

# **Undergraduate Experimental Research in Optics and Photonics**

Waylin Wing

Central Michigan University, Mount Pleasant, MI 48858

Email: wing1wj@cmich.edu

This paper encompasses the undergraduate research experience of the author at Central Michigan University. A basic overview, including technical information, of the undergraduate research is presented. Concepts such as erbium doped fiber amplifiers (EDFA), polarization, and mode-locking are explained in terms of the research. The research objectives centered on basic optical science and were motivated by applications in telecommunications and optical microfabrication.

A Research Experience for Undergraduates (REU) program is also discussed. The research methods and tasks involved in the upgrade of the Multi-Terawatt Femtosecond Laser (MTFL) located within the Center for Research and Education in Optics and Lasers (CREOL) is outlined and the results are explained. The theoretical approach (MATLAB modeling) of the laser's multipass amplifiers is analyzed. Experimental data from amplifier testing is compared to the theoretical model in order to determine functionality of the laser system and accuracy of the numerical model.

Finally, the undergraduate research experience is put into perspective pertaining to engineering education. The author will provide a student's perspective on performing meaningful and cutting edge research in an undergraduate setting. Comments targeted for both students and research advisors will be included. Conclusive remarks about the research experience are presented.

## **Research at Central Michigan University (2011 – 2012)**

### *The Experience*

My first experience with research occurred during the summer of 2011. With the help of one of my professors, I wrote a grant proposal titled "High power fiber lasers", in order to secure the "Summer Scholars" award that could be used to fund research during the summer of 2011. The grant proposal was accepted and funded by the College of Science and Technology (CST), which is located at Central Michigan University (CMU). The goal of the proposal was to construct a pulsed fiber ring laser for the study of nonlinear materials and microfabrication utilization. The fiber ring laser was to be constructed in the Electromagnetics Research Laboratory (ERL) located within my institution. The original research was only funded through the summer of 2011. However, I was able to continue the research throughout the 2011-2012 school year by working as a research assistant in the ERL. A schematic of the fiber ring laser is shown in Figure 1, and a photograph of the fiber ring laser platform is shown in Figure 2.

During the summer of 2011, my main objectives were to (1) become familiar with the fundamental concepts of my intended research, and also (2) to learn about the process of professional research. Completing these objectives was considerably harder than I had perceived. The first objective is relatively straightforward but challenging. The concepts that are needed to pursue deeper understanding in any field are always going to be difficult to master, and this was

the first time I was experiencing this feeling. Undergraduate coursework allows students to learn the basic tools they will need to solve basic problems; this is quite different from the concept of research. I learned through my first research experience at CMU that you will need advanced tools which are sometimes very specific to a given field. For example, my electromagnetics course taught me about Maxwell's equations and basic electromagnetic theory; however, I needed advanced material and understanding of new concepts to grasp the idea of how a laser (Light Amplification by the Stimulated Emission of Radiation) works. Through my "Summer Scholars" research award, I was beginning to see that I would need advanced tools and knowledge in order to conduct research in the fields of optics and photonics.

The second objective of learning how to conduct professional research is also a rigorous task. In the beginning, I did not know how to go about starting my research, let alone make any progress. The amount of resources available and the broadness of my topic seemed overwhelming at the time. I needed a lot of guidance from my research advisor as to what to read and what to do in the laboratory. Even when I had something to read and learn about, I had little or no idea why it was important to my research topic. Over time, I was able to increase my research abilities and efficiency.

