UNIVERSITY of ROCHESTER

LABORATORY FOR LASER ENERGETICS

2022 SUMMER HIGH SCHOOL STUDENT RESEARCH PRESENTATIONS

Wednesday, 24 August 2022
LLE Coliseum

1:30–1:35	Welcome	Dr. R. S. Craxton
1:35–1:45	Presentation of the 2022 William D. Ryan Inspirational Teacher Award	Dr. C. Deeney
1:45–2:00	Introduction	Sara Davies
2:00–2:10	Determining the Absorption Efficiency of a Flow-Through Pd-Bed as a Function of Initial $^4He:D_2$ Ratio and Flow Rate	Elizabeth Norris
2:10–2:20	Computational Modeling of Electron Density Polarization in Liquid Crystals using Time-Dependent Density Functional Theory	Vinay Pendri
2:20–2:30	Measuring the Mode Field Diameter of Single Mode Fibers Using the Knife-Edge Technique	Olivia Fietkiewicz
2:30–2:40	Chiroptical Properties and Mesophase Stability of Saturated Chiral Dopants for High-Peak-Power Liquid Crystal Device Applications	Jenny Zhao
2:40–2:50	Energy Prediction on the OMEGA EP Laser System Using Neural Networks	David Villani
2:50–3:00	Measurement of the Refractive Index of KDP and ADP Crystals at Low Temperatures	Grace Wu
3:00–3:10	Mitigating Hydrodynamic Instabilities in the Deceleration Phase of Inertial Confinement Fusion	John Giess
3:10–3:20	Investigation of Microwave-Induced Chemical Etching	Jayden Roberts
3:20–3:35	Break	
3:35–3:45	Development of a National Ignition Facility Laser Configuration with X-Ray Backlighting of a Foam Ball Target	Alisha Upal
3:45–3:55	Terahertz Time-Domain Characterization of Biological Tissues Modeled Using COMSOL Multiphysics	Arjun Patel
3:55–4:05	Direct Drive Uniformity Calculations for a Future High Gain Laser Facility	Sara Davies
4:05–4:15	Viability Testing of Polymer Coating for Optical Cleaning Applications	Jackson McCarten
4:15–4:25	Measuring the Performance of Molecular Sieve Driers	Rick Zhou
4:25–4:35	Characterizing a Cryosorption Pump for Collecting Tokamak Exhausts	Samuel Gray
4:35–4:45	Design, Fabrication, and Testing of a 3D-Printed Optomechanical Assembly for the MIFEDS Coil Characterization Station	Micah Kim
4:45–4:55	Containerized Application Management for Cloud-Based Scientific Analysis	Cameron Ryan
5:00–5:30	Tour of the OMEGA and OMEGA EP Lasers	Mark Labuzeta, David Canning

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Determining the Absorption Efficiency of a Flow-Through Pd-Bed as a Function of Initial $^4He:D_2$ Ratio and Flow Rate

Elizabeth Norris
Brighton High School
LLE Advisor: Mark Wittman

The LLE Isotope Separation System utilizes a uranium-powder bed to absorb hydrogen from vessels containing protium, deuterium, and radioactive tritium prior to isotopic separation. However, trace ^3He, the decay product of tritium, accumulates over the uranium, impeding the absorption of hydrogen. A prototype was developed to test "flow-through" capabilities, the ability to push and pull gas bidirectionally using a pump, which could disrupt the ^3He build-up. The prototype apparatus was composed of a palladium-powder bed, a variable flow restrictor, and a turbo-molecular pump. Data on absorption efficiency was collected as a function of initial $^4He:D_2$ ratio and restricted gas flow rate. These results indicate that pumping gas through the bed increases absorption efficiency, but have also shown the risk of bed contamination from pump exhaust.

Computational Modeling of Electron Density Polarization in Liquid Crystals using Time-Dependent Density Functional Theory

Vinay Pendri
Pittsford Mendon High School
LLE Advisor: Kenneth Marshall

The change in electron density distribution of saturated and unsaturated liquid crystals in response to 113-fs gaussian laser pulses was computed using real-time time-dependent density functional theory (TDDFT) with the molecular modeling software *NW Chem*. Calculations were conducted using three different orientations of 900-nm linear polarized light incident on the long molecular axis to study the change in electron density as a function of incident laser polarization. This work will serve as the basis for further investigation of TDDFT's applications in liquid crystal and optics research to model areas of application interest such as photochemical reactions, laser damage resistance, polarizability, and dielectric constant.

