

WPI

Creating a Mechanical Mask Aligner workaround to be used with Photolithography

A Major Qualifying Project Report Submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE in
partial fulfillment of the requirements for the Bachelor of Science by:

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Abstract

Worcester Polytechnic Institute has an unused and very valuable piece of equipment in the basement of Higgins Lab. This piece of equipment is the Photolithography machine. It has not been running in a decade and would cost an incredible amount to have it sent in to be fixed. A machine like that would be very useful for research purposes due to the uses of photolithography in micro builds and circuits. The purpose of this MQP was to build a mechanical work around for the old mask aligner system and allowing the machine to be revived in the future. The precision of this work around has been undefined but expected to be within a few microns with plans laid out for improvements.

Introduction

Worcester Polytechnic Institute (WPI) has many State-of-the-art machines at its disposal. Some older and in worse condition than others. One such machine is a Photolithography machine that has been out of use for at least a decade. As with any piece of equipment it is an investment, and this one has not been paying itself off. The objective of this MQP was to find out what some of the issues with this model. After turning on everything it was clear that the individual components of the photolithography machine were in working order.

The issue was with the computer that runs the software that was supposed to make all the components work together. At first it would not boot up and would enter the BIOS screen. Through navigation of that, I realized that it was a Windows 98 machine. The computer, however, never got past the windows logo. Trying to get it up and running, it had to be taken out of its enclosure. This had to be done carefully as it was hard pressed and wouldn't budge without some manipulating. Then having to make sure that none of the cables and wires get unplugged as the point was still to try reviving the computer.

After replacing the motherboard battery and making sure that it wasn't trying to open and strange drivers or USB ports the computer managed to get booted up in safe mode. However, nothing then would make it turn on normally and it would always get frozen on the windows logo screen. After multiple failed attempts, and consultations with WPI technical support throughout the process, it was determined that the computer would continue malfunctioning and the software and drivers on it, could not be recovered. The next step of the

Project was to create a mechanical work around that would bypass the need for a computer and just use the UV light source that is contained within the machine. This will be talked about further in the Design Process section.

Background

Any photolithography machine must have certain items. The primary being the wafer that the material would be deposited on. The mask is usually made from quartz glass, which allows almost all the UV rays to pass through it uninhibited. The mask is where the pattern for the circuit would be etched. This Etch would block some of the light from reaching the Solution. The solution is a mix of chemicals in which a photoresist is dissolved (Dr. R. BN. Darling). When exposed to the right wavelength waves the properties of a photoresist can be changed. In the case of photolithography this wavelength ranges in the UV spectrum and can be as little as 193 nanometers (Mark. C). The properties also change by making the photoresist insoluble in the solution and allowing it to deposit in the chosen pattern. As the layers are then extremely thin since the light is operated on a timer, multiple passes must be made. Usually this would consist of 20-30 exposures (Mark. C). It also must contain a light source that can produce light in the ultra-violet spectrum. Due to the high intensity of the light source, there often must be a line of liquid nitrogen going to it to cool down the light bulb as without it, the bulb could overheat and explode.

To begin a spin coater is used to spread an even layer of solution on the silicon wafer. The thickness can be controlled by changing the speed of rotation of the wafer (Jeff Tsai). Once the mask is then aligned with the wafer the expose can begin. A light source will turn on as

mentioned previously. It does not shine directly at the wafer but rather gets focused by multiple lenses and mirrors that will direct the UV waves to exact positions at exact angles. This is important as even a slight change in angle could affect the amount of photoresist that reacts. The exposure time is controlled by a shutter that will open and close to control whether the ultra-violet waves reach the mask. Once the desired thickness is reached the wafer can be developed to remove any additional solution and leave the bonded photoresist behind (J. M. Nano-Link).

The importance of Photolithography can be seen in many different areas of today's society, especially in the process of building microscopic circuits. With technology moving towards making smaller and smaller equipment, a current limiting factor is the standard creation of circuits. On a Precise and well calibrated photolithography machine one-micron channels and grooves can be placed on the circuit. In today's world a common use for photolithography is for processor chips. The smaller the features, that are created, the more of them can be placed on a chip. This technology has rapidly advanced in recent times, making items such as computers significantly faster, lighter, and smaller.

The mask aligner that WPI is in possession of is the EV620 created by the EV Group. It contains an aligner, microscope, as well as the light source with a timed shutter. It is a high-quality aligner able to create features as small as 100 nanometers (EVG).

Design Process

While designing the mask aligner, many things had to be kept in mind. The most important was the limited space considerations of where the current Mask aligner was situated in the machine, and where the microscope was above it. As seen on Figure 1. The four main design requirements were as follows; to be able to align the glass mask and the wafer within one micron of each other, to use the existing infrastructure of the current aligner to hold the new aligner (so that the existing light source can be used), the whole structure has to be able to be disassembled with relative ease in a clean room environment while wearing protective gear, the material has to be suitable for a cleanroom environment. Another consideration that affected material selection is the fact that the part will be under intense UV light. It was concluded that the best way to achieve these considerations was to perform the alignment using an external microscope and outside of the existing machine, and only then place it in.



Figure 1: The original mask aligner in the cleanroom

To conserve cost and weight the material picked was Aluminum 6061. The decision was also made to re-use parts of the old mask aligner such as the chucks and the micrometers. These parts were chosen as none of them are permanently attached to the mask aligner. The chucks are simply placed on top of the translation piece of the aligner, and certain other parts such as the micrometers can be easily put back on within minutes. No permanent disassembly

of the machine was conducted. This played a big part in how the design would look as well since the chuck was a flat plate. Figure 2. The mask aligner must allow the mask and the wafer to be positioned relative to each other in the x, y directions and rotation. This is an important process to allow each of the layers of lithography to be aligned in ways that can build more complex structures than in a single exposure as the current machine has a sort of slot under the light source, the first iteration of the design had it hanging off it. This would have allowed for a lot of room for the rotating piece as well as room for the X and Y axis of rotation. This design can be seen on Figure 3. This Design worked off having multiple plates stacked on top of each other. Quarter inch plates were chosen as this would keep the height relatively low while giving the ability to maintain structural integrity, and still allowing for indentations to be made. The original design contained 1 base plate, A rotational piece, the Chuck plate, a Wafer and a mask (Those are in standard sizes that are bought). A piece to hold the mask, a piece to press it all together, 4 wing nuts and bolts, and 4 pieces that would allow it to hang off the slot.

