Friday, September 12, 2013

T.Fr_A1

Alternative Approaches to High Energy Density Fusion

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In this talk I will discuss approaches to high energy density (HED) fusion that have been pursued from the early 1990's to the present, and offer some thoughts on future directions. Around 1990, two new developments were added to the existing mix of HED drivers: fiber Z-pinches and petawatt-class short pulse lasers. The fiber pinches created localized regions of high density, and theory[1] suggested that dense, cool, radiatively-collapsed regions might be resistively stabilized. I considered combining the two technologies: a 10-20 megampere pinch to locally compress DT to hundreds of grams per cubic centimeter or greater and a several picosecond laser pulse that would supply 10's of kJ to rapidly heat the fuel to ignition. Max Tabak independently invented the idea using laser compression and we, along with several others, launched the Fast Ignition concept[2]. Fast Ignition remains a work in progress, and I will discuss a suggestion on how magnetic fields – not necessarily of the pinch type - might be used to aid the process.

In the late 1990's, Max and I again collaborated on the double-ended pinch fusion concept, this time using z-pinches as x-ray sources for indirect drive fusion[3]. Imploding pinches, despite (or perhaps, in part, because of) being strongly unstable against Rayleigh-Taylor and other modes, are efficient, powerful, relatively reproducible x-ray sources. Experiments on the double-ended hohlraum at Sandia National Laboratories have validated the basic concept[4]. The concept required a large energy source (~ 18MJ) to reach viable capsule drive temperatures. I will discuss a potential improvement on our original concept that induces axial flow in the imploding pinch, causing the stagnation and emission region to move through the entrance hole of a smaller diameter hohlraum, thereby increasing the drive temperature.

In recent times, the National Ignition Facility has provided new possibilities as well as puzzles in the path toward fusion. One mystery has been the need for drive multipliers to match the capsule hydrodynamics and bang time. Experiments with Viewfactor targets, which are ignition hohlraums with one end removed to provide a capsule-like view of the x-ray illumination, have shown that the drive seen by the capsule is indeed lower than the drive inferred from the entrance hole. The open view of the hohlraum also exposes the existence of unexpected structure in the x-ray illumination and the effects of cross-beam energy transfer on beam spots. I will conclude with thoughts on how we might address some of the remaining challenges in the drive toward ignition.

References

[1] M. Haines, et. al., Proc. 2nd Int. Conf. on Dense Z-pinches, Laguna Beach, CA, 203 (1989).
[2] M. Tabak, J. Hammer, et al., Phys. Plasmas, **1**, 1626 (1994).
[3] J.H. Hammer, M. Tabak, et al., Phys. Plasmas, **6**, 2129 (1999).
[4] M.E. Cuneo, et al., Phys. Rev. Lett., **88**, 215004 (2002).

T.Fr_A2

Revisiting Shock-driven Exploding Pushers: Insights into Fields and Plasma Flows, Nucleosynthesis, and Kinetic Effects*

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Though shock-driven exploding pushers (SEP) were the first implosions in ICF, they subsequently received diminishing attention except, in part, as a tool for testing and calibrating diagnostics. But recent developments have demonstrated that SEP is a platform providing novel opportunities for a variety of incisive studies of HED phenomena in both basic science and ICF. For example, fusion in D^3He-filled SEPs provides monoenergetic 3.0-MeV protons, 14.7-MeV protons, and 3.6-MeV alphas. These particles, emitted nearly isotropically, have been used to “backlight” a wide variety of HED experiments, resulting in radiographs of plasma-flow dynamics and self-generated fields in plasma jet collisions; in magnetic reconnection; in Rayleigh-Taylor instability growth; as well as in direct- and indirect-drive ICF implosions. In addition, these monoenergetic nuclear products are being used by researchers to study the stopping power of warm and cold classical, non-classical, and degenerate plasmas.

From a different point of view, however, SEPs are intrinsically interesting in their own right, and not just as a tool for probing and illuminating conditions and dynamics in HED plasmas. Two very important topics where this is true are nucleosynthesis and kinetic phenomena. For the former, conditions of the SEP plasma can mirror conditions in the early Universe or in stellar interiors. To that end, a number of experiments have recently been performed, or are being planned, for the Omega laser facility and include, among others, ^3He-^3He fusion (3^{rd} and dominant energy-producing step in the Sun); T-3He fusion (relevant to early Universe light-element generation); and D-H fusion (the 2^{nd} step in the solar p-p chain, but also important in the evolution of protostars). As for kinetic phenomena, the mean free paths of ions in SEPs can be comparable to or greater than the implosion scale size when the fuel plasma density is sufficiently low and the temperature sufficiently high. Such conditions lend themselves to investigating kinetic effects and the possible breakdown of hydrodynamics. With that objective in mind, a recent series of experiments on Omega has probed such implosions in which the initial fuel density of D^3He was systematically varied from ~ 25 to 1 atm.

This presentation will give an overview of the above topics and future directions, all of which utilize the versatility of the shock-driven exploding pusher in its present-day incarnations.

*This overview represents work done in collaboration with students and colleagues at MIT, LLE, LLNL, GA, LANL, and SNL. It has been supported in part by the U.S. DoE-NNSA, the National Laser Users Facility, LLE, and LLNL.

OP.Fr_A3

Ion-Beam Plasma Interaction and High Energy Density Physics at GSI and FAIR in Darmstadt

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Approximately 200 scientists from 45 institutes and 16 countries worldwide are members of the HEDgeHOB [1] collaboration. They prepare novel experiments at FAIR (Facility for Antiproton and Ion Research, for details see report by Professor B.Yu. Sharkov) to study thermophysical, transport, and radiation properties of high-energy-density (HED) matter, generated by the impact of intense heavy ion beams on dense targets. Thus intense heavy ion beams open a new pathway to address the regime of Warm Dense Matter with precision experiments. The unique energy deposition characteristics of heavy ion beams assure that macroscopic volumes are heated fast and in a very homogeneous way, such that temperature gradients as well as density gradients are very low compared to other methods. Since heavy ion beams are generated from accelerators their intensity is well known and the deposition of ion energy in matter can be measured with high spatial and temporal resolution, this is in contrast to many other methods to induce high energy states in matter. Our contribution consists of two parts

In the first part of this report we will discuss electronic collisions with ions which determine the energy loss and charge state distribution of heavy ions in plasma. In a wide range of plasma parameters using discharge plasma, z-pinch plasma, and laser plasma an enhanced energy loss and enhanced charge state of heavy ions traversing the plasma is observed. This part of the report is a synopsis of the experiments that were carried out over more than two decades. Interaction processes of heavy ions with plasma, like energy deposition and charge changing cross sections are known to change if the target is highly ionized matter. This effect is of importance to Fusion physics and especially ignition science, since charge particle transport in ionized matter is one of the issues that needs further investigation, especially, since ignition of a small pellet, filled with a deuterium-tritium mixture, heated by X-rays in a hohlraum is not yet demonstrated.

