robustly integrated code suite compared to a single code approach, demonstrate the integrated code suite's application to modelling the heating of buried layers on Orion, and asses the potential of such experiments for the validation of modelling capability in advance of more ambitious HEDP experiments, as a step towards a predictive modelling capability for FI.

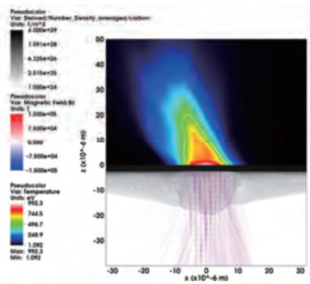

Figure 1: Ion density and B_z from the EPOCH simulation of laser absorption in solid density diamond plotted with the heating profile from a THOR simulation using a particle source derived from EPOCH, at t = 1.026ps. White contour shows T=500eV.

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P.Tu_73

On exploring extreme field limits in laser matter interaction

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We discuss interaction of intense laser pulses with ultrarelativistic electron bunches and collision of two or more intense laser pulses for studying extreme field limits in the nonlinear interaction of electromagnetic waves. In the regimes of dominant radiation reaction, powerful emission of ultra short high brightness gamma-ray pulses occurs. An electron positron pair creation from vacuum in the 3D electromagnetic configurations is considered. High intensity colliding laser pulses can create abundant electron-positron pair plasma, which can scatter the incoming electromagnetic waves. This process can prevent one from reaching the critical field of quantum electrodynamics at which vacuum breakdown and polarization occur. It is shown that the effects of radiation friction and the electron-positron avalanche development in vacuum depend on the electromagnetic wave polarization.

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P.Tu_74

An Investigation into Implementation Issues for a Modern PIC Code.

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EPOCH is a freely available, modern Particle-In-Cell code developed at the University of Warwick. It has been developed with the goal of creating an easily extensible framework to facilitate the inclusion of a variety of new and interesting physical modeling packages. The code has seen widespread adoption and is proven to be robust and highly scalable. It is distributed with a number of physics packages including collisions [1], ionization [2] and gamma-ray emission/pair-production due to QED effects from high-intensity (>10PW) laser sources [3]. This poster presents a broad overview of the algorithms used along with some test cases which highlight key design and implementation issues.

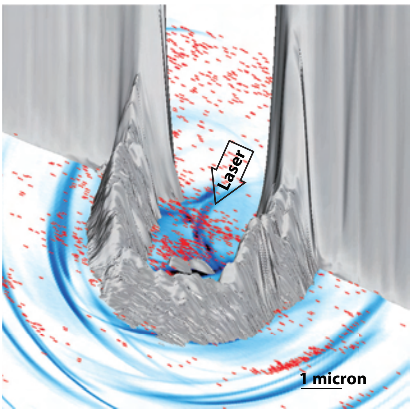

Figure 1: Gamma-ray generation from a high-intensity laser source.

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P.Tu_75

Particle In Cell Modeling of Electron Source from Experiments on the Titan Laser

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We apply particle-in-cell (PIC) modeling with no free parameters to recent fast ignition related experiments conducted on the 1054nm/150J/0.5ps short-pulse Titan laser at Lawrence Livermore National Laboratory. Multilayer planar targets were irradiated at intensities greater than 10^20 Wcm-2 to study laser-to-electron coupling, electron beam divergence, and the hot electron energy distribution. Experimental diagnostics included measurements of buried fluor Kα x-rays, escaping electrons, and bremsstrahlung. The PIC simulations of the experiment were conducted in two stages: a high resolution laser plasma interaction (LPI) simulation using measured on-shot laser parameters but with a subscale target; and a lower resolution transport simulation containing the full scale (> 1 mm^3) multilayer target but using an electron beam derived from the LPI simulation. Quantitative comparisons between the synthetic diagnostics and the absolutely calibrated experimental observables will be presented with the inferred hot electron beam properties.

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P.Tu_76

Dressed Charge of Electron by Radiation Reaction

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With the progress of the ultra-intense short pulse laser technology, the maximum intensity of the lasers have reached the order of 10^{22}W/cm^2. Now, several institutes are aiming at higher intensities of over 10^{25}W/cm^2 (for example, ELI project in Europe [1]). It is expected that these lasers can investigate the regime of ultra-intense fields by QED effects, electron-positron pair creation, and annihilation. Since lasers represent a multi-photon system, it is considered this regime is in the non-linear QED regime.

However, when an electron interacts with lasers with intensities over 10^{22}W/cm^2, it is predicted that the radiation reaction effects are large [2]. Therefore, we need to consider this in the QED regime. One way to take this into account is, that when the radiation reaction acts on an electron, it emits an electromagnetic wave (the Liénard-Wiechert field). This field is not static, but dynamically changing. The strong field can induce virtual electron-positron pairs, and from the macroscopic point of view, vacuum polarization. We consider that the radiation reaction field induces vacuum polarization around an electron. When we take into account these physical process, it is useful to use the theory of non-linear QED. Our dynamics is described as follows:

$$\mathcal{L} = \bar{\psi}(x)\left(i\hbar c \not{\partial} - mc^2 \mathbb{I}\right)\psi(x) - j^\mu A_\mu - \frac{1}{4\mu_0} F_{\alpha\beta}F^{\alpha\beta} + \frac{\alpha^2\hbar^3\varepsilon_0^{\,2}}{360 m_0^{\,4} c}\left[4\left(F_{\alpha\beta}F^{\alpha\beta}\right)^2 + 7\left(F_{\alpha\beta}{}^*F^{\alpha\beta}\right)^2\right] \tag{1}$$

This is the lowest approximation of the Heisenberg-Euler Lagrangian [3] and is suitable for a description of the vacuum polarization. From this we get Maxwell's equations,

$$\partial_\mu\left[F^{\mu\nu} + \mu_0 c \frac{\partial\Theta}{\partial\left(\partial_\mu A_\nu\right)}\right] = \mu_0 j^\nu \tag{2}$$

and the vacuum polarization is

$$\Xi^{\mu\nu} = \frac{\alpha^2\hbar^3\varepsilon_0^{\,2}}{45 m_0^{\,4} c}\partial_\mu\left[4\left(F_{\alpha\beta}F^{\alpha\beta}\right)F^{\mu\nu} + 7\left(F_{\alpha\beta}{}^*F^{\alpha\beta}\right){}^*F^{\mu\nu}\right] \ . \tag{3}$$

This polarization behaves as a "dress" of the charge. We discuss this dress charge generated by the radiation reaction.

