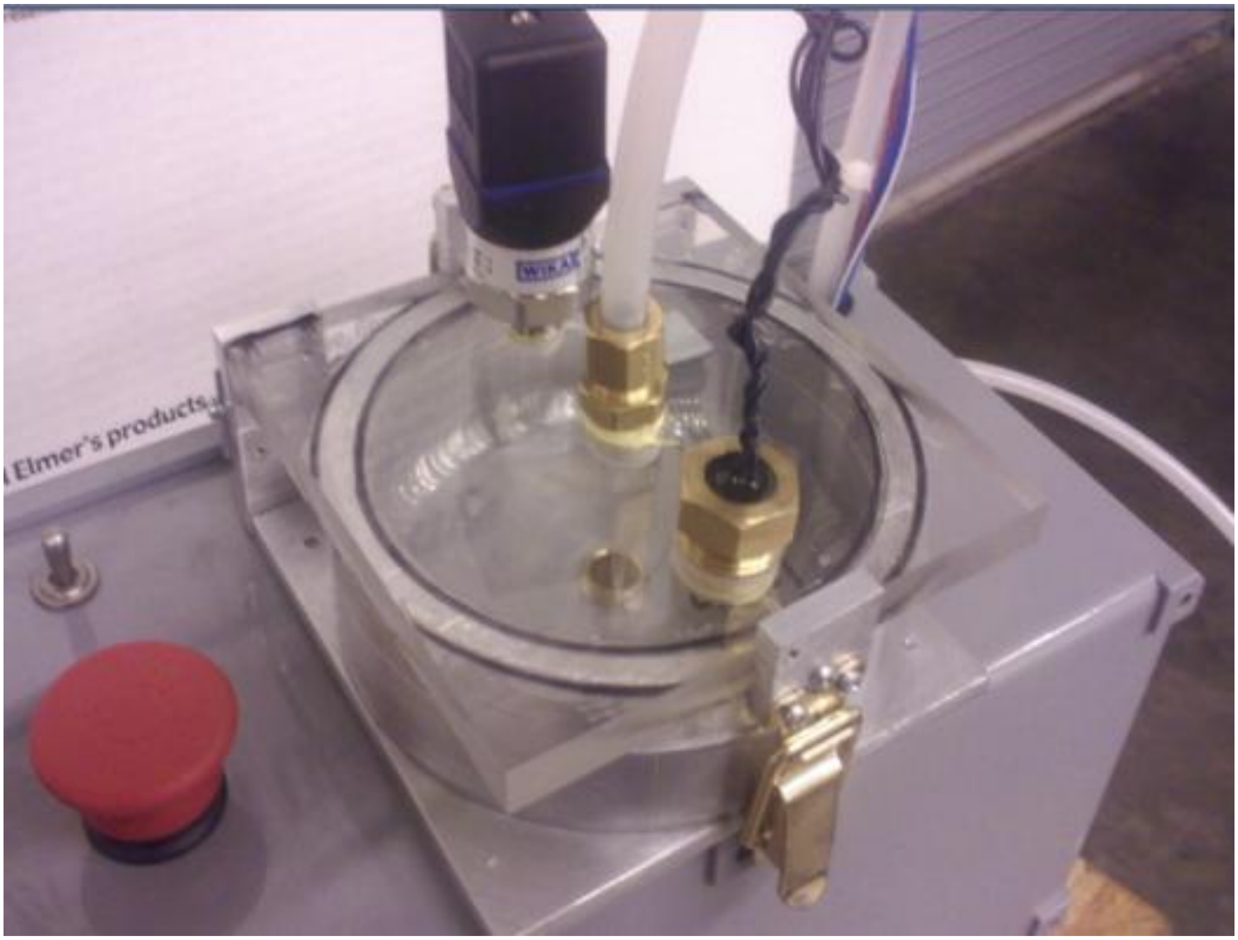
Economical, Isotropic Silicon Etching Machine

Amanda Herrick, Jason Kloess, Sarah Verner, John Wang
Design Review 3
March 22, 2010



Abstract

The equipment used to isotropically etch silicon wafers for MEMS (Micro Electro-Mechanical Systems) applications is very expensive. Due to this, the amount of growth of this developing technology is limited to entities with large monetary resources. The goal of this project is to design an alternative piece of equipment which achieves the same results but at a more economical cost. The introduction of a less expensive alternative will expand MEMS technology to more people and in turn technology will be able to progress at a faster rate.

Executive Summary

Professor Nikos Chronis has approached us with the opportunity to dramatically reduce the cost of an isotropic silicon etcher for use in the MEMS industry. This will allow this equipment to be used in private research facilities and universities where a large budget is not present. The current system uses Xenon Difluoride (XeF_2) to etch exposed silicon on a pre-masked standard 4-inch diameter wafer. A secondary goal is to reduce the size of the system to approximately desktop size. The most important customer requirements for this project are keeping the cost low, safely removing the harmful products of the reaction (Hydrofluoric Acid, HF), reducing the size of the device, ensuring the uniformity of each etch, and incorporating a well-controlled valve system. The associated engineering specifications are to produce a prototype for less than $800, allow no more than 0.01% leakage, keep the design within the size of 1m x 1m x 1m, ensure greater than 98% uniformity, and reach steady state conditions within 2 minutes.

Our chosen alpha design featured a combined etching/expansion chamber to be fabricated out of aluminum. The top plate, top side, bottom side, and bottom plate were bolted together and sealed with gaskets between each layer. The system was enclosed within a microwave, which was donated to our team. A knife valve was placed between the top and bottom sides and used to separate the etching a expansion chambers. We chose this concept because it was the simplest design and also the most economical as it eliminated the separate expansion chamber, minimized the number of valves in the system, and utilized aluminum, which is relatively inexpensive. The final prototype design was altered slightly from our alpha design. To allow our sponsor to observe the silicon wafer during the etching process, the top plate was machined from acrylic. The acrylic top plate was attached to the aluminum top side via epoxy. We also determined the bolts to be too cumbersome to remove each time a wafer needed to be inserted and instead incorporated a hinge and latch to ease user operation of the system. The gaskets were replaced by an o-ring due to complications manufacturing them and to provide a better seal. The prototype did not include the desired knife valve, due to cost and insufficient time for thorough testing. Finally, the microwave enclosure was found to be larger than needed and was subsequently replaced with a small electrical box, which housed the valves, tubing, and DAQ. The bottom plate remained of aluminum and was welded to the bottom side to decrease any potential leaking.

Our fabrication plan included material specifications for machining aluminum and acrylic on the mill. We also used the band saw to cut materials to their approximate sizes before milling them. The drill press, mill, and power drill were used for through holes in the system. We also used the mill to machine a groove for the o-ring. The chamber was assembled using screws and screwdrivers. The valves were bolted into the enclosure and Kynar tubing was used to connect them. Our final budget was $880 which was slightly over our initial goal of $800.

We used compressed air to test our prototype for leaks. A pressure transducer was used to measure the vacuum pressure that our system could achieve. The chamber was brought to vacuum pressure ten times and the pressure achieved after 30 seconds of pumping was recorded. The average pressure reached was -12.4 gauge psi with a standard deviation of 0.06 gauge psi. The optimal operating pressure for the system is -14.0 gauge psi. Testing revealed a leak in the epoxy seal. This accounts for the lower pressure and the inability of the system to maintain vacuum. To eliminate this problem, we recommend machining the entire chamber from acrylic to avoid unnecessary risky seals. We also strongly advise incorporating a knife valve into the system to increase the seal and the uniformity of the gas dispersion.

TABLE OF CONTENTS

INTRODUCTION

It costs nearly $100,000 to purchase the equipment used to etch silicon wafers used in the MEMS industry (see Appendix F for system pictures and Appendix G for price quotes). MEMS technologies are used to make miniaturized circuitry, micro-fluidics devices, micro-sensors, as well as many other applications. Due to its enormous cost, the equipment necessary to produce these chips is only accessible to large universities and corporations with large funding sources. In order to increase the availability of this resource to smaller institutions with less funding, our sponsor Professor Nikos Chronis has expressed a goal to redesign this equipment in a more economical fashion. With the introduction of this new, more cost-effective device to the market, the growing MEMS industry will be open to more ideas and will be able to advance more rapidly.

BACKGROUND INFORMATION

The current system uses Xenon Difluoride (XeF_2) as a working gas in an isotropic silicon etching process to etch 4 inch diameter silicon wafers. In this reaction, XeF_2 has a high selectivity for silicon. When the molecule comes into contact with the silicon, it dissociates to Xenon (Xe) and Fluorine (F), where the Fluorine does all of the etching. See Figure 1, below.

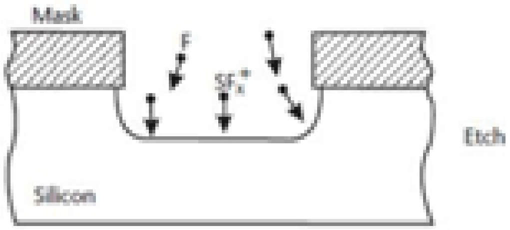


Figure 1: Cross-sectional view of etching process with XeF_2 gas.

The process as a whole uses a cycle which repeats until the desired amount of etching is achieved. There are two chambers that are used: an expansion chamber, where the XeF_2 gas is taken from a supply tank to expand to the desired pressure and volume, and the etching chamber, where the silicon wafer is placed and where the chemical reaction takes place. Figure 2, below, shows this cyclic process. First, the silicon wafer is loaded into the etching chamber. Nitrogen gas (N_2) is then flooded into the chamber in order to purge the tank of contaminants (such as water vapor, which will combine with XeF_2 [2] to form the highly toxic HF [4]). Next, a vacuum of 10^{-4} Pa is established in the etching chamber, while the XeF_2 is expanded in the expansion chamber. Once both of these tasks are achieved, the working gas is sent into the etching chamber and begins to etch the silicon. After a task-specific amount of time, the reaction products are evacuated to a fume hood and the process repeats.

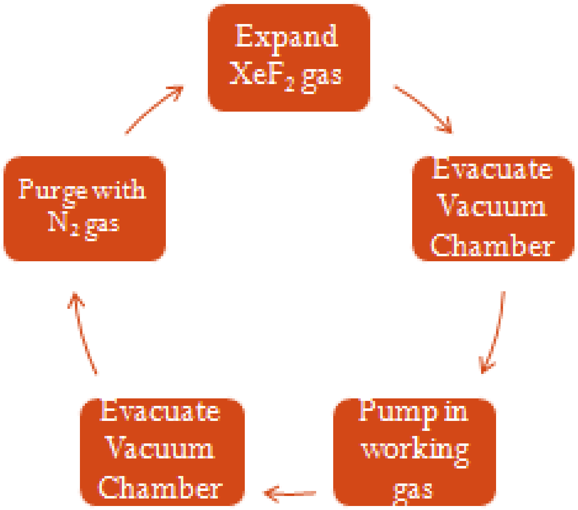


Figure 2: Cyclic process for gas flow in silicon etching cycle.

Within the etching chamber, a dispersion system is employed in order to maintain uniformity of etching. This is simply a plate with several holes through which the working fluid must pass before reaching the wafer..

We have identified three main challenges for this project: budgeting, dispersing the etching gas uniformly, and maintaining vacuum seal. Under the current budget of $800, it will be difficult to incorporate all the features of current market products and expensive components. For initial cuts, our team has proposed reducing the number of costly valves in the system, with the possibility of using three-way valves as well as less expensive plastic valves. We will also eliminate the cost of an onboard computer by designing the system to be compatible with any computer that has LabVIEW. Lastly, the use of an external vacuum port will allow the system to connect to any existing vacuum pump. To maintain etch quality and uniformity, we are concerned with the even dispersion of the etching gas, XeF_2. To disperse the gas evenly we must maintain a high vacuum environment and consider different dispersion plate designs. Maintaining the vacuum seal is very important for product safety as well as quality. Leakage of the etching gas XeF_2 is potentially hazardous to the system operator as it forms hydrofluoric acid (HF) when exposed to moisture in the air [2, 4]. Also, a bad seal will result in an increase in pressure, which affects the etching rate and the etching uniformity. We will be using a dry o-ring to seal the etching chamber. The currently used etching chamber and o-ring seal on the Xetch machine is provided below in Figure 3.

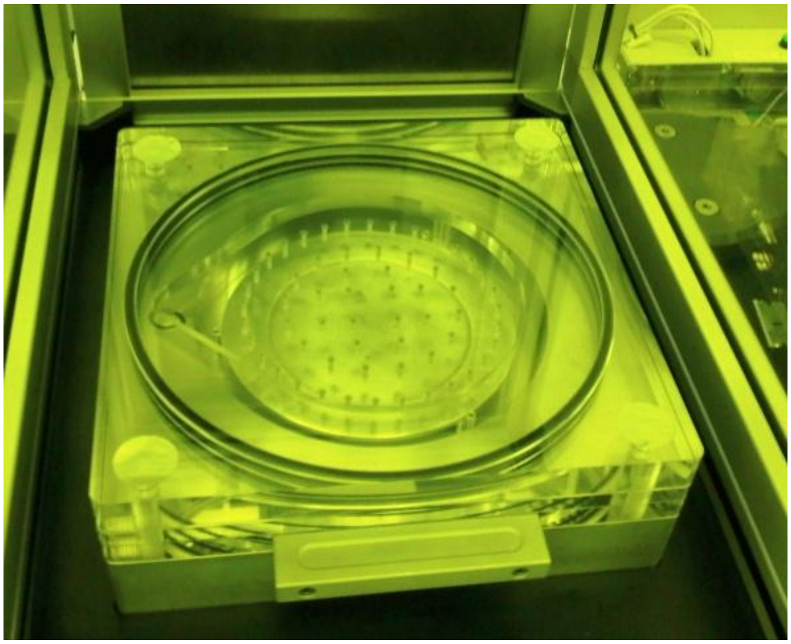


Figure 3: Etching chamber of Xetch machine

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

After receiving our project description and meeting with our sponsor, Professor Chronis, we established a list of customer requirements and engineering specifications to meet these requirements. A Quality Function Deployment (QFD) chart was then created in order to decide which of these requirements and specifications are most important. Furthermore, benchmarks were used to determine the importance of each requirement.

Customer Requirements
The customer requirements for the product we are designing were established by what our sponsor requested. After meeting with our sponsor, it was determined that our etching machine needed to be/have:

1. Well-controlled valves
2. Desktop size
3. LabVIEW compatible
4. Uniform dispersion
5. Viewing window
6. Maximal etching speed
7. Safe disposal of reaction wastes via hose/tube
8. Minimal leakage
9. Accepts standard wafer sizes

Out of these requirements, having well-controlled valves, uniform dispersion, and a combination of safely disposing the reaction waste and minimal leakage were the most important. Without well-controlled valves, the user will not be able to correctly etch any sort of design on a silicon wafer. Also, the Xenon difluoride (XeF_2) must be evenly dispersed onto the silicon wafer in order to have an even etch depth. Lastly, the safety of the user is the most important. Any leakage of XeF_2 may cause it to react with the moisture of the air, causing the formation of hydrofluoric acid (HF). Any exposure with HF is hazardous and deadly. Therefore, minimizing leakages and having a safe disposal system is crucial.

Engineering Specifications

From our list of customer requirements, engineering specifications were produced to give each requirement a specific quantity. From this process, we were able to produce a list of engineering specifications that our design must satisfy:

1. Reaches a steady-state condition within 1 minute
2. Maintains a vacuum pressure of 10^{-4} Pascal
3. Contained within 1 x 1 x 1 meter cube
4. Costs less than $800
5. Reaches required pressure within 2 minutes
6. Works properly at room temperature (15º-30º C)
7. Leaks less than 0.01%
8. Securely handle a 4 inch diameter wafer

Benchmarking

We evaluated two benchmarks: the Xetch e1 and X3 systems. From each system's manufacturer's specifications, we assigned values to evaluate if they met the aforementioned customer requirements. The e1 system was determined to meet all of the customer requirements except the extraordinary cost of the system. Our design should meet or exceed all of these requirements as well and be significantly lower in cost.

QFD Chart Organization

After determining the customer requirements and engineering specifications for our etching machine, a QFD chart, located in Appendix D, was developed. The customer requirements were listed on the left side of the chart while the engineering specifications were listed on the top of the chart. Each customer requirement was weighted based on importance with a value between 1 through 10. In the center of the chart, the strength of relationship between each requirement and specification was determined with scores of 1 (weak), 3, or 9 (strong). At the very top of the chart (the "roof"), the correlation between each engineering specification is evaluated. Also, it was established whether each engineering specification is needed to be maximized, minimized, or set as a target. Our design and benchmarks were then scored from 1-5 on how well they satisfied each of the customer requirements. At the bottom of the QFD chart, the target or limit values and difficulty of each engineering specification were determined. From all the values inputted into this table, the maximum relationship values, weight/importance, and relative weight of each specification were calculated.

CONCEPT GENERATION

In order to produce a wide variety of potential designs for the economical silicon etching machine, our team first divided the machine into seven primary functions. Then two brainstorming sessions were held. The first focused on the generation of numerous ideas without regard to design/concept evaluation. The second session focused on narrowing these ideas and combining them into six complete designs.

The functions that were chosen for our system are as follows:

1. Etch Silicon
2. Evenly Disperse Etching Fluid
3. Enclose System
4. Create Vacuum
5. Control Moisture Level
6. Load Wafer
7. Control/Monitor Leakage

Function 1: Etch Silicon

This function is critical to the operational goals of the machine and is the most basic of functions. During the brainstorming sessions, we did not constrain this function by enforcing the use of only chemical etching or the use of only XeF_2. The following concepts are those which the team had chosen after the extensive brainstorming session.

1. Use of any halogen as an etching agent (i.e. Chlorine or Bromine). Since Fluorine is the principle etching agent in the current system, as mentioned in the background section, we hypothesized that the use of a pure halogen may be equally as effective. If successful, it would also be more efficient on an etching potential versus etching fluid mass basis.
2. Use of lasers. In this concept, a tactile mirrored surface would be vertically positioned over the wafer and a laser(s) would shine onto the surface. The array of mirrors would be programmable in order to achieve the desired etched pattern.
3. Use of current etching fluid, XeF_2. To maintain a realistic design concept, the original system etching fluid was included as a concept. Although not listed here, we also discussed the use of different states of the etching fluid, for example, Xenon Difluoride as a saturated liquid.

Function 2: Evenly Disperse Etching Fluid

This function is critical to customer requirements. It is very important for MEMS applications that the quality and evenness of the etching process be very high. All relevant sketches and drawings are presented in Appendix I.

1. Diffuser: In this concept an array of mini-diffusers will be positioned between the etching surface and the inlet of the working fluid. The fluid will pass through the narrow end of the diffuser and exit through the larger portion thus scattering the fluid. The specific positioning of the diffusers will allow for an even dispersion of working gas onto the etch surface.
2. Multiple inlets: In this concept, the working gas will be passed through several inlets which are all parallel to the etching surface and positioned circumferentially around the etching chamber. This will allow the working fluid to enter from all directions, thus eliminating the time delay associated with allowing the fluid to enter from only one side of the chamber.
3. Fan: This concept uses the idea that the introduction of turbulent flow will result in a more even dispersion of the working gas. In this concept, the fan would be positioned vertically above the etching surface, and the working fluid would enter from the chamber side wall near the fan blades.
4. Diffuser and mesh: This concept simply combines the first concept of a diffuser array with the addition of a mesh in order to more evenly disperse fluid. In this concept, the gas would first pass through the mesh to break it from a streamline flow. It would then pass through the diffusers as described above.
5. Tactile mirrored surface: This concept is paired with the laser concept from function 1 and was described previously.

Function 3: Enclose System

This function is important for safety as well as usability reasons. If the mechanism is not properly enclosed, then it would be much more difficult to detect any leaks which would lead to highly dangerous situations (as described previously). All relevant sketches and drawings are presented in Appendix I.

1. Plexiglas: In this concept the user will be able to have full view of the etching process while it is in operation. In addition, the system will be fully enclosed and capable of directing unwanted waste chemicals to a nearby fume hood. In this concept, Plexiglas will be joined with metal elbows and covered with a gasket material to prevent leakage.
2. Microwave casing: This concept arose from the access the team was given to an old microwave. It already has an enclosure as well as a window with a door. This would allow for easy access and viewing of the etching process as well as the enclosure and ventilation of any dangerous gases which may be formed.
3. Riveted sheet metal: This concept is similar to the Plexiglas concept however the containment of the internal workings of the mechanism will be composed of pieces of sheet metal which are joined by rivets. There will additionally be a gasket material added over the joints to prevent any leakage.
4. None: This concept would expose all components of the mechanism with the assumption that the entire operation would take place under the safety of a fume hood. All the components would be attached to a rigid plate underneath.

Function 4: Create Vacuum

This function is critical to mechanism efficiency and safety. If the etching chamber does not maintain proper vacuum pressure, the concentration of etching fluid will be lower resulting in lower etching efficiencies. Additionally, if the chamber is not properly evacuated, moisture may be present in the system which will result in the formation of hydrofluoric acid (as mentioned previously).

1. Single Pump: This concept was conceived to mimic the current design. Our sponsor can also provide us with an adequate vacuum pump.
2. Cryogenic ion pump: This type of pump is ideal for creating high vacuum levels (very low pressure), however it is very large and expensive.
3. Multiple pumps: This concept was generated to achieve the vacuum more quickly.

Function 5: Control Moisture Level

The control of moisture level is a very important safety function of the device. If moisture enters either the vacuum or expansion chambers then the formation of the highly toxic hydrofluoric acid will form. This presents a safety and health risk to the user and must be prevented.

1. Hydrometer: This sensor will be placed within the expansion and etching chambers in order to detect the presence of water vapor. If there is vapor present, the system will continue to purge until it has been evacuated (as determined by the sensor readout) and then proceed to the next step in the process.
2. Heat wafer: This concept involves heating the silicon wafer to a temperature which would cause any liquid water on the wafer to vaporize. Then the vapors released would be evacuated by an inert gas.
3. Purge with inert gas: This is the current method of moisture and byproduct removal.

Function 6: Load Wafer

This function will affect the usability and efficiency of the machine. The goal is to create a loading mechanism which is easy and safe for the user as well as maximizes efficiency of the etching process, especially when multiple etched wafers are to be manufactured. All relevant sketches and drawings are presented in Appendix I.

1. Mechanical arm: This concept involves using a mechatronic device to lift the upper portion of the etching chamber during wafer loading and then seal the two pieces again once the user has loaded the wafer. This would maintain consistency of the seal to prevent leakage from the etching chamber during operation.
2. Cartridge/Magazine: This concept features a cylinder which holds multiple wafers at one time. The wafers are progressed in the cartridge by a spring loaded back stop. The opening in the etching chamber has a seal and mechanical stops around the perimeter in order to prevent the working fluid from reaching the remaining wafers in the cylinder.
3. Tray loader: This concept uses the technology used in a compact disk drive in a laptop or computer. The user presses a button which ejects a tray with a slot into which the user may place a wafer. The button is then pressed again and the tray will be sealed within the etching chamber again.
4. Clamp with hinge and airtight seal: This design features a hinging upper portion to the etching chamber such that the user may unlock the clamps and then lift the top of the chamber in order to load the wafer. The top is then replaced and the clamps are locked. A seal would be present between the two halves of the chamber in order to maintain a seal between the two portions while the clamps are locked.

Function 7: Control Leakage

This function is critical to the safety of the user and those working around the operation of the machine. If any of the working fluid, XeF_2 were to escape, the formation of hydrofluoric acid could occur due to the water vapor naturally present in the air.

1. PH sensor: This concept would place a PH sensor just outside the mechanism casing. If a leak were to occur, hydrofluoric acid would be produced thus creating an acid environment just outside the machine. If the sensor detects a rise in the ambient PH, the process will stop and all fluids will be evacuated to the fume hood immediately. The user will also be notified.
2. Inject dye: This concept involves coloring the working fluid with a dye as it enters the expansion chamber. Then photovoltaic sensors located on the outside of the system will detect if any of the dyed gas escapes. As with concept 1, if any leak is detected, the system will turn off and immediately evacuate all chambers to the fume hood.

CONCEPT EVALUATION AND SELECTION

Evaluation

In this section, we will evaluate each design concept separately by function. We felt this was most relevant as we are focusing on improving several components of the system and not on redesigning the entire system. The concepts that show the best performance for each function will then be combined into the final system design.

Function 1: Etch Silicon

From our design concepts, we considered several methods of etching the silicon wafer: use of another halogen gas, use of lasers, and use of the current etching gas Xenon Diflouride (XeF_2).

The use of a different halogen that reacts with silicon could potentially be cheaper than the XeF_2, however, since there are time and monetary constraints the cost of researching and developing another halogen gas as a new etching fluid would be too expensive.

Lasers would eliminate the need for tanks and a valve system. However, the systems they would eliminate would not make up for their own complexities. One of these added complications would include manufacturing a highly complicated tactile mirrored surface. This would entail using hundreds of micro actuators to control the respective mirror array. In addition, the controls involved in coordinating the mirrors to achieve a desired etch pattern would be highly sophisticated and temporally taxing.

The current etching gas is already an established technology that is known to have successful results. It is available for purchase and is already accepted in industry and academic sectors alike. However, this gas is known to be dangerous, especially when in contact with water vapor, like those present naturally in the atmosphere.

Below, Table 1 p. 12, is a Pugh chart comparing each concept to the customer requirements and weightings used in the QFD. From this technique, it is clear that the security offered in the XeF_2 will outweigh the potential, yet unknown benefits of the other two concepts.

Customer Requirements	**Weighting**	**Halogen**	**Laser**	**Xenon Difluoride**
well-controlled valves	*9*	1	0	1
desktop size	*8*	0	0	0
uniform dispersion	*9*	0	0	0
viewing window	*1*	1	1	1
maximal etching speed	*4*	0	0	0
safe disposal of waste products	*10*	0	0	0
minimal leakage	*9*	0	0	0
standard wafer size	*9*	0	0	0
low cost	*10*	-1	-1	0
TOTAL		**8**	**-1**	**18**

Table 1: Pugh chart of function 1, etch silicon

Function 2: Even Dispersion of Gas

The concepts developed for the even dispersion of gas include: a diffuser array, a fan, tactile mirror (for use with lasers), mesh, and multiple inlets.