Only for a few cases, where the plasma is ideal, and fully ionized, experimental data exist and can be explained within the framework of a modified Bethe-Bohr-Bloch stopping theory. For dense, non-ideal, and partially ionized plasma the experimental and theoretical data base is only starting to develop. The physics of such dense and strongly coupled plasmas is closely related to those states of matter with high energy density and high pressure above 1 megabar, and heavy ions are an ideal tool to generate these states.

Heavy ion energy coupling to matter is completely different from that of lasers, heavy ion kinetic energy couples cleanly into the volume of matter (fusion fuel respectively). The second part of the report is about the generation of high energy density states and warm dense matter with intense ion beams and we discuss new diagnostic methods based on proton microscopy.

References

HEDgeHOB Collaboration: http://hedgehob.physik.tu-darmstadt.de:

OP.Fr_A4

Laboratory astrophysical collisionless shock experiments on Omega and NIF*

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We are performing scaled astrophysics experiments on Omega and on NIF. We report new results from high power laser experiments showing large, stable, reproducible electromagnetic field structures that arise in counter-streaming interpenetrating supersonic plasma flows in the laboratory. Self organization, whereby energy progressively transfers from smaller to larger scales in an inverse cascade, is widely observed in fluid flows, such as in the nonlinear evolution of multimode Rayleigh-Taylor and Kelvin-Helmholtz instabilities. There are many scenarios in astrophysics where self organization involving magnetic or electric fields in collisionless settings is observed. Examples include the generation of the cosmic magnetic field, collisionless shocks in supernova remnants, relativistic shocks and particle acceleration in gamma-ray bursts, and internal structures in star forming regions of molecular clouds. Creating scaled collisionless flows in the laboratory to study astrophysically relevant self organization is a challenging proposition. These surprising structures, predominantly oriented transverse to the primary flow direction, extend for much larger distances than the intrinsic plasma spatial scales, and persist for much longer than the plasma kinetic timescales. Their origin may be magnetic field advection from the recompression of the Biermann battery fields in the midplane. Our results challenge existing models of counter-streaming plasmas and are motivating significant theoretical and computational work to better understand large-scale and long-time plasma self-organization. [1,2,3] Plans for radiative supernova Rayleigh-Taylor experiments and Diverging Supernova experiments will also be presented.

[1] N. L. Kugland *et al.*, Nature Physics, **8**, 809-812 (2012)
[2] J. S. Ross *et al.*, Phys. Plasmas **19**, 056501 (2012)
[3] D. D. Ryutov *et al.*, Phys. Plasmas **20**, 032703 (2013))

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O.Fr_A5

Ion energy loss at maximum stopping power in a laser-generated plasma

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In this work, the ion energy loss in a laser-generated plasma for a projectile velocity v_{ion} close to the thermal velocity v_{th} of the plasma electrons, i.e. at maximum stopping power, was measured for the first time. For this purpose, a thin target foil was irradiated from both sides by high-energy laser beams, creating a 200 eV fully-ionized homogeneous carbon plasma[1], which was probed by carbon ion bunches at a projectile energy of 0.5 MeV/u, obtained by deceleration through a solid foil. This setup resulted in $v_{ion}/v_{th} \sim 1$. The energy loss in the plasma was deduced from a time-of-flight measurement after a 0.5 m distance by using a specially developed CVD-diamond detector, well-shielded against plasma radiation (see Fig.1).

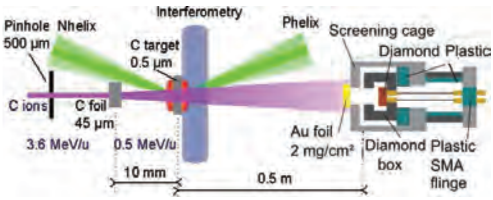

Fig.1: Experimental setup for the energy loss measurement at stopping maximum in plasma

In this parameter region of the ion-plasma interaction, perturbative approaches to the stopping power like the Bethe formula are expected to fail, and important discrepancies exist between the different theoretical models[2], reaching up to 30% in the present case of a hot ideal plasma. First experimental results are presented, which should allow, with the help of plasma simulations[3], to benchmark the stopping theories and numerical codes. This is of relevance for all ion-plasma interaction processes in ICF and most notably the stopping of alpha particles in the burning fuel.

[1] A. Frank et al., *Physical Review Letter*, Vol. 110, 115001, 2013
[2] D. Gericke et al., *Physical Review E*, Vol. 60, 01, 1999 and Vol. 67, 037401, 2003
[3] An. Tauschwitz et al., *High Energy Density Physics*, Vol. 9, 158-166, 2013

O.Fr_A6

Heavy ions energy loss experiments in dense plasma using hohlraum targets

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We report on heavy ion energy loss experiments in dense carbon plasma heated by hohlraum generated X-rays. The energy deposition of ions in plasmas is a key question in ICF simulations, for the evaluation of heavy ions as drivers or ion driven fast ignition concepts. The GSI Helmholtzzentrum für Schwerionenforschung offers the unique possibility to create a dense plasma with the hight energy laser PHELIX and to probe it with a heavy ion beam from the UNILAC accelerator. A special double hohlraum configuration has been designed to generate a homogeneous carbon plasma with an electron density of 10^{22} cm^{-3}, an temperature of 15 eV and an ionization degree of 4. In our last experiments in 2012 with a Ca^{17+} ion beam with 4 MeV/u we observed an increase oft the stopping power of up to 100%. These results are compared with new theoretical models and simulations.

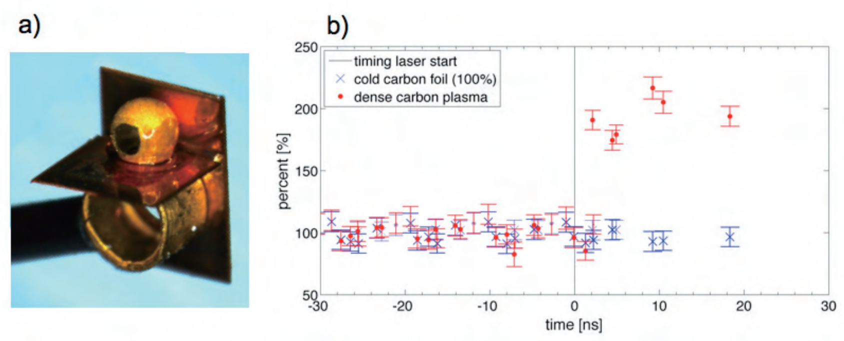

Figure 1: a) Double hohlraum target. b) Energy loss measurement in a cold carbon and a plasma

References
[1] A. Frank et al., Physical Review E, 81,020640 (2010)
[2] A. Frank et al., accepted in Physical Review Letters (2013)
[3] T. Hessling et al, Physical Review E, vol 84, id. 016412 (2011)
[4] An. Tauschwitz et al., High Energy Density Physics, Vol. 9, 1, p. 158166 (2013)

O.Fr_A7

Non-LTE Radiation Transport in the Modelling of Implosions

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Much of the material during the ablation and implosion of the capsules used on the National Ignition Facility is in non-LTE conditions where the transport of radiation is also important. Since the deposition of the energy from the radiation into the ablator provides the energy for the implosion, accurate modelling of this process, along with the non-LTE atomic kinetics and equation of state, must be performed.

