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LABORATORY FOR LASER ENERGETICS
UNIVERSITY OF ROCHESTER

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Retrieval of 3D Information from Focal Depth Scans with an Optical Microscope .... Mathew Atalla

Computational Modeling of Three-Ring Phenyl Benzoate Compounds to Investigate Frequency-Dependent Dielectric Anisotropy for Dual-Frequency Liquid Crystals .... John Luger

Quantitative Assessment of 1 MHz Megasonic Cleaning of Optical Surfaces .... Caleb Youngblut

Integrating Neutronic Data for 3D Hotspot Reconstruction Using a Deep-Learning Convolutional Neural Network .... Karthik Jaligama

Crystal Growth Rates in Dense Astrophysical Plasmas .... Manveer Singh

Feasibility Study of Neutron-Neutron Elastic Scattering Using Two Neutron Beam Sources .... Leixi Chen

Characterizing Photoresist Pillar Reflow During a Nanofabrication Hard-Bake .... Hailey Wardell

Characterizing Bulk Etch Velocities of CR-39 .... Rebecca Camilleri

Hydrodynamic Modeling of a Proposed High-Intensity Laser Experiment on the National Ignition Facility to Study the SRS Instability .... Ella Rogala

Optical Constants and Radiation Transport for Inertial Confinement Fusion Materials .... Stefanos Tedla

Measurement of Ion Temperature from Cryogenic Implosions with Cherenkov Detectors .... Michael Shi

Pulse Shape Optimization for Inertial Fusion Energy Targets .... Eli Gray

Use of Palladium Catalyst to Maximize Separation Efficiency of Hydrogen Isotopes .... Malena Leastman

Application of Adhesives for Fabrication of Ultra-Thin Second Harmonic Generation KDP Crystals for NSF-OPAL .... Sean Della-Torre

Designing MIFEDS Coils for Minimal Debris Generation .... Caleb Krenzer

Analysis of Post-Fill Submicron Features on Cryogenic DT Targets .... Emmanuel Nyibule

Retrieval of 3D Information from Focal Depth Scans with an Optical Microscope

Mathew Atalla
McQuaid Jesuit High School
LLE Advisor: Douglas Broege

Traditional microscopy techniques, such as Scanning Electron Microscopy or Atomic Force Microscopy, provide highly detailed images, but can only be used for surface characterization. Thus, a non-destructive, cost-effective, and timely technique for obtaining 3D models of structures beneath the surface of transparent materials was developed using an optical microscope and MATLAB (Matrix Laboratory). A focal depth scan, a stack of images at slightly varied altitudes, was necessary to obtain full 3D data, as optical microscopes can only view a single plane at a time. With a stack of images that when put together form a full 3D model, MATLAB was used to detect the desired features and obtain data containing the coordinates of these points. MeshLab, a plotting software, was then used to plot the points and create a surface over them. This tool will be used in creating models of cracks beneath the surface of glass optics.

Computational Modeling of Three-Ring Phenyl Benzoate Compounds to Investigate Frequency-Dependent Dielectric Anisotropy for Dual-Frequency Liquid Crystals

John Luger
Brighton High School
LLE Advisor: Kenneth L. Marshall

Dual-frequency liquid crystals (DFLCs) are of interest for electro-optical applications that require fast rise and decay times of the optical response. Such behavior arises when the dielectric anisotropy ($\Delta\varepsilon$) of the LC undergoes a frequency-dependent change in sign (crossover frequency). DFLC mixtures are generally formulated empirically using two or more LCs: one possessing a $+\Delta\varepsilon$ with a high frequency relaxation and another with stable $-\Delta\varepsilon$. For two LCs with $+\Delta\varepsilon$ modeled separately at various frequencies using *NWChem*, the model predicts that the $\Delta\varepsilon$ remains approximately constant for frequencies $<10^{14}$ Hz with brief periodic oscillation of $\Delta\varepsilon$ followed by a reduced $\Delta\varepsilon$ at frequencies $>10^{16-17}$ Hz. The predicted $\Delta\varepsilon$ is within 10% agreement with experimental data at $<10^{3}$ Hz, confirming the model's validity for predicting LCs' crossover frequencies.

Quantitative Assessment of 1 MHz Megasonic Cleaning of Optical Surfaces

Caleb Youngblut
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LLE Advisor: Kyle Kafka

The operational environment of laser systems can deposit particles onto optical surfaces, and this surface contamination can reduce the performance of optics by decreasing the laser-induced–damage threshold. This work investigates the effectiveness of 1 MHz ultrasonic (megasonic) cleaning for removal of small microparticles from flat glass samples. Megasonic cleaning efficiency is quantified by using optical microscopy to analyze the size and quantity of particles observed before and after the cleaning procedures. For the experiments, samples were contaminated with polydisperse particles of copper or silica having diameters around 1 μm, representing a realistic and relevant variety of particle shapes, sizes, and materials. Comparative graphs of cleaning efficiency as a function of particle size and material are presented. Furthermore, cleaning in a basic (pH-10) solution was shown to significantly improve the cleaning efficiency of silica. These results may be relevant for the removal of particles from critical optics.