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P.Tu_77

Resistive inhibition of laser-driven fast electrons at metal-dielectric interface

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The interaction of intense ultra-short lasers with solid targets leads to generation of bright x-ray, energetic ions and electrons. Fast electrons generated at the plasma critical surface [1] transport energy deep inside the target. These mega-ampere, fast electron currents are susceptible to self-induced fields located both at the target-vacuum boundary and inside the bulk media. In particular, the propagation of fast electrons crossing a metal-dielectric interface can be strongly inhibited due to the magnetic field generated via resistive gradients [2,3]. We present experimental evidence of fast electron experiencing resistive inhibition at the metal-insulator interface. On the basis of rear side electron spectra and shadowgram images we have inferred that the electron of energy less than hundreds of keV are completely stopped at the interface. Furthermore, time-resolved polarimetric magnetic field measurement with a rear side probe beam clearly reveals the presence of an additional magnetic field due to the metal-insulator boundary that could be playing a role in the inhibition of electron transport.

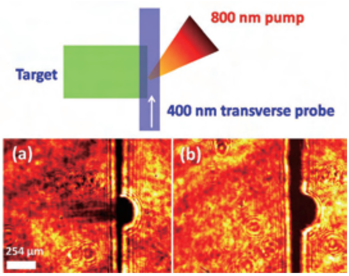

Fig. 1: Shadowgram of fast electrons in (a) Silica (b) 300 nm Aluminium coated Silica target

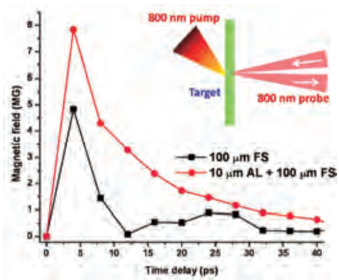

Fig. 2: Temporal evolution of interface magnetic field

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Probing ultrafast dynamics in intense-laser-generated solid-density plasmas

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Pump-probe diagnostics offer complete temporal- and spatial-mapping of a plasma and have been extensively employed [1, 2] in understanding intense laser-plasma interactions. However, these diagnostics have mostly been confined to low-density plasmas ($\lesssim 10^{21}$ cm^{-3}) for probe beams in the optical and infrared regions because such light cannot penetrate deeper. An unambiguous mapping of the high-density (almost solid-like) plasma, however, is crucial due to its relevance in investigating relativistically intense laser interactions with solids [3], laboratory astrophysics [4], warm dense matter [5] and inertial fusion [6], where imploded fuels thousand times solid density need to be monitored.

Here, we report the probing of a near-solid density plasma using an ultraviolet (λ = 266 nm) probe, which can penetrate to densities of 10^{22} cm^{-3}, nearly an order of magnitude higher than the critical density of the 800 nm, femtosecond pump laser . Time-resolved pump-probe reflectometry as well as Doppler spectrometry techniques have been coupled, showing an initial red shift in the spectrum of the reflected probe pulse, followed by a blue shift at longer probe delays. The aforesaid behaviour of the probe pulse may be explained by a laser-driven shock moving inward and a subsequent hydrodynamic free expansion in the outward direction.

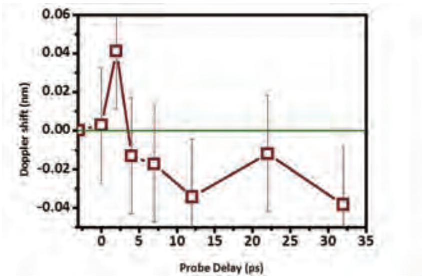

Figure 1: (a) Time-dependent normalized spectrum, (b) Doppler shifts, (c) calculated velocities of the critical surface of the probe in fused silica at 1.4×10^{18} W cm^{-2}.

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P.Tu_79

Improved Electron and Ion Acceleration via Relativistic Intense Laser Grating Target Interaction

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A two-dimensional PIC numerical study of the enhanced electron and proton acceleration using thin solid structured targets (≤ 10 λ_0) in the interaction of a high intensity (10^{19}-10^{20} W/cm^2) ultra-short (≤ 100 fs) laser pulse is presented here. An overdense plasma with an electron density n_e=100n_c is considered and the grating parameters are chosen so that the resonant excitation of a surface plasma wave is achieved at an oblique laser incidence of 30° [1]. In the case where the surface wave is excited we find an enhancement of the maximum ion energy of a factor ~ 2 compared to the cases where the target surface is flat [2]. This increase is correlated to the efficient electron heating when the surface wave is excited.

This work was performed using HPC resources from the GENCI-CCRT project t2012056851.

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P.Tu_80

Ion acceleration based on the interaction between high power laser and cluster medium

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A cluster is a material state that lies between gas/plasma and solid, and exhibits prominent characteristics associated with the large ratio of surface to volume. When the medium consists of such clusters, which we refer to as *clustered medium*, *cluster mode* is found to exist, where the electromagnetic wave (laser) can propagate even in the case that the average density of the medium is higher than the cut-off density due the effect of surface polarization [1]. As the laser intensity increases, the medium loose such a property while it reveals prominent nonlinear feature such as extremely high absorption characteristics of laser energy, higher harmonics generation and emission of radiation, high energy particle acceleration ascribed to Coulomb explosion, etc.

Recently, high energy ion generation aiming at medical applications using the interaction between laser and cluster medium has been explored. Fukuda et al. performed experiments using a medium consisting of CO_2 cluster which size is around a several hundred nanometer embed in helium gas and short pulse high power laser (pulse length~30fesec, intensity~10^{18} W/cm^2), and found that laser pulse propagates in the medium with self-focusing and collimated high energy ions which maximum energy exceeds 20MeV/n are produced [2].