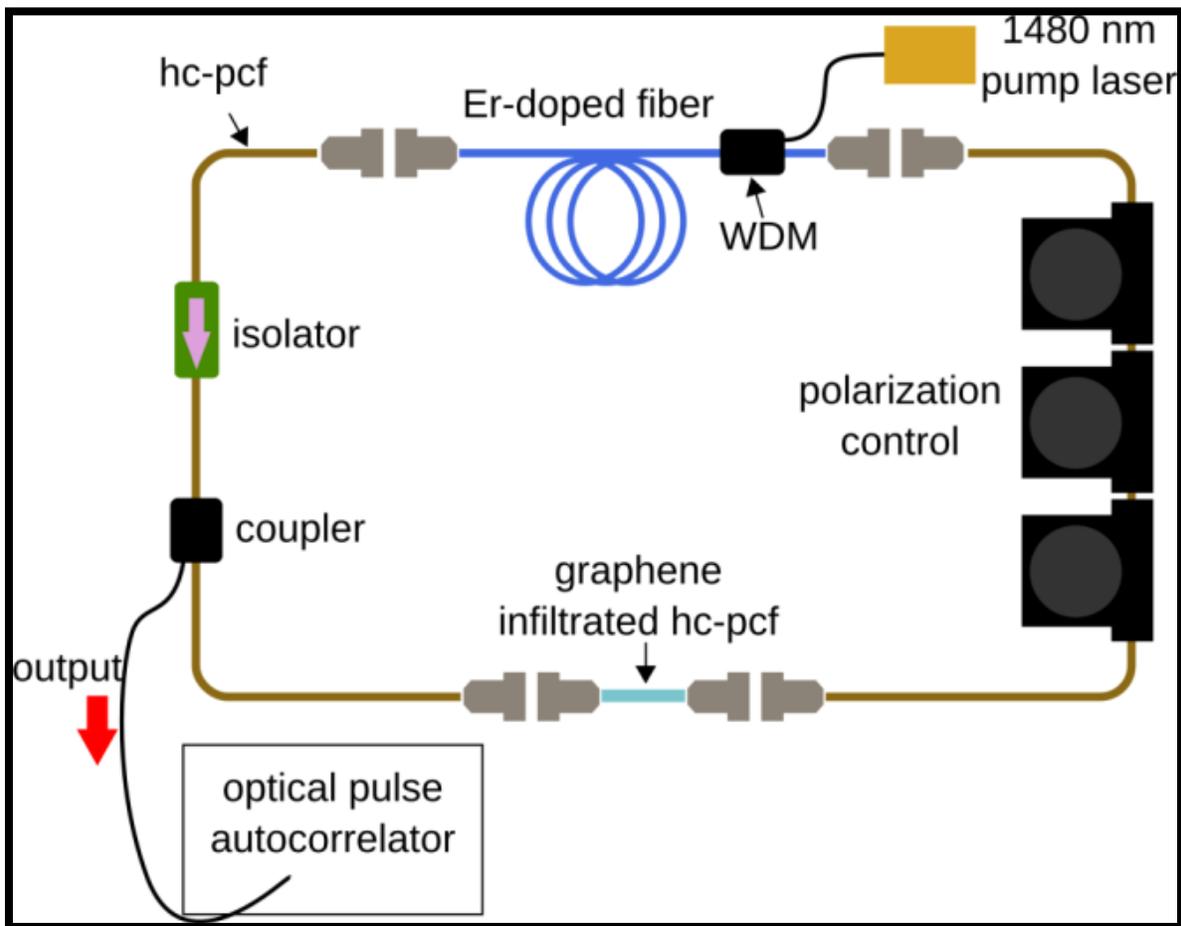


Figure 1. The schematic of the fiber ring laser.



Figure 2. A photograph of the fiber ring laser platform.

### *Technical Work*

Building a pulsed fiber ring laser required extensive planning and calculation. There are many things to consider: these include the laser gain medium, fiber ring laser cavity length, operating polarization, operating power, and the mode-locking mechanism, to name a few. Once the specifications of the fiber ring laser were decided upon, the next step was to order the components and put them together so that the laser could work. After the initial set up, certain parameters were modified in order to meet the original specifications. A description and explanation of the aforementioned specifications are shown below:

*Gain Medium:* The rare earth metal erbium was chosen as the gain medium for this fiber ring laser. The main reason erbium was chosen is because it emits energy in the 1550 nanometer wavelength range, which is a common wavelength for telecommunications because of its low attenuation as the light travels through the fiber.

*Polarization:* The fiber ring laser operates with polarized light. This is due to the fact that the light exiting the gain medium is polarized, causing the light in the entire ring laser to be polarized. A polarization controller is used to manipulate the polarization of the light within the ring laser.

