UNIVERSITY of ROCHESTER

LABORATORY FOR LASER ENERGETICS

2023 SUMMER HIGH SCHOOL STUDENT RESEARCH PRESENTATIONS

Wednesday, 30 August 2023
LLE Coliseum

Zoom Option:
https://rochester.zoom.us/j/93278957870?pwd=T3k0c2IwY3c2SmxsK2hheFRPeWIzdz09

1:30–1:40	Welcome	Dr. R. S. Craxton
1:40–1:55	Introduction	Edward Wu
1:55–2:05	Laser Pulse Shape Prediction on the OMEGA EP Laser System Using a Convolutional Neural Network	Michael Yu
2:05–2:15	Optimizing Multi-Shock Solid Sphere Designs for the National Ignition Facility	Shawn Nordstrom
2:15–2:25	Prospective Integration of Machine Learning into the Multi-Objective Optimization of Time-Dependent Electron Density Calculations in Laser-Exposed Liquid Crystals	Sophie Khan
2:25–2:35	Beam Pointing Optimizations for DT Wetted-Foam Targets on the National Ignition Facility	Andrew Pitolaj
2:35–2:45	Measuring the Mode Field Diameter of Single-Mode Fibers Using the Near-Field Technique	Marianna Hodgins
2:45–2:55	Analysis of the Historical Operating Data of the Hydrogen Isotope Separation System to Optimize its Performance	Aariv Mody
2:55–3:05	Developing a MIFEDS Coil Alignment and Assembly Station	Maxwell Braithwaite
3:05–3:15	Improving Data Service Access using Large Language Models with Retrieval-Augmented Generation	Cam Mazzacane
3:15–3:35	Break	
3:35–3:45	Development of New Beam Configurations for OMEGA to Achieve Highly Uniform Indirect Drive Implosions with Cubic Symmetry	Edward Wu
3:45–3:55	Optimization of Planarization Coatings for Textured Birefringent Laser Optics	Alexander Song
3:55–4:05	Exploring Gallium Alloys for the Development of Self-Healing Final Mirrors for Laser Fusion Energy Power Plants	Gregory Demos
4:05–4:15	Developing Automated Tools for Aperture Metrology	Maya Gopakumar
4:15–4:25	Quantitative Assessment of 1-MHz Ultrasonic Cleaning of Multilayer-Dielectric Diffraction Gratings	Shuwen Ding
4:25–4:35	Contamination Identification using Raman Spectroscopy	Mark Atalla

UR LLE

250 East River Road
Rochester, New York 14623–1299
(585) 275-5101

4:35–4:45	Evaluation of Model-Independent Energy Spectra from Neutron Time-of-Flight Diagnostics using a Variable P-Spline Technique	Logan Canfield
4:45–4:55	Quantifying Isotherms Within the Hydrogen-Palladium and Deuterium-Palladium Systems	Lina Yang
5:00–5:30	Tour of the OMEGA and OMEGA EP Lasers	Mark Labuzeta, David Canning

2023 SUMMER HIGH SCHOOL STUDENT RESEARCH PRESENTATIONS

LABORATORY FOR LASER ENERGETICS
UNIVERSITY OF ROCHESTER

Wednesday, 30 August 2023

Laser Pulse Shape Prediction on the OMEGA EP Laser System Using a Convolutional Neural Network

Michael Yu
Pittsford Mendon High School
LLE Advisor: Mark Guardalben

Future laser systems used to develop inertial fusion energy (IFE) will operate at higher repetition rates than current fusion-class laser systems, requiring real-time feedback control and optimization of laser pulse power. In addition, these laser systems will rapidly generate large amounts of data that must be used to maintain calibration of laser models and to identify unsafe operating conditions. Accurate laser predictive models must therefore be developed that support these requirements. Laser performance prediction in the long-pulse beamlines of the OMEGA EP laser system is currently done using a physics-based model, PSOPS. A convolutional neural network was developed and trained using PSOPS data to predict both pulse shape and energy and found to be within approximately 4% of PSOPS predictions while having 100x faster processing speed. These results are an encouraging step in the development of laser predictive models that support future IFE laser facilities.

