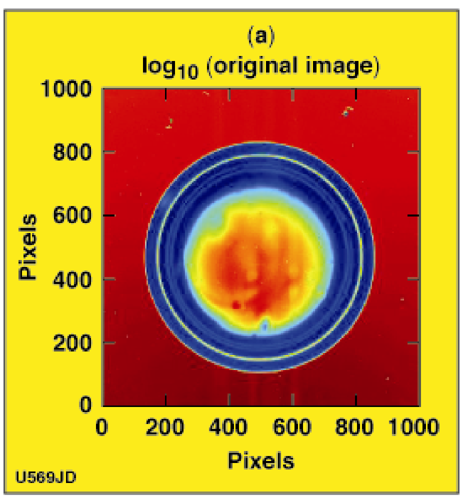
T.C. Sangster Press Release

Cryogenic DT and D_2 Targets for Inertial Confinement Fusion

Scientists implode the first targets on the OMEGA laser that scale to ignition on future mega-joule class laser facilities

November 1, 2006Wednesday, 2:00-3:00 pm
Tutorial Session QT1:
Philadelphia Marriott Downtown - Grand Salon ABF

Researchers at the University of Rochester's Laboratory for Laser Energetics (UR–LLE) are studying high-convergence implosions using targets that scale to ignition on laser facilities such as the National Ignition Facility (NIF) and the Laser Megajoule Facility (LMF) in France. These millimeter-scale targets consist of a thin outer shell of deuterated plastic and contain a ~95-μm layer of frozen deuterium–tritium (DT) fuel. The inner-surface roughness of these layers is consistently below 1-μm rms. This roughness meets the requirements for both direct- and x-ray-drive ignition on the NIF and was achieved using a process called β-layering (thicker regions of ice are preferentially heated by the radioactive decay of the tritium). UR-LLE researchers will use the data collected from these implosions to validate the predictions of the multidimensional radiation-hydrodynamics simulation codes that are used to design the direct-drive ignition experiments for the NIF.



The bright ring in this shadowgraph of a cryogenic DT capsule is used to determine the inner-surface roughness of the ice, a key parameter in achieving ignition on future laser facilities.

Further information: PDF version (this will be a link to the longer summary below)
Extended summary of work and images:

Contacts:
T. Craig Sangster, LLE, (585)-273-2350, cell (585) 727-1108, csan@lle.rochester.edu
Robert L. McCrory, LLE, (585)-275-4973, rmcc@lle.rochester.edu
David D. Meyerhofer, LLE, (585)-275-0255, ddm@lle.rochester.edu
David R. Harding, LLE (585)-275-5850, dhar@lle.rochester.edu

Further information:

Philadelphia, PA: November 1, 2006: A demonstration of controlled thermonuclear ignition and energy gain is perhaps the most compelling experiment being planned for the National Ignition Facility, currently under construction at Lawrence Livermore National Laboratory. This facility has been designed to focus the power of 192 laser beams onto a millimeter scale target containing the fusion fuels deuterium and tritium (DT). With the right target design, the lasers at the NIF should compress the DT fuel to hundreds of times its original density while heating it to temperatures much hotter than the surface of the sun. If this occurs as expected, a thermonuclear burn wave will be initiated in the compressed DT, burning a significant fraction of the fuel and producing much more energy than was required to compress and heat the target. The secret to success lies in designing and fabricating the “right target design”.

For over a decade, the Laboratory for Laser Energetics at the University of Rochester (UR-LLE) has been developing the scientific and engineering basis to create and characterize ignition-scaled DT targets. The difficulty is that the DT fuel, which is a gas at most temperatures, must be solid, or ice, so that as much fuel as possible can be put into the target. To get DT to become ice, the gas must be cooled to the triple point (coexistence of solid, liquid and gas phases), about 19.7 degrees Kelvin or some 424 degrees below zero Farenheit! To further complicate the design and fabrication, the DT fuel must form a relatively thin shell around a relatively large void. With this fuel configuration, the shell of fuel implodes when the target is irradiated by the laser. Much higher density fuel can be assembled by imploding a shell rather than by trying to compress, say, a solid ball (imagine a hail stone) of DT. To make targets like this, scientists at UR-LLE fill a thin plastic shell with high pressure DT gas and then cool it under pressure to the triple point. The DT ice will form a layer on the inside surface of the plastic shell. The correct cryogenic DT fuel shell thickness can be obtained by adjusting the gas fill pressure (for example, 1000 atm of DT gas in an 860-micron diameter thin plastic shell will create a solid fuel layer approximately 95-μm thick on the inside of the plastic shell).