A diffuser array would allow the gas to be expanded in an array which would evenly distribute the gas over the wafer. This design differs from the current diffusion plate in that it features conical holes (with a narrow diameter flow inlet and a large diameter flow outlet) in comparison to cylindrical holes. This will present a slight manufacturing level of difficulty.

The fan would be used to disperse the gas as it flows in from a direct line. This would be simple in that there would be little manufacturing involved in the actual fan as it would likely be purchased. The difficulty with this concept would be the electrical input leads needed to control the fan. Since the fan will need to be operational in vacuum, we would need to incorporate air tight electrical connections.

The tactile mirror, as mentioned in the previous section, would allow the system to be small (since it would not require tanks and valves), however the implementation of this type of technology would be involved in regard to mechanical fabrication as well as control implementation.

The mesh would be inexpensive to incorporate into the design. However, we have not tested this and we do not know how effective (or ineffective) it would be in practice.

Multiple inlets would be used in conjunction with a diffusion plate in attempt to eliminate some of the transient causes of unevenness associated with having only one inlet. This would require more manufacturing time; however, this would not be beyond the scope of our machining capabilities.

The Pugh chart below, Table 2, outlines the strengths and weaknesses of each concept as compared to the customer requirements previously outlined. The selected concept for fabrication is the diffuser array.

Customer Requirements	**Weighting**	**Diffuser**	**Fan**	**Mirror**	**Mesh**	**Multiple Inlets**
well-controlled valves	*9*	0	0	0	0	0
desktop size	*8*	0	0	0	0	0
uniform dispersion	*9*	1	-1	1	0	1
viewing window	*1*	0	0	0	0	0
maximal etching speed	*4*	1	-1	1	0	1
safe disposal of waste products	*10*	0	0	0	0	0
minimal leakage	*9*	0	-1	0	0	0
standard wafer size	*9*	0	0	0	0	0
low cost	*10*	1	-1	0	1	-1
TOTAL		**23**	**-28**	**13**	**10**	**3**

Table 2: Pugh chart of function 2, even dispersion of gas

Function 3: Enclose System

The concepts developed to enclose the system are: Plexiglas, microwave casing, riveted sheet metal, and no enclosure.

The Plexiglas enclosure would allow for a high amount of user visibility during the etching process; however it is an expensive material.

The microwave casing from a broken microwave is large enough to accommodate the tanks and valve system and it also has a door with a viewing window already built in. The microwave will need to be modified slightly to incorporate a vent to the fume hood. This will present minimal manufacturing challenges.

Riveted sheet metal will offer a similar structure to the microwave casing; however it will require additional costs and manufacturing time.

No enclosure assumes that the device will be operated in a fume hood at all times. While this may help to evacuate any leaks, it offers no primary protection to the user against highly caustic and toxic fumes which may be produced if the device malfunctions.
The Pugh chart below, Table 3, outlines the strengths and weaknesses of our concepts as compared to the customer requirements given previously.

Customer Requirements	**Weighting**	**Plexiglas**	**Microwave**	**Riveted Metal**	**None**
well-controlled valves	*9*	0	0	0	0
desktop size	*8*	1	1	1	1
uniform dispersion	*9*	0	0	0	0
viewing window	*1*	1	1	-1	1
maximal etching speed	*4*	0	0	0	0
safe disposal of waste products	*10*	0	1	0	0
minimal leakage	*9*	1	1	1	-1
standard wafer size	*9*	0	0	0	0
low cost	*10*	-1	1	-1	1
TOTAL		**8**	**38**	**-2**	**10**

Table 3: Pugh chart of function 3, enclose system

Function 4: Create Vacuum
The functions developed for creating a vacuum in the etching chamber are as follows: single pump, cryogenic ion pump, and multiple pumps.

The use of a single pump will minimize both cost and size, which are two primary customer requirements. The single pump may increase etching time and efficiency by a small amount.
The use of a cryogenic ion pump, while increasing etching time and efficiency, will add a significant amount to the cost and size. The use of multiple pumps will result in similar benefits as well as disadvantages.

The Pugh chart, Table 4 p. 15, outlining the strengths and weakness of our concepts is given below.

Customer Requirements	Weighting	Single Pump	Cryogenic Ion Pump	Multiple Pumps
well-controlled valves	*9*	0	0	0
desktop size	*8*	1	-1	-1
uniform dispersion	*9*	0	1	1
viewing window	*1*	0	0	0
maximal etching speed	*4*	1	1	1
safe disposal of waste products	*10*	0	0	0
minimal leakage	*9*	0	1	1
standard wafer size	*9*	0	0	0
low cost	*10*	1	-1	-1
TOTAL		**22**	**4**	**4**

Table 4: Pugh chart of function 4, create vacuum

Function 5: Control Moisture Level

The concepts generated for controlling moisture level in the system are: using a hydrometer, heating the wafer, and purging with an inert gas.

A hydrometer will monitor the relative humidity within the enclosure and thus a control sequence could be implemented in which the system would be purged of its contents until the hydrometer read a negligible amount at which point the cycle would proceed. The addition of the hydrometer will add another amount of complexity to the control scheme as well as increase cost.

Heating the wafer will only change the state of water which may exist on the wafer from liquid to vapor which does not address the problem. In addition, it will add an unnecessary amount of complexity and cost to the system.

Purging the system with an inert gas will remove all contents within the tank, thus eliminating any water vapor present, assuming that the source tanks have not been contaminated.

The hydrometer and purging with an inert gas both scored highly and both will be incorporated into the final design. The hydrometer will be used as an output for the user to verify that no harmful fumes are being produced and the inert gas will be incorporated into the system and controls.

The Pugh chart below, Table 5 p. 16, compares our concepts with the customer requirements

Customer Requirements	Weighting	Hydrometer	Heat Wafer	Purge with Inert Gas
well-controlled valves	*9*	0	0	0
desktop size	*8*	0	0	0
uniform dispersion	*9*	1	1	1
viewing window	*1*	0	0	0
maximal etching speed	*4*	1	1	1
safe disposal of waste products	*10*	0	0	0
minimal leakage	*9*	0	0	0
standard wafer size	*9*	0	0	0
low cost	*10*	1	-1	1
TOTAL		**23**	**3**	**23**

Table 5: Pugh chart of function 5, control moisture level

Function 6: Load Wafer

The concepts generated for loading the wafer are as follows: mechanical arm, cartridge, tray loader, and a clamp, hinge and seal system.

The mechanical arm will maintain a consistent and uniform seal with each exchange of wafer, by virtue of the design. However, this design would introduce a great deal of unnecessary cost and complexity.

The cartridge concept would allow for multiple wafers to be loaded into the system at once. This would increase the efficiency of the process; however, it would also introduce a greater amount of complexity as well as would require additional space in the design.

The tray loader would also provide an efficient loading method, however the method by which the seal would be implemented would be difficult and complicated. Additionally, incorporating any kind of motor to drive the tray in and out of the etch position would add cost and complexity.

The clamp, hinge, and seal concept is simple and robust. It will allow the user to change wafers one at a time and will be easily sealed after switching wafers from the chamber. In comparison, it is inexpensive and simple from a manufacturing standpoint.

The Pugh chart below, Table 6 p.16, shows a comparison of these concepts with our customer requirements. The clamp, hinge, and seal concept will be implemented in our alpha design for its simple, robust, and cost-effective aspects.

Customer Requirements	**Weighting**	**Mechanical Arm**	**Cartridge**	**Tray Loader**	**Clamp, Hinge, Seal**
well-controlled valves	*9*	0	0	0	0
desktop size	*8*	0	0	0	0
uniform dispersion	*9*	0	0	-1	1
viewing window	*1*	0	0	0	0
maximal etching speed	*4*	0	0	-1	1
safe disposal of waste products	*10*	0	0	0	0
minimal leakage	*9*	-1	0	-1	1
standard wafer size	*9*	-1	-1	1	1
low cost	*10*	-1	-1	1	1
TOTAL		**-10**	**-1**	**-3**	**41**

Table 6: Pugh chart of function 6, load wafer

Function 7: Control Leakage

The concepts for addressing the risk of system leakage are injected dye and PH sensor. If the etching gas comes in contact with water, hydrofluoric acid will form.

The dye would allow the user to visually determine if the system is leaking. However it may be cumbersome to inject the dye after expanding the XeF_2.

The PH sensor would allow the user to detect any hydrofluoric acid present in the system. It may introduce an additional expense; however safety is paramount to the effective usage of the equipment so additional costs would be appropriate. The Pugh chart below, Table 7, determined that the PH sensor was the most effective option for our system.

Customer Requirements	**Weighting**	**Injected Dye**	**PH Sensor**
well-controlled valves	*9*	0	0
desktop size	*8*	0	0
uniform dispersion	*9*	0	0
viewing window	*1*	0	0
maximal etching speed	*4*	1	1
safe disposal of waste products	*10*	0	0
minimal leakage	*9*	0	1
standard wafer size	*9*	0	0
low cost	*10*	1	1
TOTAL		**16**	**25**

Table 7: Pugh chart of function 7, control leakage

CONCEPT SELECTED: ALPHA DESIGN

To select the best design concept, a Pugh chart was used to compare each concept across each function and determine which concept best met the specific criteria outlined in the customer and engineering requirements. The following sections will detail which concept excelled in each function and why. In the Pugh chart, a (+1) was given if the criterion could be satisfied effortlessly, a (0) was given if the criterion may or may not be satisfied, and a (-1) was given if the criterion could not be satisfied easily. See Appendix J for CAD model images of selected concept.

Etching Gas/Mechanism

To match the current system, the desired final design uses the bottled XeF_2 to etch the silicon wafer and bottled N_2 to purge the system. The current Xetch system uses a small internal tank of XeF_2 and our design will incorporate similar sized bottle and connection to the valve system.

Gas Dispersion

We determined that some of the different dispersion mechanisms could be easily combined and used together. The Pugh chart for the gas dispersion function determined that in the final design, a diffuser and multiple inlets would be used together in orders to create more uniform flow through the holes and over the silicon wafer. The multiple inlets of XeF2 into the etching chamber will also create more uniform gas flow above the nozzle and avoid dead zones in the etching pattern.

System Enclosure

The microwave was kept as a definite possibility since it has a sealing door and ventilation system already installed. It also has a nice array of buttons and place for LCD screen to allow for user input directly on the machine (instead of using an external computer). The structure is very similar to the riveted sheet metal enclosure and is already in our possession, so both were kept as strong possibilities.

Vacuum Formation

After discussing with an Xetch technical representative and reviewing the machine's manual [5], multiple pumps was not chosen since the current pump is more than strong enough and adding an additional pump will only further complicate the complex valve timing and flow control system. Lastly, to stay within the cost reduction of the current system, a cryogenic system was not further explored along with an expensive ion pump (capable of 10^{-7} Pa vacuum pressure [1]). The Pugh chart for the vacuum function reflects these considerations.

Well Controlled Valves

In all concepts except for the laser design, each system used an etching fluid with the flow controlled by a series of gate valves. In the current Xetch system, the valves are operated by compressed air which was decided early on to be substituted for electronically controlled valves by the customer. Our selection for electronically controlled valves was limited to a couple types of valves: solenoid poppet, bonnet sealed and diaphragm sealed. Although the specific valve selection is still underway, each design was assumed to have the same type since each can operate at the same pressures and flow rates.

Moisture Control

Since the XeF2 etching fluid produces highly dangerous HF acid when in contact with water (even vapor in atmosphere), H_2O management is especially important in the final design. The current system uses a thermal management system for the expansion chambers and thorough N_2 purge between loading and unloading the wafer. A similar dry, high purity N_2 purge system and cycle will be used in the final design. In addition, a hydrometer mounted to the outside enclosure will monitor the humidity of the ambient air to alarm if the enclosure is an unsafe humid environment (no AC or dehumidified Lab environment).

Wafer Loading Mechanism

Minimal leakage is a two-fold important customer requirement since it limits the risk of HF exposure and improves the etching speed and quality. To meet this requirement, a simple hinged and latched o-ring seal was chosen similar to the current etching chamber used in the Xetch machine. Pins will also hold the wafer above the vacuum and have milled notches that form the perimeter of the standard 4” wafer.

System Leakage

As mentioned previously, minimal leakage is highly important. Since HF is the primary product to minimize and safely ventilate, a PH sensor will also be installed into the enclosure around the etching chamber. This was chosen over the injected dye method since it can actively monitor this PH level and record large spikes over time.

Initial Project Plan

Our goal for this project is to construct an economical, isotropic silicon etching machine by the Design Expo on April 15th, 2010. The most critical challenge for this project will be designing a gas flow system than can be fully controlled via LabVIEW software and is contained within the $800 system budget. This initial alpha design phase should be completed before the second design review (DR2) on February 18th, 2010. From feedback in DR2 and further progress on the LabVIEW interface and electrical schematic, this alpha design will be reviewed and modified where necessary to produce a final design before DR3 on March 18th, 2010. This final design selection will then be fabricated and assembled to produce an alpha prototype before DR4 on April 1st, 2010. This alpha prototype will then be tested and evaluated based on the previously stated customer requirements in time for the University of Michigan Design Expo on April 15th. A more detailed project plan including specifics from the problem analysis below can be found in the Gantt chart, attached in Appendix E.

Detail Project Plan (DR3 to Expo)

The project plan has been slightly modified since DR2 and is stated below (time considered: DR3 to Design Expo, April 15 2010).

In the following week (DR4 progress report), the previously stated components will be ordered and shipped. The McMaster parts should arrive within the week if 2-3 day shipping is selected. During this shipping period, the LabVIEW program can be further improved and then DAQ/electrical layout can be started. The microwave enclosure is well stripped and cleaned, but the other panels can be sanded and prepped for paint. Holes for the fume hood vent and XeF2 access port (tentative) can be drilled as well the top panel. Lastly, the entire enclosure inner cavity can be cleaned. When the raw chamber materials are received, fabrication of the chamber will start.

The fabrication of the chamber will closely follow the previously mentioned fabrication plan. If everything goes according to plan and depending on availability of the water jet or laser cutting machine, this can be completed in 3-4 days and final assembly can start. If the solenoid and other flow components arrive during this fabrication process, they can be arranged in the enclosure and the tubing can be cut to length between the valves. The Swagelok fittings will only be clamped tight and sealed once all components are in place, but the tubing can sit loose in the valves and fittings till then. Lastly, the valves can be connected to the electrical layout and the DAQ.

After assembly and before the design expo, three main quality tests will be performed to evaluate our prototype: (1) burst/crush/leak test (pressurize chamber/lines) (2) working fluid distribution test (oxidation of plate), and (3) LabVIEW software validation (flow control and valve timing). If the valves do not open/close at the correct time, the pressure in each chamber will not be correct and the silicon etching process will not complete. This timing along with volume and pressure measurements of the expansion chamber will also be measured to determine recommended etching times for a certain depth. The uniformity of the gas dispersion will also be evaluated using the oxidation of the plate to determine if the gas flows over the wafer.

FINAL CONCEPT DESCRIPTION

The design of the prototype is very similar to the final concept design. It will consist of all the main components in the final design except for the knife valve and an extra gasket. A diagram of the etching chamber is shown in Figure 4. The etching chamber will now only consist of one enclosed volume instead of two. The input gas will not expand to a specified pressure before the etching process in our prototype. This prototype design will also test one question that was brought up early in the design phase: “Is the expansion chamber necessary?” With this method, the XeF_2 will naturally diffuse from the chamber inlet over the silicon wafer. The XeF_2 flow will be shut off when the chamber pressure reaches the expansion pressure under normal operation (a more detailed testing method will be discussed in a later section). The removal of the knife valve will also affect the LabVIEW program that is controlling the system. Two smaller changes to the system consist of the clamping system on the top lid and the XeF_2. Instead of using a clamp and pins, there will be bolts used instead. The chamber will be constructed so a hinge and clamp could be added at a later date if desired. Also, there will be no XeF_2 container in the system enclosure; instead the system will run with an inert gas inlet.

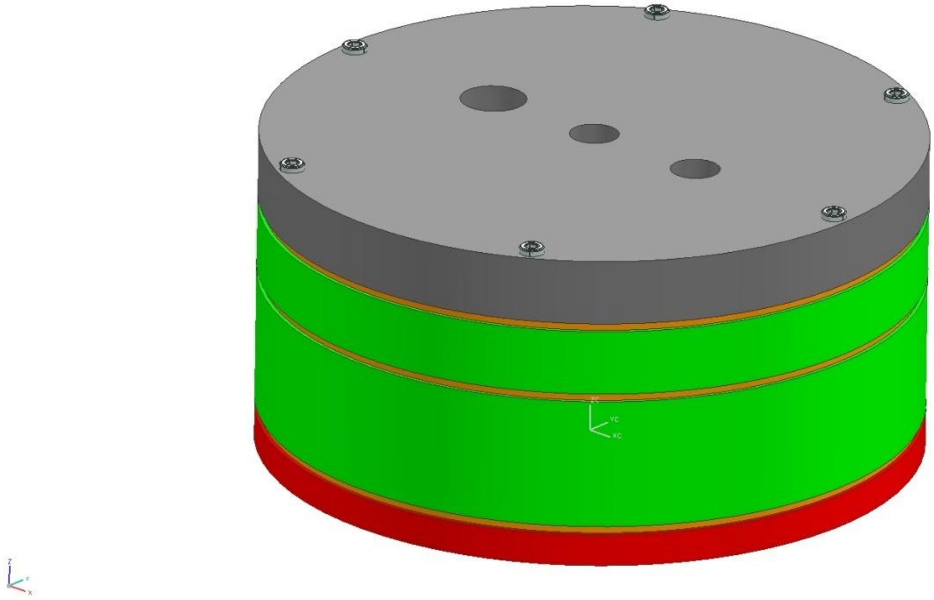


Figure 4: 3D model of prototype etching chamber

Removing the knife valve will not greatly affect the feasibility of our design during testing. Without the knife valve, it is not possible to test if the valve will keep the lower segment of the chamber in vacuum while the upper chamber is expanding the entering gas. However, it is possible to test if the chamber can maintain a vacuum pressure and expand the gas to the correct pressure during the process. Changing the clamping system will not affect testing, and XeF_2 will not be used during testing.

The reason that the knife valve is being removed in the prototype is because of cost and limited availability. The total cost of the entire design is $875.60 + shipping. However, the initial price quote of the knife valve, $674.41, may be questionable due to the size of the actuator needed to run it. Other domestic vendors that supply similar or smaller valves cost $2000-$3000. Therefore, the cost of the valve alone will be greater than the rest of the components combined. It would be reasonable to test out the entire system without the knife valve because if our experiments indicate that the knife valve is not needed, money will be saved.

ENGINEERING PARAMETER ANALYSIS

This section details the methods used to determine the appropriate material fracture toughness, K_{ic}, and the thickness, *t*, for the etching chamber in order to prevent break and crush. We explored three materials: aluminum, polycarbonate, and polymethyl methacrylate (acrylic). A safety factor of 4 was used throughout all calculations. The material properties were taken from the CES Edu Pack software and are listed below in Table 8. [6] For our system, we require the minimum thickness, *t*, to be less than or equal to 0.25 in.

Property	Units	Aluminum	Polycarbonate	Polymethyl Methacrylate
Young's Modulus, E	psi	9.86×10^6	0.29×10^6	0.325×10^6
Yield Stress, σ_{ys}	ksi	4.35	8.56	7.8
Fracture Toughness, K_{IC}	ksi $\text{in}^{1/2}$	20	1.91	0.637
Poisson's Ratio, v	--------	0.32	0.391	0.384

Table 8: Materials considered for fabrication and their respective properties

Leak-Before-Break Criterion

In choosing an appropriate material to manufacture the etching chamber from, it is important that the structure will first leak before it breaks. This is to reduce the severity of the failure and allow time for the user to detect the problem and correct it accordingly. Using Eq. 1 [7] below, we calculated the fracture toughness, K_C, for each material. From Eq. 2 [7] we calculated the stress intensity factor for the materials and by Eq. X3 [7] determined if they would leak first before breaking. In the calculation, *B*, the crack length, was taken to be the thickness of the material we are using (0.25 in.).

$$K_c = K_{IC}\sqrt{1+\frac{7}{5B^2}\left(\frac{K_{IC}}{\sigma_{ys}}\right)^4} \qquad \text{Eq. 1}$$

$$K_I = \frac{2}{\pi}\sigma\sqrt{\pi a} \qquad \text{Eq. 2}$$

The chamber will not leak if: $K_I < K_C$ Eq. 3

The results of these calculations are recorded below in Table 9.

	Units	Aluminum	Polycarbonate	Polymethyl Methacrylate
K_c	ksi $in^{1/2}$	2001.1	1.96	0.637
K_I	ksi $in^{1/2}$	331.7	331.7	331.7
Meets K_I<K_c	ksi $in^{1/2}$	yes	no	no

Table 9: Results from Leak-Before-Break analysis

Cyclic Fatigue Analysis

Our sponsor, Professor Chronis, specified that the silicon etching machine should operate for three years, etching an average of three etchings per work day (assumed 5 days per week). Thus, the system must undergo 2340 cycles. An S-N curve (log(N) vs maximum stress) for each material was used in conjunction the specified number of cycles to determine the stress that will cause failure after N specified cycles. The values of stress for Aluminum and Polycarbonate are tabulated in Table 10, and the S-N curves can be found in Appendix S. If the hoop stress (with a safety factor of 4) is less than the failure stress, the material will not fail under fatigue. The hoop stress was calculated using Eq. 4, where *P* is the pressure, *r* is the internal radius, and *t* is the thickness.

$$\sigma = \frac{Pr}{2t} \qquad \text{Eq. 4}$$

	Units	Aluminum	Polycarbonate
S-N stress	MPa	400	37.9
Hoop Stress	MPa	1.82	1.82
Meets Hoop Stress<S-N stress	ksi $in^{1/2}$	yes	yes

Table 10: Results from Cyclic Fatigue Analysis

Crush Analysis

We also determined the minimum wall thickness, *t*, of the etching chamber to ensure that the structure would not crush under a vacuum pressure of 1.45×10^{-8} psi. Using Eq. 5 [8] we calculated the minimum wall thickness of the chamber for each material, where *OD* is the outer diameter (5 in.), *E* is Young's Modulus, *P* is the pressure difference (100 psi), and *v* is Poisson's ratio. The results of these calculations are listed below in Table 11.

$$t = OD\left[P\left(\frac{1-v^2}{2E}\right)\right]^{1/3} \qquad \text{Eq. 5}$$

	Units	Aluminum	Polycarbonate	Polymethyl Methacrylate
Min. Thickness, *t*	inches	0.069	0.003	0.221

Table 11: Results for minimum wall thickness for crush analysis

Engineering Decisions
The results of our calculations show that while all three materials fall within our desired wall thickness of 0.25 inches, only the aluminum meets the leak-before-break criterion. In addition, both aluminum and polycarbonate satisfy fatigue requirements. After further discussion with our sponsor, Nikos Chronis, we decided to manufacture the base plate from aluminum and the top lid from polymethyl methacrylate (acrylic) to allow for viewing of the wafer during the etching process. We justify using this material for the top lid because only the forces acting upon the lid need to be consider, which are due to the pressure difference. Since the pressure is much smaller than the yield strength of this material ($1.4\text{x}10^{-2}$ kpsi vs. 8.56 ksi) the acrylic can be used for the top portion of the etching chamber.

CFD Analysis
After our initial design selection for DR2, our sponsor mentioned he would like to combine the expansion and etching chamber into one unit to minimize the amount of XeF2 used per cycle since some fluid is left in the lines after expansion. We then proposed three intermediate concept designs for the etching chamber to meet this concern, provided in Appendix L. Each had a different flow path and gas dispersion method. In order to objectively analyze each, a 3D CAD model was created of the fluid contained within each design in order to perform an idealized CFD analysis of each. After these simulation and further discussion with Professor Kurabayashi, it was determined that this analysis would only apply to the purge and possibly evacuation phase of the etching cycle. The etching and expansion portion would be out of the ideal gas regime and would require a more sophisticated Monte Carlo analysis. Eq. 6 below shows this gas mean-free path calculation, which for our conditions is 35.26 m. This is clearly out of the size range for the chamber so the previously performed CFD analyses are not applicable under the extreme vacuum pressure.

$$l = \frac{k_B T}{\sqrt{2}\pi d^2 p} \qquad \text{Eq. 6}$$

From the CFD analysis and mean-free path calculation, it was determined that a dispersion plate with a diffusive hole pattern may not be the best way to disperse the XeF2 gas evenly. Instead, a more immediate gas release method was considered such as a rotation butterfly or shutter valve and a sliding gate or knife valve. Details on each of these valves can be found in the following section.

In Appendix C is the design analysis of the economical etching machine. Three major topics about the final design are discussed:

1. Materials selected from a functional performance aspect
2. Materials selected from a environmental performance aspect
3. Manufacturing process and analysis for real-world production

It is important to keep these three topics in mind. Not only does the final design have to work properly, it must also be designed for low environmental impact, as well as for easy production in relatively large quantities. If the final design fails in one of these analyses, it may be unbeneficial to produce the product, and another design must be developed. Passing all three requirements ensures the probability of developing a successful final product.

