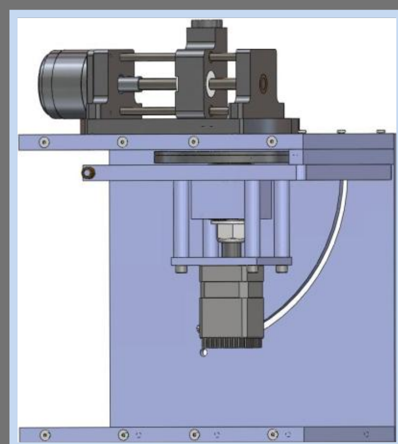
Team 02

Mask-less Photolithography System

ME 450: Design & Manufacturing III (Fall 2009)



Abstract:
Research in the semi-conductor industry is limited by a MEMS micro-fabrication process called Photolithography. The conventional photolithography process is used to create patterns in the micro scale by implementing the energy of light to expose a photo-restive material on a silicon wafer. The conventional process is neither time nor cost efficient. In addition; new machines designed for rapid prototyping are still expensive. Therefore; we developed a cost efficient mask-less photolithography system for rapid prototyping in laboratory environments. The purpose of this report is to discuss engineering specifications, existing technologies, engineering analysis, final prototype, and manufacturing plans. We also included a validation plan, which is included as future work, to verify the performance of the system and determine that all specifications have been met.

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1 Executive Summary

Photolithography entails the patterning of a photo-resistive material on a silicon wafer using the power of ultraviolet light. Conventional photolithography requires a mask, which essentially acts as a stencil to project patterns onto silicon wafers. Dependency on masks complicates the fabrication as a new mask must be generated for each new design. Generating a new mask is neither cost nor time efficient. The goal of this project is to develop and manufacture an inexpensive *mask-less* (without a mask) photolithography system for laboratory settings for use in rapid prototyping of patterns on silicon wafers.

Our Sponsor, Dr. Chronis, has defined a set of top requirements that we must fulfill for the project. Top requirements are that the system should be able to pattern micro-scale features accurately and precisely, relatively inexpensive, small, light weight, and fast. In order to quantify the engineering specifications, we investigated other existing products and determined that the core specifications are: 1) minimum feature size target is10 µm over the entire range of the wafer 2) cost of less than \$1000 3) footprint of no more than 2 x 2 feet^2 and a height of 3 feet 4) weight less than 30 lb 5) patterns should be able to be administered through CNC-like software applications (i.e. TurboCNC, KCAM, MACH 3) and 6) rate of area exposed should be less than 6 cm^2/ min (time to expose the wafer should be less than 15 – 20 min).

Concept generation was done primarily though brainstorming and functional decomposition. We selected three concepts for further analysis. After a rigorous comparison of each concept against the specifications, we determined that the rotating wafer design concept was the most feasible idea that would meet the engineering specifications. We then analyzed each design challenge in details to determine the feasibility of machining, assembling, and testing the system. Our team solidified the final design using SolidWork to determine the processes we needed in order to manufacture the prototype.

The prototype was manufactured with minimum changes to the initial design. The manufacturing plan includes processes such as milling, lathing, drilling, and cutting. We employed an automatic milling machine, automatic lathe machine, drill and band saw machine. The actual budget exceeded the planned budget by \$400. After completion of manufacturing, we were able to successfully control the system via Labview. As a part of the future plan, we will validate our system to determine exposure time, minimum feature size, calibration and alignment of laser position.

We suggest that if the prototype were reproduced, that an exceptionally accurate fabrication method for the fixture assembly should be used. Our prototype is structurally and mechanically sound. The only improvements that could be made would be to incorporate a more time accurate testing software (not LabVIEW), a cRIO, a high resolution DAQ unit, a mounting mechanism for adjuster screws for use on the optical system mounting plate, and an adjustable tray for the pinhole.

2 Introduction

Our sponsor Dr. Nikos aims at developing a mask-less photolithography system for rapid prototyping in a laboratory environment. Conventional systems use masks, which add extra expenses, and current mask-less system are high cost. The system requires competitive minimum feature sizes and that it be made for a fraction of the price posed by existing products. The final prototype could be implemented in the industrial sector because it is less expensive and more time efficient than conventional masked lithography.

3 Literature Review

Based on existing technologies in the field of photolithography and related fields, topics of research included types of light sources and different methods to control the intensity of light in order to create patterns. It is also focused on positioning systems of the substrate and optics. We determined that we can classify photolithography into three main subsets: Masked, mask-less, and electron-beam lithography (E-beam lithography). Mask-less photolithography can be further broken down into programmable masks and laser lithography as demonstrated in Figure 1 below.

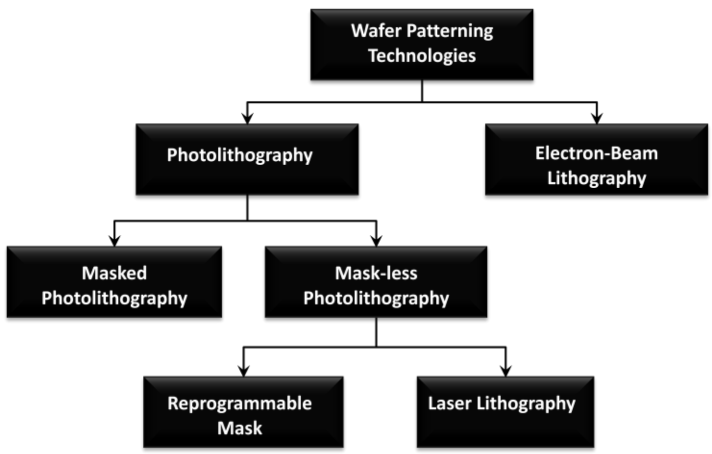

Figure 1: Classification Tree of Existing Technologies

3.1 Masked Photolithography

Photolithography is a manufacturing process mainly used in the semi conductor industry. The process utilizes the energy of light, such as ultraviolet light, to transfer 2-D and 3-D geometrical features through a mask onto the surface of a substrate / silicon wafer. The photo-mask contains the master image, which is transferred onto the wafer [1]. The pattern transfer process consists of two parts: a photo-process, during which the desired pattern is transferred through a photo-mask onto a photosensitive film; and a chemical process which removes unwanted photosensitive material after exposure [2].

Photo-masks pose technical and financial complications effecting quality and final cost of the manufactured silicon wafer. One technical complication of masked photolithography is alignment. Alignment of the photo-mask complicates the process during exposure. When the photo-mask is not perfectly aligned with the underlying layer, regions of the underlying layer may overlap forming what is known as “disorder” [3]. The disordered wafer shows visible faults in its geometrical features [4]. The slightest misalignment jeopardizes the uniform distribution of the electrical resistance [5]. Mechanical shift errors may also occur during exposure of misaligned photo-mask. A financial complication effecting masked photolithography is the high cost of manufacturing photo-masks. The manufacturing cost of the photo-mask continues to rise as the market demand for complex shapes and high resolution patterns increases. The manufacturing cost depends on size of the mask and the complications of the patterns. It also depends on type of raw materials, fabrication process, and special expertise required in manufacturing the photo-mask. The manufacturing cost of the photo-mask accounts for 40% of the final product's cost [6] (however this number will decrease with increasing production volume of chips fabricated).

The complication of using conventional photo-lithography directed the market to focus on alternative methods such as the mask-less photolithography technique. This innovative process has been introduced to the market as an attractive solution that might lead to cost-effective micro-scale lithography manufacturing technique. The process eliminates the use of a photo-mask by introducing more sophisticated optical and mechanical systems.

3.2 Mask-less Photolithography

There are two subcategories of mask-less photolithography: Reprogrammable masks and laser lithography. Reprogrammable masks were found to use two distinct types of technologies. The first technology involves the implementation of arrays of micro-scale mirrors and was found in a patent, and is currently used in industry under Intelligent Micro Patterning, LLC[13]. Each mirror has two positions, one reflects light to the substrate, and the other one reflects light to a UV light sink. By controlling each of these micro-scale mirrors individually, it is possible to achieve minimum features of 15 µm for relatively low costs ($40,000). A schematic of the system, which we have sampled from the Intelligent Micro Patterning web site, is shown below in Figure 2. The Mercury Arc Lamp produces the UV light source which is directed to the "smart filter" or the array of mirrors as described earlier. These mirrors receive a signal from the computer and then reflect light respectively through the optics and ultimately onto the substrate. [7]

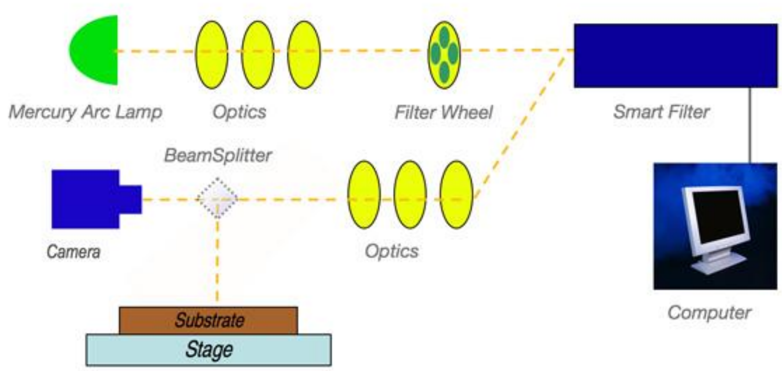

Figure 2: Functionality of the Array Mirrors [13]

The second technology involves the use of a liquid crystal display (LCD) to filter light. This technology however is not yet used in industry. Therefore, detailed information is limited. The

LCD screen has the benefit of varying levels of UV light through the screen allowing the user to pattern in different levels of the photo-resist, as shown in Figure 3 on page 8. The LCD screen can vary the light that passes through from zero to 100 percent. The figure below shows the wafer, part #12, being exposed to light through the mask, part #2. [8]

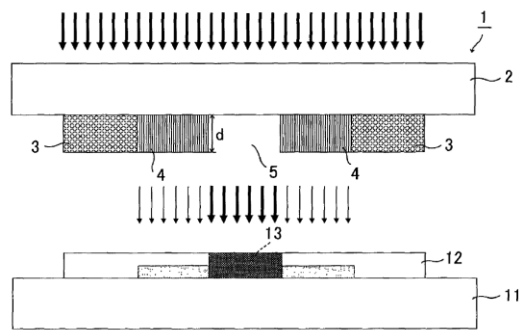

Figure 3: Functionality of LCD Screen [8]

The second classification, laser lithography, implements the reliability of diode lasers. Diode lasers can produce very fine laser beams, with the assistance of optical systems, which can in turn produce minimum features in the area of 1 - 3 µm. We found one system applying this technology that exists in the market today costing $100,000.[14]

3.3 Electron Beam Lithography

Electron Beam Lithography cannot be classified as photolithography; however it is used in industry to achieve the same goals as photolithography does. The technology involved in electron beam lithography is the exact same technology used in electron microscopes, in fact there exists a relatively cheap addition (<$100,000 - http://www.jcnabity.com/) to convert an electron microscope to an E-Beam lithography system. E-beam lithography is capable of high resolutions, or minimum feature sizes, averaging 8 nm. However, this high degree of detail does not come without its drawbacks. E-beam systems are extremely expensive ($1 – 3 million +), and take extremely long to write substrates. For example, one particular system produced by JEOL Inc. requires 18 days to pattern a 1 cm^2 area [9]. However the basic technology implemented in this system, the electron gun, could be of use to us for our prototype. This technology is also used for producing the masks made in conventional masked photolithography due to its extreme precision.

4 Project Requirements & Engineering Specifications

After researching the background information in the field of photolithography, it is then necessary to focus in on the deliverables and the initial direction of our prototype. In order to refine the scope of the project, it is necessary to acquire the sponsor's desired final attributes of our prototype. From these desires, we must arrive at realistic, numerical specifications in order for us to design a sponsor-satisfactory prototype.

4.1 Customer Requirements

The main project requirements, which our sponsor Dr. Nikos Chronis has defined, are that that we produce a working, mask-less, photolithography system for a very low cost in comparison to existing systems. He also requires that the system be accurate (repeatable), precise, and it contains feature that are comparable to similar mask-less systems on the market. He also voiced numerous other characteristics that he would like to see in the final prototype. The physical dimensions should be small enough to fit on a bench-top in a small laboratory, and the system should be light and compact. In terms of the system's user interface, it should have a relatively steep learning curve over time. It should also be easy to use, meaning that the process of designing patterns on a computer interface and transfer said patterns to the substrate should be as easy as pressing the print button on the computer and receiving an image from the printer. The system should also have a quick turnover time to expose the wafer, because this is important in rapid prototyping. Finally the design should be stable, because any significant vibrations will effect overall performance.

After several meetings with our sponsor, we have been able to refine his needs and wants for our final prototype. We list the top seven customer requirements in order of importance in Table 1 below. Our sponsor Dr. Nikos Chronis has confirmed that these are the most important requirements.

Priority	Requirement
1	Cost
2	Competitive features
3	Easy to use
4	Quick Processing Time
5	Small
6	light weight
7	Stability

Table 1: Top 7 prioritized listing of sponsor requirements

4.2 Competition & Benchmarking

To determine the feasibility of our engineering targets, and to determine specific values in which to compare to, we analyze current competitors in our market. Based on our research, there are two mask-less photolithography producing companies who are our closest competitors: Intelligent Micropatterning[13] and Heidelberg Instruments[14]. All known specifications for their products are shown under the Benchmarking section in our QFD chart (Appendix 1).

Intelligent Mircopatterning's XCEL, shown in Figure 4 on page 6, offers a minimum feature size of 15 µm at a cost of $40,000. The price is far out of range for prototyping budget, however the system size and weight are very small, being 20 x 16 x 40 in^3 (DxWxH) and 70 lbs respectively. The background technology employs several arrays of thousands of micro-scale mirrors which are controlled by integrated software, as described in the literature review section in section 3.2. It is able to pattern areas up to 25 in^2 with the addition of the optional manual stage, although this would increase the overall system cost. A mercury arc lamp is focused through optics onto the mirror, and in order to generate a pattern, the computer angles certain mirrors which deflect light away from the substrate.

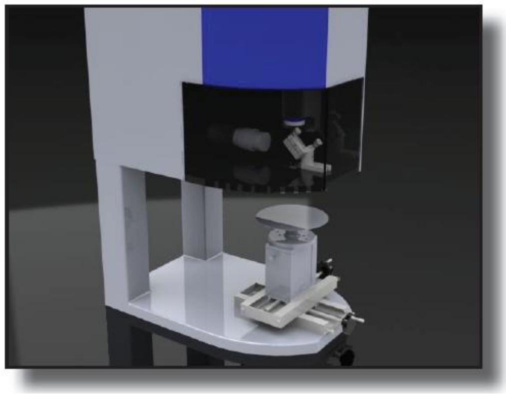

Figure 4:Intelligent Micropatterning's XCEL (Taken from [13])

The Heidelberg Instruments' µPG101, shown in Figure 5 below, also closely matches our project requirements. It produces minimum features from 3 to 1 µm at a cost of $100,000. Although the price for this company's product is even further out of our range, it produces finer minimum features compared to the XCEL. The footprint is 29 x 23 in^2 and the height is roughly 24 in (estimated from picture of the product). The weight was not provided in the product specifications sheet; however the product's write speed was included in the specifications sheet which provides us with a benchmark of 3 – 30 mm^2/min. The technology employed in this design is via a solid state diode laser with a 400mW power output, which is our only benchmark for laser use in the application of mask-less photolithography. It also implements an XY-stage for positioning of the substrate.

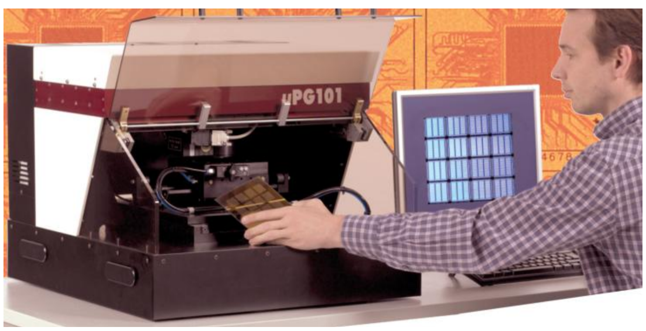

Figure 5: Heidelberg Instruments' µPG101 (Taken from [14])

4.2 Engineering Targets

After determining the requirements for the project and taking a close look at our competitors, we are finally able to convert our basic requirements into quantitative specifications in which we can then use to build our prototype. We determined the specifications based on technologies normally used in industry and direct input from our sponsor. The specifications, in order of priority of completion in comparison to close competitors are listed in Table 2 below. The information for prioritizing is based on correlations from our quality functional design (QFD) shown in Appendix 1.

Priority	Specification	Target Value	Micro Patterning: XCEL	Heidelberg Instruments: µPG101 (3 - 1 µm)
1	Wafer Positioning Precision (µm)	± 5	~	~
2	Cost (USD)	< $1000	$40,000	$100,000
3	Minimum feature size (µm)	10	15	3 - 1
4	Wafer Positioning Accuracy (µm)	± 1	~	~
5	Intensity of light source	200 mW (laser) 200 W (lamp)	200 W	~400 mW (based on a similar model)
6	Computer interface	CAD Software or any Tooling Code Producing Program	Peripheral Software	Peripheral Software
7	Exposure Speed (cm^2/min)	6	~	0.3 – 0.03
8	Patterning Area (in)	3.77 (Diameter)	~	4x4 - 1.2x1.2
9	Footprint (in^2)	13 x 8.5	20 x 16	29 x 23
10	Weight (lbs)	≈ 10.3	70	~
11	Height (in)	14.5	40	~ 24
12	Vibrational Amplitude (µm)	< 1	~	~
13	Optical System	150 x reduction (laser)	~	~
14	Photo-resistive Material	g and h-line	g, h, and i-line	g and h-line
15	Wavelength of light source (nm)	405	360	~

Table 2: A Complete List of Our Specifications vs. Competition's Specifications

The highest priority specification of is the precision of wafer positioning. In order to maintain our high standard for minimum feature size, we need to be certain to a reasonable degree that the laser position is very repeatable. Repeatability will allow the user to pattern multiple wafers with only minor variations between them. Accuracy, although important, is not the highest priority for the purposes of our design. The main area of focus of the design is in rapid prototyping, so if the entire pattern is shifted from the exact center of the wafer, the pattern will still be able to be used for further testing. Only when an entire circuit is made and the entire surface of the wafer is used will accuracy be a large problem. However, we still view it as important to achieve a good accuracy, which is why we have set the accuracy to be ±1µm.

In order to improve the accuracy and precision of wafer positioning, high resolution motors and motor drivers are needed. Servo motors cost hundreds of dollars whereas stepper motors for our application would cost less than one hundred dollars. The benefit of stepper motors is that they do not require closed-loop-feedback to achieve consistent results; they are "feed-forward" devices. However, to achieve the target accuracy and precision in positioning with stepper motors, an expensive motor driver is needed to break down each step into fractions of a step. This high step resolution generates high density digital waveforms necessary to position our wafer and laser sled. This High Speed Digital Input/Output (HSDIO) requires certain data acquisition cards to accurately coordinate. Our provided data acquisition card does not have the required onboard clock required to accurately time our waveform.

The budget was initially set to be less than $400, however, with the high cost of our competitor's products it was clear that budgeting changes needed to be made. Our sponsor has allowed us to invest roughly $1000, with the intention of re-using some of the critical components for a final design in the future. There are many key components of this system that affect the cost. Some of the main components are the accuracy and precision of wafer positioning, complexity and power output of the optical system, and the minimum feature size possible (which is also linked to the complexity of the optical system). Additionally, the higher the power output of the light source, the more money will have to be put into power supplies and the power source itself increases in price.

The drivers for minimum feature size are the size of the pinhole (if used), the number of lenses used, and the power output of the light source. Lenses for our purposes are not extremely expensive (in the range of $25 – 40 per lens)[23], however pinholes and pinhole mounts are expensive, ranging from $50 for the pinhole and $150 + for the pinhole mount depending on how high the resolution of the mount is. This is one of the most important specifications that we have to achieve in our project; in fact, the minimum feature size is the driving force for determining the rest of the specifications in our prototype.

The intensity of the light source drives the maximum area per minute that can be exposed. The greater the power output the faster we can expose the photo-resistive material. Our target intensity should be greater than 200 mW for a laser and greater than 100 W for a lamp source. These targets are based on our benchmarking specifications, and are lower because of the high cost of the benchmark values has the potential of pushing ups past the budget limitation.

The specification for the computer interface is derived from direct input from our sponsor. He would like the system to be used as one uses a printer with documents on the computer. Someone should be able to enter in a pattern, say as an image, and have a program read it and send instructions to the system causing an automatic response and exposure of the substrate. This specification could be satisfied through the implementation of a program that could read a design on a CAD program, and translate the design to G-code, which is standard CNC code. This will be a very difficult specification to satisfy in the timeline of this class.

The initial exposure time suggested by the sponsor was 10 minutes per wafer. We determined that with our competitor's exposure times, it is indeed possible to pattern an entire wafer in 10 minutes. However, for our sponsor's purposes, he may not necessarily be exposing the entire wafer since he is only interested in patterning specific designs, therefore write times could in fact be under his suggested time.

The patterning area is the maximum area on the wafer that we would be able to pattern. Ideally we would like to pattern the entire wafer, however due to design restrictions on the fabrication of the wafer; it is possible that we will not be able to. As shown later, our design only allows for a patterning diameter of 3.77", however as mentioned before, with rapid prototyping, this is not a main concern. Our sponsor has also asked that we leave enough room for the possibility of fitting a 5x5" mask into the assembly; therefore we have taken this into account for the parameters of the assembly design.

The footprint, height, and the weight specifications have all been defined based off of input from our sponsor and benchmarking. Our system should be considerably smaller and lighter than existing systems, such that it could be easily moved by a single person.

The vibration amplitude in the plane of the silicon wafer is very critical to ensure the target minimum feature size. If there is a constant vibration, then features will be inflated by the amplitude of this vibration. To determine the specification, we assume that vibrational amplitudes of no more than 10% of the minimum resolution are acceptable. From this percentage we arrive at the specification for maximum vibration amplitude of 1 μm.

We were unable to find a benchmark for optical systems other than general schematics of optical assemblies. However we determined that for a standard laser beam width of roughly 1.5 mm, the optical assembly should reduce that width by 150 times in order to meet the target for the minimum feature size. If a lamp is used, there may not need to be any reduction in the lamp source unless it would be cost effective to focus the intensity of the lamp over a smaller area, thereby increasing the power output of the system.

There are standard photo-resistive materials defined as g-line, h-line, and i-line. These materials will react below certain wavelengths of light. Specifically g-line will react below a wavelength of 440 nm , h-line below 405nm, and i-line below 360 nm. Our sponsor has conveyed to us that he wishes to use a g and h-line and consequently we chose our target wavelength as 405 nm (blue light).

4.4 Quality Functional Deployment

In order to determine which engineering specifications should take higher priority based off of correlations with the sponsors wants, we created a quality functional deployment (QFD) chart (Appendix A). We determined our priority of specifications from this chart; we also determined how our closest competitors' specifications compared to our engineering targets for our prototype.

5 Concept Generation

We have significantly improved understanding of our project though analyzing sponsor requirements, benchmarking, and determining numerical and non-numerical specifications. In order to analyze the functionalities of our concept, we created a functional decomposition chart [Appendix B]. The purpose of the functional design chart is to both break down main functions into sub-functions, and to study the inputs and outputs of the system. Based on this diagram, we were able to determine that the main functions of our prototype are to constrain the wafer, activate the light source, and position the wafer. The main inputs to our system are the pattern, power to system, the wafer itself, and human interaction. Key losses are due to heat and light.

The subsequent step in concept generation is to brainstorm. We first brainstormed individually, and later we came together as a group to try and generate more ideas. Initial brainstorming was not as limited to sponsor requirements, as the main goal was to produce as many ideas as possible. Brainstorming for this project was extremely difficult due to our limited knowledge of photolithography at the time; however, we managed to produce four potential design concepts.

5.1 CD-Player w/ Laser

5.1.1 Description

This design concept utilizes a rotating fixture to hold the silicon wafer, with a radial moving light source. The fixture will be rotated using a servo / stepper motor and an optical encoder will be used to monitor the position. This rotation will have accurate angular position, velocity, and acceleration. The angular velocity of the fixture is coupled to the radial position of the light source. Maintaining a constant perpendicular velocity is very important because the minimum exposure time of the photo resistive material is constant (due to the nature of the photo-resist). Controlling the radial position of the light source may require the use of a linear motor / linear actuator / ball screw /acme threaded rod and a linear / rotating encoder in order to accurately and precisely position the light source. The concept drawing is shown below in Figure 6.

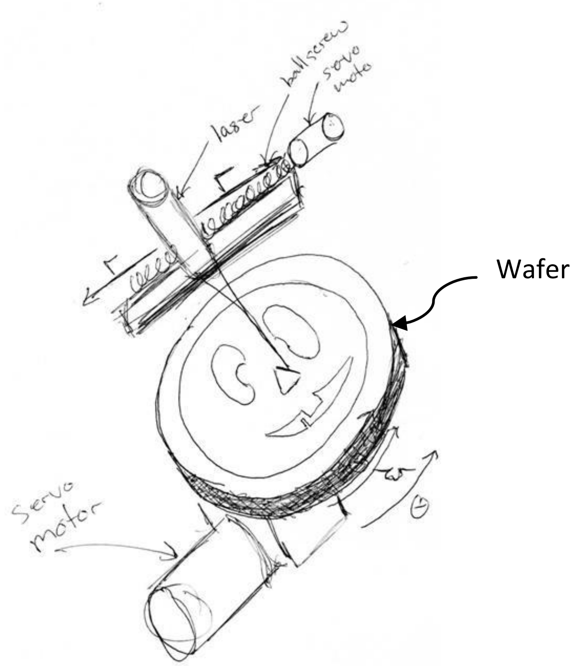

Figure 6: Rotating Wafer Design

5.1.2 Technology Background

The background technology in this concept is derived from the fact that a CD player is capable of writing extremely accurately and very quickly. The concept would employ a conventional blue-ray disk player's laser which has the capabilities to write up to 0.32 μm in the radial direction, and roughly the same in the circumferential direction as can be seen in Figure 7[15]. This technology is well understood, and therefore it may be fairly simple to find resources on the subject.

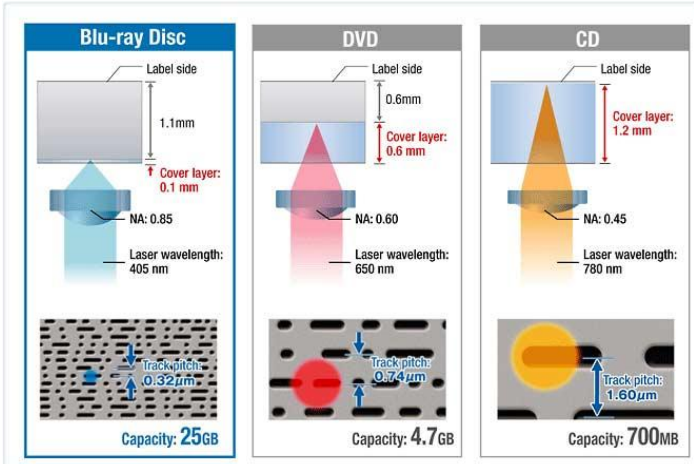

Figure 7: Current Resolutions of Lasers [15]

5.1.3 Manufacturability

This concept would involve a limited amount of custom work. We would only need to fabricate the structures to hold the servo motor, wafer, and laser in place. However, tolerances are very important in this concept, and would cause some difficulties in manufacturing. For example, the fixture must have a primary moment of inertia axis about the center of rotation; otherwise vibrations will cause inconsistencies.

5.1.4 Advantages/Disadvantages

The main advantages are that the system would be relatively cheap to produce (compared to our other concepts), and would be easy to manufacture since most parts can be ordered pre-made (i.e. a blue ray player disk drive). Challenges might arise in the precision and accuracy required to machine the parts that are needed. For example if we need to create our own laser-track assembly, a high degree of precision would be required to machine the parts.

5.2 XY-Stage w/ Laser

5.2.1 Description

The XY-stage, used by most companies in the field of photolithography, inspired the idea of employing a fixed light source and a linear XY-stage to transfer high resolution patterns onto the surface of the wafer. Incorporating the use of automated linear stages is an extremely efficient means to provide reliable and precise positioning. Displacement in the Z direction, however, will be fixed throughout the process with the exception of initial aligning with the laser. A custom made fixture, attached on top of the linear stage will provide a secured positioning system with minimal displacement. The fixed light source, possibly a blue laser, would emit a light that passes through a custom made optical system. The optical system could be an array of mirrors, lenses, or prisms that is securely mounted. In order to decrease the cost, we proposed implementing a laser adapted from a Blue-Ray DVD system as in the rotating wafer concept. The concept drawing is illustrated below in Figure 8 below.

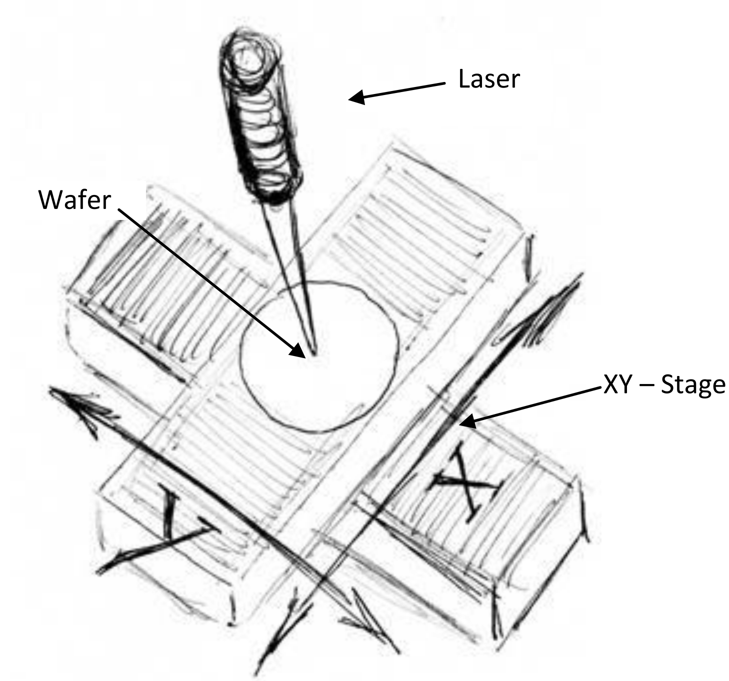

Figure 8: XY-Stage Design

5.2.2 Technology background

The linear stage will be driven by either a stepper motor or a servo motor. The motor will be coupled to a lead-screw shaft directly without any mechanical reduction. The lead screw translates the rotational motion to linear motion with high precision. The choice of the lead screw type will be determined by the specified pitch, which is defined as the distance the stage will move for one complete turn of the lead-screw shaft. By determining the pitch of the lead screw and the steps per revolution provided by the motor, we can determine the resolution of the stage.

5.2.3 Manufacturability

Manufacturability would be simple for this concept. We would order many parts of the design including the XY-stage, servo / stepper motors, the laser assembly, and the optical configuration. Manufacturing an XY-stage ourselves would be extremely time inefficient, and could be a semester long project in itself to produce one with the accuracy we require for our prototype.

5.2.4 Advantages/Disadvantages

As mentioned earlier, the XY-stage will provide high resolution for patterning the wafer. However, manufacturing and assembling the components will add sophistication and complexity to the system. Implementing the linear stage will contribute to more than half of the total cost, which will exceed the budget allowance. Our team proposed designing and manufacturing a custom made stage. However; certain specifications, such as straightness have to be met in order to achieve the required resolution. Implementing lead screws will provide accurate displacement with high resolution of the XY-stage, however lead screws require regular maintenance in the form of lubrication to retain their accuracy. The lead screws should be cleaned and re-lubricated every year or 1000 hours of use to maintain nominal performance. The lead-screw should be wiped clean with a lint-free cloth and new lubricant applied [16].

5.3 Electron Gun

5.3.1 Description

Based on our literature review, we decided to try and find a way to implement the technology of the electron gun. This concept involves a high powered electron gun, four high powered electromagnets, and a high powered and high resolution voltage source (not shown). The electrons would be accelerated through the electron gun, and the four magnetic fields would be supplied specific voltages that would create a vector location for each electron. The wafer would remain stationary throughout the entire process. A concept drawing is shown below in Figure 9.

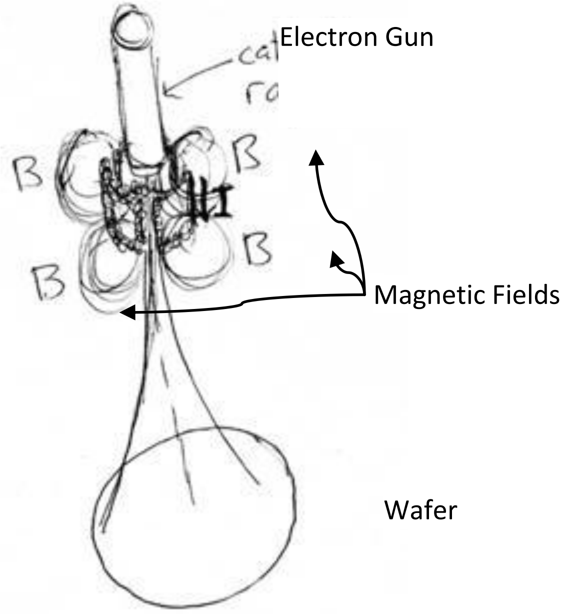

Figure 9: Electron Gun Design

5.3.2 Technology background

The reason we chose to consider E-beam lithography, despite its extremely high costs, is due to the realization that electron lithography is based on the same concept as conventional CRT monitors. The CRT monitor uses a cathode ray tube that works exactly the same way as the electron beam lithography systems, in that there is an anode and a cathode separated by an inert gas in a vacuum, and the electrons are excited through heat transfer and shoot through the anode. The difference between a CRT monitor's electron gun, and the electron guns used in E-beam lithography, is the power that goes into exciting the electrons. E-beam machines need the electrons to go fast enough to remove photo-resist off of the substrate. Electron beam microscopes also implement electron beam collectors which concentrate the beam so that it is small enough to achieve the proper resolution [9].

