Detailed Design

6.1 Introduction

This section of the report describes everything necessary to build the sensor modification. The new optical design layout is displayed with all necessary distances and angles, based on the dimensions of the components used. In addition, the dimensions of the molds used to manufacture redesigned PDMS cubes are included. The Bill of Materials describes all pieces necessary to construct the different sub-systems of the SPP sensor. All purchased components and their specifications are listed in the Purchased Component Specification section. The Detailed Design section fully describes the new system design with all information necessary to actually construct the design with the components listed in the Bill of Materials. The reasoning behind each design feature and calculations to constrain and determine system performance are included. Finally, the Product Lifecycle section discusses different aspects of the system such as re-usability, disposal of parts, and other important manufacturing and use considerations relevant to the design.

6.2 Electro-Optical Layout Architecture

The optical beam interaction through the system is summarized in the figure below.

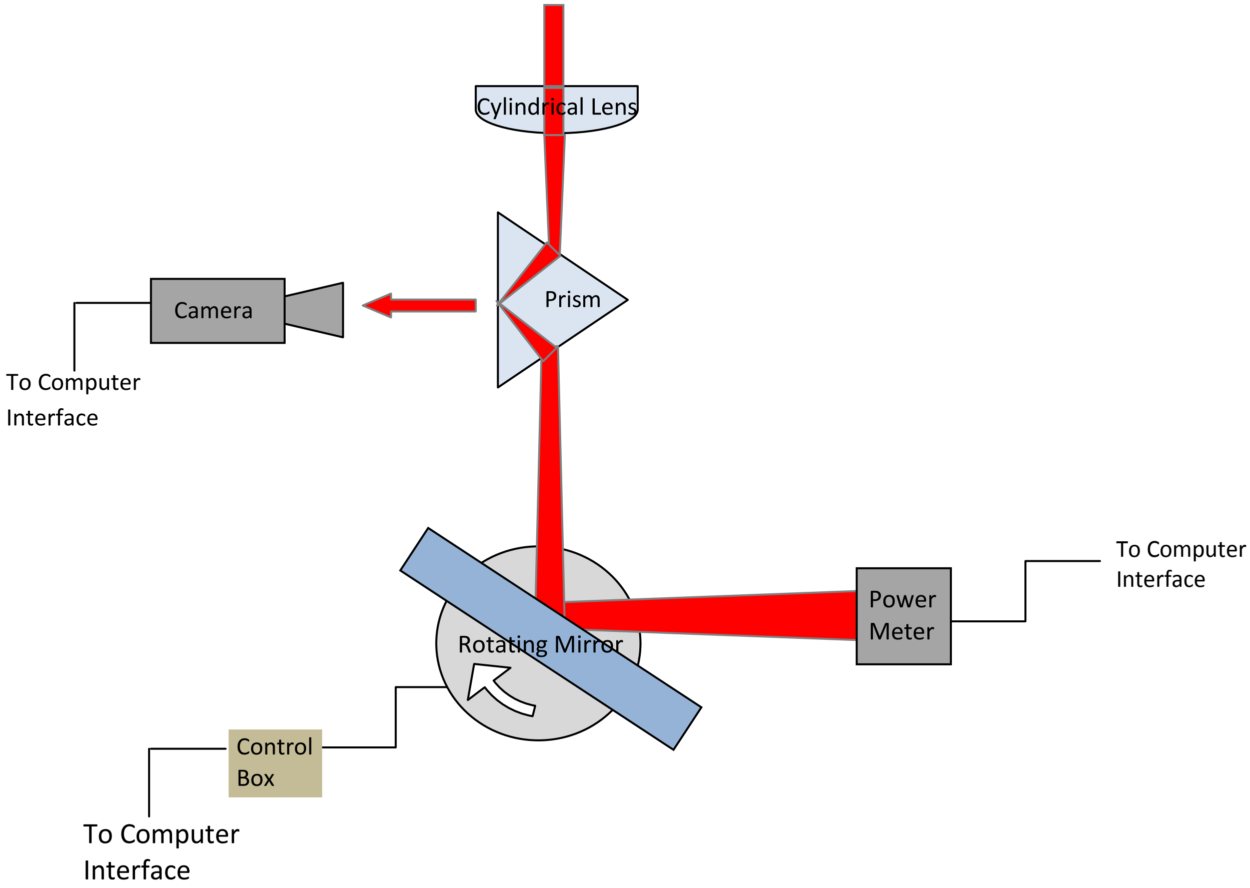


Figure 6.1: Illustration of the laser beam optical path through the system, and the locations at which data is siphoned into the computer for analysis.

From this figure, the path the beam takes can be mapped out as the following:

1. The collimated beam enters the flow cell subsystem by travelling through a 7.5cm focal length cylindrical lens which focuses the beam down into a vertical point plane.
2. The focused light is then incident upon the prism which directs the light towards the gold/dielectric interface attached to the hypotenuse of the prism. When the prism is positioned correctly, the vertical point plane is incident upon the SPP producing interface.
3. Light is then partially reflected off the gold interface and sent towards the rotating mirror, while the light not reflected interacts with a surface structure and is sent towards the camera mounted behind the flow cell. The camera information is then collected by the LabView program.
4. The reflected light is then reflected again by a rotating mirror which redirects the beam towards a power meter. At this point the beams cross sectional geometry is an oval, longer in the horizontal direction (due to the cylindrical lens), and must be scanned across the small aperture of the power meter. A full measurement of the beam is done by rotating the mirror so that the entire length of the beam has been measured by the power meter.
5. LabView then couples the data from camera measurements with that collected by the power meter, allowing for a double layer of data dependent on the beam angle incident on the prism.

Camera System Addition

Capturing the light directed out of the SPP producing interface will be done by a CCD camera mounted behind the fluidic half of the Flow Cell. This will allow for a continuous stream of data which can be analyzed in real time. This data will be fed into LabView and coupled with the data collected from the power meter. To allow for analysis on the level of microns, a fixed magnification lens with a magnification doubler will be used. This will increase the magnification of the camera system by 8x (4x doubled) and provide a pixel resolution of about 0.6 microns. **[Include Resolution Calculations?]**

Cylindrical Lens Change

Enhancing the current optical layout includes replacing the 100mm focal length cylindrical lens with a 75mm focal length cylindrical lens. Decreasing the focal length of the lens will increase the angle at which the laser beam converges, therefore necessitating the flow cell to be closer to the cylindrical lens. This will tighten up the optical assembly and allow for more breadboard room to be spent on alignment check structures and rail clearance.

Optical Path Redirection

Adding a camera system to the back of the flow cell assembly (off the fluids half of the cell) causes a problem when considering current system beam path. If the camera assembly were added to the current optical system layout the light beam would be interrupted/blocked when the flow cell is turned to measure its refractive index limits. Surface imaging modifications to the sensor include rearranging the optical interfaces in order to prevent beam path interruption.

Designing the new optical path arrangement involved flipping the orientation of the prism (and respectively the flow cell). This would change the direction in which the right angle vertex is oriented by about 180°, and positioning the rest of the optical devices in order to accommodate this flip.

6.3 Bill of Materials

6.3.1 Component Overview

The following is the bill of materials required to build the system modification. Since the modification is designed around a previously constructed system in an established optical lab, most of the components are already incorporated into the sensor or are owned by the lab and not currently in use. Items which are already a part of the sensor are not listed below. However, such components that are integral to the new system design, or whose purpose has been changed, are included.

Optical System

Thorlabs CCD Camera
Edmund Optics 8x Magnification Lens
Edmund Optics DL Doubler Tube
Newport 75.6mm Cylindrical Lens
Newport Posts and Spacers

Flow Cell Assembly

Newport Right Angle Prism

Gold Slides

PETP Flow Cell

Index Matching Fluid

PDMS

Sylgard 184 kit

Beaker 150 mL

Stirring rod

Syringes

Curing Dish

Clean Room Baking Foil

Copper tube slices 1.5mm diameter

Vacuum oven

3mm x 3mm mold

Stage and Armc

- Newport Linear Translational Stage 1.8in travel
- Newport Linear Translational Stage 1.0in travel
- Thorlabs Imperial Breadboard
- Rotational Stage
- [ARM]

6.4 Purchased Component Specifications

The table below lists all the components purchased to implement the new design. The components already present from the previous design are not included, as they were already purchased and implemented. In addition, components that were already present in the lab are not included. All important specifications are included in the table.