Optimizing Multi-Shock Solid Sphere Designs for the National Ignition Facility

Shawn Nordstrom
Hilton High School
LLE Advisors: Radha Bahukutumbi and Sam Miller

In direct-drive inertial confinement fusion implosions, the coupling of the laser into the target is a critical aspect determining implosion performance. In this project, a two-pulse laser pulse shape that launches multiple shocks into solid spheres is optimized for use on the National Ignition Facility (NIF). Experiments on the NIF can potentially diagnose these shocks through radiography. This optimization study simulates variations of the laser pulse shape, including the launch time of the second shock, the slope of the second pulse, and the extent to which the two shocks are supported. The goal is to create sufficient spatial resolution and contrast between the two shocks to permit their diagnosis. Through synthetic radiographs, an optimal pulse shape has been identified that can potentially be used to diagnose laser energy coupling throughout the laser pulse.

Prospective Integration of Machine Learning into the Multi-Objective Optimization of Time-Dependent Electron Density Calculations in Laser-Exposed Liquid Crystals

Sophie Khan
Pittsford Mendon High School
LLE Advisor: Kenneth Marshall

Liquid crystals, because of their unique molecular ordering, are vital components of LLE's OMEGA laser in the form of waveplates and polarizers. To ensure the stability of the liquid crystal devices in this system, it is imperative to understand their response to laser pulses through electron density modeling. However, the computational time and cost of these resource-intensive calculations increase rapidly with structural complexity, with individual job times spanning up to several years on high-performance computing clusters. Basis sets (collections of functions that define a molecule's wave function by offering approximate solutions to Schrödinger's equation) are a central element in these calculations and are chosen based on their size and complexity. To minimize calculation time while maintaining computational accuracy, optimal basis sets were systematically identified for calculations on three distinct liquid crystal molecules (5CB, PCH, and CCH) using a series of various multi-objective optimization methods. This work is the foundation for the integration of this problem into machine learning, which will utilize this methodology to train models to automate the process of basis set selection.

Beam Pointing Optimizations for DT Wetted-Foam Targets on the National Ignition Facility

Andrew Pitolaj
Gananda High School
LLE Advisor: Stephen Craxton

Beam pointing designs for proposed deuterium-tritium (DT) wetted-foam targets have been developed for use on the National Ignition Facility (NIF). These targets are composed of a layer of plastic foam containing liquid DT, surrounded by a thin or thick plastic shell. There is DT gas at the vapor pressure in the center of the target. Compared with solid cryogenic DT targets, wetted-foam targets are easier to produce. Three targets were considered: two 3.0-mm-diameter targets with thin and thick plastic shells and a thin-shell 4.6-mm target with greater foam thickness. In order to ensure maximum implosion uniformity, hundreds of simulations were run in which the 2-D hydrodynamics code *SAGE* was utilized to alter the defocus and pointing parameters of each of the NIF's 192 laser beams. This work yielded four optimized designs that show a velocity rms deviation between 1 and 2 percent. For the 4.6-mm target, the best azimuthal uniformity was obtained with all beams defocused 3.5 cm. However, since some of the NIF beams can not be defocused this distance, a design with 2.5-cm defocus was developed as a practical alternative. This work demonstrates the feasibility of DT wetted-foam target studies on the NIF.

Measuring the Mode Field Diameter of Single-Mode Fibers Using the Near-Field Technique

Marianna Hodgins
Palmyra-Macedon High School
LLE Advisor: Sara Bucht

Single-mode fiber finds widespread applications in both telecommunications and the scientific realm. Within LLE, it plays a crucial role in the fiber amplifiers that initiate the OMEGA and OMEGA EP amplifiers, along with various other uses. An essential characteristic of single-mode fiber pertains to the mode field diameter (MFD), conventionally ascertained as the width at which the intensity decreases to 1/(e^2) of its peak within the fiber. Understanding the MFD holds significance in mitigating loss during fiber coupling or splicing and in foreseeing the behavior of light upon its exit from the fiber. The near-field technique is a method of measuring the MFD that uses a camera to capture an image of the light at the tip of the fiber. In order to make sense of this data, in addition to this image, the position of the fiber and the magnification of the imaging system must be known. In this work a setup was built that could be configured in three ways: (1) a confocal configuration to position the fiber, (2) a setup to calculate magnification, and (3) a configuration recording data on the camera. Using this technique, an MFD of 6.5 µm was measured for SM980 fiber at 1064 nm.