FINAL PROTOYPE DESIGN DESCRIPTION

The proof-of-concept design that was produced contains an etching chamber on top of a 3-valve system, which is enclosed in a plastic enclosure. The etching chamber is split into four different pieces. An aluminum cylinder is welded on top of a solid, square aluminum plate. A hole is drilled through the aluminum plate for the evacuation of any gas in the etching chamber. There is a groove that is machined into the rim of the cylinder, for which an O-ring is placed into the groove. On top of this cylinder is another aluminum cylinder with an acrylic plate joined onto it with epoxy. The acrylic plate has three holes drilled into it. The holes are for the humidity sensor, pressure sensor, and the gas inlet tube. The two plates are connected to each other via two hinges, and two latches. Inside the plastic enclosure, there are three valves screwed securely on the enclosure. In order for the Kynar tubing to connect to the valves, each valve has a Swagelok adapter attached to it. Kynar tubing from two of the valves are connected to a pipe tee. The outlet tube from the previous tee and a relief valve are connected to another tee. The outlet from that tee is then connected to the acrylic plate. The tubing from the aluminum plate is then connected to the third valve, which is connected to the vacuum pump. The solenoids from the valves, along with the power switch and emergency stop button, are connected to a DAQ, which is then connected to the laptop which is controlling the system. An image of the final prototype is below in Figure 5 (a) and an electrical diagram in Figure 5 (b).

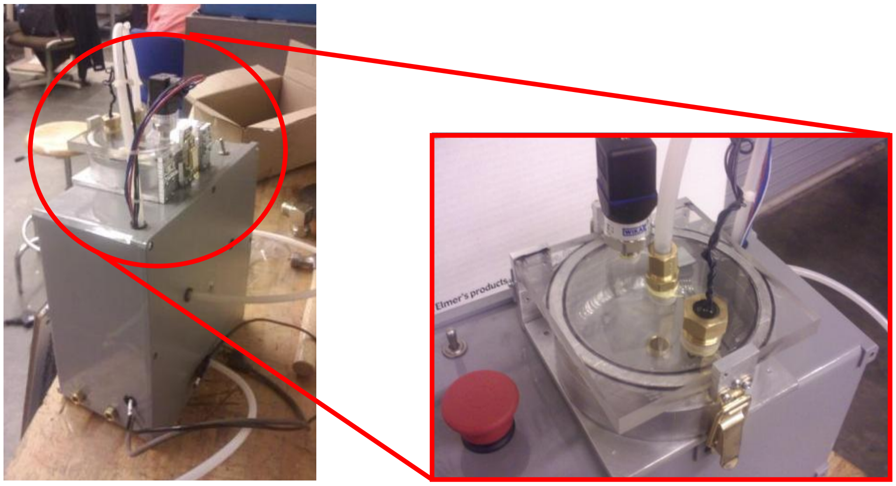


Figure 5: (a) Image of final prototype

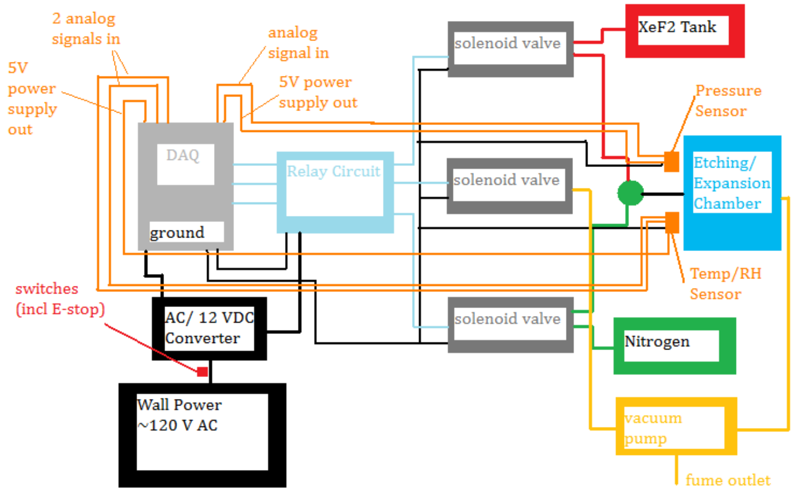


Figure 5: (b) Updated electrical diagram

Execution of Design Prototype

The final design prototype was altered slightly from the Alpha Design; a complete list of engineering change notices is provided in Appendix B. The alterations were due to modified customer requirements as well as compensation for ease of use and ease of assembly. The first change was the use of a clear acrylic material as the top piece of the device, rather than aluminum, as originally planned. This change was initiated by our sponsor's request post-DR3 to have a viewing window to which a microscope could be attached in order to monitor the etching process. Because this change was made, we were unable to weld both the top and bottom plates to their respective cylindrical sections. This was the later source of a leak.

The second major change that was made was the incorporation of a pair of hinges and latches instead of six bolts and two completely separate pieces. This change was made in order to increase the ease of use of the device. If the device were manufactured into two separate pieces, the user would need to loosen and tighten six very thin, very long bolts each time he/she wished to exchange a wafer in the device. In addition to reducing user friendliness, this method would cause increased wear on the bolts which were to be used, likely resulting in early fatigue of the device. Because the design was changed to use hinges and a latch, it also made more sense to incorporate an o-ring seal between the mating faces at the joint. So, instead of using gaskets between each layer, the bottom two pieces of aluminum were welded together and the acrylic top plate and lower cylinder of aluminum were fastened with epoxy resin.

Before validation began, our prototype had one latch in the front of the device and two hinges across the back. During pressurization testing, we became aware of a leak between the mating surfaces. This problem was due to an uneven aluminum surface, which was resolved with sanding the surface smooth, and due to a gap caused by the play in the hinges. In order to resolve the second issue, a second latch was added to the back side of the device, between the two hinges. The implementation of the electrical and controls went as according to plan, no changes were made.

The last change that occurred between the prototype and Alpha design was modification of the enclosure used. In the Alpha design it was proposed that a microwave casing be used to house the electronics as well as the XeF_2 tank and pump. Instead, a much smaller plastic electrical box was used as the enclosure. This change was made in order to incorporate an enclosure which required less modification as well as allocated a more appropriate amount of space for the amount of hardware it was to contain. The enclosure in the prototype allows the user to keep the XeF_2 tank as well as the pump external to the system. This allows for easier regular maintenance of the device (switching out tanks) as well as reduces the size of the device. An outlet line comes out the back of the tank to connect to the Nitrogen supply, albeit a tank or a wall line.

PROTOTYPE FABRICATION PLAN

Please refer to Table 12 on the following page which describes the manufacture process for each part. Following the manufacture plan is a flowchart of a detailed assembly plan. The parts will be manufactured in the order in which their components and materials arrive. We expect to receive materials from McMaster-Carr and local hardware stores first. Thus, the first component to be manufactured will be the expansion/etch chamber. Since we intend on manufacturing the device to accept a knife valve at a later date, we will machine the chamber with some amount of flexibility in order to accommodate for variation in the actual valve received within supplier tolerances. Lastly, to fabricate everything correctly and safely, the additional safety report details components and processes that will require extra attention to detail and special safety considerations.

Part #	Part Description	Starting Material	Process Number	Process Description	Machine Used	Feed/Speed	Safety Measures
1	Base Plate	Aluminum Plate 6"x6"x0.25"	1	Mill plate into 5"x5" square	Mill with .25" end mill	1600 rpm	Normal mill safety
			2	Face surface	Mill with 0.25" end mill	1600 rpm	Normal mill safety
			3	Drill hole	0.375" - 1/32" Drill bit	1000 rpm	Normal mill safety
			4	Tap hole	3/8" NPT	By Hand	Normal tapping safety
			5	Drill pin holes	Drill bit: 0.125"	1000 rpm	Normal mill safety
2	Bottom Side	Aluminum Tubing, OD: 5" ID: 4.5" height: 2"	1	Size to approx 1" height	Band Saw	1600 rpm	Normal band saw safety
			2	Face top and bottom	Mill with 0.25" end mill	1600 rpm	Normal mill safety
3	Base Plate + Bottom Side	Aluminum components	1	Weld parts together (Bob)	TIG Welding	N/A	Normal welding safety
4	Bottom Side	Aluminum Tubing, OD: 5" ID: 4.5" height: 2"	1	Mill O-ring Groove with CNC machine (Marv)	Mill with 1/16" end mill	1600	Normal mill safety
5	Top Side	Aluminum Tubing, OD: 5" ID: 4.5" height: 2"	1	Size to approx .5" height	Band Saw	1600 rpm	Normal band saw safety
			2	Face top and bottom	Mill with 0.25" end mill	1600 rpm	Normal mill safety
6	Top Lid	Acrylic Plate 12"x12"x0.5"	1	Cut plate into rough 5" x 5" square	Band Saw	N/A	Normal band saw safety
			2	Face surface	Mill with 0.25" end mill	800 rpm	Normal mill safety
			3	Drill holes	Drill bits: 0.5" - 1/32", 0.375" - 1/32", 0.25" - 1/32"	600 rpm	Normal mill safety
			4	Tap Holes	0.5" NPT 0.375" NPT 0.25" NPT	By Hand	Normal tapping safety
7	Aluminum Squares for Hinges and Latch	Aluminum, 0.25" thickness	1	Roughly cut 8 1" squares	Band saw	N/A	Normal Band saw safety
			2	Face surfaces	0.25" end mill	1600 rpm	Normal mill safety
			3	Drill holes for hinges/latches	7/64" drill bit	1000 rpm	Normal mill safety
8	Base Plate + Bottom Side	Aluminum component	1	Drill holes for hinges/latches	#43 drill bit	1000 rpm	Normal mill safety
			2	Tap holes	4-40 tap	By Hand	Normal tapping safety
9	Top Lid	Acrylic Plate 12"x12"x0.5"	1	Drill holes for hinges/latches	#43 drill bit	800 rpm	Normal mill safety
			2	Tap holes	4-40 tap	By Hand	Normal tapping safety
10	Plastic Enclosure	Plastic, 16"x12"x6"	1	Drill holes for tubing and mounting	Hand drill with step drill	By Hand	Normal drilling safety

Table 12: Detailed initial manufacturing plan

Chart 1, below, is a flowchart of a detailed assembly plan. Based on FEMA analysis as well as failure analysis, we are confident that the components of our design will not fail before, during, or after assembly (which will take place in the Undergraduate Machine Shop), barring unusual circumstances (such as accidental dropping of parts etc.) All manufacturing will take place in the Undergraduate Machine Shop supervised by Bob Coury on the first floor of the GG Brown building. CAD drawings of all parts to be manufactured are in Appendix J.

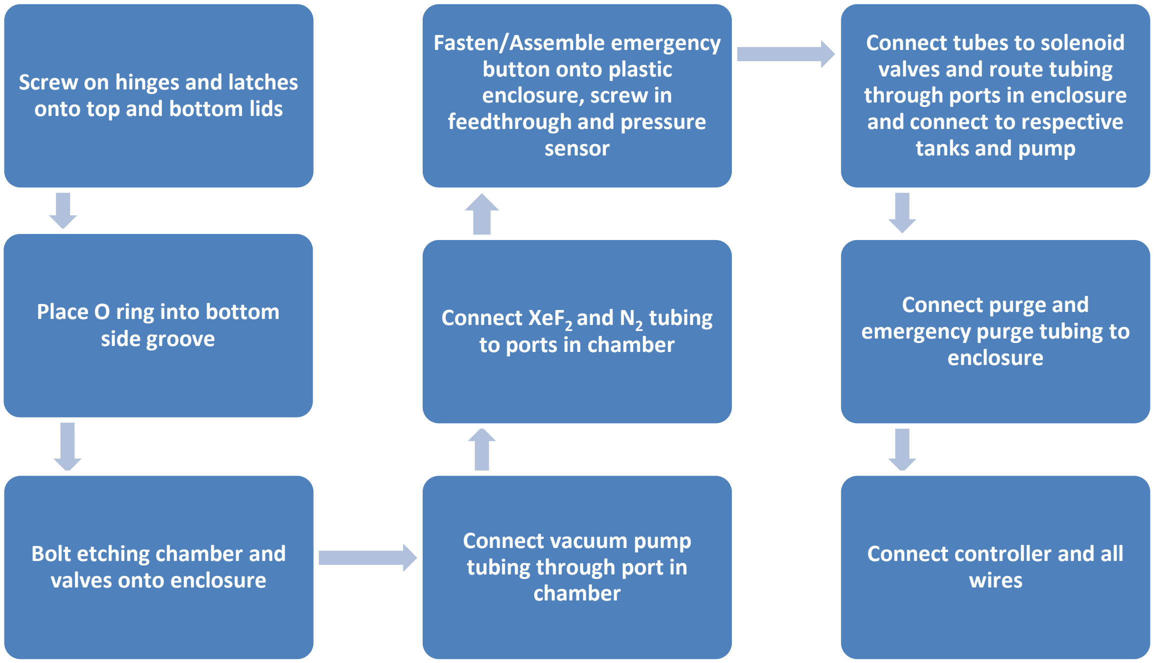


CHART 1: Assembly flow chart

VALIDATION RESULTS

Initial Validation Plan

Our primary concern in relation to device failure risk is any failure which results in leakage of the working fluid into the humid atmospheric air. As previously mentioned, this will readily cause the formation of hydrofluoric acid (HF), which is extremely dangerous and can result in death.

Due to the danger of using XeF_2, all validation testing during the course of this project will be performed with inert gases, such as air. It is expected that further testing may be performed after the completion of this project with real working fluids under the supervision of trained clean room personnel and within a vented fume hood/room. All testing is anticipated to take place in an area equipped with a fume hood. This location has not yet been determined.

Burst/Crush/Leak Test: This test will assess the failure of the etching expansion chamber assembly. A LabVIEW program separate from the actual control program will be written in order to effectively and efficiently perform this test.

The assembled subsystem will be connected to an input gas line (likely air or N_2) and a vent line as well as the vacuum pump to be used as during normal operation. The system will be submerged completely in a tank of water. The system will be cycled between maximal pressure and operational vacuum for 100 cycles. The system will be monitored over this time to assess if any bubbles escape the tank (leakage) or if any mechanical or material failures arise (such as cracks or holes). Also observed will be all joints connecting tubing to the chamber. It is assumed that these junctions are representative of joints connected to valves (as the electric valves cannot be submerged in water without damaging the solenoid).

TO BE NOTED: The use of molecular nitrogen is acceptable to be used in leak test since its molecular size is smaller than that of XeF_2 and thus it would leak more readily.

Working Gas Distribution Test: This test will initially test the validity of eliminating the expansion chamber (use without knife valve). Since the use of the actual working gas is highly dangerous at this stage in the design process, a safe oxidizing agent, such as molecular oxygen, will be used. In this test, a substance of similar shape to a wafer but of a readily oxidizing agent will be inserted into the chamber. The system will run as it would for silicon etching; however, the oxidizing agent will replace the XeF_2. After the cycle has run, the material will be inspected for uniformity of oxidation on the surface of the material. This will be repeated 10 times in order to collect enough data for statistical measurements and conclusions to be drawn.

LabVIEW Software Validation: Early in development (just after sensors arrive in-house), the LabVIEW software will be edited by all team members in an effort to debug the program. After this has been completed, the software will be tested on the assembled mechanism connected to inert gases with no wafer present. The pressure will be monitored and cycles will be timed by the team in order to ensure that the user inputs are executed properly. This process will be repeated 5 times with 5 different time/pressure configurations.

The software will also be tested for safety. For instance, the team will input an unattainable pressure into the interface and ensure that the system responds properly. The emergency stop button and humidity sensor safety features will also be tested to validate the safety protocol on the machine (discussed in detail in the safety report).

Final Performed Validation and Results

In order to validate that our prototype works, we ran a couple different tests on it. Our initial test was to run compressed air into the system to check if there were any leaks and if all the electrical components were working properly. The valves that were connected to the air source and to the vacuum pump were open, while the third valve was closed.

The second test checked if the etching chamber could withstand and hold a vacuum pressure. The pressure inside the etching chamber while the vacuum was running was measured. Also, the time it took for air to leak back into the etching chamber while the vacuum was off and valves were shut was measured. From the results of these two tests, it was concluded that the prototype is not completely sealed at the top etching chamber between the acrylic top and the aluminum cylinder. This problem can be solved by combining these two pieces into one part and fabricating the entire top part from one large block of acrylic, which is discussed later in this report.

There were several limitations to these experiments. One limitation was measuring the vacuum pressure in the etching chamber. The pressure sensor that was originally used was not working properly, so an external sensor was used. Also, the leak prevented the etching chamber from both reaching and maintaining a complete vacuum pressure. Another limitation was the calibration of the temperature and humidity sensors. Both sensors were outputting a voltage instead of temperature and humidity. The result from the maximum achieved vacuum pressure is provided below in Table 13.
The other tests outlined in our initial validation plan were not performed largely due to the presence of a leak. Until a new prototype can be constructed (for example out of one uniform piece of acrylic), these tests cannot be performed.

Trial	*Vacuum Pressure After 30s (gauge PSI)*
1	-12.32
2	-12.36
3	-12.38
4	-12.42
5	-12.3
6	-12.42
7	-12.44
8	-12.44
9	-12.44
10	-12.46
AVERAGE	**-12.398**
STANDARD DEVIATION	**0.055337349**

Table 13: Pressure results from vacuum tests

DISCUSSION

Design Improvements and Future Work

Due to time and cost constraints and issues encountered during the manufacturing process of the prototype, we have produced a number of recommended design improvements. We will address improvements for the following system components:

1. Etching/Expansion Chamber
2. System Control Program

To minimize expenses, we selected aluminum as the material for the etching/expansion chamber. We welded aluminum tubing to an aluminum plate to create the bottom half of the e chamber. Because a viewing window was necessary clear acrylic was attached and sealed to an aluminum tube using epoxy. To avoid potential leaks from this sealing process, we recommend machining the entire chamber from acrylic.

We also suggest integrating a knife valve into the system to further improve the seal between the etching and expansion chambers. This steps needed to incorporate this valve will be explained in detail in the evaluation section below.

For the prototype we utilized LabVIEW as our system control program. Although our program runs smoothly, we suggest, as further work, that an Arduino onboard chip be incorporated into the system. This would allow the etching machine to be self-functioning and eliminate the need for an external computer and for the user to own LabVIEW. This would also require the integration of an LCD touch screen for user inputs into the system.

Self-Evaluation

One of the many problems encountered during prototype fabrication was the inconsistency in dimensions of the purchased bulk materials used to create the etching chamber. The aluminum tubing did not have an equal wall thickness all the way around the tube thus making the inner wall and outer wall not perfectly concentric (or within tolerance). This would have created a problem with the gasket and bolt sealing method and was one of the major reasons we switched to the o-ring seal instead, as discussed previously. McMaster did have the option to have ground materials which have a much closer tolerance to the advertised nominal dimensions. In hindsight, this may have been a preferred choice however at the time this was viewed as too costly of an option. The main take-away from this encountered problem was to create a design that is not highly constrained to loosely tolerance parts (i.e. o-ring seal instead of concentrically placed gasket).

Another problem our group came across was the difficulty of sealing the etching chamber in both over-pressure conditions (purge part of cycle) and vacuum conditions (etching and expansion part of cycle). Most seals are good in one condition and not the other, so finding a seal that can coexist in both was a challenge. The gasket method mentioned previously may have been an optimum choice, however limitations including difficulty in removing the wafer, uneven chamber wall thicknesses, and size of bolts required proved this method unfeasible. The o-ring method seemed to be the easiest method to incorporate into the Alpha design from DR3 (originally using gaskets) and accommodate the recently updated chamber opening mechanism: dual hinge and latch method.

Not only was the interface between the two halves of the chamber a sealing issue, but the epoxy interface between the top lid and top side piece created another place for air to leak in or out. Gluing two dissimilar materials together in pressure or vacuum applications has an undesired effect between bond strength and interface seal: both affected by the surface condition of the two pieces. When gluing two surfaces together, for bond strength it is desired to have two rough surfaces so the glue can seep into the imperfections and have a stronger hold on each piece. However, for interface sealing it is desired to have two smooth surfaces that are flush with each other so air cannot leak through the imperfections and pores in the surface of the material. To remedy this situation, it would be optimal to construct the entire top piece of the enclosure out of one piece of acrylic and seal that the surface of the knife valve with o-rings. The design for this is discussed in detail below in the recommendations section.

Although some design changes were unavoidable, such as the sealing method due to inconsistencies in material dimensions, one in particular could have been anticipated. In DR3, the top and bottom sides of the enclosure were fastened to the lid and base plate using 3/32” cap screws. It was mentioned by our sponsor after review that a hinged and latched enclosure would be preferred. If this were established and emphasized early on, a more exact and secure hinge mechanism could have been designed rather than creating one from scratch in the machine shop. Also more robust hinges could have been purchased in advanced and incorporated in the design if this was accounted for earlier in the design process. The current hinges are sufficient for the current prototype, but they still have some “wiggle” in them which creates an opening and closing of the enclosure that is not perfectly stable.

Another design change that could have been anticipated was the wafer holding method using the Acetal pins. This material was chosen over aluminum so it would not scratch the wafers during placement and removal. It also is very nonreactive with a variety of chemicals. Although the pins were only 1/8” in diameter, it was designed to have a notch milled out to create a ledge to place the wafer pins. This would be slightly difficult with a rigid material but not impossible. However, upon receiving the Acetal rod material, it was more flexible than we had anticipated and could not withstand the forces associated with milling a notch. Therefore, instead of having the wafer placed on a ledge on each of the six pins, it was decided to create two circular patterns of pins to hold the wafer. The inner ring rests under the wafer and provides solely vertical support. The outer ring rests just outside the outer diameter of the wafer contains the wafer over the inner ring, providing a horizontal constraint. This design could have been accounted for in the beginning and was much easier to manufacture rather than milling a notch in a small pin.

Another unforeseen problem that eventually limited our validation testing was the pressure sensor ordered. On McMaster’s website, the analog pressure transducers are not labeled as gauge or absolute pressure sensors and are just denoted by their pressure range (i.e. 0 – 25 **psi**, not psig or psia). Since the 0 reference value was not specified, we were left to interpret this on our own. In hindsight, we should have figured this to be psig since this is the most common application however, calling McMaster to specify a psi absolute sensor may have been a better route to order this sensor. Instead this was ordered along with many other items and the mistake was not realized until the sensor arrived.

After it was determined this sensor was for gauge pressure applications, we order the appropriate device, but the absolute series sensors had a two week build-to-order delay. Due to this, the sensor arrived after validation testing and the design expo presentation. Our sponsor was able to provide us with a substitute sensor that was sufficient for testing with a digital readout.

RECOMMENDATIONS

As mentioned previously, the knife valve was an expected addition to be introduced to the system after the prototype was completed. With this significant addition, the etching enclosure must be slightly modified. The base plate can be used as is however an adapter plate must be fabricated to connect it to the ISO-F flange on the knife valve. This adapter plate consists of 8 equally spaced M8 bolts pattern with a 145mm central pattern diameter. The top lid is to be re-fabricated from one piece of inch thick acrylic and this will be fastened to the top of the knife valve with the same bolt pattern. A full assortment of updated CAD models for the existing prototype and future additions can be found in Appendix B.

The knife valve found in Appendix P is powered by a pneumatic actuator, controlled by an electronic solenoid with both a position indicator and single acting closing spring. This solenoid control and position indicator can be simply added into LabVIEW and connected to the DAQ with the DIN 7 pin output. This addition along with adjusting the torque to be equal for both the tubing and fitting to chamber connections will eliminate all the possible areas for any gas to leak in or out of the system. The final stack-up of the etching chamber can be seen below in Figure 6 (a) and (b) for both and top and bottom view.

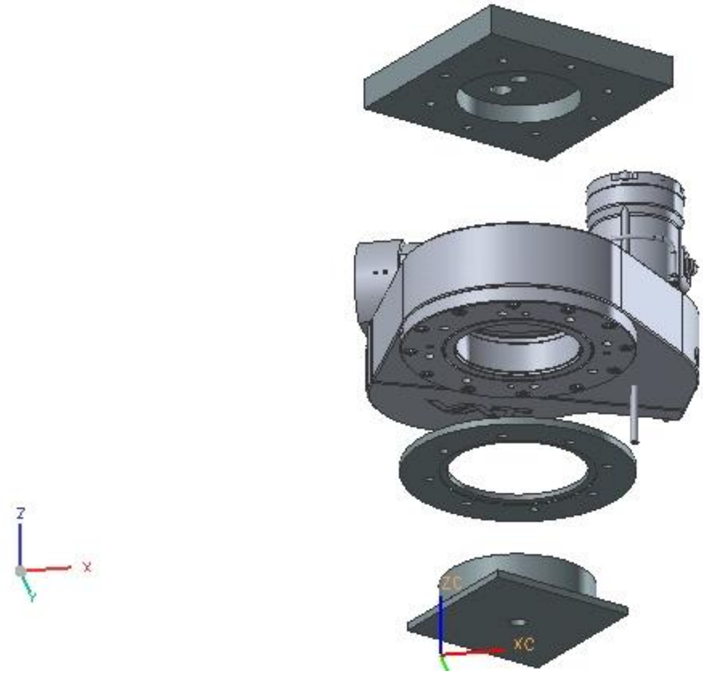


Figure 6 (a): Bottom View of Explosion of Recommended Final Design

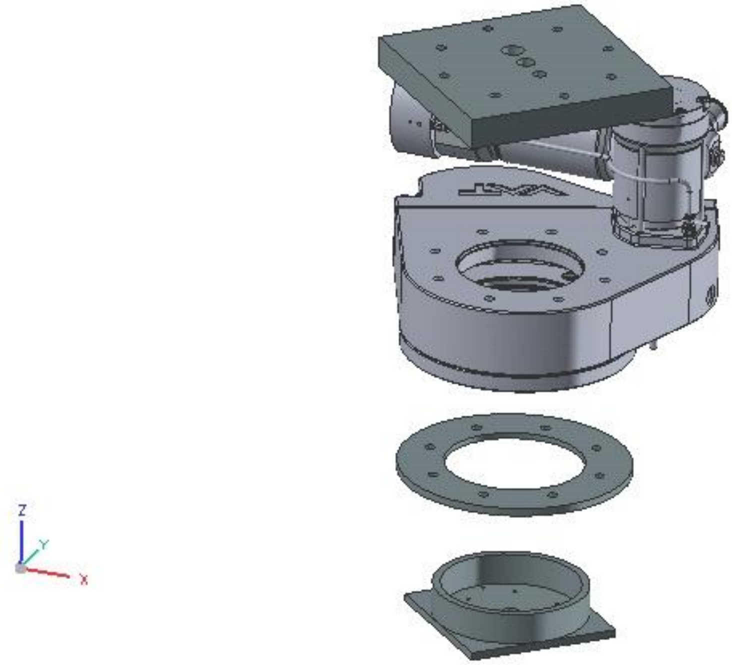


Figure 6 (b): Top View of Explosion of Recommended Final Design

As shown in the images above, the knife valve is relatively large compared to the current enclosure. In order to properly support this addition, vertical supports must be added to the inside of the enclosure so the weight of the chamber and knife valve does not crush or deform the plastic system enclosure. This can be accomplished with four round stock pieces of either aluminum or PVC in the center of the enclosure. Each end can then be bolted to the top and bottom of the enclosure and threaded into the center of the support. The placement will be dependent on the available space around the solenoid valves and electrical wires or gas plumbing.