Table 6.1: Purchased Components

Component	Cost	Specifications
InfiniStix 4.0x 23mm WD Video Lens	410.00	Edmund Optics NT64-882

DL 2x Tube	195.00	Edmund Optics NT39-686
MT Compact Dovetail Linear Stage 0.375 in XYZ Travel	249.99	Newport MT - XYZ
Linear Stage 1.81 inch Travel	289.99	Newport M – 433
Linear Stage 1.0 inch Travel	239.99	Newport M – 423
Imperial Breadboard	49.90	Thorlabs
Rotational Stage 360° coarse, 5° fine, rotation micrometer	319.99	Newport 481 – A
Plano-Convex Cylindrical Lens BK7 75.6mm EFL	281.00	Newport CKX075AR.14
PETP Flow Cell Fabrication Projection	800.00	
Lexan Sheet	4.95	8x11 sheet
Total	**2840.81**	

6.5 Detailed Design

6.5.1 *Optical Design*

Relative to the previous system, the new optical layout was designed to accommodate an imaging system positioned behind the fluids half of the new flow cell, while preserving previous system sensitivity, precision, and the refractive index range capable of being measured.

As shown in Figure 7.2 of the system layout a mirror on a controlled rotation motor is mounted on a linear rail. The rotational mirror system was designed by the previous design team to sweep the output beam from the flow cell across the photo detector (power meter). This mirror reflects the light not absorbed by an excited Surface Plasmon-Polariton, which occurs at the back of a prism mounted in the flow cell. All of these interfaces are built on a 3ft x 2ft breadboard which is positioned so that the light beam enters from the top left corner. The beam then travels through Iris 1 and Iris 2, where Iris 2 controls the beam size. Iris 2 can be operated to clip the beam if it is found to be too large to be completely reflected off the following beam directing mirrors. The beam then travels to the beam directing mirrors 1 and 2 which have been positioned 135° and 28° respectively off the horizontal. Each of the four mirrors in the new layout have been rated to accurately reflect a beam whose incidence angle is less than 45°, and have been placed in the layout to fulfill this specification.

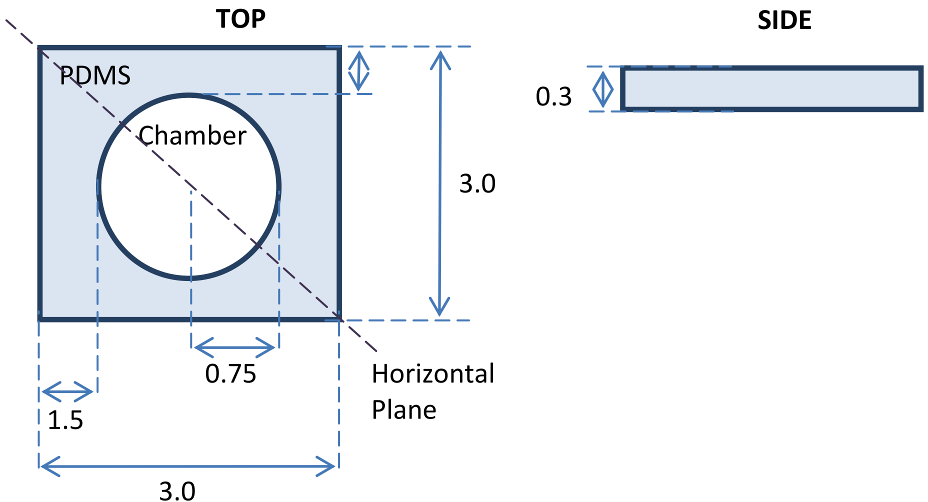
The refractive index range measurable of the modified system will be preserved. This means that the final modified SPP sensor is capable of measuring refractive indices which correspond to a Winspall angle range of 72°-101°. Accepting that the full rise and fall of the SPP resonance dip is required to make an accurate measurement of the SPP, the full width of the Plasmon must be measured. The size of the Plasmon also increases as the refractive index value increases, and has been taken into consideration when deciding upon a width margin. From previous SPP sensor measurements the average width of a SPP is ±5°, which will reduce the measureable Winspall angle range to 73.5°-98.5°. This Winspall range corresponds to a refractive index range of 1.265-1.363, which allows this sensor to be ideal for measuring water based liquids which tend to have an index of refraction value around 1.33.

Figure 6.1 – This illustration shows the modified optical layout. The top image shows the minimum required Winspall angle of 72°, while the bottom image shows the maximum required Winspall angle of 101°.

Determining the precision of the new system will be done by taking multiple measurements of the same liquid dielectric and quantizing the error seen between measurements. Determining the sensitivity of the system will be done by measuring the refractive index of a liquid whose index of refraction is known. Error between the measurement and known value will be the error in refractive index of the modified system. System precision and sensitivity requirements are outlined in the client stated objectives, and will be used as the accepted values when determining the success of the modified system.

6.5.2 PDMS Design

The cells will be cast using a clean room tin foil square mold, in which a copper slice of tubing will be placed to reserve the fluid chamber space. The copper tubing will be brushed to remove the oxidized layer and any grease that may have been left on it during manufacture. Then it will be soaked in Acetone for 24 hours and dried. The needles will be inserted through the horizontal plane of the PDMS square. This will allow for the needle to be supported by a longer distance of PDMS than if it were to be pierced at one of the axis. It will also allow for the curvature of the fluid chamber to align slightly to the curvature of the needle end.



6.5.3 Flow Cell Design

Mechanics

The mechanics of the system can be seperated into two distinct parts. The flow cell that houses the componenets to created the surface plasmon polariton, and the stage that the flow cell and the camera are attached to. Both mechanical parts are very important to creating, measuring, and observing a surface plasmon polarition.

Flow Cell

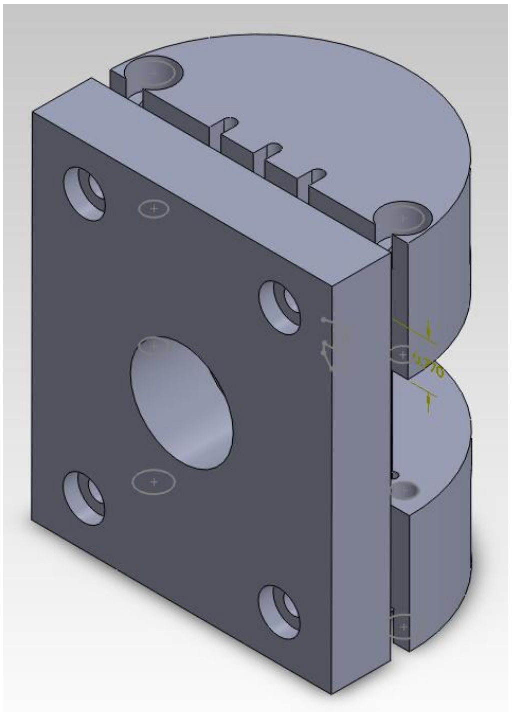


Figure 6.4: Complete flow cell design (PETP material)

The flow cell will be made up of two primary sides that will hold all the components together in a single cell. The front side of the cell which holds the Lexan and PDMS will slide into the backside of the cell which houses the prism.

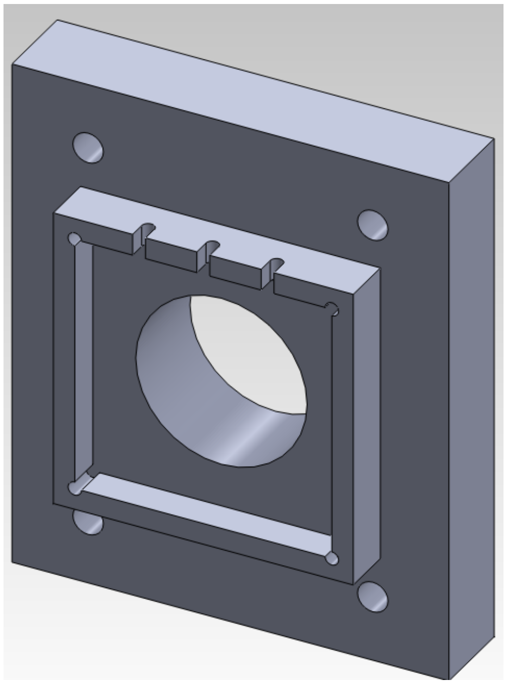


Figure 6.5: View of the inward side of the fluids half of the flow cell.

The front side of the cell will be a rectangle with a center square that extrudes out. The center of the cell will also have a 2.00 cm diameter hole to allow observation of the metal-dielectric boundary. Since thinner components will be used, the width of the front side of the cell can also be made thinner. The total width of the front side will be 1.6cm. The thinner frontside will allow for the camera to have free movement without worrying about hitting the cell since the working distance of the camer is longer than the cell. The width of the back side will be 1.0 cm while the width of the center extruding square is 0.6 cm. The center square will house the Lexan slide and the PDMS cells. To prevent the frontside from touching the prism, the depth of the center square is 0.4cm. This depth will completely house the Lexan and support the eges of the PDMS cell while exposing most of the cell. To create support, the thickness of the square is 0.25 cm. Small divits will be cut into the edge of the extruding center to make sure that the PDMS cell is visible when the two pieces are joined. The dimensions for all the views are in centimeters.