Integrating Neutronic Data for 3D Hotspot Reconstruction Using a Deep-Learning Convolutional Neural Network

Karthik Jaligama
Mendon High School
LLE Advisor: Ka Ming Woo

The performance of inertial confinement fusion (ICF) implosions is sensitive to the three-dimensional (3D) morphology of the hotspot and shell configurations. The ability to reconstruct 3D hot spots is crucial for assessing the impact of 3D implosion asymmetries. A deep-learning convolutional neural network (CNN) model, which reconstructs 3D hot-spot structures for ICF capsules, has been upgraded. The 3D hotspot geometry on OMEGA is recovered from x-ray images measured from multiple lines of sight, further integrated with neutronic data such as areal density, ion temperature, and hot-spot flows. In order to handle the huge amount of data required to train the CNN, we investigated a new strategy in which 3D profiles used in the CNN model were represented as a small number of eigenmode coefficients. The CNN model is trained with synthetic nuclear data generated using the Monte Carlo code *IRIS3D*. This improved model is expected to yield more physics-constrained 3D reconstructions for OMEGA implosions. In the future, it is hoped to integrate data from the hydrodynamics code *RIGEL* in order to generate a large-scale database for future research, and to improve the fidelity of the CNN reconstructions.

Crystal Growth Rates in Dense Astrophysical Plasmas

Manveer Singh
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LLE Advisor: Brennan Arnold

White Dwarf (WD) stars go through a period of cooling in which a crystal begins to form inside the WD. The growth of this crystal causes energy to be released. However, astronomers have observed that WDs release more energy than initially expected. One possible hypothesis for the release of extra energy could be the movement of heavy ions within the WD. Molecular dynamics simulations were run to extract the growth rate of the crystal. The simulations were initialized in a rectangular box with solid particles in one half and liquid particles in the other. The growth of the crystal was observed. The velocity of the crystal interface was extracted at different temperatures. It was found that as the temperature decreased the rate of crystallization tended to increase; however, if the temperature was too low the rate of crystallization tended to decrease due to the ions taking longer to find a position in the lattice to form the crystal. Later, the extracted velocities will be used to help understand whether free-floating crystals can be formed.

Feasibility Study of Neutron-Neutron Elastic Scattering Using Two Neutron Beam Sources

Leixi Chen
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LLE Advisor: Dr. Chad Forrest

The neutron-neutron scattering length provides a direct check on charge symmetry and charge independence of the nuclear force. Current approaches to determining this scattering length through indirect measurements have resulted in inconsistencies that could be resolved with direct neutron-neutron scattering measurements. Through analytical modeling and Monte-Carlo simulations (repeated randomized sampling), we have studied the experimental feasibility of direct measurements of neutron-neutron scattering. To obtain high-yield neutron pulses, we propose to use the extremely high-power NSF-OPAL laser beams to hit converter targets that will then generate two high-yield neutron beams. These beams will collide with each other at a small angle, either head on or glancing, to produce scattered neutrons that will be detected. This model was tested with various detector viewing angles, beam collision angles, and neutron energies to find the optimal outcome that produces the greatest probability of detecting scattered neutrons. This work validates previous beliefs in the difficulty of producing a large number of events.

Characterizing Photoresist Pillar Reflow During a Nanofabrication Hard-Bake

Hailey Wardell
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LLE Advisors: Russell Dent, Brittany Hoffman

Diffraction gratings are a fundamental component of the chirped-pulse-amplification process on the OMEGA EP Laser System. The gratings are used to stretch laser pulses so that they can be effectively amplified without damaging the amplifier medium and then to compress the pulses to high intensity. Diffraction gratings are manufactured using nanofabrication. A hard-bake, a thermal treatment, can be utilized to minimize photoresist (PR) pillar sidewall roughness through melting or reflow of PR pillars (thus changing the PR pillar geometry). Hard-bake experiments were done on ten samples across a span of temperatures, 140°C-158°C, increasing incrementally by 2°C. Atomic force microscopy, data analysis with Python, and scanning electron microscopy were performed and used to quantify the height, width, and roughness of features, thereby demonstrating that the ideal parameters for hard-baking with silica wafers are ~148°C for 60 seconds. These parameters yielded the smoothest PR pillar sidewalls without compromising the height of the features, a result which has the potential to improve diffraction grating quality