Another addition that must be reconstructed is the hinge and latch mechanism. Since the additions to the current enclosure are relatively large and complex, and exact model of the hinge and latch brackets were omitted since these will have to be design and fabricated after the new chamber is completed. However, a few design considerations are provided below.

- To have a more robust hinge, on single centerfold hinge that stretches the length of the chamber will provide and stronger opening mechanism.
- Hinge brackets can still be fastened to the top lid and base plate but need to extend out to provide enough clearance for the knife valve.

CONCLUSION

To fulfill all of the customer requirements and engineering specifications for our project, we brainstormed many different ideas for our etching system. The system was first broken down into different functions and different ideas for each function were developed. A morphological chart was then generated containing different system designs using these ideas. Also, a desired design was produced using the best and most suitable options for each function. From these designs, a Pugh chart was then created to judge each system and to determine if it satisfied each customer requirement. It was confirmed from this chart that our desired design was the best out of all possible designs. It was determined that our system will have:

1. Xenon Diflouride (XeF_2) as the etching gas
2. Elimination of the expansion chamber and simplified dispersion method
3. Sheet metal as the system enclosure with polycarbonate as the top viewing plate
4. A single pump to evacuate the gas
5. A hydrometer and nitrogen purge to remove moisture from the system
6. A hinge and clamp with an air tight o-ring seal
7. Two-way valves combined with the existing layout

The aluminum etching/ expansion chamber was cut on a band saw to the approximate size, and then machined within a tolerance of ±0.01 of an inch. The aluminum base plate was welded to the bottom side and then a groove was machined into the top of the bottom side for the o-ring seal. Epoxy was used to attach the acrylic top plate to the aluminum top side. The chamber was then assembled using bolts to attach the hinges and latches.

The electronic layout of the system was designed based on the voltage and current requirements of each component (solenoid valves, sensors, and DAQ). The details of this layout are described in a prior section. The controls for the project were designed using LabVIEW.

We used compressed air to test our prototype for leaks and the ability to maintain vacuum. A pressure transducer was used to measure the vacuum pressure that our system could achieve. The chamber was brought to vacuum pressure ten times and the pressure achieved after 30 seconds of pumping was recorded. The average pressure reached was -12.4 gauge psi with a standard deviation of 0.06 gauge psi. The necessary pressure for the system is -14.0 gauge psi.

Our validation activities also revealed a leak in the epoxy seal. This accounts for the lower pressure and the inability of the system to maintain vacuum. To eliminate this problem, we recommend machining the entire chamber from acrylic to avoid using epoxy as a seal between acrylic and aluminum. We also strongly advise incorporating a knife valve into the system to increase the seal and to optimize the uniformity of the gas dispersion.

ACKNOWLEDGEMENTS

We would like to thank our Professor Katsuo Kurabayashi and our sponsor Professor Nikos Chronis. We would also like to thank Mostafa Ghannad-Rezaie for giving us a tour of the clean room and Trushal Chokshi for giving us background information about micro controllers and onboard chips.

REFERENCES

[1] Lessard, Philip A. Dry vacuum pumps for semiconductor processes: Guidelines for primary pump selection. Vacuum Science Technology, Volume 18 Issue 4, p. 1777-1781. Jul/Aug 2000.

[2] (Safety sheet for XeF_2) <www.xactix.com/XeF2%20MSDS.pdf>

[3] (Xetch data sheet) <http://www.xactix.com/Xetch_e1_specs.htm>

[4] (Safety sheet for HF) < www.chem.purdue.edu/chemsafety/Equip/hfmsds.pdf>

[5] Xetch X3 Series System Manual. XACTIX Inc. Manual Version: X3-4.1R1. Copyright 2000-2005

[6] CES Edu Pack 2009 software

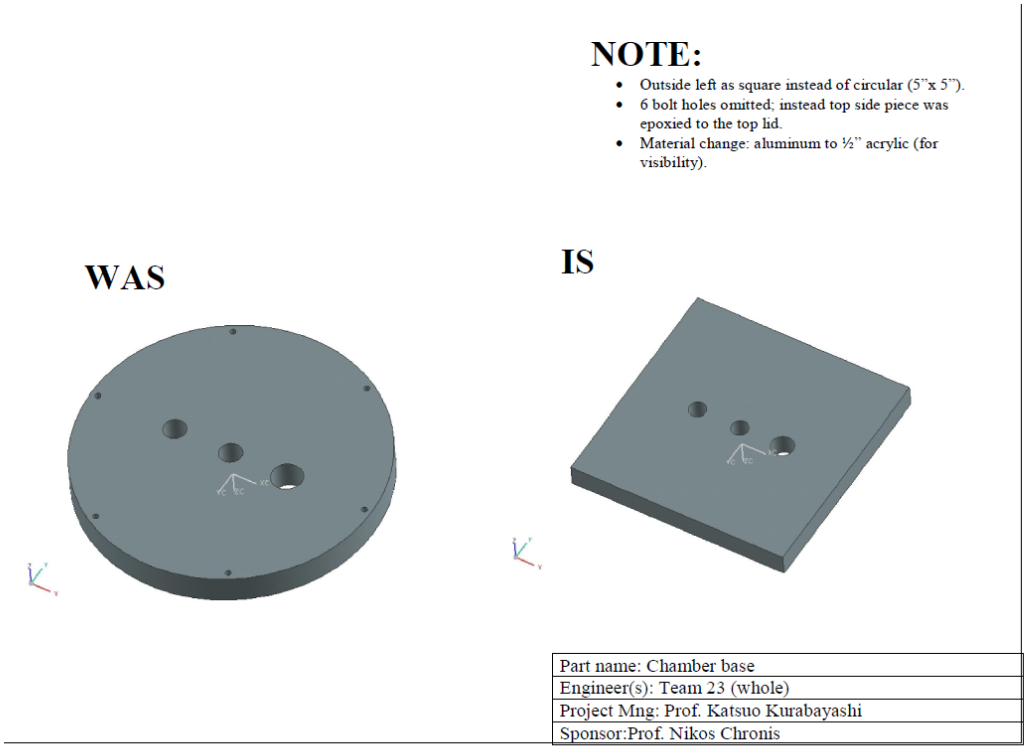
[7] Perez, Nestor, *Fracture Mechanics*, Kluwer Academic Publishers, USA, 2004.

[8] Cortesi, Roger, *Crush Depth of Simple Cylinders and Endcaps*, Accessed Mar. 16, 2010, http://rogercortesi.com/portf/pressvesfailure/presvesfail.html.

APPENDIX A: Bill of Materials

Item	Quantity	Source	Catalog Number	Cost	Contact
Electrical Feedthrough	1	Omega	PFT2NPT-2CU	$60.00	Omega.com
2-Way Valves	3	Omega	SV3502	$114.00 ea	Omega.com
PVDF Tubing	8 ft	McMaster-Carr	5390K34	$3.44 ft	McMaster.com
Swagelok Adapter (3/8" NPT)	2	McMaster-Carr	50385K46	$10.55 ea	McMaster.com
Relief Valve	1	McMaster-Carr	8088K14	$23.98	McMaster.com
Swagelok Adapter (1/2" NPT, NPTF)	2	McMaster-Carr	5272K196	$6.63	McMaster.com
Swagelok Adapter (1/4" NPT)	6	Ace Hardware	N/A	$3.95 ea	Acehardware.com
12"x12"x1/4" Aluminum Sheet	1	McMaster-Carr	9246K13	$19.00	McMaster.com
¼" thick, 12" Length, 4.5" ID Al Tube	1	McMaster-Carr	9056K551	$47.31	McMaster.com
Pressure Gauge	1	McMaster-Carr	3196K999	$153.82	McMaster.com
Humidity Sensor	1	Precon	HS2000V	$29.95	Precon.com
Emergency Stop Button	1	Omron	A22E-MP-01	$42.22	Omron.com
Swagelok Tee Fitting	2	McMaster-Carr	5272K252	$13.51 ea	McMaster.com
Acetal Rod	4 ft	McMaster-Carr	8497K11	$0.38 ft	McMaster.com
12" x 12" x ½" Acrylic	1	McMaster-Carr	4615T51	$18.86	McMaster.com
Latches	2	Ace Hardware	N/A	$5.95	Acehardware.com
Hinges	2	Ace Hardware	N/A	$3.99	Acehardware.com
Plastic grommet	5	Ace Hardware	N/A	$1.29 ea	Acehardware.com
Vacuum Tube Fitting	1	McMaster-Carr	4518K481	$19.68	McMaster.com
Vacuum Ring	1	McMaster-Carr	4518K621	$6.28	McMaster.com
Vacuum Aluminum Wing-Nut	1	McMaster-Carr	4518K711	$7.00	McMaster.com
Electrical Box	1	Doug Verner	N/A	Donation	N/A
Electrical Wires	1	Doug Verner	N/A	Donation	N/A
Bread Board	1	Doug Verner	N/A	Donation	N/A
DAQ	1	John Baker	N/A	Rental	N/A

APPENDIX B: Description of Engineering Changes Since DR3 (Change Notices)



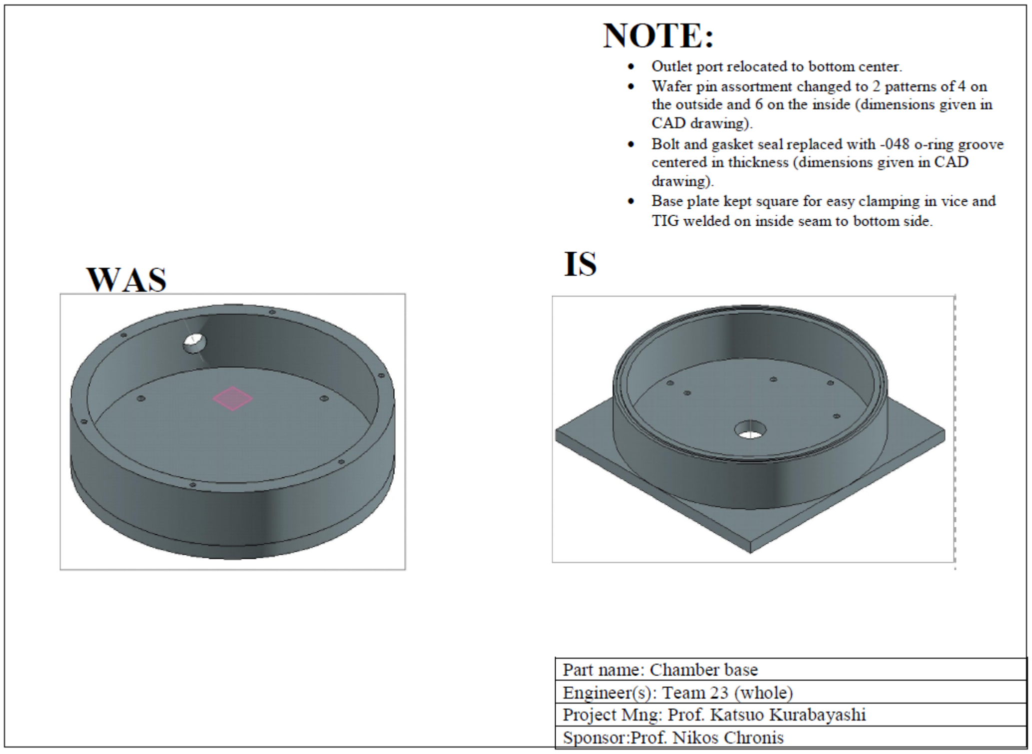
NOTE:

- Outside left as square instead of circular (5"x 5").
- 6 bolt holes omitted; instead top side piece was epoxied to the top lid.
- Material change: aluminum to ½" acrylic (for visibility).

WAS

IS

Part name: Chamber base
Engineer(s): Team 23 (whole)
Project Mng: Prof. Katsuo Kurabayashi
Sponsor:Prof. Nikos Chronis



NOTE:

- Outlet port relocated to bottom center.
- Wafer pin assortment changed to 2 patterns of 4 on the outside and 6 on the inside (dimensions given in CAD drawing).
- Bolt and gasket seal replaced with -048 o-ring groove centered in thickness (dimensions given in CAD drawing).
- Base plate kept square for easy clamping in vice and TIG welded on inside seam to bottom side.

WAS

IS

Part name: Chamber base
Engineer(s): Team 23 (whole)
Project Mng: Prof. Katsuo Kurabayashi
Sponsor:Prof. Nikos Chronis

APPENDIX C: Design Analysis Assignment from Lecture

1. Material Selection Assignment (Fundamental Performance)

Introduction

Our proposed design for an economical silicon etching machine is broken up into 4 main sub-systems: etching/expansions chamber, system enclosure, gas plumbing, and electrical connections. Since the etching/expansion chamber system contained the most fabrication and construction time, it was selected to perform the materials selection analysis (functional performance). The first section contains the analysis for the aluminum base and bottom side part while the second section contains the analysis for the acrylic top plate. These two pieces were viewed as the two most critical components of the etching/expansion chamber. A final prototype photo is provided below in Figure 1.

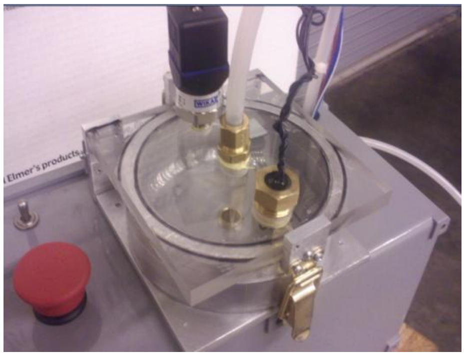


Figure 1

COMPONENT ONE: Base Plate and Bottom Side Part

Function

The top acrylic plate and top side part has one main function for our etching machine: Maintain structural integrity while also maintaining pressure and vacuum environments within the chamber.

(1) <u>Provide visualization to the user</u>

An important customer requirement to the successful operation of the etching machine is the ability of the user to view the progress of the etching process. Thus, a transparent material, acrylic, was used in order to allow the ability to view the inner workings of the chamber during operation by use of a microscope or simply the human eye.

(2) <u>Maintain structural integrity while also maintaining pressure and vacuum environments within the chamber.</u>

Since leakage is a critical design issue, it is very important that the system maintains structural integrity during its working conditions.

Objective

(1) Maximize failure stress, minimize mass

Constraints

(1) Minimal purchase thickness (1/16’’), Maximum working pressure of 25 psi gauge.

Index

(1) $M=\sigma_f/\rho$ (maximize M)

Material Indices

Incorporating the above stated functions, objectives, and constraints, the following material indices were produced in Table 3 below.

Function	Objective	Constraint	Index
Structural Integrity	Maximize failure stress, minimize mass	Minimal purchase thickness, maximum working pressure of 25 psi gauge	$M = \sigma_f/\rho$ (maximize M)

Top Material Choices (from CES)

Using the CES material software, five chamber materials were identified that meet the above constraints: High Carbon Steel, Low Alloy Steel, Stainless Steel, Aluminum Alloy, Copper Alloy. Raw material pricing is provided as well in the table below.

Material	Price USD/lb
High Carbon Steel	0.328-0.361
Low Alloy Steel	0.366-0.402
Stainless Steel	2.96-3.25
Aluminum Alloy	0.697-0.766
Copper Alloy	1.43-1.58

Final Choice

Using the CES software and factoring in material costs, AISI 6061 aluminum was chosen as the material to construct the base plate and bottom side part. Its high strength to weight ratio in both yielding and fracture make it an ideal candidate for pressure and etching chambers. Although it is relatively expensive compared to standard steels, the size of the aluminum tubing and base plate made this piece able to fit into our budget of ~$800.

COMPONENT TWO: Top Acrylic Plate and Top Side Part

Function

The top acrylic plate and top side part has two main functions for our etching machine: (1) Provide visualization to the user and (2) Maintain structural integrity while also maintaining pressure and vacuum environments within the chamber.

(3) Provide visualization to the user

An important customer requirement to the successful operation of the etching machine is the ability of the user to view the progress of the etching process. Thus, a transparent material, acrylic, was used in order to allow the ability to view the inner workings of the chamber during operation by use of a microscope or simply the human eye.

(4) Maintain structural integrity while also maintaining pressure and vacuum environments within the chamber.

Since leakage is a critical design issue, it is very important that the system maintains structural integrity during its working conditions.

Objective

(2) Maximize transmittance of light through the material with a minimal index of refraction.
(3) Maximize failure stress, minimize mass

Constraints

(2) Thickness specified (t=0.5’’), Optical Quality required, Refraction Index in the Optical Quality range (~1.5)
(3) Minimal purchase thickness (1/8’’), Maximum working pressure of 25 psi gauge.

Index

(2) No index for this objective
(3) $M=\sigma_f/\rho$ (maximize M)

Material Indices

Incorporating the above stated functions, objectives, and constraints, the following material indices were produced in Table 3 below.

Function	Objective	Constraint	Index
Visualization	Maximize transmittance	Thickness specified, Optical Quality Required, Refraction index ~1.5	No index
Structural Integrity	Maximize failure stress, minimize mass	Minimal purchase thickness, maximum working pressure of 25 psi gauge	$M= \sigma_f/\rho$ (maximize M)

Top Material Choices (from CES)

Using the CES material software, five chamber materials were identified that meet the above constraints: Acrylic (PMMA), Polycarbonate, Polypropylene, Cellulose polymers, Polylactide. Raw material pricing is provided as well in the table below.

Material	Price USD/lb
Acrylic (PMMA)	72.4-76.2
Polycarbonate	1.66-1.83
Polypropylene	55.6-56.8
Cellulose polymers	61.2-81.2
Polylactide	75.5-78

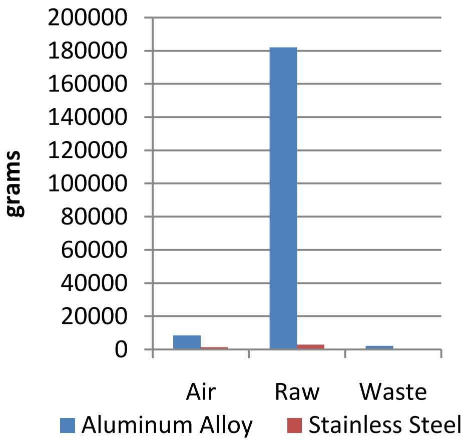
Final Choice

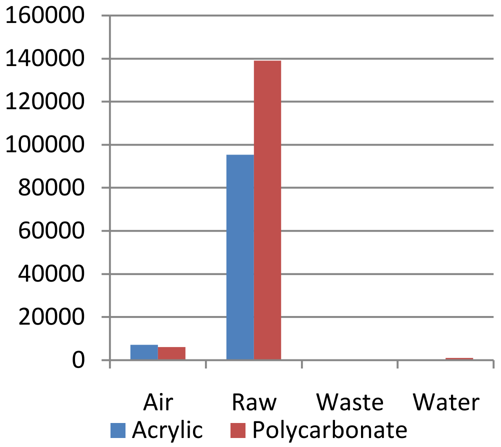
Using the CES software and factoring in material costs, acrylic was chosen as the material to construct the top plate and AISI 6061 was chosen for the top side part (for the reasons discussed which rationalize the material for the bottom side part). The Acrylic was chosen for its high yield stress and optimal optic qualities as well as its use in the current market model. Since it is currently being used for the same function, we have confidence that it will work equally as well in our system. In addition, acrylic was chosen due to its immediate availability during our manufacturing period.

Although the acrylic of the thickness necessary for the application is more expensive than using a material like the aluminum used for the bottom plate, the necessity of a viewing area during the etching process made the acrylic a necessary choice.

2. Material Selection Assignment (Environmental Performance)

The results of the DFE are shown at the end of this section (p. X). From the results, it was determined that between aluminum alloys and stainless steel, stainless steel has the lowest impact on the environment. Between acrylic and polycarbonate, polycarbonate has the lowest impact on the environment. So, it would be recommended that in the future, a more environmentally friendly material be chosen in place of an aluminum alloy, such as stainless steel.





In addition, there could be improvements in several other areas: New Concept Development, Physical Optimization, Material Use Optimization, Distribution Optimization, Impact Reduction During Use, and End-of-Life Systems Optimization.

To improve within new concept development, we recommend the use of recycled aluminum/acrylic for the chamber to save on energy from production and resources. Also, as mentioned previously, an alternate material to aluminum should be considered. Machining the enclosure from all acrylic may be a feasible option. The knife valve is also a recommended improvement to increase the quality of the seal, which would reduce the amount of harmful chemicals released into the environment.

To physically optimize our system, we recommend optimizing the chamber dimensions such that no extra material is used. Also, the pipe/valve layout should be optimized in order to minimize the amount of tubing needed and the size of the enclosure to be used.

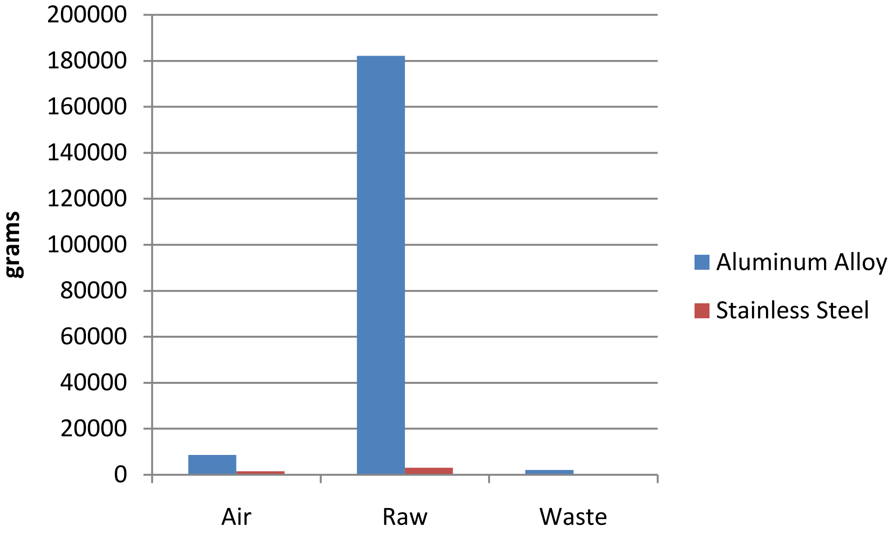
To optimize our material use, we propose to utilize only one material for manufacturing of the etching/expansion chamber. This was mentioned previously in the suggestion of using acrylic exclusively.

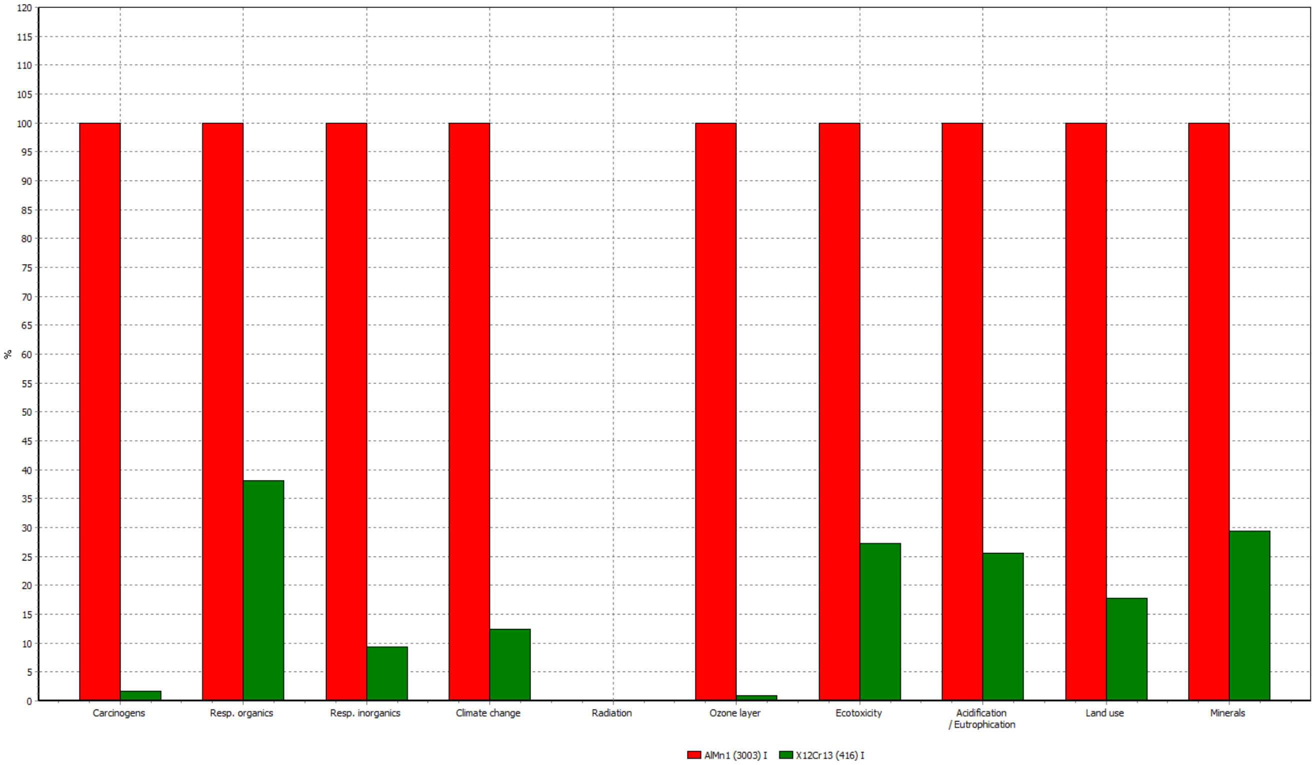
To optimize production, we propose to manufacture more than one system at a time which would minimize the amount of wasted materials. For our prototype, we needed to order more material than was actually used in the implementation of the device. Additionally, we recommend using optimal cutting angles and speeds during full production to minimize the amount of harmful particulates released into the air during the manufacturing process. Finally, we again propose the use of acrylic exclusively in order to avoid the dangerous emissions associated with the welding of aluminum.