In order to understand the underlying physical mechanism of the experiment, we performed simulations using EPIC3D (Extended Particle based Integrated Code) which includes key atomic processes and relaxation processes self-consistently in fully relativistic three dimensional configuration [3] and investigate the interaction systematically of medium of carbon clusters embedded in helium gas. We have found that the synergetic interplay of different mechanism as 1) ion acceleration of cluster ions due to Coulomb explosion of individual cluster, 2) compression and acceleration of background helium gas due to the Coulomb explosion of clusters, 3) magnetic vortex generation and associated pinching near the rare surface, 3) sheath acceleration at the interface between the medium and vacuum, play an important role in realizing the particle acceleration observed in the experiments. A self-organization process resulting from the complex interaction between clusters and background gas is found to regulate the dynamics.

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P.Tu_81

Modelling of Intense Ultra Short Laser Interaction with Atomic Clusters

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The interaction of high-intensity ultra short laser with atomic clusters has been a subject of intense research in the past few years. The earliest model developed to study this interaction was based on hydrodynamic approach. For relatively smaller clusters, alternative approaches like particle-in-cell (PIC) and molecular dynamic (MD) are more appropriate. The heating of the cluster and its subsequent evolution is governed by coulomb explosion (CE) and hydrodynamic expansion (HE) depending upon the population of electrons inside the cluster. CE is valid when a significant number of electrons leave the cluster. In case of the HE, the cluster expands due to electron gas pressure that builds up inside it. Both of these extreme cases lead to isotropic emission of ions from the cluster. When the laser irradiated clusters consist of intermediate population of inner electrons, ion emission happens to be anisotropic due to the combined action of laser and radial field inside the cluster. More energetic ions are emitted along the laser polarization direction rather than the perpendicular direction. It is seen that this nature of anisotropy changes when few cycle laser pulses are used: yield of ions is more along perpendicular rather along parallel direction of laser polarization (atypical anisotropy). Furthermore, we observe that for 1 or 2 cycle pulses, the carrier-envelope phase (CEP) also become important.

For relatively large clusters, we have developed a hydrodynamic model taking into account the radial and temporal variation of density, temperature and electric field as clusters expands [1]. Electric and magnetic field are obtained by solving Helmhotz equation coupled with 1D Lagragean hydrodynamics. Some results of this study are presented in this paper. Enhancement in energy absorption is seen as compared to uniform density nano-plasma model. It is also observed that resonance occurs at critical density rather than 3 times the critical density. For small clusters, we have developed a 3D relativistic MD code [2]. The trajectories of electrons and ions are followed by the relativistic equation of motion. We present our main results for the atypical anisotropy in this paper. There exists an optimum pulse duration for this type of anisotropy. For the cases we considered, this anisotropy happens to be the maximum for laser pulse duration of ~ 10 fs. We have also found an optimum laser intensity and cluster size for this anisotropy. We rationalized these results by spatially anisotropic shielding effect arising due to the oscillation of the electronic charge cloud within the cluster. We also present our recent results on effect of CEP on cluster ionization for 2 and 8 cycle pulses [3]. For 8 cycle pulses, we find that CEP is not important but results changes for 2 cycles pulse. Results are explained on the basis of collisional ionization. For 2 cycle pulse, the electron emitted after tunnel ionization will produce more ionization if it sees the rising edge of the laser electric field at the time of its birth. For longer pulse consisting of many cycles, this effect gets averaged out and ionization is independent of CEP.

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P.Tu_82

Self-Generated Magnetic Field during the Interaction of a High Contrast High Intensity laser beam with thin targets : a Way to Collimate Charged Particles

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Recent important developments in high intensity laser beams (I > 10^{18} W.cm^{-2}) have taken place over the last decade, in various domain such as Fast Ignition (FI) [1] or the production of secondary sources, e.g. X-rays [2, 3], positrons [4] or ions [5] all with important possibilities for scientific or societal applications. For example, protons beams which are accelerated through the well-known TNSA mechanisms (Target Normal Sheath Acceleration) [6] during the interaction of an ultra-high intensity laser beams with solids target have exceptional properties such as a very high particle number (~10^{12}-10^{13}) with MeV energy in tens of picosecond time scale and expands laminarly. However, many applications require that the divergence of such ion beams needs to be reduced and controlled. We will present a new experimental tool allowing to focus achromatically and in a controlled (tuneable) way charged particles in order to achieve beam collimation. This device takes advantage of the dynamics of self generated magnetic fields generated during the interaction of a high intensity, high contrast laser beam with solid targets. Results and simulations will be presented.

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P.Tu_83

Deflection of MeV electrons by large-scale magnetic fields in 3D simulations of intense laser-solid interaction

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During the interaction between >10^{18} W/cm^2 lasers and solid targets, relevant to the Fast-Ignition scheme [1], acceleration in the few microns of *pre-plasma* in front of the solid surface can generate electrons above the laser ponderomotive energy (a few MeV). Previous experimental studies [2-4] observed that, with a large incidence angle (45°), electrons are directed close to the laser axis as it provides more acceleration. Using three-dimensional particle-in-cell simulations, we find that, with a small incidence angle (16°), these electrons can instead be deflected away from the laser direction, towards the other side of the target normal.

We explain this effect through a new mechanism arising from magnetic fields existing in the pre-plasma, generated by the fast-electron currents. The dominating contribution is from electrons accelerated by the reflected laser light. Conditions required for obtaining this effect are shown to be fairly common in picosecond laser experiments at relativistic laser intensity.

Simulations were carried out on the Livermore Computing Center's Sierra cluster under a LLNL Grand Challenge allocation. This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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P.Tu_84

Experimental evidence of significant longitudinal temperature gradient and strong shock formation in solid targets heated by laser-driven relativistic electrons

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We present experimental results of relativistic electron beam (REB) transport in solid aluminum targets, paying special attention to the longitudinal spatial dependence of the REB-induced target heating. The experiment was performed using high intensity laser pulses (> 10^{19} W/cm^2) with high intensity contrast (> 10^{10}). Absolute Kα-fluorescence and time-resolved thermal-emission yields are reproduced by calculations using a sequence of simulation tools: we employed a 2D particle-in-cell code to evaluate the REB source, a 3D hybrid code to simulate the REB transport through the targets and a 2D hydrodynamic-radiative code to predict the shock formation and thermal emission upon REB energy deposition.