5.3.3 Manufacturability

This system would be relatively simple to manufacture, because again, all of the parts can be purchased. However, all of the parts that need to be purchased are very expensive (electron gun, power source, electromagnets, ect.).

5.3.4 Advantages/Disadvantages

The system has the potential to produce very high resolution features. However the physics involved is very difficult to calculate (quantum mechanics). The system's power requirements would be extremely high, which would in turn increase the weight of the system due to the massive power supply required. Due to the high cost for capable electron guns and the electromagnetic system, this prototype would be far over budget restrictions.

5.4 Reconfigurable Mask

5.4.1 Description

The reprogrammable mask uses smart glass technology to control the passage of light through the mask. Essentially the design is not maskless, however it still meets the design specifications set out by our sponsor. The design entails the use of two 4 inch by 4 inch pieces of smart glass. Smart glass is a new material which, when electrically induced, changes from opaque to transparent. Each 4 x 4 inch piece of glass is divided into 10 micron strips that are individually controlled. The second piece of smart glass is placed at a 90 degree angle with respect to the first. To generate a pattern, a row and column are activated by an electric current, and where those two lines intersect becomes transparent. This arrangement is outlined in Figure 10. To create a patterned wafer the silicon wafer is first placed in a fixture underneath the reprogrammable mask. A UV light above the mask is then turned on. The pattern is sent to the mask in a grid format and each column is activated one by one. As each column is activated, the associated rows with that column are also made transparent. The pattern is then transferred to the mask.

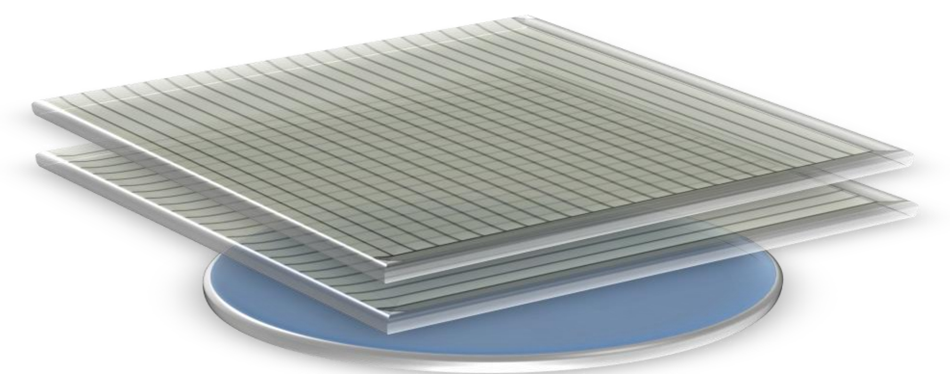

Figure 10: Reprogrammable Mask Design

5.4.2 Technology Background

In order to further understand the functionality of the smart glass technology, we researched the topic extensively. Smart glass, or switchable glass is technology, is used to reduce the heating and cooling costs of a building. During the summer, the switchable glass becomes opaque, or even reflective, to reduce the heating of the building and reduce the cooling costs [17]. Figure 11 on page 14 shows the makeup of the transition metal oxide switchable glass (adapted from 17). The glass is produced by sputtering, a technique that sprays the material onto a substrate in even amounts. This requires an expensive machine to produce said materials.

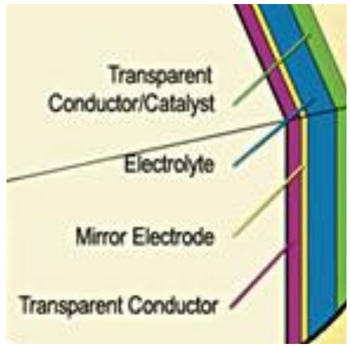

Figure 11: Transition Metal-oxide Switchable Glass

5.4.3 Manufacturability

A difficult aspect of this design is its manufacturability. According to Tom Richardson of the Environmental Energy Technologies Division of the Lawrence Berkeley National Laboratory, the technology required to produce this type of material has not been produced yet. Another issue is creating the independently controlled strips. A method to create these strips is outlined in Figure 12 as adapted from 18. Atomic force microscope (AFM) lithography strips the transition metal layer and creates the needed gap.

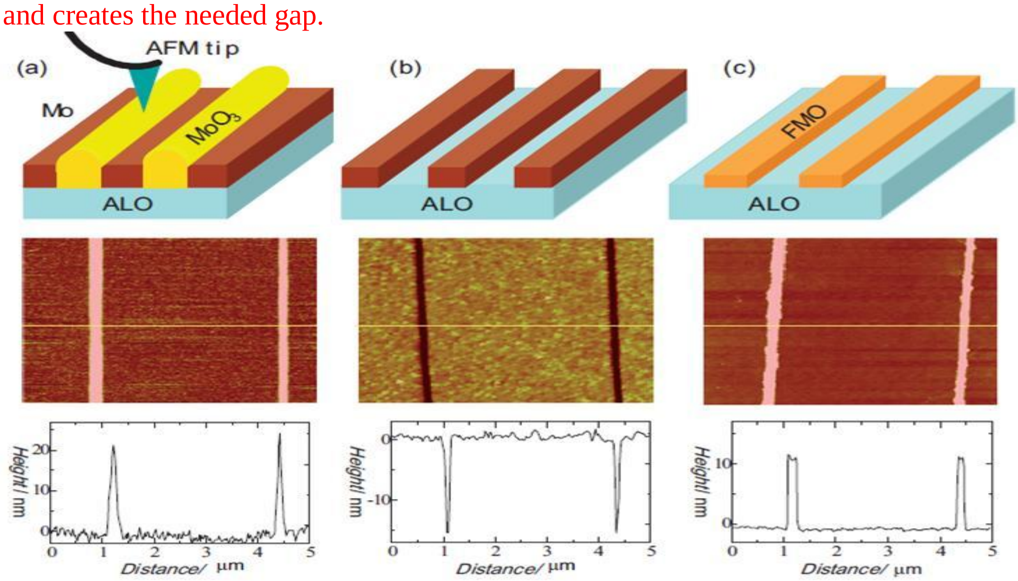

Figure 12: AFM Lithography[18]

5.4.4 Advantages and disadvantages

The main advantage to this design is its industry changing characteristics. No one has created a reconfigurable mask using smart glass technology. The ease of programming and precision are also advantages to this system. This design is simple and effective. However, the cost of to create such a model is well beyond our budget constraints. The cost to create this design is a minimum of two thousand dollars. Also, there are many durability issues. After a few thousand cycles, the metal becomes less transparent.

6 Concept Selection

Each concept is reviewed with consideration of all advantages and disadvantages of the designs with respect to the engineering targets. For comparison purposes we implemented a Pugh chart which is shown at the end of this section. The results of the Pugh chart will ultimately help us select the primary concept design.

6.1 Concept Analysis

Our first task it to objectively consider the advantages and disadvantages of our designs. It is important for us to consider each design equally and to not have a preconceived notion on which design is best.

6.1.1 Rotating Wafer

The rotating wafer design is a low cost design, and is easy to manufacture. A majority of the complicated parts can be taken from existing products and altered to fit our design. The difficulty with this design is combining all parts accurately and achieving high precision. Also, there may be stability issues regarding the vibrations of a spinning disk.

6.1.2 XY Stage

The XY stage can generate highly accurate results. Through our research we have found that the majority of mask-less photolithography systems use such devices for positioning. These systems have extremely high accuracy. The main disadvantage, however, is the extravagant cost of the system in addition to the fact that it is not a pioneering design to implement the XY stage. We have also come to the conclusion that either buying or building a stage of such accuracy is well beyond our allowed budget [16].

6.1.3 Electron Gun

This design has the highest level of accuracy. Consequently this system would also have the highest cost. Initially we believed a simple cathode tube would generate the required electron beam, but a higher powered electron beam is required. Ultimately this device is infeasible for the scope of this project in the time allotted for this course.

6.1.4 Programmable Mask

The programmable mask is a tempting design with high potential. Since this design does not have any moving parts, it is easier for the user to work with and for us to program. Also, the lack of moving parts removes the potential hampering of resolution due to vibrations in the system. However, according to Tom Richardson of the Lawrence Berkeley National Laboratory, the technology is not has not be developed to the point that would make this mask feasible. There are durability issues to the switchable glass. After a few thousand cycles the glass becomes less transparent.

6.2 Alpha Design Selection

We then quantitatively analyze the advantages and disadvantages of each concept and grade them according to the specifications from our QFD. This comparison is outlined in our Pugh chart (Table 3 below).

Specification/ Desired Attribute	**Weight**	**Rotating Wafer**	**XY Stage**	**Electron Gun**	**Programmable Mask**
Wafer Positioning Precision (µm)	7	2	3	4	1
Cost (USD)	6	4	2	1	3
Minimum feature size (µm)	5	3	2	4	1
Wafer Positioning Accuracy (µm)	4	2	3	4	1
Exposure Speed (cm2/min)	3	3	2	1	4
Weight (lbs)	2	4	2	1	3
Vibrational Amplitude (µm)	1	1	2	3	4
Ease of Use	4	4	2	1	3
Ease of Fabrication	3	4	3	2	1
Ease of Programmability	2	4	3	1	2
Uniqueness	1	3	1	2	4
	Score:	**118**	**91**	**92**	**79**

Table 3: Pugh Chart

From this qualitative comparison, it is easy to see that our selected concept choice is the rotating wafer design. The main reason for this choice is the low cost coupled with easy fabrication and high precision and accuracy. These reasons and the results of the Pugh chart lead us to choose the rotating wafer as our alpha design.

7 Selected Concept Description

The spinning wafer concept consists of three main sub systems / assemblies, the table assembly, the laser assembly, and the fixture. The laser assembly is the upper portion of the overall design floating above the table assembly, as seen in Figure 13. The laser assembly consists of the laser frame, laser, optical lens, laser sled, ball screw, servo motor, linear bearings, and linear/rotary optical encoder. The table assembly is the dimensionally larger portion of the design as seen in Figure 13 on page 17, comprising of the fixture, shaft, bearings, motor, motor plate, motor mounting poles, bearing block, main plate, and main support poles. The fixture is shown between the main table plate and the laser assembly, and its function is to secure the wafer.

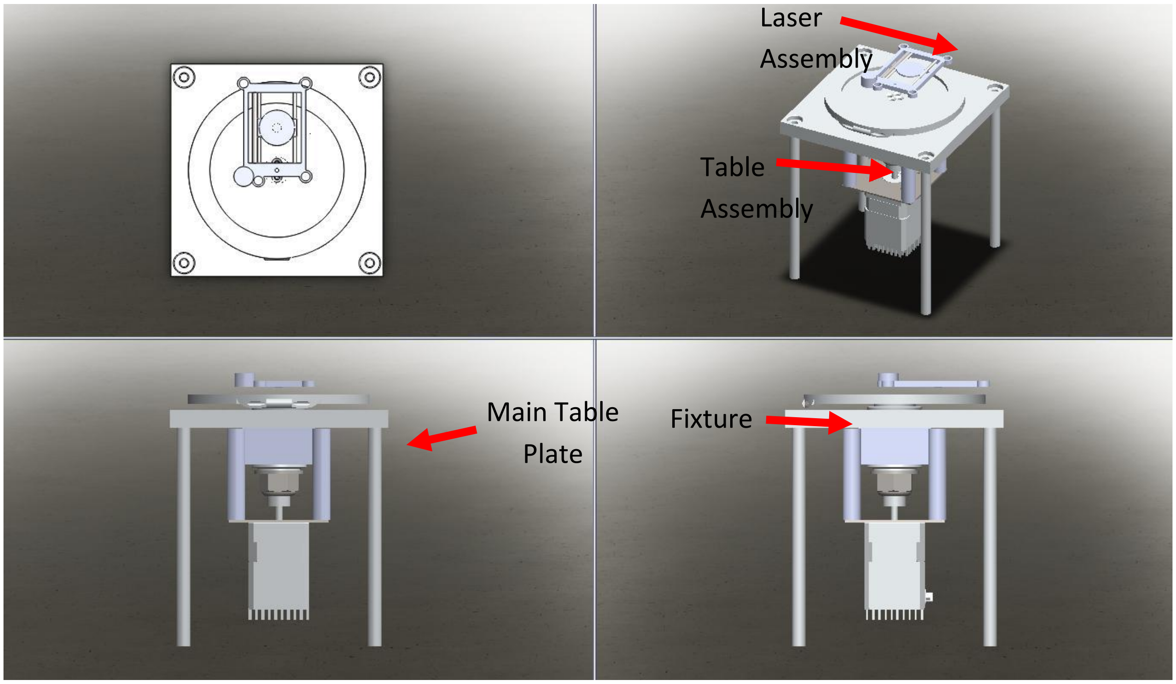

Figure 13: Alpha Design

7.1 Laser Assembly

The laser frame is the main support for the entire laser assembly, it holds everything in place. The laser and optical lenses are all incorporated in the laser sled, which has linear bearings that allows it to glide along the path of the linear bearing shafts. For precise motion control of the laser sled, a (zero back lash) ball screw is used to convert rotational motion into linear motion. The motor is attached to the ball screw, which rotates the ball screw. The motor has an integrated encoder for relaying the position of the laser sled. This is shown in Figure 14 below. Most likely we will have to make modifications to the existing laser sled assembly in order to achieve the required patterning area.

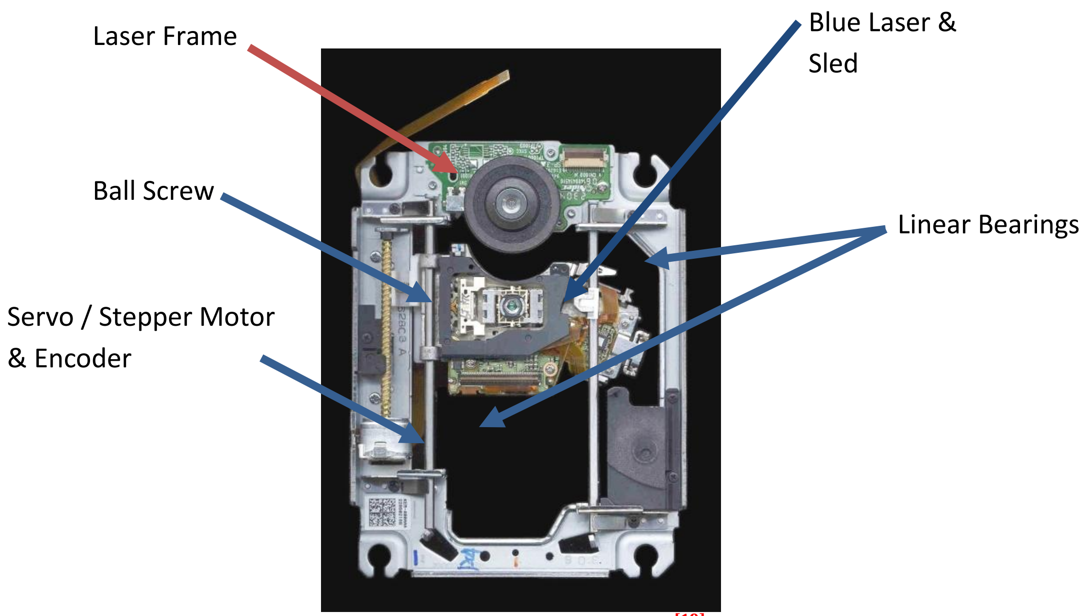

Figure 14: Laser Assembly [19]

7.2 Table Assembly

The main plate supports the entire table assembly by the main support poles. Attached to the main plate is the bearing block, which houses the tapered roller bearings. At the top of the assembly the fixture is attached to the shaft that runs through the bearings in the bearing block. Using a nut at the end of the shaft the bearings are sandwiched, self aligning the shaft and fixture so that the motor can be properly attached to the shaft. The motor is attached to the shaft by a set screw. The motor is attached to the main plate through the motor mounting poles and the motor mounting plate. This is shown in Figure 17 below.

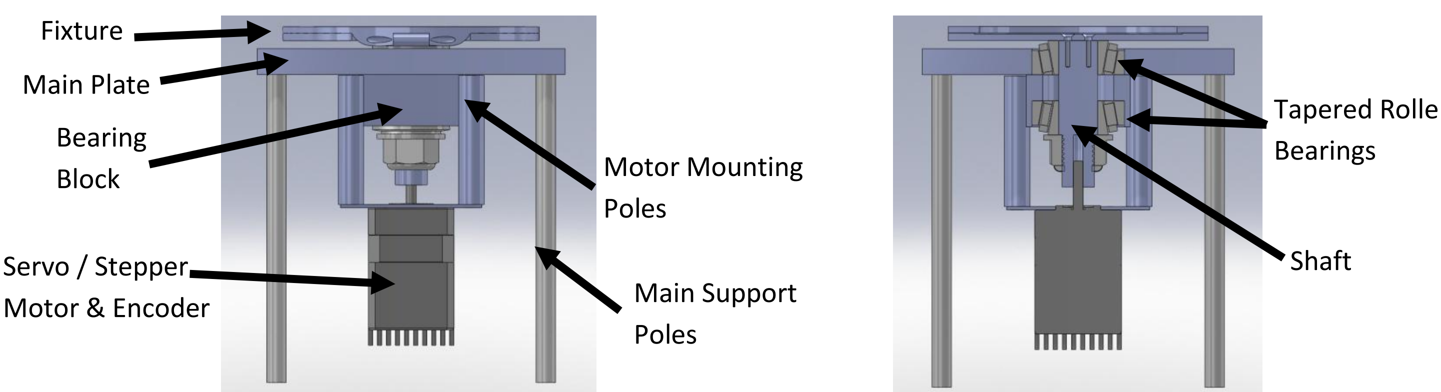

Figure 15: Table Assembly

7.3 The Fixture

The fixture will be bolted onto the shaft via four screws in the center of the fixture. The fixture has been designed such that the user can easily open, close and latch the part closed. In order to ensure that the wafer does not rotate inside of the fixture, a soft rubber O-ring will be applied to the inner lip of the fixture, which will provide enough pressure to fix it. A figure of the fixture is shown below in Figure 16.

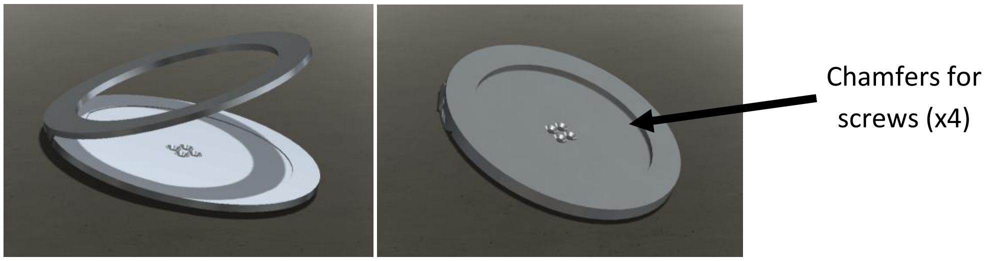

Figure 16: The Initial Fixture (Left = open; right = closed)

8 Engineering Design Parameter Analysis

In order to further develop our selected concept, we performed very thorough engineering analysis on the distinct topics of: optics, statics, dynamics, and controls.

8.1 Optics

Based on our specifications for a laser, we needed to find a diode laser which has a power output between 200 and 400 mW with a wavelength of 405 nm in order to expose g and h-line photo-resistive materials. To achieve that target minimum feature size, we must decrease the final beam diameter to 10 µm. If we do this using only a 10 µm pinhole, we would lose significant power unless we use very high powered lasers. Because high powered lasers are out of our budget range, we need to be able to shrink the initial beam diameter, thereby focusing the intensity of the laser to a smaller area so that we can achieve higher power outputs through the pinhole. The most feasible way to do this is a via an afocal dual-lens system which would shrink the beam diameter, without losing the benefit of the initially collimated light source. An afocal lens system consists of two single-sided convex lenses

In order to determine how many times an afocal dual-lens lens system reduces the beam diameter, we divide the focal length of the larger lens by that of the smaller one. Since we need to move from the standard laser beam diameter of 1.5 mm to 10 µm, we would need a beam reduction of 150 times. Based on restrictions in size of the system, we determined that smaller lens diameters would be more fitting for our project. As a result we decided to use a 6 mm lens with a 72 mm focal length, and a 3 mm lens with a 3 mm focal length which will reduce the initial beam diameter by 24 times. These lenses should also be coated with Magnesium Fluoride (MgF_2), which provides a completely uninhibited transfer of light at 405nm. Cost effecting lenses with 500 mm focal lengths do exist, however, a 503 mm (roughly 20 inches) in height lens housing would be very tall and therefore unstable.

We must determine the Depth of Focus (DOF), or Rayleigh Length, to make sure that the lenses are spaced at the appropriate distance apart (i.e. ensure that the focal lengths intersect). The DOF is the distance from the focal point, where the light is approximately collimated. To calculate this, we must first find the beam waist w_o. The relationship between this value and the laser beam wavelength λ, and the divergence angle θ are shown in equations 1 and 2[10].

$$w_0 = \frac{\lambda}{\theta \cdot \pi} \qquad \text{Equation 1}$$

$$\theta = \tan^{-1}\frac{R_{l1}}{FL_{l1}} = \tan^{-1}\frac{R_{l2}}{FL_{l2}} \qquad \text{Equation 2}$$

With w_0 we can calculate Z_0 using equation 3.

$$Z_0 = \frac{\pi}{\lambda} \cdot w_0^2 \qquad \text{Equation 3}$$

The depths of focus in determining the tolerances of the optical assembly. We have calculated the depth of focus, Z_0 to be 75 micrometers by using equation 3. This value is the addition of the two depths of focus to ensure that the two depths of focus coincide.

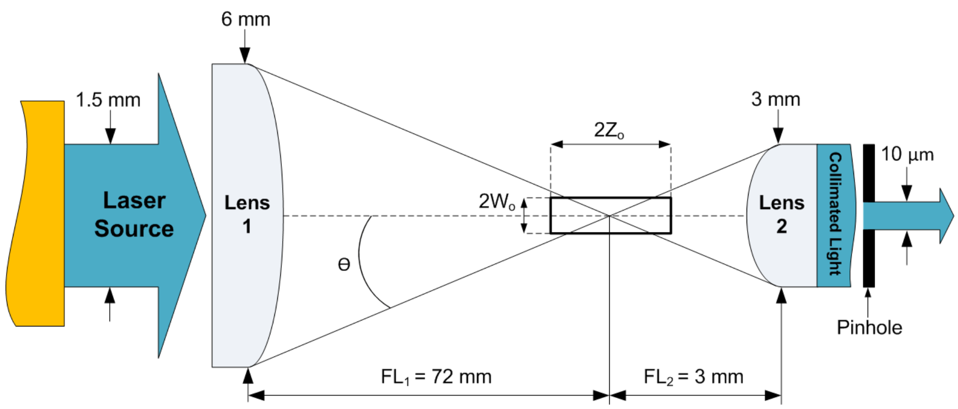

Figure 17: Optical Parameters of the Double-Convex Lens System

***Not to scale**

After we reduce the size of the laser, the laser power output will change. We must determine the power output to calculate the exposure speed. The user will be able to input the given exposure energy in mJ/cm^2 in LabVIEW. Using the power output and the exposure energy we can calculate the exposure time. To calculate power output, we used equation 4 which relates power output P to original power of the laser P_0, radius of beam w_0, and radius of pinhole r.

$$\boldsymbol{P = P_0 * \left(1 - e^{\left(\frac{-2r^2}{w_0^2}\right)}\right)}$$

Equation 4[10]

Starting with a laser that outputs 200 milliwatts, we achieve a 10 milliwatt output through the pinhole onto the substrate. Using a photo-resist with exposure energy of 100 mJ/cm^2 we can pattern the substrate at 6 cm^2 per minute. [24]

8.2 Dynamics

Our design uses the high speed rotation and control of a fixture. To do this we use a stepper motor. We need to make sure that we select a motor that can handle the required torques. The torque of the motor determines the angular acceleration we can achieve. The higher angular acceleration we have the faster we can resist a wafer. In our design, we will not only need to speed up the wafer at the start of the exposure, but also between radii to ensure an appropriate exposure time. In the previous section we determined the output of the laser to be 10 milliwatts per 100 μm^2. Using the exposure energy of 100 mJ/cm^2, we determined that the maximum tangential velocity is 1 m/s. This is outlined in equations 2 and 3. E is the exposure energy; P is the power output of the laser.

$$\frac{E/100\mu m^2}{P/100\mu m^2} = t/100\mu m^2 \qquad \textbf{Equation 2}$$

We pattern a 100 μm^2 portion at one time, therefore,

$$\frac{1}{t/_{100\mu m^2}} * \frac{1\,meter}{10^5\,(10\mu m)} = t/_{100\mu m^2}$$ **Equation 3**

For our model, we will pattern each radial position of wafer at a time. After the points at a certain radial position are patterned, the laser sled moves to a new radius. With this relationship we can derive a relationship between angular acceleration and time. We analyze this relationship to determine the maximum angular acceleration needed. The sled moves 1.58 microns per radial increment. The sled moves inward once per revolution. We determine the radial position of the sled as a position of time using equations 4 and 5 . In this equation r is the radial position,

$$\frac{dr}{dt} = 1.58 \cdot 10^{-6} \cdot 2\pi\omega$$

Equation 4

$$\omega = \frac{V}{r}, where\ V\ is\ the\ tangental\ velocity\ at\ 1\ m/s$$

$$\frac{dr}{dt} = \frac{1.58 \cdot 10^{-6} \cdot 2\pi}{r}$$

Equation 5

We then integrate equation to find the radial position with respect to time. This new relation is outlined in equation 6.

$$r = .0508 - .004456\sqrt{t}$$ **Equation 6**

We then relate the angular velocity to the constant tangential velocity and the radial position and then differentiate this relationship with respect to time to find the angular acceleration with respect to time. This last function is shown as equation 7.

$$\alpha = \frac{0.00223}{(0.0508 - 0.00446t^{.5})^2 t^{.5}}$$ **Equation 7**

We set the maximum angular velocity to be 1000rpm. We then find the radial position of the sled that correlates to that angular velocity and the tangential velocity of 1 m/s. We then find the time it takes to get to that position and insert that time into equation xx to find the maximum angular acceleration. The maximum angular acceleration turns out to be roughly 9 radians/sec^2. However, for our stepper motors to remain highly accurate, we must make sure that the applied torque remains as far away from the maximum torque of the motor as possible. As shown in Figure 18, the torque at 1000 rpm is roughly 38 oz-in. We then determined that the rotational inertia of the shaft, motor and fixture from Solidworks. This value, 1.11 lb-in^2, along with the torque of 38 oz-in is inserted into equation xx to give us a maximum angular acceleration to be 832 radians/sec^2. This gives us a large factor of safety and high precision in our positioning system. .

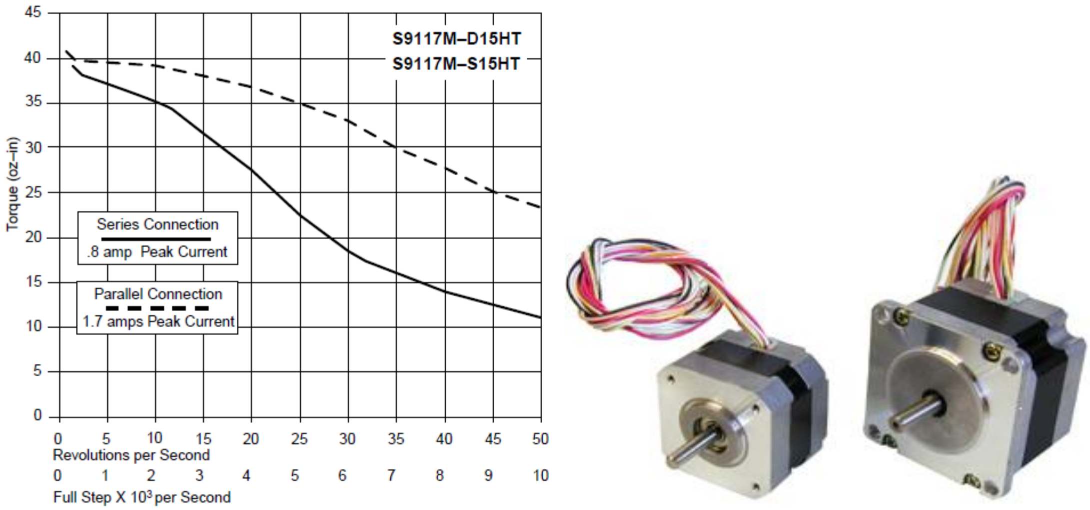

Figure 18: Torque curves for stepper motor. Dashed lines are for purchased motor.[25]

8.2.1 Bearing Life

We are using a tapered roller bearing to hold the weight of the fixture. When using bearings, it's important to find the lifetime of that bearing. The equation that determines the life of a tapered roller bearing is outlined in equation 4. L_D is the lifetime of the bearing in rotations, L_{10} is the catalogue lifetime of 1 million rotations, C_{10} is the catalogue rated force and F_D is the force on the motor.

$$L_D = L_{10} * \left(\frac{C_{10}}{F_D}\right)^{\frac{10}{3}} \qquad \text{Equation 8}$$ [26]

After calculating the lifetime of the bearing we have determined that it is not a factor in the longevity of the device. The lifetime of our bearing is in the range of billions of years. [27]

8.2.2 Vibrations

Vibrations in the plane of the wafer are an important piece of this project that we have to consider. Theoretically of course, there should be no vibrations at all. However, we are restricted by the accuracy of machining instruments in such a way that there could be imperfections that would cause significant vibrations. However, to accommodate for these inaccuracies in machining, we will overbuild the fixture system such that vibrations should be avoided. Also, some vibrations are generated from the stepper motors. We reduce this occurrence by using micro stepping motor drivers that are specifically designed to reduce vibration.

8.3 Statics

We determined that the most probable locations for failure are on the shear stress which holds the screws together. Our system has been overbuilt do accommodate for all of the static loads, however for completeness we have attached FEMA in Appendix H.1.

8.4 Control

We will use LabVIEW to control the positioning of the laser and wafer. We are using stepper motor driver boards to move the motors and to increase the resolution of the positioning system. The stepper motor driver used for the wafer positioning system enables us to have 51,000 steps per revolution. This gives us a resolution of 6 microns at the outer edge. The stepper motor driver board for the optical system allows for 3200 steps per revolution. Combining this with the 40 turns per inch worm gear allows for 128,000 steps along the radius of the wafer. The combination of these two positioning systems allows us to achieve the desired resolution. Figure 24 shows the microstepping motor driver for the wafer positioning system. Information regarding how the dynamics of the system affect the fixture, see Appendix H.2.

Figure 19: USDIgital's MD2S Microstepping Motor Driver [27]

Both the stepper motor drivers and the laser take a pulsed input from LabVIEW. Being able to coordinate pulses allow us to accurately time the positioning of the wafer, positioning laser and turning on of the laser.

8.4.1 LabVIEW coding

To accurately control the position of the wafer, we must derive a the positioning code using LabVIEW. The driving motive behind the LabVIEW code generation was to coordinate the motion between the two motors and the laser. We determined that the best method in completing this task is to generate a coordinated waveform of ones and zeros to be sent to the motor and laser drivers from the data acquisition unit. This enables us to be certain that the three components are synchronized and ensure us the accuracy that we need. For use to use the digital waveforms, we had to implement the use of the low level DAQmx VI. We are able to send digital signals over multiple lines at the same time. The digital waveform is first generated based on a JPEG picture. The JPEG must be set to 1500 pixels per inch and 256 RGB color format. The picture must also be a 10-1 size reduction. We suggest using Microsoft Visio because of its unique shapes and design that can be implemented. The LabVIEW coding used to create the digital waveform is shown in Appendix xx. After the waveform is created and saved, we can easily output to the data acquisition unit using DAQmx VI.

The use of this LabVIEW coding is quite complex, so we also used coding we could use to test the motors accuracy. This coding is shown in Appendix xx. This coding can position the wafer and the laser sled in either direction. We used this to verify the motor's position accuracy.

9 Prototype Description

9.1 The Fixture

Initially the fixture was designed as a hinged cover as described in the selected concept section. However, after further development of the concept, we determined one key problem with this design: it was not symmetrical about the point of rotation, and this would induce significant vibrations. A change in design was needed, and as a result we analyzed many different designs.

All rejected concepts for the fixture are outlined in Appendix D.1, including the initial fixture design. We chose the design shown in Figure 20 below. This fixture will be secured by four high thread count screws, and a rubber O-ring (shown on Side B of the top part of the fixture) will apply pressure to the wafer to ensure that there is no relative motion between the wafer and the fixture. The fixture will be attached to the motor shaft, as described in the chosen design description (section 7.3 on page 19). The key difference in this design is that it is perfectly symmetrical and recesses are built into the fixture so that removal of the wafer is easier.