We will discuss this modelling, the techniques used - both in the physics and the numerics - and the resulting conclusions as to the effects of the radiative transport and implications for the design or optimisation of future capsule implosions.

As regards the numerics, we will discuss the acceleration of the 3D spherically symmetric radiation transport using graphics processing units (GPUs) and the tractability of the problem on desktop-scale computers, the non-LTE energetics and equation of state. The faster radiative transport algorithms allow the use of a more detailed radiation field and the impact of this on line trapping and energetics will be shown.

The difference between the characteristics, both qualitative and quantitative, of the implosion using different materials will then be examined, in particular as regards the simplicity and reliability of capsule design through assessing the similarity of the problem to idealised ablation.

References

[1] E.G. Hill and S.J. Rose, HEDP 8 4 307 (2012)
[2] E.G. Hill, M. Sherlock and S.J. Rose, in preparation (2013)

O.Fr_A8

The ViewFactor Experiments at the National Ignition Facility

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The ViewFactor experiment is designed to get a truer measure of the x-ray drive seen by an ignition capsule, with reduced Laser Entrance Hole (LEH) source size correction. Figure 1 shows the ViewFactor target. One half is identical to the conventional ignition hohlraum and LEH whereas the other half is truncated 2 mm beyond the hohlraum center, with an opening equal to the diameter of the hohlraum. Instead of a capsule, there is a 3 mm diameter, thin-walled (20 to 30 μm) CH ball. The ball provides the CH blowoff needed to create plasma conditions near the LEH end that are similar to plasma conditions in an ignition hohlraum. At the peak of the laser power, the CH has completely ablated and thus it does not interfere with the x-ray drive measurement. The view of the x-ray drive diagnostic (DANTE) through this open end is similar to the view of the ignition capsule at 37° above the hohlraum axis, which should be representative of all angles in the limit of symmetric drive.

ViewFactor experiments are done in pairs: Open end UP, and Open end DOWN, in order to measure the radiation drive from both ends and to obtain images (time-resolved and time-integrated) from both ends.

The results from the ViewFactor experiments will be presented: they indicate less drive on the capsule than predicted by models. The images show 8 fold symmetry in the outer beams that is a function of time and energy transfer, as shown in the time-integrated image in Figure 2. The methods of using time-resolved images of the LEH to correct the radiation drive measured from the LEH end will be discussed.

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

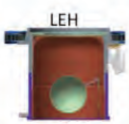

Figure 1: ViewFactor target

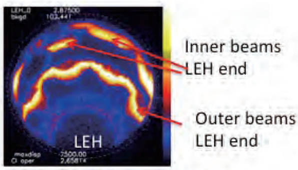

Figure 2: Time-integrated image looking into OPEN end at 18o to hohlraum axis at x-ray band of 3-5 keV

O.Fr_B1

Simulations of HED laboratory astrophysics experiments of nested jets and accretions shocks in cataclysmic variables with the FLASH code

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In this poster, we will present 2D radiation hydrodynamics simulations using the FLASH code used to interpret recent laboratory astrophysics experiments performed on the LULI2000 laser facility. Two sets of experiments were obtained recently (POLAR and nested jets) and are discussed here.

In the POLAR project [1], we study the accretion shocks in magnetic cataclysmic variables (mCVs). These are binary systems containing an accreting magnetic white dwarf which accretes matter from a secondary star. Due to the intense magnetic field, the accreted matters is guided by the magnetic field lines and falls with supersonic velocity onto the white dwarf surface, creating a reverse radiative shock. We will present recent experiments aiming at studying the shock formation and dynamics, and compare them to simulations.

In a second experiment, we focused on the nested outflows occurring in the collimation of an astrophysical jet due to ambient media of lower density, like winds [2]. In a similar approach, the experimental results will be shown and discussed on the base of FLASH code simulations.

References

[1] E. Falize et al. High Energy Density Physics, Volume 8, Issue 1, p. 1-4. (2012)

[2] E.G. Blackman, R. Perna, ApJ, 601, L71 (2004)

O.Fr_B2

Generating Collimated Magnetized Plasma Flows Relevant to Astrophysical Jets

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Collimated jets are prominent features in astrophysics that have been observed in many classes of astrophysical objects, including [1] active galactic nuclei, young stellar objects, gamma-ray bursts, and soft x-ray sources. Similarities observed in these vastly different systems has led to the general consensus that these jets are likely created by the same phenomena, namely an accretion disc with an embedded magnetic field. Present-day laser facilities provide a unique opportunity to recreate these systems under controlled conditions in the laboratory.

A laser-irradiated plastic cone may be used to generate a well-collimated plasma jet. A schematic of the target and jet are shown in Figure 1a with results from a CRASH [2] simulation shown in Figure 1b. Experiments were performed at the TITAN laser facility at Lawrence Livermore National Laboratory using multiple target types to investigate the effect of target geometry on the jet parameters. A Bitter magnet was implemented to apply a constant axial magnetic field along the jet axis with the ability to increase the applied field up to ~10 T. Experimental results will be presented from optical diagnostics and proton radiographs that characterize these collimated plasma flows under varying degrees of magnetization with β values down to ~1 where magnetic fields play a dominant role in the jet dynamics.

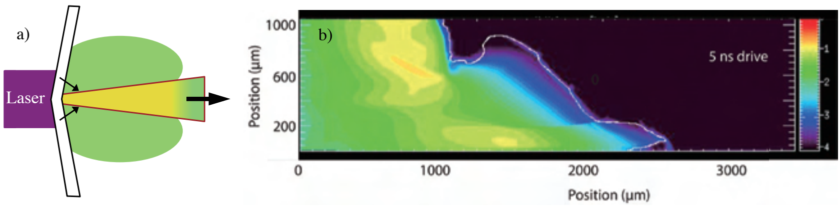

Figure 1 (a) Schematic of an irradiated cone target that produces a collimated jet. (b) Density distribution of a collimated jet calculated by the radiation-hydrodynamic code CRASH for a 100-μm-thick plastic cone target irradiated by a 5 ns drive pulse. The color scheme is on a log-scale for fluid densities ranging from 10^{0}-10^{-4} g/cm^3 and illustrates the radial and axial variation in the jet density.

References

[1] P. M. Bellan et al., Phys. Plasm., 16, 041005 (2009)
[2] B. Van der Holst et al., Astrophys. J. Supp. Ser., 194, 23 (2011)

† Einstein Fellow through the Smithsonian Astrophysical Observatory.

O.Fr_B3

X-ray measurement of the structure of strongly driven carbon at LCLS

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We have explored the phase diagram of carbon at high temperature and pressures. Despite the fact that carbon is one the most common elements on Earth, the phase boundaries and melting properties of carbon are still poorly understood. Yet liquid carbon may exist as a thermodynamically stable phase near the cores of Uranus and Neptune contributing to the magnetic moment of these planets, on white dwarfs and in carbon rich extra solar planets. In a first step, an optical laser transformed the carbon sample into its liquid phase. Then it was further ionized and probed at different delays by a short pulse of x rays. The angular dependence of the scattered light reveals a unique, highly correlated state, where the electrostatic energy significantly exceeds the thermal energy of the ions and electrons.