The results reveal the energy deposition scaling in both resistive- and collision-dominated regimes. In particular, the combination of thin targets and ultra-high-contrast laser pulses has permitted to access transport regimes where the REB current density is greater than 5×10^{11} A/cm^2 and the energy deposition is entirely dominated by resistive effects. Under such experimental conditions, we can reasonably assume that the incident current is perfectly neutralized by the return current over the entire thickness of the target. As a result, our measurements can serve as a reliable reference data for REB transport codes.

Also, the experimental results clearly show the shock formation due to the longitudinally inhomogeneous REB energy deposition. With only 0.7 J of on-target laser energy, the shock pressure is found to reach considerably high values, of the order of tens of Mbar. The ability of laser-driven fast electrons of generating Mbar shocks through solid samples using low-energy (< 1 J) laser systems opens up exciting perspectives in several fields ranging from inertial confinement fusion (in both shock- and fast-ignition schemes) to laboratory astrophysics and high-energy density physics in general.

P.Tu_85

Observation of ultrafast surface transport of laser-driven fast electrons in a solid target

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The development of tabletop intense ultrashort lasers has provided a great impetus to study diverse areas such as relativistic optics, high-energy-density science and laboratory astrophysics. All these applications are driven by the laser-generated fast electron beams. These fast electrons born near the plasma critical surface, carry most of the energy deposited by the laser pulse. The transport of fast electrons is governed both by the self-generated azimuthal magnetic field (B) and the longitudinal electric field (E) present inside the target or at the target-vacuum interface. These self-induced fields can redirect most of the energy far away from the laser focal spot by the well-known ExB drift [1], causing significant surface transport [2].

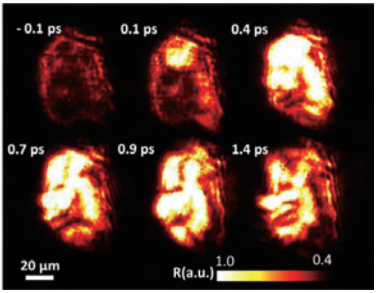

Figure 1: Snapshots of the reflectivity, indicating rapid lateral transport at different time-delays.

We address the crucial physics of fast electron surface transport by using (i) time- and space-resolved surface ionization measurement by pump-probe reflectometry, (ii) time- and space-resolved surface magnetic field measurements via polarimetry, (iii) surface electric field measurements via the energy of protons accelerated by the sheath field at the target front and finally, (iv) two-dimensional particle-in-cell (2D-PIC) simulations and their comparison with the experiments. Our temporal resolution on the femtosecond scale and spatial resolution on the micrometer scale has enabled a clear delineation of the surface transport process. We observe the non-local nature of this ionization process attributable to the E x B drift of the fast electrons.

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P.Tu_86

Superhot Electron Generation Using Structured Targets

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We describe the results of a numerical study of the enhancement of hot electron generation using front surface target structures. We find that orders of magnitude enhancement of yield is possible at energies well above the ponderomotive energy using structures that are inexpensive to produce.

Enhancement of hot electron generation by grazing incidence laser excitation of a target has recently been treated by Kluge, et al. [1]. We have employed particle-in-cell modeling using the code LSP [2] to develop optimized targets to generate superhot electrons. The simulations were performed in 3D using an energy conserving implicit algorithm and modeling pulses based on the newly commissioned Scarlet laser at The Ohio State University (15 J, 30 fs, peak intensity of 5 x 10^{21} W/cm^2). Fig. 1 shows the results for three target geometries: 10 μm "spikes" on 3 μm centers (Fig. 1a), 10 μm "fins" with 3 μm spacing (Fig. 1b), and a flat target with a 1 μm scale length preplasma added for improved coupling. As seen in Fig. 1c, the structured targets far outperform the flat target at high energies. The fins target produced 20% higher total yield as well, whereas the spikes target gave the best high energy conversion. We discuss the physical basis for these results and present model results of the use of structured targets to enhance short wavelength radiation generation and ion acceleration.

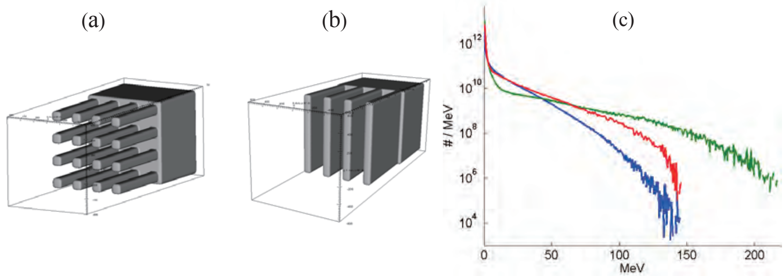

Figure 1: (a) "Spikes" target, (b) "Fins" target, and (c) resulting electron spectra 5 μm into solid density after laser excitation of spikes (green), fins (red), and flat (blue) Al targets.

This work was supported by the Ohio Supercomputer Center and performed under the auspices of the AFOSR under contract FA9550-12-1-0341.

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P.Tu_87

Resonant absorption and not-so-resonant absorption in ultrashort, ultraintense laser-plasma interaction

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An analytical model for laser-plasma interaction during the oblique incidence by an ultrashort ultraintense p-polarized laser on a solid-density plasma is proposed. Both the resonant absorption and not-so-resonant absorption are self-consistently included. Different from the previous theoretical works[1,2], the physics of resonant absorption is found to be valid in more general conditions as the steepening of the electron density profile is considered. Even for a relativistic intensity laser, resonant absorption can still exist under certain plasma scale length. For shorter plasma scale length or higher laser intensity, the not-so-resonant absorption tends to be dominant, since the electron density is steepened to a critical level by the ponderomotive force. The laser energy absorption rates for both mechanisms are discussed in detail and the difference and transition between these two mechanisms are presented.