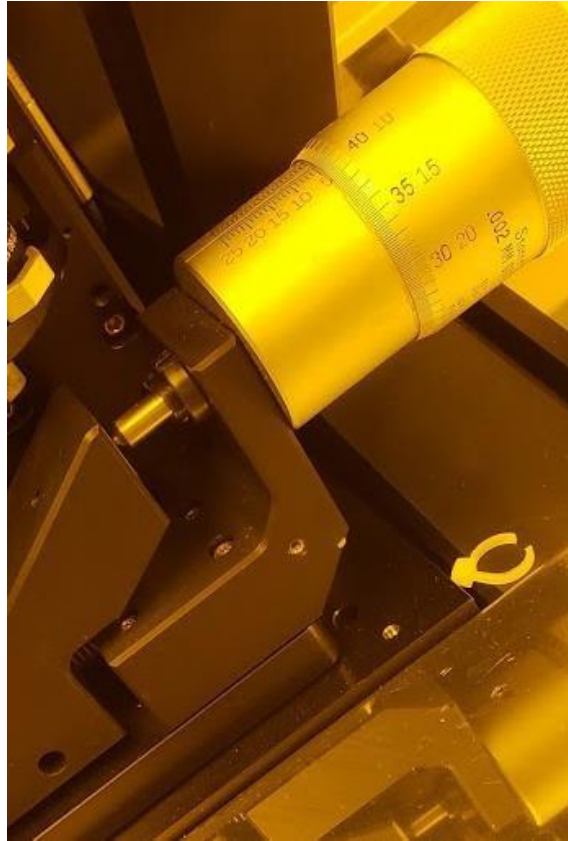


Figure 2: Micrometer attached to mount of original mask aligner.

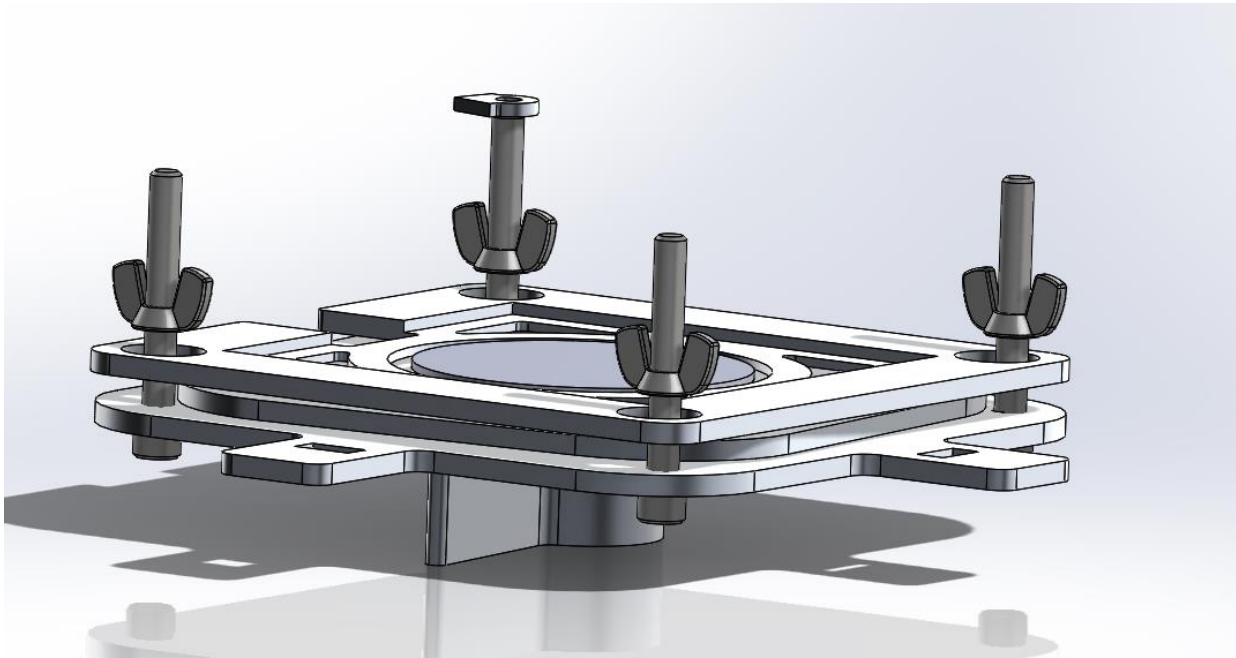


Figure 3: Original design of mask aligner with bottom rotational piece.

The first plate to be made was the plate that presses everything together as it was the simplest, only having 4 clearance holes for the bolts, and a center hole for the mask. This part could then also be double checked against the machine, to make sure that all of it fit. It didn't the Top part of the aligner didn't go back far enough to fit the inserts. However, it did fit at the bottom where the old mask holder would be placed as the bolts held it tightly there. Figure 4. This meant part of the design had to change. Specifically, the Rotational piece that supports the chuck had to somehow be put above the base plate instead of through it which led to the second iteration of the design.

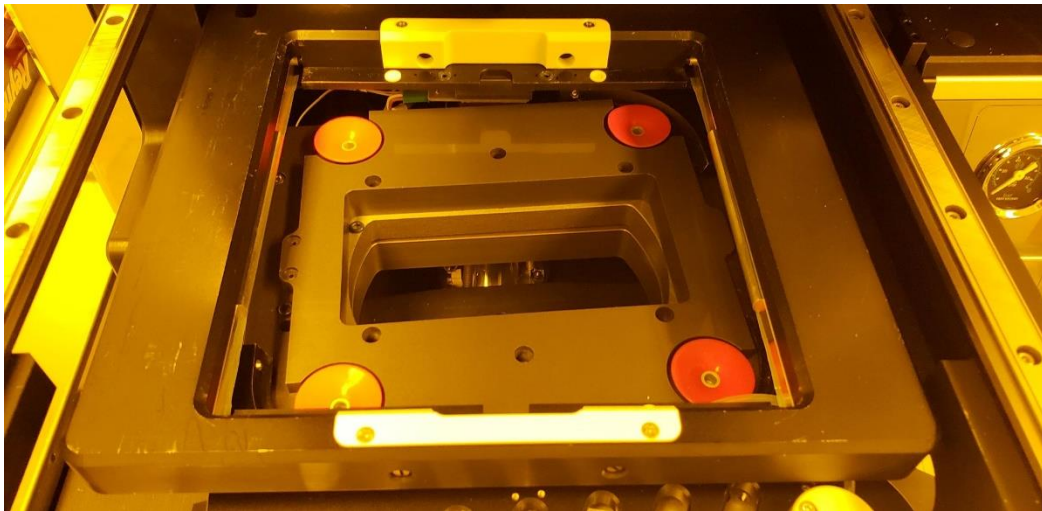


Figure 4: Original mask holder. Bolts are situated approximately over the red circles.