O.Fr_B4

Structural investigation of SiO_2 at extreme temperature and density using Si K-edge XANES

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With the recent discovery of many exoplanets and super-Earth, modeling the interior of these celestial bodies is becoming a fascinating scientific challenge. In this context, it is crucial to accurately know the equations of state and the physical properties of the constituent materials. Among these, silicates, $MgSiO_3$ together with its dissociation products MgO and SiO_2, are of major importance since they can be found in the mantle of earth-like planets or in the inner core of Saturn-like planets. Their behavior at high temperatures and pressures drives different scenarios and modeling [1].

Our goal is to access the physics involved at the microscopic level (electron and ion structures at the atomic scale), from which starts *ab initio* simulations that aim at calculating any macroscopic properties. We present here a study of the electronic structural properties of fused silica at Mbar pressures using X-ray Absorption Near Edge Spectroscopy (XANES). This is a first step in the investigation of $MgSiO_3$ complex system behavior, including dissociation occurring under conditions relevant to planetary interiors.

The results were obtained in two different experimental campaigns on the LULI2000 and TITAN lasers at the Ecole Polytechnique and LLNL respectively. With an approach previously validated on high-pressure aluminum [2, 3], we obtained high quality XANES data at different well-controlled temperature and density conditions using laser driven shock waves. Coupled to *ab initio* calculations [4], these results provide us information on the evolution of the electronic structure, pair correlation functions and the associated Si-O bounding ordering of the system. Moreover, the K-edge modification gives information on the SiO_2 gap dependence in temperature and density.

References

[1] K. Umemoto *et al.*, Science **311**, 983 (2006)
[2] A. Lévy *et al.*, Phys. Rev. Lett. **108**, 055002 (2012)
[3] A. Benuzzi-Mounaix *et al.*, Phys. Rev. Lett. **107**, 165006 (2011)
[4] V. Recoules *et al.*, Phys. Rev. B **80**, 064110 (2009)

O.Fr_C1

Status of SACLA and its applications to high energy density science

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Recently, X-ray Free Electron Lasers (XFELs), such as the Linac Coherent Light Source (LCLS) [1] and SPring-8 Angstrom Compact free electron LAser (SACLA) [2], have successfully generated brilliant, femtosecond X-ray pulses. XFELs open new frontiers in atomic physics and x-ray optics, and the structural analysis of biological nanoparticles. XFELs are expected to open new high energy density science (HEDS)

SACLA has two types of XFEL focusing system: a 1-μm focusing system with a KB mirror [3] and a two-step focusing system with two sets of KB mirrors for 50-nm focusing. These focusing systems realize ultra-high intense X-ray pulse (over 10^{20} W/cm^2 with 50-nm focal spot), which has not ever existed in laboratories. These ultra-intense X-ray pulses are applied to creation of hot/warm dense plasma, atomic molecular optics and X-ray nonlinear optics.

In HEDS experiment, spectroscopy is a key technique for both characterization of XFEL pulses and study of high energy density state. An on-axis single-shot spectrometer is available for characterization of XFEL of both frequency and temporal domains. We measured spikes of XFEL spectrum with resolution of 14 meV and determined the pulse duration combining with an XFEL simulation [4]. In addition, this spectrometer is available for the absorption spectroscopy.

. In the presentation, we will report the performance of SACLA, the experimental station, and HEDS applications.

References

[1] P. Emma et al, Nature Photon. 4, 641 (2010).
[2] T. Ishikawa, et al, Nature Photon. 6, 540 (2012).
[3] H. Yumoto, et al, Nature Photon. 7, 43 (2013).
[4] Y. Inubushi, et al, Phys. Rev. Lett. 109, 144801 (2012).

O.Fr_C2

Interaction of intense X-ray laser pulse with solid materials

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Intense X-ray pulse form recent Xray Free Electron Laser(XFEL) can open new region of research works of interaction with solid matter. At Japanese X-ray laser facility, a femtoseconds X-ray pulse can be focused on the solid target with intensity of higher than 10^{19}W/cm^2. In this intensity, we expect nonlinear optical phenomena because that intense xray modifies inner shell electrons largely even in the solid density material. The rate of the photoionization/ excitation of 1s electron is as large as the rate of the Auger relaxation. This means during this x-ray pulse, there is vacancy of 1s electron in almost all the atoms of the solid. Normally this 1s electron vacancy is suddenly reoccupied with L shell electrons. Keeping the vacancy of 1s electrons means the energy level of the residual 1s electron is modified to higher energy level due to the stronger binding with nuclear charge. By using Kramers–Kronig relations relation, we expect large change of optical constant in x-ray region.

As well-known, the dynamical control of x-ray is very difficult and the real part of the optical constant for xray is almost unity and is not changed largely with normal method. However, the above mentioned change of the electron system may induce relatively large change of optical constant. To consider the jump of the optical constant between K- absorption edge, it will be several times of 10^{-4}. This number is not large but the same order of optical refractive index which is induced with UV light for optical fiber. Therefore, we can design the active photonic device for multi-keV xray laser beams.

Up to now, we find large change of transmission of x-ray at intensity of over 10^{19}W/cm^2 with 8keV XFEL. In addition, the phase front of the transmission x-ray is also changed. These experimental evidences will be one of the sign for the start of new optical control device for Xray lasers.

O.Fr_C3

Probing of Complex Interaction Dynamics of Ultra-Intense Lasers with Solid Matter with XFELs

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The interaction of ultra-intense lasers with solid foils can be used to accelerate ions to high energies well exceeding 60 MeV [1]. The non-linear relativistic motion of electrons in the intense laser radiation leads to their acceleration and later to the acceleration of ions. Ions can be accelerated from the front surface, the foil interior region, and the foil rear surface (TNSA, most widely used), or the foil may be accelerated as a whole if sufficiently thin (RPA). For increasing laser intensity especially in the latter case it is well known that the growth rate of instabilities emerging from the non-linear electron motion can be large enough to influence and disturb the acceleration process [2].

Here, we focus on the most widely used mechanism for laser ion-acceleration of TNSA. Starting from flat foils in a regime where instabilities do not play a role we show by simulations how increasing laser intensity leads to the growth of various instabilities. The exact dynamics depend very sensitively on the chosen initial parameters which has a tremendous effect on electron dynamics. Recent experiments performed at DRACO suggest that also in the TNSA regime the instability development may be of importance with respect to ion spectra, spatial distribution and maximum energy.

It is evident that the time-resolved experimental observation with nanometer resolution is crucial for understanding the laser absorption, creation of energetic electrons and electron transport in matter with respect to the afore mentioned instability physics but also for ambipolar expansion and shock formation at the surfaces at buried layers. Novel intense and coherent X-ray sources in combination with ultra-intense short-pulse lasers as at the Helmholtz Beamline at European XFEL will allow probing of plasmas on time and spatial scales otherwise not accessible. We investigate the feasibility of various X-ray techniques for this purpose, such as the small angle x-ray scattering (SAXS), Faraday rotation and the local change of index of refraction by bound-bound resonances in ionized matter.