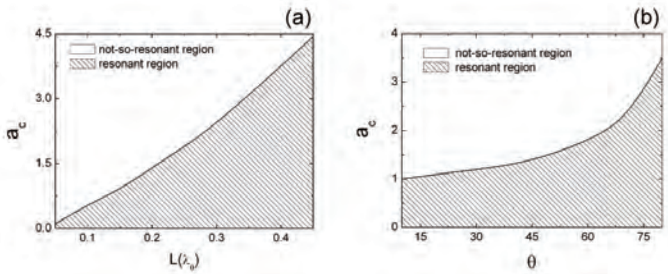

FIG. 1. (a) The critical laser amplitude as a function of the density scale length for $\theta = 45^0$, (b) The critical laser amplitude as a function of the incident angle for $L = 0.2\lambda_0$.

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P.Tu_88

MA Current Transport Accompanying Resistive Magnetic Fields in Solids

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Ultrahigh currents [mega-ampere (MA)] of suprathermal (MeV) electrons, that are driven through solids using relativistic laser pulses (with intensity > 10^{18}W/cm^2), lie at the heart of numerous applications such as the generation of ultra-short secondary sources of particles and radiation (ions, x-rays, positrons, or neutrons), and fast ignition of inertial confinement fusion. For all these applications, metals are preferred as target materials since they can provide enough cold electron return current to neutralize the forward laser-generated current and allow MA current propagation which exceed the Alfvén critical current. At solid density, these beams are not prone to the Weibel electromagnetic two-stream instability, since it is collisionally damped [1]. Instead, resistive magnetic fields have been suggested to collimate or focus the otherwise divergent electron beams. By tuning the target ionization dynamics, which depend both on the target material properties and on the input electron beam characteristics, controlling the growth of resistive magnetic fields that feedback on the current transport has been demonstrated [2]. In Ref. [2] gold shows confinement of fast electron current in a single channel while aluminum displays greater divergence and modulated transport. However in the prior research done by Stephens et al. [3], they had demonstrated a more focused transport in aluminum than a plastic target. To better understand the problem, we have conducted detailed 2D particle-in-cell (PICLS [4]) simulations using a non-equilibrium ionization model to study electron and energy transport inside simulated aluminum conductor and plastic insulator targets. The simulation results are consistent with what was seen in Ref. [3]. Using these results, we have derived an intensity scaling of the resistive magnetic field, and verified it in comparison with the previous simulations. This scaling is useful when the laser condition or target material is changed to understand whether the fast electron flows are confined into a single channel or will have a divergent transport pattern.

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P.Tu_89

Laser pulse distortion in a weakly-relativistic plasma

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In the field of laser-plasma interactions, energetic electrons have been a concern for research since long time [1]. In common plasmas, these energetic electrons are generated by the damping of plasma waves excited by the laser. Most laser-driven fusion processes observed these laser heated energetic electrons as a pre-heater which pre-heats the target and affects the fuel compression [2]. At relativistic intensities, thermal-electron production is the key process of the fast ignition concept of the inertial confinement fusion. Therefore, in fast ignition experiments, it is realistic to consider the relativistic effect for laser propagation in a thermal plasma. Also, large numbers of energetic electrons are generated during high-intensity laser interaction with solid target. Several mechanisms have been proposed to generate and transport these energetic electrons. At relativistic intensities, Ohmic heating and wakefield may be crucial to accelerate electrons in the propagation direction [3].

We present particle-in-cell simulations demonstrating the pulse distortion of a laser pulse by incorporating the role of plasma electron temperature in weakly relativistic plasma. If the laser pulse duration is larger than the electron relaxation time and the laser intensity is at reasonable level, then the weakly relativistic case in a collisional plasma should be adopted with appropriate simulation parameters. The combined role of both the relativistic mass effect and the thermal effect modifies the plasma equilibrium density. Based on this density modification, we attribute this to study the pulse distortion in this weekly relativistic regime. A high-intensity laser pulse gives rise to a relativistic ponderomotive force on electrons and redistributes the plasma density, consequently, the refractive index of plasma becomes modified. The electron temperature also contributes in this nonlinearity and resulting in distortion of the laser pulse. A high-intensity laser pulse gives rise to a relativistic ponderomotive force on electrons and modifies the plasma density. The electron temperature also contributes in this nonlinearity and resulting in distortion of the laser pulse. As the laser pulse propagates, the front part of the pulse acquires higher group velocity compare to the tail part. The difference in the group velocities at different part of the laser pulse distorts the pulse shape. Our finding through particle-in-cell (PIC) simulations shows the crucial effect of plasma electron temperature on this nonlinear process in weakly relativistic regime.

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Bright super-intense high-frequency coherent radiation production with ultra-intense laser-matter interactions

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We discuss the bright super-intense sources of coherent XUV, x-ray and gamma-ray radiation from ultra-intense laser-matter interactions brought about by the advent of multi-terawatt and petawatt lasers. Such the sources can be realized through combining various regimes of strongly nonlinear dynamics of ultra-intense electromagnetic waves in plasmas and special configurations of laser beams and tailored targets, which can be viewed as *relativistic engineering*. Strongly compressed intensified pulses are produced by relativistic flying mirrors formed in plasmas due to double Doppler effect [1]. Bright high-order harmonics are generated by oscillating mirrors [2] and by plasma flow caustics [3], in particular by the relativistic whistle [4]. Super-intense gamma ray flash is produced by a petawatt laser pulse irradiating tailored targets [5]. State-of-the-art techniques recently enabled the proof-of-principle demonstration of the relativistic flying mirror concept [6] and the discovery of comb-like spectra embracing the water window originated from the bow wave caustics formed in plasma [3].

This scientific area paves the way towards attosecond x-ray pulses focusable to nanometer spots where the electromagnetic field is strong enough to produce the effects predicted by nonlinear quantum electrodynamics [7].