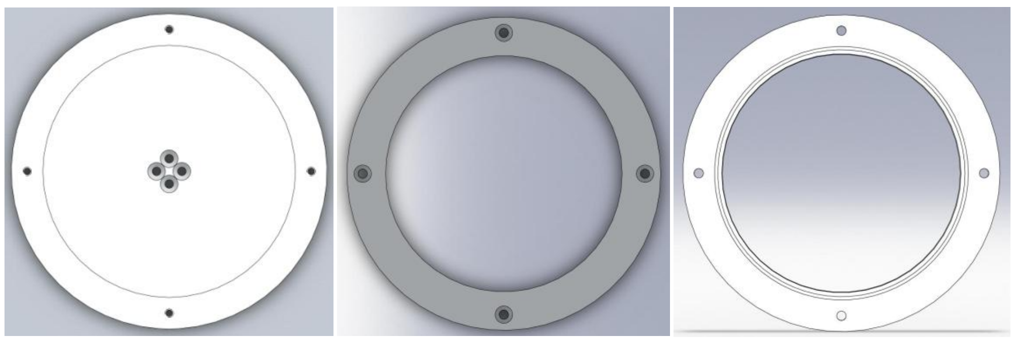

Figure 20: Design for the Fixture

This fixture design answers the problem of symmetry vs. simplicity and removal of the wafer from the fixture; however, there is still a small portion of the wafer that is missing which prevents a perfect circular shape. This missing piece could possibly throw off the inertia of the assembly, and needed to be analyzed. After looking deeper into this potential problem, we calculated from SolidWorks that the mass fraction of the missing piece of wafer divided by the total mass of the fixture + wafer was negligible. Therefore we can neglect vibrations due to the missing mass of the wafer. Figure 21 shows the fixture assembly with wafer.

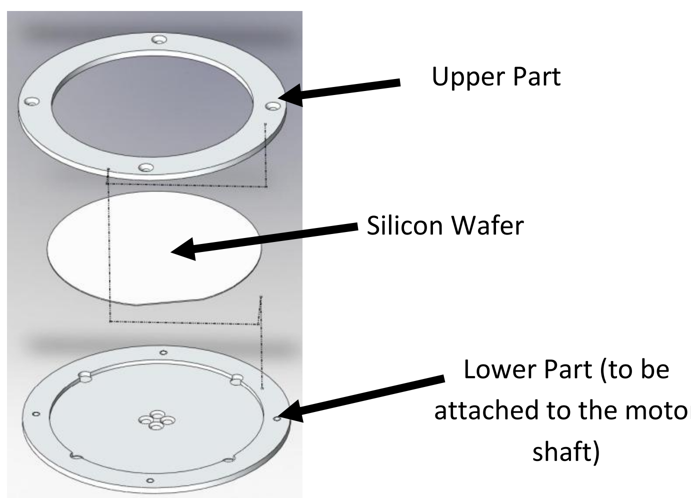

Figure 21: Fixture Assembly with Wafer

9.2 Table Assembly

Another design challenge arises when we have to remove the wafer from the fixture. Since the wafer will lie directly underneath the laser assembly, we must find a way to either move the entire table assembly or the entire laser assembly for better access to the fixture. There were a few other concepts which we considered, and those are shown in Appendix D.2. We finally decided that we would choose the design outlined below in Figure 22: Table Assembly.

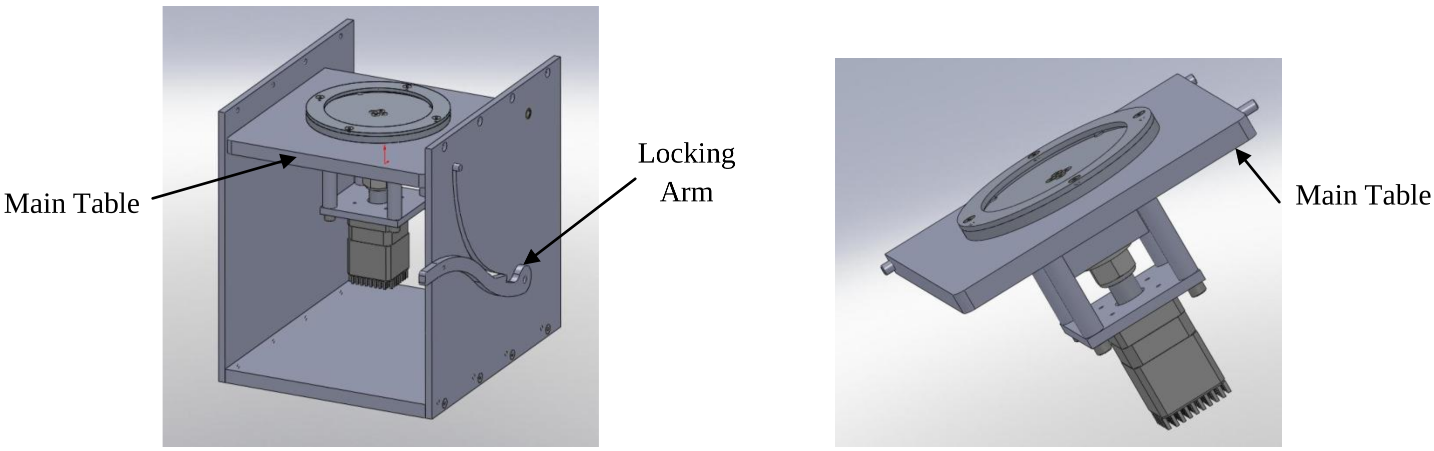

Figure 22: Table Assembly

It is a rotating table assembly which is comprised of the fixture, fixture shaft; bearings, bearing block, and motor. The entire assembly rotates downward (into the page), locking into position via the locking arm, allowing easy access and removal of the wafer from the fixture.

Aside from the implementation for rotation of the design plate and the locking arm, everything else in the table assembly from the initial concept description remained the same.

9.3 Laser Assembly

The initial concept was to implement a modified blue-ray track, however, after further consideration, it has been determined that we cannot employ that concept. Although a standard blue-ray drive may indeed have the accuracy and the resolution to meet our engineering targets, we could not determine how to control because the inputs to control the device are far greater in number than we had expected. Information upon the inputs was not readily found and companies were not willing to distribute the information. Also the distance of travel for the integrated acme threaded rod is only about 1.5 inches, while our design target is for two inches of travel. Based on the setbacks in the implementation of a standard Blue-ray DVD drive, we resorted to designing our own laser assembly.

The main function of the laser assembly is to position the laser beam radially across the spinning wafer surface. After we brainstormed and concept generated on how to actuate the laser we came to our prototype laser assembly shown below in Figure 23. We generated one more concept which is described in Appendix G.3. The main components of the laser assembly are the laser sled, the linear bearing shafts, the linear bearing supports, the acme threaded rod + nut, and the motor. We designed our laser assembly to have 3.5 inches of travel radially, and through a series of lenses and a pinhole, and a theoretical 10 µm spot size.

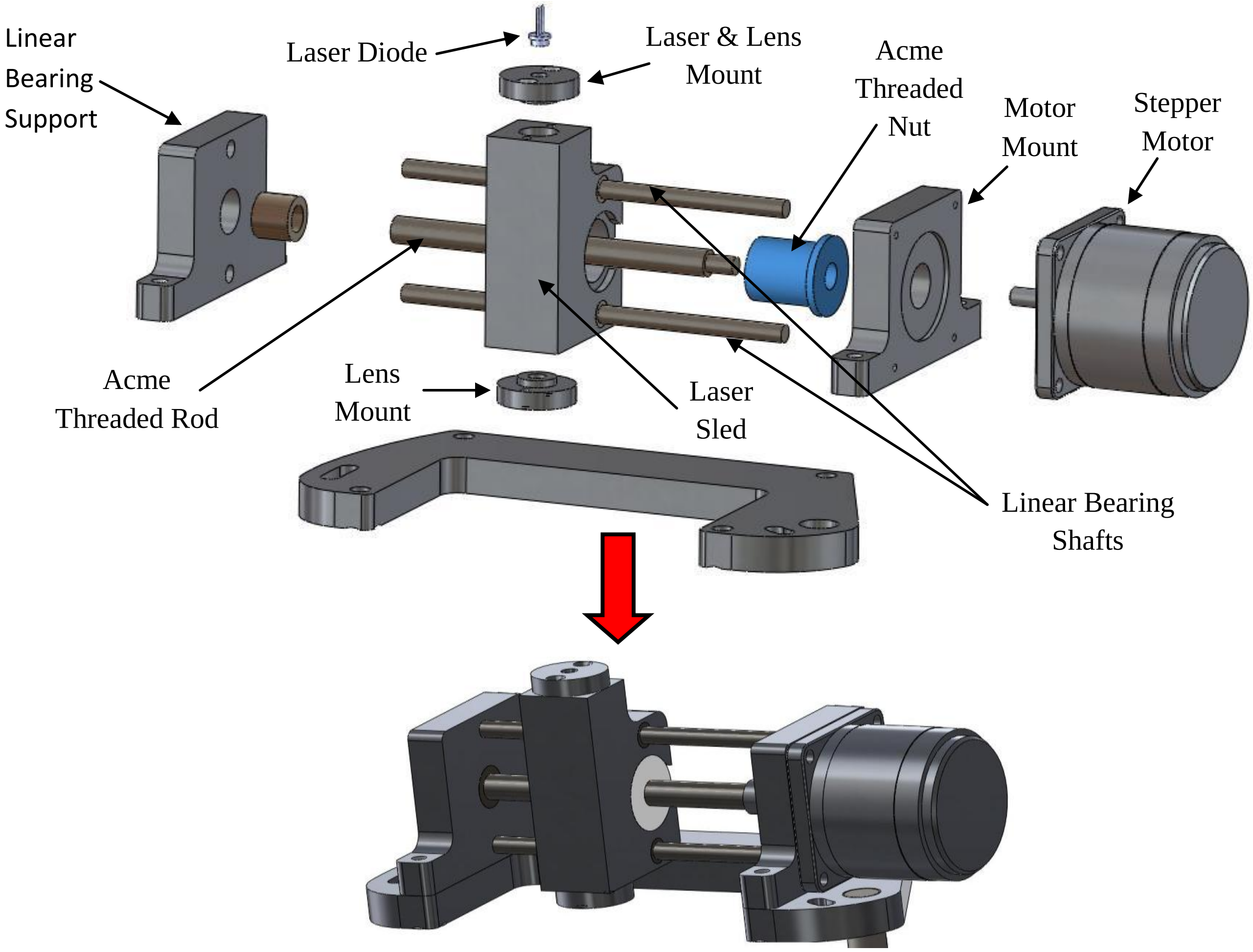

Figure 23: The Laser Assembly

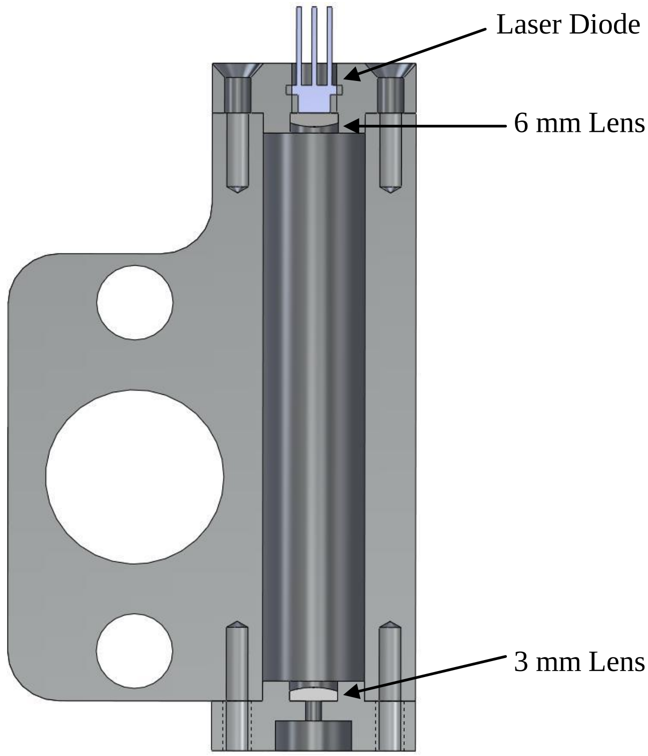

Figure 24: Cut-away of the Laser Sled (3mm lens not to scale)

9.4 The Chassis

The chassis is a new yet clearly anticipated development since the initial concept description, and is shown in Figure 23 below. Although the chassis is simple in nature, it is by no means a trivial piece of our design. It provides three main features: supports the entire system, encloses the laser assembly so that no laser light can reach the users eyes (safety), and the locking arm is incorporated into it to hold the table assembly in place for removing the fixture (ergonomics). The issue of whether or not it would be easy to access the fixture came up when designing the chassis. In order to prove that this design would function well, we assembled a rough prototype of the chassis + table assembly shown in Figure 25. Our group member with the largest hands is shown reaching into the assembly, and it can be seen that there is enough room to access the fixture.

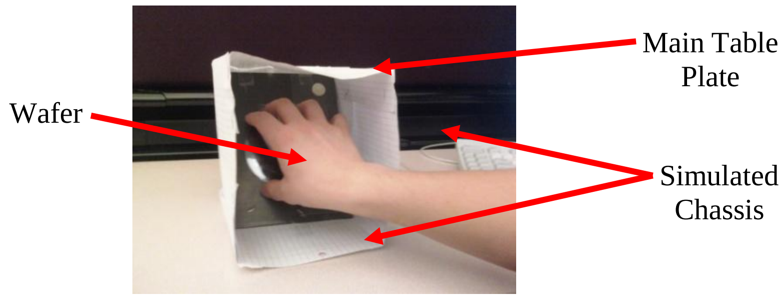

Figure 25: Rough Prototyping of the table assembly

9.5 Final Design Description

During the design process, we analyzed all aspects of fabricating and assembling the parts that constitutes the system with the machining processing and limited budget at our disposal. Therefore; our prototype was upgradeable to a final design with minor changes. Furthermore; the system is fully functional and performance of further validation will ensure that all engineering specifications have been met except the requirement for the minimum size feature.

The mechanical components of the final design such as shafts, screws, stepper motors and chassis have not changed. They however required about $100 extension in the budget. The design of the fixture of the final design can be optimized and down sized to reduce the raw material used to construct it. However, for its purpose of providing maximum stability of the wafer and sustainability of loads while rotation, the fixture is sufficient.

As an improvement upon our prototype, a proper wire harness to route the wires is considered as a part of the design plan in order to lower the chances of high current noise. In order to achieve this step, proper mounting positions for the supplies and motor drivers was considered. As a result of the limited budget, we could not purchase a dependable and certified laser diode. We sought an alternative route to purchase an inexpensive laser diode. Even though we were able to purchase a laser diode that was previously implemented in a CD-ROM, it was inoperable because it was missing the wiring map.

Also due to the limited budget, we could not purchase the DAQ unit with an on-board 1 MHz clock. Purchasing such a component is extremely important to achieve the required speed of the stepper motor operating the fixture. We also implemented a TTL driver and limit switch for the laser assembly, which were not a part of the design plan, ensure that the system is capable of maintaining its reference position in case of improper shutdown.

We also upgraded the micro-stepping driver of the laser assembly with the MD2S micro-stepping motor driver, which is used to control the stepper motor of the fixture, to improve the accuracy in the radial position. We also decided not to pursue the purchase of a high end optical encoder as we planned to control the system via an open loop rather than closed loop feed-back system. The optical encoder, of choice is CP-950-HHC High Resolution Encoder from Allied Motion, produces up to 1 million pulses per revolution at a rate of 2MHz. An optical encoder at the end of the laser assembly motor will also give us a high accuracy in positioning. However, creating a closed loop feed-back system is rather complicated.

Figure 26 shows the finished prototype. Appendix K has a series of finished design pictures.

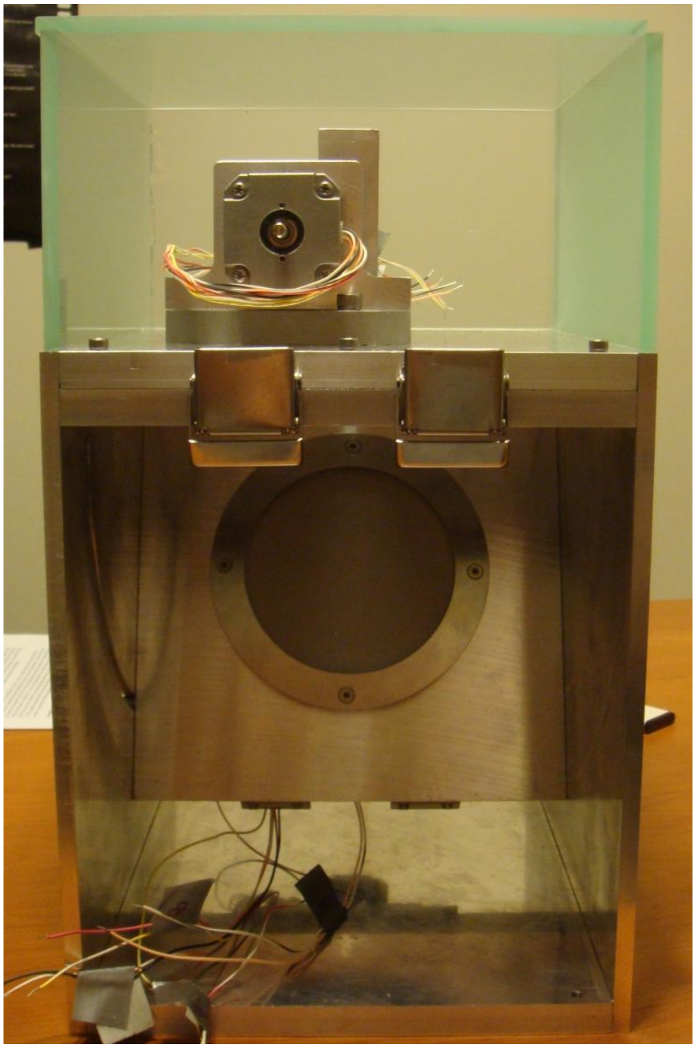

Figure 26: Finished prototype

10 Fabrication

After our prototype has been strictly defined and outlined, we can then ordered all necessary parts and materials needed. We kept a detailed bill of materials for all purchases which is listed as a reference in Appendix E. Fabrication was coordinated through projecting the number of operations needed in addition to estimated times to complete each operation. Our initial project plan was extremely rigorous, requiring that we spend 61 hours and roughly 7.5 days to do 22 to machine and assemble 22 different parts. We followed the project plan extremely well, spending an estimated 51 hours and 9 days to machine and assemble the entire prototype. A detailed list of our project plan is shown for reference in Appendix F.

10.1 Machining

10.1.1 Laser Diode and 6mm lens Mount - 10micron Pinhole and 6mm lens Mount

The Laser Diode and 6mm lens Mount and 10micron Pinhole and 6mm lens Mount both have two steps in their machining processes. These parts will start off as round 1-1/8" OD aluminum rod and be machined to the proper OD using a standard manual lathe. Next, a CNC mill will be used to bore out holes, machine faces, and drill mounting holes into each mount. These parts require an accuracy of roughly 0.0005".

10.1.2 Laser Sled

The Laser Sled is machined in several steps using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside profile is machined using CAD generated G-code. The bore for mounting the ACME Threaded Rod Nut and the bolt pattern is manually programmed into the CNC mill and executed using end mills, drill bits, and reamers. Next, the Laser Sled is unbolted from the fixture and placed in the CNC mill vise. In this orientation a hole will be drilled and reamed to size through the entire Laser Sled. Holes for mounting the Laser Diode and 6mm lens Mount & 10micron Pinhole and 6mm lens Mount are drilled and taped. These operations require an accuracy of roughly 0.0005".

10.1.3 Linear Bearing Support

The Linear Bearing Support is machined using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside profile is machined using CAD generated G-code. Next the holes for the Linear Bearing Shafts are milled using manually programmed CNC code. These operations require an accuracy of roughly 0.001".

10.1.4 Motor Mount

The Motor Mount is machined using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside profile is machined using CAD generated G-code. Next, the holes for the Linear Bearing Shafts and the recessed mounting surface are milled using manually programmed CNC code. These operations require an accuracy of roughly 0.001".

10.1.5 Main Laser Chassis Plate

The Main Laser Chassis Plate is machined using the CNC mill. First, the stock material will be cut using the OMAX water jet machine and then drilled and reamed for proper screw size using a Bridgeport mill. Only hole position is and an accuracy of roughly 0.002" is required.

10.1.6 Fixture (bottom)

The Fixture (bottom) is machined in several steps using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside and inside profile are machined using manual G-code. These operations require an accuracy of roughly 0.001".

10.1.7 Fixture (top)

The Fixture (top) is machined in several steps using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside and inside profile is machined using manual G-code. The Fixture (top) is then flipped over and re-bolted to the fixture plate and the rubber o-ring slot will be machined using manual G-code. These operations require an accuracy of roughly 0.001".

10.1.8 Fixture Shaft

The Fixture Shaft is machined using a standard manual lathe and then CNC machine. This part starts off as round 7/8" OD aluminum rod and is machined to the appropriate OD using a standard manual lathe. Next, the part is moved to a CNC mill for drilling and tapping the proper bolt patterns. This part requires an accuracy of roughly 0.0005" for the diameters and 0.0005 for the bolt patterns.

10.1.9 Main Table Plate

The Main Table Plate is machined in several steps using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside profile is machined using manual G-code. Next, the Main Table Plate is removed from the fixture and mounted in the vise to be drilled and reamed for the ¼" Dowel Pins. This part requires an accuracy of roughly 0.001".

10.1.10 Bearing Block

The Bearing Block is cut from a 2 x 2" aluminum block using a band saw, and is then surface machined, drilled and tapped. Next, the Bearing Block is mounted to the Main Table Plate and then placed in the CNC mill and for milling the appropriate concentric bearing bores. These operations require an accuracy of roughly 0.0005" for the concentric bearing dimensions and 0.001" for all other dimensions.

10.1.12 Motor Mounting Rods

The Motor Mounting Rods start off as 1/2" round aluminum stock. The rods are drilled and taped in a standard manual lathe and cut off using a parting tool. Next, the rods are placed in a manual mill and machined to equal height. This part only has to be equal in height to all the other Motor Mounting Rods. Accuracy of 0.02" is acceptable for this part.

10.1.12 Motor Mounting Plate

The Motor Mounting Plate starts from a 1/4" thick aluminum stock and via a manual mill, is machined to size and then drilled. Accuracy of 0.02" is acceptable for the outer dimensions of this part, while the bolt pattern has to be within 0.002".

10.1.12 Side Plate (slotted)

The Side Plate (slotted) is machined in several steps using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside profile and slot are machined using manual G-code. These operations require an accuracy of roughly 0.001".

10.1.12 Side Plate

The Side Plate is machined in several steps using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside profile is machined using manual G-code. This part requires an accuracy of roughly 0.001".

10.1.12 Bottom Plate

The Bottom Plate is machined in several steps using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside profile is machined using manual G-code. Next, the Bottom Plate is mounted in the CNC mill, drilled and then tapped. This part requires an accuracy of roughly 0.001".

10.1.12 Complete Laser Assembly Mounting Plate

The Complete Laser Assembly Mounting Plate will be machined in several steps using the CNC mill. First, the stock material is drilled and bolted to a fixture plate. Next, the outside profile, slot, and clearance whole for the fixture are machined using manual G-code. Next, the Complete Laser Assembly Mounting Plate is mounted in the CNC mill on both sides, drilled and then tapped. This part requires an accuracy of roughly 0.001".

10.1.12 Laser Assembly Cover

The Laser Assembly Cover is cut via a laser cutter, and thengueld together using a super-strong adhesive. Accuracy is not a key issue in this case, it is required only to cover the laser assembly and be able to bolt down.

10.2 Assembly Process

After we manufacture each part, we must then assemble the system. Our design is quite complex, so we must have a detailed assembly plan. This plan is outlined in the following pictures and descriptions. Under each picture the directions for assembly are provided.

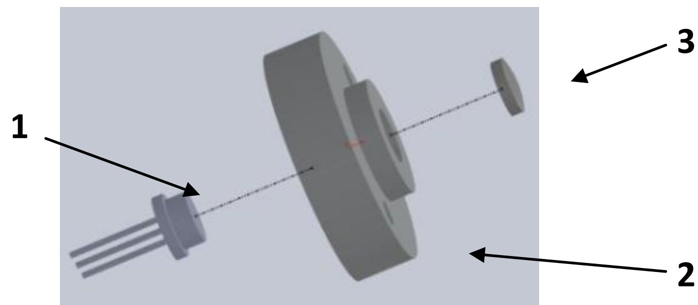

Figure 27: Upper Laser Diode and Lens Assembly (A) – (1, 2, 3)

Insert laser diode **(1)** into Laser Diode and 6mm lens Mount **(2)** securing with hot glue. Next insert 6mm diameter 72mm focal length lens **(3)** into Laser Diode and 6mm lens Mount **(2)** with the flat surface of the lens contacting the mount **(2)** and secure using hobby glue.

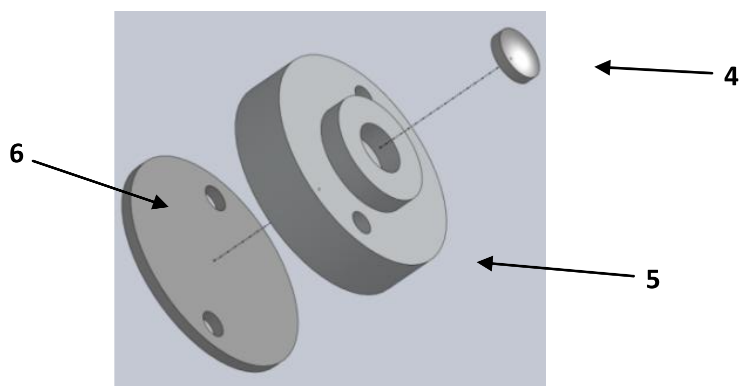

Figure 28: Lower Lens Assembly (B) – (4, 5, 6)

Insert 6mm diameter 3mm focal length lens **(4)** into the 10micron Pinhole and 6mm lens Mount **(5)** with the flat surface of the lens contacting the mount **(5)** and secure with hobby glue. Next, align the 10micron Pinhole **(6)** and its mounting holes to that of the 10micron Pinhole and 6mm lens Mount **(5)** mounting holes.

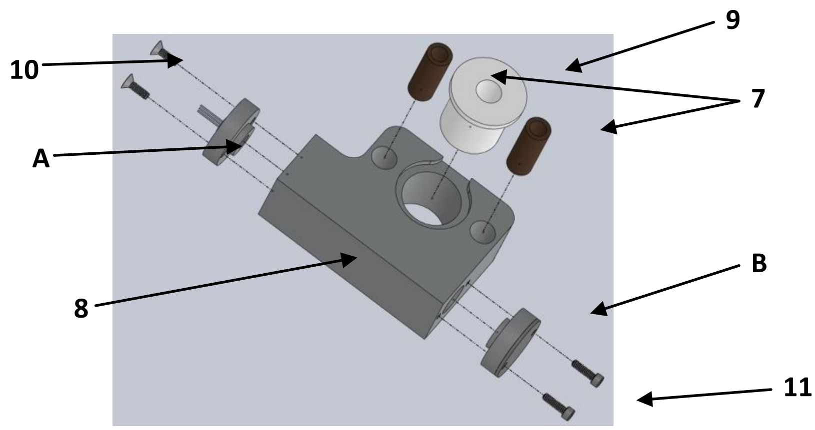

Figure 29: Laser Sled Assembly (C) – (A, B, 7, 8, 9, 10, 11)

Press fit both the 1/4" Bronze Bushings **(7)** into the Laser Sled **(8)** as shown above. Next, slide the ACME Threaded Rod Nut **(9)** into the Laser Sled **(8)** and using the ACME Threaded Rod Nut **(9)** supplied mounting screws to secure the ACME Threaded Rod Nut **(9)** to the Laser Sled **(8)**. Next, screw the Upper Laser Diode and lens Assembly **(A)** to the Laser Sled **(8)** using two 4-40 x 3/8" Flathead Socket Screws **(10)**. Next, screw the Lower Lens Assembly **(B)** to the Laser Sled **(8)** using two 4-40 x 3/8" Socket-head Cap Screws **(11)**.

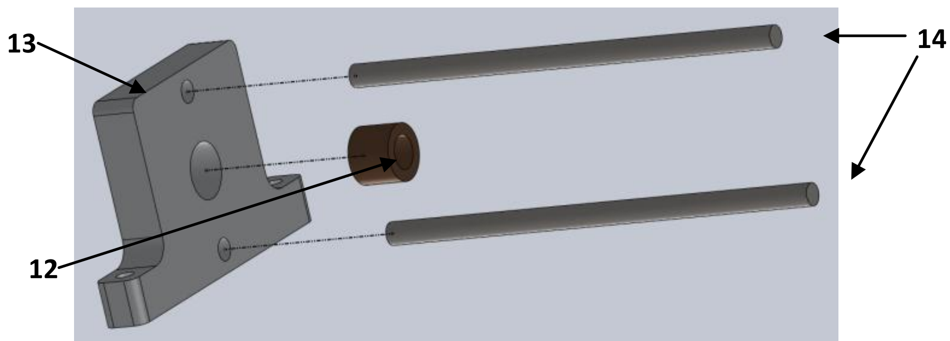

Figure 30: Linear Bearing Support Assembly (D) – (12, 13, 14)

Press fit the 3/8" Bronze Bushing **(12)** into the Linear Bearing Support **(13)**. Next, slide the Linear Bearing Shafts **(14)** into the Linear Bearing Support **(13)**.

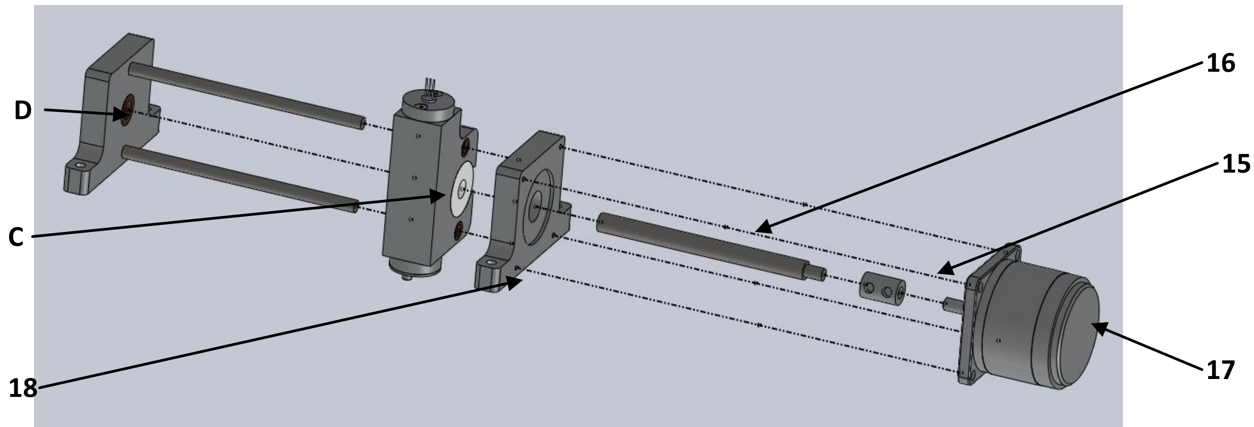

Figure 31: Linear Bearing Support, Motor Mount, and Motor (E) – (C, D, 15, 16, 17, 18)

Slide the Linear Bearing Shafts **(13)** of the Linear Bearing Support Assembly **(D)** through the 1/4" Bronze Bushings **(7)** in the Laser Sled Assembly **(C)** so that the Laser Sled Assembly **(C)** is in contact with the face of the Linear Bearing Support **(13)**. Next, slide the Motor Coupler **(15)** onto the recessed portion of the ACME Threaded Rod **(16)** and then tighten down the Motor Coupler **(15)** set screw. Next, slide the Motor Coupler **(15)** onto the NEMA Size 17 Motor **(17)** shaft and tighten down the Motor Coupler **(15)** set screw. Next, carefully slide the ACME Threaded Rod **(16)** and Motor Coupler **(15)** through the Motor Mount **(18)** making sure that the NEMA Size 17 Motor **(17)** is flush and its mounting holes are aligned with the Motor Mount **(18)** and its mounting holes. Next, with the NEMA Size 17 Motor **(17)** supplied screws secure the NEMA Size 17 Motor **(17)** to the Motor Mount **(18)**. Next, slide the Linear Bearing Shafts **(13)** of the Linear Bearing Support Assembly **(D)** with the Motor Mount **(18)** linear bearing support holes.