*Mode-locking:* To generate a pulsed laser, the phases of the laser modes in the cavity must be locked together. This means that when the phases of the laser modes align in space and in time,

the modes will interfere constructively. At other points in time, the laser modes will interfere destructively, which leads to pulses within the fiber ring laser. To mode-lock this fiber ring laser, amplitude modulation (active mode-locking) was implemented.

## **Research Experience for Undergraduates (REU) at the Center for Research and Education in Optics and Lasers (CREOL)**

### *The Experience*

Prior to the summer of 2012, I had applied to several Research Experience for Undergraduates (REU) programs. These programs are funded by the National Science Foundation (NSF) and are intended for undergraduate students interested in research. These programs usually take place during the summer months and typically last about 12 weeks. The selected undergraduates are given topics to research under the guidance of a mentor and graduate students. I was accepted into two programs; one was related to optics and photonics, and the other one was related to the use of antennas and communication. I chose to participate in the REU program that was related to optics and photonics; at the University of Central Florida (UCF). The department that I worked in was called the Center for Research and Education in Optics and Lasers (CREOL). During my time at UCF, I was exposed to graduate-level research and state-of-the-art optical equipment. My research topic during this program was solid-state amplification in a Multi-Terawatt Femtosecond Laser (MTFL). Basically, I worked exclusively with the amplification of a high-power, ultrashort pulsed laser. This topic dealt heavily with a power upgrade of this laser, and as such, I gained a lot of hands on experience with building a laser from the ground up. Figure 3 shows photographs of the diffraction grating used in the laser and the laser beam cross section. Besides the technical skills, I was able to gain insight on advanced education and graduate life.

Theoretically, I learned about several advanced concepts dealing with laser operation. For example, I learned about chirped pulse amplification (CPA) [1], solid-state amplification, and material damage thresholds. About half of each day I spent at CREOL involved studying and learning about advanced concepts that were related to my topic. These were concepts that, for the most part, I would not learn about in undergraduate coursework. My knowledge and understanding of optics increased greatly during this summer.

Technically, I picked up several techniques that are useful in any optics or photonics laboratories. I spent a great deal of time aligning laser light and adjusting optics. One technique I learned was to align a laser beam using two mirrors and a pair of irises. If a laser beam hits the two mirrors before the irises, it is possible to align a laser to travel along any line made by the two irises. I also learned about techniques to adjust optic stages and adjust sensitive optical equipment.

Finally, I was able to understand how to more efficiently conduct research during my time spent at UCF. At CREOL, there is not an undergraduate population; it is mostly graduate students, post-docs, and professors. Since this was the case, I was routinely surrounded in a research-driven environment, and I was able to pick up important tips and methodologies that have improved my research ability.

The REU program at UCF allowed me to gain an immense amount of technical and practical knowledge. I was able to see how graduate students deal with taking classes and conducting research. The REU program also sponsored trips to industry; in my case, we visited Northrup Grumman, Lockheed Martin, and Ocean Optics. These visits were useful because they let me see what electrical and optical engineers do in an industrial setting. At the conclusion of the REU program, I presented a poster and wrote a paper [2], which further increased my skills in dissemination.

### *Technical Work*

The main objective during the REU at CREOL was to upgrade the MTF. Upon arrival, the entire system was being taken apart and rebuilt. The main objective of the REU was to model the solid state amplifiers within the MTF. To do this, MATLAB was used to model the energy and fluence through the gain medium of the amplifier. Figure 4 shows the experimental configuration of the multipass solid state amplifier. Figure 5 shows MATLAB models of fluences through the gain medium. Figure 6 shows the theoretical output energy along with the experimental values.

The MATLAB code was based on the properties of the gain medium as well as the characteristics of the laser pulses entering the medium. For the gain medium, properties such as the absorption coefficient and width were required. For the laser pulses, characteristics such as the beam profile and initial energy were needed. Based on these parameters, the Frantz-Nodvick equations for solid state gain mediums were used in order to model the energy and fluence.

