MASTER OF SCIENCE
IN
APPLIED PHYSICS

HIGH ENERGY LASERS FOR SHIP-DEFENSE AND MARITIME PROPAGATION
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High Energy Lasers (HELs) are a new class of weapons that may be of great value to the Navy in the near future. A high-power Free Electron Laser (FEL) is being designed using short Rayleigh-length resonators to increase the spot size at the mirrors and hence avoid mirror damage. Three-dimensional simulations are used to study the effects of an electron beam misalignment (electron beam tilt). This thesis shows that the proposed design is tolerant of typical electron beam misalignments. The performance of a step-tapered undulator is also studied for the 100 kW proposed upgrade of the Jefferson Laboratory FEL. The results of this research show that the gain is above the required threshold for the 100 kW design while the energy spread does not change significantly over any undulator design. The spectrum of the proposed FEL shows that most of the power is concentrated around the fundamental frequency. It is shown in this thesis that smooth FEL pulses can significantly reduce the negative effects of absorption and scattering. Recent HEL science and technology developments are discussed for both Free Electron and Solid-State Lasers.

KEYWORDS: Free Electron Laser, Solid-state Lasers, High Energy Lasers, Short Rayleigh Length, Step-taper Undulator, SSHCL, Laser Propagation

ACTIVE MIRROR ALIGNMENT FOR FREE ELECTRON LASERS
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This thesis investigates active mirror alignment systems of a free electron laser (FEL) for future integration as a ship self-defense weapon. An issue with this integration is the effect of low-frequency shipboard vibrations on the optical cavity mirrors. Alignment of the cavity mirrors is required for the proper operation of any type of laser. Mirror alignment is especially critical for an FEL because the electron beam and optical mode must substantially overlap. Laboratory FEL facilities, along with other laboratory high energy facilities that employ active mirror alignment systems, are investigated. In addition, a model theory for controlling the vibrations of a single-degree-of-freedom system is developed, and experiments with a simple mirror alignment system are described. Reduction of an impressed vibration amplitude by a factor of five is achieved, compared to a factor of fifteen that is achieved in major laboratory systems with sophisticated control systems. The purpose of these efforts is to understand the underlying physics of vibration control. The knowledge forms a basis for follow-on research towards the development of a prototype shipboard active mirror alignment system.

KEYWORDS: Free-Electron Lasers, Directed Energy Weapons, Active Control, Vibration Stabilization

DESIGN AND FIRST OPERATIONS OF THE LINEATE IMAGING NEAR-ULTRAVIOLET SPECTROMETER (LINUS)

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Spectral imagery provides a new technology for target detection, defeat of camouflage, concealment and deception, and detection of chemical/biological agents in the atmosphere. The Lineate Imaging Near Ultraviolet Spectrometer (LINUS) is designed to image a narrow passband in the UV portion of the Electromagnetic spectrum. The imaging spectrometer views a 0.5 degree vertical strip, while observing a 20-40 nm wide band currently centered at 300 nm. The 512 x 512 pixel focal plane provides 0.1-1.0 nm spectral resolution, depending on slit width in the dispersive optic instrument. It is designed to scan a 2.5 degree horizontal pattern. The instrument has been calibrated spectrally, and its response to sulfur dioxide has been measured. First observations with the scanning instrument in the laboratory and outdoors at NPS are presented. This work demonstrates that LINUS can detect SO2 down to concentrations less than 100 ppm.

KEYWORDS: Sulfur Dioxide, Gas Detection, Ultraviolet (UV), Imaging Spectrometry, Lineate Imaging Near Ultraviolet Spectrometer (LINUS), Spectral Imaging

COMPUTER-CONTROLLED PHOTODETECTOR CHARACTERIZATION SYSTEM (DESIGN AND CONSTRUCTION)

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This system was designed to evaluate the response characteristics of photodetectors operating at wavelengths in the 1 micron and 8-12 micron range. A Quartz-Tungsten-Halogen source was used for visible and near-IR energy, and a dedicated IR element provided gray-body radiation with a peak at 1150 Kelvin. A monochromator was employed in conjunction with a six-position filter wheel to provide precise control of energy incident on the photodetectors. Variations in the efficiency of components were compensated for through normalization based on the energy incident on the photodetectors. An intuitive, computer-based interface was developed to automate data collection, and provided numeric and graphic representations of data as it is being collected. At completion, data is exported to a spreadsheet file. A commercial silicon detector was successfully characterized, and accurate voltage response and responsivity curves were generated. A pyroelectric detector was used to verify proper operation of gratings and filters at infrared wavelengths. The system is suitable for its intended purpose, and will be capable of characterizing detectors designed to operate in the 3-5 micron range with the installation of appropriate filters and gratings.