Analysis of the Historical Operating Data of the Hydrogen Isotope Separation System to Optimize its Performance

Aariv Mody
Pittsford Sutherland High School
LLE Advisor: Mark Wittman

The LLE hydrogen Isotope Separation System is used to upgrade the deuterium-tritium (D-T) mixture used in inertial fusion experiments at LLE in two ways: to remove the protium (H) build up from water vapor and polymeric materials, and to rebalance the T/D ratio due to tritium's radioactive decay. The system has been operated for nine years. The historic data was analyzed to see if three parameters affect the tritium-extraction efficiency: 1) total amount of gas on the system, 2) the tritium fraction of that gas, and 3) the number of transfers between the separation media (cycles) during the separation process. Since the historic data was "mined" instead of using a systematic experimental program, there is much scatter in the data. Therefore, apart from possible diminishing returns as the amount of tritium on the coils increases, it was determined that there is no significant correlation between these parameters and the separation efficiency, and therefore no optimal value or range of these operating parameters.

Developing a MIFEDS Coil Alignment and Assembly Station

Maxwell Braithwaite
Webster Thomas High School
LLE Advisor: Jonathan Peebles

The Magneto Inertial Fusion Electrical Discharge System (MIFEDS) is a tool that many physicists use to create magnetic fields in their experiments on both the OMEGA and OMEGA EP Lasers at LLE. MIFEDS works by sending electrical current through a coil comprising one or more turns to create magnetic fields. These coils are hand wound, so they are not always accurate to their design. The MIFEDS system is held in Ten Inch Manipulators (TIMs), which can move the coils on the X, Y, Z axes, but prior to this work there has been no method for checking or adjusting any twist or angle that may be present in the coils. Defective coils can cause substantial time delays or a failure of the experiment if not discovered ahead of time. Using a previously designed optical imaging system, a coil characterization stand has been built so that coils can be metrologized prior to being fielded on experiments. Stereolithographic 3D printing has been used to unite existing parts into a fully functioning coil characterization stand. The stand has already been used to verify coil alignment for a shot day on OMEGA EP.

Improving Data Service Access using Large Language Models with Retrieval-Augmented Generation

Cammarata Mazzacane
Pittsford Mendon High School
LLE Advisor: Richard Kidder

LLE stores a large amount of documentation in on-site databases. This work investigates how large language models (LLM’s), a form of generative artificial intelligence that has knowledge of English language semantics, may be employed by users of LLE facilities to access information in these databases. A large sampling of equipment documentation, safety procedures, experimental procedures, and publications significant to work at LLE was ingested into various LLM’s to compare their usefulness to conventional document lookup and searches. An application was developed which implements LLM’s to query large amounts of data using on-site computational resources. Users can write prompts in natural language, and receive accurate natural-language responses that utilize information from LLE databases. A high-dimensional vector database was employed that efficiently encodes semantic information from documents to provide context to language models at runtime, entirely avoiding computationally expensive training. Experimental results have shown that this work can be expanded to other data services, including application programming interface calls.