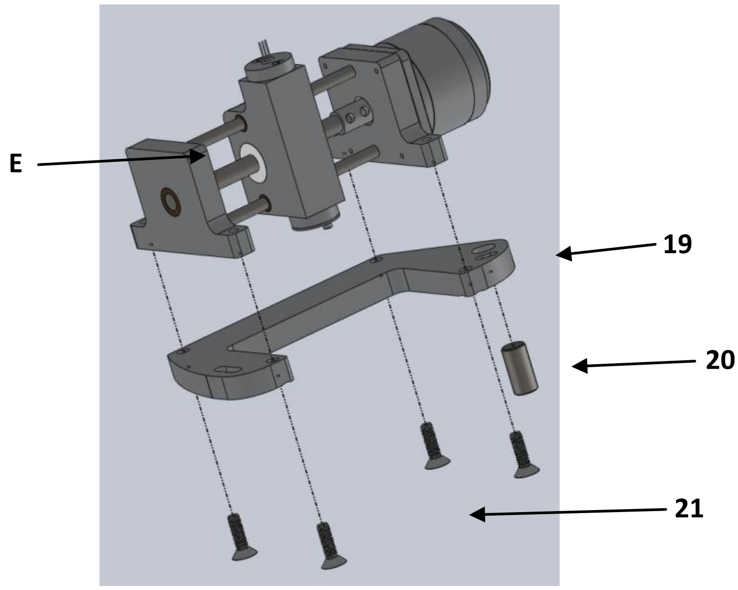

Figure 32: Complete Laser Assembly (F) – (E, 19, 20, 21)

Press the 1/2” x 1” Dowel Pin **(20)** into the Main Laser Chassis Plate **(19)**. Next, using the 1/4”-20 x 1/2” Flathead Screws **(21)** attach the Linear Bearing Support, Motor Mount, and Motor **(E)** to the Main Laser Chassis **(19)**. – (Figure 31, page 35)

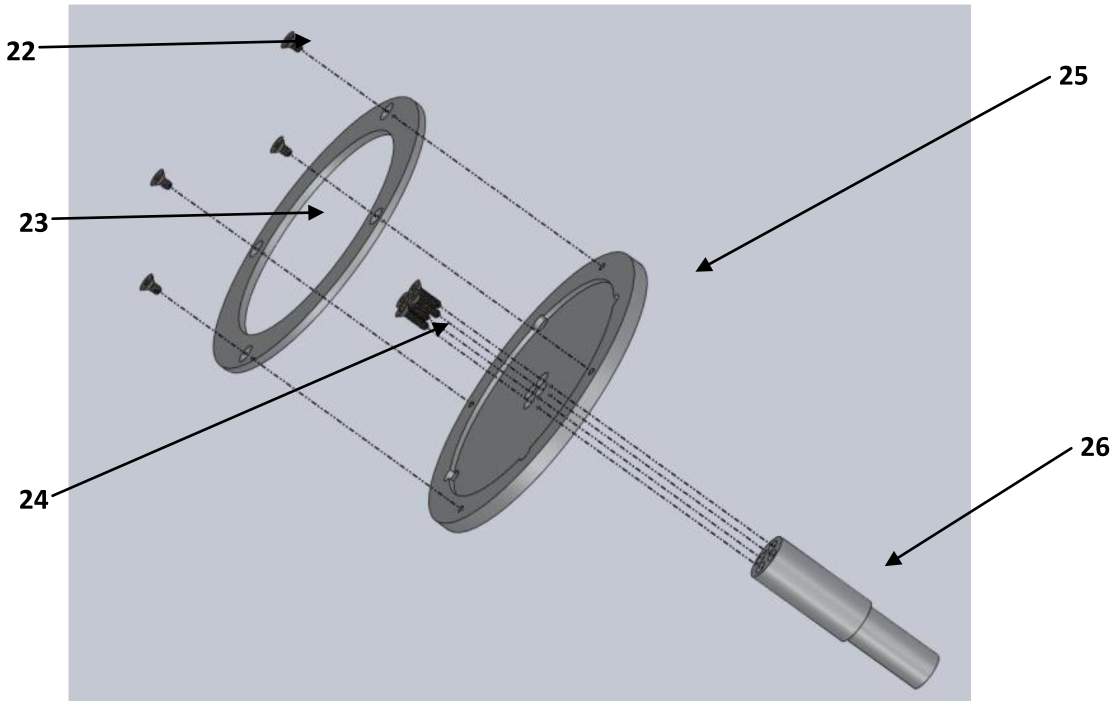

Figure 33: Fixture Assembly (G) – (22, 23, 24, 25, 26)

Attach the Fixture (bottom) **(25)** to the Fixture Shaft **(26)** using four 5-40 x 1” Flathead Screws **(24)**. Next, Attach the Fixture (top) **(23)** to the Fixture (bottom) **(25)** using four 6-32 x 1/4” Flathead Screws **(22)**.

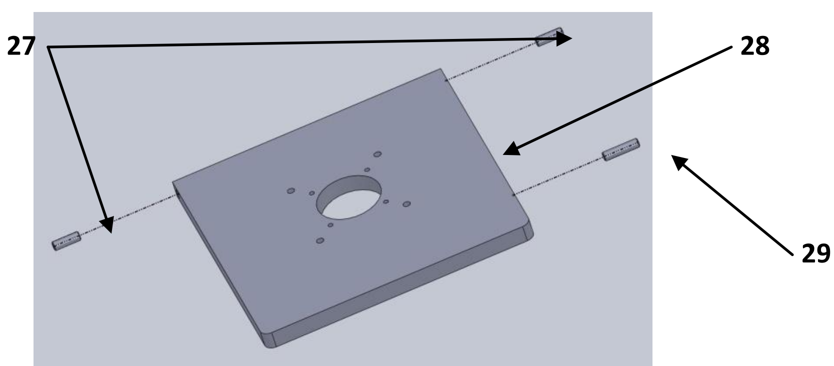

Figure 34: Main Table (H) – (27, 28, 29)

Press fit two 1/4” x 3/4” Dowel Pins **(27)** and one 1/4” x 1” Dowel Pin **(29)** into the Main Table Plate **(28)** as shown in Figure 34.

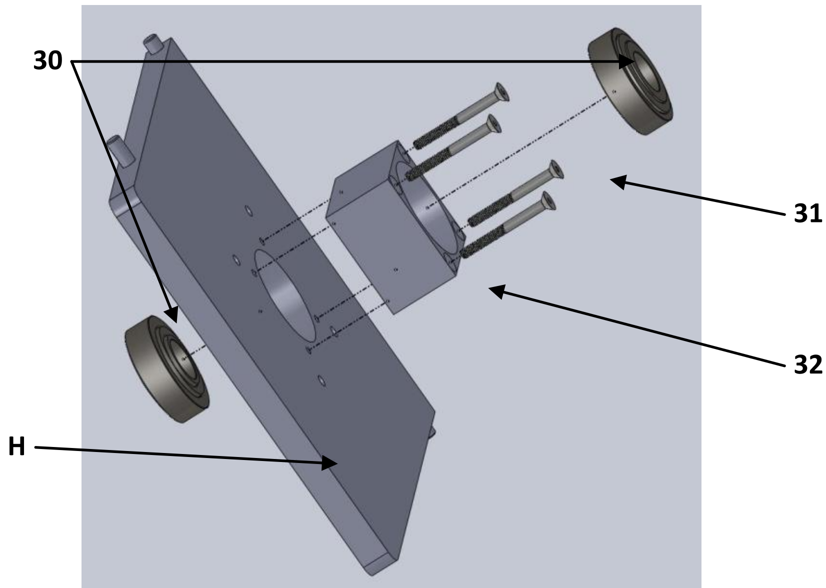

Figure 35: **Table Assembly (I) – (H, 30, 31, 32)**

Using four 1/4-20 x 1 3/4" Flathead Screws **(31)**, attach the Bearing Block **(32)** to the Main Table **(H)**. Next, press fit the Outer Bearing Race **(30)** into the Bearing Block **(32)** and the Main Table **(H)**. Next, place the Inner Bearing Assembly **(30)** into the Outer Bearing Race **(30)**.

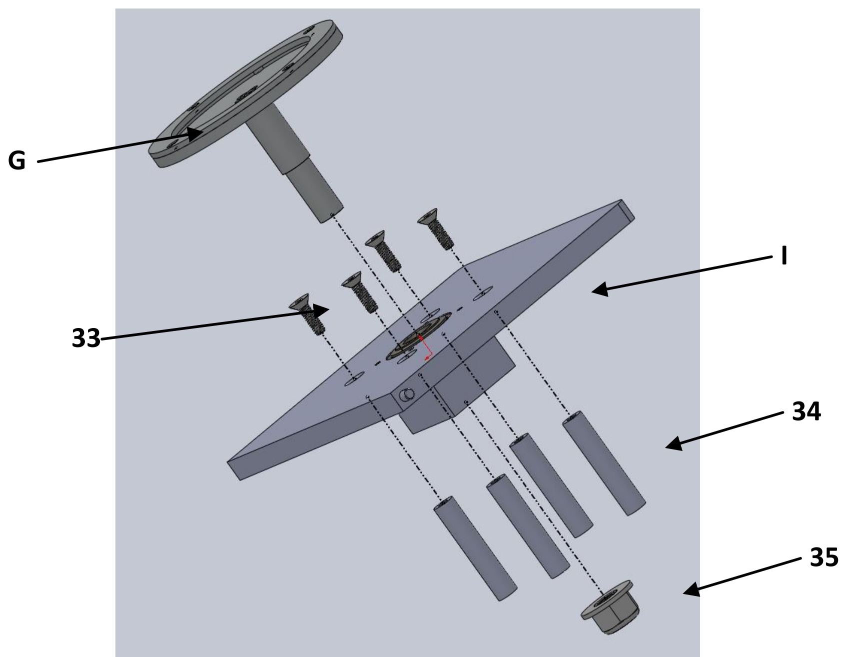

Figure 36: **Fixture and Table Assembly (J) – (G, I, 33, 34, 35)**

Using four 1/4"-20 x 1" Flathead Screws **(33)**, attach the four Motor Mounting Rods **(34)** to the Table Assembly (I). Next, slide the Fixture Assembly **(G)** through the two Bearings **(30)** and secure the Fixture Shaft **(26)** using the Locking Nut **(35)** applying (10Nm's) to insure only one degree of freedom (rotation).

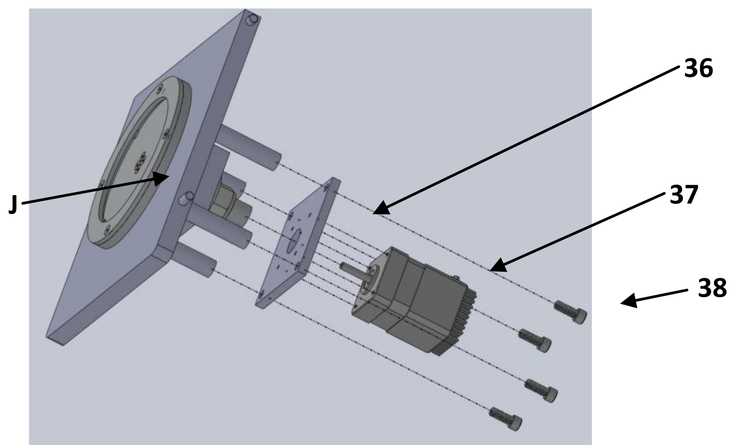

Figure 37: **Fixture, Table, and Motor Assembly (K) – (G, I, 33, 34, 35)**

Attach the NEMA Size 17 Motor **(37)** to the Motor Mounting Plate **(36)** using the NEMA Size 17 Motor **(37)** supplied mounting screws. Next, attach the Motor Mounting Plate **(36)** to the Fixture and Table Assembly **(J)** using four 1/4"-20 x 1/2" Socket Head Screw's **(38)**.

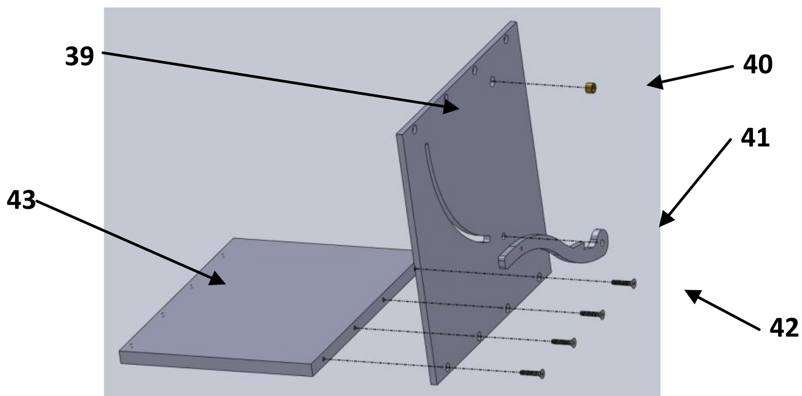

Figure 38: **Chassis Assembly [1 of 4] (L) – (39, 40, 41, 42, 43)**

Press fit the 1/4" Bronze Busing **(40)** into the Side Plate (slotted) **(39)**. Next, using four 1/4"-20 x 1" Flathead Screws **(42)** attach the Side Plate (slotted) **(39)** to the Bottom Plate **(43)**.

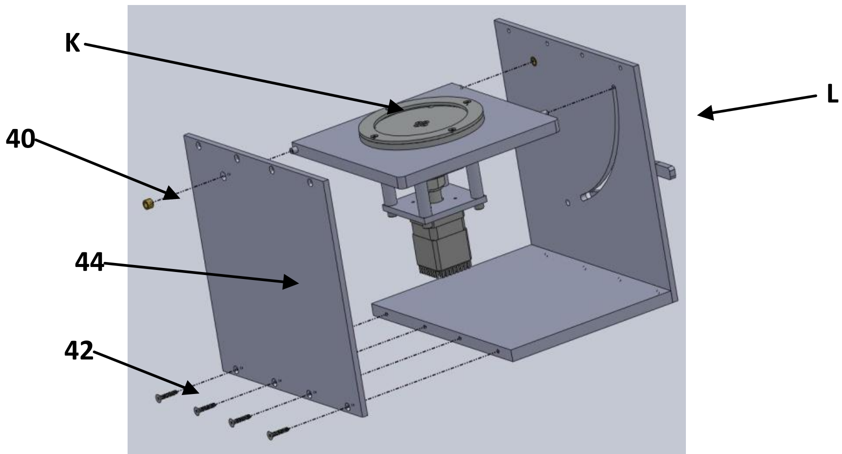

Figure 39: **Chassis Assembly [2 of 4] (M) – (K, L, 40, 42, 44)**

Insert one of the 1/4” x 3/4” Dowel Pins **(27)** of the Fixture, Table, and Motor Assembly **(K)** into the 1/4” Bronze Busing **(40)** of the Chassis Assembly [1 of 4] **(L)**. Next, press fit the 1/4” Bronze Busing **(40)** into the Side Plate **(44)**. Next, insert one of the 1/4” x 3/4” Dowel Pins **(27)** of the Fixture, Table, and Motor Assembly **(K)** into the 1/4” Bronze Busing **(40)** of the Side Plate **(44)**. Next, attach the Side Plate **(44)** to the Chassis Assembly [1 of 4] **(L)** using four 1/4”-20 x 1” Flathead Screws **(42)**.

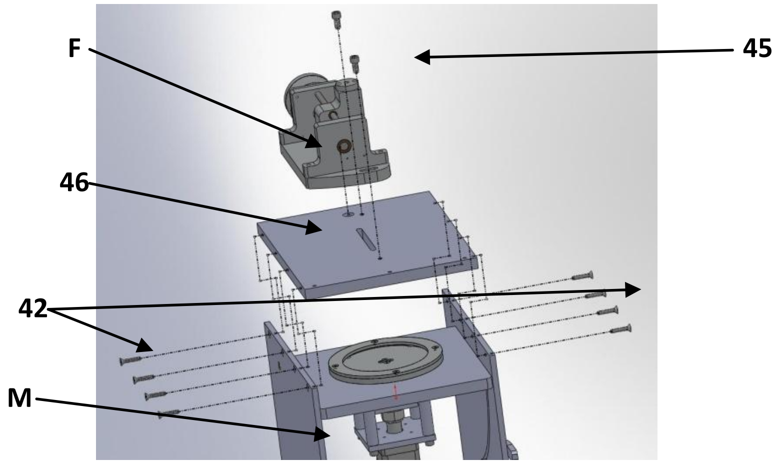

Figure 40: **Chassis Assembly [3 of 4] (N) – (F, M, 42, 45, 46)**

Attach the Complete Laser Assembly Mounting Plate **(46)** to the Chassis Assembly [2 of 4] **(M)** using eight 1/4”-20 x 1” Flathead Screws **(42)**. Next, attach the Complete Laser Assembly **(F)** to the Complete Laser Assembly Mounting Plate **(46)** using two 1/4”-20 x 1” Socket Head Screws **(45)**.

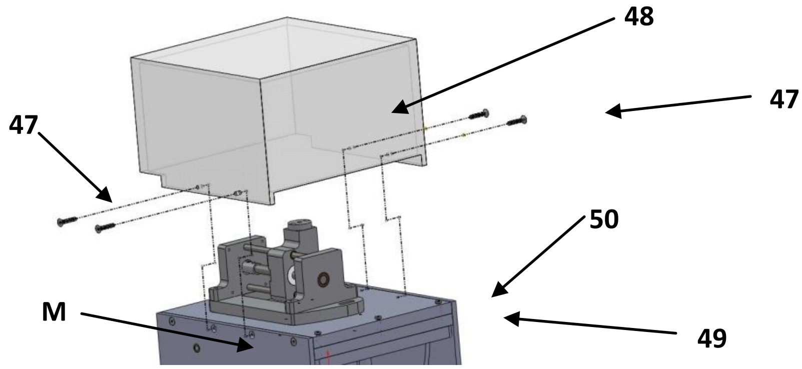

Figure 41: **Chassis Assembly [4 of 4] (O) – (M, 47, 48, 49)**

Attach the Laser Assembly Cover **(48)** to the Chassis Assembly [3 of 4] **(N)** using four 1/4”-20 x 1” Socket Head Screws **(47)**. Attach the reference plate **(49)** using three 1/4”-20 x 1” socket Head screws **(50).** Shown in Figure 42 is what the final assembly looks like.

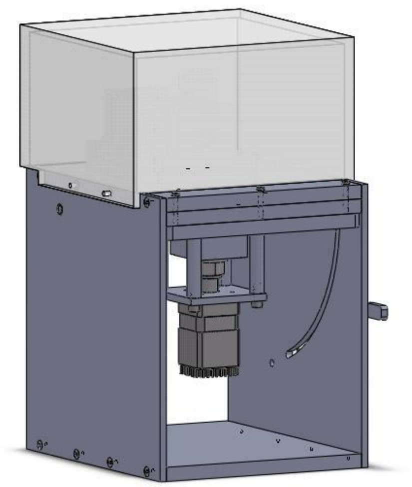

Figure 42: The Complete Assembly

11 Validation of Final Product

After completion of the system, we validated its ability to meet the engineering specifications. The validation process provides quantitative testing our final product. We were unable to fully validate our final product. We created a laser driver board to test our laser, and after its completion, we were unable to turn on the laser. We tested its inputs and determined that we are unable to use this diode. Our specifications and budget limitations led us to the purchase of this product, which after testing, was inoperable. However, we were able to accurately control our stepper motors, and the validation is outlined in this section. Figure 43 shows the circuitry used in the testing of the laser.

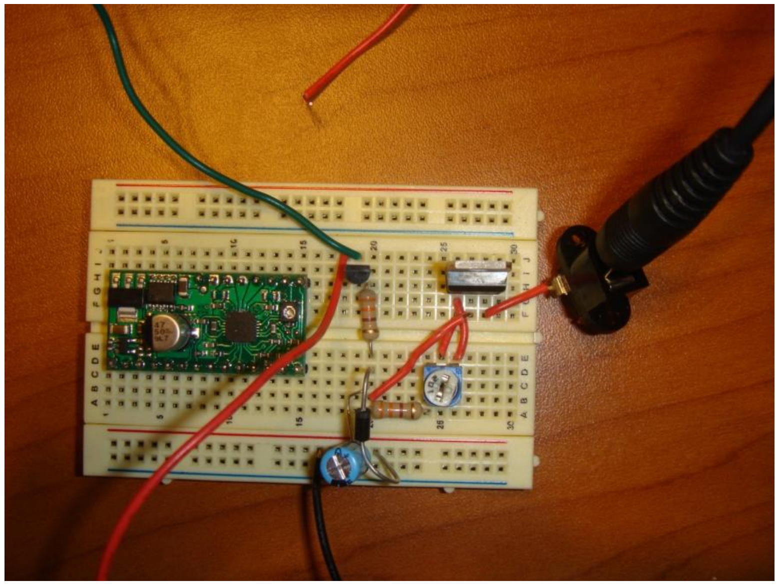

Figure 43: Laser Driver Circuit

11.1 Validation of laser sled positioning

We moved the laser sled to an adjacent point to one of the laser mounts. We then measured the distance between the laser sled and the laser mounts with calipers. After recording the distance, we moved the laser sled radially outward with a distance equal to .25 inches. We then measured the distance between the laser mounts and the laser sled and compared it to the previous measurement. We found that the laser sled consistently met the precision requirement needed for positioning the laser sled.

11.2 Validation of wafer positioning

We were successful in the angular control of the wafer. The high-precision stepper motor driver allowed us to accurate position the wafer. We were able to determine the precision by turning the fixture for many revolutions and recording its position relative to its starting position.

11.3 Future Validation

Once a reliable laser source is found, along with a data acquisition card that has the appropriate timing hardware, the complete validation of our system can be completed.

11.3.1 Calibration and Alignment of Laser Position

In order for the laser to accurately right on the wafer, it must know the center of rotation. We must calibrate the laser assembly to the center of rotation. To do this we place the laser assembly as close as we can to the center of rotation by controlling the position of the laser assembly along with the angle of the laser assembly. We then place a wafer in the machine, spin in it and turn on the laser to expose the photoresist. After developing the wafer, we can tell the distance that the laser is from the center of rotation. If the result is a circle, the radius of that circle is the distance from the laser to the center of rotation. We continue this process until the resulting shape is a dot. This point will be the zero, and applied to the LabVIEW code.

11.3.2 Minimum Feature Size

In this validation experiment, we will expose three points that extend radialy from the center. The size of these points is then analyzed to determine the feature size and whether or not the speed of the motor needs to be adjusted. The speed of rotation affects the exposure time of the substrate along with the positioning of the wafer and laser assembly. This assures that all aspects are coordinated correctly.

11.3.3 Position Precision and Accuracy

In this test we will expose the same pattern onto several wafers. We will then assess the ability of the system to reproduce this pattern. This experiment will analyze the system's accuracy and precision. We expect the system to reproduce designs with the 10 micron precision. We will measure the angle and distance of the pattern from the center of the rotation of the wafer.

11.3.4 Exposure Speed

We will program the system to pattern a square centimeter on the wafer. We will then time the system's ability to complete this task. We will also run several tests where the square centimeter area is placed on different parts of the wafer. We will also check the accuracy and precision of the system with this method.

11.3.5 Precision of Cycle Readjustment

We will pattern a line radially from the center of the wafer. This will check for the system's ability to position itself correctly. Any deviation from the line will be measured. We will repeat this test several times and average the distances from the line.

12 Discussion

We succeeded in designing and manufacturing a working prototype as an initial step for further research. Our system however needs further analysis and investigations in order to implement precise and accurate patterns in the micro-scale.

12.1 Design Critique

Breaking down the system into mechanical and mechatronics aspects makes it feasible to diagnose the functionality of each component and how it fits into the grand scheme of the project. The mechanical aspect of our system meets the engineering specifications. First of all, we constructed the system from aluminum alloy 6064. We succeeded to select a material that is light weight, total weight of the system is less than 15 lb, and thus, provides flexibility in mobilizing the system. We also achieved dimensions that are comparable to a PC tower or an office printer. During the validation process, we determined that our system provides mechanical stability, minimal deflection, and negligible vibration. As a part of the future work, we can decrease the size of the prototype by 25%. Along with this we are able to reduce the quantity of the raw material used to construct the system. Redesigning the optical system and implementing an automatic mechanism to align the laser sled is a necessary step. This mechanism can be achieved by employing adjuster screws that provides precise and accurate translational motion to the optical system.

The mechatronics aspect of the system needs improvements in order to optimize performance. First of all, advanced graphical user interface should be employed to implement complicated patterns on the surface of the silicon wafer. LabView, even though can be used to pattern simple shapes as circles or lines, The resolution of these shapes is limited because LabView is a control software rather than a CAD software. Transferring complicated patterns can be achieved via CNC-like software applications such as TurboCNC, KCAM, or MACH software. This software is user friendly and relatively inexpensive, at a cost less than $400.

The system can be upgraded with the implementation of a CCD camera that can be attached to the laser sled. Implementing such a technique will enable us to control the alignment of the translational motion of the optical system and ability to reposition the laser diode in the case of unplanned events.

The system requires an advanced data acquisition system in order to optimize performance of the stepper motors. The data acquisition unit instrumented in the current process does not possess the appropriate timing hardware for high speed digital output. When generating a digital wave forms, the DAQ does not abide by the waveform's associated frequency. The DAQ sends extremely high frequency waveforms, larger than the 2MHz maximum output frequency of the stepper motor driver. Due to the limited resources at our disposal we could not manipulate the speed and frequency generated by the DAQ card. In addition; we determined that the DAQ card sends random frequencies to the micro controller of the laser diode and the drivers of the stepper motors in an uncontrollable frequency. The data acquisition system we would pursue is classified as DAQ cards used for high speed digital input/output (HSDIO). These data acquisition cards allow sending high frequencies with the ability to time them.

Implementing an emergency switch to turn off both the stepper motor and the laser diode is a very crucial element. Immediate termination of the process is required, especially in the case of unexpected events. Implementing a physical switch can help eliminates potential hazards and facilitate creating a safe work practice. In addition; it complies with OSHA and EH&S requirements. Implementing such a mechanism also provides protection to the drivers, micro steppers, and the laser diode.

During the validation process, we determined that the laser diode is inoperable. Therefore; we believe that we should not compromise quality with cost when it comes to parts selection. However, we were given a limited budged and cost was a main constraint, we were forced to seek alternative and cheap components.

13 Recommendations

Implementing a laser source in the system poses extremely high levels of hazards. We will employ a blue laser diode which provides a continuous light beam with 405 nm frequency. We determined that laser interaction with the surface of the wafer may generate fumes and gas byproducts. Therefore, the system must be placed in a room equipped with a ventilation system. In addition, the application requires high intensity laser beam which may generate ionizing radiation in the forms of neutrons, gamma or x-rays [28]. Personnel protection equipment must be worn throughout the exposure operation in order to avoid direct contact with the laser beam, which might cause eye injury and in some cases blindness. Therefore; individuals operating the system are required to receive safety training sponsored by OSHA Organization to understand the hazards of operating a laser.

Reflection, unintended directions, and fumes produced are some of the consequences that might result due to laser interaction with different intermediates. The path of the beam might be manipulated if a bending magnet is placed in the vicinity of the system. Therefore; personnel operating the system must not wear any reflective objects or necklace while the laser is engaged to keep the laser on its appointed path [29].

Electric shocks, poor grounding and accessible wires are all factors that might lead to dangerous incidents associated with the use of our system. In order to reduce these risks, personnel need to follow the wiring map when dissembling or installing new components if necessary. However, we recommend that any maintenance or upgrading process must be conducted by an expert.

Operating the system must be conducted in a dust free environment to keep the optical lens clean. Dust might accumulate over time causing a malfunction in the optical system and overheating in the power supplies and motors. The research laboratory should maintain certain cleanness and keep out unauthorized personnel. In addition; the system must be placed in a maintained temperature environment to avoid overheating in the system and thermal expansion in the lens array [29].

Disassembling parts of the system must be done carefully and under supervision as tolerance plays a main role in delivering the precise results. Placing the system on a vibration free table is recommended in order to eliminate excessive vibrations. We also recommend that special care must be considered during implementing the lens in the laser sled. The assembling process is extremely important and difficult. Scratches, even minor ones, on the surface of the lens can cause malfunction. In addition, applying excessive force on the tweezers while holding the lens might damage the lens.

14 Conclusion

Our sponsor Dr. Nikos Chronis has asked us to develop a maskless photolithography system for rapid prototyping in the laboratory environment. The idea behind this project is to create a cheap comparable maskless photolithography system that can be placed on a bench top and expose and entire pattern in under 30 minutes. This will greatly reduce the overhead of photolithography and broaden the availability to low income research.

Through the information gathered from our literature review and sponsor meetings, we have determined the requirements and engineering specifications relevant to the problem at hand. Using these requirements we produced several concepts, which through vigorous concept analysis and selection, resulted in our alpha design. Our alpha design consisted of a rotating silicon wafer and a radial moving laser. Through further analysis of our alpha design we have determined stresses, torques, moments of inertia, and all relevant information leading us to our final prototype.

Our final prototype consists of a Laser, Fixture, Table, and Chassis Assembly. Using Stepper motors, Motor Drivers, Power Supplies, TTL Laser Driver, DAQ, and LabVIEW we control the system to position expose and pattern the wafer. Our final design would consist primarily of changes to electronics and not physical dimensions. Such things as switching to a servo motor and high resolution optical encoder are examples of such changes.

We have completed our final prototype by the deadline. Our final prototype can accurately position the wafer along with the radial position of the sled. However, the optical system was not able to be turned on, and therefore the optical system of the prototype could not be verified. Also, to be able to implement the necessary high speed digital output (HSDIO), a data acquisition card with the necessary on-board clock from National Instruments is necessary. With the improvement on our prototype in these areas will lead to our final design of an inexpensive mask-less photolithography device.

15 Acknowledgements

Thomas Bress, John Baker, Grad shop John, Dan Johnsen, and of course our sponsor who gave us the opportunity to make this prototype a possibility.

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Appendices

A Quality Functional Development Chart

This chart shows the correlation between customer requirements and technical requirements. Everything is weighted 1 – 10, 10 being the highest. This chart is useful for benchmarking and prioritizing the order in which engineering issues should be solved. Correspondence between each technical requirement also helps to identify correlations between engineering specifications.

Photolithography System QFD

#	Technical Requirement	Weight	Footprint	Height	Exposure Speed	Wafer Positioning Accuracy	Wafer positioning Precision	Use of optics (lens system)	Wavelength of light source	Intensity of Light Source	Vibrational Amplitude	Computer interface	Cost	Patterning Area	Photoresistive Material	minimum feature size
1	Weight															
2	Footprint	7														
3	Height	7														
4	Exposure Speed															
5	Wafer positioning Accuracy															
6	Wafer positioning Precision															
7	Use of optics (lens system)	7			10											
8	Wavelength of light source	5			9											
9	Intensity of Light Source				10											
10	Vibrational Amplitude															
11	Computer Interface															
12	Cost					10	9	7				6				
13	Patterning Area															
14	Photoresistive Material								10							
15	minimum feature size				8			10			7		9			

Technical Requirements

#	Sponsor Needs	Customer Weights	Weight	Footprint	Height	Exposure Speed	Wafer Positioning Accuracy	Wafer positioning Precision	Use of optics (lens system)	Wavelength of light source	Intensity of Light Source	Vibrational Amplitude	Computer interface	Cost	Patterning Area	Photoresistive Material	minimum feature size
1	Cheap	10					8	9	7		6		5	10			
2	Competative features	9	5	4	3	6	8	9		1	1			7	6	2	10
3	Easy to use	8											10				
4	Fast process	7				10					10				7		9
5	Small size	6		10	9												
6	Light weight	5	10									8					
7	Stability	4										10					
		Raw score	95	96	81	124	152	171	70	9	139	80	130	163	103	18	153
		Scaled	0.56	0.56	0.47	0.73	0.89	1	0.41	0.05	0.81	0.47	0.76	0.95	0.6	0.11	0.89
		Relative Weight	6%	6%	5%	8%	10%	11%	4%	1%	9%	5%	8%	10%	7%	1%	10%
		Rank	**10**	**9**	**11**	**7**	**4**	**1**	**13**	**15**	**5**	**12**	**6**	**2**	**8**	**14**	**3**
	Benchmarking (Closest Competators)	Intellegent Mirco Patterning's XCEL	70 lb	16 x 20 in^2	40 in	-	-	-	-	Lamp 360 nm		-	Integraed Software	$40,000	5x5 in^2	g/h line	15 μm
		Intellegent Mirco Patterning's XPRESS	200 lb	60x 24 in^2	40 in	-	-	-	-	Lamp 360 nm		-	Integraed Software	$135,000	4x4 in^2	g/h line	1 μm
		Heidelburg Instruments Micro PG101	-	29x 23 in^2	~ 24 in	0.3 - 0.03 cm^2/ min	-	-	-	Laser 405/ 375 nm		-	Integrated Software	$100,000	4.4x4.4 (3μm) 1.2x1.2 (1μm)	g/h line	3-1 μm
		Direction	↓	↓	↓	↑	↓	↓	T	T	T	↓	-	↓	↑	T	↓
	Technical Requirement Units		lb	W x D in^3	in	cm^2/ min	μm	μm	x reduction	nm	W	μm	-	USD	in^2	-	μm
	Technical Requriement Targets		13.6	24 x 24	24	1,032	1	5	150	405	0.2	0.5	G-Code	400	4x4	g/h line	10

Figure 44: QFD Chart

B Functional Decomposition

Our functional decomposition outlines the functions of our design problem. The inputs to the system are pattern, in the form of a digital signal, wafer, and electricity. The outputs in this system are heat, friction, light and the patterned wafer.