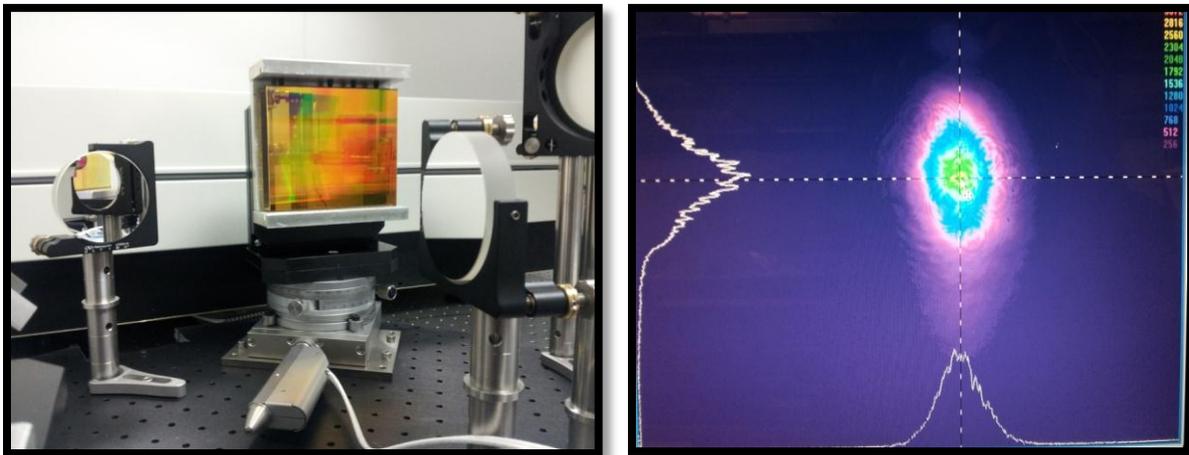


Figure 3. (left) The diffraction grating used in the Multi-Terawatt Femtosecond Laser. (right) The laser beam cross section.