Development of New Beam Configurations for OMEGA to Achieve Highly Uniform Indirect Drive Implosions with Cubic Symmetry

Edward Wu
Pittsford Sutherland High School
LLE Advisor: Stephen Craxton

In light of the recent demonstration of breakeven on the National Ignition Facility (NIF) using indirect drive, interest in future indirect drive facilities has increased. A promising approach is the spherical hohlraum with six laser entrance holes (LEHs), which has cubic symmetry and potentially better uniformity than the cylindrical hohlraum (two LEHs) used on the NIF. While the 60-beam OMEGA laser is primarily a direct drive fusion facility, configurations using a 48-beam subset are proposed that would offer the unique capability of performing highly uniform experiments with a six-LEH hohlraum. Several configurations are possible because beams can be directed into more than one LEH. Using the 3-D view-factor code *LORE*, simulations yielded irradiation nonuniformities on the capsule as low as 0.13% (rms) at a high albedo. In addition, the hohlraum radius was varied to investigate the tradeoff between obtaining good uniformity and achieving a high radiation temperature. Future laser systems based on the OMEGA geometry and designed for direct drive could use these configurations to provide a versatile indirect drive capability.

Optimization of Planarization Coatings for Textured Birefringent Laser Optics

Alexander Song
Victor High School
LLE Advisor: Nate Urban

Birefringent optics that are textured with thick and thin portions to produce different polarization states are under development to improve the target irradiation uniformity for inertial confinement fusion. However, to avoid the optic deflecting the laser beam, the surface of the optic needs to be coated with a material that provides a flat exit surface without affecting the polarization. This work focused on dip coating optics in a polymer solution because this is already in practice for large-aperture optics on OMEGA. The forces acting on the substrate during a dip coat are highly variable and were studied by varying the withdrawal speed, temperature, and solution properties. This provided insight into the balance between capillary and viscous forces. It was determined that fast withdrawal rates with high temperatures and polymer concentrations (viscous forces dominating capillary forces) produced surfaces whose topography did not correlate with that of the uncoated surface. This work will provide important mechanistic guidance on the selection of coating parameters for textured optics as limited studies have been published on this topic.

Exploring Gallium Alloys for the Development of Self-Healing Final Mirrors for Laser Fusion Energy Power Plants

Gregory Demos
Pittsford Mendon High School
LLE Advisors: Marcela Mireles, Brittany Hoffman

The survivability of the final optic in laser-driven fusion energy reactors, which must sit in the line of sight of high-energy neutrons and gamma rays, is a key issue and no solution currently exists. Based on theoretical considerations, a proposed solution involves the use of grazing-incidence liquid-metal mirrors (GILMM's). In this work, this concept has been experimentally tested using gallium alloys as potential candidate materials for GILMM's. Reflectivity measurements and laser damage threshold are the performance properties of greatest interest. The liquid metal alloys showed high reflectance for a broad range of wavelengths and angles of incidence. Damage testing experiments indicate that the ablation (damage) threshold of gallium alloys under exposure to 355-nm, 5-ns laser pulses is on the order of 1.7 J/cm^2 at normal incidence, suggesting that an operation fluence > 100 J/cm^2 can be supported by an ~85° GILMM configuration. This exploratory work is the first of its kind and serves as the groundwork for future research into this promising approach.

Developing Automated Tools for Aperture Metrology

Maya Gopakumar
Pittsford Mendon High School
LLE Advisor: Steven Ivancic

An automated method was developed using Python to precisely measure the openings in tantalum aperture arrays, specifically designed for the Knock-on Deuteron Imaging (KoDI) diagnostic used in inertial confinement fusion experiments on OMEGA. KoDI utilizes penumbral imaging, in which deuterons pass through an aperture to form a cloud-like distribution on film, which is reconstructed into an actual image using a maximum likelihood algorithm. A typical array consists of ~300 apertures that are averaged over for finer resolution. However, the algorithm assumes that each aperture is perfectly circular while irregularities in shape and size can distort the image. This work automates the process of working with a high-resolution imaging setup to quantify the eccentricity, major axis length, and minor axis length of all 300 apertures. This approach allows for accurate characterization of the apertures in a time-efficient manner that was not possible using traditional manual methods, directly increasing the precision and reliability of KoDI experiments.

