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LABORATORY FOR LASER ENERGETICS
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A Design for a Shock Ignition Experiment on the NIF Including 3-D Effects

Laura Tucker
Brighton High School
LLE Advisor: Stephen Craxton

A design for a plastic shell target has been developed for a proposed experiment for the National Ignition Facility (NIF) to investigate a two-stage shock-ignition concept in which 96 beams are used in each step (compression and ignition). To compensate for the NIF's beam configuration, the polar drive method was used, which involves pointing the beams toward the target equator. The beam pointings were also adjusted in the azimuthal direction. Two-dimensional hydrodynamic simulations using the code *SAGE* were combined with 3-D predictions of energy deposition to produce 3-D density profiles. Numerous simulations varying the selection of the 96 beams and the beam pointing, focusing, and energy ratios were used to identify an optimum design for the compression stage. Including variations in both θ and φ, the center of mass of the imploded shell has an rms deviation of just 8 μm after implosion through 400 μm.

X-Ray Backlighting of a Shock Ignition Experiment on the NIF

Thomas Mo
Webster Schroeder High School
LLE Advisor: Stephen Craxton

A computer code *Blackthorn* has been written to model the radiography of an imploding fusion target using an x-ray backlighter. *Blackthorn* traces x rays from the backlighter source through the target to a camera placed at an arbitrary angle, using a 3-D representation of the target density, to produce a contour plot of x-ray transmission. *Blackthorn* has been used to model an imploding plastic-shell target proposed for a shock-ignition polar-drive experiment on the NIF. The shell density is obtained by combining 1-D profiles calculated using the code *LILAC* with a 3-D representation of the center-of-mass radius calculated using *SAGE*. A polar view can be used to diagnose the azimuthal uniformity of the target around the equator, while an equatorial view can be used to diagnose the balance of compression between the polar and equatorial regions. X rays of energy around 4 keV would be suitable for the proposed experiment.

Determination and Correction of Optical Distortion in Cryogenic Target Characterization

Francis White
McQuaid Jesuit High School
LLE Advisors: Dana Edgell, Mark Wittman

The DT ice layer in cryogenic targets used for direct-drive inertial fusion experiments must have an rms surface roughness less than 1 μm for successful implosion. The solid fuel layer is characterized by both shadowgraphy and x-ray phase-contrast imaging in layering experiments being performed at LLE. Optical distortion present in these characterization methods must be determined and corrected for accurate measurement of the fuel layer's uniformity. It was determined that x-ray images inherently possess distortion less than 0.1 μm. To calibrate the shadowgraphic imaging system, a zoom scan was performed using a regularly spaced dot array to center the optical axis of the imaging system on the center of the capsule and determine the imaging system's distortion. It was found that distortion varies with magnification and must be calibrated for each field of view. It was determined that the best focus varies slightly with magnification and must be corrected when changing the field of view. Finally, the known ℓ-modes of a surrogate "bright-ring" target were reproduced by correcting for distortion using the information obtained from these calibration experiments.

Liquid Crystal Beam Shaping Devices Incorporating Coumarin-Based Photoalignment Layers

Katherine Wegman
Pittsford Mendon High School
LLE Advisor: Kenneth L. Marshall

Liquid crystal (LC) devices incorporating photosensitive polymers based on coumarin were investigated for laser beam shaping applications. Presently, the OMEGA EP laser system uses pixelated metal beam shaping devices, though their relatively low damage threshold (approximately 0.2 J/cm^2) makes them poor options for long-term usage. LC devices present multiple advantages over metal beam shapers, including their higher damage threshold (9-18 J/cm^2). Previously, 10-μm pixelated LC beam shapers were fabricated by patterning a commercially available cinnamate-based photopolymerizable LC alignment material (ROLIC) through a mask using polarized UV light to control the LCs' orientation. This project investigated fabrication and characterization of LC beam shaping devices employing a coumarin-based linearly photopolymerizeable polymer (LPP) synthesized at LLE as an alternative to the cinnamate-based LPP. It was determined that the coumarin-based LPP could be photolithographically patterned, but more research is needed to improve coating

uniformity and determine the UV irradiation conditions necessary to improve pixel resolution.