Measuring the Mode Field Diameter of Single Mode Fibers Using the Knife-Edge Technique

Olivia Fietkiewicz
Our Lady of Mercy School for Young Women
LLE Advisor: Sara Bucht

Single mode fiber is used extensively in both telecommunications and the scientific community. At LLE, single mode fiber is used in the fiber amplifiers that seed the OMEGA and OMEGA EP amplifiers, among other applications. An important property of single mode fiber is the mode field diameter (MFD), which is traditionally determined as the $1/e^2$ width of the intensity inside the fiber. Knowledge of the MFD is important for preventing loss when coupling or splicing fibers and predicting how light will behave when it exits a fiber. The knife-edge technique, unique for its simplicity, is a method of measuring the MFD that uses a razor edge to incrementally cut off the amount of light that reaches a power meter. A knife-edge setup was built and tested by comparing the measured MFD of two types of single mode fiber with vendor specifications. The MFD of SM980 fiber, a fiber commonly used at LLE, was measured to be 6.0±0.1 µm at 1053 nm. This setup is a key step for improving LLE's technical knowledge of fibers, such as polarization-maintaining and other specialty fibers.

Chiroptical Properties and Mesophase Stability of Saturated Chiral Dopants for High-Peak-Power Liquid Crystal Device Applications

Jenny Zhao
Pittsford Mendon High School
LLE Advisors: Kenneth Marshall and Nathaniel Urban

Liquid crystal polarizer (LCP) devices are critical optics on the OMEGA laser that are used to produce circularly polarized light. The laser-induced damage thresholds of liquid crystals (LC's) at 1054 nm are consistently higher in saturated materials (i.e. organic molecules without π-bonds) than in their unsaturated counterparts. The current chiral dopant CB-15 used in the OMEGA LCP is unsaturated, so it possesses a low laser damage threshold, limiting its lifetime and functional operational wavelength to 1054 nm. A range of different saturated chiral dopants (both isotropic and mesogenic) was evaluated over a wide range of concentrations in two nematic LC mixtures. The factors considered included helical twisting power (HTP), UV absorbance, solubility, and orientation. Evaluation of these mixtures using polarizing optical microscopy and UV-VIS-NIR spectrophotometry showed that cholesterol oleate was one of the most promising saturated chiral dopant candidates due to its high HTP, low UV absorbance, good solubility, and ability to reinforce planar LC orientation.

Energy Prediction on the OMEGA EP Laser System Using Neural Networks

David Villani
The Harley School
LLE Advisor: Mark Guardalben

OMEGA EP is a kilojoule-class laser system with four independently configured beams. The laser performance is currently predicted using a physics-based model, PSOPS, which takes into account the highly nonlinear nature of the amplification and wavelength conversion processes. An alternative neural network model was created and trained using simulated data from PSOPS to predict the required laser input energies for a wide range of output energies and pulse shapes. The network model predictions were found to be within 0.05% of PSOPS predictions with 1000x faster processing speed. The network was trained and tested on a broad range of pulse shapes and configurations on beamlines 3 and 4. Although initial training time was 3 hours on a GPU, by implementing transfer learning the network was retrained in only 24 minutes to accurately predict a new category of pulse shapes. The network model provides a proof-of-concept for laser performance prediction using neural networks and can be implemented as an efficient, accurate replacement for certain PSOPS functions within OMEGA EP shot operations.

Measurement of the Refractive Index of KDP and ADP Crystals at Low Temperatures

Grace Wu
Pittsford Mendon High School
LLE Advisor: Ildar Begishev

Potassium dihydrogen phosphate (KDP) and ammonium dihydrogen phosphate (ADP) are nonlinear optical crystals used to convert radiation of high-power, large-aperture infrared lasers into the deep-ultraviolet range. The current temperature-dependent Sellmeier equations for both KDP and ADP don't correspond to experimental data at low temperatures. In this work the refractive indices of KDP and ADP were measured at different temperatures to allow the equations to be modified. Initially, the refractive indices of both crystals were measured at room temperature and checked by comparison with existing values. Prisms from KDP and ADP crystals were then placed inside a two-chamber cryostat, and two laser beams of different wavelengths (633 nm and 533 nm) were aligned to the prisms. Liquid nitrogen was pumped into the cryostat, cooling the crystals down from approximately 300 K to 200 K. The refractive indices were measured for ordinary and extraordinary beams based on the positions of the refracted beams as the temperature changed. The experimental data were compared with the original equations and fitted to new curves.