To optimize distribution, we recommend ordering all materials from one company at the same time to minimize the amount of packaging needed as well as the ecological impact associated with delivery.

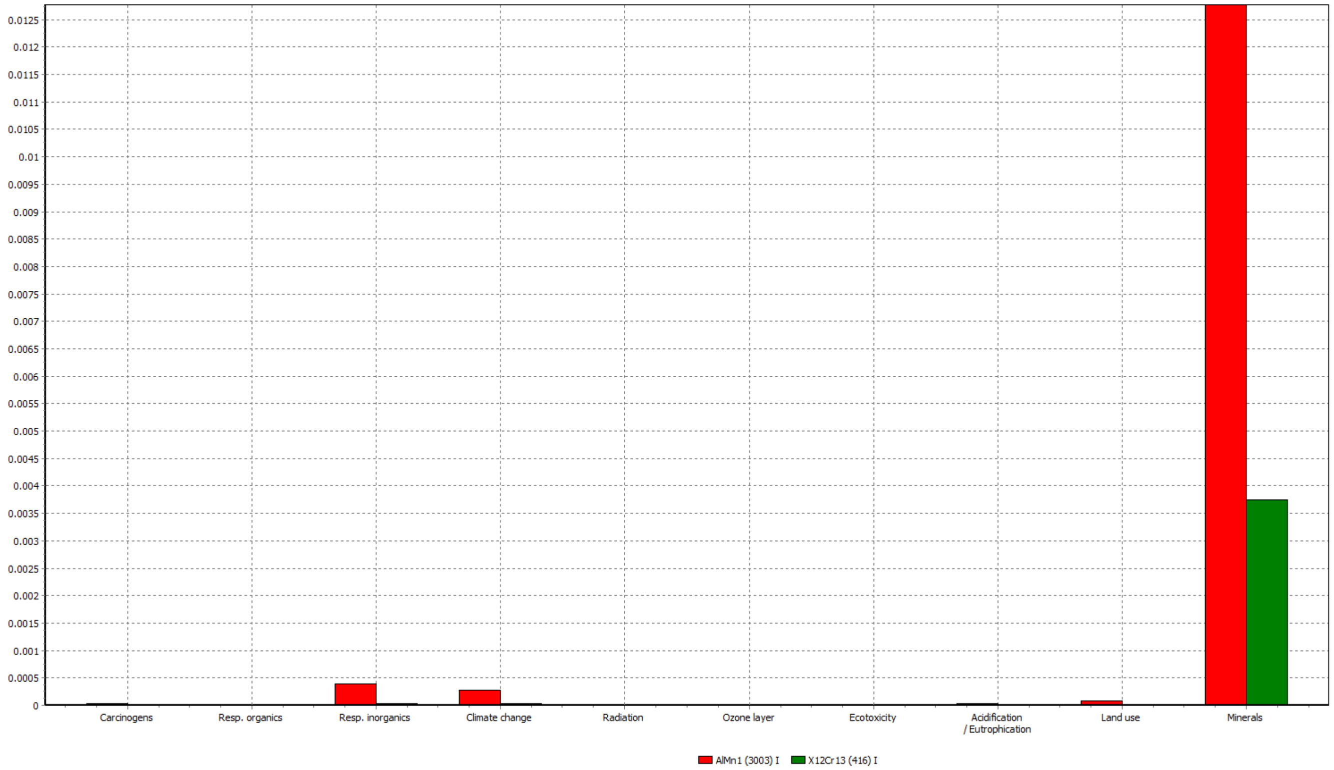
To reduce our environmental impact during mechanism use, we recommend that the user regularly check that the machine maintains a good seal, to avoid hazardous leakage to the ambient. In addition we also recommend the user always operate under a fume hood for both personal and environmental safety.

Finally, to optimize end-of-life systems, we recommend maximizing the amount of recyclable materials used in the production of the device such that when its operational life is over, it can be dismantled and recycled.

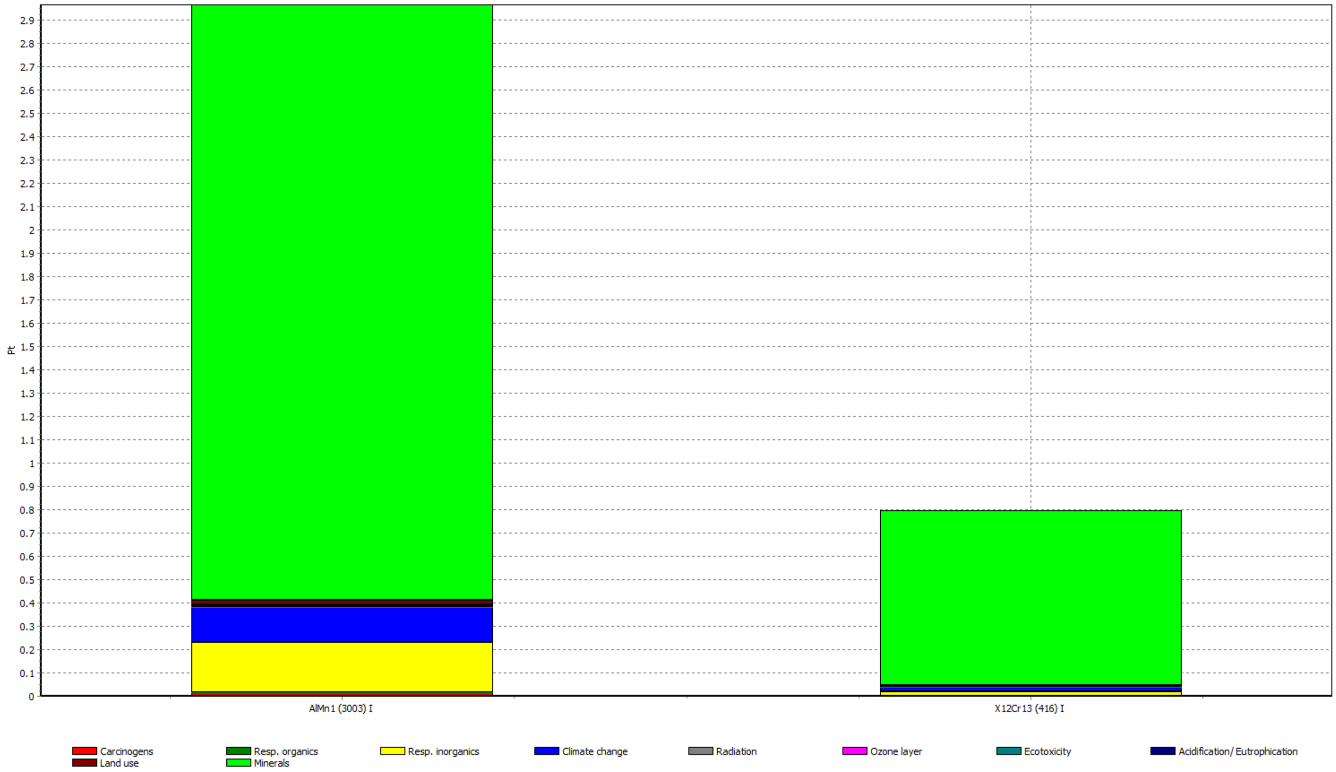




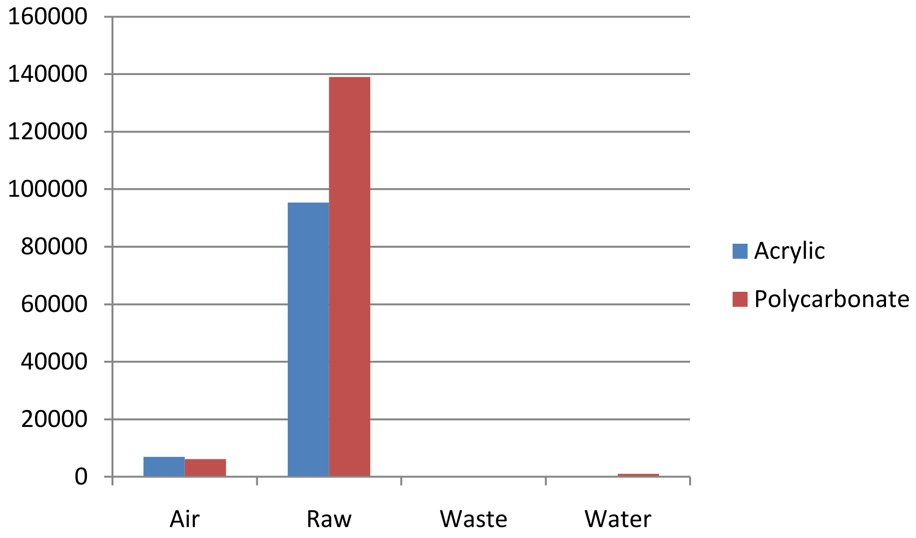
Comparing 1 kg 'AlMn1 (3003) I' with 1 kg 'X12Cr13 (416) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / characterization

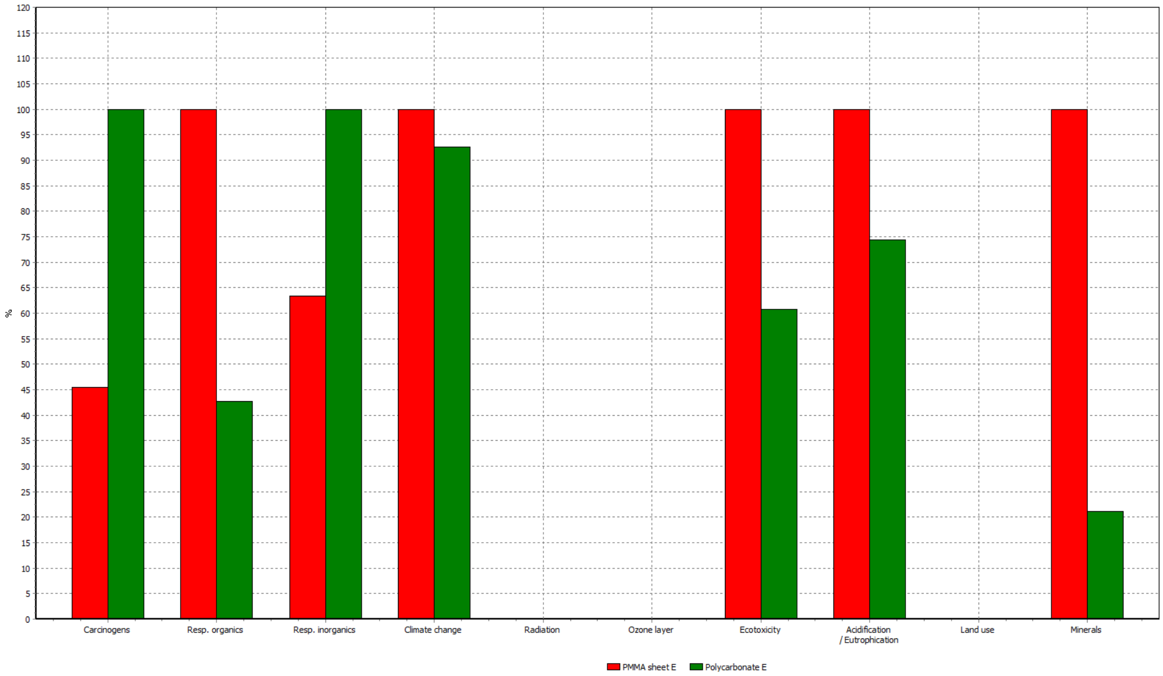


Comparing 1 kg 'AlMn1 (3003) I' with 1 kg 'X12Cr13 (416) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / normalization

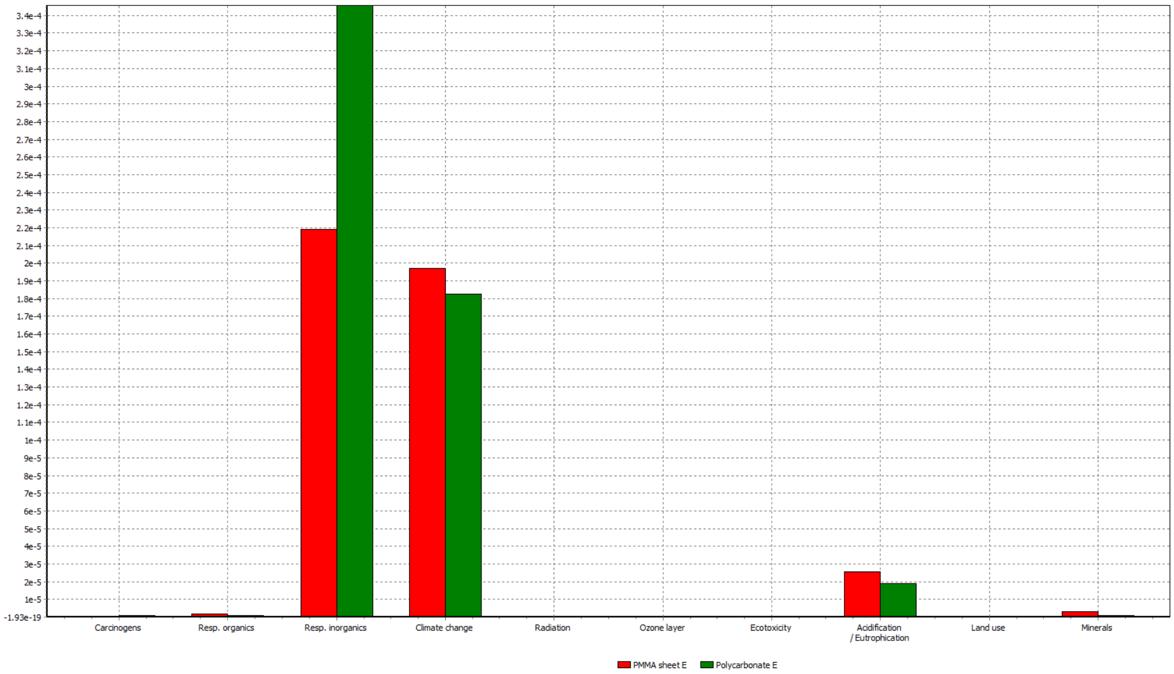


Comparing 1 kg 'AlMn1 (3003) I' with 1 kg 'X12Cr13 (416) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / single score

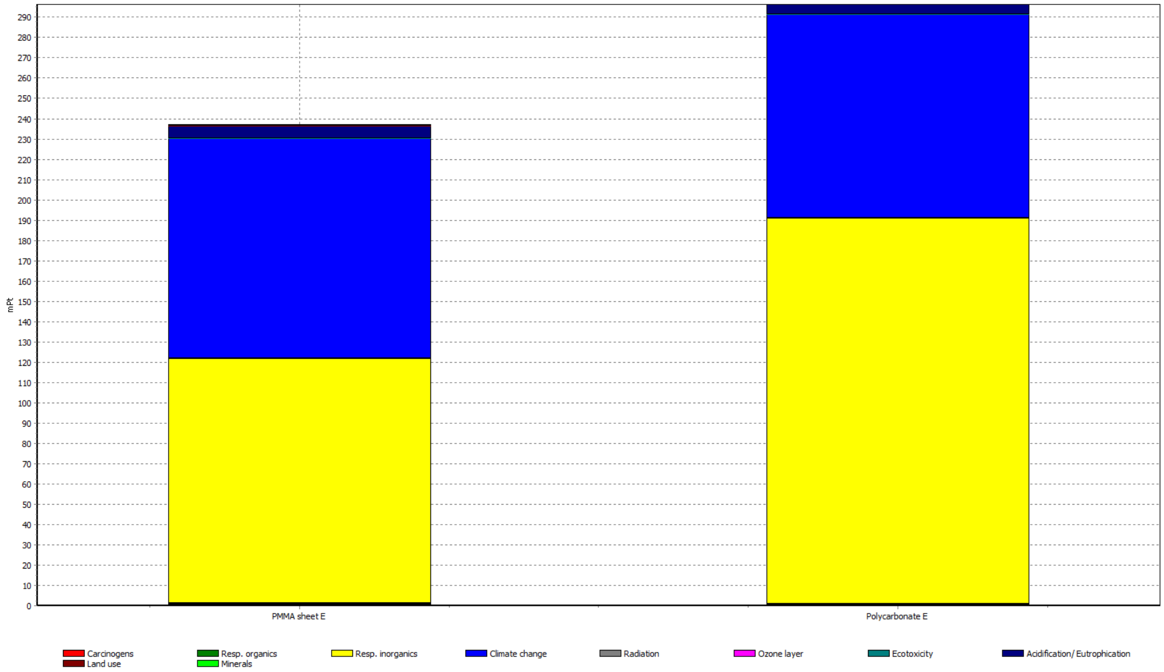




Comparing 1 kg 'PMMA sheet E' with 1 kg 'Polycarbonate E'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / characterization



Comparing 1 kg 'PMMA sheet E' with 1 kg 'Polycarbonate E'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / normalization



Comparing 1 kg 'PMMA sheet E' with 1 kg 'Polycarbonate E'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / single score

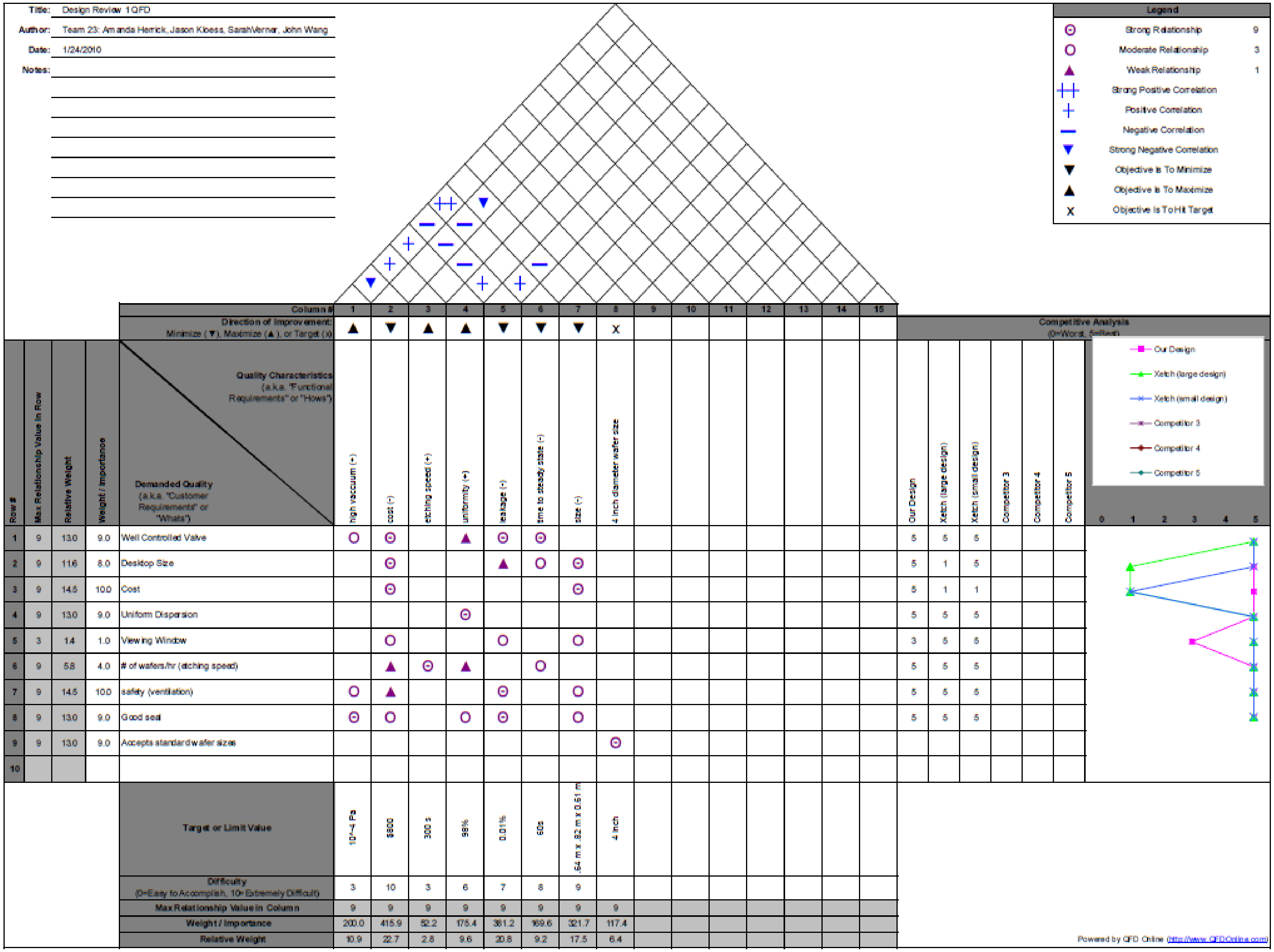
3. Manufacturing Process Selection Assignment

1. The production volume for the economical etching machine would be approximately 25-50 per year. This machine is designed for colleges, research facilities and small MEMS producer companies/suppliers. Simpler versions of machines may be sold at a lower price. These “one-off” machines may not include a lower quality/cheaper vacuum pump or knife valve. The knife valve may be removed for simpler experiments. This may increase the production volume to 100-250. However, it is most likely that each consumer that decides to purchase one of these machines would only buy a maximum of two.

2. The two materials used for these components are acrylic and aluminum. The acrylic will be used for the top plate and the aluminum will be used for the base plate + bottom side component. Both of these pieces will require the use of the mill. The only major difference between the milling process milling/drilling speeds will be different. The acrylic will require a slower miller speed because it is brittle and it may melt during milling process. There will be an addition process for the aluminum component. The plate and bottom side pieces will needed to be welded together. The reason why the top plate and top side parts are not combined in to one component is because acrylic cannot be welded onto the aluminum top side piece. That is why it was proposed that the future design of the top plate and top side part are to be made by one block of acrylic. This would eliminate any chance of leaking between these two parts.

   Neither of the components will need to be heated treated or have any type of coating applied to them. The location and diameter of each hole that is drilled into the top plate can have a relatively poor tolerance because the holes will be threaded and their locations are not very important. The hole in the bottom plate can also have a relatively poor tolerance because of the same reasons. The O-ring groove on the cylindrical piece will require a good tolerance because it is a major component in preventing the etching chamber from leaking. Also, careful machining is required because the groove is located on top of the ¼” thick wall of the cylinder. The diameters and locations of the holes for the pins will also need a good tolerance. Interference fits are needed to keep the pins securely placed onto the base plate. The locations of these holes/pins are also important because they will keep the silicon wafer from moving during the vacuum/etching process.