Modeling Absorption Spectra of Optically Switchable Azobenzenes

Andrew Yu
Pittsford Sutherland High School
LLE Advisor: Kenneth L. Marshall

Azobenzenes have the unique ability to undergo reversible isomerization between two forms (the straight *trans* and the bent *cis*) when exposed to certain wavelengths of light. When embedded in liquid crystal matrices, azobenzenes can function as optically triggered switches regulating the permeability of a membrane to gases. These membranes are limited by the amount of light energy necessary to trigger conformational changes in the azobenzenes, and the amount of thermal motion necessary to cause relaxation from *cis* back to *trans* (at higher temperatures). Thus, an optimal azobenzene dye dopant would have an energy barrier low enough to facilitate photochemically induced changes from *trans* to *cis*, but high enough for thermal relaxation to the *trans* state to be minimized. In order to identify such molecules, a series of azobenzenes were modeled in Spartan and Gaussian03. Spartan's molecular mechanical modeling capability was used to calculate thermal relaxation barriers from *cis* to *trans*, while Gaussian03 used density-functional theory to quantify photochemical barriers from the *trans* state to the *cis*. The resulting data were compared, and it was found that nitro groups lowered photochemical barriers, aminoester groups raised thermal relaxation barriers, and dimethyl amino groups lowered both.

Electron-Ion Relaxation Rates in Inertial Confinement Fusion

Barry Xu
Brighton High School
LLE Advisor: Suxing Hu

During inertial confinement fusion (ICF), a cryogenic target is compressed by laser-driven shocks. The electrons absorbing the laser energy transfer that energy to the ions in the corona and the shock-heated ions thermally equilibrate with the electrons in both the uncompressed target shell and the compressed hot spot. The rate of energy transfer is important for ICF because it directly affects the fusion output of the target. To accurately calculate the rate, the Coulomb logarithm must be evaluated. Four different models have been proposed to calculate the Coulomb logarithm. Each of these models was entered into the hydrodynamics code LILAC and used for simulations corresponding to an OMEGA shot and a design for the National Ignition Facility. The simulations show significant differences in laser absorption, areal density, and neutron yield, which can be observed in experiments. A joint model, combining a model for the shell and a different model for the hot spot and corona, has been proposed to account for the whole ICF implosion.

X-Ray Imaging with Compact Kirkpatrick-Baez Microscopes

Andrew Chun
Brighton High School
LLE Advisor: Frederic J. Marshall

X-ray imaging is needed to diagnose inertial confinement fusion (ICF) implosions. For example, radiography using an x-ray backlighter target allows the size, symmetry, and density of both the compressed core and surrounding shell to be determined. One means of imaging ICF target x-ray emission is a compact Kirkpatrick-Baez (KB) microscope. Before a KB microscope is used, the KB optic must have its best focus location and resolution determined. Test exposures were taken with an electron-beam-generated x-ray source. The test target was a copper grid with 25.4 μm diameter wires and a reference hole to align different exposures. A PV-Wave program was written to efficiently take lineouts across the image. These lineouts graph the film density of the shadows created by the mesh grid. Measurements of the edge response of the shadows were subsequently used to determine the best focus positions in the images, as well as the point spread function near best focus. The calibrated mirror pairs will assist the continued development of a 16-image KB microscope.

Reducing UV Near-Field Beam Modulation on OMEGA EP by Angularly Detuning the Frequency Conversion Crystals

Kyra Horne
Fairport High School
LLE Advisor: Mark Guardalben

The frequency-conversion crystals (FCC's) mounted in the OMEGA EP laser system are used to convert an infrared beam to a third-harmonic ultraviolet beam. Currently, the FCC's are angularly tuned to maximize the conversion efficiency. When operated in this manner, the laser damage thresholds of the current UV optics require that the IR laser intensity be maintained at a relatively low level (~1 GW/cm^2). In this regime, small IR intensity variations produce large UV intensity variations, causing the UV beam to be highly modulated. We show, both in simulations and experimentally, that by angularly detuning the doubler crystal, the UV beam intensity modulation can be significantly reduced. Measurements on OMEGA EP show a reduction in peak UV fluence of 13% for the detuned FCC. Standard deviations of the UV beam fluence distributions were 21% and 14.7% for the tuned and detuned cases, respectively, indicating a significantly smoother beam for the detuned FCC for the same UV energy. This should allow more energy to be delivered to a target while maintaining peak intensities below the damage threshold limit.