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P.Tu_91

Atomistic Simulation of Ablation Processes in a Femtosecond Laser Pulse

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An ultrashort laser pulse yields unprecedented features in ablation processes of solid targets and provides new applications in a wide range of areas. Periodic ripple structures have been recently found after irradiation of repetitive pulses with a laser fluence near the ablation threshold [1, 2]. The periodic ripple is expected to promote contacts between heterogeneous materials and biological compatibilities [3, 4]. However, the ablation processes by ultrashort-pulse irradiation is complicated; therefore, a detailed analysis needs theoretical approaches especially for nonequilibrium and noncontinuum regime that appears in a picosecond-order dynamics.

In this paper, we present the ablation processes of platinum caused by a femtosecond laser pulse using a three-dimensional molecular dynamics model combined with the two-temperature model. We can classify the ablation dynamics into three categories by clustering features which depend on a laser fluence above the ablation threshold. With low laser fluence, spallation is found since the surface layer of the solid target breaks away due to a tensile pressure wave. Homogeneous nucleation of nano-size clusters takes place with middle fluence in the liquid layer after the target surface layer is superheated and melts, although the surface layer fragments and vaporizes with higher fluence, which results in the gasification of the target.

We have examined the cluster formation of the ablated platinum above the ablation threshold by varying laser fluence and characterized these categories in terms of size distribution of the emitted clusters. The size distribution obeys a power-law for the high laser fluence, while plateau region is found for the middle fluence. Furthermore, the mechanism of the difference among three formation types may be explained balance between the laser-induced pressure and binding energy of the atoms.

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O.Tu_A13

Detailed Modeling of Ignition Implosion Experiments on the National Ignition Facility

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The recently completed National Ignition Campaign (NIC) on the National Ignition Facility (NIF) showed significant discrepancies between 2-D simulation predictions of implosion performance and experimentally measured performance, particularly in thermonuclear yield. This discrepancy between simulation and observation persisted despite concerted efforts to include all of the known sources of performance degradation within a reasonable 2-D simulation model, *e.g.*, using measured surface imperfections and radiation drives adjusted to reproduce observed implosion trajectories [1]. This talk updates the status of our efforts to improve our simulation fidelity and better match the performance observed in NIF implosion experiments as a steppingstone to a more predictive modeling capability. In particular, the results of more recent experimental observations are being added to the 2-D simulation model, specifically measured inflight long-wavelength asymmetries and the larger than expected perturbations seeded by the capsule support tent. In addition, efforts are continuing to run several full-capsule 3-D simulations with resolution adequate to model the growth of the dominant unstable hydrodynamic modes and without the need to approximate the surface imperfections in 2-D. Finally, simulations using modified inputs (*e.g.*, surface roughness) as well as modified physical models (*e.g.*, opacity and equation of state) are being explored as a source for clues to the remaining discrepancies between simulation and experiment.

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Scaling laws for NIF ignition from first principles

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We have developed an analytical physics model from fundamental physics principles and used the model to derive a thermonuclear ignition criterion and implosion energy scaling laws applicable to NIF ICF capsules [1]. We analytically derived the scaling laws for implosion and the ignition threshold factor (ITF) from first principles. The scaling laws relate the fuel pressure and the minimum implosion energy required for ignition to the peak implosion velocity and the equation of state of the pusher and the hot fuel. When a specific cold adiabat path is used for the cold fuel, the new scaling laws recover the NIC ITF dependence on the implosion velocity, but when a hot adiabat path is chosen, the model agrees with the NIC data. Model predictions for the ratios of mass, aspects, volumes, areal densities, and energies of the hot spot to pusher and to total fuel and predictions of the hot fuel pressure are in good agreement with the NIC experiments. The newly derived ITF shows a much stronger dependence on both equation of state and implosion velocity than the LASNEX-based NIC ITF [2].

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O.Tu_A15

Direct Drive Targets for the Megajoule Installation UFL-2M

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Development of the direct drive target schemes for the megajoule installations is a topical problem of the up-to-date inertial fusion physics. The choice of possible schemes and solutions depends essentially on the irradiation conditions. The installations both running (NIF) and under-construction (LMJ) are destined to the 3ω irradiation in PDD (polar direct drive) configuration.

The UFL-2M installation that is under construction is based on 2ω irradiation and a symmetrical scheme of the direct drive target irradiation. Under these conditions, possible schemes for the direct drive targets demonstrating the ignition and the achievement of G=10-20 gain are considered in this report. At the same time, the possibilities are analyzed for the target compression and ignition with a reliability reserve at the conditions that can deviate from the standard ones, and if our understanding of the physics of processes is not completely adequate to the physics of real processes.

O.Tu_A16

Science and code validation program to secure ignition on the Laser Mégajoule

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For several decades, CEA/DAM has been validating its ICF codes at the kJ and tens of kJ levels, through design and interpretation of experiments on facilities such as Phebus, Nova, LIL, and Omega. This can be too limited a ground to warrant extrapolation by two orders of magnitude, to MJ experiments [1]. Instead, we anticipate that additional validation steps, at sub-MJ energy, are needed to strengthen the predictive capabilities of these codes for ignition designs on LMJ.

An analysis of our current ignition design [2] and of data from the National Ignition Campaign [3] suggests that particular attention should be devoted to the following threats

- i/ exceedingly large backscattered energy that would be reabsorbed in the long plasma upon exiting the hohlraum;
- ii/ excessive inner cone absorption in the capsule ablator or outer-cone gold bubble;
- iii/ poor predictions with current codes of hydrodynamic instability growth rates, that would jeopardize our understanding of threatening vs benign instability modes, and result in underestimated mix levels.

Building on this analysis, we will review our path forward in the form of future discriminating experiments that should help us resolve these issues, either at Omega or as initial experiments to be performed on LMJ starting in 2015.

This effort, by which the efficiency of numerical models will be improved parallel to experimental developments at LMJ, paves a progressive way towards robust ignition designs on LMJ.