The base plate:

Relatively simple. Originally had a clearance hole and indent for the rotational piece in the middle. The second and final prototype has two perpendicular wings on which the micrometers are mounted. 4 threaded holes that keep the bolts in a constant position also allow the part to be place and attached.



Figure 5: Base Plate physical part.

Rotational Piece:

The new rotational piece is a square like plate with 3 corners removed for clearance and one with a tight clearance hole that's allows the piece to rotate about one of the bolts that holds everything together. It has an indented space for the chuck to be placed in. Due to the lack of space between the chuck and the bolts, the bolts had to be slightly machined for clearance. Later in this paper, a possible alternative for the bolt will be discussed.



Figure 6: Rotational Plate physical part

Mask Holder:

Another square like plate with a square indent in the middle to hold the mask. In that square there is a through hole to give access to the UV light. The bolt holes on this piece are much larger to allow the plate to freely make X-Y translations. There is also a cut out on the side of the plate to allow clamping of the mask.



Figure 7: Mask Holder. Place upside down when using.

Press/Rise plate:

This plate was originally designed to allow winged nuts to provide even pressure on the rest of the mask aligner to hold all the moving pieces in place. This was later moved down a position as the Mask holder had to be higher up to fit better with the micrometers. As well as allow for better spacing between the mask and the chuck.



Figure 8: Mask Press. This piece used to allow the nuts to be pushed down, but now acts as a large washer between the mask and chuck

Micrometers and mounts:

The micrometers were taken off the old mask aligner that is built into the original machine as they are large and suitable micrometers that can be taken off and put back on without causing any harm to the original aligner. In the first design their built-in mounts were going to be re-used as well, but due to the changes new mounts had to be manufactured. For the X and Y axis the mounts go into the base plate wing and get held tightly by a precise clearance and gravity. The rotational piece uses the same mount, but it is put on sideways (with the wing going through a hole) making the micrometer a lot lower and being able to be used on the rotational piece (reference figure X). A notch had to be made in the base plate to accommodate the side of the micrometer. This micrometer gets locked in place by one of the other ones as it goes has just enough room to go past the other mount hole.



Figure 9a and 9b: Micrometers being mounted on a wing. **Figure 10:** notch that gives micrometer more space

All the plates are held together by winged nuts that can and should be adjusted by hand. It's enough by hand as for every 0.5 in-lbf of torque that is applied, the clamping force increases by 6.67 lbs. This is calculated using this equation. $T = KDP$ where T is the Torque. K is the friction constant. D is the diameter of the bolt, and P is the clamping force. The bolts are made of steel so the constant of friction can be assumed to be around 0.2. The bolts are a standard 3/8th of an inch thread. This means that there are 6.67 lbs./in² of force on every corner for every 0.5 in-lbs. As the holes of the now top plate are larger, wide washers had to be used to further allow equal distribution of force. The standard mask aligner uses contact forces of between 290 mBar and 1 Bar, which converts to being between 4.2 lbs./in² to 14.5 lbs/in². Thus, much higher pressures can be achieved even by hand.



Figure 11: Wing nut tightened on washer that distributes pressure on mask holder.

At the end a Last-minute change had to be made with two of the top plates. To fit around the built-in microscope the two top plates had to have a part of their side cut out to accommodate for it. This opportunity was also used to cut off unused parts of the four-inch-long bolts to make them more user friendly.



Figure 12: on left is the cut bolt. On right is the original.

Results:

The resulting aligner is quite easy to use. Under a microscope a person would start with the base plate with the bolts already in it. The rotational piece would then be inserted on top as shown in Figure 13. Once it is centered one of the two available chucks would be placed in the indent. The 'slots' in the middle would fit over their equals on the second plate. This increases how well the chuck fits on the rotation plate as well as keeping those two plates in the same orientation. This allows for the wafer to be rotated independent of the rest of the aligner. To keep the wafer in position and attached to the chuck a vacuum tube would go to the existing

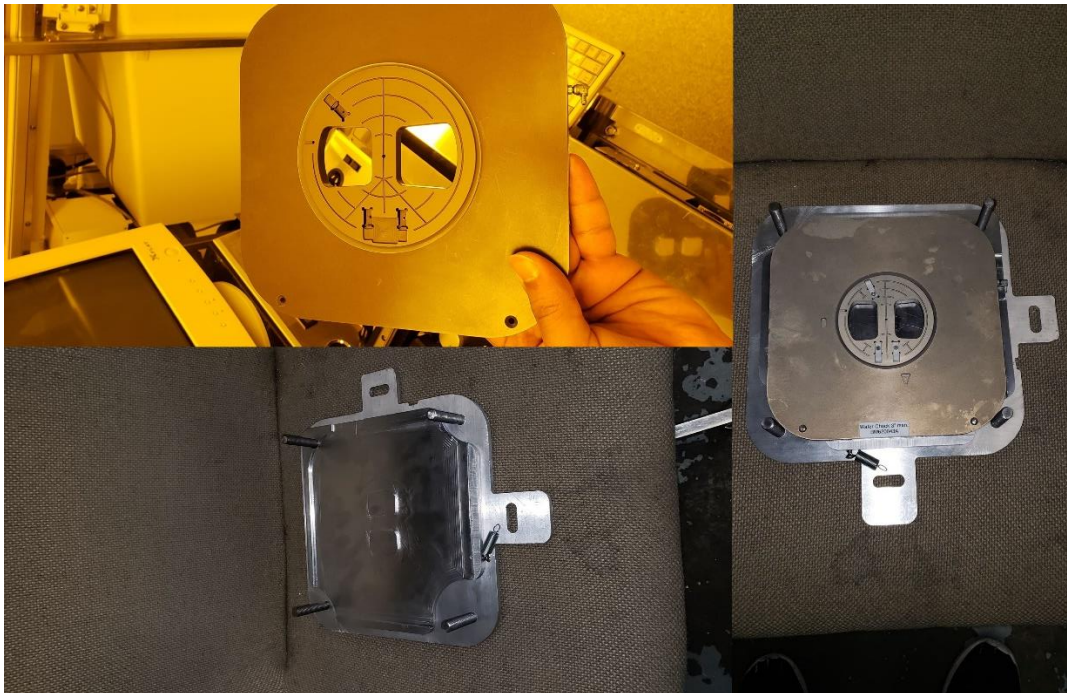


Figure 13: The rotation piece on base plate, and with chuck

nozzle. Next would go the simple plate to provide clearance. And lastly for the plates, the mask holder would be placed with the mask attached to it. The user then would try to align the two relatively by hand.