References

[1] S.A. Gaillard et al., Phys. Plasmas **18**, 056710 (2011)
[2] F. Pegoraro and S.V. Bulanov, Phys. Rev. Lett. **99**, 065002 (2007)

O.Fr_C4

Spectroscopic measurements of ablation plasma generated with laser-driven intense extreme ultraviolet (EUV) light

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Recently Extreme Ultraviolet (EUV) light has attracted much attention for many applications, especially as a radiation source for advanced photolithography technology that enables further device integrations. To date, high-power and high-fluence 13.5 nm EUV source has been widely studied and developed. However, the physics of EUV ablation has not been clarified yet and is expected to be quite different from that of laser ablation, resulting in uniform energy absorption and isochoric heating. It is well known that thermal ablation is the dominant process in laser ablation when a low energy and ns pulse laser light, for example 1064 nm YAG laser, is injected [1]. On the other hand, EUV light can penetrate through plasma and energy can be directly deposited into dense region because of its large cut off density. Since difference in heating mechanism results in difference in plasma properties, this study aims to understand the heating of EUV ablation by measuring plasma in comparison with that of laser ablation.

EUV irradiation was performed by injecting a Nd: YAG laser (1064 nm) into solid Xe target and wide-spectral range (8-20 nm) EUV light emitted from the Xe target was focused into a sample. On the other hand, Laser irradiation was performed by injecting a focused Nd: YAG laser directly into the sample. The peak power density was 4.2×10^9 W/cm^2 and irradiation spot was ~100 μm for both cases. In this study, Si plate was used as the sample. The electron density and temperature were determined using visible spectroscopy with a time resolution of 20 ns.

The observed spectra included several peaks and continuous components for both EUV and laser ablation. Electron temperature derived from the peaks for laser ablation using the Boltzmann plot was typically 3-4 eV and that for EUV ablation was 1.5-2 eV. The electron density was in the order of 10^{18} cm^{-3} for both EUV and laser ablations. The electron temperature difference between EUV and laser plasma increased with decrease of electron density as the time. Spatial distribution of plasma parameters was calculated by using HELIOS code [2]. The electron temperature of EUV ablation was much smaller than that of laser ablation, showing a consistency with the experimental results. It implies that the EUV energy was deposited into high-density region and each particle receives smaller energy. In the paper, heating mechanisms and plasma properties will be further presented and discussed.

References

[1] B. N. Chichkov, C. Momma, S. Nolte, F. von Alvensleben, A. Tunnermann, Appl. Phys. A **63** 109 (1996)

[2] HELIOS simulation code web site: http://www.prism-cs.com/Software/Helios/Helios.htm

O.Fr_A9

Rugby Hohlraum Experiments on the National Ignition Facility

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Rugby-shaped hohlraums have been fielded for the first time on the National Ignition Facility [1]. Rugby-shaped (vacuum) hohlraums have been previously fielded [2] on the Omega Laser Facility and shown to increase hohlraum flux by ~20%. This new platform is designed to maximize beam clearance from both the laser entrance hole [LEH] and the capsule, minimize crossed beam energy transfer, and maintain high internal radiation temperatures. The rugby-shaped hohlraum has a midplane radius of 3.5 mm, a radius of 1.77 mm at each LEH, and a total length of 10.5 mm.

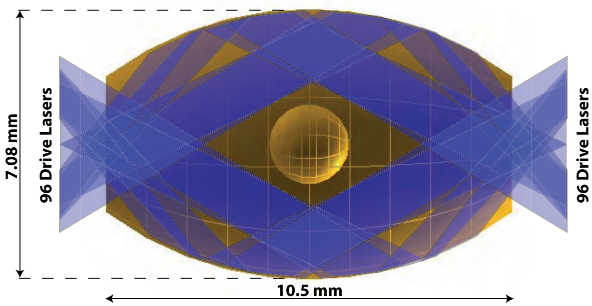

Figure 1: The rugby-shaped hohlraum heated with a total of 192 NIF laser beams.

Initial experiments have focused on maximizing laser/target energy coupling at energies ranging from 0.76 MJ to 1.3 MJ. Coupling has been measured with a suite of backscatter diagnostics. Laser beam propagation is assessed using x-ray imaging diagnostics and implosion symmetry is measured using a gated x-ray framing camera. Future experimental plans utilizing the rugby-shaped hohlraum platform will be discussed.

References

[1] Lindl et al., Phys. Plasmas 11, 339 (2004)

[2] Philippe, F. et al. Phys Rev Lett **104**, (2010).

O.Fr_A10

Beryllium Ignition Target Design for Indirect Drive NIF Experiments

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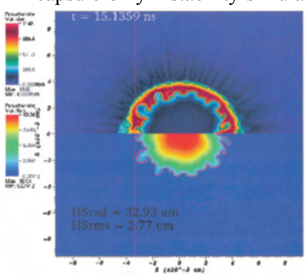
As an alternative to plastic targets currently under-performing on NIF, we are investigating capsules with a beryllium ablator. It has lower opacity and therefore higher ablation rate, pressure, and velocity [1,2]. We recently designed 300, 345 and 420 TW NIF laser pulses for an ignition capsule based upon the Rev. 5 SymCap beryllium design of Steve Haan, in the standard 5.75 mm hohlraum. We used these to test, in integrated radiation-hydrodynamics simulations, sensitivity of the main implosion characteristics to variations in the hohlraum fill gas density, laser beams pointing, and cross-beam energy transfer. However, the Rev. 5 design does not account for recent NIF experimental results that suggest that hohlraum radiation delivers more preheat and less drive to plastic capsules. Therefore, an improved beryllium design is required. Incorporating the appropriately degraded drive, we employed 2D integrated radiation-hydrodynamics simulations with a DCA atomic model, assumed the standard NIF dopant-layer pyramid, and scanned the (ablator thickness, fuel ice thickness, Cu dopant level) parameter space to identify a number of potentially attractive designs with fusion yields up to ~19 MJ. We found the standard scanning technique, based upon one-dimensional capsule-only simulations driven by a frequency dependent source (FDS), to be unsatisfactory since it fails to modify the FDS to properly account for the hohlraum-capsule interaction. This results in highly inaccurate Herrmann island diagrams that strongly depend upon the initial FDS. Instead, we performed integrated 2D capsule and hohlraum simulations, tuning the shock structure by adjusting the laser pulse.

Selecting an optimal design for NIF beryllium experiments requires minimizing sensitivity to perturbation growth. The figure shows temperature and density profiles at the ignition time from a 2D capsule-only instability simulation seeded with the outer surface perturbations corresponding to Rev. 3 beryllium design specifications. The capsule was driven by 1.45 MJ of laser energy, with an assumed 17% backscatter loss and an arbitrary 15% power loss in the fourth pulse to account for the as yet unexplained energy loss observed in NIF plastic capsule implosions. We anticipate this or a very similar capsule to be the basis for the first NIF beryllium experiments. The experimental results will then be used to adjust the hohlraum model and capsule opacities to further optimize the ignition design.



