SOUTHERN ILLINOIS UNIVERSITY EDWARDSVILLE

Undergraduate Research Academy (URA)

Cover Sheet

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STUDENT Amy Winkler

MENTOR Dr. Hamad and Dr. Noble

PROJECT TITLE Design of a Laser Using Trivalent Europium Doped Silicate Glass

ABSTRACT: The abstract is a brief, comprehensive summary of the content of the proposal in about 150 words *in plain language*. Reviewers receive their first impression from this abstract. The information needs to be concise, well organized, self contained, and understandable to persons outside your academic discipline.

Since the invention of the laser in 1960, scientists and engineers have worked to find new materials and new designs for lasers and to optimize them. Now laser applications exist in virtually every field of science, industry, and research. The diversity of these applications is possible because of the different types of lasers made available by researchers. The purpose of this project is to design a laser using europium doped silicate glass medium, a medium that has never been used before. This medium emits light in the orange range of the spectra, a frequency that is relatively unexplored in previous research. Although europium doped glass has never been used as a medium for a laser, it has all the properties desired of a lasing medium. The scope of this project is to analyze this medium for its specific lasing characteristics and design a laser cavity for it.

Upon submitting this proposal, I verify that this writing is my own and pledge to fulfill all of the expectations of the Undergraduate Research Academy to the best of my abilities. I understand that failure to do so may result in return of fellowship money to the University and forfeiture of academic credit and honors recognition.

Amy Winkler's Signature
Signature of the Student

I am able, willing, and committed to providing the necessary facilities and to take the time to mentor this student during this project. I verify that this student is capable of undertaking this proposed project.

Abdullatif Hamad and Bradley Noble's Signatures
Signature of the Faculty Mentor

This project is within the mission and scope of this department, and the department fully supports the faculty mentor and student during this venture.

___Oktay Alkin and Tom Foster's Signatures____
Signature of the Department Chairperson

I testify that all necessary research protocols (human, animal, toxic waste) have been fulfilled, and I support this proposed faculty-student scholarly activity as within the mission of the College/School.

___Paul Seaburg and Wendy Shaw's Signatures____
Signature of the Dean of the College/School

Introduction and Significance:

Lasers are becoming an integral part of our society. Almost everyone is familiar with the concept of lasers and most people have come into contact with them, whether through laser light shows at the Science Center or through laser pointers in the classroom. In addition to providing entertainment and highlighting important points on a blackboard, lasers are used by industrialists, information technologists, surgeons, and researchers for a wide variety of applications. Industrialists use highly intense lasers to cut and drill holes in metals [2]. Computer users enjoy the high speed data transfer made possible by transmitting information using laser light [3]. New medical procedures like laser eye surgery would not be possible if not for the highly intense precision and focusable nature of lasers [4]. The variety and diversity of lasers becoming available through the efforts of laser researchers are the reason lasers are becoming a preferred technology in so many fields.

The unique characteristics that different types of lasers can exhibit are what make certain lasers more suited for some applications than others. In laser eye surgery for example, no one wants the same laser used for cutting steel to be the one used to alter his or her cornea [4]. Some of the characteristics that make lasers different from each other are the emitted wavelength (the color of the laser light), intensity, efficiency, and precision. These differences are often due to the medium used to make the lasers, or the laser medium. The laser medium is that active part of the laser that gives off photons, or light particles. The significance of studying new laser mediums is that often new characteristics are discovered which may make new laser applications possible.

In this project, I propose to construct and analyze a laser using the medium silicate glass doped with trivalent europium ions (also referred to as europium doped glass or Eu^{+3}:glass). This medium is produced by melting glass and "doping" it, or inserting new elements or ions, with europium (a rare earth metal). The ground breaking significance of this project is that europium doped glass has never been used in previous laser design and its characteristic wavelength (orange light at 611nm) is one that is not been efficiently produced by any other laser. The construction and analysis of this laser contributes to the growing knowledge bank of lasers and may prove to be a more efficient or cheaper alternative to some lasers in use. In the event that europium doped glass does not prove a usable medium for a laser, the data gathered about its characteristics and the characteristics of the experiment itself may still be of use to other researchers. However, the odds of europium doped glass being unusable to make a laser are very slim.