The uniformity of the inner surface of this layer is a critical factor in determining whether the target will ignite or fizzle. As the high-density fuel shell begins to decelerate and compress during an implosion, any inner surface perturbations on the ice will grow due to the Rayleigh–Taylor instability. If the initial amplitude of these perturbations is too large, the conditions for ignition and burn do not occur. For the first time ever, spherical shell DT targets being fabricated at UR-LLE have an inner-ice-surface roughness below 1-μm rms, the specification for ignition targets designed for the NIF. The roughness of the inner ice surface is measured using optical shadowgraphy. The light from an optical plane wave reflects (total internal reflection) off the inner surface of the ice creating a bright ring in the image plane as seen in Figure 1(a). This ring represents the location of the inner surface relative to the center (or surface) of the CH capsule. A power spectrum of the ice roughness can be generated by fitting the Fourier amplitudes of the azimuthal radial variations. By rotating the capsule with respect to the viewing axes, an arbitrary number of independent shadowgraphs can be used to create a 3-D representation of the inner ice surface as shown in Fig. 1(b). The peak-to-valley surface variation of this 3D ice surface is no more than 2.5 μm on a total ice thickness of 95 μm. The ignition specification for both direct and x-ray drive is ~1.0-μm rms in all modes. Figure 2 compares the power-spectrum decomposition of the ice-surface roughness of the target in Figure 1(a) and the ignition specification. The measured power spectrum is 0.77-μm rms in all modes and 0.24-μm rms above mode ten, comfortably below the ignition requirement. This is the first time that such ignition quality ice has been produced in a target imploded by a laser.

One of the key measures of target performance is the fuel areal density during the fusion burn. For these high-convergence implosions, charged-particle and x-ray spectroscopic techniques have been used to infer a fuel–shell areal density between 100 and 200 mg/cm^2. This corresponds to a DT density between 20 and 40 g/cm^3 (this is 80 to 160 times solid density). The confinement time for these plasmas is approximately the interval during which neutron emission (fusion) occurs. This is measured to be ~200 ps. In 1957, Lawson showed that the product of ion density and confinement time determined the minimum conditions (or criteria) for fusion energy. The Lawson criterion for these DT plasmas is then greater than 1×10^{20} s/m^3, significantly higher than previously achieved using inertial confinement.

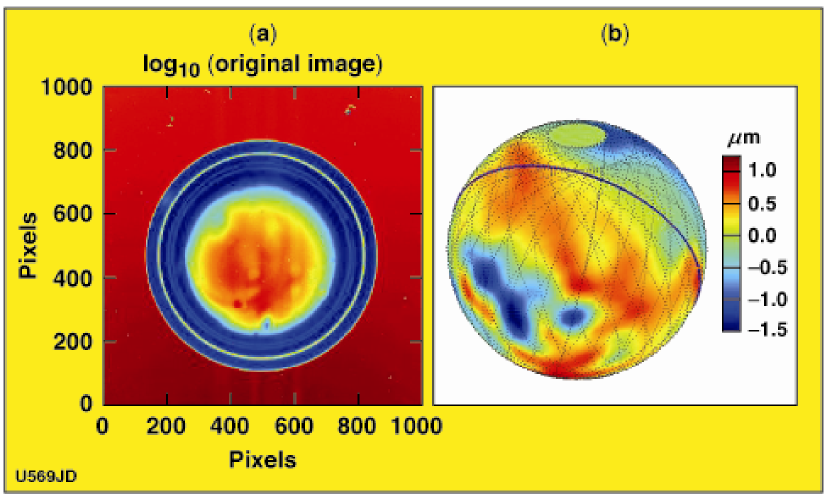


Figure 1(a): The shadowgraph shows the bright ring of light refracted off the inner ice surface. The radial variation of the position of this ring is proportional to the inner-ice-surface roughness. (b) Multiple shadowgraphs are used to reconstruct an inner-ice-surface representation. The color map represents deviations (in microns) of the inner surface with respect to a perfect spherical surface at the average radius of the ice

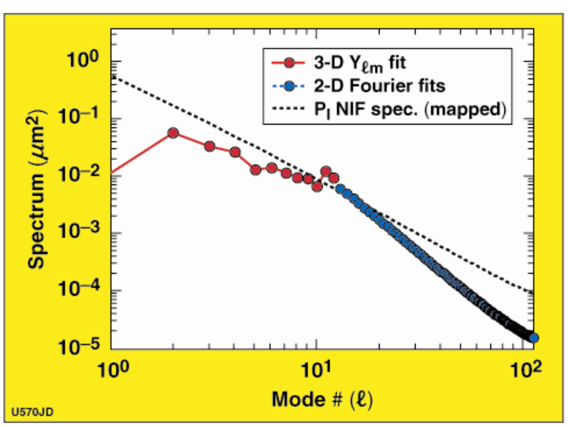


Figure 2: The average power spectrum of the fitted perturbations on the inner ice surface based on the 3-D reconstruction for one of the recent DT implosions. The dotted line represents the direct-drive ignition design specification for targets to be imploded on the NIF.

List additional supporting talks:
[ZO1.00001] Studies of Adiabat Shaping in Direct-Drive, Cryogenic-Target Implosions on OMEGA, D. D. Meyerhofer
Friday, November 3, 2006
[VO2.00002] Numerical Investigation of Proposed OMEGA Cryogenic Implosions using Adiabat-Shaping Techniques, P. W. McKenty
Thursday, November 2, 2006
[GO2.00008] Inferring Areal Density in OMEGA DT Cryogenic Implosions, P. B. Radha
Tuesday, October 31, 2006