Mitigating Hydrodynamic Instabilities in the Deceleration Phase of Inertial Confinement Fusion

John Giess
McQuaid Jesuit High School
LLE Advisors: Valeri Goncharov, Jack Woo

The Rayleigh Taylor (RT) hydrodynamic instability can reduce the temperature in the hot spot and limit target performance in inertial confinement fusion. The RT instability is formed when a lower density material pushes on a higher density material. RT growth amplifies shell imperfections at the outer surface during shell acceleration and at the inner surface during deceleration. We investigated mitigation techniques for RT perturbation amplification at the deceleration phase. This includes shock mistiming to increase the entropy and reduce the density at the inner part of the shell. These shocks propagate into the shell at the beginning of the implosion. In a nominal design, the shocks are timed so they all merge only in the lower density void region of the target. We changed the height of the foot (early part of the pulse) to see the effect of the shocks merging inside the shell. We then calculated the RT growth rate using the change in the density scale length and inner radius. We found a design with a high foot that still reaches burn conditions. This design has a larger density scale length and limits RT growth.

Investigation of Microwave-Induced Chemical Etching

Jayden Roberts
Brockport High School
LLE Advisor: Steven Ivancic

CR-39 is a solid-state nuclear track detector that can be used to collect information on critical performance metrics of inertial confinement fusion implosions, such as the areal density of the confined fuel. Charged particles emitted from reactions occurring inside the target damage polymer bonds in the CR-39. These damages are on the scale of nanometers, and thus require further treatment to be recorded by instruments such as optical microscopes. LLE currently uses a several-hour chemical etching process to develop particle tracks. Microwave radiation has been proposed to work in tandem with chemical etching to greatly increase the rate at which tracks develop. A study of microwave-induced chemical etching was undertaken and found to fully develop alpha particle tracks in CR-39 in 40 minutes as opposed to 6 hours in conventional chemical etching used today.

Development of a National Ignition Facility Laser Configuration with X-Ray Backlighting of a Foam Ball Target

Alisha Upal
Pittsford Sutherland High School
LLE Advisor: Stephen Craxton

A laser configuration was developed for a National Ignition Facility (NIF) experiment that will use an 1100 micron radius foam ball target. Foam ball targets may have applications in future fusion energy plants. The 192 laser beams in the NIF are divided into 48 quads of four beams each, sorted into four rings in each hemisphere at angles of 23.5, 30.0º, 44.5º, and 50.0º from the vertical. Two quads are used for x-ray backlighting to provide images of a shell formed from the foam ball during the experiment, one quad in the upper hemisphere and one in the lower hemisphere. It was therefore necessary to repoint the NIF beams in the θ (longitudinal) and φ (latitudinal) directions to compensate for these quads. The 2D hydrodynamics simulation code SAGE was used to maximize the uniformity of the target's implosion. These simulations found velocity non-uniformity values for the converging shock wave formed by the laser pulse as low as 1.40% RMS. The new laser pointing design is expected to be applicable to a variety of experiments requiring beams to be used for backlighting.

Terahertz Time-Domain Characterization of Biological Tissues Modeled Using COMSOL Multiphysics

Arjun Patel
Brighton High School
LLE Advisors: Debamitra Chakraborty and Roman Sobolewski

Terahertz is one of the least studied frequency ranges on the electromagnetic radiation spectrum. One of its most interesting and unique properties is the ability to safely penetrate materials such as plastics, papers, or dry wood, allowing the completion of non-destructive testing. This investigation focused on THz characterization of biological tissues by measuring electric field distributions in both healthy and cancerous tissues and attempting to differentiate them. Using COMSOL Multiphysics, a program designed to simulate physical phenomena, a THz-emitting antenna with a GaAs substrate was created to model the real experiment. The electric fields through healthy and cancerous porcine liver were simulated and contrasted. The difference in electric field strengths between these two tissues was 2126.6 V at their respective centers. Additionally, experimental tissues typically used for THz time-domain spectroscopy are paraffin-embedded, so it was necessary to computationally model the effects of paraffin on the transmitted electric field distribution. It was concluded that a layer of paraffin around the biological tissue would not alter the electric field through it.

Direct Drive Uniformity Calculations for a Future High Gain Laser Facility

Sara Davies
Pittsford Sutherland High School
LLE Advisor: Stephen Craxton

This work investigates the optimization of uniformity for direct drive experiments on a possible future laser facility larger than the National Ignition Facility (NIF). The NIF has 48 quads, each with 4 beams. The proposed facility uses 96 quads. A key feature of the facility is that it can simultaneously do both direct and indirect drive. Indirect drive will use octahedral hohlraums (spherical hohlraums with six laser entrance holes), which promise greater uniformity than the cylindrical hohlraums used on the NIF. The 2-D hydrodynamics code SAGE was used to calculate beam pointings that provide maximum laser irradiation uniformity. This task is complicated because the design, like the NIF, uses non-opposing beam ports. The optimum pointing design minimizes the repointing angles of the beams and results in a nonuniformity of 0.41% (RMS), with no beam repointed by more than 14.1° (compared with ~36° for direct drive designs on the NIF). These results show that the optimized design promises highly uniform direct drive implosions on a facility also capable of highly uniform indirect drive.