Separately, europium ions and glass have been analyzed in laser research and are used in lasers like the europium doped yttrium oxide ($Eu^{+3}:Y_2O_3$) laser and the industrial neodymium doped glass (Nd:glass) laser. The $Eu^{+3}:Y_2O_3$ laser was constructed by N.C. Chang at the General Telephone and Electronics Laboratories in 1963 [1]. Yttrium oxide is a type of crystal which can have many undesirable qualities as a host material, or the doping material, as compared to glass. A good example of the crystal versus glass argument is the comparison of neodymium doped glass (Nd^{+3}:glass) lasers with neodymium doped yttrium aluminum garnet (Nd^{+3}:YAG) lasers, both popular for industrial applications. YAG, which is another type of crystal, is a much less efficient medium than glass to house neodymium due to its smaller and more rigid structure [7]. The significance of using europium doped glass may be as great as making a more efficient laser or may be solely in its cheap production. Glass can be mass produced more easily and more cheaply than mediums like crystal making it a potentially cheaper alternative.

Literature Review:

How does a laser work?

A laser is composed of three basic elements: a lasing medium, a pumping agent or energy supply, and a resonant cavity. The lasing medium is the most important element in the design. There are many properties that the medium must have in order to *lase*. First, the medium must emit a photon when it decays from a higher energy state to a lower one. (Not all materials or energy states emit energy in the form of a photon when they decay.) Another requirement is called population inversion. Population inversion occurs when there are more atoms in a higher energy state than in a lower one, or the ground state. Thirdly, atoms in the medium that are in the higher energy state must have a relatively long lifetime, i.e. the atoms should be able to "live" in that higher energy state for some time on the order of microseconds. The idea of a long lifetime relates to the desirable characteristic that photons, or light particles, not be emitted spontaneously, as that reduces the efficiency of the laser. As might be supposed, not many materials exhibit these characteristics and are therefore suitable for making an efficient laser.

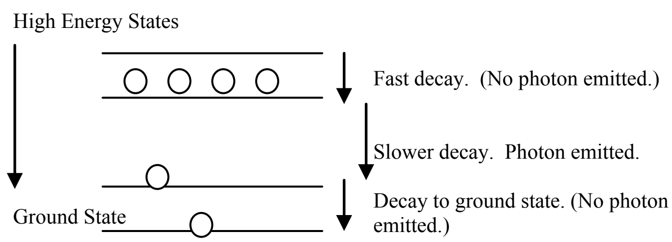


Figure 1 Population inversion diagram showing four energy states.

The next element is the pumping agent, or the energy source of the laser. The textbook *Laser Electronics* refers to the pumping process as the most crucial issue in laser research [7]. The author goes so far to say that any medium (even jello) lases when hit hard enough. The idea behind the pumping agent is that it needs to excite the lasing medium to the appropriate state and produce population inversion so that the medium emits a photon. How the pumping agent and the medium work together to make the lasing action is what makes the laser efficient or not. (Jello has no known pumping agent that could make an efficient laser.)

The last basic consideration is the design of the resonant cavity. The resonant cavity is where the photons emitted by the medium bounce back and forth and amplify by causing the release of other photons. Another way to describe the amplification of the photons in the cavity is to say that they are gaining intensity. The cavity is typically comprised of two mirrors, one almost 100% reflective and the other less reflective. The light that is emitted by the laser escapes through the less reflective mirror. Another job of the resonant cavity is to filter out any unwanted wavelengths or frequencies emitted by the medium. Not all of the energy released by the medium is at the appropriate wavelength and frequency. Occasionally, the medium spontaneously releases unwanted energy into the system. By designing the cavity to an appropriate length, the cavity can act as a filter that only allows the desired frequencies to resonant and amplify.

Development of Some Solid State Lasers

The first laser was developed in 1960 by Dr. T. H. Maiman using ruby as the medium and flash lamps as a pumping agent and emitted an intense red light at 694.3 nm [5]. One of the benefits of using ruby was the widely broadened states to which an atom could be excited. The more widely a state is broadened, the more likely that state is to become excited by the pumping agent. In other words, widely broadened states increase laser efficiency. Ruby lasers can operate at 70% efficiency [7].

Two more lasers, Nd^{+3}:YAG and Nd^{+3}:glass, somewhat motivate the research on europium doped glass because the comparison shows the significance of the medium in laser design. Nd^{+3}:YAG laser, one of the workhorses in the industry, was also discovered in the 1960s and emitted light in the infrared at 1.06μm [6]. It has a high gain and narrow width of broadened states. The narrow width makes Nd^{+3}:YAG a less efficient laser but at the same time lowers the pumping threshold, which is the minimum amount of energy needed to start the lasing actions. Nd^{+3}:glass emits light at the same wavelength of 1.06μm as its predecessor Nd^{+3}:YAG, but the broader states of Nd^{+3}:glass make it a more efficient medium. Glass is a better host in some ways than YAG as it can be made very uniform, can host many different materials, can be polished to a high degree of accuracy, and can be easily produced in large quantities. Due to its inhomogeneous and larger structure, glass can be doped to greater densities than YAG which increases the intensity of the beam emitted. A downside to the use of glass as a host is its poor thermal conductivity which makes the removal of heat from the laser system very difficult [7]. For the laser design in this project, this difficult will have to be addressed. A good cooling system design, therefore, will be crucial to the overall laser design.