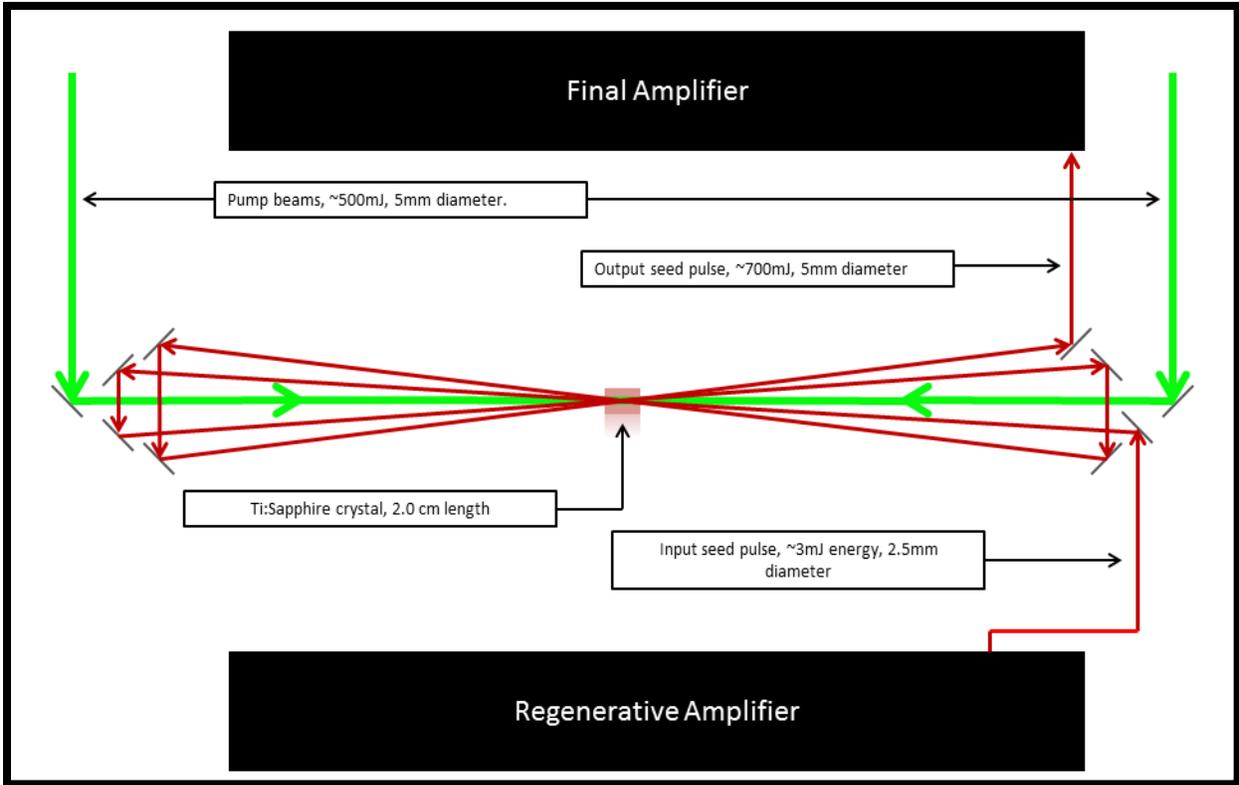


Figure 4. The experimental configuration of the multipass solid state amplifier within the Multi-Terawatt Femtosecond Laser.

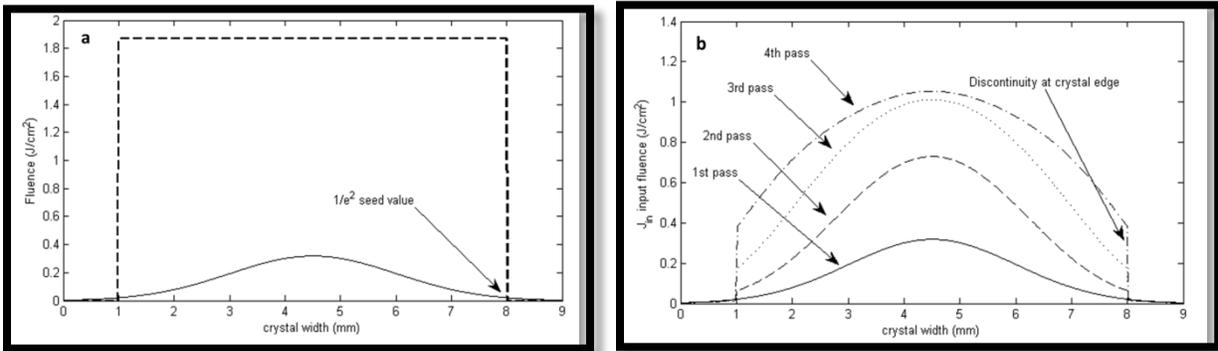


Figure 5. (left) The pump and seed energy in relation to the gain medium width. (right) The output fluence per pass as a function of gain medium width.