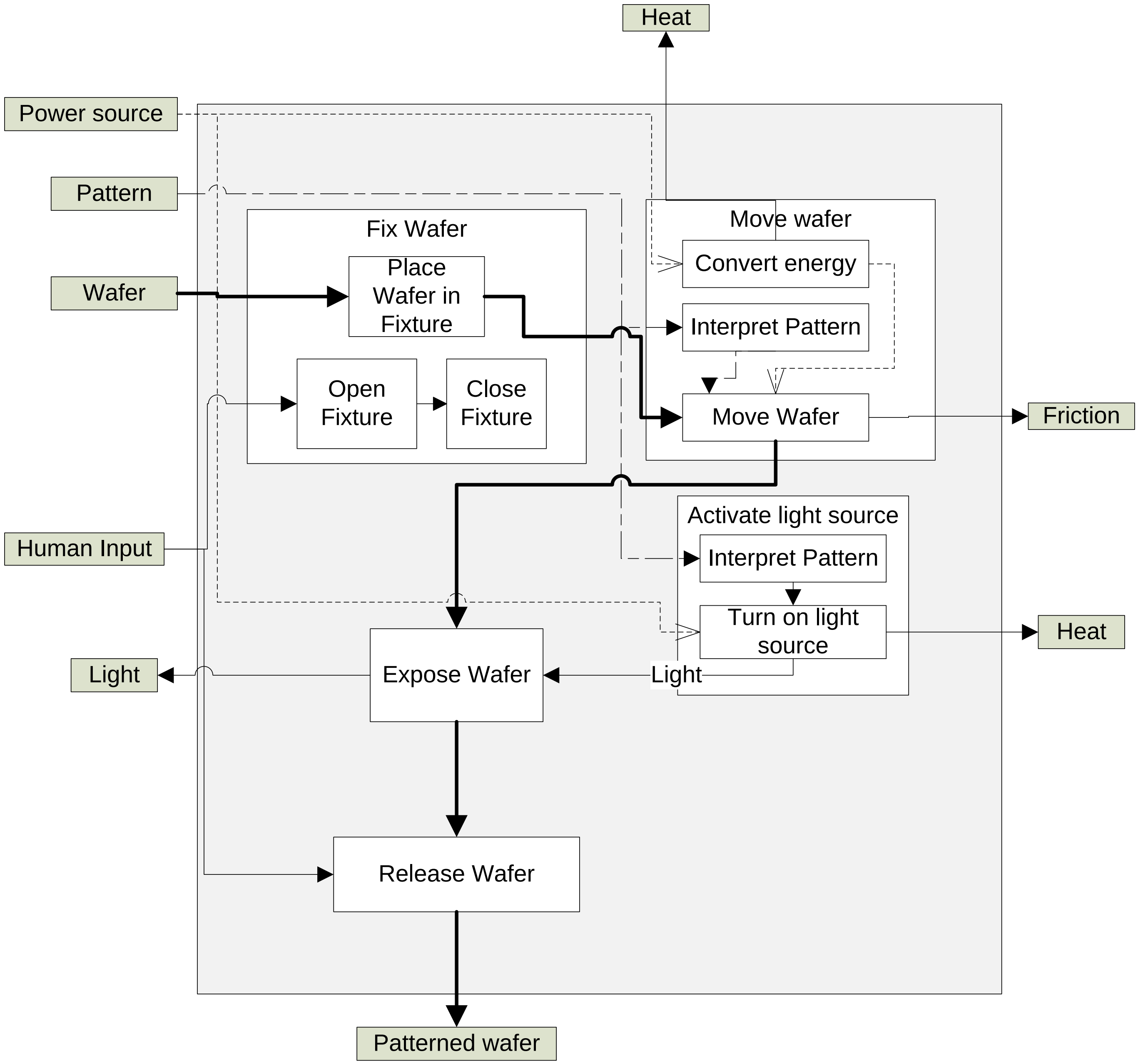


Figure 45: Functional decomposition of the maskless photolithography design problem

C Design Changes during Prototyping

During the prototyping phase of our project, there were three simple design modifications. Here we will show the evolution of the planned prototype to the actual prototype design for each change made.

C.1 Bottom Fixture

The initial design is as shown below in Figure 46. We designed four symmetrical recesses to improve the ease of removing the wafer. However, during manufacture of the fixture, we noticed that the flat end of the fixture already allowed for easy removal. As a result, we neglected the planned machining operation.

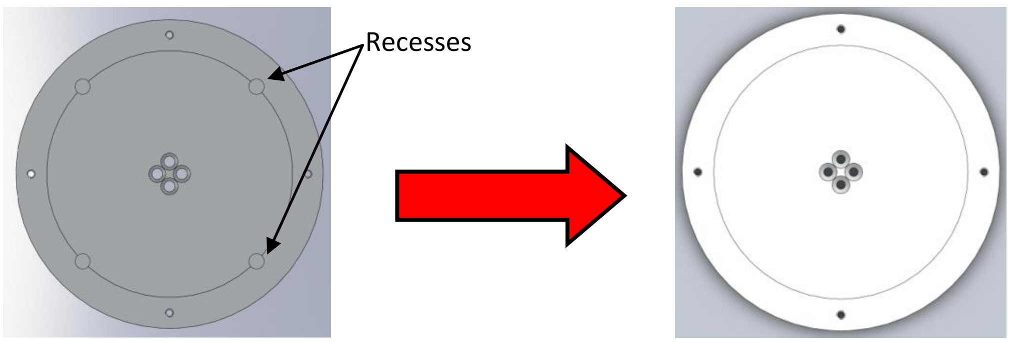


Figure 46: Evolution of the Bottom Fixture Design

C.2 Laser Assembly Mounting Plate

During assembly, we discovered that the tapered roller bearings are thicker than we anticipated. We designed the system such that there was only about one millimeter of clearance between the fixture and the laser assembly mounting plate. The extra thickness from the bearing made the fit impossible. As a result, we programmed CNC machine to mill a 5-1/8" diameter by 1/8" deep pocket into the laser assembly mounting plate to allow room for the fixture to freely rotate. Although this design change was unexpected, our overall design ultimately improved as a result. In fact, by recessing the fixture into the laser assembly mounting plate, we completely prevent any laser light from escaping the wafer during exposure.

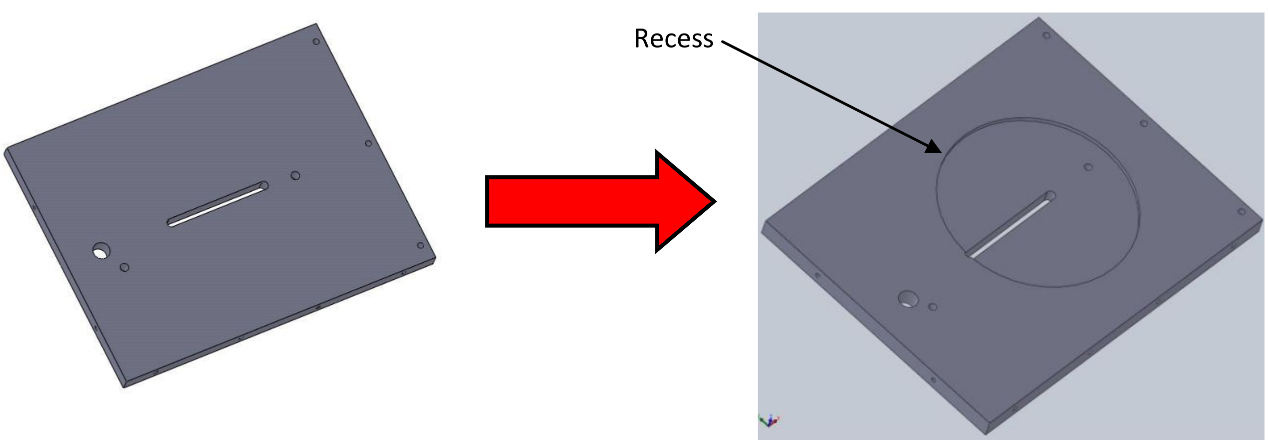


Figure 47: Evolution of the Laser Assembly Mounting Plate Design

C.3 Laser Assembly Cover

The initial plan was to fabricate the laser assembly cover from sheet metal and then weld it together and screw it onto the rest of the assembly. However, there were two main issues with our choice of aluminum sheet metal: 1) Aluminum cannot be welded to itself and 2) after cutting the sheet metal, it became very sharp on the edges, which provokes safety concerns. As a result, we determined that it would be more time efficient and safe to use the laser cutter to create an acrylic laser assembly cover. The new acrylic plastic worked very well, providing an additional aesthetic appeal which the sheet metal did not include.

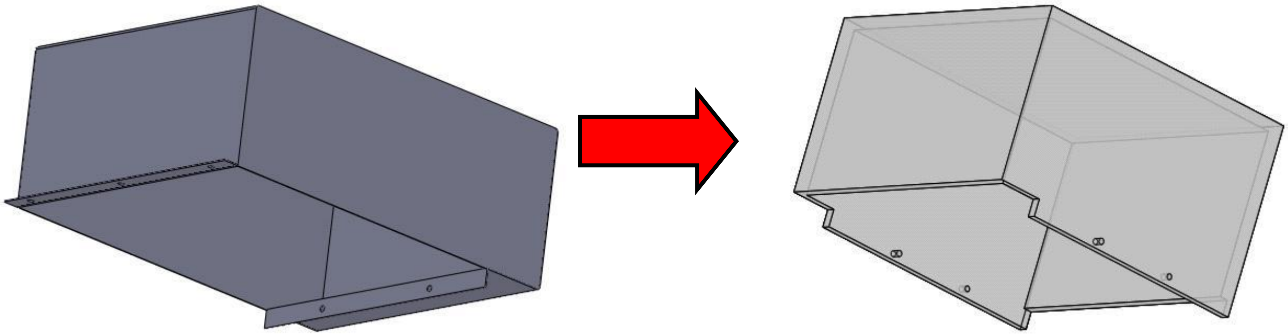


Figure 48: Evolution of the Laser Cover Assembly Design

D Material Selection

In order for us to determine to verify the materials for the wafer and for the laser sled, we analyzed potential materials in terms of functional performance, environmental performance, and manufacturing process selection. We utilized our experience to deduce that 6061 precision ground aluminum should be used for the majority of the parts. This is because of the metals high machine-ability, low cost, and low weight. The density (ρ) of this aluminum is roughly 2.7×10^3 kg/m^3, the Young's Modulus (E) is 6.8-7.15×10^{10} Pa, and the Shear Modulus (G) is 2.6-2.73×10^{10} Pa at roughly $13.00/kg.

D.1 Functional Performance

In choosing materials, we only considered materials which operated near the range of 6061 aluminum.

D.1.1 The Fixture

1. **Function:** To hold the silicon wafer secured such that it can rotate with the fixture.
2. **Objective:** To minimize the mass.
3. **Constraints:** Must not fail in shear stress, high rigidity, and a constant diameter.
4. **Material Indices:** Our first constraint is in the mass
   - Minimize mass: $m = Ah\rho$ $\quad A = \pi R^2(l_1 - l_2)$
   - Must not Fail in Shear: $\tau = \frac{F}{A} \leq \sigma_u$ $\quad G = \frac{\tau}{\gamma}$ $\quad \gamma = \frac{\Delta x}{l} = const.$
   - Common Variable is the area (A): $m = \frac{Fh}{\gamma}\frac{\rho}{G}$
   - Material Indices: $\boldsymbol{M = \frac{G}{\rho}}$
5. **Top Five Material Choices:**
   - Aluminum, S520: LM10-TB, cast→ ρ = 2.54×10^3 ; Cost = $2.20/kg; G = 2.6×10^{10} Pa
   - Aluminum, S356 (a):LM29-TE, cast→ ρ = 2.6×10^3; Cost = $1.90/kg; G = 3.2×10^{10} Pa
   - Aluminum, 5083, wrought, H111→ ρ = 2.6×10^3; Cost = 1.80/kg; G = 2.3×10^{10} Pa
   - Glass ceramic (N11)→ ρ = 2.45×10^3; Cost = $5.50/kg; G = 3.02×10^{10} Pa
   - Silica (96%)→ ρ = 2.2×10^3; Cost = $8.00/kg; G = 2.85×10^{10} Pa

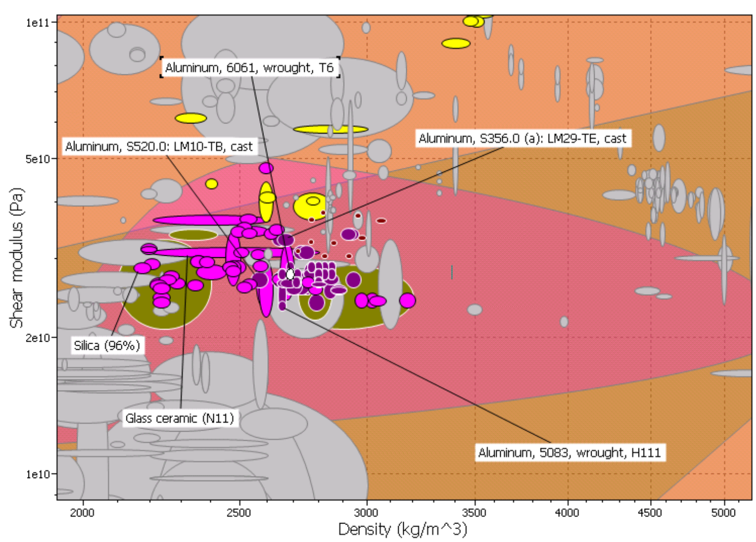


Figure 49: Material Selection near Al 6061

6. **Final Choice Description:** The goal is to find a material with a lower density and a similar Shear Modulus. The glass and silicon are considerably less dense, however they are higher cost and harder to machine, therefore we only considered Aluminum. The ***5083 aluminum*** is the cheapest and has the lowest density of the other aluminum alloys (by $0.1x10^3 kg/m^3$). As a second choice we would have selected Aluminum, S356 because of its similar properties.

D.1.2 Linear Bearing Shafts

1. **Function:** To secure the laser sled from rotating.
2. **Objective:** To minimize mass.
3. **Constraints:** Must not deflect, fixed length L.
4. **Material Indices:**
   - Minimize mass: $m = AL\rho$
   - Must not Deflect: $S = \frac{F}{\delta} < \frac{CEI}{L^3}$ $I = \frac{\pi}{4}r^4 = \frac{A}{4}r^2$
   - The common parameter is A: $m = \frac{4S}{Cr^2}L^4\frac{\rho}{E}$
   - Material Indices: $\boldsymbol{M} = \frac{\boldsymbol{E}}{\boldsymbol{\rho}}$
5. Top Five Material Choices:
   - Epoxy/ aramid fiber→ $\rho = 1.38x10^3$; Cost = \$50.00/kg; $E = 7x10^{10}$ Pa
   - Cyanate ester/HM carbon fiber→ $\rho = 1.62x10^3$; Cost = \$200.00/kg; $E = 3.3x10^{11}$ Pa
   - Epoxy SMC (carbon fiber)→ $\rho = 1.5x10^3$; Cost = \$21.00/kg; $E = 8.5x10^{10}$ Pa
   - Aluminum, 8090, wrought→ $\rho = 2.55x10^3$; Cost = \$28.00/kg; $E = 8.2x10^{10}$ Pa
   - Boron nitride (HP)→$\rho = 2x10^3$; Cost = \$43.00/kg; $E = 9.86x10^{10}$ Pa

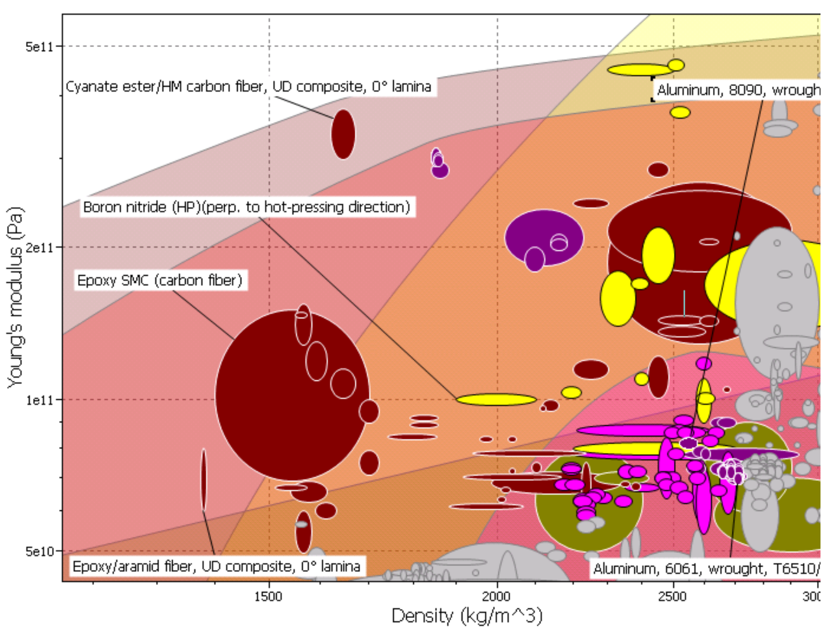


Figure 50: Material Selection near Al 6061

6. **Final Choice Description:** The goal was to find a material with lower density and with similar Young's Modulus. Most other choices had lowest density, however the cost for all other choices was higher than our budget would allow. Accordingly, we determined that ***6161 Aluminum*** is still the best material selection because it is common, cheap, and rigid enough to meet our

specifications. The second closest material which we could have used is the Epoxy SMC (carbon fiber).

D.2 Environmental Performance

D.2.1 Linear Bearing Shafts- 6061 Aluminum vs Carbon Fiber

The volume of one Linear Bearing Shaft is $4.22x10^{-6}$ m^3; therefore the total volume would be $8.44x10^{-6}$ m^3. The density of 6061 aluminum is $2.7x10^3$ kg/m^3, therefore a mass of the two shafts would be (m=ρV) $22.78x10^{-3}$ kg. If we use the Epoxy SMC (carbon fiber) with a density of $1.5x10^3$ kg/ m^3, the mass of the shafts would be $12.66x10^{-3}$ kg.

Shown below in Figure 51 is the characterization of the two different material choices. The aluminum alloy is worse for human health due to its high percentage of carcinogens and repertory organics. It is also very toxic in the environment. The process for producing aluminum is very toxic for the environment.

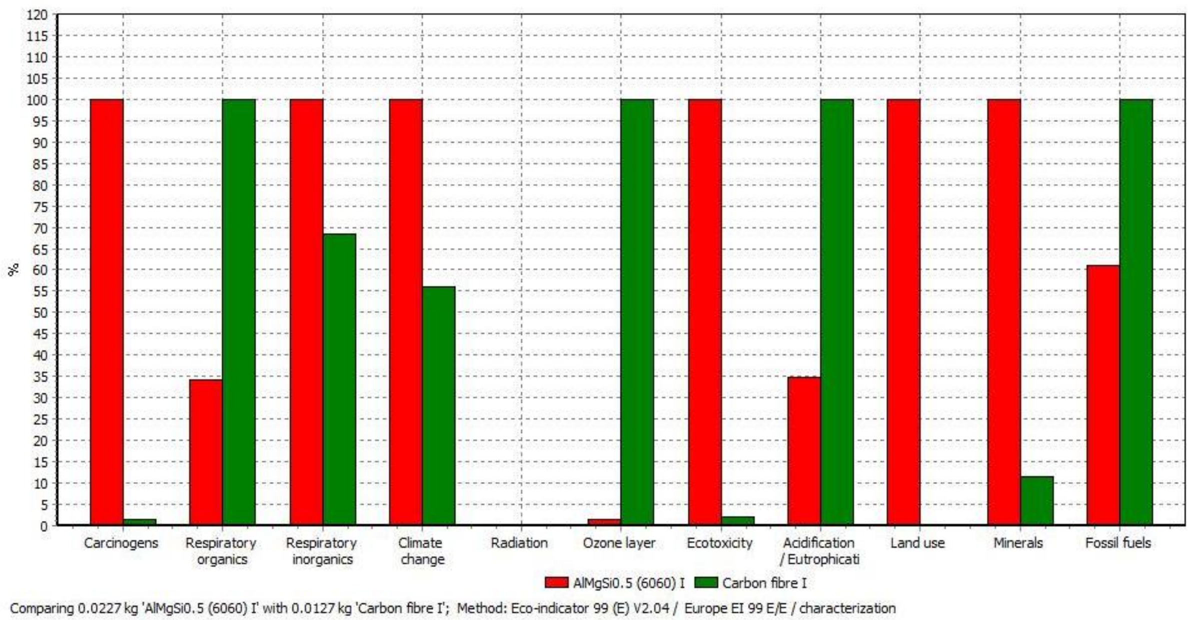


Figure 51: Characterization of 6061 Al vs Carbon Fiber

Shown in Figure 52, Figure 53, and Figure 54 is the damage assessment, normalized and weighted, of human health, the ecosystem, and resources. Access to Aluminum is limited by the reserves worldwide, whereas carbon fiber is not. As also pointed out in the last figure, aluminum is considerably worse for human health and the environment.

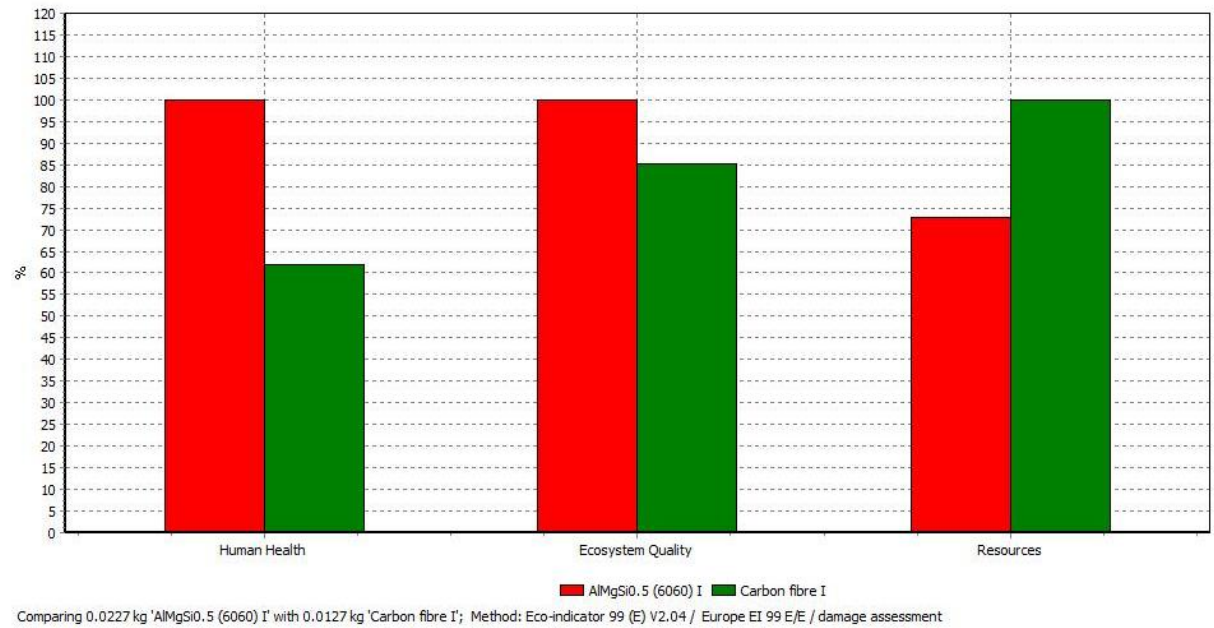


Figure 52: Damage Assessment of 6061 Al vs Carbon Fiber

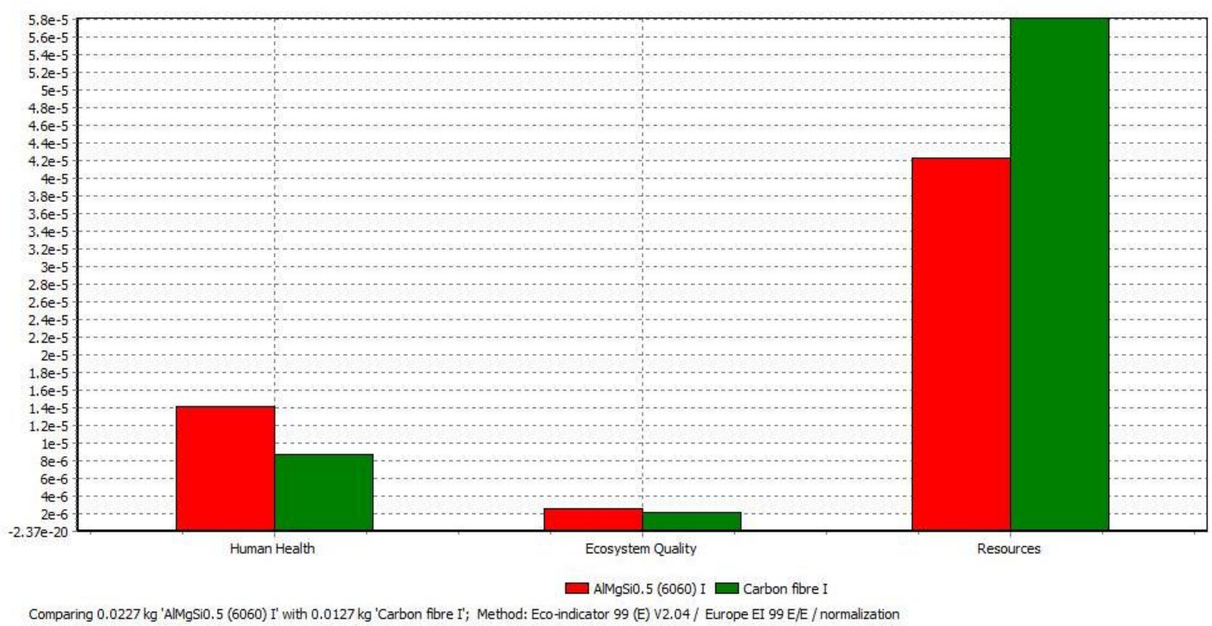


Figure 53: Normalization of 6061 Al vs Carbon Fiber

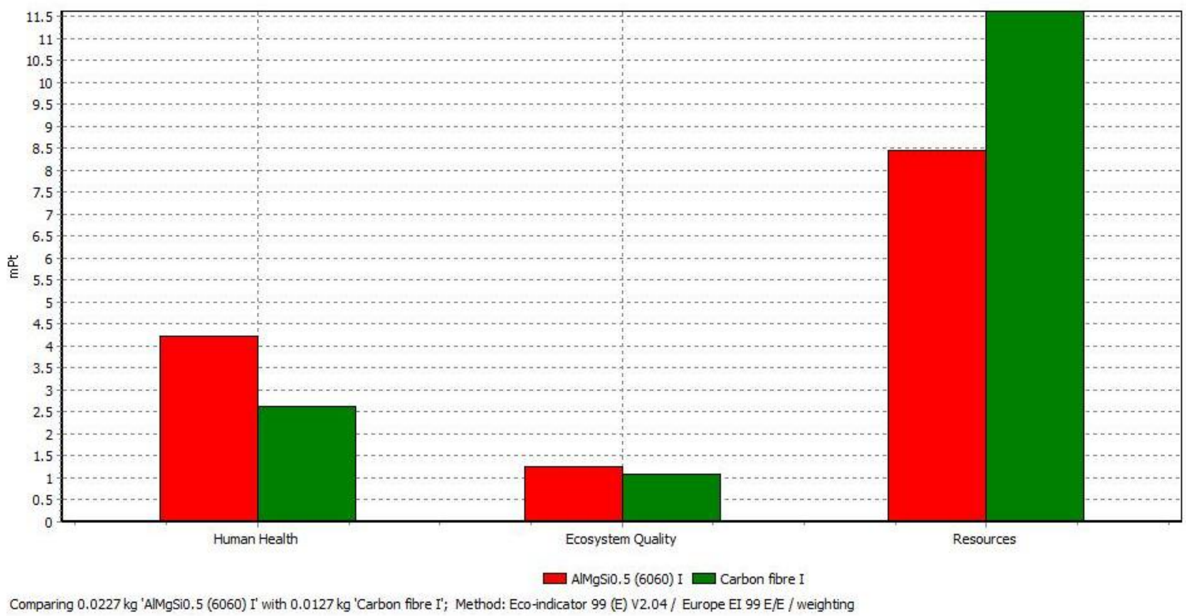


Figure 54: Weighting of 6061 Al vs Carbon Fiber

Overall, aluminum clearly has a higher environmental impact than carbon fiber. However, carbon fiber is extremely brittle, and would not be sufficient for high accuracy machining. Therefore, we conclude that 6061 aluminum is indeed the best overall choice for material selection of the linear bearing shafts.

D.3 Manufacturing Process Selection

This section outlines the possible mass production of our product. To do this we must first analyze the possible production volume of this device. Our device will essentially create a new market for photolithography. We will be able to make this device extremely affordable for researchers and universities everywhere. We predict that most universities around the world will be interested in purchasing our product, and possible multiple orders for our product. This leads us to believe that we could see production volumes in the range of 1,000-10,000 pieces.

Process Selection

We implemented the use of CES process selector in determining the high volume production method of our device. We set certain constraints on production, cost and shapes. For this process, we choose the parts that will be made out of aluminum. In the previous section we determined that the possible materials are two differing types of aluminum. We set another constraint on material. This led us to two different processes, forging and die casting. With our product, tolerances are very important. This leads us to choose die casting. According to CES, die casting has better tolerances and will be better suited for our design. The elimination process is shown bellow

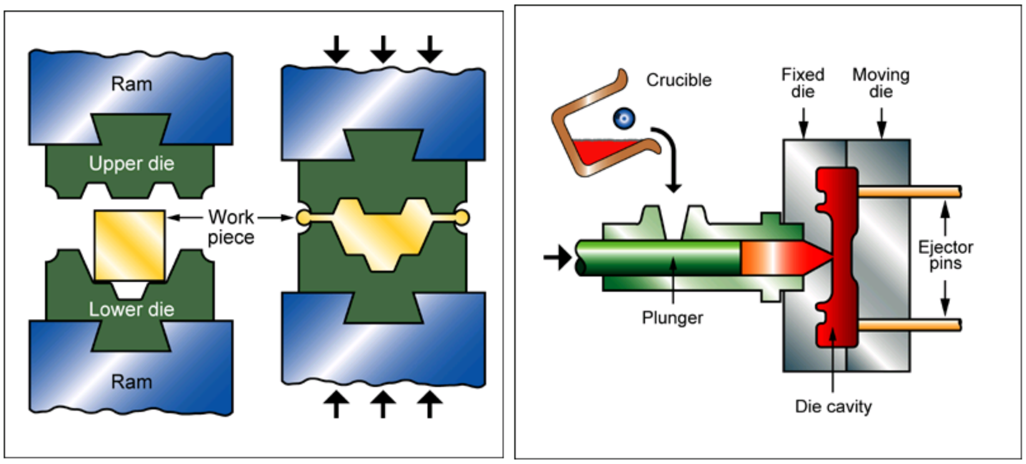


Figure 55: Forging and Die casting process illustration from CES

3-D printing	1	✓	✗
Blow molding	0	✗	✗
Compression molding	1	✗	✓
Cutting	1	✓	✗
Deposition-based prototyping	0	✗	✗
Die casting	2	✓	✓
Drilling	1	✓	✗
Expanded foam molding	1	✗	✓
Extrusion	1	✓	✗
Filament winding	0	✗	✗
Forging	2	✓	✓
Injection molding	0	✗	✗
Investment casting	1	✓	✗
Laser-based prototyping	0	✗	✗
Lay-Up methods	0	✗	✗
Machining	0	✗	✗
Polymer extrusion	0	✗	✗
Powder injection molding	0	✗	✗
Pressing and sintering	2	✓	✓
Pultrusion	0	✗	✗
Resin casting	0	✗	✗
Resin transfer molding (RTM)	0	✗	✗
Rolling	1	✓	✗
Rotational molding	0	✗	✗
SHAPING	1	✓	✗
Sand casting	1	✓	✗
Sheet forming	1	✓	✗
Sheet stamping, drawing and blan...	1	✓	✗
Thermoforming	0	✗	✗

Figure 56: Elimination Process

D.4 Summary of CES, SimaPro, and Design for Safety

We learned a great deal about material selection and design safety with the utilization of CES and SimaPro. It is extremely important to develop safe engineering design solutions, and these tools will help us meet this core value in the future. CES is a very valuable tool for obtaining accurate and up-to-date information about material properties, cost, and manufacturing processes. SimaPro is an effective tool for analyzing the environmental impact of a vast array of materials. Additionally, we gained much confidence in our design and manufacturing plan through the development of our safety report. The safety report allowed us to assess potential hazards associated with machining, assembling and utilizing the prototype. The safety report also helps us create a coherent manufacturing plan by planning ahead.

E Bill of Materials

This bill of materials has been very carefully managed to be as accurate as possible. However, because we purchased these parts through our sponsor, the shipping fees are not known. A good estimate would be to include roughly $300.00 extra for shipping and handling fees, which would place the overall budget at $1,369.03. The most expensive single item which we purchased was the US Digital micro-stepping driver for the rotating the fixture's motor.