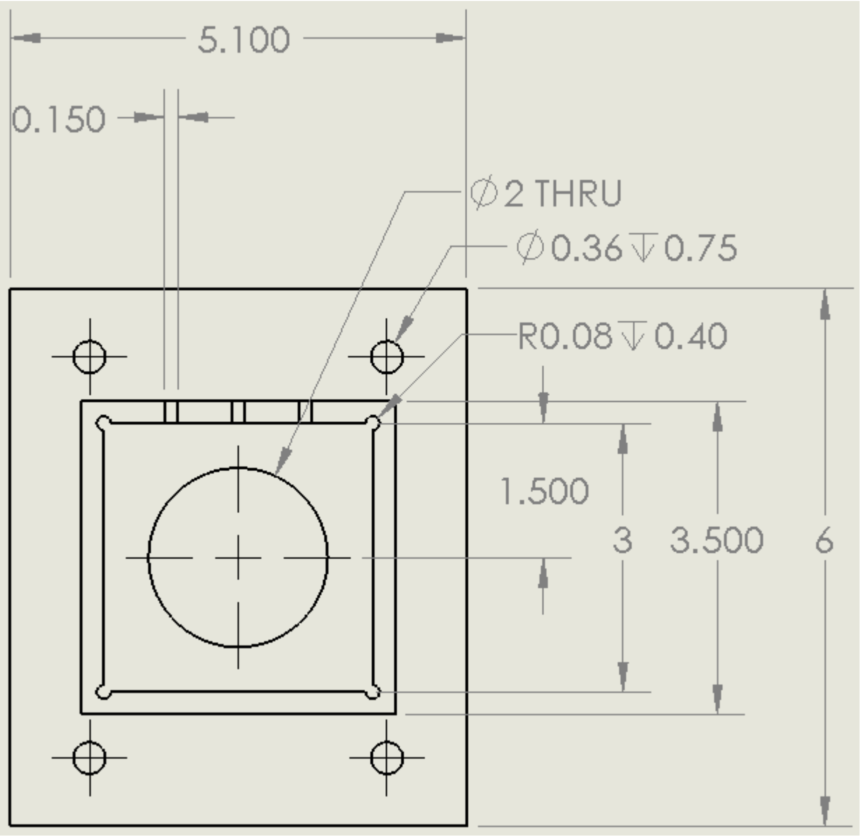


Figure 6.6: View of the inward side of the fluids half of the flow cell in blueprint form to show all relevent dimensions in centimeters.

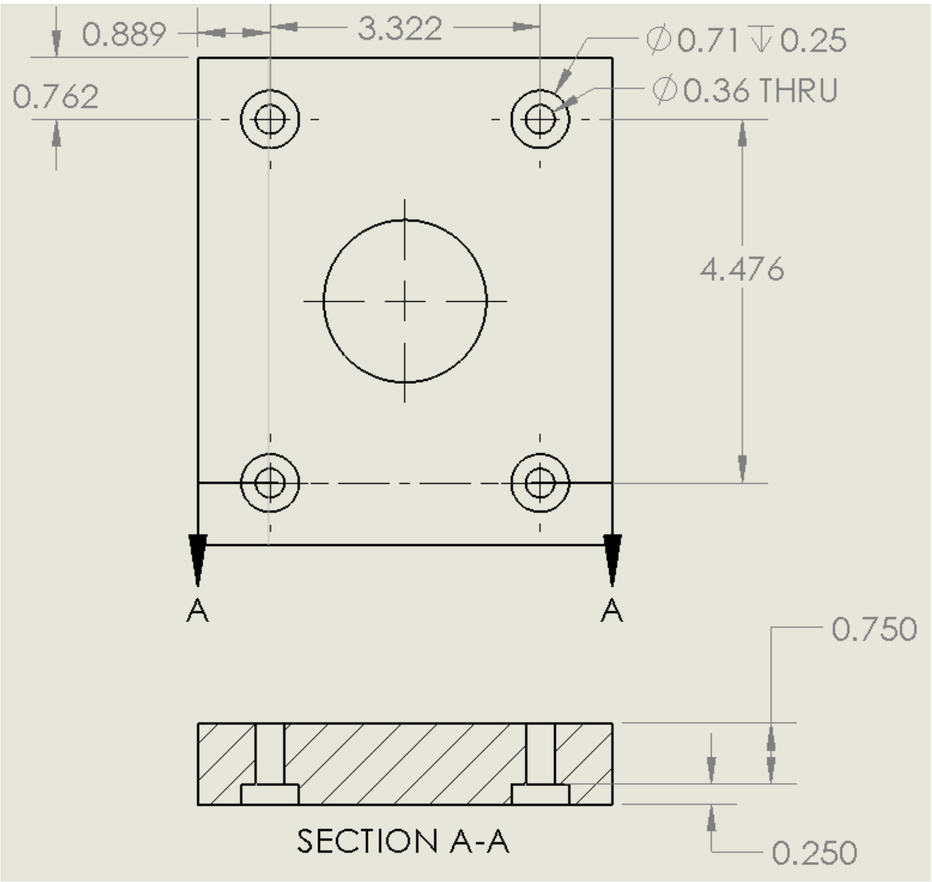


Figure 6.7: View of the outward side of the fluids half of the flow cell in blueprint form to show all relevent dimensions in centimeters.

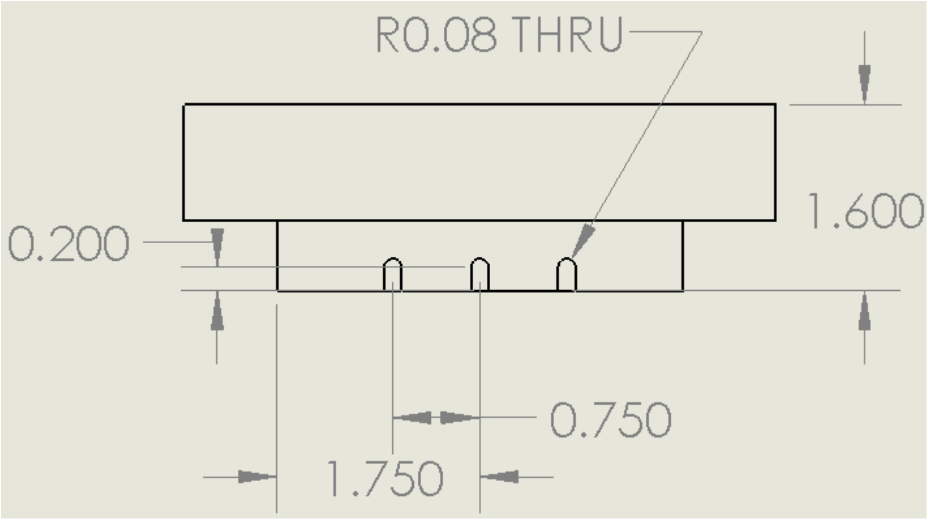


Figure 6.8: Top view of the fluids half of the flow cell in blueprintform to show all relevent dimensions in centimeters.

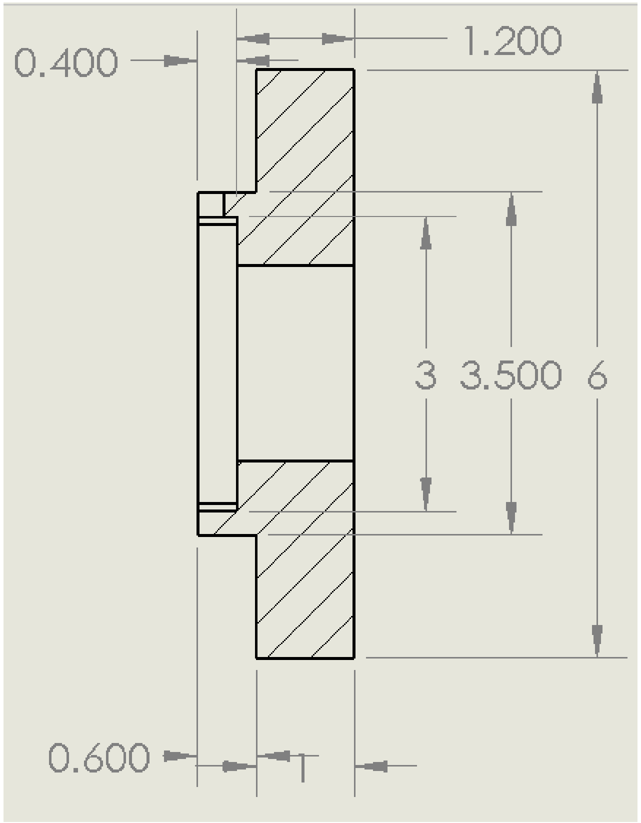


Figure 6.9: Side cut view of the fluids half of the flow cell in blueprint form to show all relevent dimensions in centimeters.