APPENDIX D: QFD diagram



Title: Design Review 1 QFD
Author: Team 23: Amanda Herrick, Jason Kloess, Sarah Verner, John Wang
Date: 1/24/2010
Notes:

Legend		
⊙	Strong Relationship	9
○	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

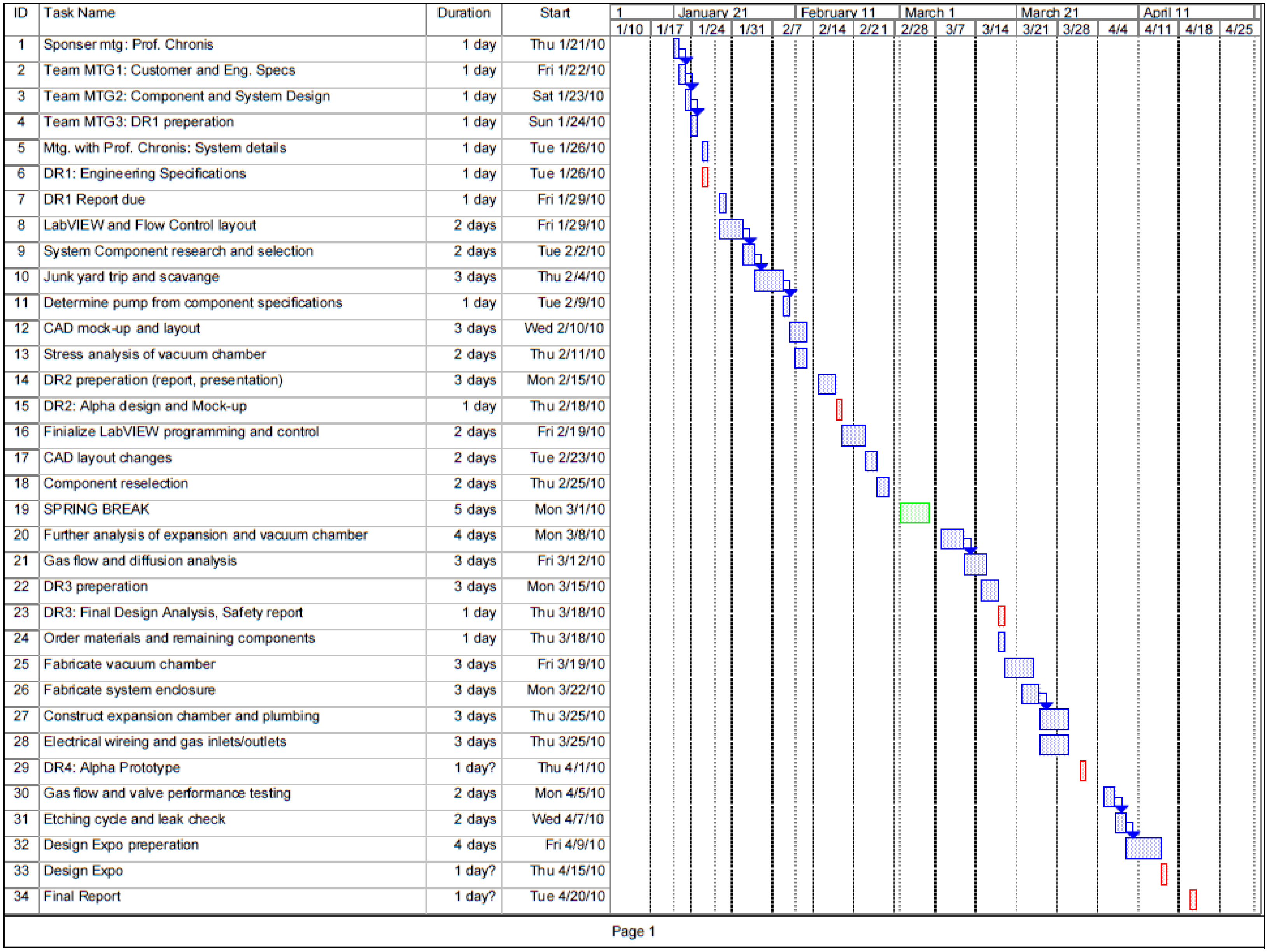
Row #	Max Relationship Value In Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	▲	▲	▼	▼	▼	X							
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	high vaccuum (+)	cost (-)	etching speed (+)	uniformity (+)	leakage (-)	time to steady state (-)	size (-)	4 inch diameter wafer size							
1	9	13.0	9.0	Well Controlled Valve	○	⊙		▲	⊙	⊙									
2	9	11.6	8.0	Desktop Size		⊙			▲	○	⊙								
3	9	14.5	10.0	Cost		⊙					⊙								
4	9	13.0	9.0	Uniform Dispersion				⊙											
5	3	1.4	1.0	Viewing Window		○			○		○								
6	9	5.8	4.0	# of wafers/hr (etching speed)		▲	⊙	▲		○									
7	9	14.5	10.0	safety (ventilation)	○	▲			⊙		○								
8	9	13.0	9.0	Good seal	⊙	○		○	⊙		○								
9	9	13.0	9.0	Accepts standard wafer sizes								⊙							
10																			
				Target or Limit Value	10^-4 Pa	$800	300 s	98%	0.01%	60s	.64 m x .82 m x 0.61 m	4 inch							
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	10	3	6	7	8	9								
				Max Relationship Value in Column	9	9	9	9	9	9	9	9							
				Weight / Importance	200.0	415.9	52.2	175.4	381.2	169.6	321.7	117.4							
				Relative Weight	10.9	22.7	2.8	9.6	20.8	9.2	17.5	6.4							

Competitive Analysis
(0=Worst, 5=Best)

Row #	Our Design	Xetch (large design)	Xetch (small design)	Competitor 3	Competitor 4	Competitor 5
1	5	5	5			
2	5	1	5			
3	5	1	1			
4	5	5	5			
5	3	5	5			
6	5	5	5			
7	5	5	5			
8	5	5	5			
9						
10						

Powered by QFD Online (http://www.QFDOnline.com)

APPENDIX E: Gantt Chart



ID	Task Name	Duration	Start
1	Sponser mtg: Prof. Chronis	1 day	Thu 1/21/10
2	Team MTG1: Customer and Eng. Specs	1 day	Fri 1/22/10
3	Team MTG2: Component and System Design	1 day	Sat 1/23/10
4	Team MTG3: DR1 preperation	1 day	Sun 1/24/10
5	Mtg. with Prof. Chronis: System details	1 day	Tue 1/26/10
6	DR1: Engineering Specifications	1 day	Tue 1/26/10
7	DR1 Report due	1 day	Fri 1/29/10
8	LabVIEW and Flow Control layout	2 days	Fri 1/29/10
9	System Component research and selection	2 days	Tue 2/2/10
10	Junk yard trip and scavange	3 days	Thu 2/4/10
11	Determine pump from component specifications	1 day	Tue 2/9/10
12	CAD mock-up and layout	3 days	Wed 2/10/10
13	Stress analysis of vacuum chamber	2 days	Thu 2/11/10
14	DR2 preperation (report, presentation)	3 days	Mon 2/15/10
15	DR2: Alpha design and Mock-up	1 day	Thu 2/18/10
16	Finialize LabVIEW programming and control	2 days	Fri 2/19/10
17	CAD layout changes	2 days	Tue 2/23/10
18	Component reselection	2 days	Thu 2/25/10
19	SPRING BREAK	5 days	Mon 3/1/10
20	Further analysis of expansion and vacuum chamber	4 days	Mon 3/8/10
21	Gas flow and diffusion analysis	3 days	Fri 3/12/10
22	DR3 preperation	3 days	Mon 3/15/10
23	DR3: Final Design Analysis, Safety report	1 day	Thu 3/18/10
24	Order materials and remaining components	1 day	Thu 3/18/10
25	Fabricate vacuum chamber	3 days	Fri 3/19/10
26	Fabricate system enclosure	3 days	Mon 3/22/10
27	Construct expansion chamber and plumbing	3 days	Thu 3/25/10
28	Electrical wireing and gas inlets/outlets	3 days	Thu 3/25/10
29	DR4: Alpha Prototype	1 day?	Thu 4/1/10
30	Gas flow and valve performance testing	2 days	Mon 4/5/10
31	Etching cycle and leak check	2 days	Wed 4/7/10
32	Design Expo preperation	4 days	Fri 4/9/10
33	Design Expo	1 day?	Thu 4/15/10
34	Final Report	1 day?	Tue 4/20/10

APPENDIX F: Current Xetch System Pictures

X3

e1

APPENDIX G: Xetch e1 and X3 system quotes

X3

- Price:

Model X-SYS-3B: 6" system,	US $157,500
Model X-SYS-3C: 8" system,	US $190,000

- Delivery: 12-14 weeks after receipt of customer down payment for Xetch®
- Incoterms: FOB Ex Works
- Terms:
  30% with order
  60% on shipment Net 30 days,.
  10% Net 30 days, after final verification test
- Other Provisions:

  Final payment will be due immediately if, due to reasons not in XACTIX Inc.'s control, final verification test in not completed 30 days after shipment.

  Operation of the Xetch requires purchase of two xenon difluoride source bottles that are not included with the system. Please contact XACTIX for help in finding a supplier of xenon difluoride.

  Customer order is non-cancelable once down payment has been received.

- Options:

Part Number	X-CO-SW-X3-AR	Advanced Recipe Package	$2,950
Part Number	X-CO-SW-X3-AM	Adv. Experimentation/Manufacturing Package	$2,950
Part Number	X-CO-SW-X3-EN	Ethernet-based remote system control	$9,750
Part Number	X-U-X3-IU	Imaging Upgrade	$19,500
Part Number	X-U-X3-CF	MFC Controlled Continuous Flow	$19.500

e1

- Price:

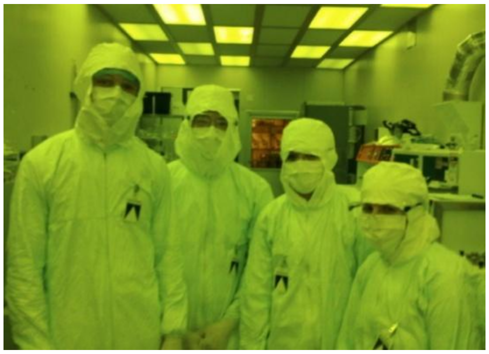
	X-SYS-EXP Xetch e1, base configuration	US $97,500
	University Discount	- US $20,000
	Net Price	US $77,500

- Delivery: 12 - 14 weeks after receipt of customer down payment.
- Incoterms: FOB Ex Works
- Terms: **30% with order**, via telegraphic transfer to our bank account **70% at shipment**, by way of an irrevocable guaranteed letter of credit drawn on a US Bank. All bank charges to be paid by customer.
- Other Provisions: Customer order is non-cancelable once down payment has been received.

  Operation of the Xetch e1 requires purchase of one xenon difluoride source bottle that is not included with the system. Contact XACTIX for help finding a supplier of xenon difluoride.
- Options:

Part Number X-CO-SW-X-AR	Advanced Recipe Package	$3,850
Part Number X-CO-SW-X-AM	Advanced Experimentation Package	$3,850
Part Number X-U-EXP-TS	Touch Screen Upgrade	$1,900
Part Number X-U-EXP-MO	Microscope Option	$8,900
Part Number X-U-EXP-IU	Imaging Upgrade (requires Microscope Option)	$22,400
Part Number X-U-EXP-PG	Process Gauge Upgrade	$4,500
Part Number X-U-EXP-HT	Heating Upgrade	$6,600
Part Number X-U-EXP-CF	MFC Controlled Continuous Flow	$22,600
Part Number VAB0031	Thin Metal Lid with View Port	$5,200
Part Number X-U-EXP-INST	Installation individually quoted.	
Part Number X-U-EXP-SUP	On site warranty and post warranty service is individually quoted.	

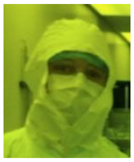
APPENDIX H: Group Bios



Amanda Herrick

Known as Mandy, she is a Michigan native from East Tawas. She fell into the engineering pathway after a positive experience at an engineering summer camp and due to her skills in math and science. After a negative experience with organic chemistry, Mandy switched from biomedical engineering to mechanical engineering. After graduation this spring with a B.S.E in mechanical engineering, Mandy plans to continue work at her current place of employment, University of Michigan Transportation Research Institute (UMTRI) for a year, before applying to graduate programs in either Industrial Design or Sustainability Systems. Mandy has also considered applying to the Peacecorp or Teach for America before pursuing another degree. Besides engineering, Mandy is involved in the Student Sustainability Initiative and also enjoys pursuing her interests in piano, drawing, sailing, design, and traveling.

Jason Kloess



Jason Kloess is from Rochester Hills, Michigan. Both of his parents work at the General Motors Tech. center and have had a significant influence on his choice for an engineering career path. After graduating from Stoney Creek High School and General Motors Technical Academy, he attended the University of Michigan's Engineering program. During the summer of his second year, he conducted research at Oakland University in Auburn Hills with Professor Xia Wang on flow patterns within bipolar plates of PEM fuel cells. An article was submitted and accepted to the *Journal of Power Sources* on the improvements of Bio-Inspired flow patterns on these bipolar plates. The following summer, he participated in a student internship at the US EPA: NVFEL specifically in the Advanced Technology Division improving the filtration system of the hydraulic hybrid UPS delivery vehicles. Currently he is conducting research with Professor Volker Sick on photo analyses of flame retardant materials. He will graduate in April and hopes to continue into a Masters Degree of Mechanical Engineering in the Energy and Environmental Sustainability program. He also enjoys playing guitar and collecting records and sneakers.

Sarah Verner

Sarah Verner is originally from Sterling Heights, MI. She chose Mechanical Engineering based on its versatility and her love of math and physics. After graduating with her Bachelor's Degree, Sarah plans to attain her Master's Degree in Biomedical Engineering through the SGUS (Sequential Graduate Undergraduate Studies) program. After completing her MSE, she will either attend medical school or obtain a PhD in either Biomedical or Mechanical Engineering. In addition to engineering, Sarah enjoys drawing, painting, creative writing, tutoring math, and playing the violin. In the near future, she hopes to get her pilot's license, spend a year living on a sailboat, and obtain her MFA in creative writing.

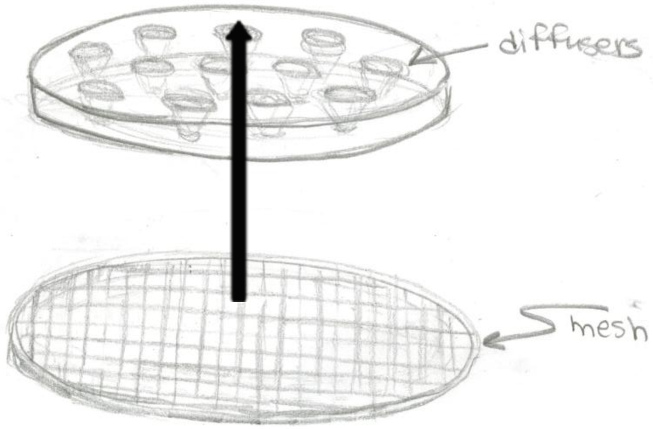
John Wang

John Wang is from Northville, MI. He became interested in Mechanical Engineering because math and science were his strengths in high school and his father currently is one. After graduation, he plans on finding a job in the Mechanical Engineering field, and plans on working for his masters or MBA after several years of working in the field. His interests consist of sports, videogames, music, and watching TV.