For precise alignment the micrometers would have to get put onto the base plate. The first of the three would go in sideways, pushing the base plate wing through the slot. The second of the micrometers would serve a dual purpose of then locking the first one in place, by fitting through the slot. Refer to Figure 9. Lastly the last of the micrometer mounts would be placed in the second wing slot. Washers and the wing nuts can be then put on the bolts; however, they should not be tightened to allow for movement. The springs can then also be placed on the secondary screws on the mounts as well as the plates to allow the plates to move with the micrometers if they are loosened. As shown in Figure 14.



Figure 14: Screws to hold springs are in the side of plates

With the springs in place, the plates should push against the micrometers, allowing the user to adjust the angle, and X-Y position accordingly. If then done under a microscope a tolerance of as low as a few microns would be achievable using this prototype. Once the mask and the wafer are aligned, the wingnuts can be tightened as far as the user can without using tools. The amount of torque used is dependent on the user, however as long as the winged nuts are not loose, that would be enough to keep the alignment. Two nuts at a time on opposing ends are recommended to avoid pushing a single corner or side and misaligning the plates. Once all the nuts are clamped, the springs and the mounts should be taken off. And the aligner is technically ready to put into the photolithography machine. Figure 15.

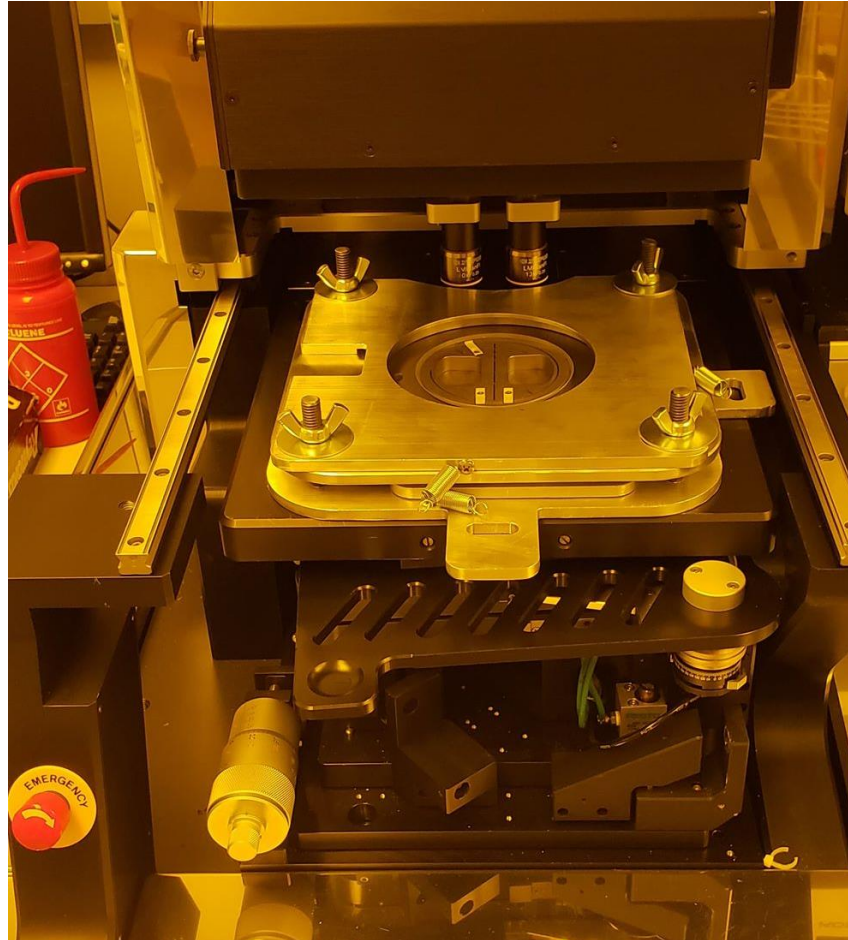


Figure 15: Custom Built mask aligner inside the original model.

Future Improvements

If given the chance to make improvements passed the prototype stage, there could be certain things added to better fit the parts together. A significant one would be to use the new design from the start, which would include the space that had to be cut out by hand for where the microscope is on the mask press and mask holder pieces. This would give it a much cleaner and precise look.

A second big change would be the use of a water jet for many of the parts instead of a milling/CNC machines and a lathe. This would allow for smaller radiuses that could be built into

the design of the part instead of manually filing them down. Certain notches and cuts that were included as an afterthought once the parts were machined, to make them fit better could also be predesigned in. The use of a water jet could also allow for much tighter tolerances, which would significantly improve the aligner's precision. Although this change is unnecessary it would make future iterations much easier to manufacture.

A third good change would be using a custom bolt or shoulder screw that could suit this part needs much further than a standard 3/8x4" bolt. It could be tailored to the needs of the machine such as having wider and smaller parts to it that would remain strong, but also more practical. Especially for the rotation piece, with the bolt being thinner at the chuck level would allow the user to rotate the piece further before coming in contact with the mounting bolts. In the prototype the Bolts were simply ground down on one side, while keeping the threads on the other. The custom bolt could also have an area with no threads which could be made to accept a bushing with a higher tolerance to the corner of the rotation piece that goes on the bolt. An example of such a bolt can be seen on Figure 16.

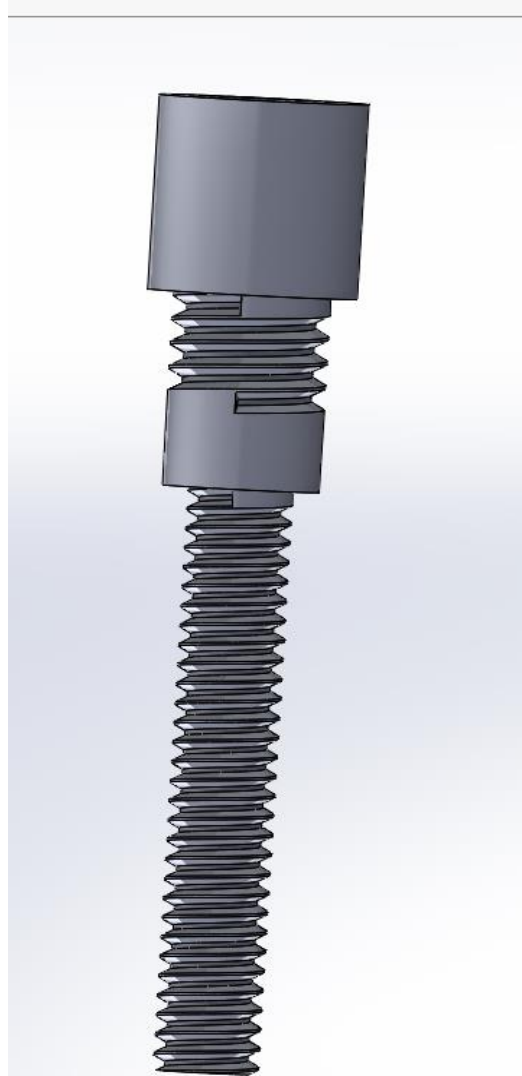


Figure 16: possible rough design for bolt.