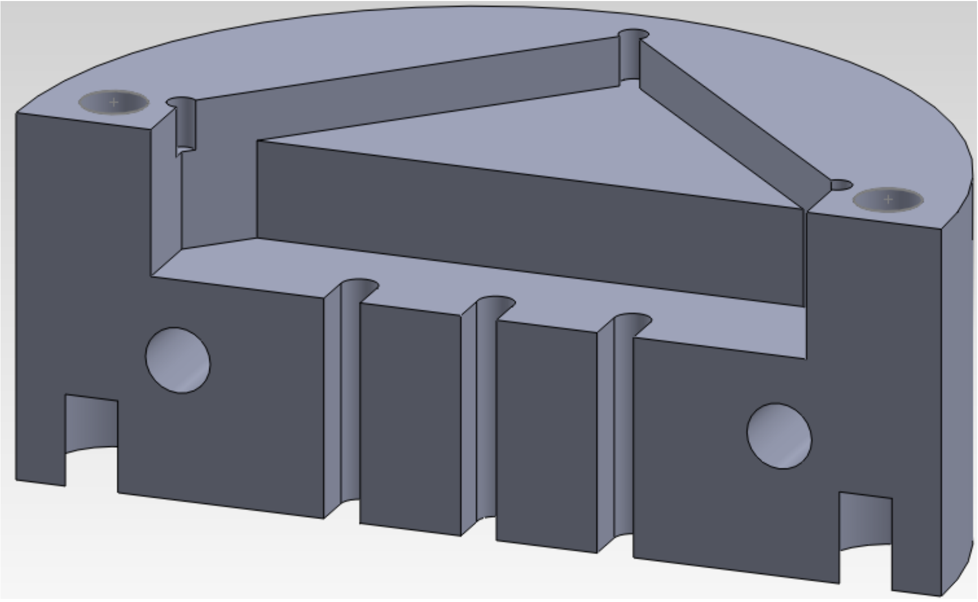


Figure 6.10: View of the inward side of the optics half of the flow cell. This design will be used for both the top and bottom prism holders.

The backside of the cell will be composed of two identical parts that will hold the prism. As can be seen from the image above, the holder will have two steps cut into the base. The first step is to provide support for the prism. The second step is to provide the opening for the frontside to slide in. When the two identical pieces are pieced together with the prism in the middle, the opening will be just big enough for the front side to slide in. The base of the holder will also have divits cut into it to provide a passage way for needles to be inserted into the PDMS.

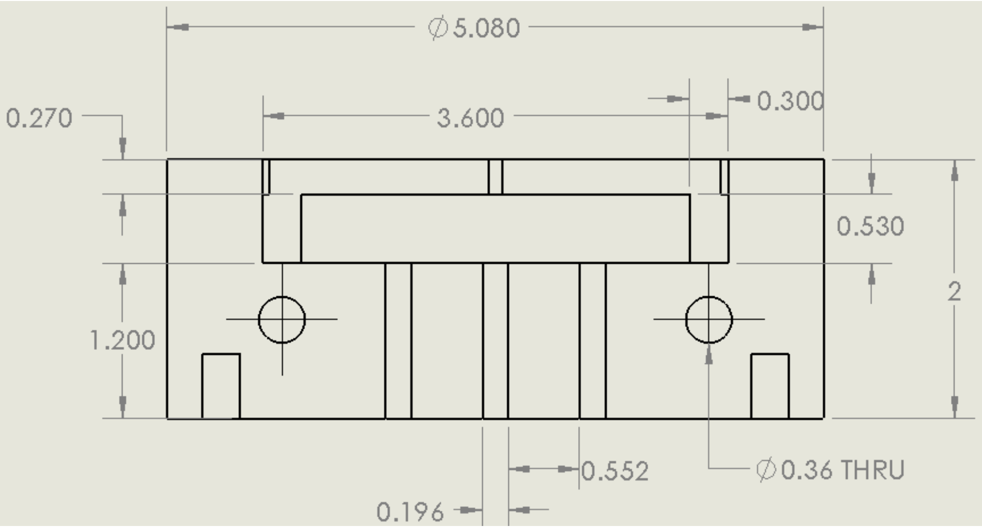


Figure 8: Front View of Back Side

Dimensions in cm

Figure 6.11: View of the inward side of the optics half of the flow cell in blueprint form to show all relevent dimensions in centimeters.

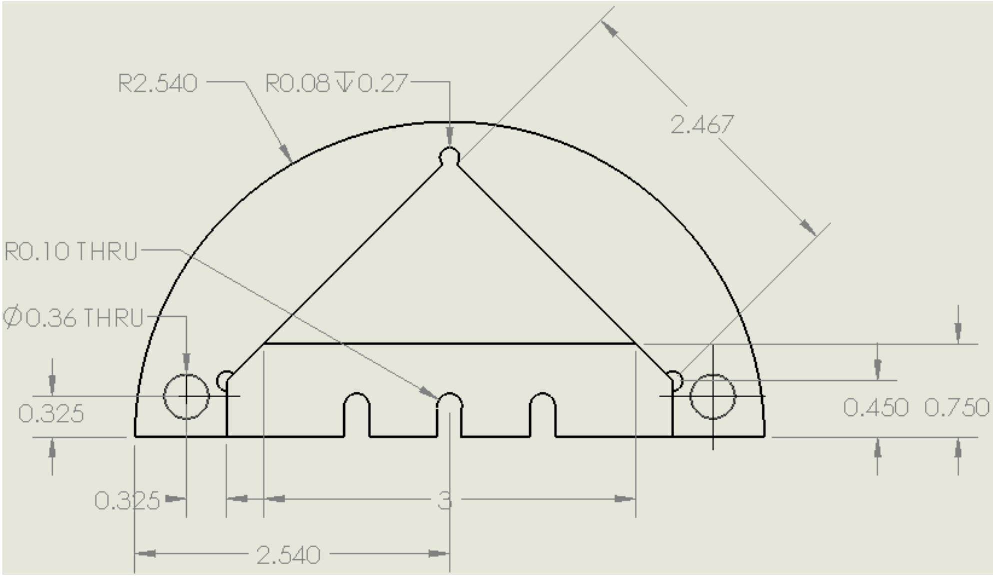


Figure 6.12: Top view of the optics half of the flow cell in blueprint form to show all relevent dimensions in centimeters.

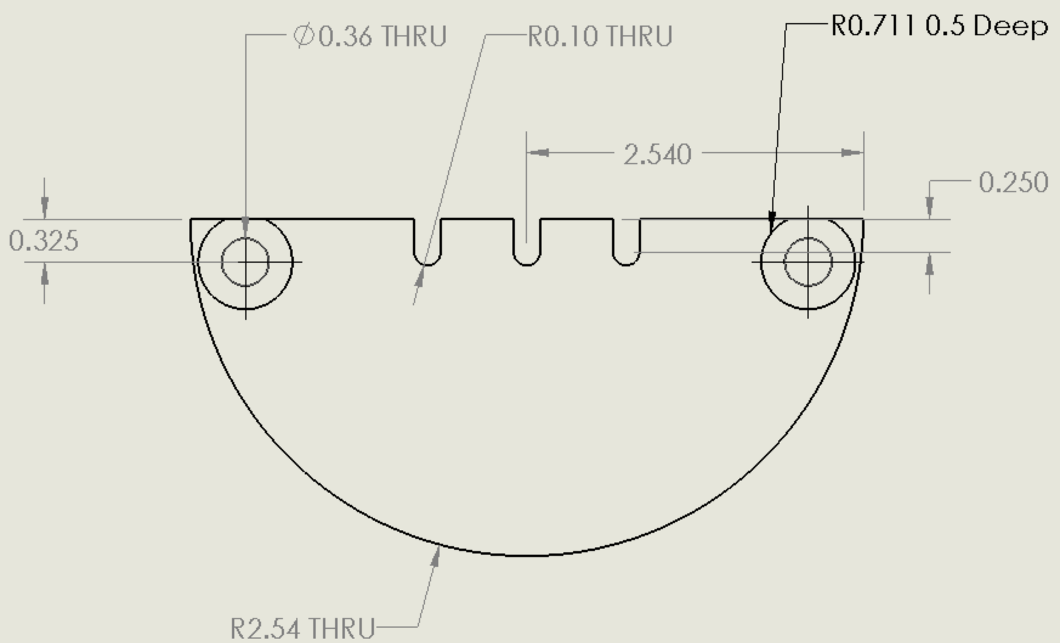


Figure 6.13: Bottom view of the optics half of the flow cell in blueprint form to show all relevent dimensions in centimeters.