Characterizing Bulk Etch Velocities of CR-39

Rebecca Camilleri
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LLE Advisors: Hannah McClow, Steven Ivancic

CR-39 is a charged particle detector used in many diagnostics at LLE. Charged particles leave trails of damage in the molecular structure when incident upon a CR-39 detector. Two track etches are used to widen the particle tracks on the surface of the detector, and a bulk etch is used to remove bulk material and erase most of the background noise from the detector. In this work, the bulk etch velocity was studied. It was found that the bulk etch velocity of CR-39 samples from the magnetic recoil spectrometer is 33.5 ± 0.5 μm/hr, while that of CR-39 samples exposed to direct proton radiography is 23.8 ± 0.9 μm/hr. It was hypothesized that the difference in bulk etch velocities was caused by the size of the pieces or process parameters like etch time and stirrer usage. Several experiments manipulating these factors were performed, and it was found that stirrer usage influenced the bulk etch velocity. While this work has not yet provided a clear answer, advancements were made to determine the factor(s) affecting the bulk etch velocities.

Hydrodynamic Modeling of a Proposed High-Intensity Laser Experiment on the National Ignition Facility to Study the SRS Instability

Ella Rogala
Our Lady of Mercy High School
LLE Advisor: Stephen Craxton

Designs were developed for the National Ignition Facility (NIF) to study the Stimulated Raman Scattering (SRS) instability in the presence of high-intensity beams. This is important for the OMEGA-Next design at LLE, which proposes to use a technique called zooming, focusing the second portion of a laser pulse more tightly to improve energy absorption, thereby producing high intensities. SRS occurs when laser light interacts with the plasma surrounding a target, creating energetic electrons that make compression more difficult. The NIF has 48 sets of 4 beams each, known as quads. The proposed experiment was modeled using the 2-D hydrodynamics code SAGE, with these quads partitioned into two groups of 24, delivering separate portions of the pulse. The first portion uses defocused beams to create plasma surrounding the target, and the second delivers high single-quad intensities at best focus. All beams are repointed to maximize the uniformity of the implosion. This design delivers single-quad intensities in the range 3.6 to 9.1×10^{14} W/cm^2, sufficient to better understand the SRS instability.

Optical Constants and Radiation Transport for Inertial Confinement Fusion Materials

Stefanos Tedla
Eastridge High School
LLE Advisor: Nathaniel Shaffer

Optical and x-ray radiation transport depends on the absorption and emission coefficients of the radiative material. These are derived from detailed atomic cross sections (absorption probability data), which involves two major steps: finding the index of refraction and the absorption coefficient, and then reducing the detailed absorption spectra into frequency-grouped mean opacities (average absorptions) and emissivities. We wrote a code that performs both tasks on atomic cross section data provided by LLE's *ROCSTAR* code. We derived, implemented, and validated a specialized rule for calculating the integral that would give the absorption coefficient and the index of refraction with full spectral detail. However, using this in radiative transport equations would be unfeasible, so the code can also simplify the full resolution opacity into multi-group Planck and Rosseland mean opacities in addition to "grey" opacities (a single mean across the entire spectrum). This completes a necessary step in making the new opacity models in *ROCSTAR* accessible to radiation hydrodynamic simulations.

Measurement of Ion Temperature from Cryogenic Implosions with Cherenkov Detectors

Michael Shi
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LLE Advisor: James Knauer

A Cherenkov detector is a quartz material that is able to detect neutrons from an imploding OMEGA target. The Cherenkov radiation is then collected and converted into an electrical signal by a photomultiplier tube (PMT). A MATLAB (Matrix Laboratory) code was developed to be able to read shot data on the P7 and H10 lines of sight for both the Cherenkov and Petal detectors (Petal uses scintillation). In analyzing the width of the neutron signal, it was determined that the widths of the Cherenkov response were narrower than the Petal. The analysis concluded that the Cherenkov is a better reference for ion temperature measurement, which depends on the neutron width, rather than the Petal, which is currently used on OMEGA. The analysis of OMEGA implosion data allows the next step of measuring the Cherenkov instrument response function to proceed. Thus, a laboratory experiment was set up using a new detector that uses varying lengths of Cherenkov radiators in an effort to find cosmic ray signals, which provide a radiation source used to test Cherenkov and Petal detectors. Current results show that the detector signals in the laboratory experiment are dominated by PMT noise and only the 75 mm length detector may see a tentative signal.