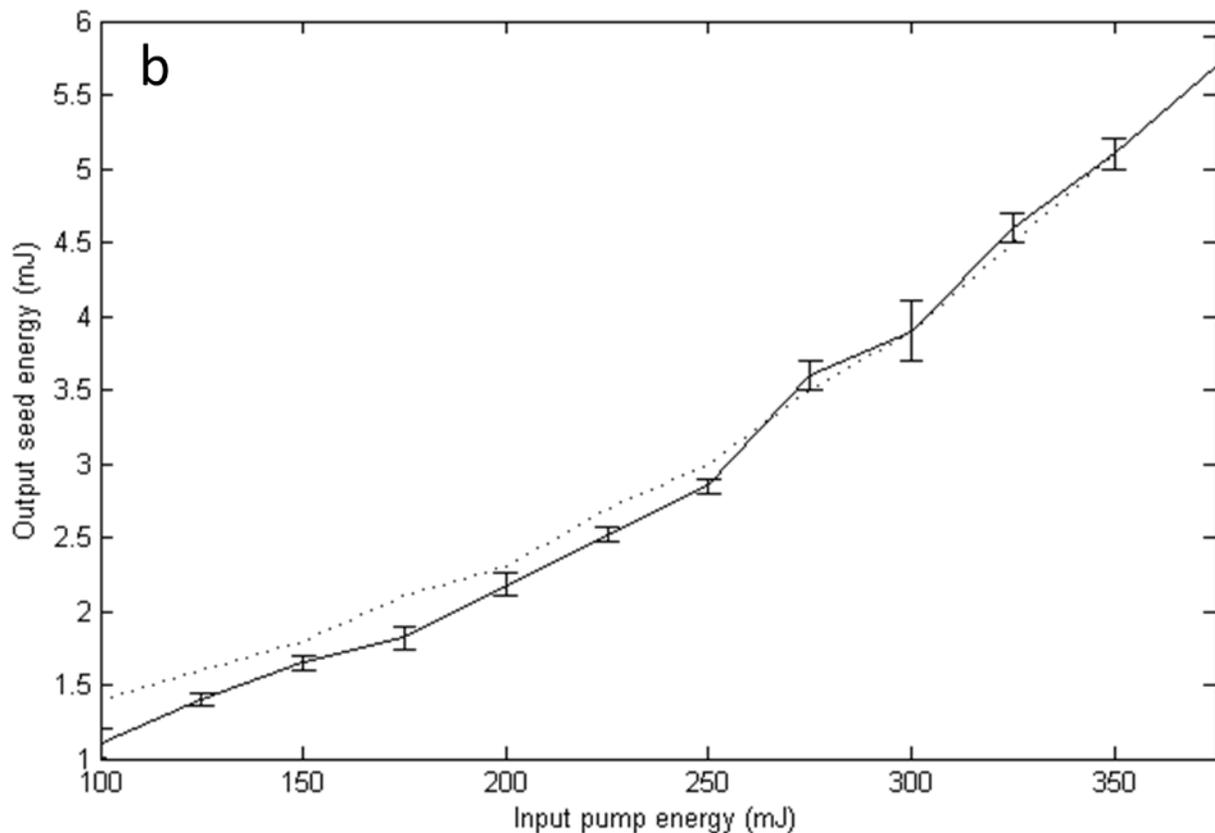


Figure 6. The theoretical (dotted line) and the experimental (solid line) values of the output pulse energy as function of the input pump energy. Note the close agreement in values.

### Research at Central Michigan University (2012 – 2013)

#### *The Experience*

As I finish up my senior year at CMU, I am continuing to participate in research in the ERL. I am working on characterizing the fiber ring laser mentioned above, and have taken up a new project concerning the Optical Angular Momentum (OAM) [3] of laser light. Figure 7 shows a few of the mirrors in the experimental configuration of the OAM project. My goals for my senior year are to continue to work on my research skills, as well as improve my technical knowledge in optics and photonics. So far, I have made significant progress on my research endeavors, and foresee positive results on my current projects.