Laser Assembly:

Part	Specifications	Hyperlink/Source	Part Number	Quantity	Cost	Sub Total	Contact Info
Lense 1	6 mm Diameter; 72 mm focal length	http://www.edmundoptics.com/onlinecatalog/displayproduct.cfm?productid=2911&StartRow=21&PageNum=2	NT32-851	1	$ 27.50	$ 27.50	1-800-363-1992
Lense 2	3 mm diameter; 3 mm focal length	http://www.edmundoptics.com/onlinecatalog/displayproduct.cfm?productID=3130	NT45-118	1	$ 31.50	$ 31.50	1-800-363-1993
Precision Pinhole	D = 10 µm	http://www.edmundoptics.com/onlinecatalog/displayproduct.cfm?productID=1794	NT56-276	1	$ 47.50	$ 47.50	1-800-363-1994
Acme Threaded Rod	Size 3/8" - 40; 6 ft long	McMaster	6350K137	1	$ 129.48	$ 129.48	(330) 955 - 9600
Precision Acme Nut	Size 3/8" - 40; Overall Length = 1"; Flange D = 1.1"; Bolt Circle (x3)= 0.875"	McMaster	6350K175	2	$ 19.43	$ 38.86	(330) 955 - 9601
Precision Linear Motion Shafts	D = 1/4 "; 10" overall length; Steel	McMaster	1144K11	2	$ 21.14	$ 42.28	(330) 955 - 9602
Sleeve Bearings (laser sled support)	Shaft Diameter = 1/4"; Length 1"; OD = 3/8"	McMaster	6391K135	2	$ 0.50	$ 1.00	(330) 955 - 9603
Sleeve Bearings (laser mounting plate rotation)	Shaft Diameter = 1/2", OD = 5/8"; L = 1/2"	McMaster	6391K212	2	$ 0.59	$ 1.18	(330) 955 - 9604
Sleeve Bearing (threaded rod support)	SD = 3/8"; OD = 5/8"; L = 1/2"	McMaster	6391K186	1	$ 1.17	$ 1.17	(330) 955 - 9604
Stepper Motor	Size 17; 31.4 oz-in torque, parallel	https://sdp-si.com/eStore/PartDetail.asp?Opener=Group&PartID=17604&GroupID=368	S9117M-D13HT	1	$ 64.13	$ 64.13	(800) 819-8900X491
Stepper Motor Driver	1, 1/2,1/4,1/8,1/16 step; 2 A/coil; Operates from 8 - 35 V.	http://www.pololu.com/catalog/product/1202	1202	1	$ 20.00	$ 20.00	(702) 262-6648
Power Supply for Optical System	24 V; 6.5 A	www.allelectronics.com	CAT# NT45-118	1	$ 26.95	$ 26.95	818-904-0524
Diode Laser	280 mW, 405 nm; Diode Voltage = 4.8V, I = 320 mA; D = 1.5mm	http://www.lasersurplusparts.com/index.php?main_page=product_info&cPath=1&products_id=100	~	1	$ 30.00	$ 30.00	8640 State Route 163 Belleville, IL. 62223 Tel: 1(618)550-9810
Laser Driver (TTL Driver)	Input 5-12VDC;Input Current : ~300mA	http://www.trossenrobotics.com/store/p/5605-Laser-Module-Red-with-TTL-Control.aspx	LD-250-COM-08654	1	$ 20.00	$ 20.00	(877) 898-1005
Power Supply of Laser Driver	12V; 300 mA	www.allelectronics.com	CAT# PS-1236	1	$ 5.50	$ 5.50	818-904-0524
					Sub Total	**$ 487.05**	

Fixture:

Part	Specifications	Hyperlink/Source	Part Number	Quantity	Cost	Sub Total	Contact Info

O-ring for wafer fixture	Pack of 5; Diameter of 0.103 in; OD = ;ID =	McMaster	5577K154	1	$ 13.10	$ 13.10	(330) 955 - 9604
Rubber for anti-wafer spinning support	1/2' x 12"; 1/32" thick; super soft	McMaster	8622K31	1	$ 9.72	$ 9.72	(330) 955 - 9605
Screws to connect top and bottom pieces(x4) of the wafer fixture	18 - 8 Scew; Thread Size = 6-32; Packs of 25; L = 3/16"	McMaster	92210A142	1	$ 6.67	$ 6.67	(330) 955 - 9605
Screws to connect fixture to fixture shaft	5-40 screws; pack of 25; L = 1"	McMaster	91253A135	1	$ 7.97	$ 7.97	(330) 955 - 9606
					Sub Total 2	**$ 37.46**	

Table Assembly:

Part	Specifications	Hyperlink/Source	Part Number	Quantity	Cost	Sub Total	Contact Info
Bearing outer ring	Shaft Diameter = 3/4"; OD = 1 - 25/32"	McMaster	5709K53	2	$ 5.13	$ 10.26	(330) 955 - 9606
Bearing inner ring roller assembly	Shaft Diameter = 3/4";Outside Diameter = 1 - 25/32"	McMaster	5709K13	2	$ 9.56	$ 19.12	(330) 955 - 9607
Bronze Sleeve Bearings for the rotating fixture	Di = 0.25 in(shaft); Do = 5/16 in; length = 1/4 in	McMaster	6391KI126	2	$ 0.30	$ 0.60	(330) 955 - 9608
Fixture Shaft Locking Nut (applies restraining force to fixture shaft)	5/8" - 11 thread; Flang Diameter = 1.33"; Pack of 10	McMaster	93298A170	1	$ 7.15	$ 7.15	(330) 955 - 9609
Socket Cap Screw (holding bearing block to main plate)	8-32; Length = 1 - 3/4"; Pack of 25 (need 4)	McMaster	92210A205	1	$ 5.53	$ 5.53	(330) 955 - 9610
Flathead screws connecting Main Table Plate to dowel pins	1/4 - 20; L = 1"; Pack of 50 (**need 4 here and 4 for laser assembly**)	McMaster	91253A542	1	$ 9.13	$ 9.13	(330) 955 - 9612
Socket Head Screws connecting motor mounting plate to dowel pins	1/4 - 20; L = 1"; Pack of 25 (**need 4 here and 7 for fixing of laser assembly and sheet metal to chassis**)	McMaster	96006A709	1	$ 12.00	$ 12.00	(330) 955 - 9613
Stepper Motor	Size 17, 51 oz-in torque, parallel	https://sdp-si.com/eStore/PartDetail.asp?Opener=Group&PartID=20609&GroupID=368	S9117M-D15HT	1	$ 67.63	$ 67.63	(800) 819-8900X491
Stepper Motor Driver	Requires 4.5A, 48V power supply for best operation	http://usdigital.com/products/motor-drivers/md2s/	MD2S	1	$ 150.00	$ 150.00	1400 ne 136TH Avenue Vancouver Washington 89684, USA; Tel: (800)763.0194
Power Supply for Fixture	48V; 120W	http://usdigital.com/products/power-supplies/ps-48/	PS-48	1	$ 68.00	$ 68.00	1400 ne 136TH Avenue Vancouver Washington 89684, USA; Tel: (800)763.0194
Fixture Shaft	7/8" D; 12" Long; 7075 Al	McMaster	90465K681	1	$ 13.10	$ 13.10	(330) 955 - 9613

Draw Latches	1-800-562-5267; Sugatsune America, Inc.	http://www.sugatsune.com/products/ProductDetails.cfm?CATID=5&SUBCATID=10&PRODUCTID=STF-40	STF-40	2	$ 10.00	$ 20.00	www.thehardwarehut.com (800)708-6649
Brass Sleeve Bearings for the rotating fixture	Di = 0.25 in(shaft); Do = 3/8 in; length = 1/4 in	McMaster	2868T1	2	$ 0.48	$ 0.96	(330) 955 - 9613
					Sub Total 2	**$ 383.48**	

Chassis:

Part	Specifications	Hyperlink/Source	Part Number	Quantity	Cost	Sub Total	Contact Info
All Metal for general Construction	6061 Precision Ground Aluminum	Alro Metals, Ann Arbor	~	1	$ 135.00	$ 135.00	(734) 213-2727
Bread Board, Limit Switch, and wiring for electronics	½" coarse thread limit switch	Radio Shack	~	1	$ 16.00	$ 16.00	(734) 327-3661
Chassis Fixing Screws	8-32 Flathead; 1" length; Pack of 100	McMaster	92210A199	1	$ 10.04	$ 10.04	(330) 955 - 9613
					Sub Total 3	**$ 161.04**	

Grand Total:	**$ 1,069.03**
Most Expensive Item:	$ 150.00

*Not Including Shipping Charges

F Project Plan

After the successful completion of fabrication, we can compare the actual time we spent fabricating vs. the projected time we estimated that we would spent (times for machining operations are only estimates). Our proposed schedule was extremely difficult to follow. Although we spent more days fabricating than we had initially projected, we spent fewer hours fabricating. Most work was done in the Graduate Lab because of the higher accuracy needed in machining, as was approved by our section instructor.

Table 4: Manufacturing Plan

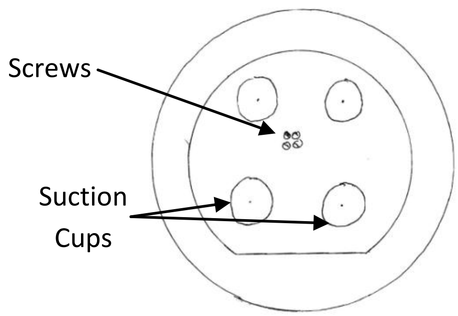
Part #	Machining Process	Machining Date	Location of Fabrication	Estimated Time (hours)
34	Motor Mounting Rods	23-Nov	Undergrad/ Graduate Lab	3
36	Motor Mounting Plate		Water Jet Lab	0.2
41	Locking Arm		Water Jet Lab	0.15
19	Main Chassis Laser Mount		Water Jet Lab	0.15
~	Fixture Plate for Machining	24-Nov	Graduate Lab	2
39	Side Plate w/ Slot			2
44	Side Plate			2
43	Bottom Chassis Plate			1
25	Fixture Bottom	25-Nov	Graduate Lab	1.5
46	Laser Assembly Mounting Plate			3
23	Fixture Top			3
32	Bearing Block			3
	Reference Plate	30-Nov	Graduate Lab	1.5
14	Linear Bearing Shafts			1.5
28	Main Table Plate			3
26	Fixture Shaft	1-Dec	Graduate Lab	3
8	Laser Sled			1.5
13	Laser Linear Bearing Support	2-Dec	Graduate Lab	2
18	Laser Motor Mount & Linear Bearing			2
2	Laser Diode Lens Mount	3-Dec	Graduate Lab	3
5	Lens & Pin Hole Mount			3
48	Laser Assembly Cover	4-Dec	Graduate Lab	1
~	Assembly and Finishing touches on machining	7-Dec	Undergraduate Lab	8
			Total Actual Time Spent Machining (hrs):	**50.5**
			Total Actual Days needed:	**9**
			Machining Time/day	**5.61**
			Estimated Time Spent Machining (hrs):	**61**
			Total Estimated Days needed (8 hrs/day):	**7.625**

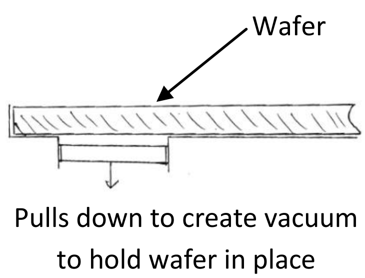
G Functional Concept Generation

Our concept generation was aided by generating concepts at the functional level and combining the best options. This section outlines the different concepts.

G.1 Fixtures

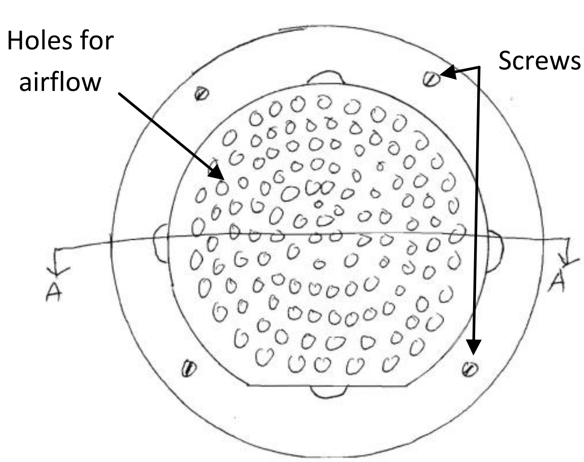
1. Vacuum-Fixture - utilizes a vacuum pressure to hold the wafer in place.
   a. Suction Cups
      - **Summary of Design:** Wafer would be fixed by manually actuated suction cups.
      - **Advantages:** Simple to manufacture, suction should provide adequate force to hold the wafer in place while spinning. Symmetry will help minimize vibrations.
      - **Disadvantages:** Physically actuating the suction cups could cause error in horizontal pitch of wafer, and or could cause insufficient force to hold wafer. Electronic actuation would be more precise, but would then defeat the purpose of simplifying design.

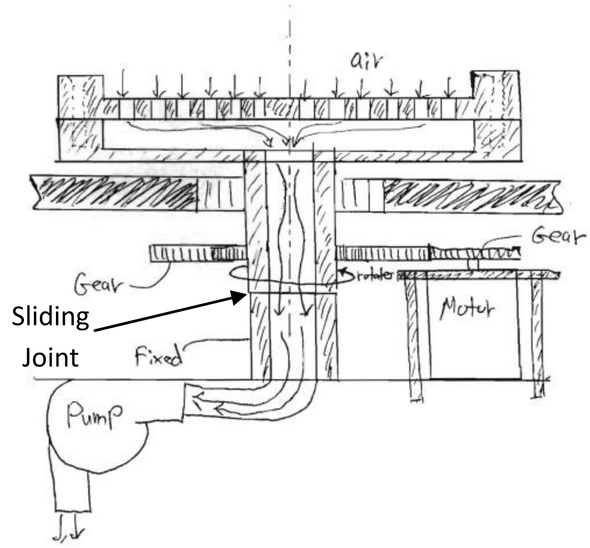




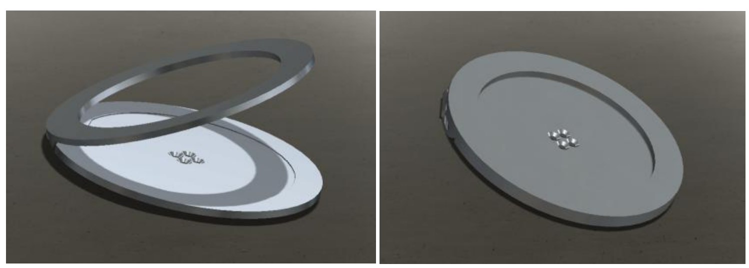
   b. Complex Suction Device
      - **Summary of Design:** Employs the force from a vacuum to hold the wafer. Holes are cut below the wafer as sources to hold the wafer. Gears would have to be press-fit around the hollow shaft in which air would flow through. The motor would also have to be geared to allow for rotation of the wafer. A sliding joint between the rotating fixture and a fixed hollow shaft would occur.
      - **Advantages:** Can Pattern the entire Area of the wafer. Position of wafer will be consistent. The suction force should be sufficient to hold the wafer. The apparatus is symmetric to minimize vibration. The vacuum force would not need to be extremely great to generate the necessary force to hold the wafer.
      - **Disadvantages:** Complex and therefore costly design; need for a pump and gearing.

*Cut-Away of Section A-A

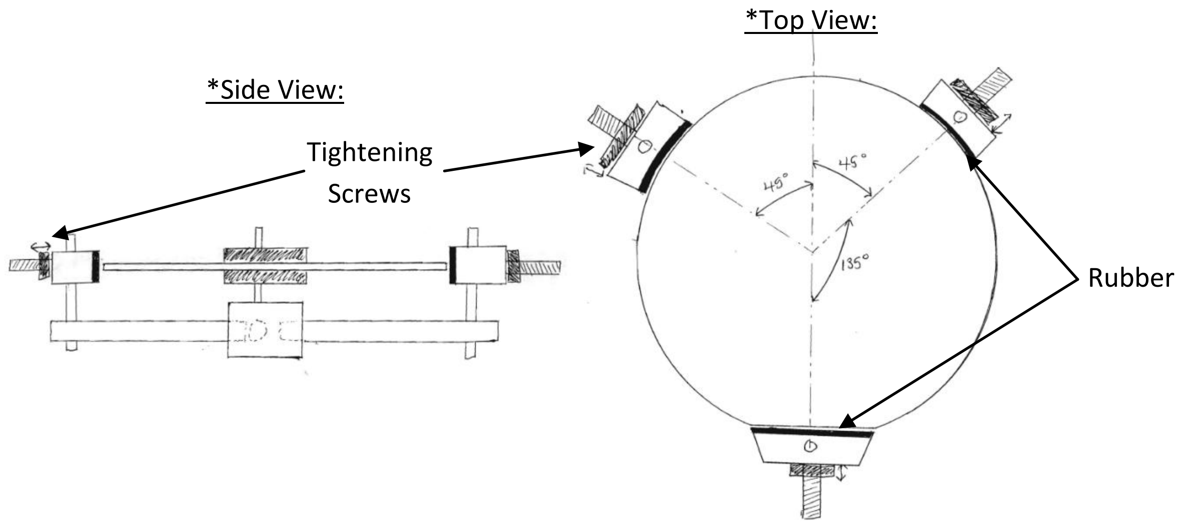




2. Hinged - This design uses a hinged cover to hold the wafer in place (As in Alpha Design)
   - **Summary of Design:** As Described in the Alpha Design Section
   - **Advantages**: Simple design, easy to manufacture. Holds wafer in place
   - **Disadvantages:** Not Symmetrical. A latch would be needed to provide the appropriate downward force to hold the wafer; however this is what throws off the inertia.

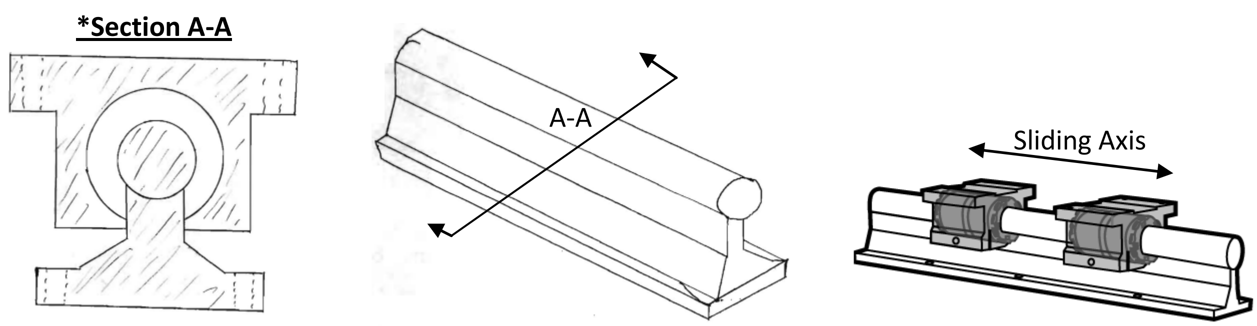


3. Three Prong Bit - Uses a bit to hold down the wafer, similar to a lathe machine.
   - **Summary of Design:** Three sides of the wafer will be constrained. Two of the three should be permanently secured, while the other side should only be used for removal of the wafer.
   - **Advantages:** This design is symmetric, and should provide adequate force to secure the wafer.
   - **Disadvantages:** Requires a high degree of precision

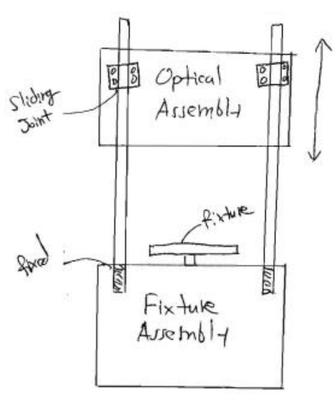


G.2 Table Assembly Movement

1. Sliding Assembly
    - **Summary of Design:** Table assembly (including motor and fixture) move along the sliding axes as shown below.
    - **Advantages:** Smooth motion and allows for angle for wafer removal.
    - **Disadvantages:** Expensive.

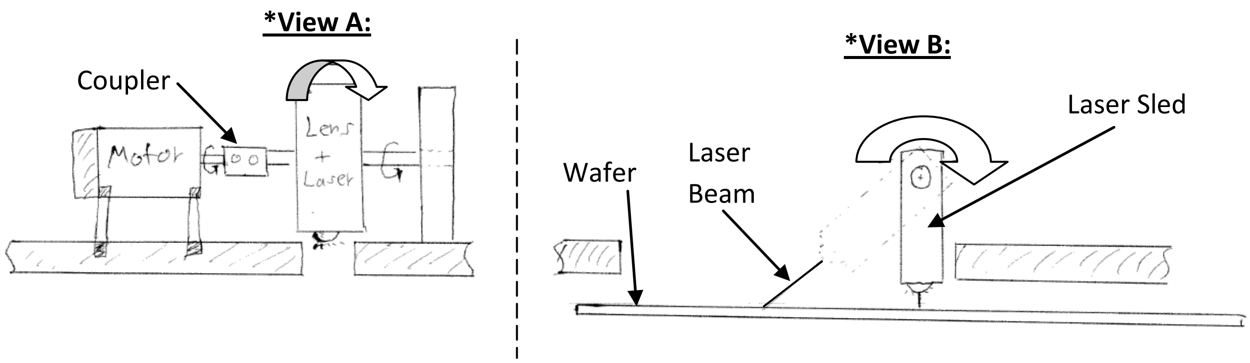


2. Lift Optical Assembly Vertically
    - **Summary of Design:** Optical Assembly moves up with respect to the table assembly.
    - **Advantages:** This would allow for smooth movement of the assembly.
    - **Disadvantages:** Would not provide an ideal angle for the user to remove the wafer.



G.3 How to Actuate the Laser

1. Rotational Actuation
   - **Summary of Design:** This design only rotates the laser sled in one direction. View A is the view in which the laser sled rotates in and out of the page, View B shows it rotating in the plane of the page.
   - **Advantages:** Simple design requiring few parts.
   - **Disadvantages:** Expensive stepper motor needed to achieve the high degree of steps per revolution needed to achieve the target resolution at the outer edges of the wafer.



H Finite Element Analysis

H.1 Static FEMA

FMEA Analysis was performed on the entire assembly. We fixed the bottom plate of the chassis, and measured the Factor of Safety of the force of gravity on the assembly. This resulted in a Factor of Safety (FOS) no smaller than 100 over the entire assembly. Therefore we can assume that static loads will not be an issue in the entire assembly.

H.2 Dynamic FEMA

The highest loads on our system will occur at the screws securing the fixture during acceleration of the fixture system. Therefore, we performed FEMA through Solid Works to model the screws and analyze stress distribution as shown in Figure 57. The top of the screw was fixed, while a force equal to that of the torque applied at the radius of the screws location was applied to the fixture shaft. The lowest FOS was 12.5, which assures that not only will the screws not come close to failure, but they will not yield at all during acceleration of the fixture

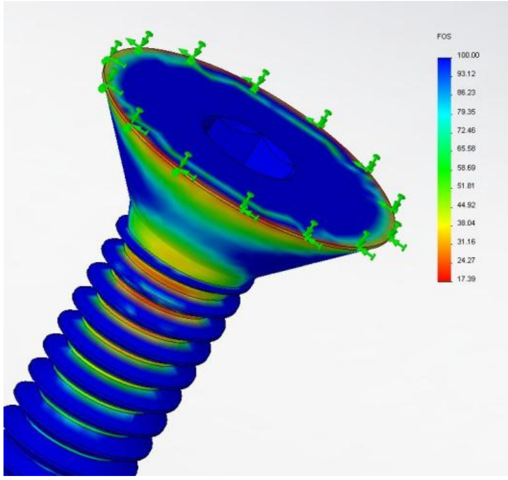


Figure 57: FOS for a Screw on the Fixture

Additionally, to test the shear forces on the fixture itself, we performed FEMA on the entire fixture assembly. Fixing the fixture assembly in several different orientations resulted in the same FEMA, showing that the lowest FOS was greater than 100. A torque equal to our motor was applied to the fixture shaft while fixing only the fixture (top) in its position. Also a force equivalent to the 10Nm torque applied to the locking nut was applied to the shaft and fixture (bottom). The results of the test are shown in Figure 58 below

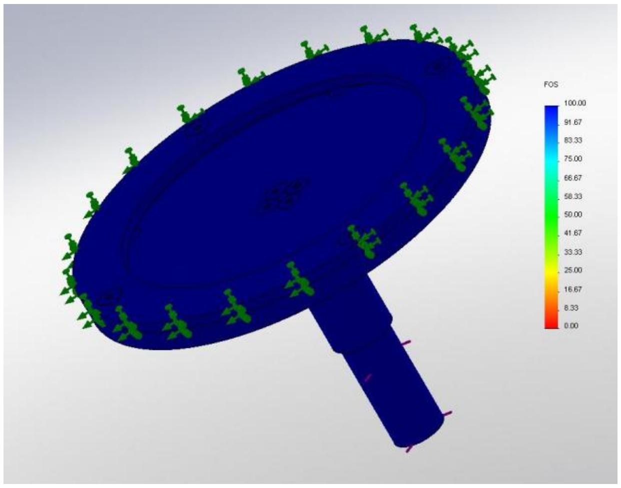
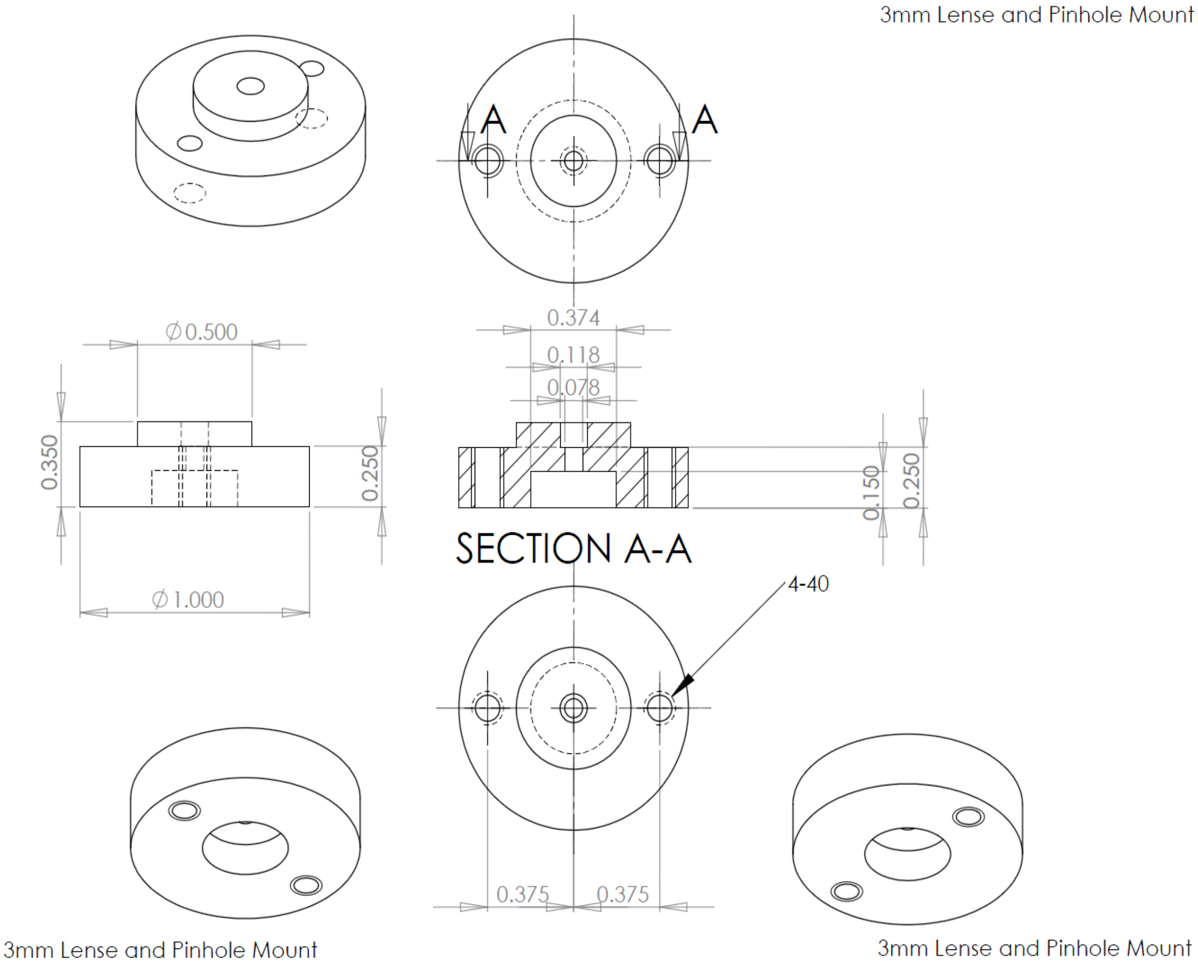


Figure 58: FOS of the Fixture Assembly

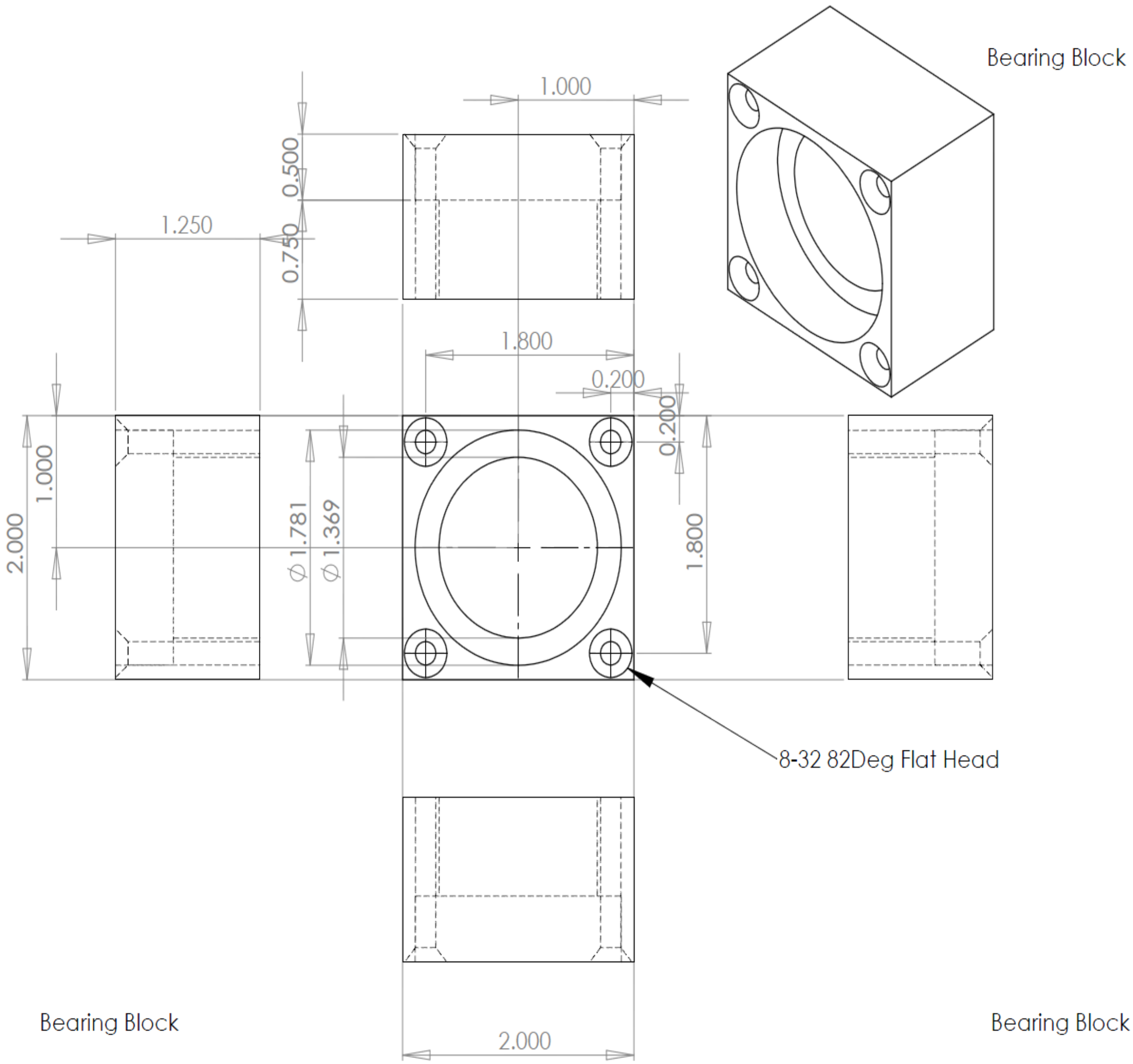
I CAD Drawing of Designed Parts

In this section, we provide CAD drawings for all components we will design and manufacture.