A less widely known laser is the europium doped crystal laser discovered and constructed by N. C. Chang who published his results in 1963 [1]. From his results, the candidacy for trivalent europium as an active ion for laser action is essentially proved. The crystal host used in his experiments was yttrium oxide, similar to YAG. The europium laser emitted light at 611nm. Xenon flash lamps, a comparatively inefficient pumping source for europium, were used to excite the medium. The conditions under which his laser performed were at 1.6kV and –50 degrees Celsius (using nitrogen gas as a coolant). The low temperature Chang was able to achieve appears to be a good temperature for the operation of this type of laser, and the use of crystal as a medium was a good choice to achieve that temperature. This temperature is more difficult to achieve using glass and most probably the laser operation for the europium doped glass laser will be at a higher temperature. Chang did face a similar problem as the developers of Nd:YAG lasers by using crystal in that it could not be doped with high levels of the lasing medium europium.

Goals, Objectives, and Operating Hypothesis:

In this project, I hope to show that trivalent europium doped silicate glass is an efficient medium for a laser. Using an optical green pumping agent, the laser should efficiently excite enough europium ions to achieve a population inversion and emit orange light. The host medium silicate glass, while bearing the downside of poor thermal conduction, may prove to be a better host than crystal by allowing higher doping levels of europium and thus a higher intensity of light produced. This experiment will further the knowledge of laser researchers by its precedence. If europium doped glass proves to be a viable laser medium, then more research may be performed on its uses and optimization.

Materials, Procedure, and Timeline:

Materials:

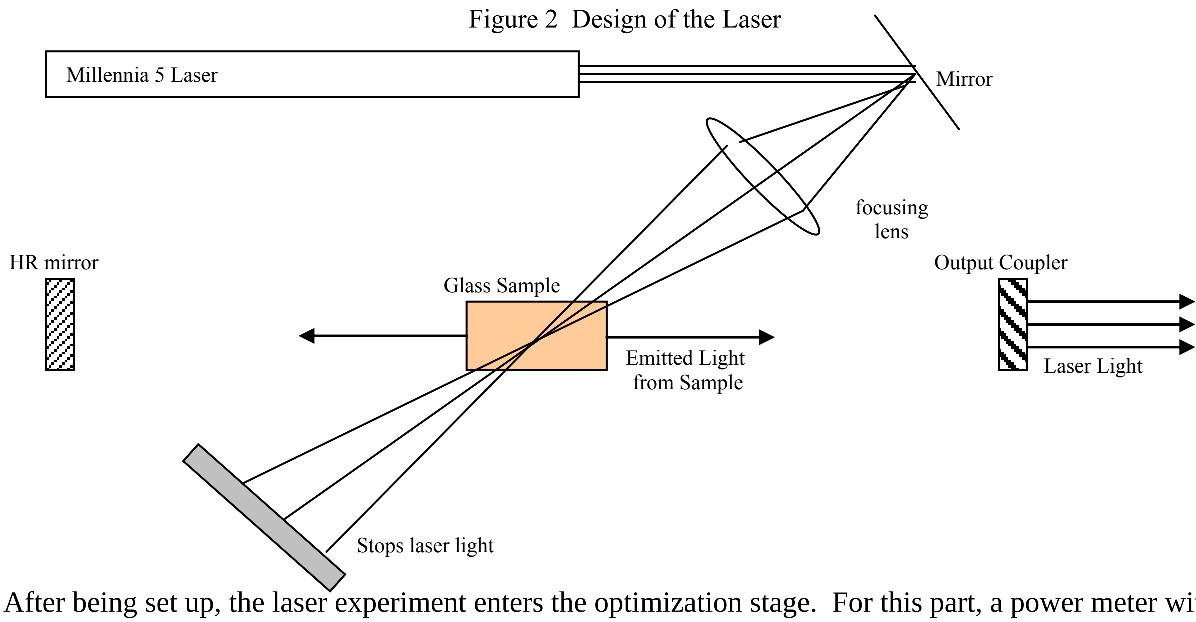
Most materials needed for this experiment are available in Dr. Hamad's lab. Materials needed specifically for this project are the sample of trivalent europium doped silicate glass as the lasing medium; pump laser, or energy source, to excite the glass sample; two high quality mirrors, mirror holders, and translational stages for the design of the cavity; and a focusing lens to focus the pump laser onto the glass sample. The silicate glass sample is doped with 10% europium oxide which is a sufficient amount to emit the orange light. To excite this sample, I use a pump laser that gives an output of 5W green laser light operating at 532nm. This pump laser also includes a chiller, which can be modified to cool the glass sample. For the design of the cavity, two mirrors, one with 100% reflectivity (a high reflection mirror – HR mirror) and the other with 70% reflectivity (the output coupler), are needed. The HR mirror is needed to allow the emitted photons to rebound back and forth through the laser medium allowing amplification to take place. The output coupler assists the rebounding and amplifying action but also allows some light to be transmitted outside the cavity. The light transmitted by this mirror is the output of the experimental laser. The mirrors need to be placed in precision mirror holders that can be adjusted vertically and horizontally for proper alignment. The HR mirror assembly needs to be placed on two precision translational stages (for two dimensional movement) for adjusting the cavity to the appropriate length. A sample holder is needed to cool the sample and should be placed on another precision translational stage for proper alignment between the two mirrors. In order to allow for cooling, the sample holder needs to be designed such that water can flow though it from the chiller.