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O.Tu_B9

Progress on Laser-Driven Ion Beam Generation for Fast Ignition and Other Applications

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We have gained significant understanding of the physics underlying laser-driven generation of intense ion beams. Based on that understanding, applied through large-scale laser-plasma simulations with the VPIC code, we have made significant and steady progress in the generation of such beams, in turn validating our understanding and modeling methods. Our experiments, which rely on specialized targets and on the unique capabilities at the LANL Trident laser facility, are diagnosed with a unique and powerful array of diagnostics. Based on this progress, we have been able to: 1) use the beams that Trident can generate for near term applications, and 2) ascertain the laser-pulse and laser-target characteristics that would yield a suitable ignitor ion beam for Fast Ignition. In this presentation we summarize the physics and the "taxonomy" of several relevant ion-acceleration mechanisms [1], essential given the debate in the understanding, modeling and proper identification of these mechanisms in recent experimental work. We summarize our relevant recent experimental progress, especially with the Breakout Afterburner (BOA) mechanism, and its role in validating our modeling capabilities. We demonstrate the success of BOA in two recent applications on Trident: record-breaking laser-driven generation of neutron beams [2] and isochoric heating of heterogeneous warm-dense matter systems. We present the VPIC simulation of a laser-generated ion beam suitable for Fast Ignition. This simulation points out the challenging laser parameters necessary for success. Finally, we point out further target refinements that may improve performance even further.

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O.Tu_B10

Efficient generation of high-fluence quasi-monoenergetic ion beams for hole-boring fast ignition using temporally tailored laser pulses

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Fast ion ignition [1] of inertial confinement fusion is considered to be a promising variant of fast ignition that could achieve high gain with low driver energy and simple target fabrication for a future fusion reactor. To realize this concept, the generation of a high fluence of fast quasi-monoenergetic ions by intense laser pulses is critical and remains a key challenge to the laser-plasma community. Stimulated by the advent of ultra-intense laser pulses, numerous simulations and analyses have shown that the hole boring of intense circularly polarized pulses into overdense targets can generate fast ions with high flux, moderate ion energy, narrow energy spread, and low spatial divergence [2], which provides a very attractive mechanism to accelerate ions for fast ignition [3].

In this paper we have derived an analytical formula for the temporal profile of a laser pulse that is used to generate a quasi-monoenergetic ion beam by hole-boring acceleration in an inhomogeneous plasma. Subsequently, an efficient hole-boring acceleration scheme is designed using temporally tailored laser pulses to generate a high fluence of quasi-monoenergetic ions suitable for fast ignition [4]. Particle-in-cell (PIC) simulations indicate that hole boring in a pre-compressed DT target with a temporally tailored pulse can generate fast ions with much higher conversion efficiency, narrower energy spread, and smaller spatial divergence, in contrast to those generated using a flat-top pulse or a Gaussian pulse. Therefore, it becomes more promising to realize hole-boring fast ion ignition using temporally tailored pulses from recent/planned high-energy ultra-intense lasers [5]. For a DT target with an areal density of 1.5 g cm^{-2}, the required energy of the tailored laser pulse for hole-boring fast ion ignition is in the order of 50 kJ.

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O.Tu_B11

Single-Shot Ultrafast Electron Diffraction and Electron Deflectometry Using Electrons Accelerated by an Intense Femtosecond Laser Pulse

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To observe ultrafast changes of atomic-scale structure in matters and electromagnetic fields near matters during phenomena, time-resolved electron diffraction and electron deflectometry using femtosecond electron pulses are useful, respectively.

The key issue to realize single-shot ultrafast electron diffraction (UED) or electron deflectometry is to develop intense short electron-pulse sources. With conventional UED instruments, an electron pulse is generated at a photocathode irradiated by a femtosecond laser pulse and accelerated in an additional external static electric field. The amount of electrons in the pulse is limited because the electron pulse expands during its flight by space-charge forces in the pulse. There are two ways considerable to avoid the space-charge effect, those are reduction of electrons in the pulse and acceleration to relativistic energy by RF accelerators. However, for the former, large amount of pulses are necessary to obtain an UED image, which is not available to observe irreversible phenomena, and for the latter, the energy is too high for conventional transmission electron microscopy (TEM). Furthermore, for the mid-energy range of around 100keV to 1MeV, corresponding to the energies of conventional TEM, there is no satisfactory method for generating femtosecond electron pulses. We have demonstrated femtosecond pulse compression of a laser-accelerated electron beam with energy of around 350keV [1,2]. The electron pulses are generated by irradiating a tightly focused terawatt femtosecond laser pulse on a polyethylene foil target, then, the pulses are compressed by using an achromatic bending magnet system. These femtosecond electron pulses have a sufficient intensity to take a single-shot diffraction pattern.

To observe the electric fields near the laser plasma produced by the interaction of intense femtosecond laser pulse with a solid target, we have developed the electron deflectometry using laser accelerated electron pulses with an electron lens [3,4,5]. It has been successfully demonstrated to observe the electromagnetic surface (Sommerfeld) wave propagating along a metal wire irradiated by an intense femtosecond laser pulse using femtosecond electron deflectometry with electron pulses accelerated by intense laser pulses [6].

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O.Tu_B12

Stable and tunable laser-wakefield acceleration and x-ray generation

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We report on several experimental campaigns on laser-wakefield electron acceleration and radiation generation from laser-driven free electrons. Using a 60 TW-Ti:Sapphire laser, we routinely obtain stable electron beams with energies of up to 0.5 GeV, beam charge of 30-300 pC and bunch durations around 5fs. Sending these beams through a miniature undulator, a first all-laser driven X-ray undulator source with photon energies in the water window (300eV) could be demonstrated. Furthermore, the betatron X-rays from wiggling electrons in the wakefield were characterized, revealing 10^8 photons/shot with typical mean photon energies of 5 keV from a 2 μm source and 10 mrad divergence. This photon beam was used to obtain phase contrast images and the first 3-D phase-contrast tomogram of a fly from a laser-driven free-electron source. Finally, we will report on the first tunable, quasi-monochromatic Thomson X-ray source in the energy range from 5 to 35 keV, obtained by colliding tunable 15-50 MeV electron beams off a short laser pulse.

We will give an outlook on the prospects of these laser-driven X-ray sources for applications.

O.Tu_C9

Precise Diagnostics for Shen Guang II upgrade facility

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SGII facility in Shanghai is under upgrading to output much more energy and high intensity, which have 8 beams with nanosecond pulses and one beam with petawatt laser.