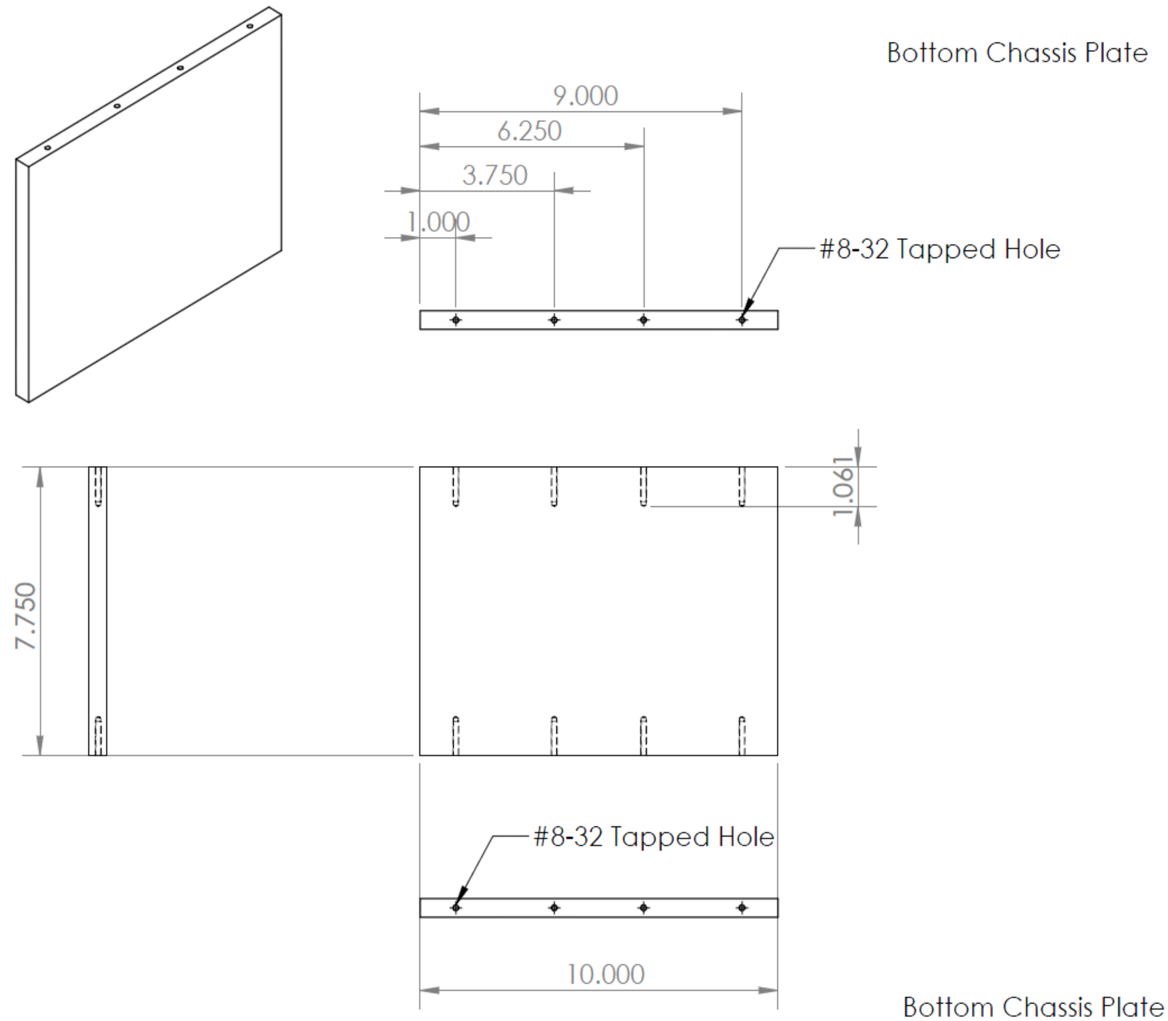
I.1 Lens and Pin Hole Mount



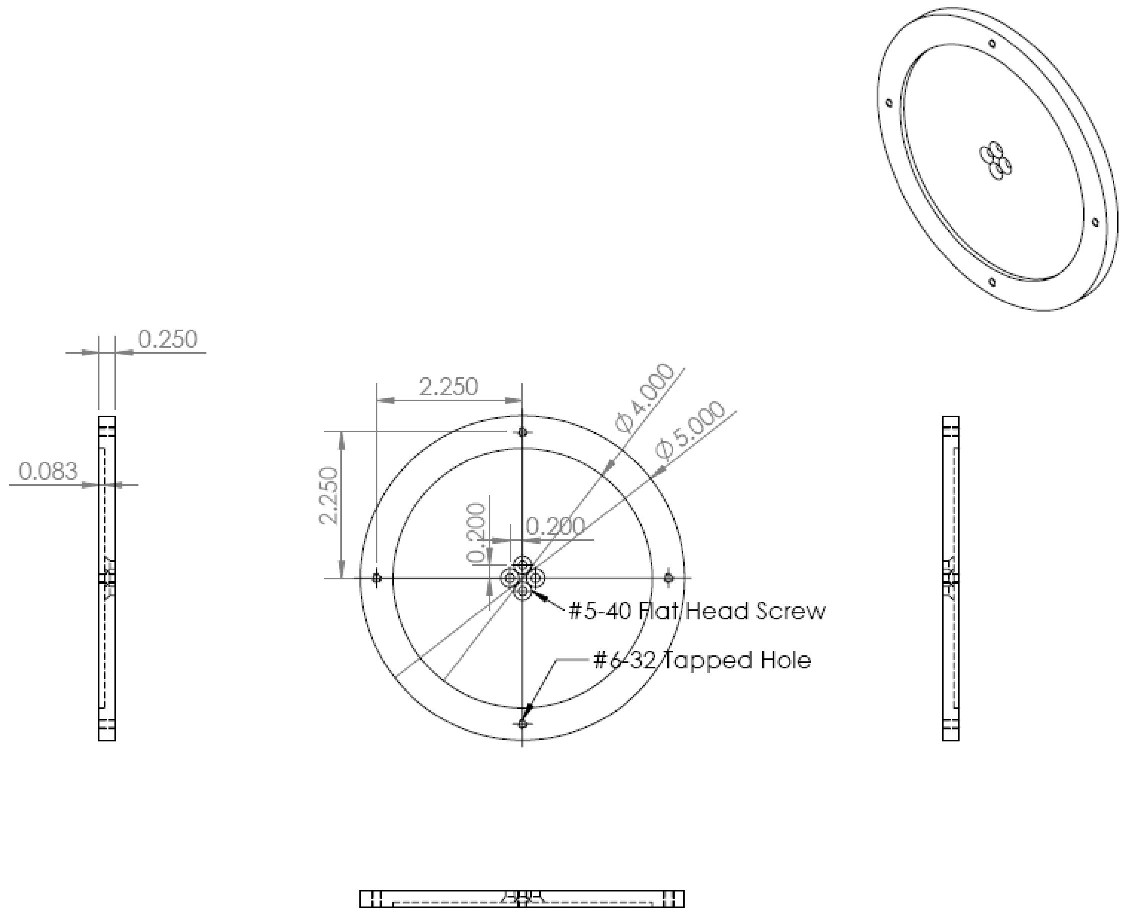
I.3 Bearing Block



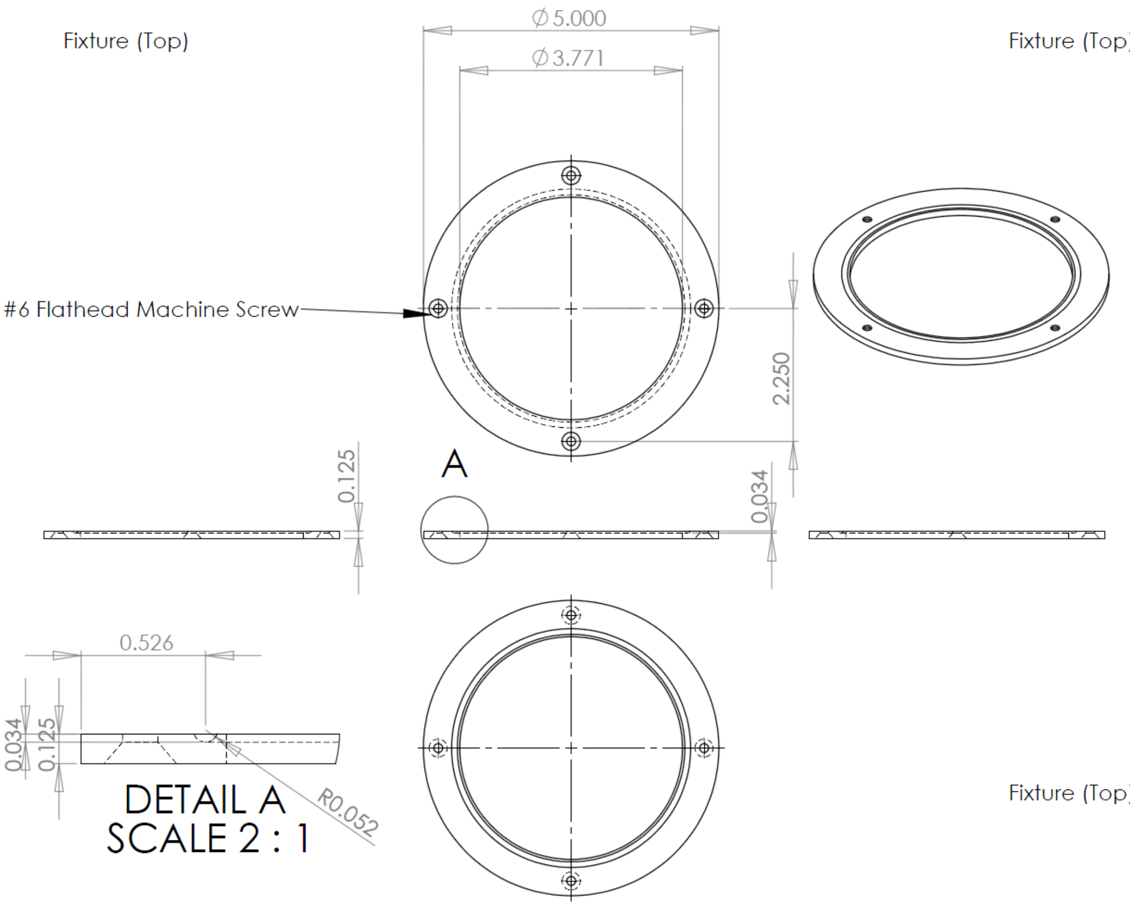
I.4 Botton chasis Plate



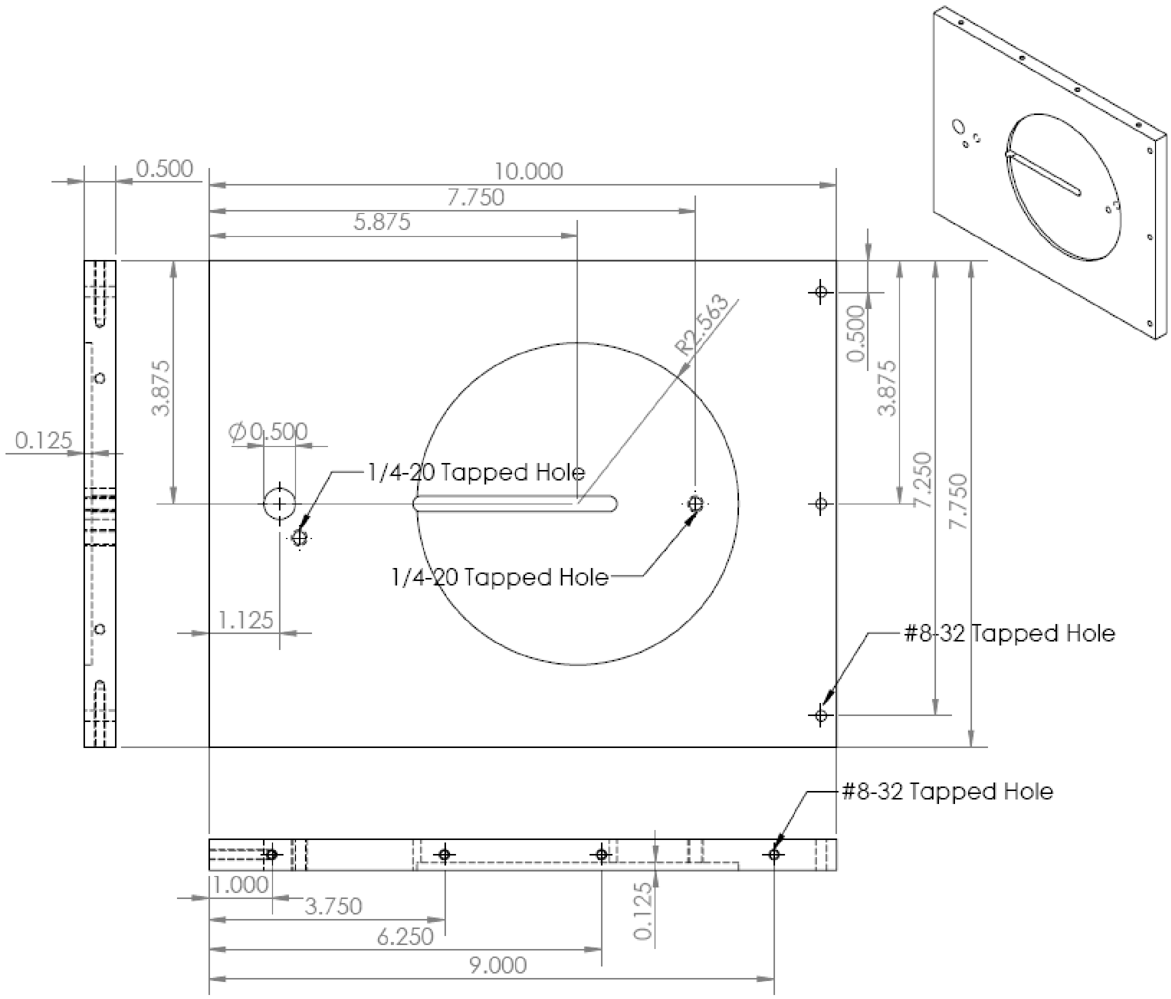
I.5 Fixture Bottom



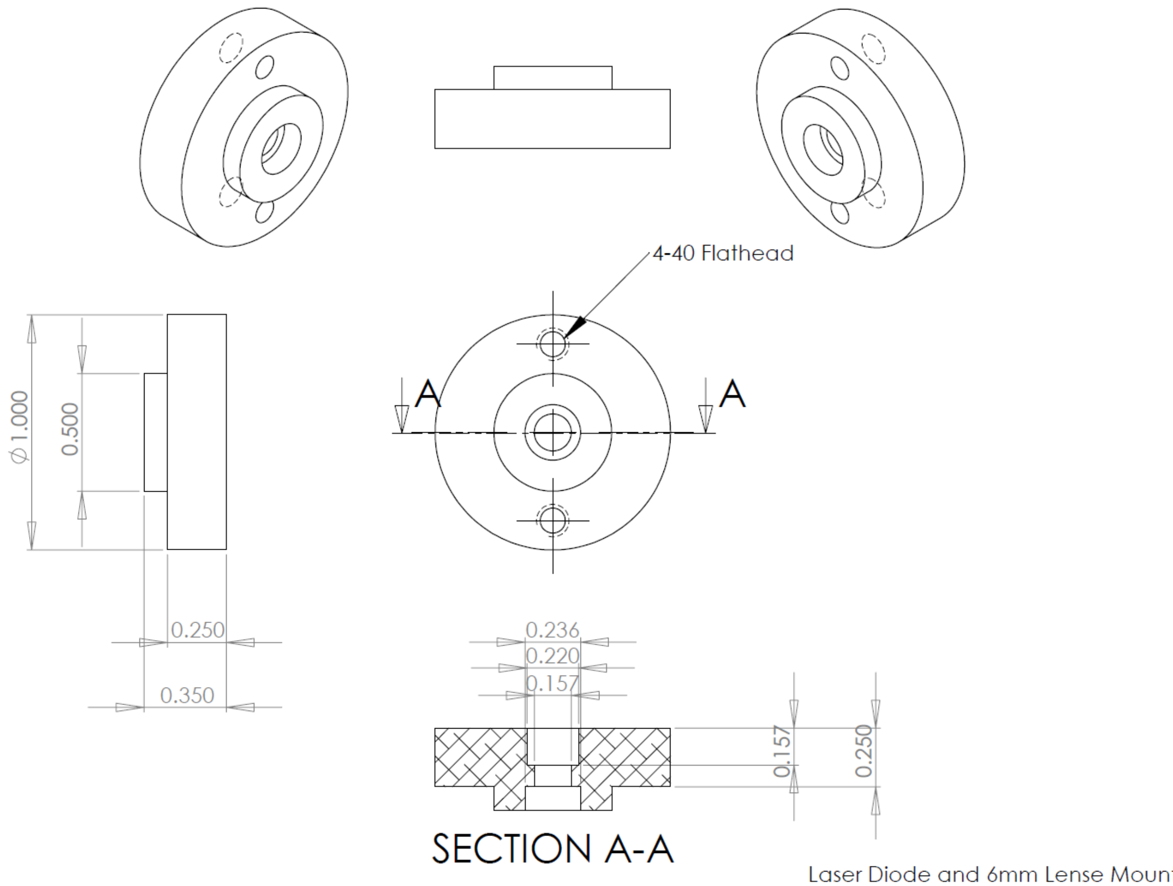
I.6 Fixture Top



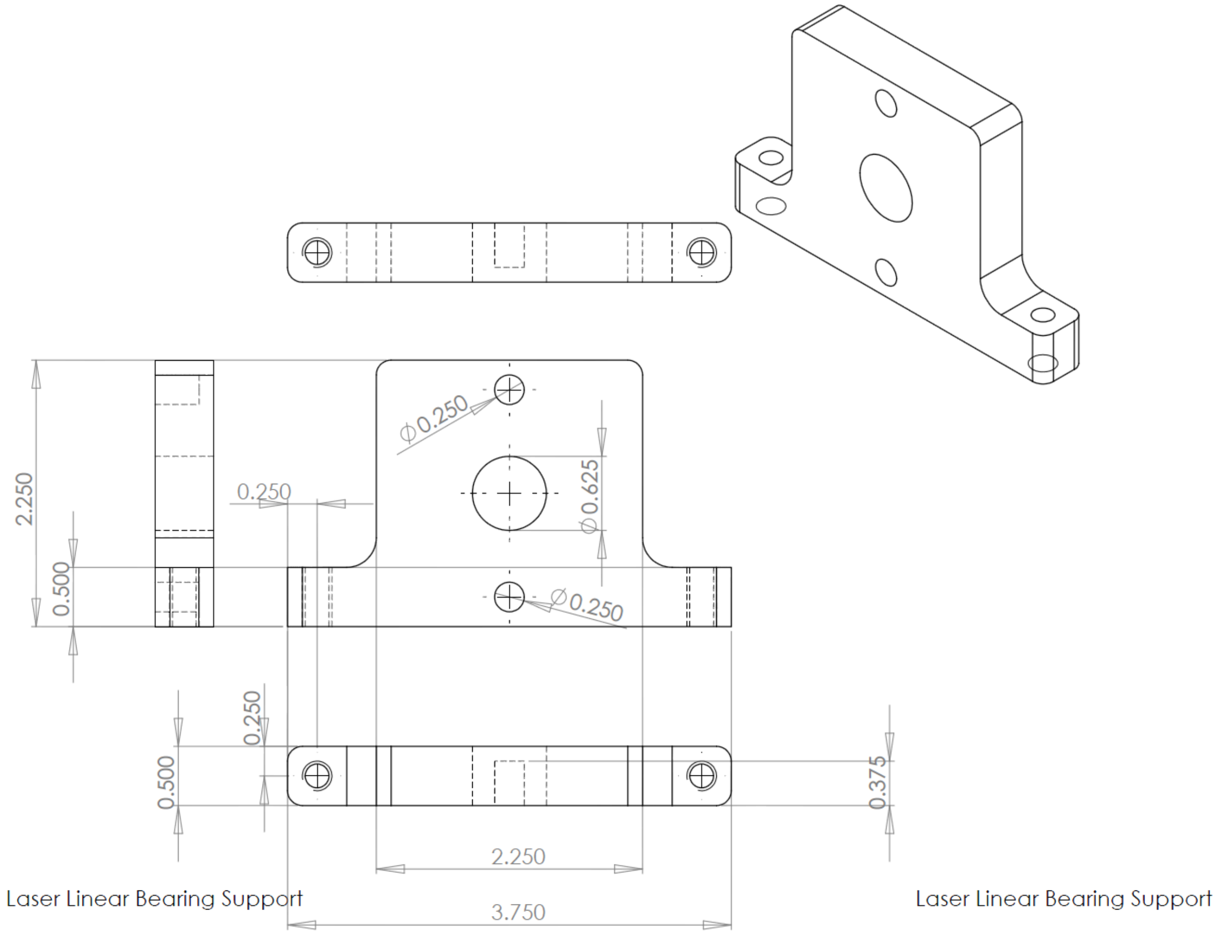
I.7 Laser Assembly Mounting Plate



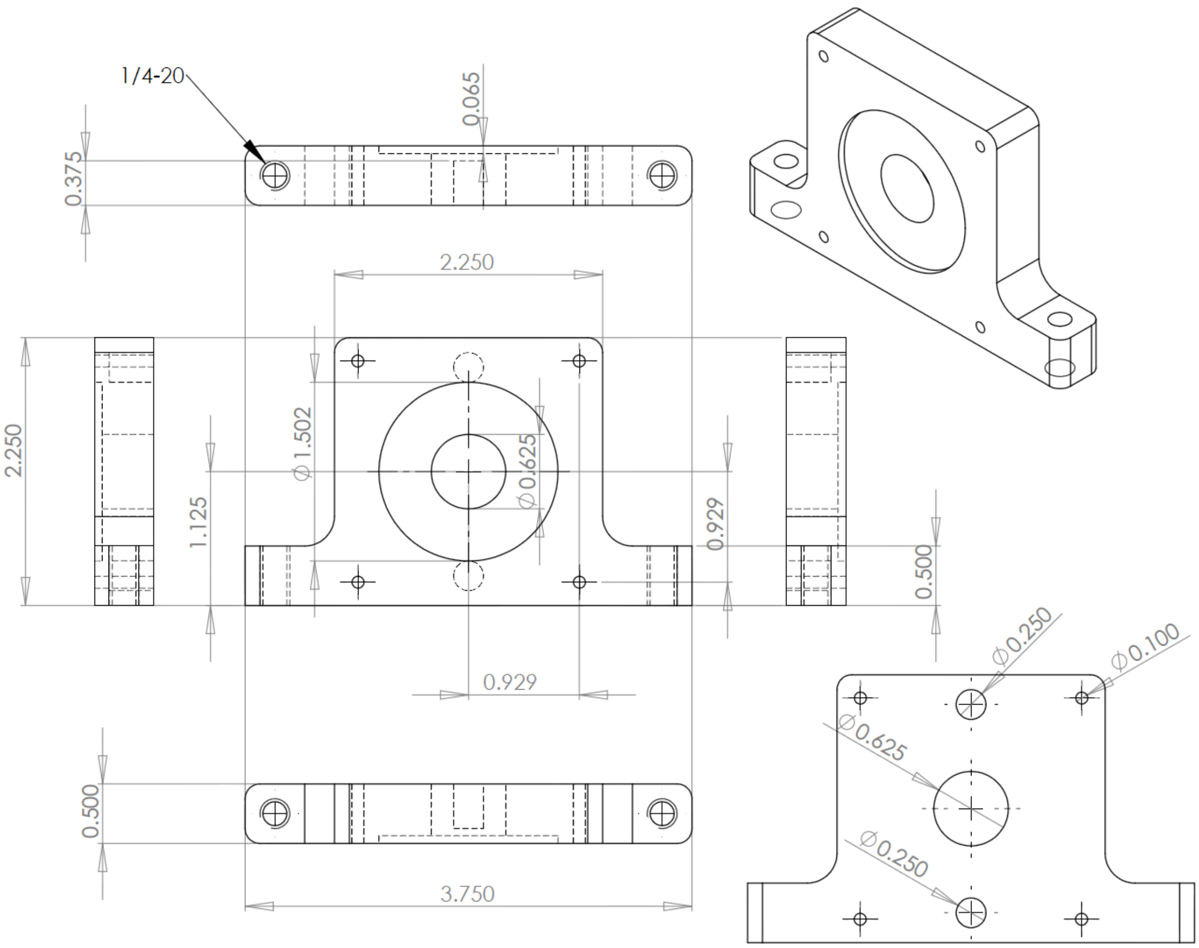
I.8 Laser Diode and Lens Mount



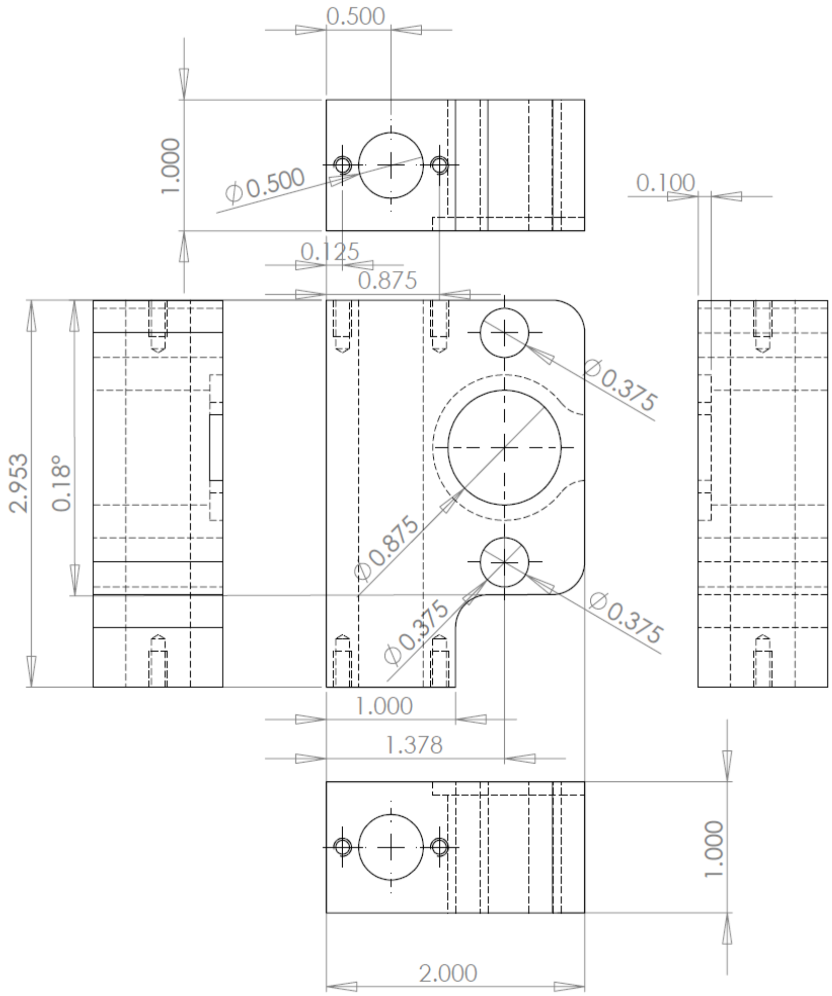
I.9 Laser Linear Bearing Support



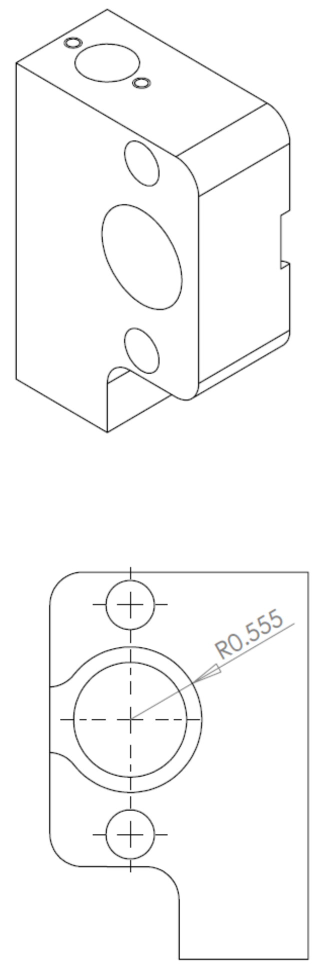
I.10 Laser Motor Mount and Linear Bearing