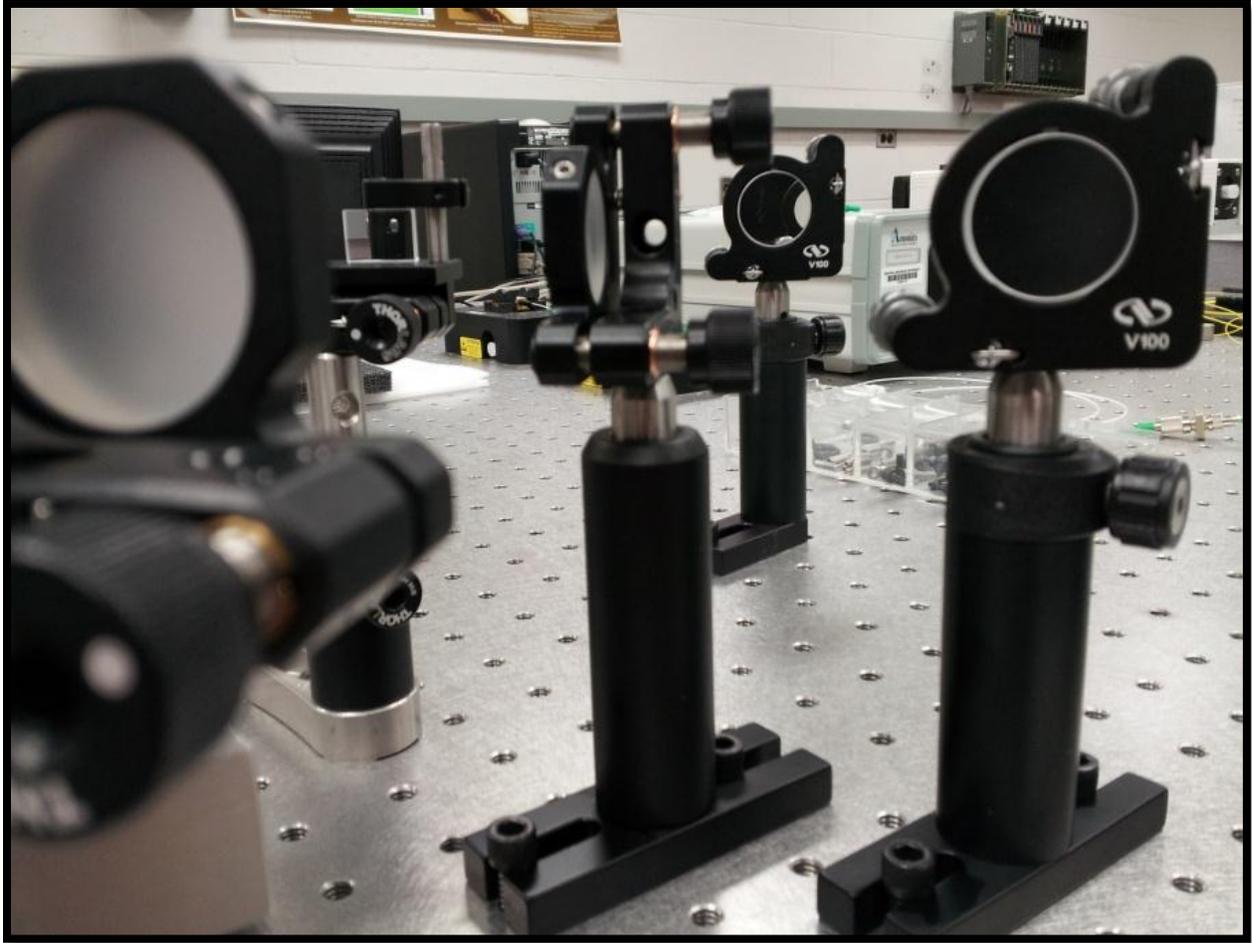


Figure 7. The highly-reflective mirrors in the OAM experimental configuration.

### *Technical Work*

Optical angular momentum is the “twisting” of light as it travels through space and time. The goal of the current research project is to experimentally show that it is possible to generate OAM states using a free space laser. To do this, a configuration using several mirrors, beamsplitters, and a Helium-neon laser is needed. Through manipulating path lengths and physical orientation of the laser beam, it might be possible to induce OAM states without the use of spatial modulators or specialized photonic integrated chips. Figure 8 shows the experimental configuration of the aforementioned project.