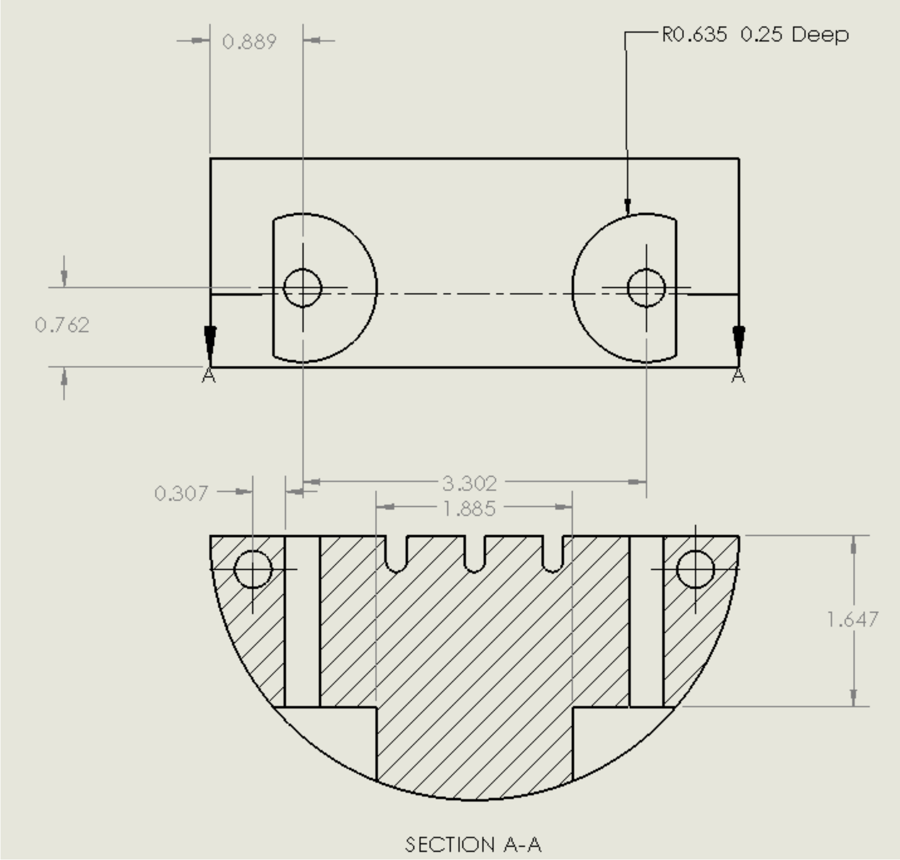


Figure 6.14: (Top) View of the outward side of the optics half of the flow cell; (Bottom) Horizontal cut view of the optics half of the flow cell in blueprint form to show all relevent dimensions in centimeters.

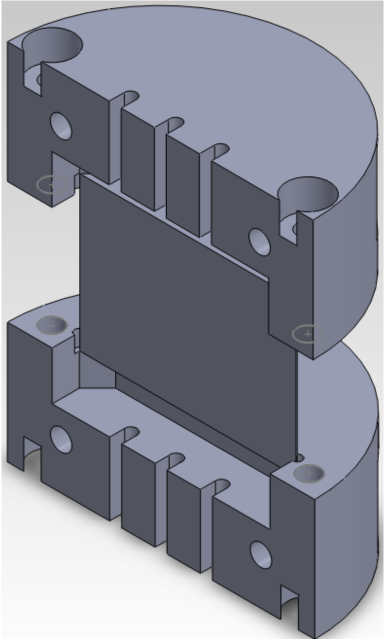


Figure 6.15: Complete optics half of the flow cell, prism included.

Support Stage

The support stage that will hold up the flow cell will be made up of multiple smaller stages that each have a specific purpose. The base layer that will sit ontop of the work table will be a 4X6 inch breadboard that will have the other components screwed down onto it. The top view of the breadboard can be seen below.

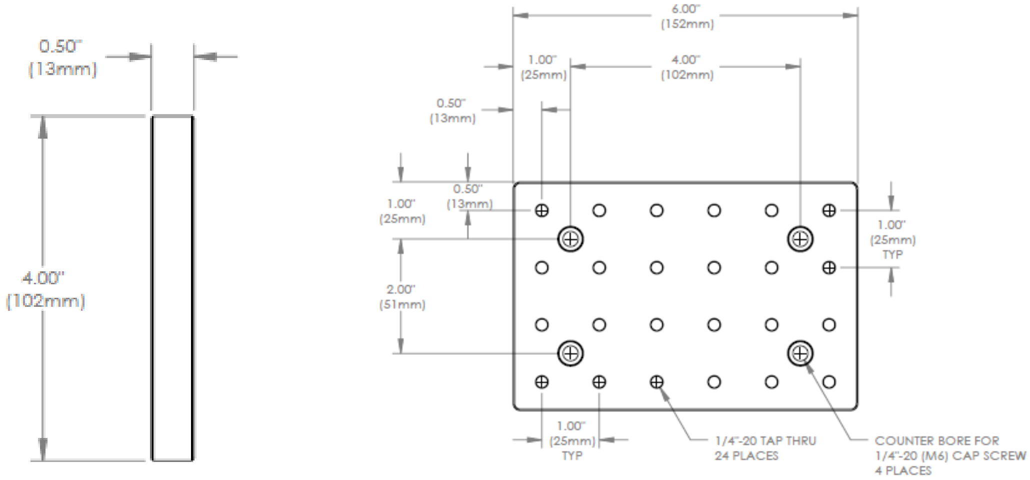


Figure 6.16: (Left) Top view of the bread board; (Right) Side view of the bread board. (Schematics and drawings for figure 6.16 courtesy of **Thor Labs Inc.**)

On top of the breadboard will sit two linear stages. The stages will sit on opposite sides of the breadboard and will be placed to allow linear movements for both the flow cell and the cylindrical lens. The linear stage that sits under the cylindrical lens will be a Newport 423 stage. The linear movement of this stage will allow the user to move the focal point of the cylindrical lens to be on the gold slide.

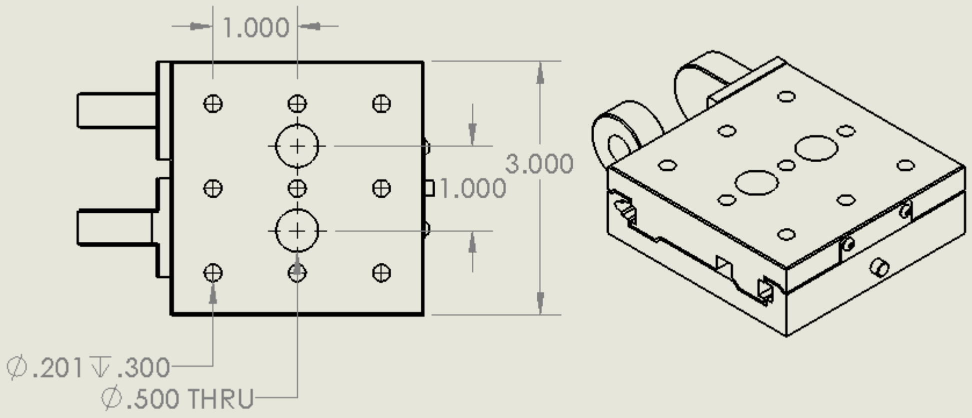


Figure 6.17: Linear stage which will sit beneath the cylindrical lens; all dimensions are in inches. (Schematic and drawing courtesy of **Newport Corp.**)

The second linear stage will support both the rotational stage and the flow cell. This stage will be a Newport 433 stage. This stage is a longer to match up with the screw holes of the rotational stage. The linear movement of this stage allows the user to align the incoming laser to any point of the gold slide.