As the part weighs a significant amount, more weight reduction design could be included in the aligner. This would include things such as removing structurally unnecessary material making it easier to move around and work with.

Although outside of the scope of this project, an important note for future users who may continue to build upon this project, the light and shutter of the original aligner should be used. After some investigation, it was seen, that the shutter is inside the light casing, and

controlled by a solenoid. It can be accessed behind the top left side cover of the machine, near the mirror that directs the light down onto the wafer Figure 17. Providing a current to the solenoid should open the shutter, and so an Arduino switch or similar microcontroller with a timer can be used to open and close the shutter to accommodate an exposure time.

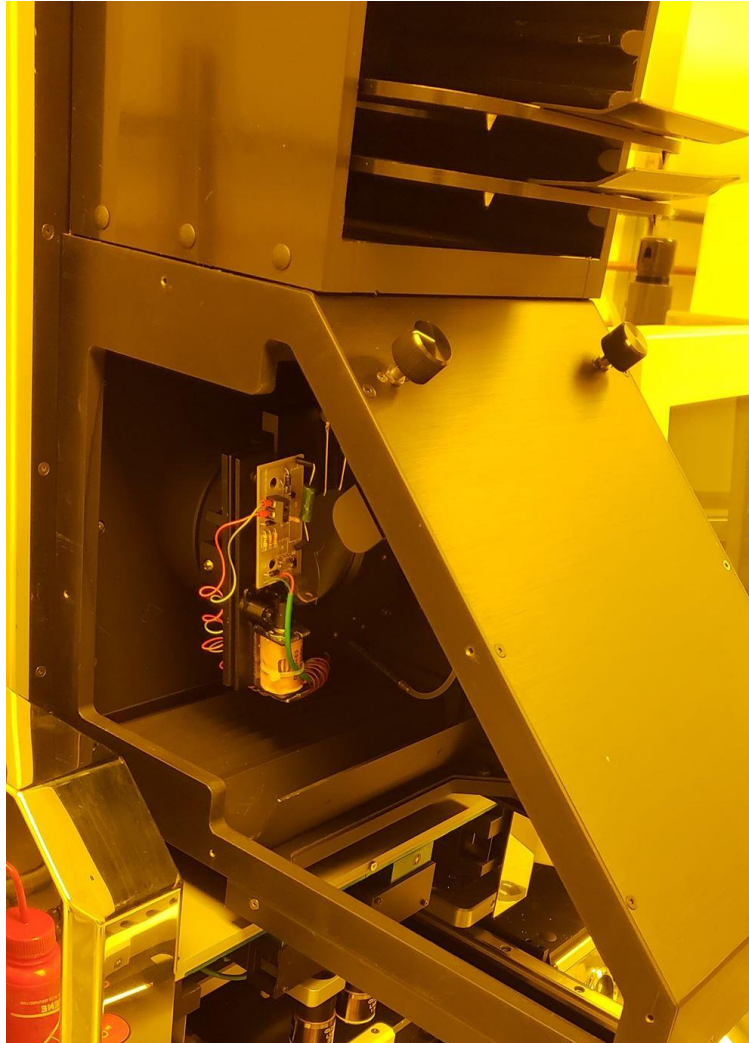


Figure 17: The side of the Photolithography machine with side panel taken off

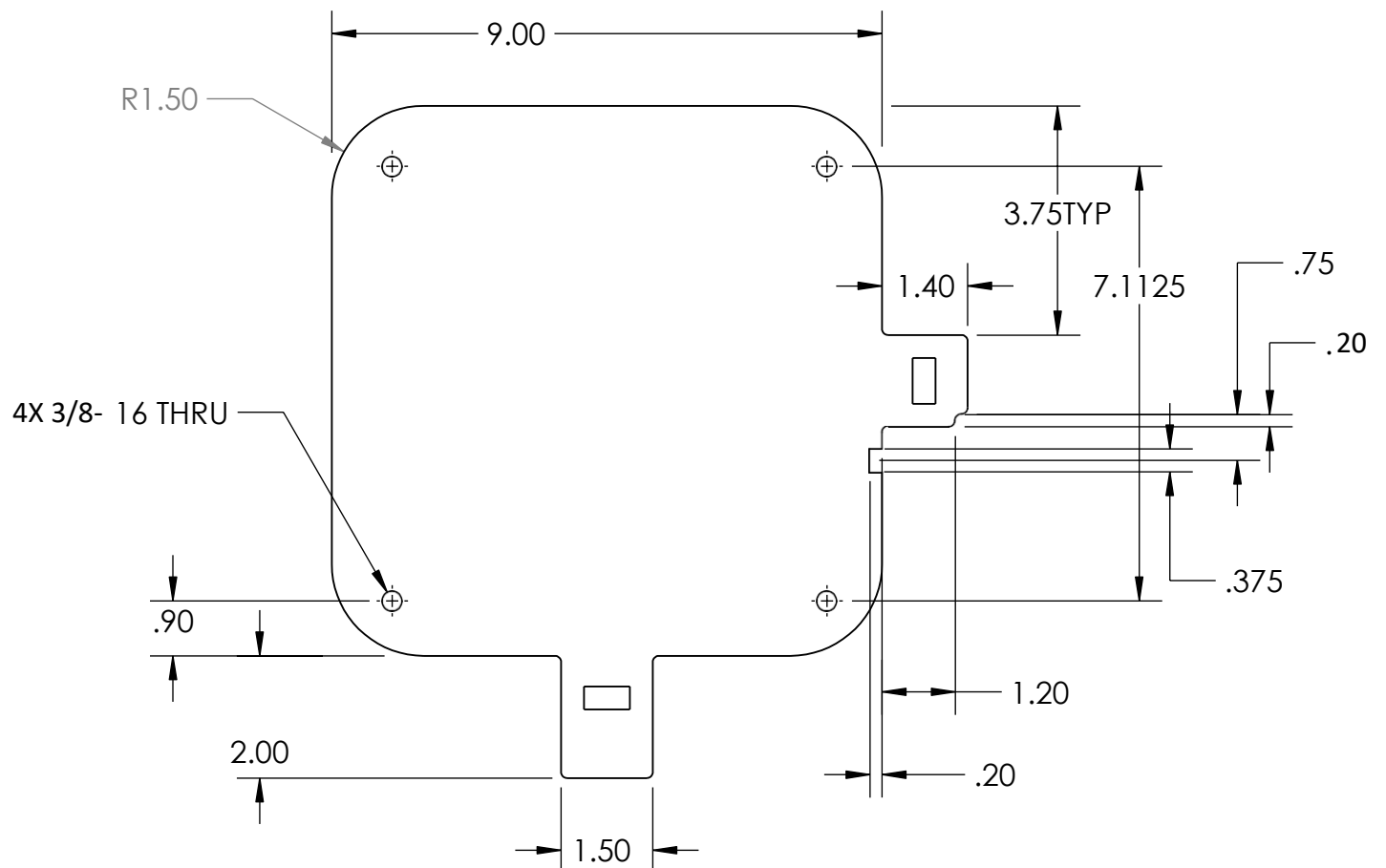
A last real improvement would also be working in a cover around it in a way that allows the alignment to happen, but also so that I can be used with the high intensity harmful UV light safely. As this was not the focus of this Project, this was omitted however in a potential future version it will be important to include something to protect the user from the UV light source, and keep it concentrated only on the mask.