Imploded Shell Parameter Estimation Based on Radiograph Analysis

George Liu
Pittsford Sutherland High School
LLE Advisor: Reuben Epstein

High target density is an important condition for achieving ignition in direct-drive fusion experiments. The density changes upon implosion: energy from laser beams heat the target, causing the surface to ablate and compress the fusion fuel. X-ray radiography is used to analyze the target's optical thickness, which in turn describes the target's density. The higher the optical thickness, the darker the shadow cast. By recording the light attenuation of a linear scan of backlighter x rays across the diameter of the target, the radiograph gives an intensity profile. The changing light intensities across the radiograph depend on three parameters: inner radius, outer radius, and optical thickness. A Fortran program was created to estimate these three parameters and their measurement variances. Due to equipment error and the finite resolution of the imaging device, uncertainty always exists in the parameter estimates. Choosing an appropriate optical thickness for the target can minimize the uncertainty in these estimates. By plotting the estimates, minimum ranges for the parameter estimation variances were found.

Optimizing the Movement of a Precision Piezoelectric Target Positioner

James Baase
Victor Senior High School
LLE Advisors: Greg Brent, Dave Lonobile

For any successful shot of the OMEGA or OMEGA EP laser systems, a target must be accurately positioned and stabilized at the location of beam convergence. New technology in the form of piezoelectric motors greatly improves upon the drawbacks inherent to existing DC motors and gearboxes. Unlike those conventional systems, piezoelectric motors can operate at cryogenic temperatures inside the target chamber. This removes a long target stalk conducive to vibration and the need for a warm operating environment. Eventually, these motors might also provide a means of actively stabilizing the target by analyzing tremors in real time. In order to gain a better understanding of these miniature motors, an experiment was carried out to determine the force a piezoelectric motor could produce with various frequencies, voltages and materials. At cryogenic temperatures, it is essential to optimize the functionality of the motor so that it moves efficiently and does not bind. It was discovered that the piezoelectric motor exerted the most force while containing slides made of PEEK, at a frequency of 894 Hz and a voltage of 126 V.

Water Desorption from Stainless Steel at Variable Temperatures

Ryan Shea
Fairport High School
LLE Advisor: Walter Shmayda

An experiment has been performed to measure the effect of temperature on the outgassing rate of tritium from stainless steel. The removal of water, and more importantly tritium, is an important issue when conducting D-T fusion experiments. Tritium is a radioactive isotope of hydrogen that can contaminate equipment and metal components of a nuclear fusion test chamber. The removal of tritium from these devices is important because it allows facility personnel to work with these devices safely. Using a helium gas stream and a glass exposure chamber insulated inside a ceramic oven, the effect of temperature on the rate of tritium desorption was measured to find the optimal temperature for the removal of tritium and water. The helium gas stream was flowed through the exposure chamber, at a rate of 100ml/min, removing surface contamination from a stainless steel coupon inside the chamber. The tritium in the gas stream was then deposited in a liquid scintillation counter (LSC) solution, enabling an LSC to measure the amount of radioactivity removed at the different temperatures. The data shows that the removal of tritium is affected by three variables: the rate or tritium diffusion to the surface from the bulk, the rate of tritium desorption from the surface, and the rate of tritium removal by the gas stream.

Modeling Water Desorption from Stainless Steel

Karin Hsieh
Webster Schroeder High School
LLE Advisor: Walter Shmayda

The removal of water from surfaces is relevant in many different industries. Experiments have been performed to study the outgassing rate of water from the surfaces of stainless steel coupons using tritium to track the removal of the water. Equations have been derived to model the outgassing rates in order to predict the amount of tritiated water taken from the coupon. By fitting these curves to the experimental data, it was found that tritium diffusivity in the bulk of the stainless steel is not the rate limiting step. It can be concluded that the tritons are not only migrating from the bulk metal, but desorbing from the oxide layer of the metal as well. The oxide layer, which is the outer layer of the metal, appears to have a higher diffusivity than that of the bulk layer. The constant higher diffusivity in the initial stages of outgassing allows the conclusion to be made that tritons desorb from the oxide layer initially, before rising up from the bulk of the metal.