Viability Testing of Polymer Coating for Optical Cleaning Applications

Jackson McCarten
Webster Schroeder High School
Advisors: Brittany Hoffman, Kyle Kafka

The performance of optics used in high power laser systems can be limited by surface contamination in the form of particles and films. Viability testing was performed for a commercial polymer (First Contact) as a strip-coat cleaning process for glass substrates, multilayer dielectric (MLD) coatings, and diffraction gratings. The polymer can be brushed or sprayed onto the desired optic surface; it is then mechanically removed once dry. Contact angle measurements, particle counts, force measurements, and damage testing were all used to determine the polymer's viability as a cleaning process. A process was developed that successfully removed contamination particles from glass substrates and MLD coatings, and prevented the polymer from leaving behind a thin film of contamination. For structured films, such as gratings, removal of the polymer was difficult, and a different application process needs to be developed.

Measuring the Performance of Molecular Sieve Driers

Rick Zhou
Brighton High School
LLE Advisors: Walter Shmayda and Matthew Sharpe

Commonwealth Fusion Systems is designing a tokamak called SPARC to demonstrate ignition in a deuterium-tritium (DT) plasma. A number of systems are being designed to deliver, recover, and purify the DT fuel. These processes generate tritiated effluents, which will be converted to tritiated water, nitrogen, and carbon dioxide in the trace tritium recovery system (TTR). The water is collected by driers in TTR. An experiment was set up to test the performance of molecular sieve (MS) driers under a variety of flow conditions. In this experiment, the carrier gas is humidified by passing hydrogen over nickel oxide. The performance of the MS drier is tracked by monitoring the dew points upstream and downstream of the drier. The dependence of mass transfer zone length (length of the MS drier that is unusable due to water leakage) on gas flow rates was measured to find the efficiency of the drier.

Characterizing a Cryosorption Pump for Collecting Tokamak Exhausts

Samuel Gray
Brighton High School
LLE Advisors: Walter Shmayda, Eric Dombrowski

SPARC, a high-field toroidal tokamak being constructed by Commonwealth Fusion Systems, will utilize the fusion reaction between tritium and deuterium. The exhaust gas contains hydrogen isotopes, helium ash, and inert gases used to control the plasma. High-vacuum turbomolecular pumps evacuate this gas from the torus. Cryo-sorption pumps accept gas from these pumps and deliver the effluent to the Torus Exhaust Purification system, where unspent hydrogen is recovered and purified. Cryo-sorption pumps can selectively pump hydrogen at high speeds in the presence of inert gases. A novel prototypic cryo-sorption pump was constructed and packed with molecular sieve 4A that is cooled to liquid nitrogen temperatures (-196 °C). The pump design requires a hydrogen capacity of 28 sL with an effective pump speed of 120 L/second at 1 torr under predicted conditions. Its hydrogen capacity and pumping speed below 1 torr are being measured to determine viability in the final application.

Design, Fabrication, and Testing of a 3D-Printed Optomechanical Assembly for the MIFEDS Coil Characterization Station

Micah Kim
Home School
LLE Advisor: Douglas Jacobs-Perkins

The magneto inertial fusion electrical discharge system (MIFEDS) produces high-intensity electromagnetic fields used in OMEGA and OMEGA EP for plasma physics and astrophysics experiments at LLE. The MIFEDS device stores 400 Joules of electrical energy in capacitors and then rapidly discharges a 20 kV, 50 kA pulse into a ~1 cm diameter coil. A coil characterization station is being built to inspect the coils for dimensional defects. This project investigates the application of 3D-printing technology to the optomechanical design of the characterization station. Establishing this engineering design principle could reduce fabrication time while maintaining optical precision. The coil characterization station will ultimately avoid experimental delays by preventing defective MIFEDS coils from being deployed.

Containerized Application Management for Cloud-Based Scientific Analysis

Cameron Ryan
McQuaid High School
LLE Advisor: Richard Kidder

Experimental data from diagnostic reports at the Laboratory for Laser Energetics (LLE) used for statistical analysis is accessed through the LLE web Application Programming Interface (API). The analysis software development pipeline is inhibited by the lack of any existing software for loading, formatting, and abstracting data from the web API. New software needs to be created redundantly to load data from the API every time new analysis software is made, or whenever external scientists make software that analyzes data observed from experiments at LLE. An application management system using software containers was researched and developed to allow new or external scientists to securely develop analysis software with LLE's physical computational resources, as well as a code-sharing repository for the distribution of diagnostic-reading software through GitLab. This can all be accessed through an easy-to-use web interface.