Diagnostics is important to a large laser facility such as LLNL, OMEGA and GEKKO [1, 2]. In Shen Guang II laser facility, diagnostics for nanosecond pulse has four functions. Energy measurement range is 10~6400J at 351nm and uncertainty is 5%. Pulse shape measurement range is 0.5~10ns and temporal resolution is 0.12ns. Near field measurement range is 160% of beam aperture and spatial resolution is 0.45mm with beam size 310×310mm^2. Far field measurement range is 1.7mrad, and performance of focal spot is 1.1 times diffraction limit (DL). Diagnostics for petawatt laser also has four functions. Energy measurement range is 10~1000J at 1053nm and uncertainty is 5%. Pulse width measurement range is 0.5~18.0ps and temporal resolution is 0.07ps. Farfield measurement range is 5mrad and performance of focal spot is 1.5DL. Pulse contrast measurement range is 80ps and dynamic range is 10^6[3].

With monitor of diagnostics, nanosecond pulse has an output of 2200J at 351nm in each beam of eight beams when pulse width is 3.5ns, and 95% energy is encircled in 7.2DL. Petawatt laser has an output of 377J at 1053nm when pulse width is 4ps, and 50% energy is encircled in 5.1DL.

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O.Tu_C10

Inertial Confinement Fusion Experiments on the Sandia Z Facility Using Magnetically-Driven Targets*

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The inertial confinement fusion effort on the Z Facility at Sandia National Laboratories is studying the use of magnetic pressure generated by the Z pulsed power facility to compress targets containing deuterium to the conditions needed for fusion. Design studies indicate it should be possible to relax the conditions required for fusion through the use of fuel magnetization and fuel preheating. This led to the development of the Magnetized Liner Inertial Fusion (MagLIF) concept [1], in which a magnetically-imploded, cylindrical metal liner target compresses fusion fuel that has been magnetized by an externally-applied axial field and preheated using a laser.

Simulations indicate it may eventually be feasible to achieve 100 kJ yields on the Z facility, a yield comparable to the energy coupled to the fuel. To do this would require a 27-MA drive current, about 8 kJ of laser energy delivered over 8-10 ns, an applied magnetic field of 30 T, and DT fuel [1]. Scaling studies suggest that high-yield (~1 GJ), high-gain (>100) targets may be possible on a future >55 MA facility using similar preheat and magnetic field parameters [2].

We have been conducting a series of liner implosion experiments with parameters relevant to MagLIF and have recently commissioned the magnetic field capability. We plan to conduct the first integrated experiments on the MagLIF concept later this year using newly commissioned laser preheat capabilities. Our initial experiments will use deuterium fuel, a drive current of about 18-20 MA, external field coils that deliver 7-10 T magnetic fields over a several cm^3 volume, and 2-2.5 kJ of preheat energy provided over 2-3 ns by the Z-Beamlet laser. We will describe our overall progress to date on MagLIF and our plans for the next two years to approach the ideal drive conditions for eventually realizing 100 kJ yields on Z.

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O.Tu_C11

Evaluation of instability growth, mitigation, and stabilization techniques in magnetized liner inertial fusion targets*

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Mitigation and control of instability growth is essential for inertial confinement fusion (ICF) concepts that magnetically accelerate metal liners such as MagLIF [1]. In this paper, we will present an overview of recent simulations and experiments designed to improve our current theoretical understanding of electrothermal and Magneto-Rayleigh-Taylor (MRT) instability growth in MagLIF liners. The initial seed for observed MRT instabilities in liner targets is not well understood. It is important to assess whether or not MRT instabilities are seeded directly from the surface roughness inherent in target fabrication or electrothermal instabilities [2], which simulations suggest are insensitive to the initial surface roughness [3]. We will present recent data and simulations that investigate the source of the MRT seed as well as discuss the importance and effectiveness of mitigating electrothermal instabilities. We are also actively testing our understanding of both single mode and multimode MRT instability growth [4,5]. Results of new experiments will be shown that investigate the growth of multimode mode MRT instability growth in a controlled manner with multiple initially superimposed sinusoidal perturbations. These experiments enable us to test code predictions of higher order mode harmonics, mode saturation, and mode coupling in the quasi-linear and nonlinear regimes. We will also show results of recent experiments and 3D HYDRA simulations that investigate the possibility of stabilizing MRT instabilities with the application of external magnetic fields or screw like helical perturbations imposed on the initial liner surface [6,7].

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O.Tu_C12

Beryllium liner implosion experiments on the Z accelerator in preparation for Magnetized Liner Inertial Fusion (MagLIF)*

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Magnetized Liner Inertial Fusion (MagLIF) [1,2] is a concept that uses a pulsed electrical current to implode an initially solid, cylindrical metal tube (liner) filled with preheated and premagnetized fusion fuel (DD or DT). 1D and 2D simulations predict that if sufficient liner integrity can be maintained throughout the implosion, then significant fusion yield (>100 kJ) is possible on a 27-MA, 100-ns Z accelerator with DT fuel. The greatest threat to the liner integrity is the Magneto-Rayleigh-Taylor (MRT) instability. 2D simulations predict that liners with initially thick walls ($R_{outer}/\Delta R \approx 6$) should be robust enough to keep the MRT instability from overly disrupting the fusion burn at stagnation. In this presentation, we will share the results of the first experiments designed to study a MagLIF-relevant liner implosion through to stagnation on Z [3]. The use of beryllium for the liner material enabled us to obtain penetrating monochromatic (6151±0.5 eV) radiographs that reveal information about the entire volume of the imploding liner. This presentation will also discuss experiments that used Z's pulse-shaping capabilities to either shock or shocklessly compress the imploding liners [4,5], as well as our more recent radiography experiments that used 2-micron-thick aluminum tracers to observe the liner's inner surface during the implosion [5]. We will also present new micro-B-dot measurements of azimuthal magnetic field penetration into the initially vacuum-filled interior of a shocked liner [5]. Our measurements and simulations reveal that the penetration commences shortly after the shockwave breaks out from the liner's inner surface. Finally, we will present preliminary results from our first magnetic flux compression experiments, an important component of the MagLIF concept.

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