An honorable mention towards improving and finishing the project would have to be, being able to see the whole process from start to finish. Having a mask and wafer, aligning them together, and then using them to do photolithography and ending up with a finished product would have been a great experience.

Appendix

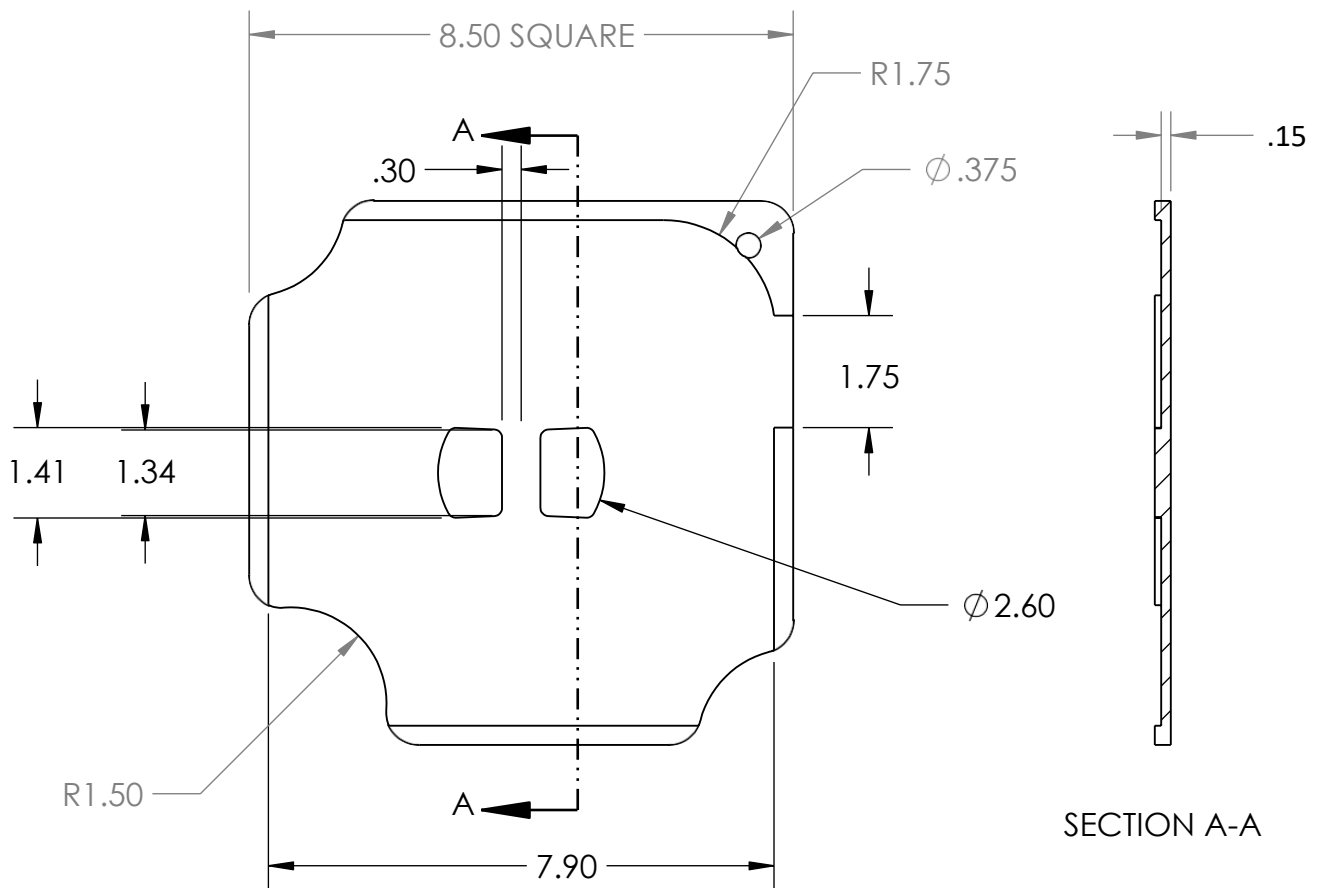
Base Plate

0.25" THICK SHEET



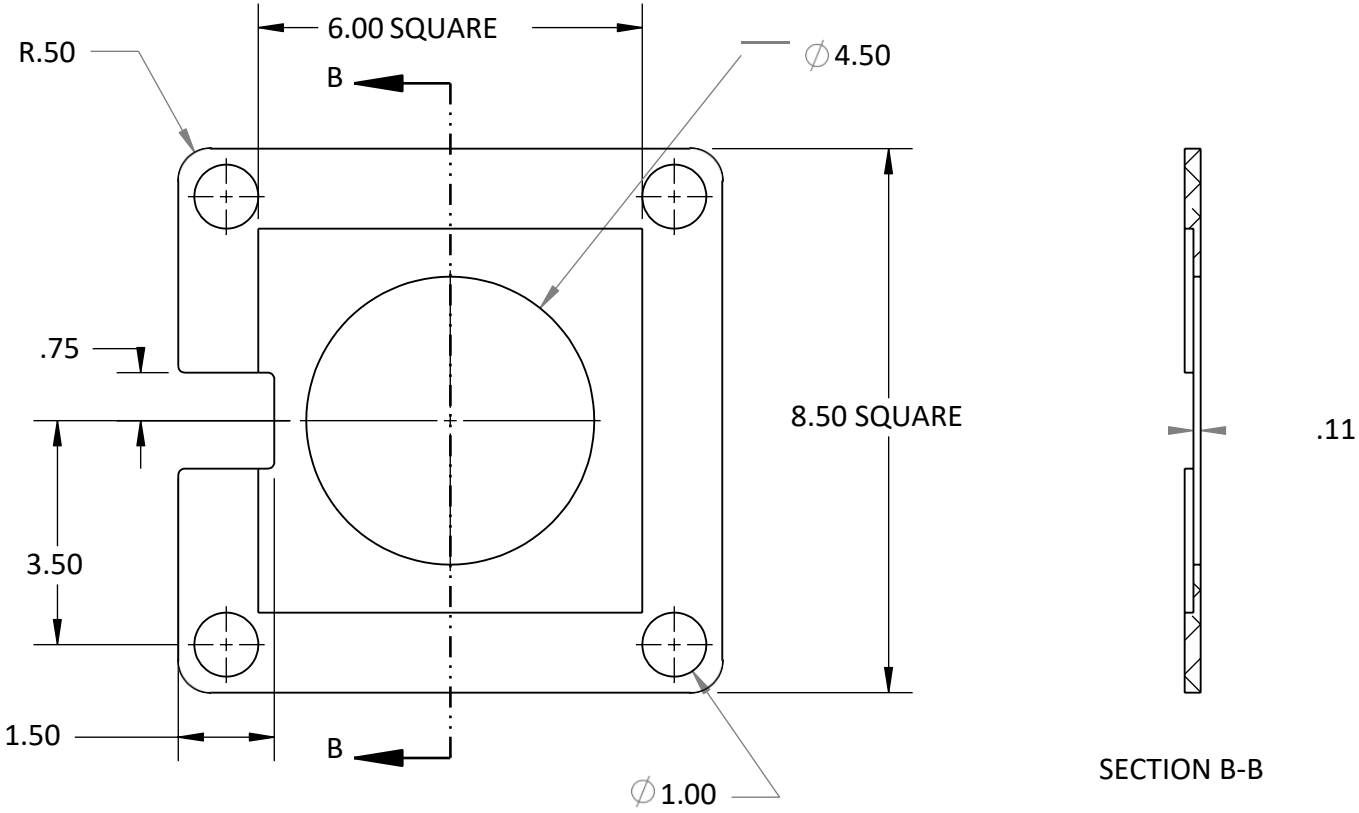
Rotation Plate

0.25" THICK SHEET TYP



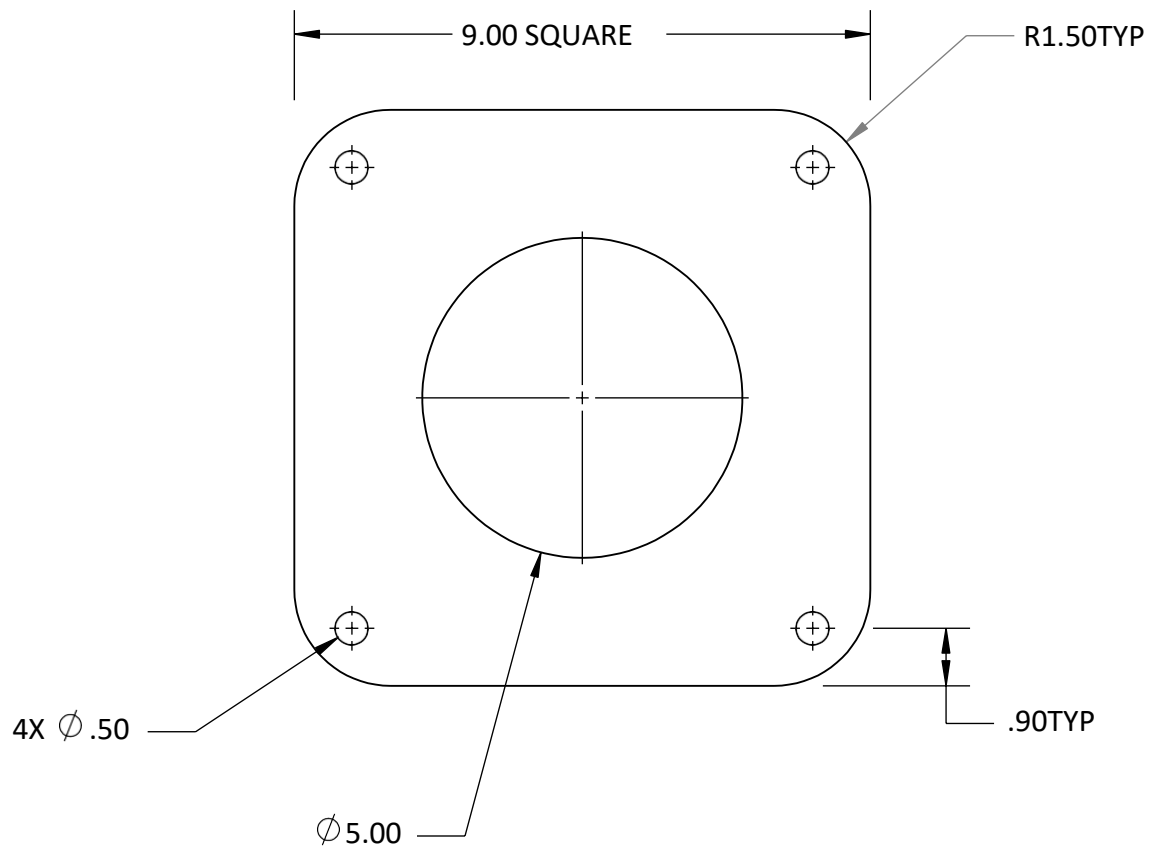
Mask Holder

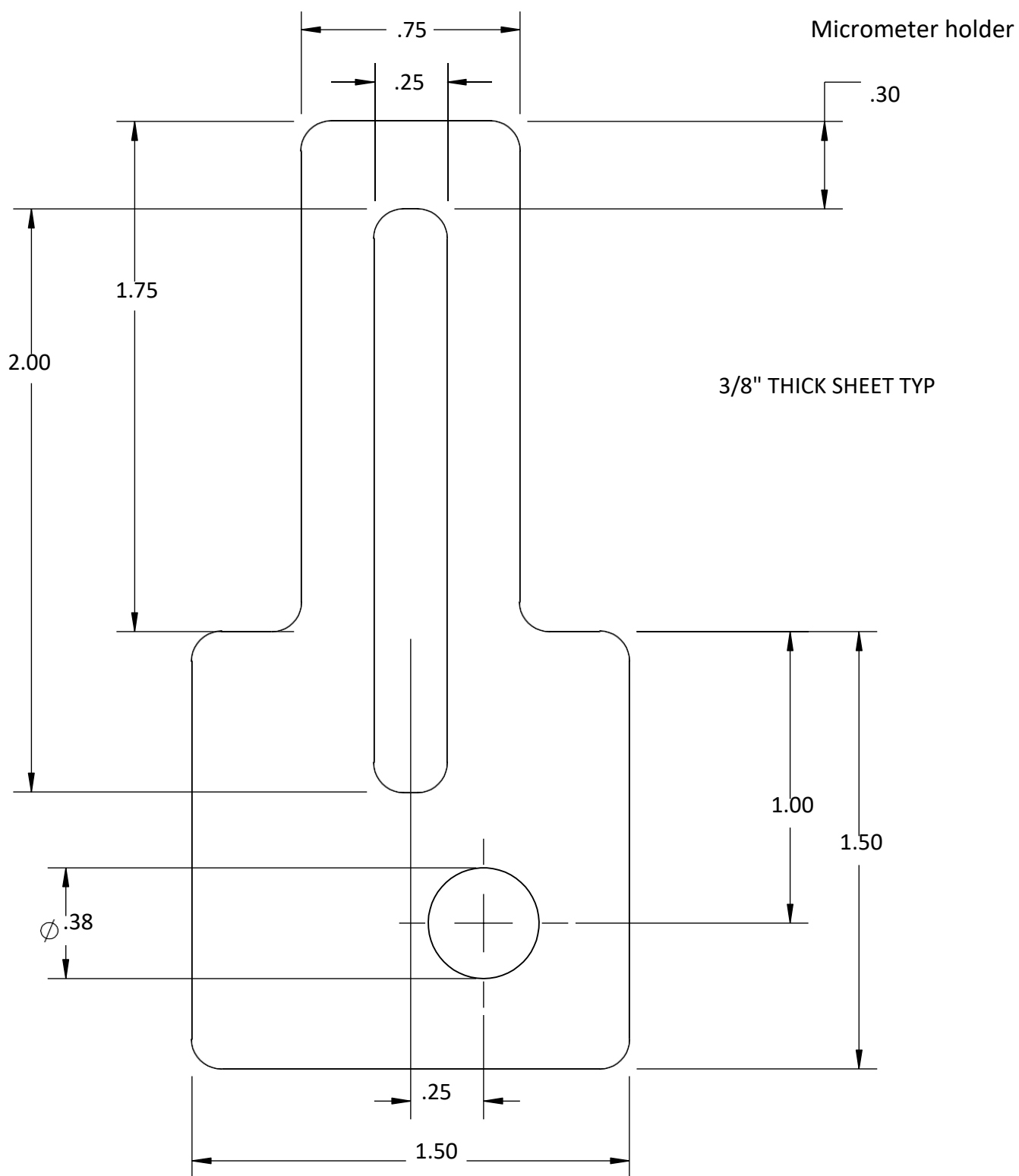
0.25" THICK SHEET TYP



Mask Press/Rise