Quantitative Assessment of 1-MHz Ultrasonic Cleaning of Multilayer-Dielectric Diffraction Gratings

Shuwen Ding
Pittsford Sutherland High School
LLE Advisors: Brittany Hoffman and Kyle Kafka

Surface contamination can reduce the optical performance of multilayer-dielectric diffraction gratings by decreasing the laser-induced damage threshold. However, many standard cleaning protocols, including 40 kHz ultrasonic cleaning, mechanically damage the fragile grating structure. This work investigated the effectiveness of 1 MHz ultrasonic (megasonic) cleaning as an alternative method. To monitor the cleaning effectiveness, fluorescent particles were used as model contamination and their fluorescence was measured as a function of time. The results showed that plastic particles with sizes from 1 to 5 µm were significantly cleaned from the grating samples, with the grating structure unaffected. Silica nanoparticles on flat glass also demonstrated cleaning for sizes as small as 100 nm. However, nanoparticles on diffraction gratings did not demonstrate a high cleaning efficiency. Scanning electron microscopy revealed that particles of size ≤500 nm were trapped in the grating grooves even after the cleaning cycle. Nonetheless, the results indicate that megasonic cleaning may be relevant for the removal of wavelength-scale particles from critical optics.

Contamination Identification using Raman Spectroscopy

Mark Atalla
McQuaid Jesuit High School
LLE Advisors: Brittany Hoffman, Stavros Demos

Contamination particles on laser components as small as ½ micron cause hot spots of high electric field to occur inside the optics, leading to damage and reduced optical performance. A significant particle load was recently found inside the OMEGA EP Grating Compressor Chamber (GCC). Previously, analysis using the available tools identified a variety of inorganic materials but also indicated the presence of organic materials. In this work, a Raman microscope was employed to test its ability to identify organic particles using spectra collected from individual particles as a signature for their chemical composition and associated vibrational modes. Particles are first visualized using the system's optical microscope and then the laser beam is focused onto them to collect the Raman spectrum. Results show that polyethylene is the most common organic particle type. Other organic molecular species include polycarbonate and polyacrylamide. Identifying these particles as well as commonly used materials inside the GCC will help find potential sources of contamination and develop solutions to minimize these sources.

Evaluation of Model-Independent Energy Spectra from Neutron Time-of-Flight Diagnostics using a Variable P-Spline Technique

Logan Canfield
McQuaid Jesuit High School
LLE Advisor: Chad Forrest

Neutron spectroscopy is one method used to measure the time-of-flight (TOF) signal of neutrons generated in inertial confinement fusion experiments. The energy spectra, inferred from the TOF neutrons, are used to diagnose key implosion metrics such as neutron yield and ion temperature. A model-independent approach to extracting the energy spectra is advantageous in that it does not rely on the presumption of a model to fit the TOF data. This approach includes the use of a b-spline, combined with a penalty matrix to restrict the overfitting of the experimental data. These techniques have been used to effectively obtain the DD and DT energy spectra, but have limited capabilities on TT energy spectra due to their complex nature. A novel variable p-spline technique was developed, in which sections of the spline with different attributes have different smoothing parameters.

Quantifying Isotherms Within the Hydrogen-Palladium and Deuterium-Palladium Systems

Lina Yang
Pittsford Sutherland High School
LLE Advisor: Matthew Sharpe

Palladium is a metal that reacts with hydrogen and its isotopes to form compounds like palladium hydride and palladium deuteride. Palladium is being explored for its applications in fusion as it can absorb a significant amount of hydrogen within its crystal lattice. An isotherm is a graphical representation of the relationship between two physical properties of a substance while keeping the temperature constant. Currently, there are no data in the published literature for temperatures between ~234 K and 293 K. Additionally, data below 234 K have large errors in the recorded equilibrium pressures. This work measured the vapor pressure of hydrogen and deuterium over palladium as a function of the gas-to-palladium atom ratio for temperatures between 158 and 295 K. This study examined the difference in behaviors displayed by hydrogen and deuterium between their performance at temperatures above and below a critical threshold, where the interaction between palladium and the gases shifts from hydriding and deuterating to adsorption. By creating a van’t Hoff plot from the collected data, it was determined that the critical threshold stands at 220 K for hydrogen and 200 K for deuterium.