Pulse Shape Optimization for Inertial Fusion Energy Targets

Eli Gray
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Traditional targets used in inertial confinement fusion consist of a cryogenic (frozen) layer of deuterium (D) and tritium (T), two hydrogen isotopes. They are expensive and time consuming to make. For fusion energy applications it has been proposed to use foam spheres soaked in liquid DT, allowing for much more cost-effective targets without the lengthy process of forming the cryogenic layer. These droplets would be subjected to a series of short laser pulses, which first create shock waves that cause the droplet to collapse inwards and then expand outwards. Later pulses keep the DT from expanding past a specified radius, forming a shell that dynamically creates the density profile of a traditional target, which can then be compressed to reach ignition conditions. A program was written that takes as input parameters the desired shell radius and inner core density and, using the 1D hydrodynamics code *LILAC*, generates a power-versus-time laser profile that can dynamically make a target with these parameters. The program was then optimized, decreasing the computation time by a factor of 4.

Use of Palladium Catalyst to Maximize Separation Efficiency of Hydrogen Isotopes

Malena Leastman
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LLE Advisor: Matthew Sharpe

The Thermal Cycling Absorption Process (TCAP) offers an efficient approach to separate hydrogen isotopes. This technique leverages the different reactivities of a palladium catalyst with the hydrogen isotopes in order to distinguish H, D, and T. This work aims to optimize catalyst design and operating conditions for maximum separation efficiency by employing a pulsed gas injection system and systematically altering the flow rate, catalyst quantity, and temperature. Data sets giving the percentage of the pulsed gas vs. time were recorded for each flow rate under different combinations of catalyst quantity and temperature. A variety of tools are then applied to each data set to determine optimal flow rates for each pulsed gas. By analyzing the relationship between catalyst quantity and operational parameters, we can identify conditions that maximize separation efficiency while minimizing palladium usage. Results from these experiments reveal that H2 and D2 exhibit different optimal flow rates, independent of temperature differences, in contrast to what has previously been assumed.

Application of Adhesives for Fabrication of Ultra-Thin Second Harmonic Generation KDP Crystals for NSF-OPAL

Sean Della-Torre
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LLE Advisor: Kenneth L. Marshall

Potassium dihydrogen phosphate (KDP) crystals will be used on the NSF-OPAL laser system to convert some of its beam energy to the second harmonic (twice the frequency). For second harmonic generation to be at its maximum efficiency, KDP crystals must be ~150 µm thick while covering a large surface area. Since it is impossible to either grow or cut a KDP crystal with such dimensions, an alternative proposal is being pursued in which a larger piece of KDP will be adhered to a base substrate and milled to the required specifications. In this work, several adhesives for bonding KDP to the base substrate were characterized for their optical properties and ability to be spread in a uniform manner with minimal defects. A blade-coating technique was tested to create uniform thin films of adhesive with a motorized thin film applicator. It was found that this technique worked equally well on large substrates as on small substrates. Multiple adhesives were identified for their favorable optical properties and their ability to provide optimum adhesion to KDP.

Designing MIFEDS Coils for Minimal Debris Generation

Caleb Krenzer
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LLE Advisor: Jonathan Peebles

The Magneto-Inertial Fusion Electrical Discharge System (MIFEDS) is a diagnostic used primarily in inertial confinement fusion and high-energy-density physics experiments on OMEGA and OMEGA EP. On a microsecond scale, MIFEDS rapidly discharges current through an electromagnetic coil, producing a magnetic field that facilitates the desired conditions for these experiments. However, the magnetic field's high concentration induces strong magnetic forces on the coil, which cause it to radially explode. This generates significant debris, which is harmful to the optics and equipment contained in the target chamber. To mitigate MIFEDS debris generation in future experiments, various coil parameters were tested and evaluated. To accomplish this, an optical system was designed that measured the transmission of affected debris shields present in the vacuum chamber for each test. This work identifies the coil parameters with the strongest impact on transmission loss, such as wire diameter, which changes the size and deposition characteristics of the debris.

Analysis of Post-Fill Submicron Features on Cryogenic DT Targets

Emmanuel Nyibule
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LLE Advisor: Dean Bredesen

In cryogenic DT targets, comprising a frozen layer of DT ice inside a plastic shell, non-ice features impact implosion performance by disturbing uniform compression. These non-ice features are either foreign materials (such as dirt or dust) or imperfections in the plastic. In October 2024, the FTS#2 cryogenic microscope was used to capture submicron-resolution images at 16 different locations, taking multiple images per location while stepping through focus level. FTS#2 was unique in capturing post-fill images, allowing us to observe features created by the DT fill process. These post-fill images, however, experience vibrations, making automatic analysis difficult. Using the FTS Vision application, an analysis of features in hundreds of pictures at three locations was used to determine and characterize defect sizes. It has been determined that post-fill features account for 70 to 80 percent of the surface area of all features, ranging in size from 0.4 to 1.2 μm^2. Additionally, by cross-referencing information from post-fill and pre-fill images it can be determined whether a feature exists outside or inside the cryogenic shell. All this information can help computer simulations figure out how the defects impact the targets' ability to implode uniformly.