References
[1] D. C. Wilson et al., Phys. Plasmas 5, 1953 (1998).
[2] R. E. Olson et al., Phys. Plasmas 18, 032706 (2011).

Alternative Hot Spot Formation Techniques in Inertial Confinement Fusion Capsule Implosions

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The baseline technique for hot spot formation in inertial confinement fusion (ICF) ignition capsule implosions[1] requires that a very thin, high aspect ratio layer at the inner surface of a DT ice shell is heated and compressed in a complex manner that is quite different from the bulk of the DT fuel. In the present paper, we propose alternative ICF capsule designs in which the hot spot is formed mostly or entirely from mass originating within a spherical volume of DT vapor. This can be done if we replace the DT ice layer with a layer of DT liquid and operate at a higher initial cryogenic capsule temperature and vapor density. In the simplest version, the DT liquid is wicked into a shell of open-cell CH foam that lines the interior of the ablator shell. In the "fast formed liquid" (FFL) design[2,3], DT is frozen into a CH foam matrix and is quickly melted just before the shot to form a pure liquid DT layer on the interior of the foam. In addition to simplifying the hot spot formation process, the wetted foam and FFL designs allow for flexibility in hot spot convergence ratio through the adjustment of the initial cryogenic capsule temperature and, hence, DT vapor density. It is found that the overall thermonuclear yield predicted for such a capsule will be less than predicted in computational simulations of the baseline ignition capsules using comparable capsule size and absorbed energy. However, the relative simplicity of the hot spot formation technique might lead to a more robust ignition experiment and an improvement in the computational prediction of hot spot behavior.

References

[1] S. W. Haan et al., Phys. Plasmas **18**, 051001 (2011).
[2] R. B. Stephens, Proc. IEEE/NPSS, 753 (1994).
[3] R. E. Olson, Fusion Technology **38**, 6 (2000).

O.Fr_A12

Application of Compressed Magnetic Fields to Ignition and Burn on the National Ignition Facility

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We are studying the impact of highly compressed axial magnetic fields on ignition and burn of targets for the National Ignition Facility. Initial seed fields of 10-100T (potentially attainable with present experimental methods) that compress to greater than 10^4T (100MG) under implosion can reduce hotspot conditions required for ignition and propagating burn through range reduction and magnetic mirror trapping of fusion alpha particles, suppression of electron heat conduction and potential stabilization of hydrodynamic instabilities. This may permit recovery of ignition, or at least significant alpha particle heating, in submarginal capsules that would otherwise fail because of adverse hydrodynamic conditions or, more generally, may permit attainment of ignition in targets redesigned to operate under reduced drive and/or lower convergence ratios [1].

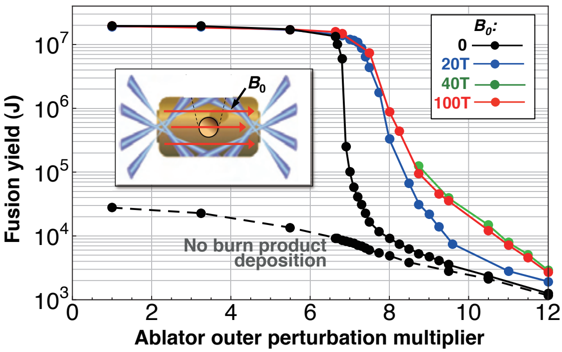

Figure 1: Fusion yield of the NIF cryo-DT ignition target versus multiplier on the amplitude of capsule outer surface perturbation under initial seed magnetic fields from 0 to 100 T [1].

We have performed initial 2-D simulations for the NIF indirect-drive ignition platform. The effect of the magnetic field is to move the ignition “cliff” to the right in that the capsule attains ignition and fusion yield at shell perturbations that would otherwise result in low yield, non-ignition (Fig. 1). We are also studying the utility of magnetic fields to volumetric ignition in high pressure, warm gas capsules and to ameliorate hohlraum plasma conditions. Potential benefits for the latter may include suppression of wall blow-off, Landau damping of SRS, range restriction of preheat electrons and use of vacuum hohlraums. Validation experiments on both magnetized capsule and hohlraum physics are highly desirable in the immediate term

[1] L. J. Perkins, et al, *Application of Compressed Magnetic Field to the Ignition and Thermonuclear Burn of Inertial Confinement Fusion Targets*, submitted to Phys. Rev. Lett (2013)

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O.Fr_B5

Energy and wawelength scaling of shock-ignited targets: Options for increasing target robustness

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We describe recent progress in the study of shock-ignited laser fusion targets. In shock ignition the fuel is first imploded at lower velocity than in conventional ICF. Close to stagnation an additional intense laser spike drives a strong converging shock, which contributes to hot spot formation. Due to the lower implosion velocity, issues related to hydrodynamic instabilities are relaxed. On the other hand, the interaction of the laser spike with the plasma occurs in a regime where parametric instabilities are expected to become relevant.

In previous publications [1] we had identified a window in laser parameter space for the ignition of a simple, small target (with fuel mass of less than 0.3 mg), previously designed for fast ignition. We had also studied aspects of the robustness to parameter deviation from nominal values as well as to hydrodynamic instabilities and non uniform irradiation. Recent work of our group was focused on the design of more robust targets (possibly amenable to testing on the NIF or LMJ) and was also supported by significant code upgrade (introduction of fully 3D laser ray-tracing, nonlocal electron transport, improved rezoning scheme).

We show that separation of the stages of fuel compression and hot spot creation introduces some degree of design flexibility [2]. Flexibility increases with target (and driver) size and allows for a compromise between energy gain and risk reduction. Having designed a reference ignition target, we have developed an analytical model for (up)-scaling targets as a function of laser energy and parameters related to hydro- and plasma-instabilities. Detailed 1D simulations confirm the model and generate gain curves, while 2D simulations show how different design options affect robustness to asymmetries caused by laser non-niformities and target mis-positioning. We also quantify the target ignition margins and discuss its dependence on laser energy and power. Finally, we show that our scaling model can be used to scale a target driven by UV laser (λ = 0.35 mm) to a target driven by green laser (λ = 0.53 mm). 1D simulations show that gain in the range 100 – 200 can be obtained for total green light laser energy in the range 1.5 – 3 MJ, while operating in the same laser-plasma regime as the UV-driven targets [3].

References

[1] S. Atzeni *et al*., *Plasma Phys. Controll. Fusion* **53**, 035010 (2011).
[2] S. Atzeni *et al.*, *New J. Phys.* **15** 045004 (2013)
[3] S. Atzeni *et al.*, *Phys. Plasmas* **19**, 090702 (2012)

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O.Fr_B6

Ablation driven by hot electrons in shock ignition

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We have developed a model for the ablation process that takes place during the ignitor laser spike in the shock ignition (SI) scenario [1,2]. For this, we have assumed that all the absorbed energy of the laser is transferred to a population of hot electrons with a temperature θ_{Hc} at the critical surface given by the empirical law $\theta_{Hc} = a(I\lambda^2)^{1/3}$, where I and λ are is the laser intensity and wavelength, respectively.