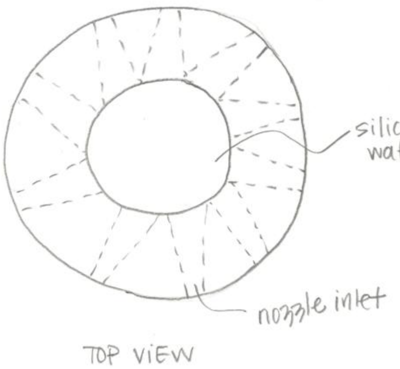
APPENDIX I: CONCEPT SKETCHES

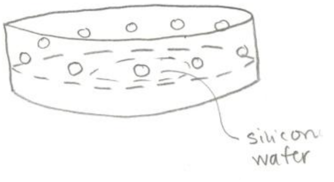
Function 2: Gas Dispersion

Diffuser + Mesh

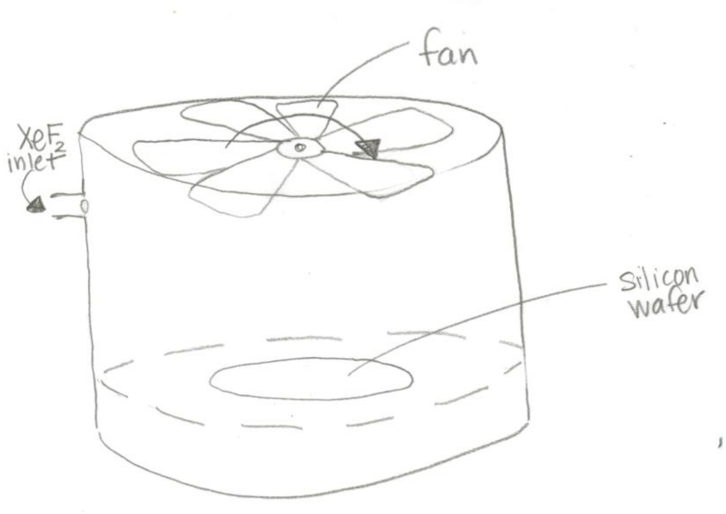


Multiple Inlets



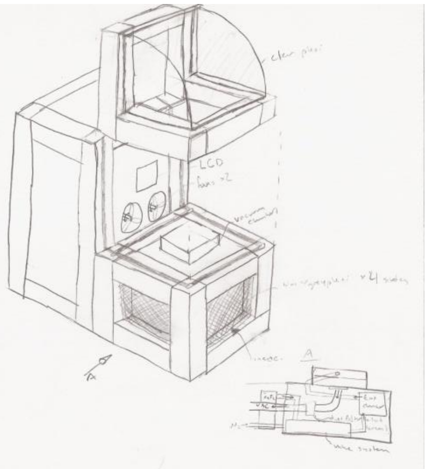


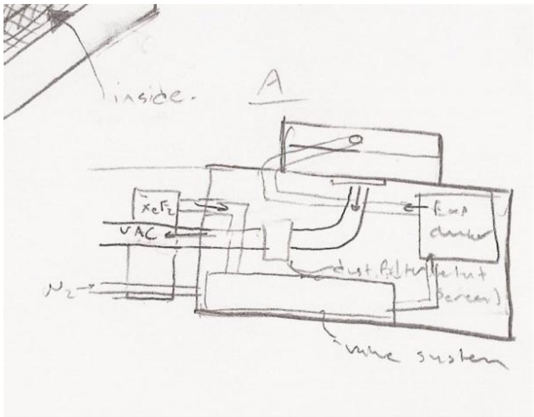
Fan



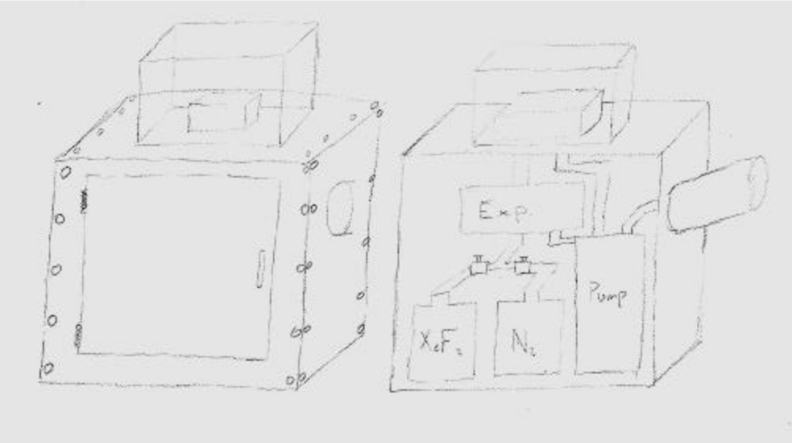
Function 3: System Enclosure

Plexiglas

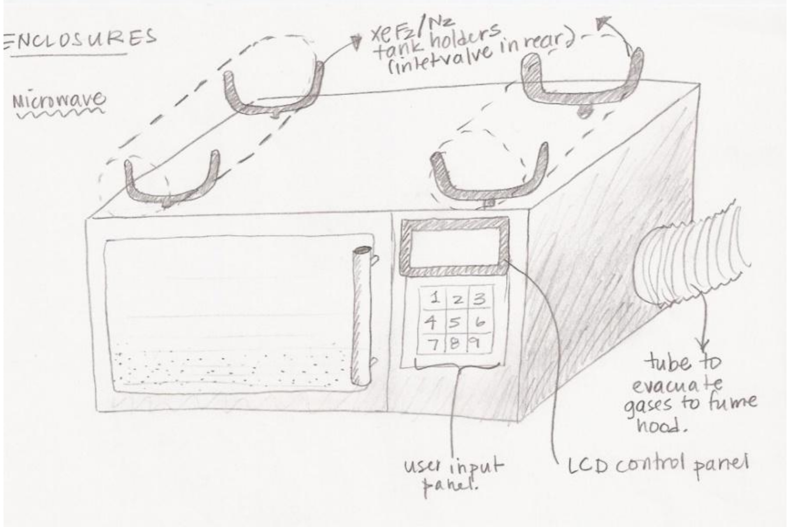




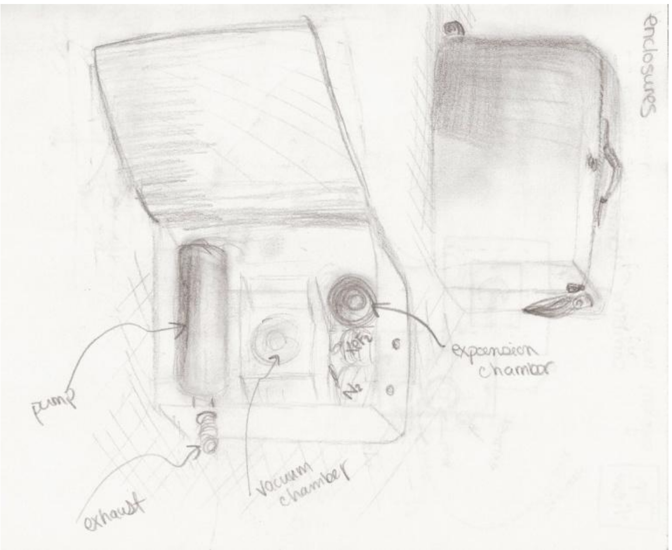
Riveted Sheet Metal



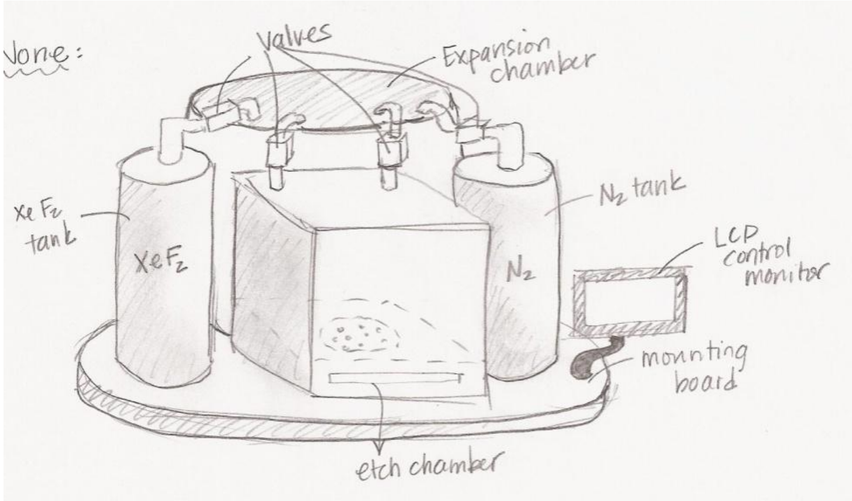
Microwave



Suitcase

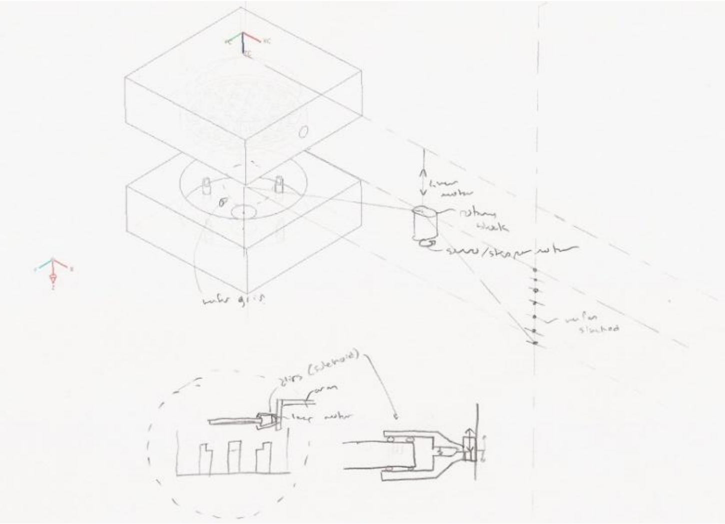


No Enclosure

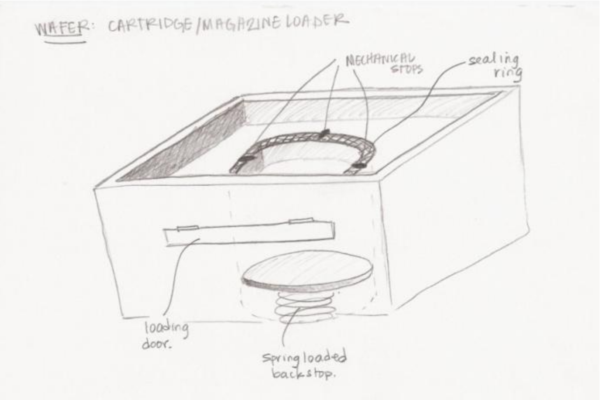


Function 6: Wafer Loading Mechanism

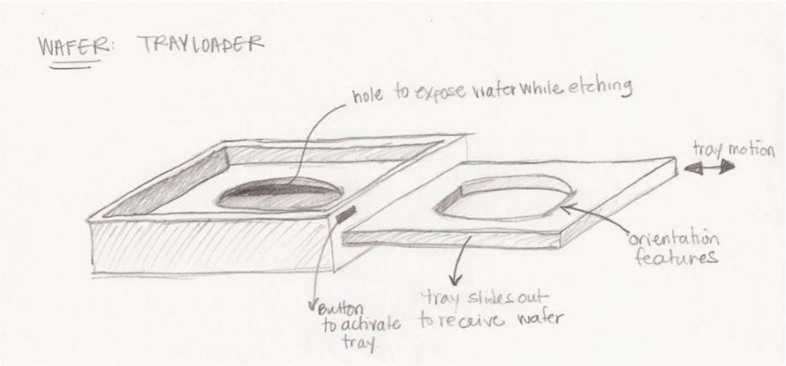
Mechanical Arm



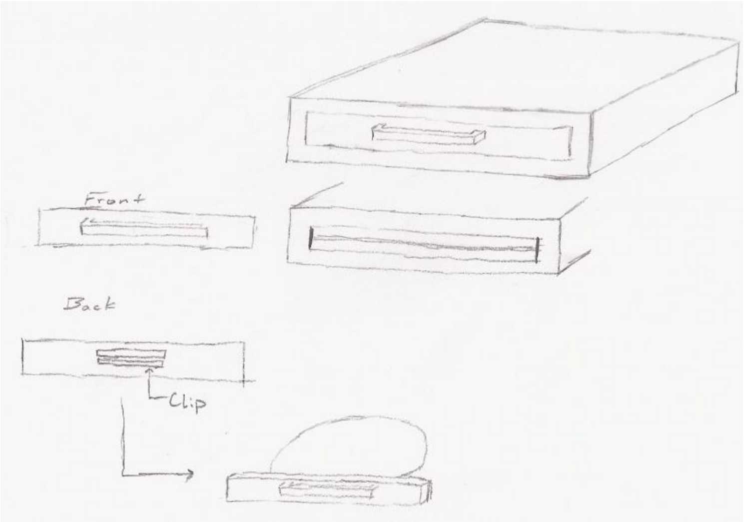
Cartridge/Magazine



Tray Loader

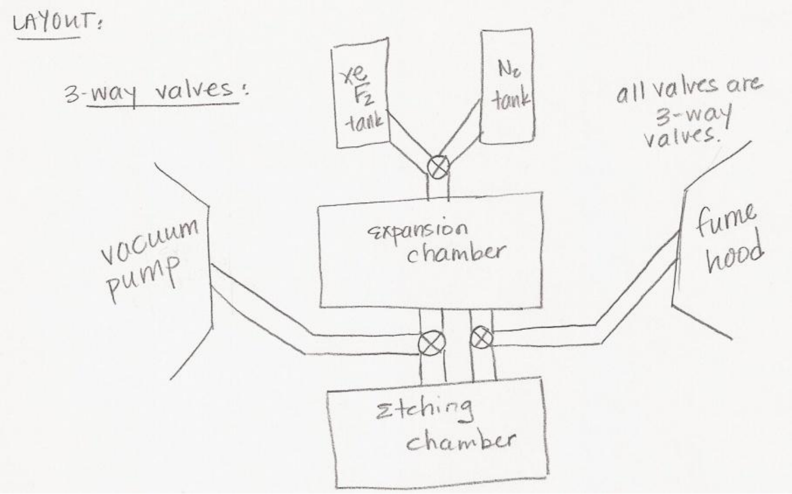


Slot Loader

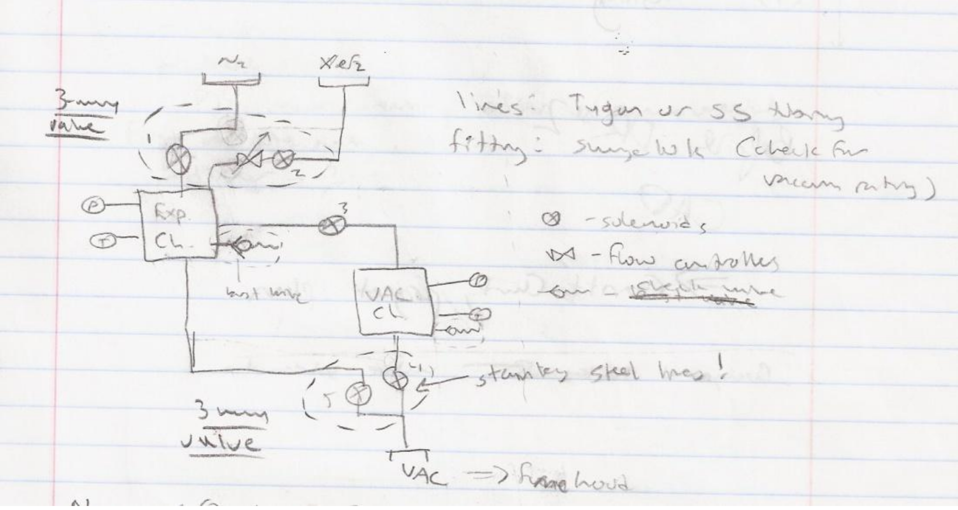


System Layout and Valve Reduction

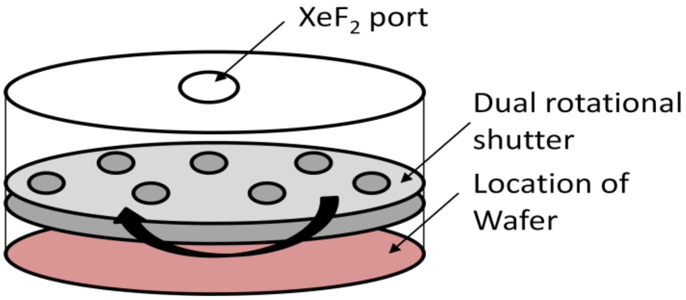
3-way valve system

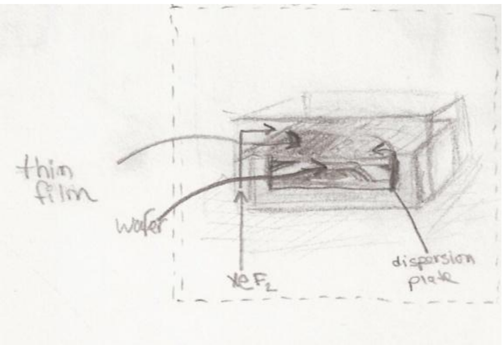


2-way valve system

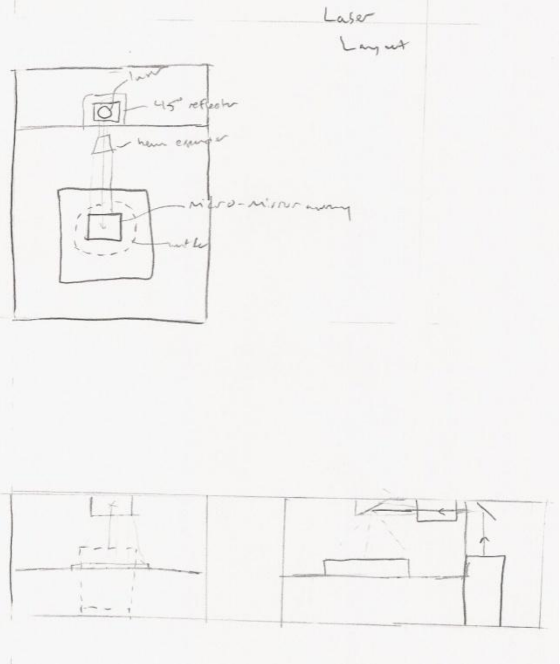


Combine Etching and Etching chamber



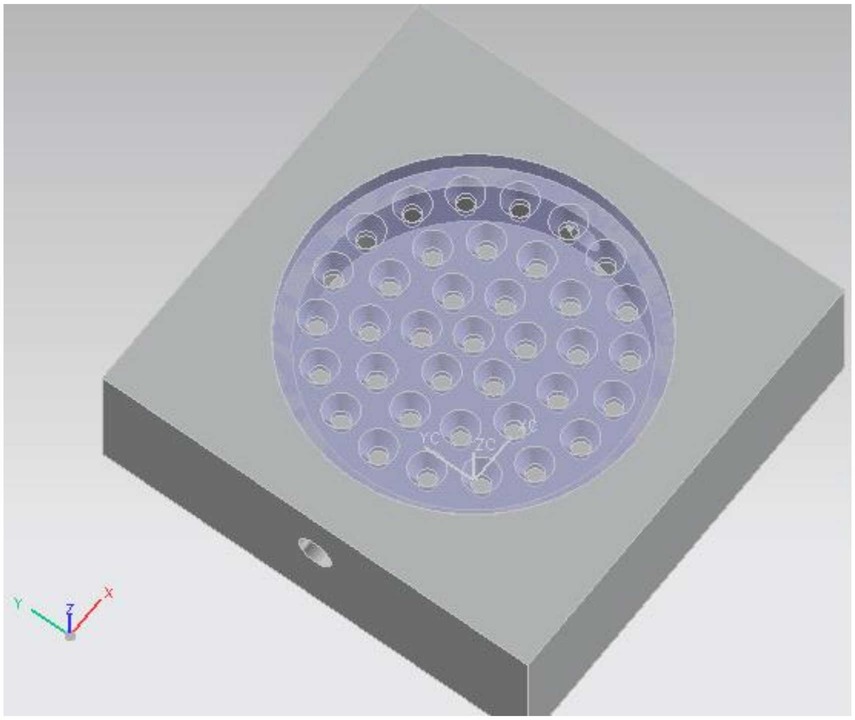


Enclosed Lasers

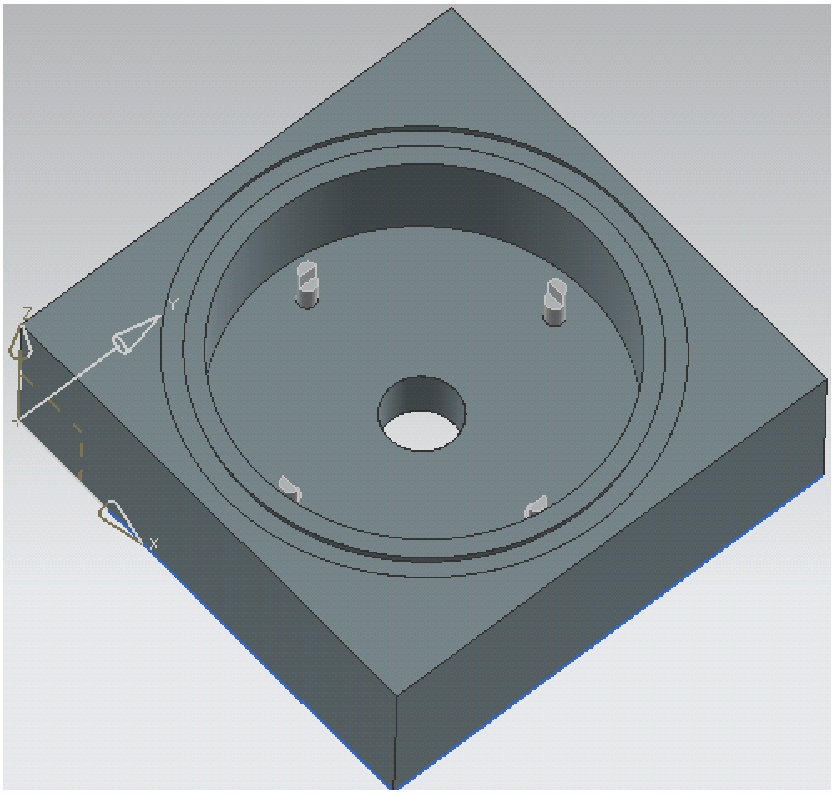


APPENDIX J: CAD MODEL IMAGES OF ALPHA CONCEPT

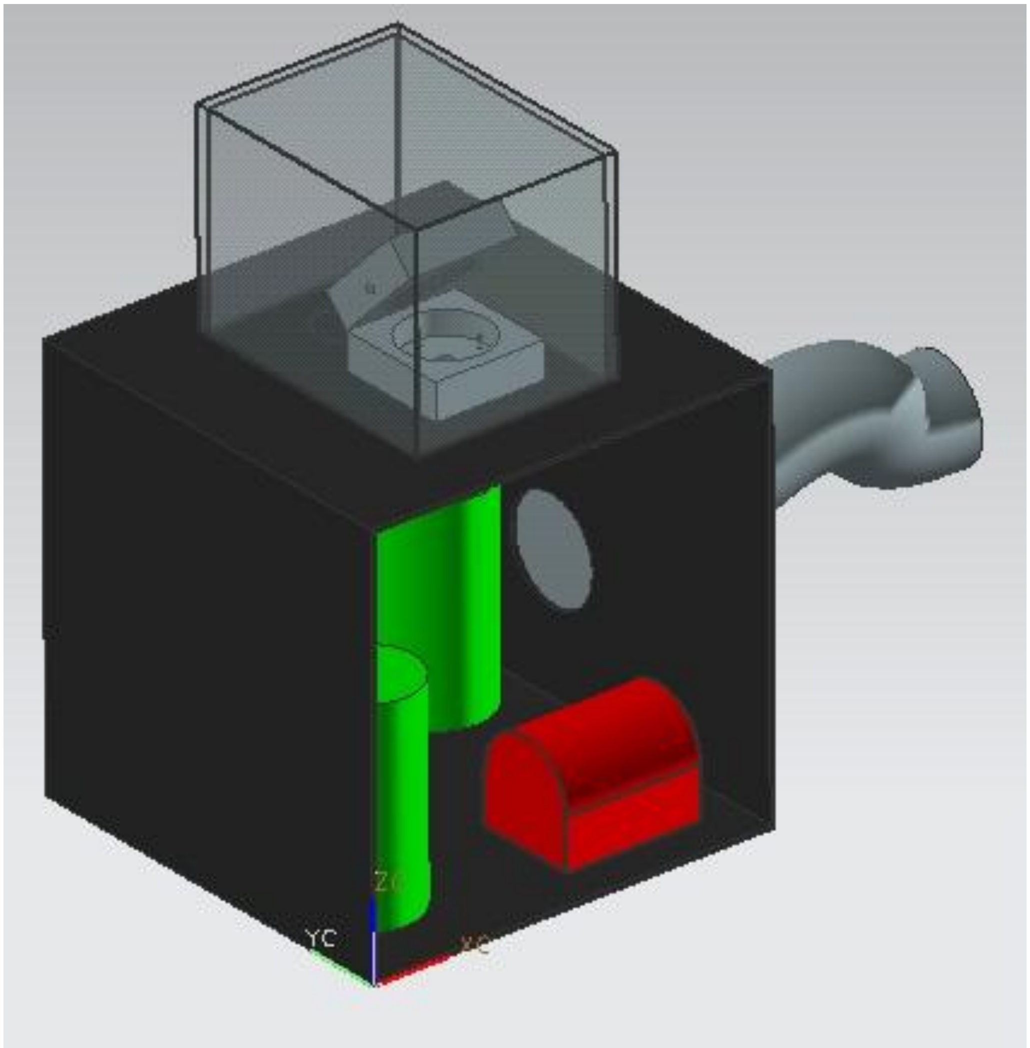
Etching chamber Lid + Diffuser Plate



Etching chamber Bottom + Wafer Holding Pins



System Enclosure and Component Placement



APPENDIX K: CFD Fluid Models and Flow Results

Simulation Performed: COMSOL Multiphysics

-Steady state Navier Stokes equations

-GMRES solver, 10e-6 convergence

-Inlet flow velocity = 1 m/s.

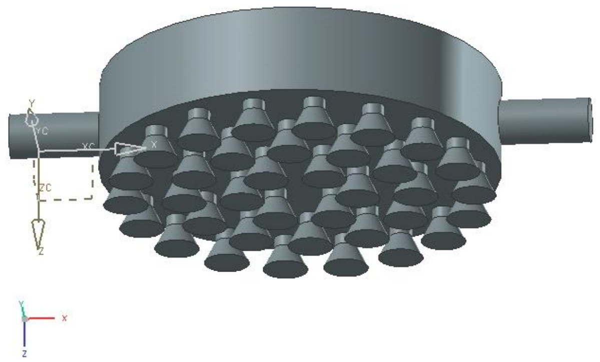
-Outlet pressure = 0.0001 Pa

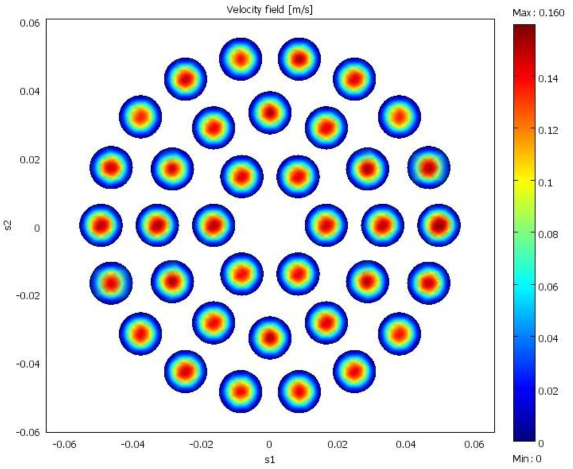
-Fluid temperature = 300 K

-No slip wall condition

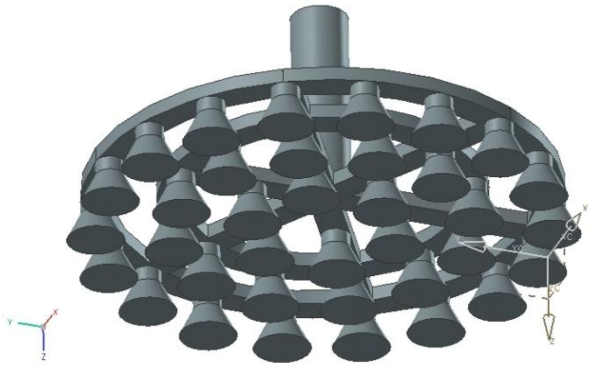
Models and Results

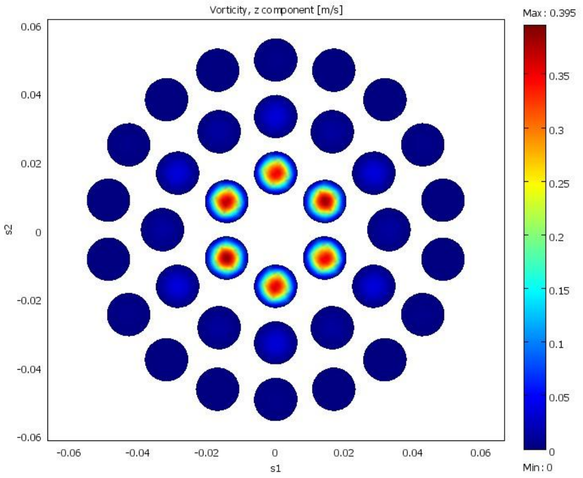
1. Open upper chamber design



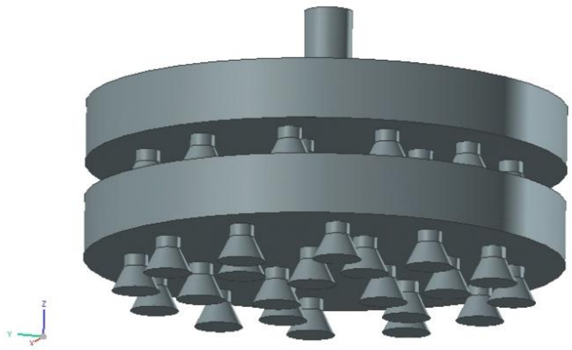


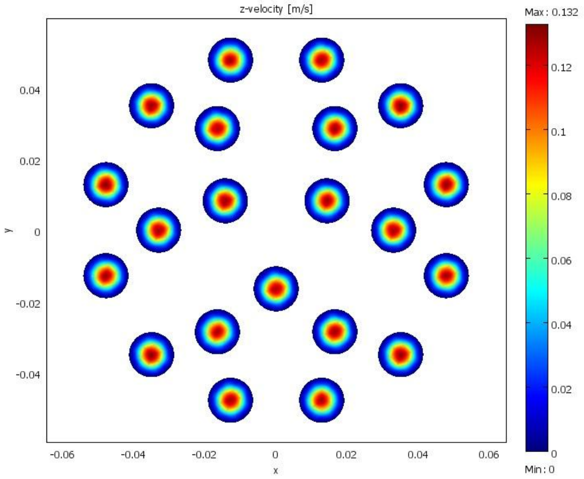
2. Circular channels





3. Lift plates





APPENDIX L: Intermediate Flow Distrubtion Designs Report

Introduction

In this brief report, four designs are presented that address the suggested design changes during the meeting held on Thursday February 18, 2010. After each design has been discussed, a simple and cursory risk assesment is performed. This paper selects two primary designs with which the team is most comfortable. We would like to discuss these two concepts (as well as the additional two, if necessary) durnig our meeting on February 19, 2010.

PRESENTATION OF THE DESIGNS

DESIGN 1: Existing design + channels in lid

This design is similar to the final design presented in DR2 with the exception of a few modifications to the upper lid of the etching chamber. Instead of having a large bored opening connected to the inlet lines, the flow of the working fluid is destributed by 1/4" channels that run underneath each hole in the diffuser plate (shown in green in image 2).

The current images show the flow coming in from the side and then making a 90 degree turn to flow up to the diffuser plate. This could be replaced with just a vertical hole coming from the top of the main lid but this will be constrained by space in the enclosure and flexibility of the inlet line. The cross section in image 4 shows this turn as well as the cross section of the diffuser plate holes.

Two subtle design features:

(1) – Each of the six branches stemming from the center of the plate are connected by two circular channels that go around the entire plate. This was created to connect all the holes in the diffuser plate and potentially eliminate dead zones in the flow pattern. Further modifications to the flow pattern will be added when a CFD model of the current design is completed and analyzed (within the next week).

(2) – The hole in the center of the diffuser plate was omitted to prevent flow of the gas from only traveling through this hole and not spreading out through the entire chamber. This will also prevent only the center of the wafer being etched and not any detail around the outside.

In assembly the diffuser plate will be sealed to this top half in order to prevent leaks aroung the outside of the diffuser plate and top half interface surface. This will be achieved with some sort of adhesive or caulking that's not reactive with the XeF_2 or HF.

IMAGE 1

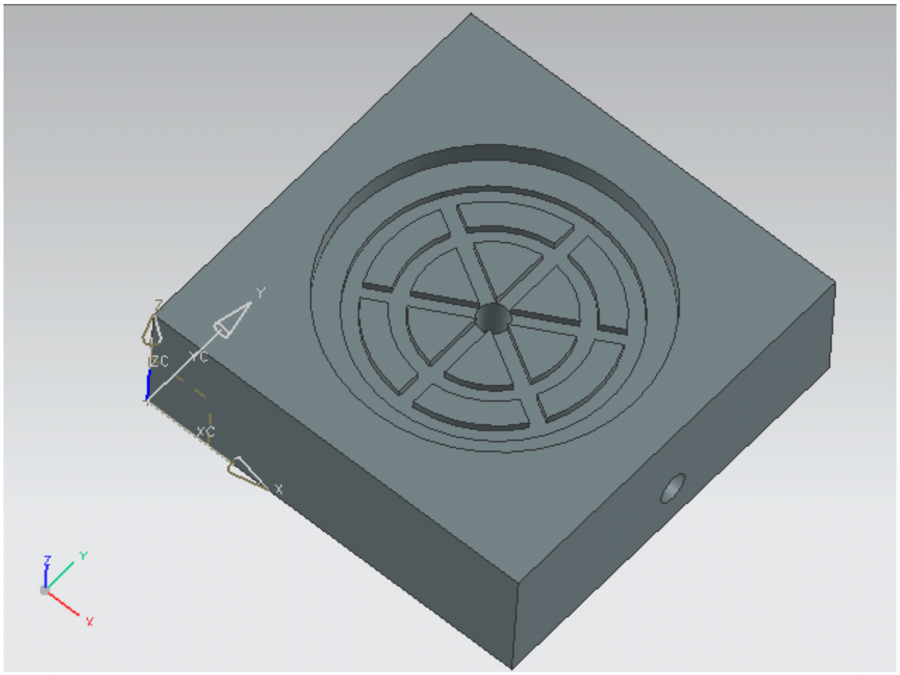


IMAGE 2

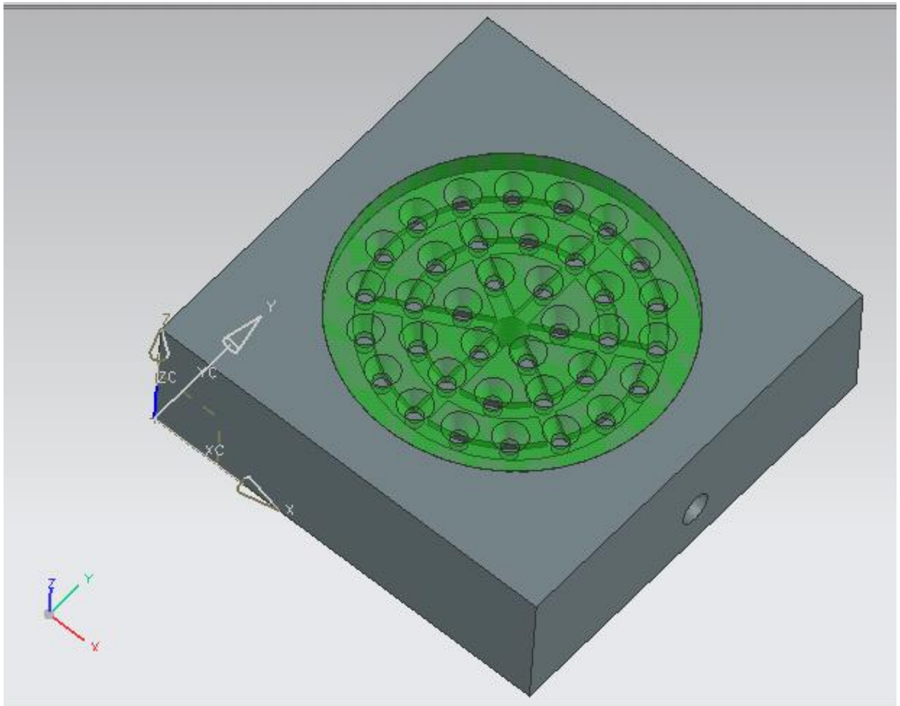


IMAGE 3

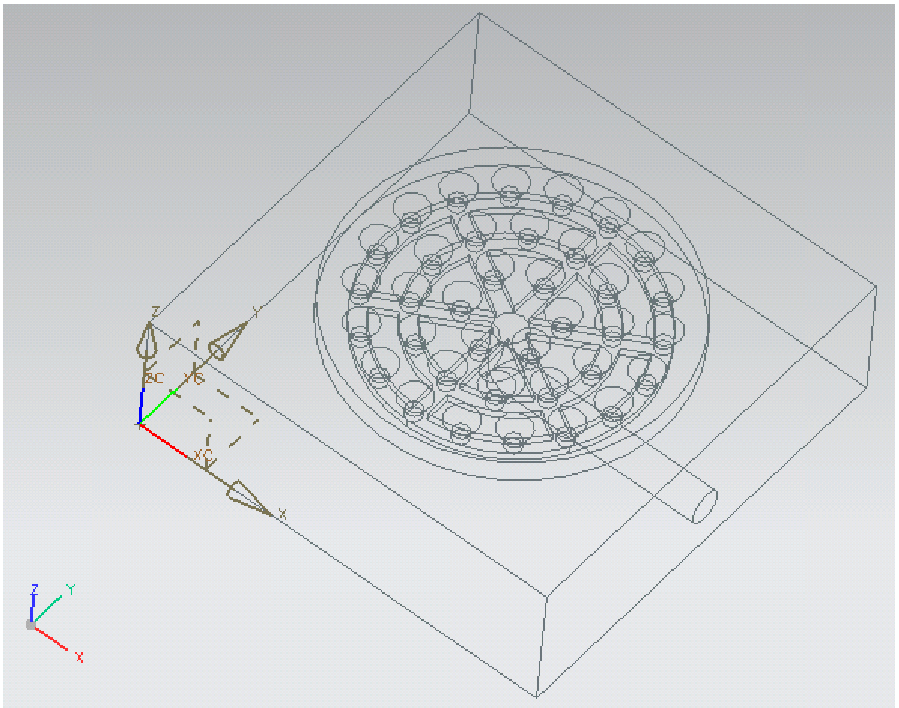
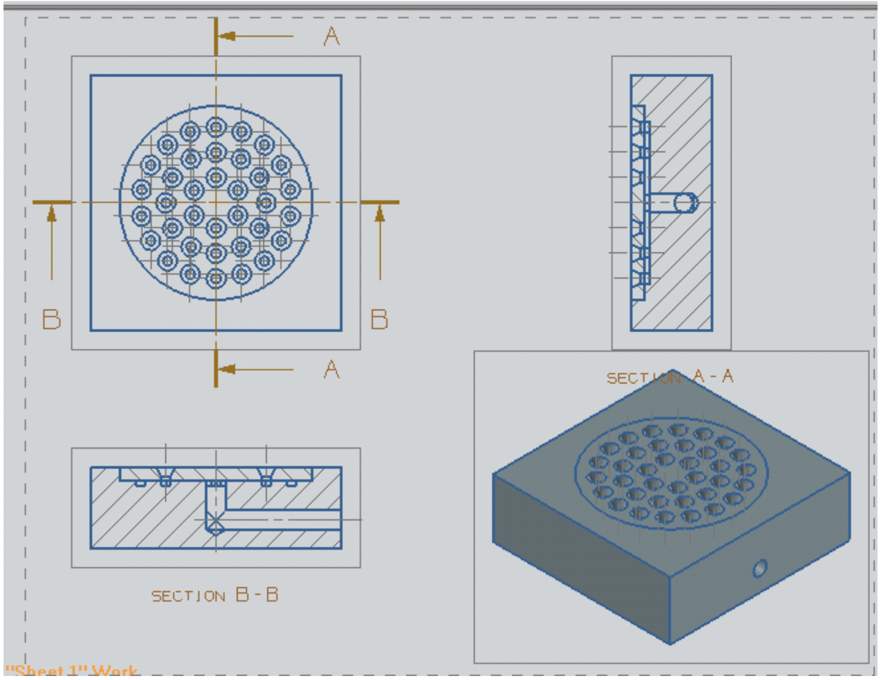