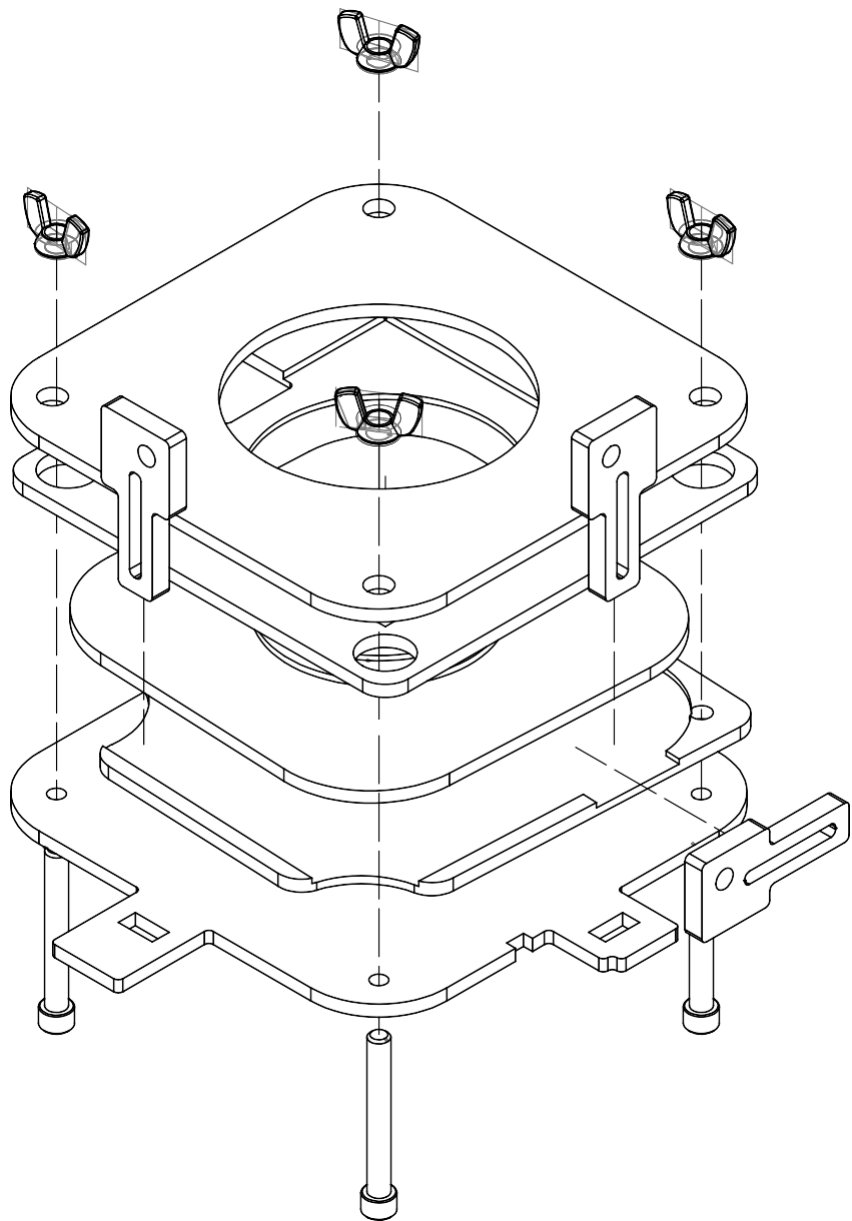
0.25" THICK SHEET TYP





ITEM NO.	PART NUMBER	QTY.
1	Bottom plate	1
2	chuck	1
3	wafer	1
4	mask holder	1
5	mask press	1
6	90044A149	4
8	90866A140	4
9	rotationpiece 2	1
10	micrometer holder	3

Mask Aligner



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