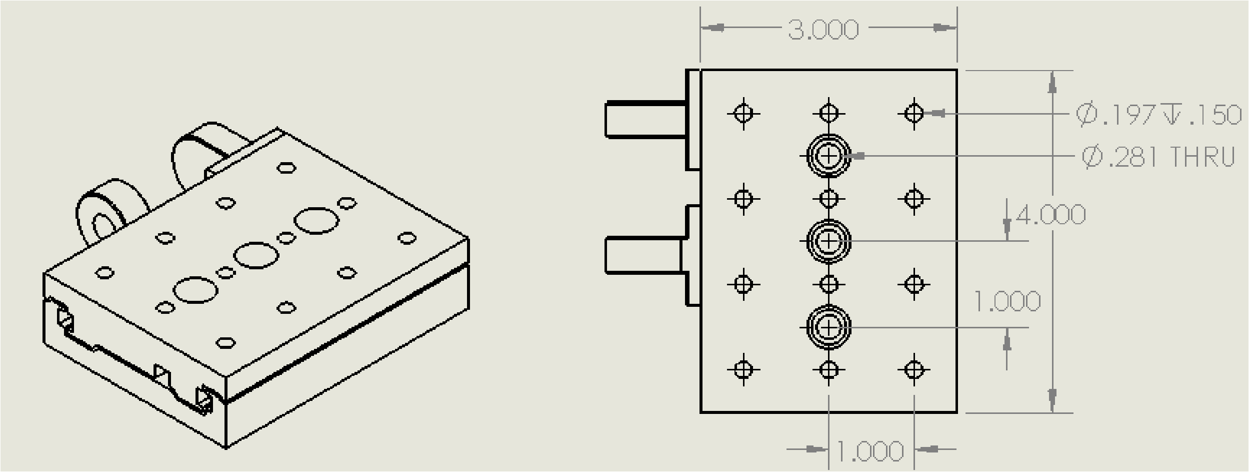


Figure 6.18: Linear stage which will sit beneath the rotational stage of the flow cell; all dimensions are in inches. (Schematic and drawing courtesy of **Newport Corp.**)

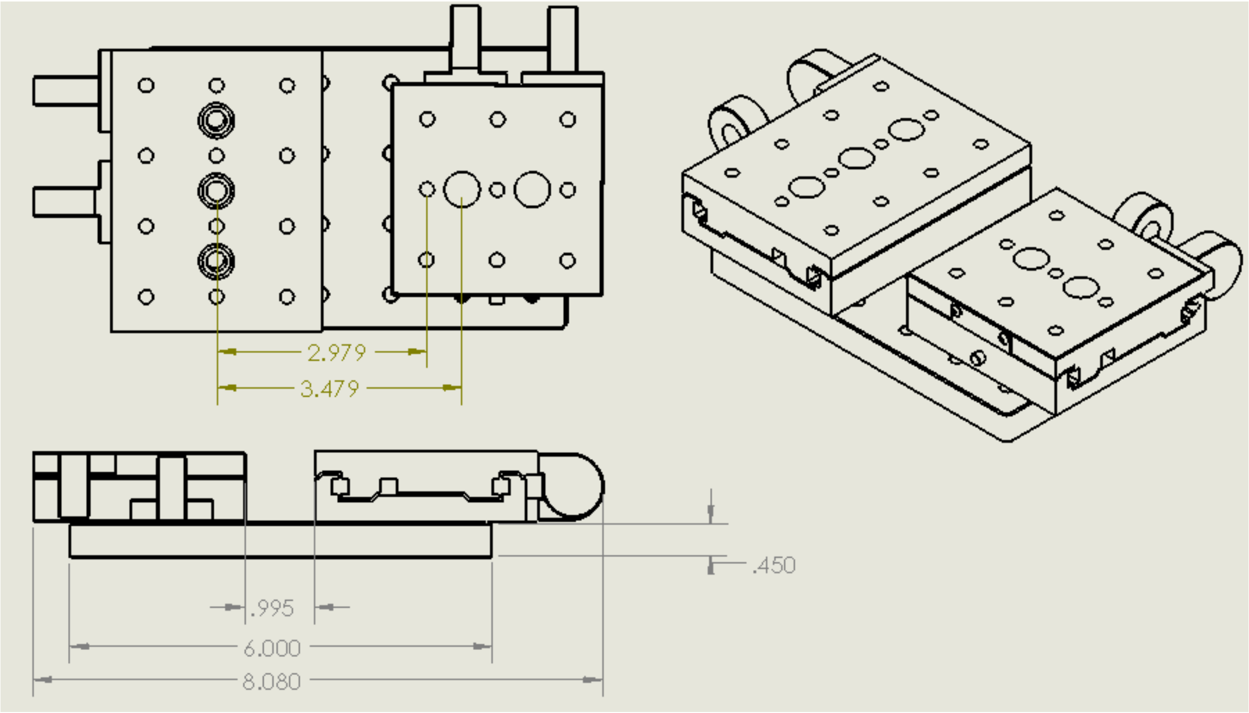


Figure 6.19: Top and side view of the linear stages and their attachment orientation to the stage breadboard.

The dimensions for the complete two stage-breadboard setup can be seen above. The two stages will be places at least 1 inch apart from each other. This provides enough room for the stage that supports the cylindrical lens to move. The distance between the two stages also allow for the focal length of the cylindrical lens to change if need be.

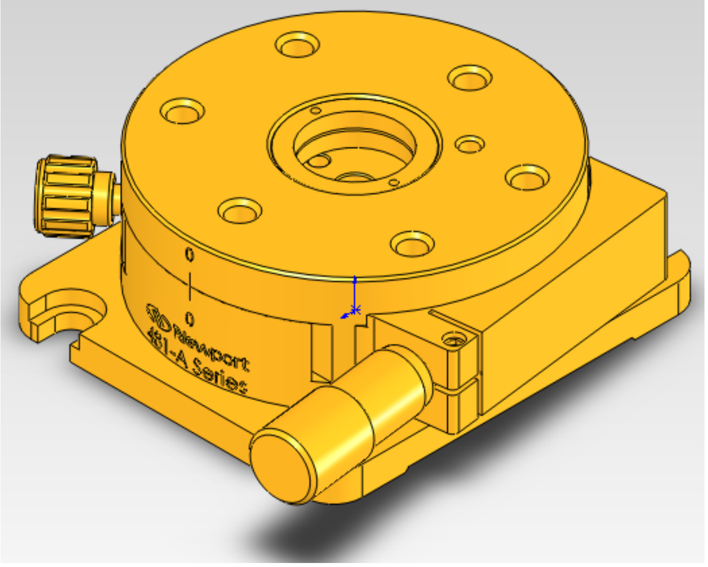


Figure 6.20: The rotational stage which will support the flow cell. (Solid Work drawing courtesy of **Newport Corp.**)

The rotational stage will sit on top of the larger linear stage. The option of motorizing the stage and having a computer program control the angle was discussed when the team was in the process of the design. Having a motorized stage had some benefits compared with a manual stage. The motorized stage can provide smaller angle movements which would increase the number of measurements that can be taken. This would also increase the quality of data that is taken. However, the price of having a motorize stage could not make up for the small increase in quality. Thus, the team decided to use a high performance manual stage. The stage is a Newport 481-A Fine Rotation. The stage will support both the flow cell and an attached arm.

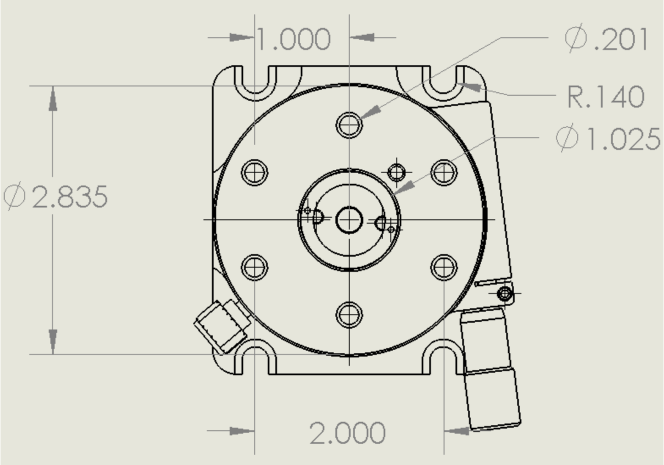


Figure 6.21: Top view of the rotational stage in blueport form to show all relevant dimensions. (Schematic courtesy of **Newport Corp.**)

Camera Mount

Keeping the camer at the same angle as the flow cell is very important. To accomplish this goal, the camera will be mounted onto the rotation stage through an extending arm. To provide support and cosistency, the arm will be about 17.0 cm long with about 9 cm extending off of the stage. To help keep the weight of the arm down, it will be manufactured out of a light weight metal like aluminum. The 9 cm is to provide the length needed by the lens to be able to see the metal-dielectric boundary. The length of the lens is 6.52 cm and the working distance is 2.3 cm. To help the camera focus and move, the camera will be attached to an XYZ-motion stage. This will allow the user to move the camer to a desired location. The XYZ-motion stage will be attached to the arm with an L-bracket. This will help keep the height of the camera low.