We find that for the short laser wavelengths envisaged for SI ($\lambda \leq 0.351$ μm), it exists a regime in which the critical surface remains sufficiently close to the ablation front to ensure an optimal laser/target coupling. In such a regime, the maximum intensity has a strong dependence on the laser wavelength $I \leq 1.6 \times 10^{11} r_0^{3/2}/\lambda^5$ (r_0 and λ in μm) an it makes possible to achieve the considerably high laser intensities required to generate the ignitor shock wave. The strong wavelength scaling of this intensity threshold for efficient coupling suggests that the laser wavelength of the ignitor pulse should be as shorter as possible.

On the other hand, for avoiding the deleterious effects of the preformed plasma we have found that a minimum ratio between the ignitor and the compression laser pulses is required, both ablation plasmas, the produced early by the compression pulse and later by the ignitor pulse can be conveniently matched.

Taking into account the previous conditions on the laser wavelength and the minimum ratio between compression and ignition pulses, it seems possible to reach ablation pressures of the Gbar order that are appropriate for launching the ignitor shock [3].

References

[1] R. Betti et al., Phys. Rev. Lett. 98, 155001 (2007).
[2] L. J. Perkins et al., Phys. Rev. Lett. 103, 045004 (2009).
[3] A. R. Piriz et al., Phys. Plasmas. 19, 122705 (2012)

O.Fr_B7

Multi-dimensional simulations of high-pressure shock formation driven by fast-electron energy deposition resolved over the hydrodynamic-time and -space scales

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One major issue to be address in Inertial Confinement Fusion (ICF) is the detailed description of the kinetic transport of laser generated fast electrons within the time and space scales of the imploded target hydrodynamics. We have developed, at CELIA, a fast, reduced kinetic model for relativistic electron transport based on the angular moments of the relativistic Fokker-Planck equation, the M1 model [1]. The self-consistent magnetic and electric fields are computed thanks to a generalized Ohm law. This model has been implemented into the 2D radiation hydrodynamic code CHIC [2]. Because of M1's high computing speed, various initial configurations can be tested within the time scale of 100 ps and spatial scale of 100 μm. In addition, due to its structure, the effects of electric and magnetic fields can easily be highlighted as well as the fast electron beam (FEB) resistive energy losses directly compared to the collisional losses.

The M1 model is used in the framework of both the Fast Ignition (FI) and the Shock Ignition (SI) schemes. Although the presented study is mainly devoted to the SI scheme, the interest for FI is also shortly discussed through an analysis of an experiment of fast electron transport in cone-in-shell spherically imploded targets recently carried out at the Omega-EP laser facility [3]. Concerning the SI scheme, it is shown that the energy transferred by the FEB from the corona to the compressed shell of an ICF target could be an important mechanism for the creation of ablation pressure. A FEB with a 30-100 keV mean energy and a 1 PW/cm^2 energy flux can create pressures higher than 350 Mbar within a few 100 ps in over-solid density compressed material [4]. The ablation layer dynamics and the shock evolution are presented in realistic configurations by varying the FEB energy spectrum and the plasma density profile. The calculation 2D geometry evidences the effects of the FEB angular distribution on the shock pressure and the effects of self-generated magnetic fields on the FEB propagation. In the time scale of a few 10 ps, the plasma-generated magnetic fields induced by non-collinear temperature and density gradients [5] may modify electron transport and the resulting shock pressure.

References

[1] B. Dubroca *et al.*, Eur. Phys. J. D 60, 301 (2010)
[2] J. Breil *et al.*, J. Comp. Phys. 224, 785 (2007).
[3] F. Beg *et al.*, private communication
[4] S. Gus'kov et al., Phys. Rev. Letters 109, 255004 (2012)
[5] Ph. Nicolaï *et al.*, Phys. Rev. E 84 016402 (2011)

Study on the transport of a relativistic electron beam in plasmas

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In the fast ignition scheme, a relativistic electron beam is considered to be the most suitable source for igniting a hot spot much smaller than the dense compressed deuterium-tritium core. In order to deliver enough energy (10kJ) into the pellet in ~10ps, the ignition laser beam should reach the intensity of I_0~10^{20}W/cm^2 if the coupling from the laser to the core plasma is about 20% for a well-collimated beam. However, studies have shown that the electron divergence increases with the laser intensity. Of particular importance is the possibility of collimating the fast electron beams with the size of the compressed core. In this talk, the effects of the imposed uniform magnetic field, ranging from 1MG up to 50MG, on the production and transport of relativistic electron beams (REBs) in overdense plasmas irradiated by ultraintense laser pulse are investigated with two-dimensional particle-in-cell numerical simulations. This study gives clear evidence that the imposed magnetic field is capable of effectively confining the relativistic electrons in space even when the source is highly divergent since it forces the electrons moving helically. In comparison, the spontaneous magnetic fields, generated by the helically moving electrons interplaying with the current filamentation instability, are dominant in scattering the relativistic electrons. As the imposed magnetic field was increased from 1MG to 50MG, overall coupling from laser to the relativistic electrons which have the potential to heat the compressed core in fast ignition was found to increase from 6.9% to 21.3% while the divergence of the REB increases significantly from 64^o to 90^o. The simulations show that imposed magnetic field of the value of 3 ~ 30MG could be more suitable to fast-ignition inertial fusion.

References

[1] D.J. Strozzi, M. Tabak, D.J. Larson et al., Phys. Plasmas 19, 072711 (2012).

O.Fr_C5

Generation of Phase - Matched Coherent Point Source in Plasma Media by Propagated X - Ray Laser Seeded Beam

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There is a significant interest in developing the coherent table-top x-ray lasers. Advent of plasma-based transient collisional excitation x-ray laser and particular, injection of coherent seeded beam, especially high-order harmonics, has tremendously improved the spatial coherence of such lasers, what allowed them to be the same widely used as synchrotron sources. Here we report experimental founding of unknown interference structure in a spatial profile of the output beam of the two-stage plasma X-ray laser. It is allowed us experimentally and theoretically discovers a new phenomenon - generation a phase-matched coherent point source of soft X-ray radiation in a plasma media by propagated X-ray laser seeded beam, which could additionally extend the applications of such lasers. We have developed a method of solving the Maxwell-Bloch equations, which has gave us finding that the observed phenomenon is due to the emergence in the plasma-amplifier of X-ray mirage in the form of the phase-matched coherent virtual point source. We found the equations describing the emergence of a phase-matched coherent virtual point source during amplification of seeded beam and show that this effect could be treated as the first observation of Mirage phenomenon in X-rays. The obtained results bring new insight into the physical nature of amplification of X-ray radiation in laser-induced plasma amplifiers and opening innovating opportunities for X-ray interferometry, holography and other applications, which requiring multiple rigidly phased sources of coherent radiation.