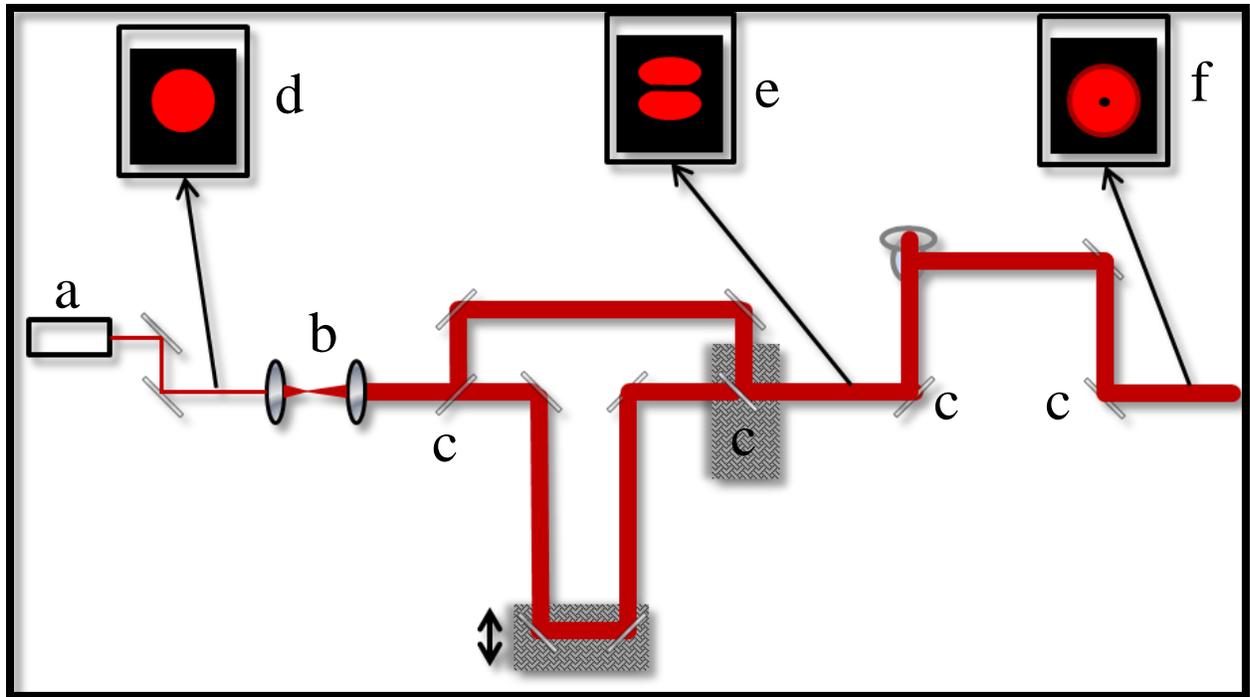


Figure 8. The experimental configuration used to generate OAM states in a free space laser. (a) is the Helium-neon laser, (b) are the lenses used to expand the beam, (c) are the beam splitters, and (d,e,f) are the beam cross sections at certain points in the configuration. The other components in the configuration are highly reflective mirrors and translation stages.

### Undergraduate research and its educational value

I would say that participating in research has had a very positive effect on my undergraduate education. Through research, I've found ways to study and learn about topics that I could not have found through my required coursework. I believe that participating in research taught me how to become more efficient in finding information and using that information to solve difficult problems. Performing research to solve real-world problems also provides a sense of meaningfulness that is hard to achieve when solving textbook problems. All of the research I have participated in for the past year and a half dealt with open-ended problems that have unknown, but important, solutions. For this reason, I feel more engaged and important when performing research as opposed to solving coursework problems.

My participation in research has opened up many doors after my undergraduate education. I am sure that my research has had a significant effect in the decision for being selected for the REU program, and for my internship opportunity this coming summer. Also, the research experience I have has allowed me to be accepted into graduate programs that deal with my field of interest. I believe that without research experience, it would have been a lot harder to get my offered my first choices of employment and accepted into graduate programs. By performing research, it shows that I have an interest in my profession and also that I can go beyond my required coursework.

Finally, my participation in research has allowed me to gain a deep understanding about what electrical and optical engineers actually do. Undergraduate coursework does not teach or

show what an actual engineer will do on a daily basis. Being involved with research, I sometimes have to work with engineers to figure out a minor problem. This exposes me to their work and their daily job tasks. When I present my work at conferences or exhibitions, I come into contact with scientists and other researchers. In general, I believe participating in research exposes you to the larger working population, something that would not happen in the typical undergraduate experience.

### **Bibliography**

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[3] Allen, L., Barnett, S. M., Padgett, M. J. *Optical Angular Momentum*. London: Institute of Physics Publishing, 2003