KEYWORDS: Detector, Photodetector, QWIP, Responsivity, Monochromator, Characterization, Characteristic Response, Detectivity, LabVIEW, Virtual Instrument, Optics, Photonics.

FREE ELECTRON AND SOLID STATE LASERS DEVELOPMENT FOR NAVAL DIRECTED ENERGY

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A MW level FEL is being designed with a short a Rayleigh length resonator to increase the spot size at the mirrors and to avoid mirror damage. In this thesis, it is found that it is desirable to focus the electron beam to improve the FEL extraction efficiency. Three-dimensional simulations show that the focused electron beam increases the extraction efficiency far beyond the required value of 0.7%. It is also found in this thesis that shifting the electron beam off-axis less than 0.3 mm, the efficiency remains above the required value. The proposed FEL design uses high power, short optical pulses whose spectrum may cover many absorption lines. The absorbed laser energy can heat up the air resulting in defocusing the laser beam (thermal blooming). This thesis shows that thermal blooming is not an issue for a moderate clear atmosphere when the stagnation zone size remains less than 10 m. A transitional step for the development of a MW level FEL weapon is the proposed 100 kW upgrade of the Thomas Jefferson National Accelerator Facility's FEL. It has also been shown in this thesis that the use of a step-taper undulator slightly improves the performance of the FEL. Finally, the potential of various high average power solid-state laser designs are reviewed.

KEYWORDS: Free Electron Laser, Propagation of High Power Free Electron Laser Pulses, Thermal Blooming, Focused Electron and Optical Beams, Desynchronism, Step-taper Undulator, High Power Solid-state Laser

3D VISUALIZATION OF INVARIANT DISPLAY STRATEGY FOR HYPERSPECTRAL IMAGERY

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Spectral imagery provides multi-dimensional data, which are difficult to display in standard three-color image formats. Tyo, et al. (2001) propose an invariant display strategy to address this problem. This approach is to mimic the dynamics of human perception. The dimensionality of the data are reduced by using a Principal Component (PC) transformation, and then displayed by making used of a Hue, Saturation, and Value (HSV) display transform.

This study addresses the PC transformation strategy, looks for a global eigenvector via 3D visualization of HSV color space information, and examines the suggested algorithm to provide the most intuitive display. The user interface created in this thesis is capable of computing the necessary implementation of the proposed strategy, viewing selected Region of Interest (ROI) in HSV color space model in 3D, and viewing the 2D resultant image. A demonstration application uses Java language including Java2D, Xj3D Player, Document Object Model (DOM) Application Program Interfaces (API), and Extensible 3D Language (X3D). The Java2D API enables the user to load imagery, process data, and render results in a two-dimensional (2D) view. Xj3D and DOM APIs are introduced to visualize Tyo's invariant display strategy in three-dimensional (3D) views and then to save results as X3D scenes. These techniques appear to be inherently valuable and can serve as the basis for further research.

Through this thesis, 3D visualization of the proposed algorithm successfully showed PC transformed data does form a conical shape in HSV color space. Also, a comparison of PC transformed data with HSV color space revealed the hue angle needed to be adjusted. The application of this adjustment to multiple

scenes produced consistent results. However, this hue adjustment left other scene elements in non-ergonomic colors and brought up the issue of further enhancement of the algorithm.

KEYWORDS: Hyperspectral Imagery, 3D Visualization, X3D, Java Xj3D Player

BARREL WEAR REDUCTION IN RAIL GUNS: AN INVESTIGATION OF SILVER PASTE LIQUID-METAL INTERFACE

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This thesis tests the effects a commercial silver paste has on the damage at the projectile-rail interface of a 4" long rail gun test section. Projectiles (0.635 x 0.635 x 0.953 cm) were pushed through the rail test section at 34 $\pm$ 19 m/s, while average current densities of 18-30 kA/cm^2 was passed through the projectile – rail interface material. The specific objective is to examine rail and projectile damage at current densities near or above those ($\approx$ 25kA/cm^2) anticipated for a naval rail gun. Voltages across the rails were monitored and changes in conductivity when solid electrical contact was broken were observed. Silver deposits were observed on the rails from the paste at a peak current of 13.3 kA, while no damage was seen on the rails until a peak current of 17.2 kA was reached, which corresponds to average current densities of 22 kA/cm^2 and 28.5 kA/cm^2, respectively.

KEYWORDS: Rail Gun, Railgun, Sliding Contact, Electrical Contact, Conductive Interface, Silver Paste, Rail Erosion, Projectile Diagnostics