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Advances in OFI soft x-ray lasers at LOA

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ABSTRACT

Generating an optical-field-ionization (OFI) collisional soft X-ray laser amplifier in a high density plasma would allow a significant increase of the saturation intensity, laser gain, and reduction of the emitted pulse duration. Due to strong refraction of the pump infrared beam in the plasma, guiding techniques have to be implemented. Using an optically preformed plasma waveguide, we successfully achieved guiding of J-energy pulses in a near-critical density krypton plasma with 50% total transmission over 5 to 10mm. X-ray lasing at 32.8nm has also been demonstrated. This technique is a step towards OFI recombination soft X-ray lasers. This pumping scheme requires the production of a cold and dense plasma. We propose to pump a high density neon VIII plasma by a frequency doubled (which will limit electron heating) intense Ti:Sa laser. Guiding of the 405nm pump pulse has already been achieved at LOA

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Observation of the surface dynamics of femtosecond laser ablation by time-resolved soft x-ray imaging technique

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The dynamical processes of the femosecond laser-induced surface modifications come to attract much attention for the micro processing. However, it is difficult to observe the femtosecond laser ablation dynamics, because of non-repetitive, irreversible and rapidly changing phenomena in a small characteristic size. Thus, the details of femtosecond laser ablation process have not been understood well. The measurement technique with the sufficient temporal and spatial resolution is necessary for the better understanding of the femtosecond laser ablation. In this study, we have developed the pump and probe interferometer and reflective imaging technique of the metal surfaces during the femtosecond laser ablation by using the laser-driven soft x-ray laser at the wavelength of 13.9 nm[1-3]. The pumping laser used for the ablation was a Ti: Sapphire laser pulse with the duration of 80 fs pulse at a central wavelength of 795 nm, and had a gaussian spatial profile. By using the x-ray imaging technique, the time resolved image of nano-scaled ablation dynamics of the platinum was obtained. At the timing of 36 ps after the femtosecond laser irradiation, the maximum surface expansion and expansion speed were measured to be about 60 nm and 1700 m/s, respectively. We have compared the plasma expansion measured by the x-ray interferometer with the ablated hole measured by the atomic force microscopy, and discussed the fluence dependence of the femtosecond laser ablation. These results lead to better understanding of the initial process of the laser ablation dynamics.

References

[1] T. Suemoto *et al.*, Opt. Exp. 18, 14114 (2010).
[2] Y. Ochi *et al.*, Jpn. J. Appl. Phys. 51, 016601 (2012).
[3] T. Tomita *et al.*, Opt. Exp. 20, 29329 (2012).

O.Fr_C8

Femtosecond laser ablation process on platinum and gold observed by plasma-based soft x-ray laser

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The Ti: sapphire laser (795 nm, 80 fs) pump and plasma-based soft x-ray laser(13.9 nm, 7 ps) probe system have been constructed.[1] In this conference, we will focus on the time-evolution of the soft x-ray reflectivity on the platinum (Pt) and gold (Au) sample during the femtosecond laser ablation. Figure 1 shows the time-evolution of the reflectivity after the femtosecond laser irradiation on the Pt and Au samples. The reflectivity changes observed both on Pt and Au can be ascribed to change of the surface roughness from and the density gradient during the ablation process. The gradual decrease of soft x-ray reflectivity at the central part of the irradiated spot was observed on both samples. The red arrows indicate the position of the reflectivity anomaly, and this reflectivity change is seemed to be caused by the ablation with threshold fluence. In addition, we will discuss the difference of x-ray reflectivity change from the dependence of the melting point between the Au at 1337 K and the Pt at 2045 K.

[1] T. Tomita *et al.*: Opt. Exp., **20**, 29329 (2012).

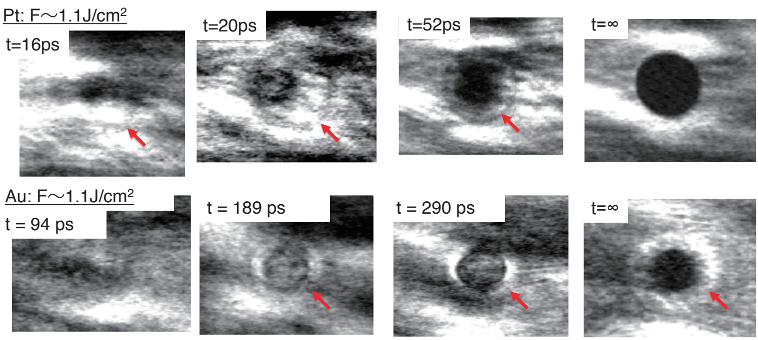

Figure1 : The time-evolution of the soft x-ray reflectivity after the femtosecond laser irradiation on Platinum (Pt) and gold (Au).

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A bright neutron source driven by relativistic transparency of solids

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Neutrons are a unique tool to alter and diagnose material properties and excite nuclear reactions with a large field of applications. It has been stated over the last years, that there is a growing need for intense, pulsed neutron sources, either fast or moderated neutrons for the scientific community. Accelerator based spallation sources provide unprecedented neutron fluxes, but could be complemented by novel sources with higher peak brightness that are more compact. Lasers offer the prospect of generating a very compact neutron source of high peak brightness that could be linked to other facilities more easily.

We present experimental results on the first short pulse laser driven neutron source powerful enough for applications in radiography. For the first time an acceleration mechanism (BOA) based on the concept of relativistic transparency has been used to generate neutrons. This mechanism not only provides much higher particle energies, but also accelerated the entire target volume, thereby circumventing the need for complicated target treatment and no longer limited to protons as an intense ion source. As a consequence we have demonstrated a new record in laser-neutron production, not only in numbers, but also in energy and directionality based on an intense deuteron beam. This enabled the use in imaging applications with high temporal resolution as the neutron beam has a pulse duration of less than a nanosecond.

The beam contained, for the first time, neutrons with energies in excess of 80 MeV and showed pronounced directionality, which makes then extremely useful for a variety of applications. Using short pulse lasers we have been able to get a radiograph of an unknown object using the hard x-rays of the laser matter interaction and neutrons of different energies. This allows also for determining the material composition of an object. The data thereby match the simulation data for our test samples.

The results also address a larger community as it paves the way to use short pulse lasers as a neutron source. They can open up neutron research to a broad academic community including material science, biology, medicine and high energy density physics as laser systems become more easily available to universities and therefore can complement large scale facilities like reactors or particle accelerators. We believe that this has the potential to increase the user community for neutron research largely.

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Probing high-energy density Plasmas at the LCLS matter of extreme conditions end station

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Abstract: The unique combination of the LCLS x-ray laser with high-power nanosecond and femtosecond laser beams at the Matter of Extreme Conditions end station allows precision pump-probe studies of high energy density plasmas. For this purpose, we are building a new 200 TW laser system to measure and uncover the underlying physics mechanism that determine the interaction of ultra intense laser beams with matter. The repetition rate and pulse width provide a natural match to the LCLS x-ray beam capabilities allowing pump-probe experiments with ultrahigh temporal resolution with very high data throughput with shot rates ranging from about 1 shot/min at 200 TW to about 5 Hz at 30 TW. In this talk we will present first Thomson scattering results with unprecedented spectral, wavenumber and temporal resolution in shock compressed matter and will discuss future experiments aimed at measuring the physical properties of dense plasmas.