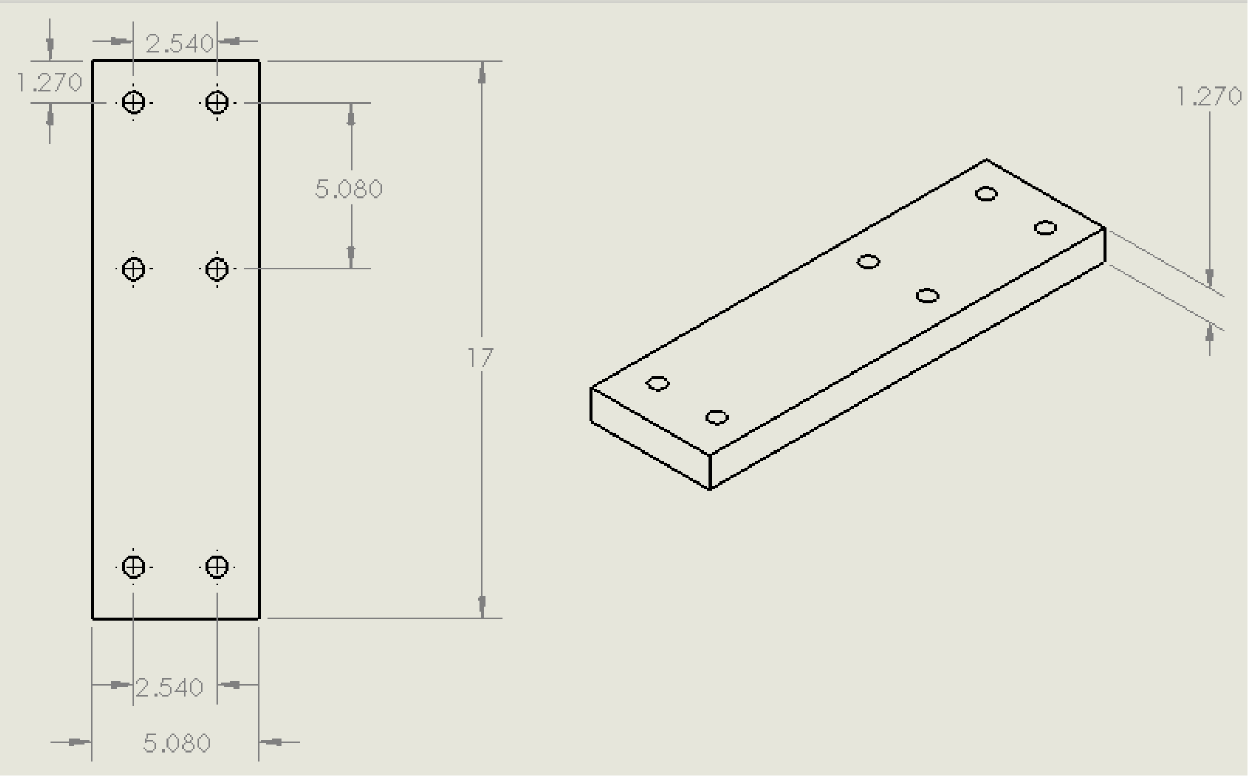


Figure 6.22: Model of the support arm which will hold the XYZ motion translational stage; all dimensions are in centimeters.

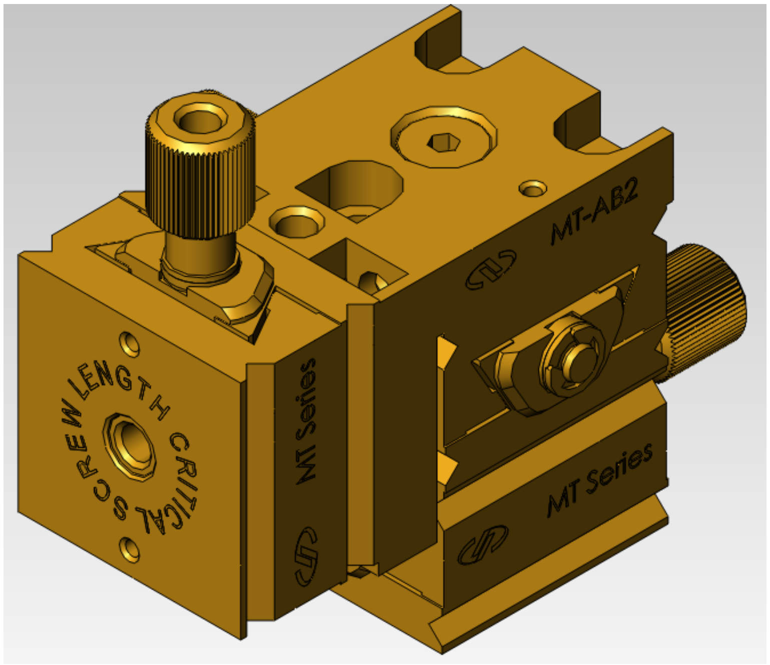


Figure 6.23: Model of the XYZ motion translational stage which will support the camera lens system. (Solid Work drawing courtesy of **Newport Corp.**)

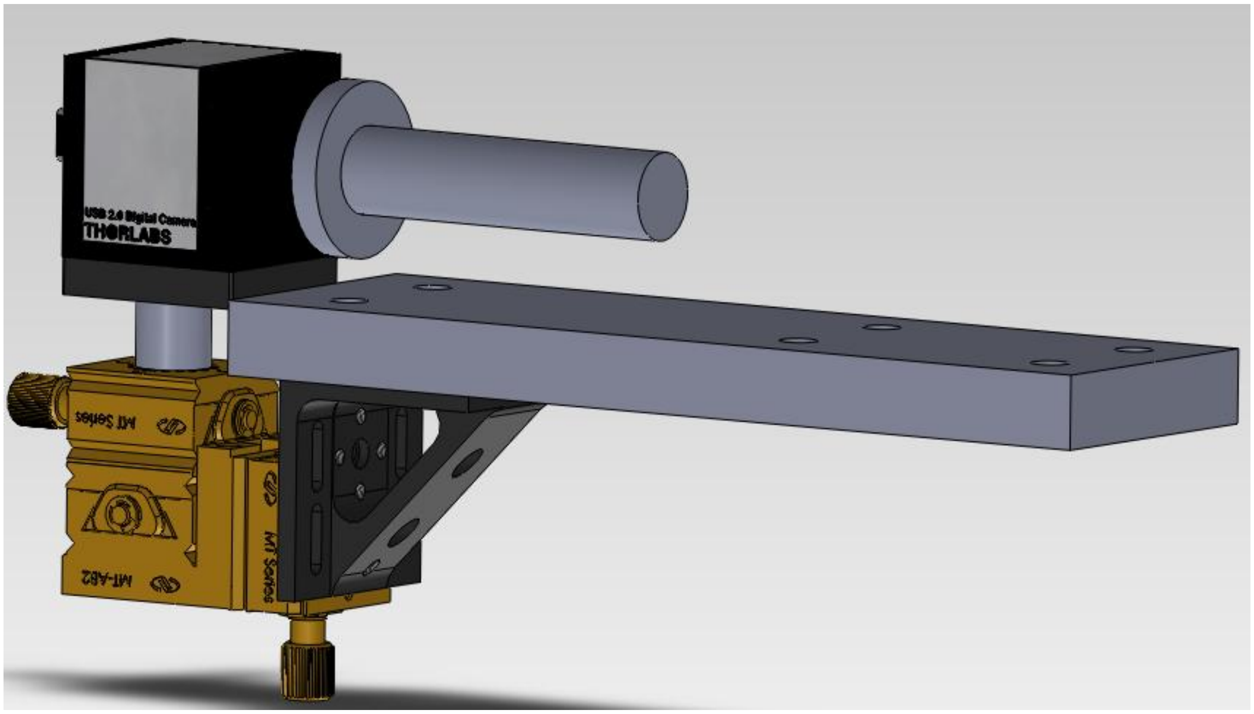


Figure 6.24: Complete model of rotational stage arm and camera attachment . (Camera Solid Works drawing and L-Bracket Solid Works drawing from **ThorLabs** , XYZ Motion Stage Solid Works drawing from **Newport Corp.**)

The arm extension will be connected to the rotational stage. To help keep the cylindrical mirror, flow cell, and camera at the same height, different height supporting rods will be used. The cylindrical lens will be placed on top of a support rod that will elevate the lens to the flow cell. The camera will also be attached to a similar rod. The flow cell will be sit on top of the arm. Figure 22 is a complete representation of the stage and support arm.

6.5.5 Camera Lens System Design

As stated before, the main priority of the modification to the original SPP sensor is to allow for a camera to observe the actual surface Plasmon wave. The design chosen for implementation requires the use of a CCD camera which will be capable of capturing the SPP response, and allow for analysis to occur in real time. The chosen camera is a DCU223; a black and white camera with a 1/3 inch sensor, and a pixel size of 4.65 microns x 4.65 microns. To provide the magnification needed to resolve micron structures is provided by an InfiniStix 4x magnification video lens in line with a DL Doubler Tube, which together, will provide the system with 8x magnification. This camera lens system will increase the camera resolution to 0.581 microns per pixel, and 59.5 microns x 44.63 microns for the active area of the camera.