I.11 Laser Sled

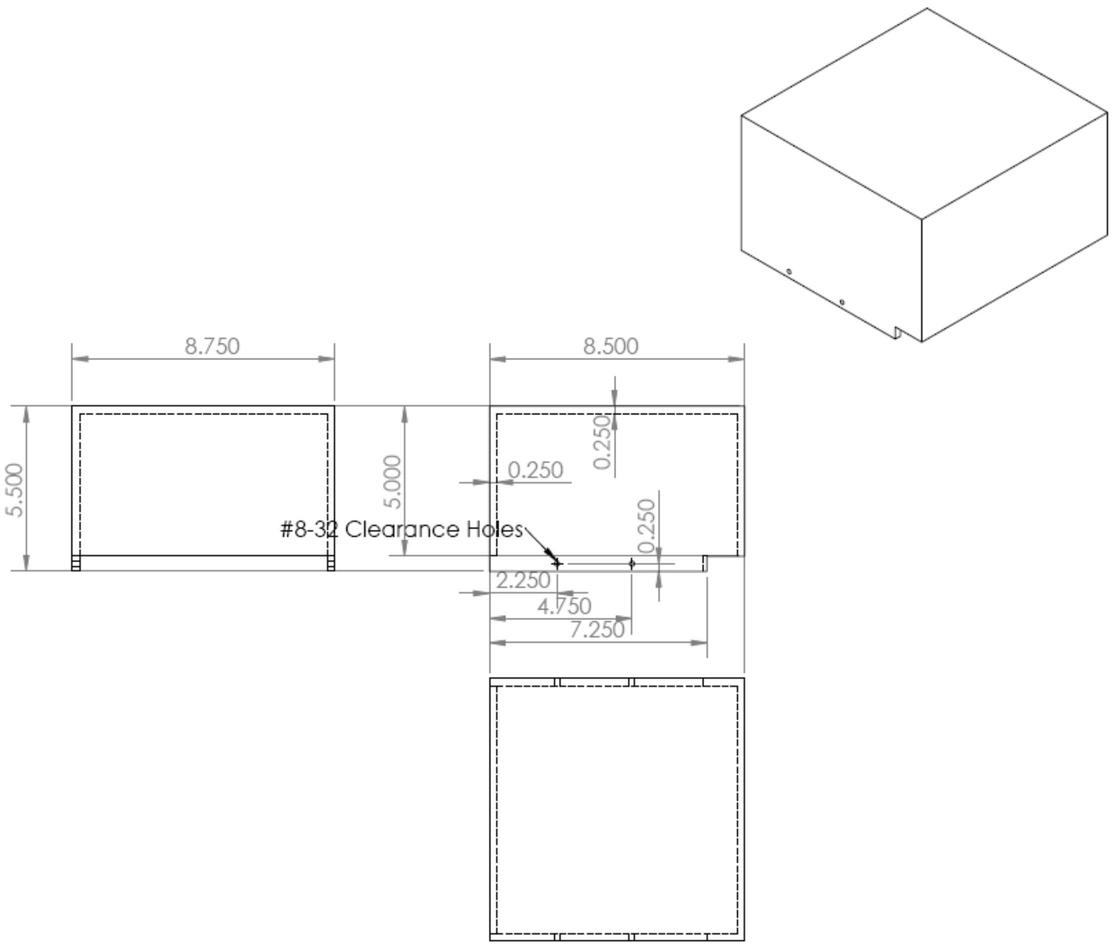


Laser Sled

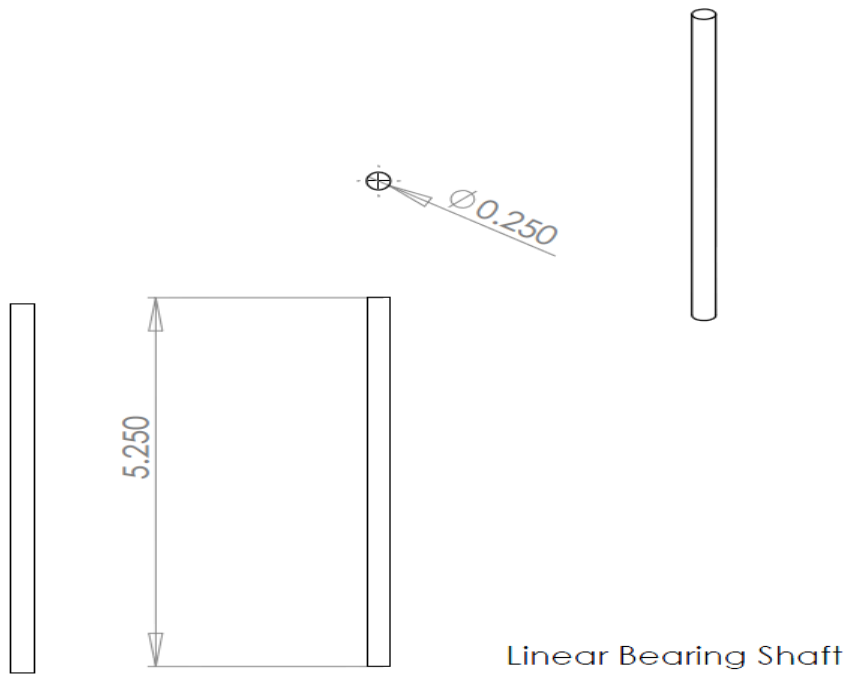


Laser Sled

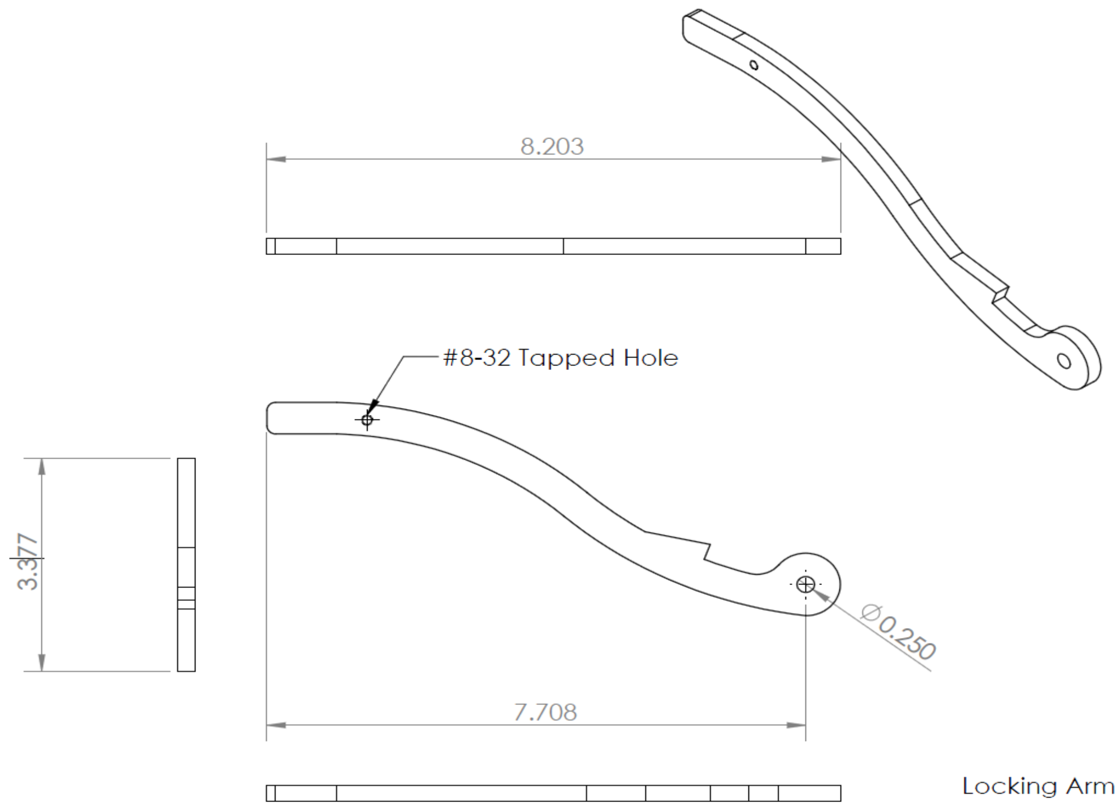
I.12 Laser Assembly Cover



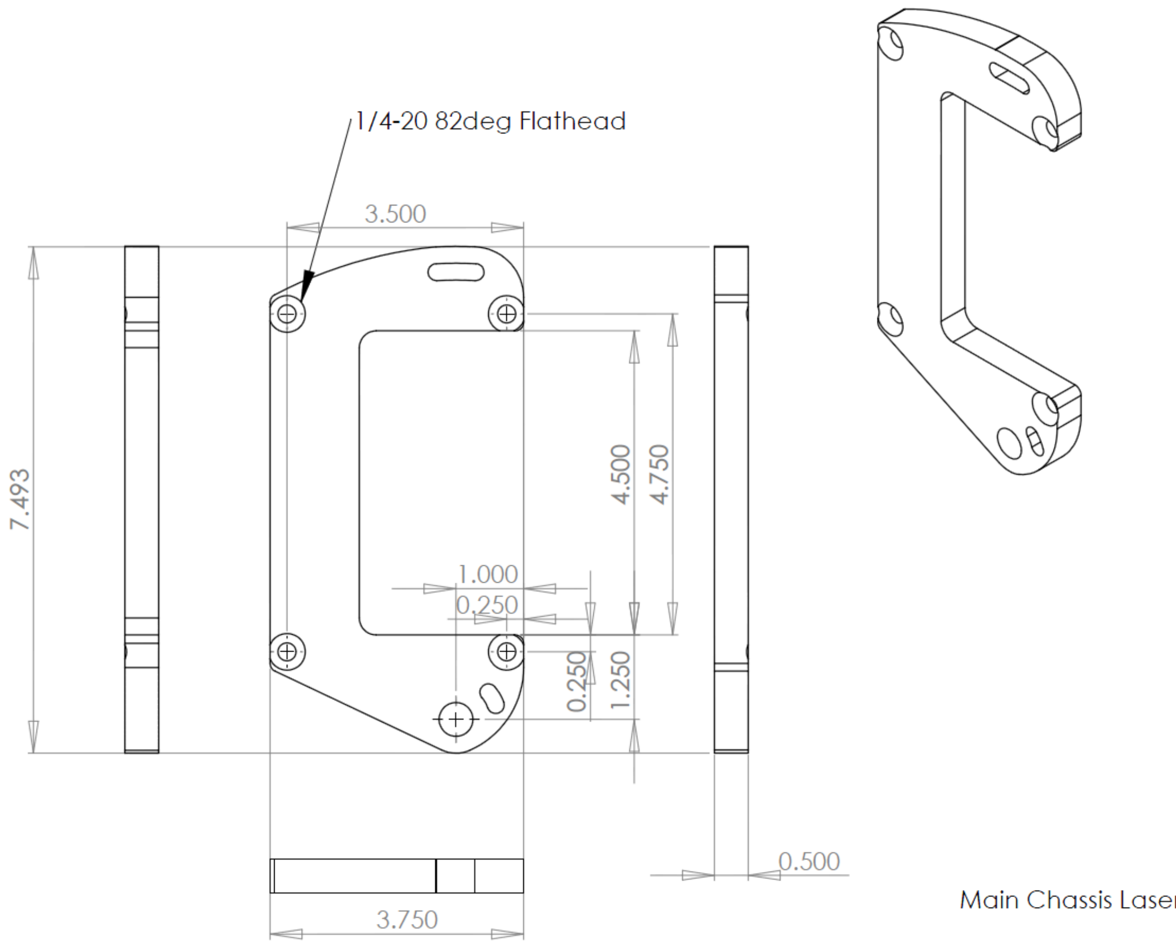
I.13 Linear bearing Shaft



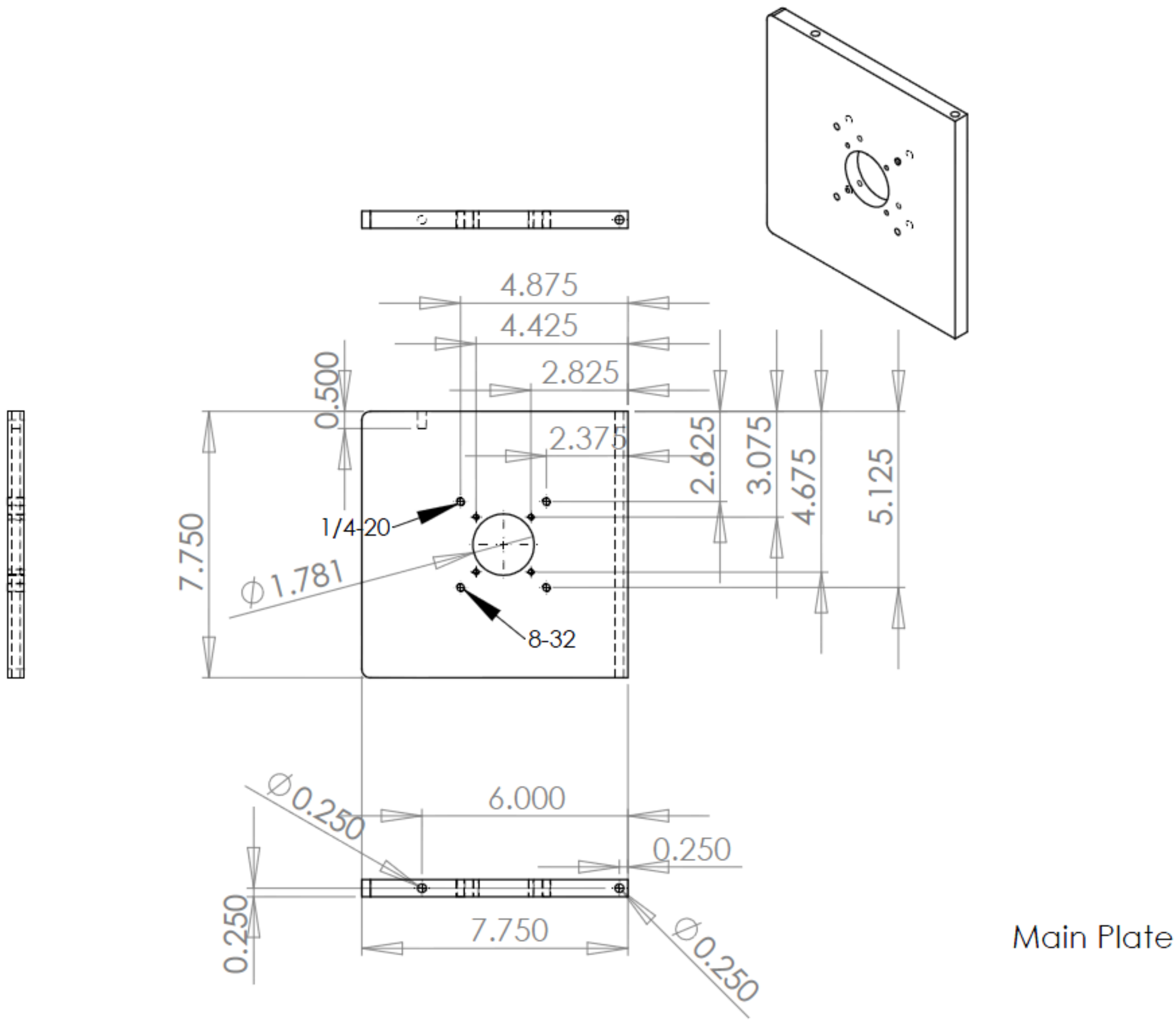
I.14 Locking Arm



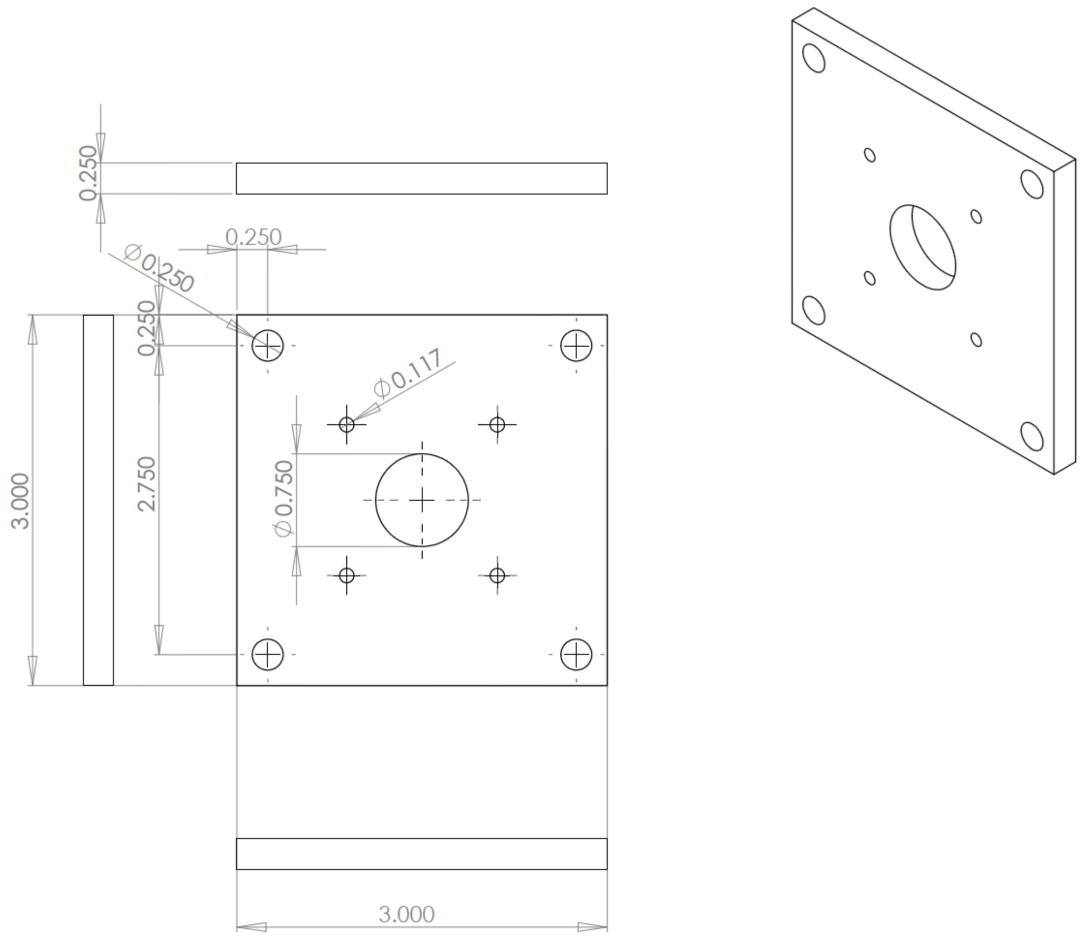
I.15 Main Chassis Laser



I.16 MainTable Plate

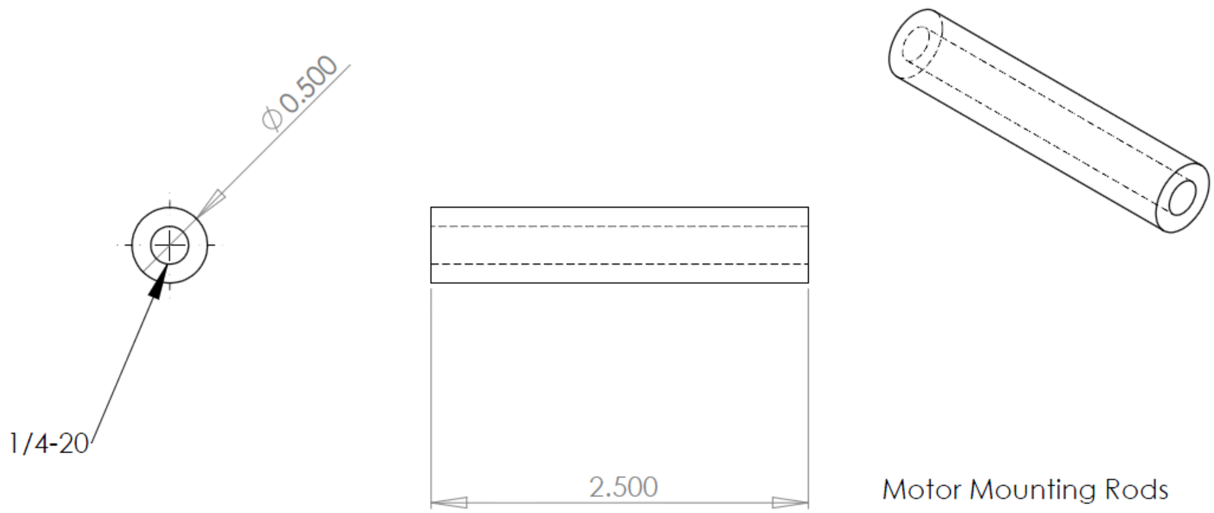


I.17 Motor Mounting Plate

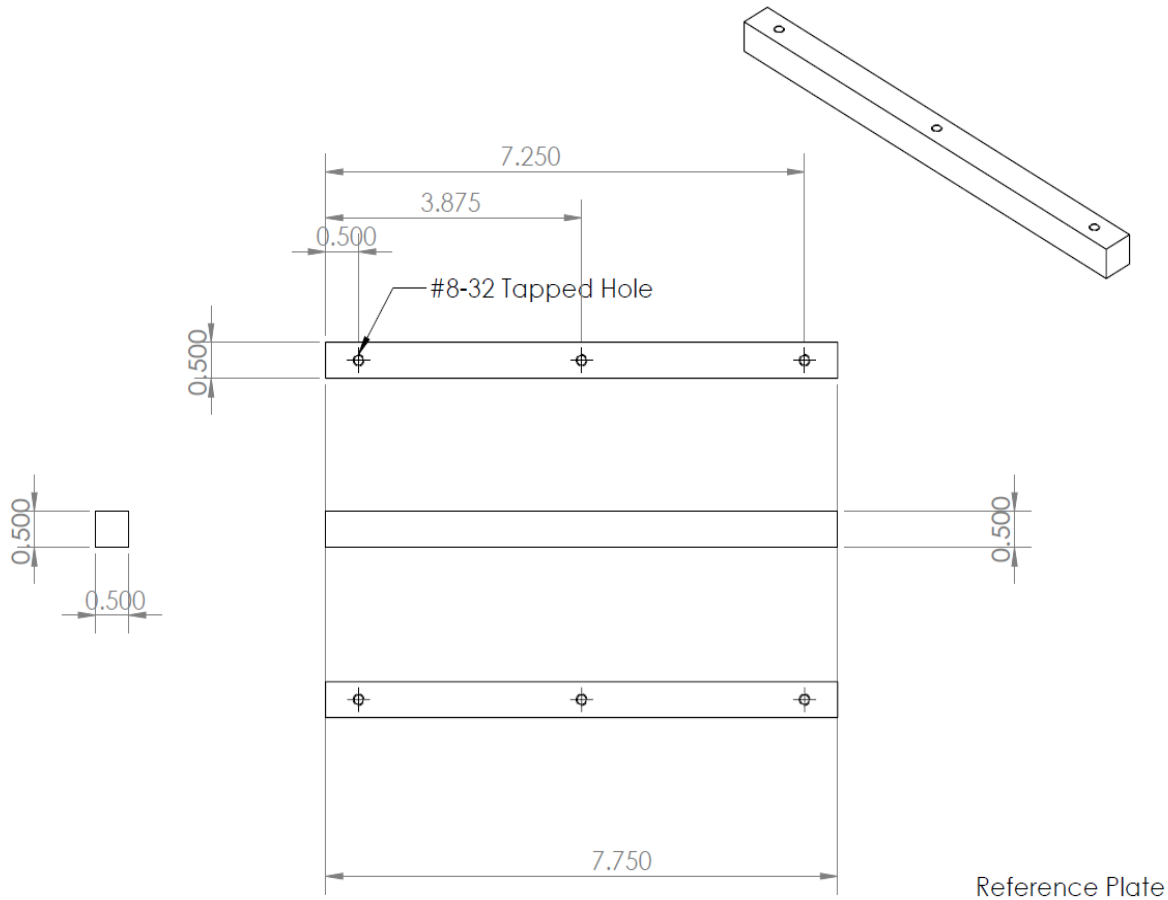


Motor Mounting Plate

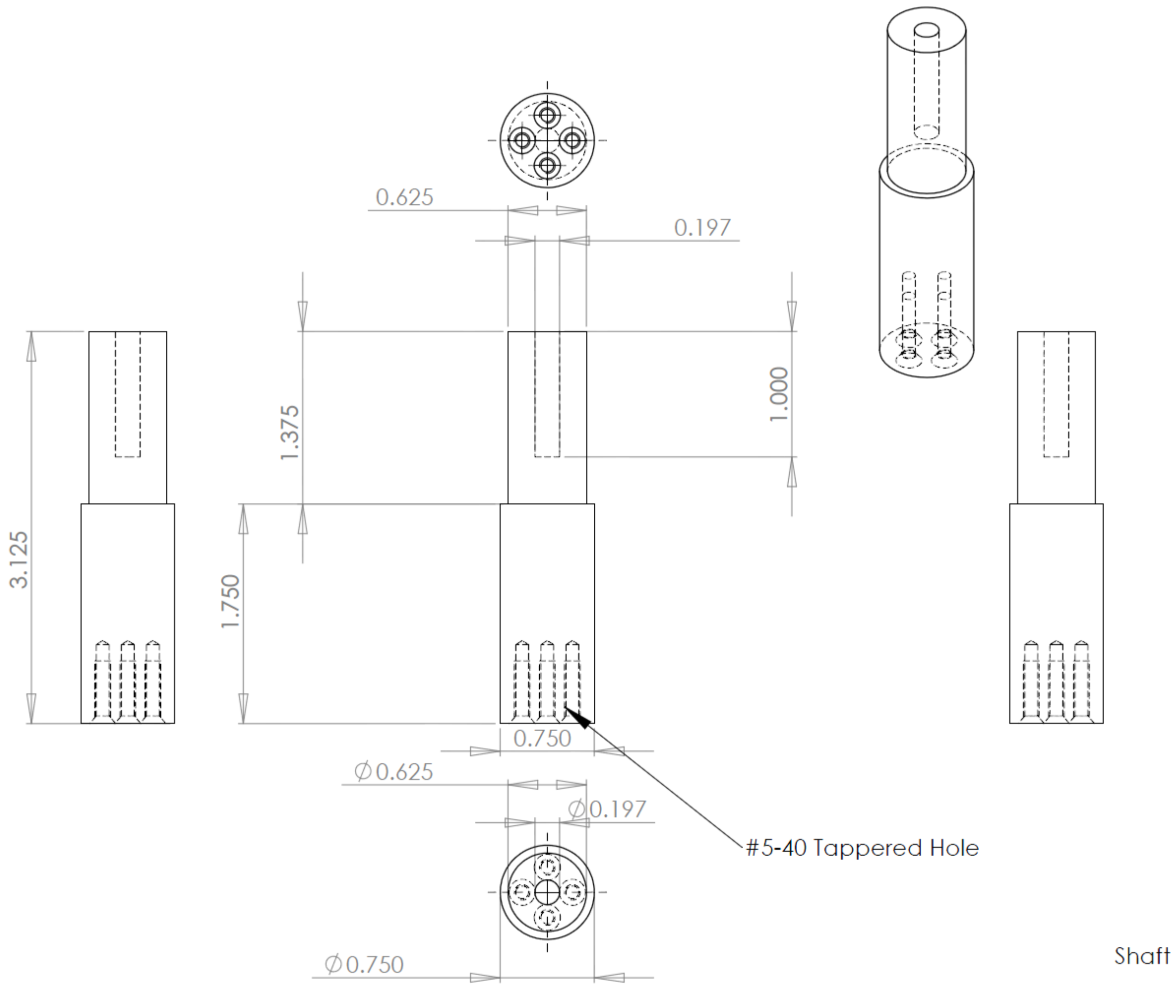
I.18 Motor Mounting Rods



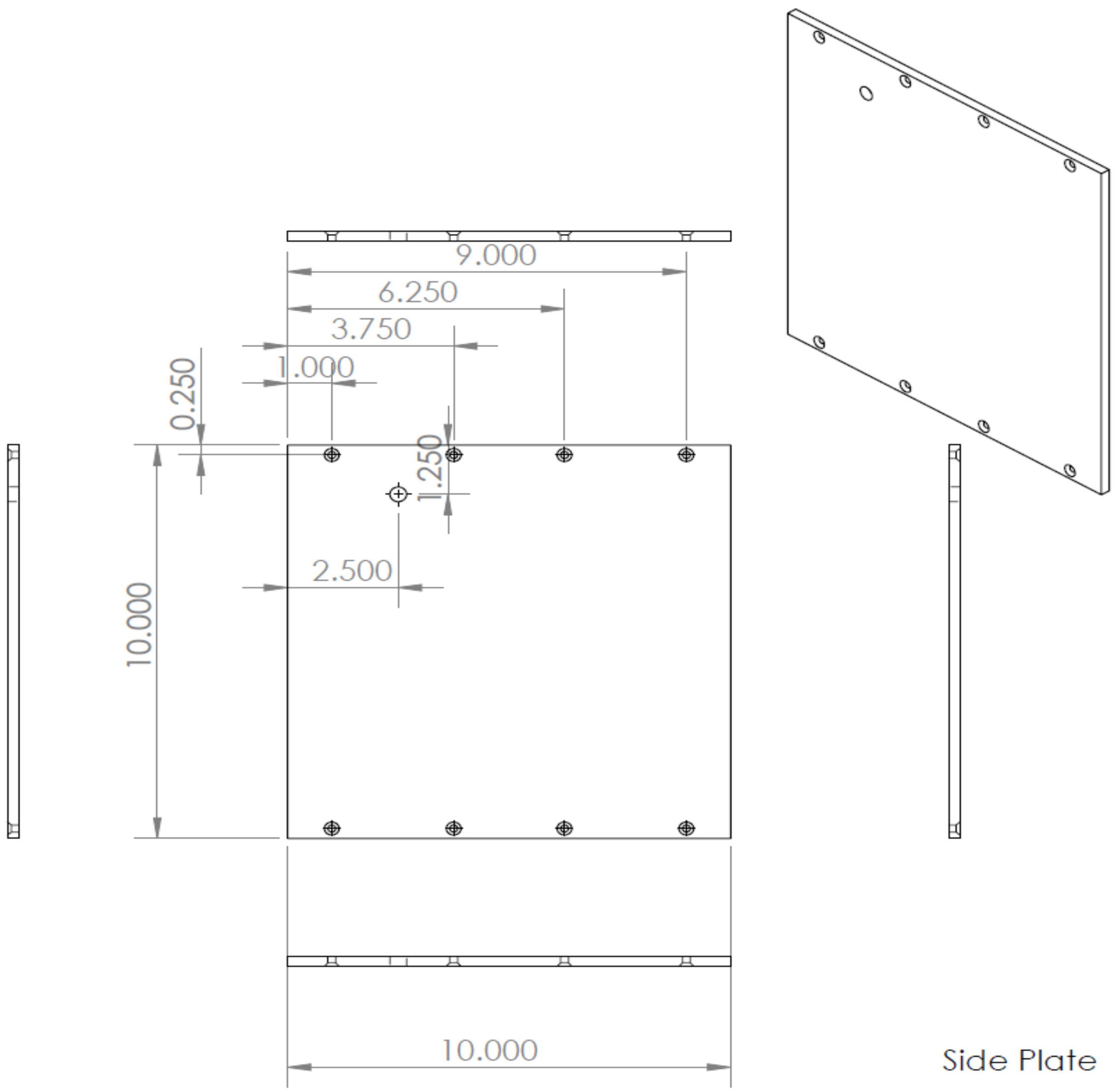
I.19 Reference Plate



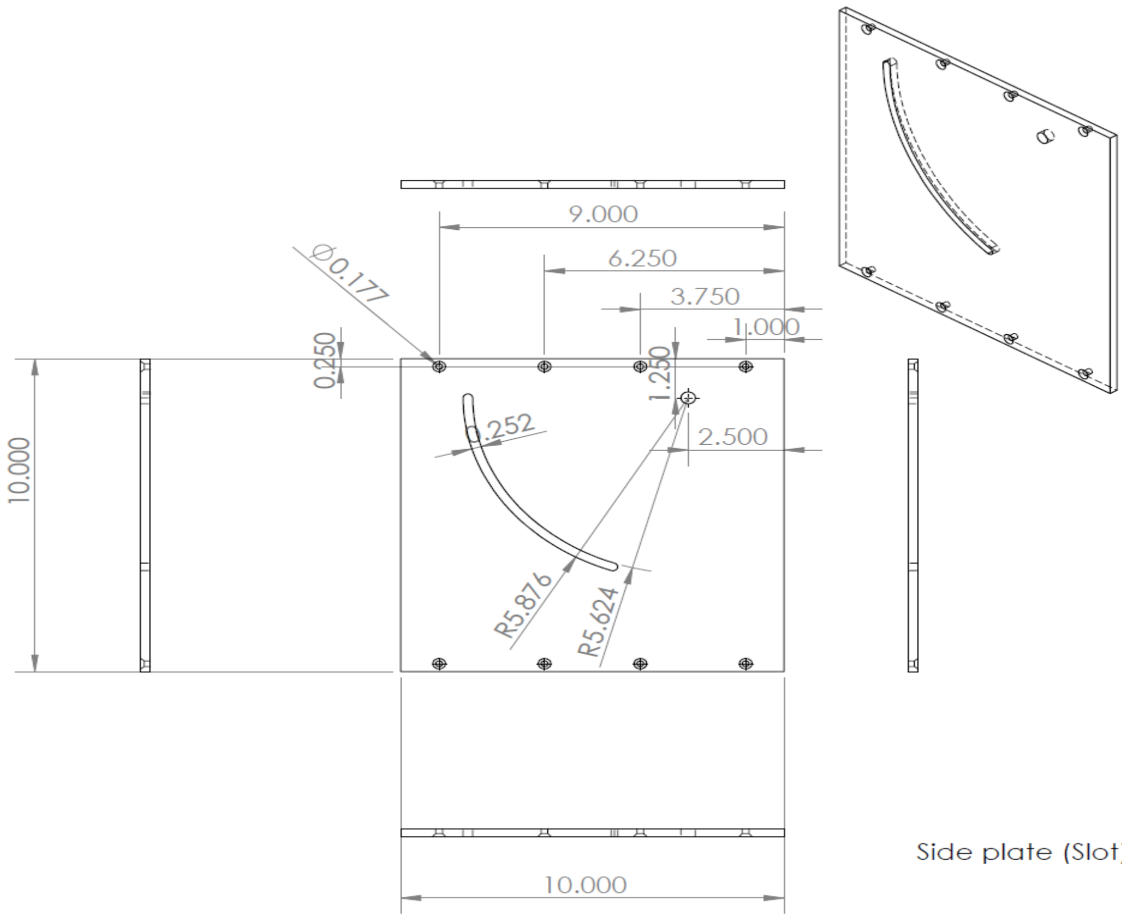
I.20 Fixture Shaft



I.21 Side Plate



I.22 Side Plate with a Slot

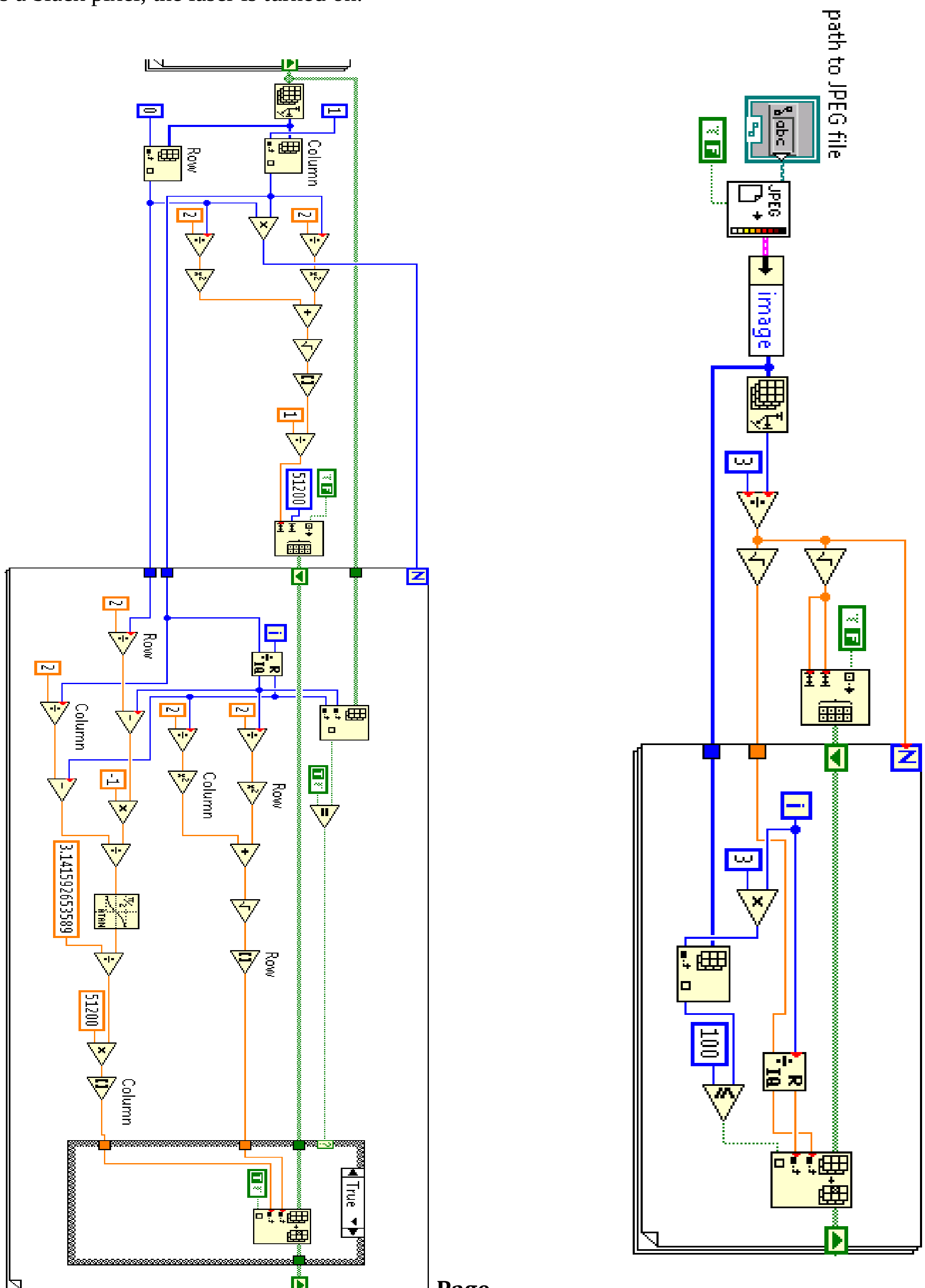


Side plate (Slot)

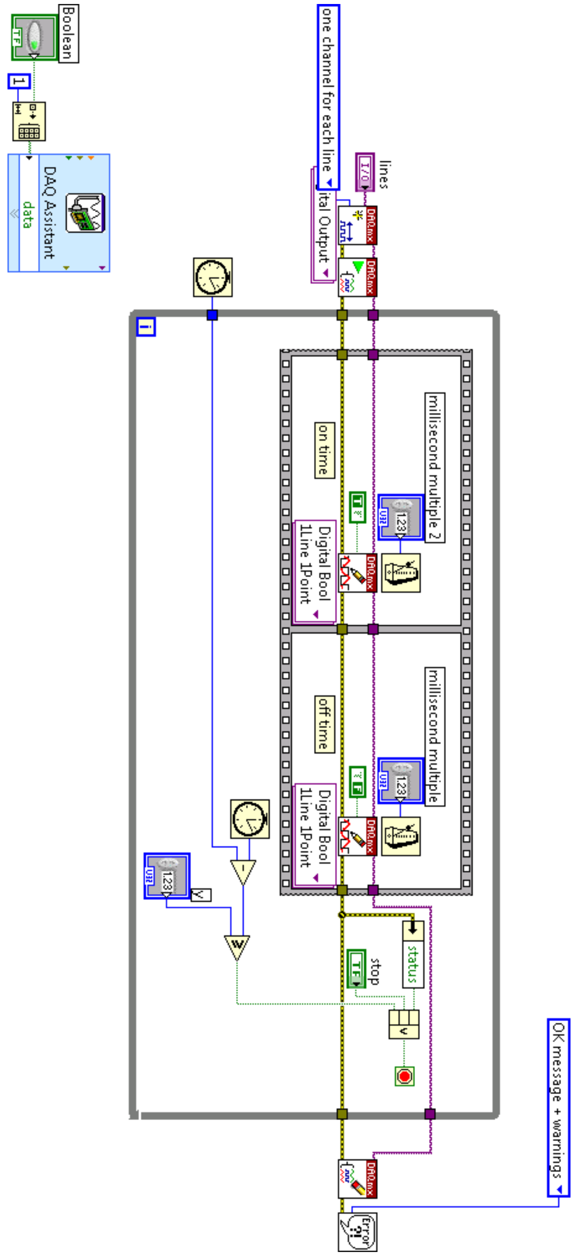
J LabvVIEW code

J.1 JPEG analyzing

This LabVIEW code analyzes a black and white jpeg and determines which pixels are black and which are white. It then interprets where they exist in catesian coordinates. It then converts it to polar coordinates where it then creates a digital waveform representing the timing of the laser. Whenever there is a black pixel, the laser is turned on.



J.2 Position verification code



K Final Prototype Pictures

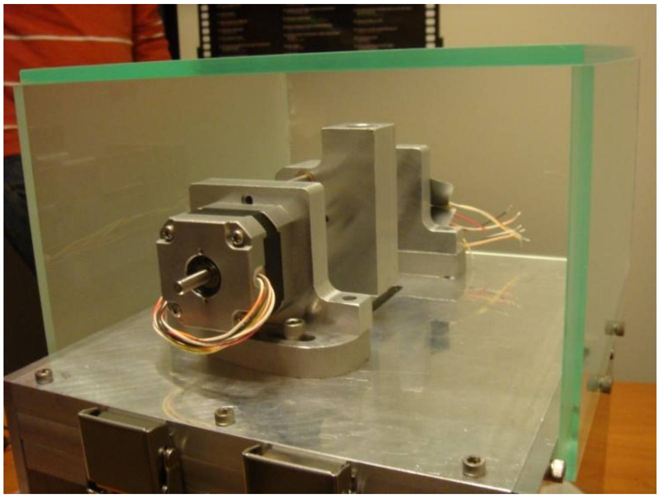


Figure 59: Laser Assembly

Figure 60: Whole Assembly-Rear