Testing and Installation of the Reticle Projector on OMEGA's Target Viewing System

Connie Jiang
Brighton High School
LLE Advisors: Douglas Jacobs-Perkins, Raymond Huff

A reticle projector was designed, built, and installed onto the Illumination side of the target viewing system of the OMEGA laser system. In this design, a 780-nm infrared laser shines through a grid to a lens at the front of the projector. This lens takes the Fourier transform of the grid pattern (reticle), which is projected into the center of the target chamber, producing a dot pattern that can be captured by each of five cameras set in place on the Imager assembly on the opposite side. By projecting the same image onto each camera, one can look for magnification, image rotation, pattern registration, and distortion, enabling periodic recalibration of the cameras. The reticle projector was first tested in a laboratory setting where images were taken, analyzed using MATLAB, and compared. Preliminary results suggest that this system is capable of detecting discrepancies in camera rotation, magnification, distortion, and misalignment between cameras.

Designing an Ontology for Experimental Diagnostics at LLE

Rob Cooper
Allendale Columbia School
LLE Advisor: Richard Kidder

Semantic web technologies were researched to determine the best format to design an ontology (a computerized representation of knowledge based on relationships between data) for LLE experimental diagnostics. The research determined that ProtégéOWL was the best platform to design the ontology, and OWL DL was the most useful syntax. Once designed, the ontology was developed into a Java application using NetBeans IDE in order to provide a centralized repository for the extraction of useful information about the diagnostics. The wide range of complex relationships mapped out in the ontology allows search results to be extremely specific and eliminates the need to manually parse documents. The results windows have been programmed to provide the user with links to other, potentially useful information. The application has also been equipped with data entry windows to allow users to increase the ontology's scope, and the simplicity of the NetBeans interface makes altering the code itself easy. As a result, the ontology can be further developed to document virtually every aspect of LLE's laser systems.

Using Surface Evolver Software to Model the Behavior of Liquid Deuterium

Eric Pan
Webster Thomas High School
LLE Advisor: Thomas B. Jones

Successful exploitation of laser fusion as an energy source requires that laser targets be produced quickly on an assembly-line basis. The final step in fabricating a laser target is the fueling operation, where cryogenic liquid deuterium is loaded into thin polymer shells. This fueling must be done remotely because liquid deuterium must be maintained at around 20 Kelvin. It is required that precise volumes of liquid deuterium are dispensed, on the order of 90 microliters per target. This task is complicated because liquid deuterium has a contact angle of zero (perfectly wetting), behaving differently from other, more familiar liquids, such as water. To address this issue, this work used *Surface Evolver*, a software tool developed by K. Brakke that uses energy minimization to evolve fluid shapes into their final equilibrium forms subject to surface tension, gravity, and other forces. The behavior of liquid deuterium between parallel plates was modeled, including parallel vertical plates with varying widths and non-parallel horizontal plates. The parallel plate geometry is favored because electrodes can be attached to the plates for precise manipulation and dispensing.

A Graphical User Interface for User Generated Opacity Data

Luke Coy
Greece Arcadia High School
LLE Advisors: Stephen Craxton, Robert Rombaut

A Graphical User Interface (GUI) was created that graphs opacity data produced by the *Aplmix* code for mixtures of elements. The GUI produces graphs that display the opacity on the vertical axis and the user's choice of density, temperature, or frequency on the horizontal axis. This provides the user with a convenient way to assess the adequacy of the density, temperature, and frequency grids chosen for use with *Aplmix*. Features of the GUI include linear or logarithmic horizontal axis, drag-and-click zooming, dynamic panning, and various customizations. If the user wants to resolve structure in the opacity as a function of frequency by adding multiple points to the frequency grid, he/she can rapidly display the spectrum at different (temperature, density) points and identify where more frequency points are required.