Procedure:

The first part of the laser design is the construction of the cavity. The cavity construction begins with aligning the mirrors. The mirrors must be perfectly parallel to each other and at the appropriate distance to filter out unwanted wavelengths and allow the orange light (611nm) to amplify. Once the mirrors are properly aligned, the sample, in its cooling holder shown in Figure 3, needs to be aligned with the mirrors such that the released photons from the sample reflect back perpendicularly. This completes the basic cavity construction.

The next step is to focus the green beam of the pump laser (shown in the figure as the Millennia 5 Laser from Dr. Hamad's lab) onto the sample. The green light strikes a mirror which directs it towards a focusing lens. The focusing lens is used to increase the light intensity of the pump laser in order to achieve population inversion. The last stage in the path of the green light is some form of a "stopper," like a dark piece of metal, to absorb the green light transmitted by the sample. This completes the laser set up shown in Figure 2.

Figure 2 Design of the Laser



After being set up, the laser experiment enters the optimization stage. For this part, a power meter with a silicon head or probe is placed in front of the output coupler. This is necessary to monitor increases or decreases in power of the experimental laser while minute changes are made to the laser design in order to maximize power output. Since the most sensitive part of the design is the length and alignment of the cavity, the HR mirror and sample can be adjusted to different lengths and angles to further perfect the length and alignment as much as possible.

The last step in the project is to analyze the laser output. There are many parameters that can be measured in order to characterize the europium doped glass laser. The main parameters are the frequency (or wavelength), the spectral width, and the spatial profile (or energy distribution across the beam) of the output. These measurements can be taken using equipment in Dr. Hamad's lab.

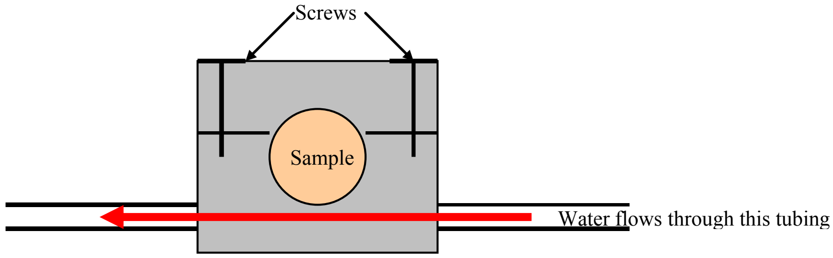


Figure 3 Sample Holder, held together by two screws

Timeline:

Constructing the sample holder (shown in Figure 3) and purchasing the mirror holders and translational stages will be completed in the first months of the Fall semester in order to begin setting up the experiment in the beginning of October. Setting up the cavity, aligning the mirrors and focusing the pump laser, will be done by the end of October. The rest of the semester will be spent on optimizing the laser output. By mid-January, I hope to have the laser functioning properly in order to begin taking measurements and characterizing the laser output. The analysis and characterization will be completed by mid-March.

<u>Budget Justification</u>:

2-Precision Mirror Holders ($100/ea)……………………………………………………….$200
3-Precision Translational Stages ($200/ea)………………………………………………….$600

Total…………………………………………………………………………………….$800

References:

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