The camera must be close enough to see the full light response directed towards the camera but far enough away to not interfere, which is done by mitigating the length of the camera lens system while keeping the working distance moderate. In this design, the camera system has a structure length of 11.149cm, plus 2.0cm for the camera USB cord, and a 23mm working distance of the lens. This layout can be seen in Figure 6.25.

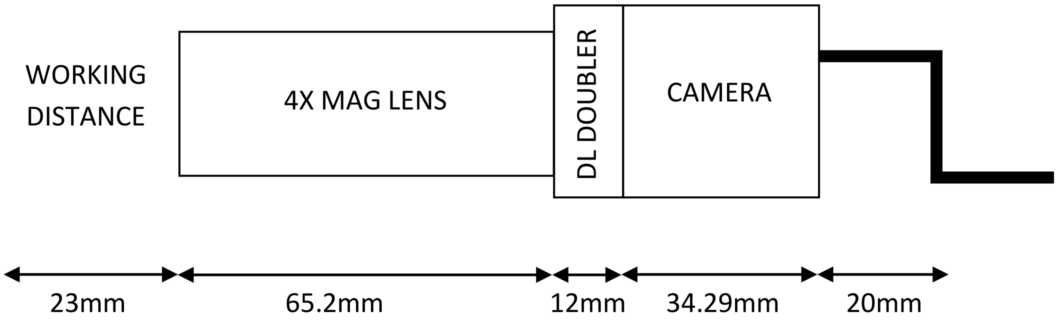


Figure 6.25 – This illustration shows the camera and lens system and the length of the entire system. This means that the distance from the gold/dielectric interface to the cord sticking out the back of the camera is 154.49mm.

6.5.6 Data Acquisition System

6.5.6.1 Data Acquisition System

One of the most essential features of our design pertaining to data collection and analysis is to have the user interface very simple so that someone without any experience in handling optical components would know how to collect data and analyze it with a very brief training. The current system has an automated rotation mirror to characterize the Plasmon resonance by mapping out the intensity profile of the output beam. This output beam is directed to a mirror sitting on a rotating motor which rotates in order to scan the beam across the detector. The rotation of the motor is programmed using a virtual instrument in labview.

6.5.6.2 Current data storage mechanism

The current User Interface requires several input parameters for each measurement set. The new surface Plasmon sensing system will still need these inputs from the user but will revamp the way how the output data is stored, collected and analyzed. Currently the data output from labview is saved in two .txt files. The first file includes information such as the date when the experiment was performed, the time at which every measurement of the Plasmon sweep was performed, the name of the user who is taking the measurements etc. and then data values which is a 2-dimensional array in which the first column of data is the rotating mirror's stage angle, the second column of data is the average beam intensity measured by the power meter, the third column is the flow cell reference angle and the fourth column is the flow cell stage angle. The flowcell reference angle and the flowcell stage angle are the same for every iteration. For every measurement by rotating the mirror on the motor, a new .txt file is created where these data values and information about the each measurement is stored. The other .txt file only saves the data values but not the information associated with every measurement. But all the data values from every measurement are saved in the same file one after the other.

6.5.6.3 Data Export for Computer Analysis

After a complete Plasmon sweep is performed, this .txt file is then imported into a MATLAB script file. This MATLAB script file calculates the winspall angle for each angle output provided by the .txt file from labview (the mirror angle, stage angle and the reference angle) using a formula. If nothing goes wrong with the every measurement for a complete Plasmon sweep, a near-Gaussian curve is expected for each measurement. This winspall angle is then converted into gold-incidence angle using a formula and each measurement curve is plotted in MATLAB with the gold-incidence angle on the x-axis and the average beam intensity on the y-axis. The current MATLAB script uses a correction factor that is hand calculated when calculating the winspall angle using the mirror angle and the stage angle. This is not an effective way to calculate the winspall angle as every Gaussian curve plots are a little off from each other when finding the Plasmon resonance angle. In our new system we have to automatically incorporate a correction factor with every measurement thus giving us Gaussian curves with a common Plasmon resonance angle.

Another drawback to the current system is that, it does not have the ability to output the all the essential information other than the plot. To retrieve this information, the user has to open up the individual .txt files to see what information every measurement holds. Also the information stored in the .txt file is not stored in a readable format which makes it complicated for a user to understand and decipher the information.

6.5.6.4 New data storage mechanism

To make this data collection and analysis more efficient, data values and information associated with every measurement would be stored in an xml file instead of a .txt file. By storing them in an xml file provides the leverage of tagging all essential information with a name as a reference to the tagged information. This xml file can then be imported into MATLAB where a script file will read all information (tagged) present in the xml file and display them in a readable and efficient format. This will give the user the ability to refer back to experiments performed in the past and pull out every relevant information associated with that experiment. This would save the user time and hassle as all the information related to an experiment would be efficiently stored and simple to decipher without any complication. Also the current data collection and storage system does not store enough information about the experiment which also needs to be inculcated. This would include information like distance from flow cell to rotating mirror, distance from rotating mirror to power meter etc. This information has to be incorporated in our new data collection and analysis system.

6.5.6.5 Graphical user interface

The UI will require the user to input several parameters which are the automated rotating mirror’s inputs which includes the step size of a single rotation, the initial angle (absolute angle), and the number of iterations which vary with the width of the beam. Then the inputs for the power meter which is the averaging time in seconds for each measurement. Other information that is not included in the current graphical user interface system like the distance from flow cell to rotating mirror, distance from rotating mirror to power meter etc would have to be included in the new user interface. Two file paths have to be specified by the user. One would be where the xml file containing the data and other essential information associated with the experiment would be saved. This file would then have to be imported into a MATLAB script file which would interpret the data collected. The other file path would be where the image of the gold-dielectric interface would be saved. This simplified user interface would allow a user with limited knowledge of labview and MATLAB to output result plots and relevant information regarding the experiment without any complication.

6.5.6.6 Camera

A very critical aspect of our new design is to be able to observe gold-dielectric boundary. This is achieved by monitoring the gold-dielectric boundary with a camera. This feature also has to be incorporated in our labview program. As of now, we haven't decided on how we would handle the images that we acquire with the camera. This will be an essential task in our design next semester.

6.6 Product Life Cycle

The product life cycle describes the life span of all materials from their creation to disposal after use, how the materials are disposed, and any recycling methods.

The gold slides have the shortest life cycle in the system. Each gold slide has a limited life span during measurements, as water and other liquids tend to oxidize the gold film at a faster rate than air. This oxidation reduces the coupling efficiency to produce surface plasmon resonance, which may affect the results in a negative manner, especially when used by the modified sensor. After a measurement run is complete, the gold slide is removed from the flow cell and placed into a labeled petri dish and stored in a bin labeled used gold slides. This allows the user to return to a previously used slide for further examination, in the case that a gold slide must be returned to in order to conduct additional testing.

The glass prisms are reusable over many measurements. After every measurement run, the prism should be cleaned before another gold slide is applied. For routine measurements, the prism can be carefully rinsed with acetone and isopropanol and air-dried. If stains remain that may hinder measurements, the prism is placed in a bin for ultrasonic cleaning. After many measurements and cleanings, permanent stains may develop. The prism is then retired, where it is only used for demonstrations and test runs. Any chemicals used in the cleaning process must be placed in the appropriately labeled disposal container.

The redesigned PDMS is a non-reusable material. Once the square has been used once or twice it must be replaced. These cubes are stored in plastic bags so that a record of design changes can be kept, along with visuals for demonstrations or system tours. The PDMS (when solid) is a non-toxic silicone-like material that may be deposited in a standard trash receptacle.

6.7 Feasibility

6.7.1 Critical Subsystem Prototype

This section describes the design chosen for demonstrating a critical subsystem of the Surface Plasmon-Polariton Modified Sensor. Demonstrating that the hardest to perform (foreseen) ability of the finished project can be achieved shows that the design goal is attainable. In the case of the modification to the current Surface Plasmon-polariton sensor, proving that the proposed design is capable of imaging the media boundary (metal-dielectric) has been decided to be the critical subsystem in need of physical demonstration.

This series of leak tests shown that the 3 mm thick PDMS cube seems to be the better than a proposed 5 mm thick PDMS square design. While it requires more skill involved to insert the needles without breaking the surface of the PDMS, it is achievable and will decrease the required amount of sample liquid to fill the flow chamber.

The pros and cons of each camera lens were then determined by testing the abilities of each individual optical setup that we have available for prototype demonstration. These tests resulted in the realization of the importance of the camera lens system being mounted upon a translational stage, and realizing that a magnification of about 10x led to difficult identification of the imaged object.

We also determined that there is an optical aberration present that we will have to correct for to improve our system resolution. Possible ways in which we can eliminate this aberration are to design the flow cell to deliver equal force around the perimeter of the Lexan window, or to replace the Lexan with an AR coated glass window.