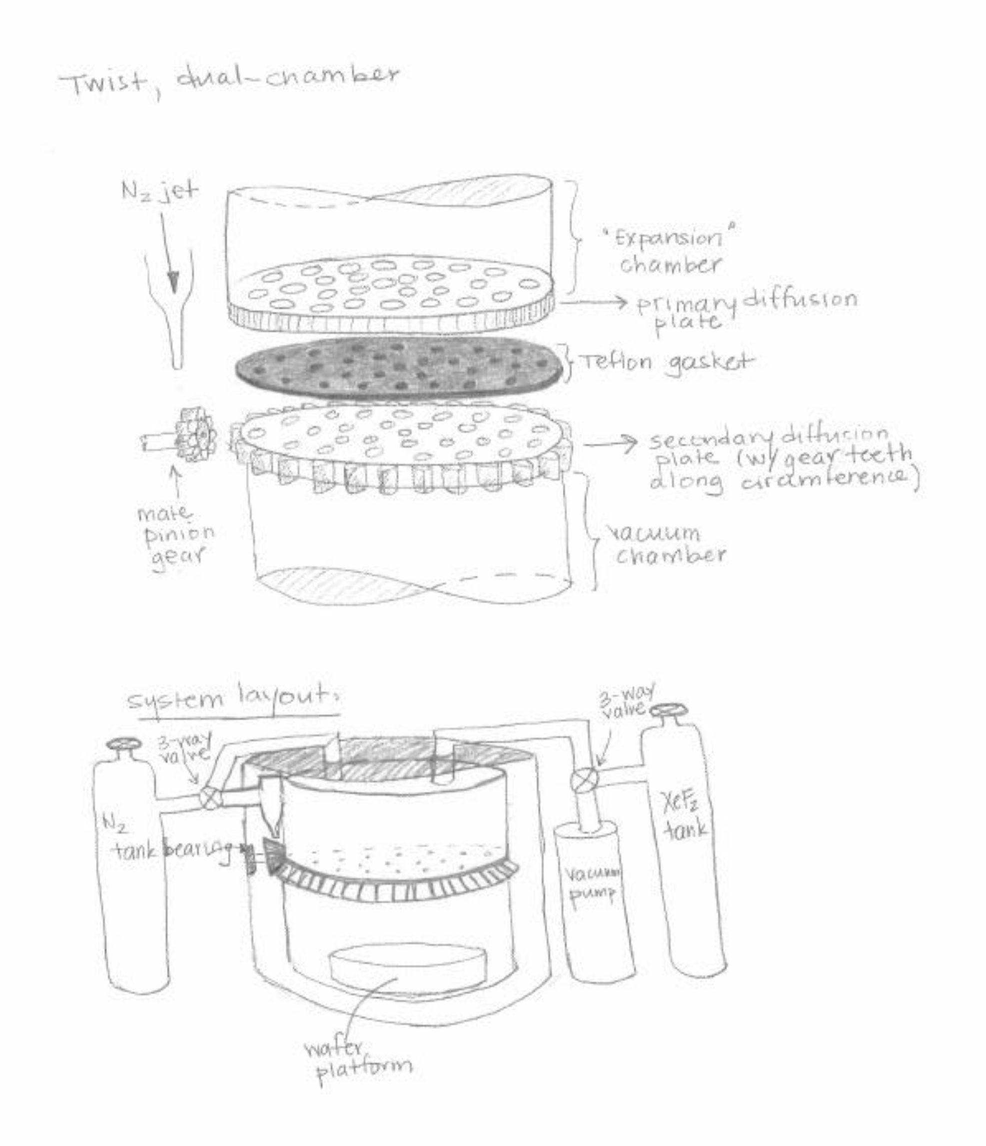
IMAGE 4



DESIGN 2: Twisting Dual-chamber with Teflon gasket

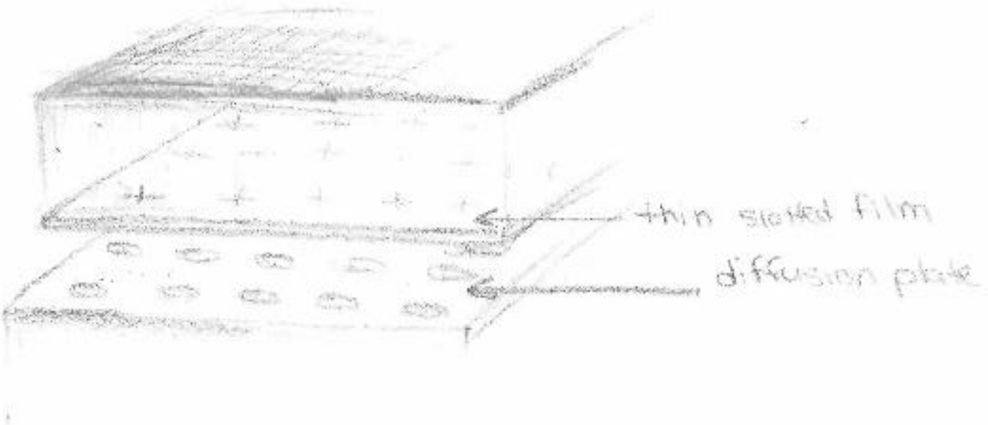
As seen in the sketches below, this design embodies the concept of twisting two similarly machined disks in order to open and close a set of diffusion holes (close by misalignment and open by alignment). In between these two disks (and affixed in some fashion to one of the disks) will be a gasket made of Teflon (in order to make the friction during the twist motion as small as possible as well as to improve the goodness of the seal between the two disks). The bottom disk will have gear teeth around its circumference. This will be used to turn the disk with a mated pinion gear. The pinion gear will be driven by compressed Nitrogen flow. The bottom chamber (which is connected to the large geared surface) must also be seated on rollers or some kind of minimal friction surface as it must rotate with the gear freely.

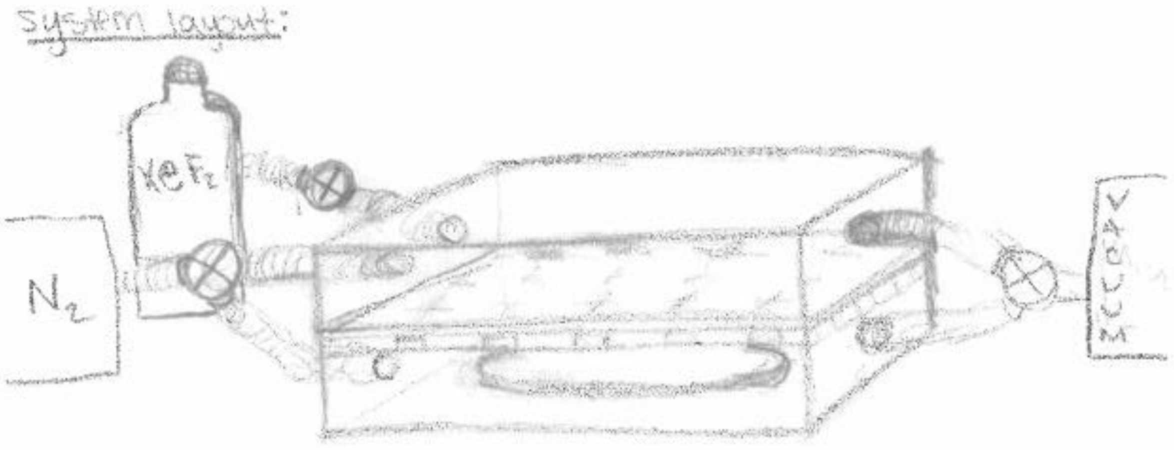
This design features only two valves; however it must also incorporate a compressor to generate enough pressure to turn the pinion gear as well as a motor to operate said compressor.



DESIGN 3: Multiple “Flap” valve design

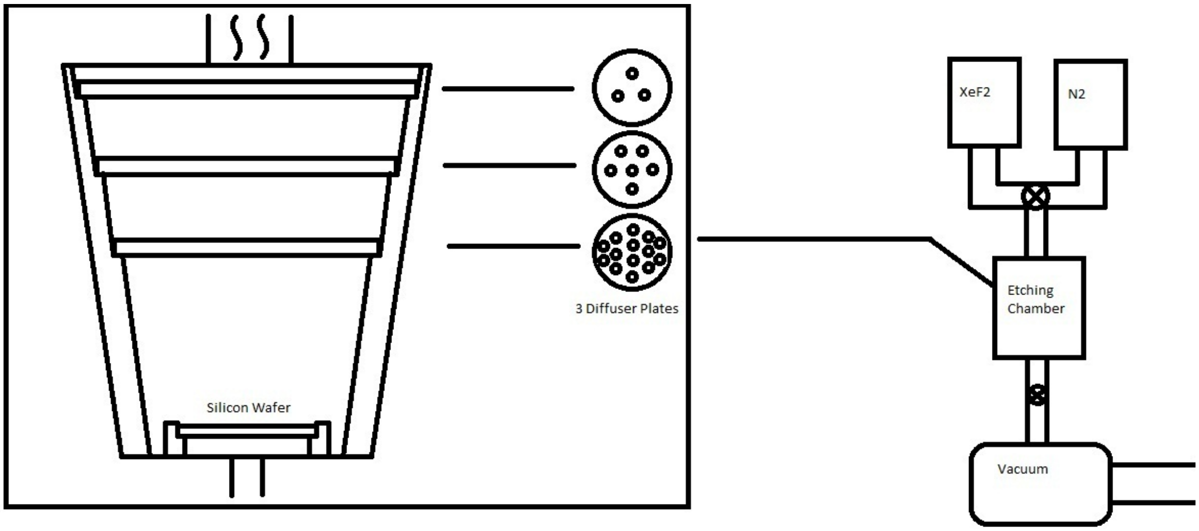
The system consists of a top (expansion) chamber and bottom (etching) chamber. Situated between the two chambers are a diffusion plate, patterned with holes, and a thin slotted film. The slots in the film are aligned with the holes in the diffusion plate. In operation, you would purge the chambers with N_2 and then evacuate the top and bottom individually. The XeF_2 would then be released into the pseudo expansion chamber and the change in pressure would force the slots open, thus releasing the etching fluid into the etching chamber. This process would be repeated until the desired etch was achieved.





DESIGN 4: Elimination of expansion chamber with diffusion hierarchy

The fourth design combines the expansion chamber with the etching chamber. There are three diffusion plates that will help to not only evenly distribute the etching gas but also to help eliminate the transient portion of the expansion of the gas into the etching chamber. Each diffusion plate has additional holes of smaller diameter as it gets closer to the etching surface. The theory behind this layering of progressively more complex diffusion plates is that the gas will be allowed to expand between layers and the fluid will become a uniform mixture by the time it reaches the surface to be etched. This will eliminate the need for an expansion chamber. An additional convenient feature of this design is that it only requires two valves and no additional controllers, motors or components from the original design.



RISK ASSESSMENT:

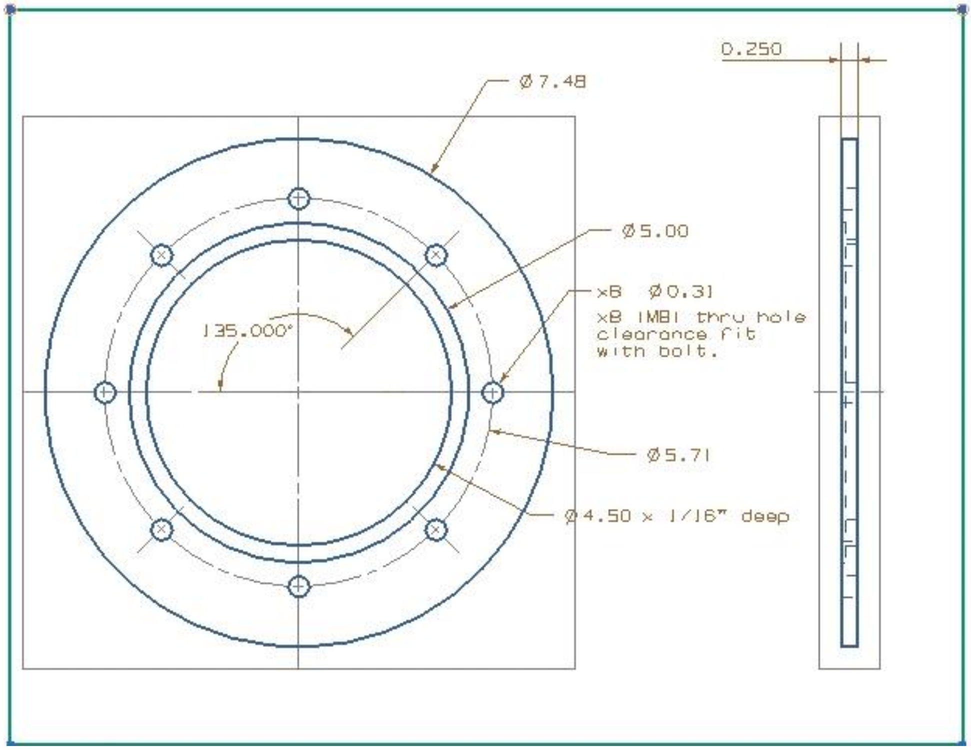
In the table below, six areas of potential failure were identified (first column). These failures were ranked on a 1-10 scale where 1 indicates that if the mechanism were to fail in this mode the design would still be able to function and 10 indicates that failure in this mode would result in catastrophic failure of the mechanism. Each design was then rated as a 1, 3, or 9. Here 1 indicates that the mechanism is not likely to fail in this mode, 3 indicates that it may fail, and 9 indicates that it is likely to fail. The scores were then weighted by their importance rating and then added. A high score in the Totals row indicates that the design is high risk for failure and a low score indicates that it is a relatively low risk for failure.

As seen in the table below, designs 3 and 4 have the lowest amount of risk associated with them, and thus the team is most comfortable pursuing either of these designs. Design 1 would also be a suitable design as it scored only 4 points worse than design 3. Design 2 has been eliminated due to the complexity of its inner workings and the time and monetary stresses that it would induce to manufacture and implement.

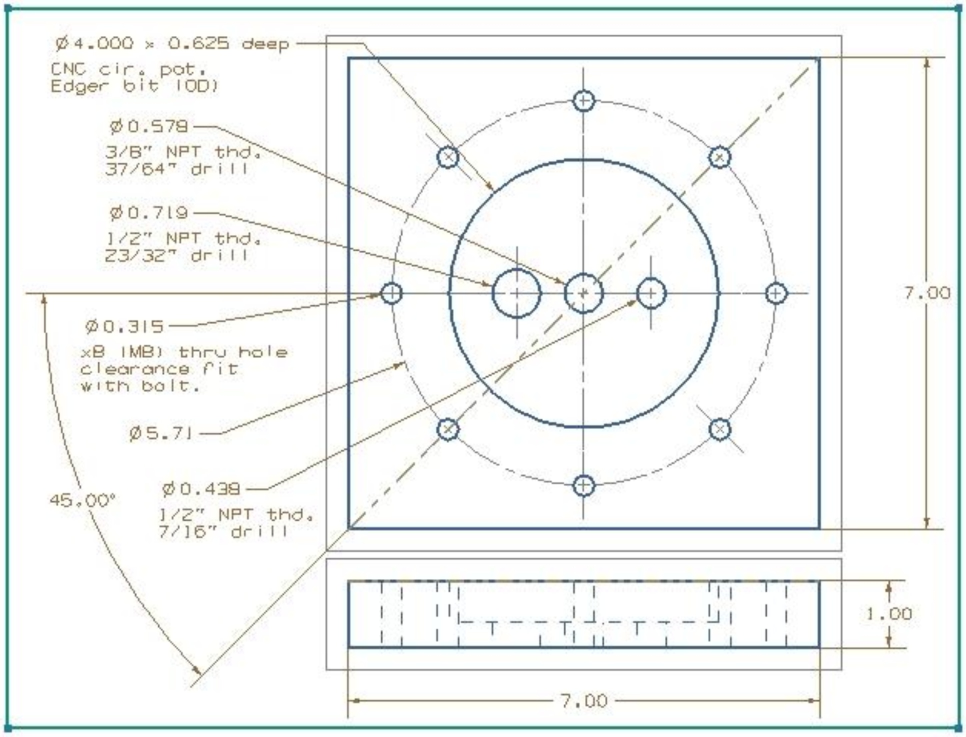
Failure Mode	**Importance (1-10)**	**1**	**2**	**3**	**4**
Loss of Seal / Leakage	4	1	9	3	1
Manufacturing Flaws	8	3	9	9	1
Complexity	5	9	9	3	1
Even Dispersion	9	3	1	1	9
Cost	10	9	9	3	1
Material Wear	6	1	9	9	1
Totals	---	196	306	192	114

APPENDIX M: CAD Drawings

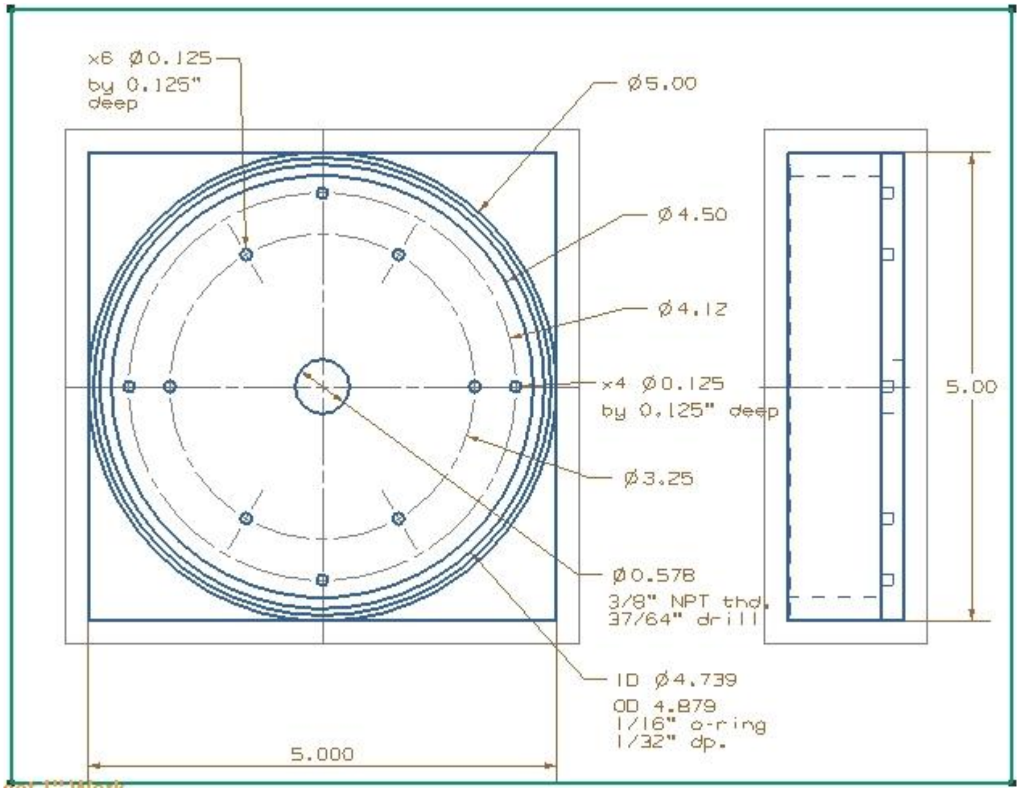
-NEW: Adapter plate



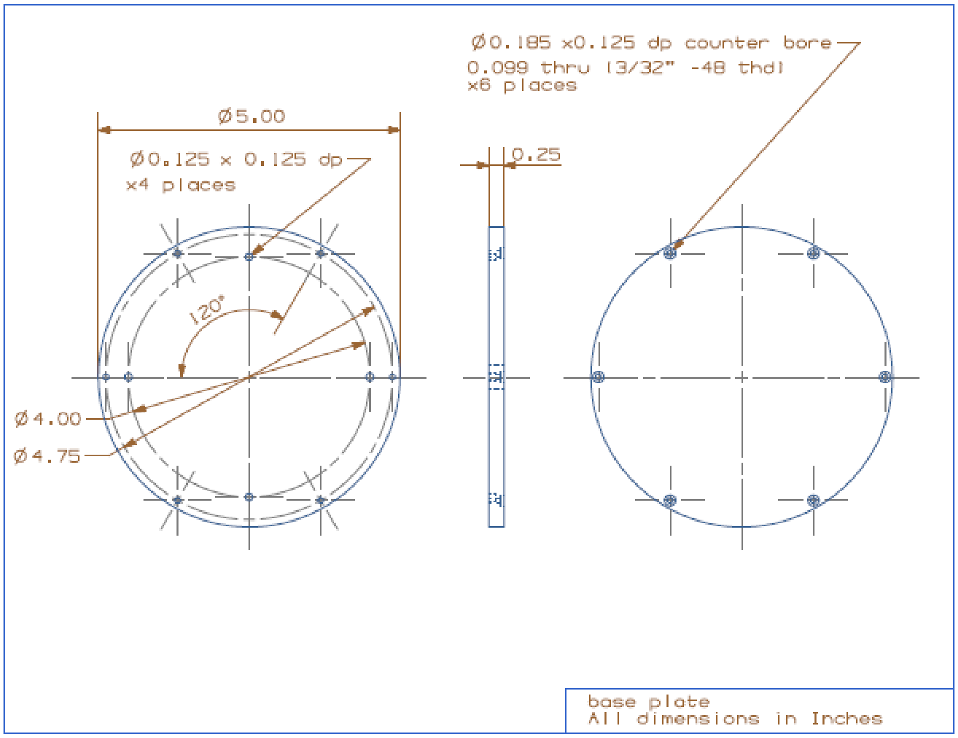
-NEW: Top lid



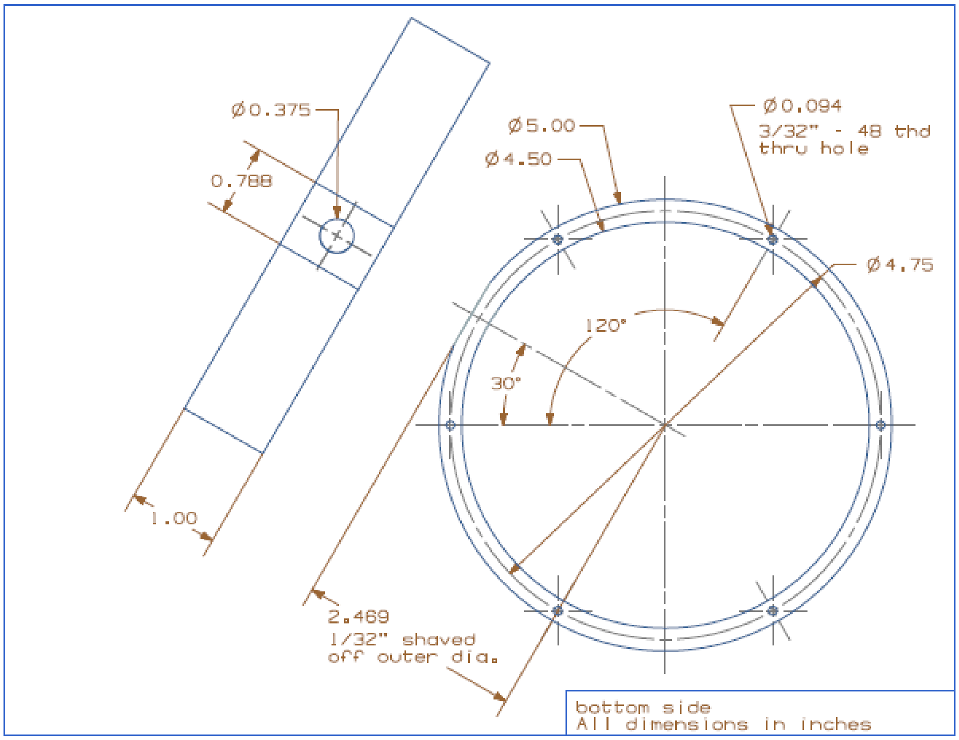
-NEW: Base



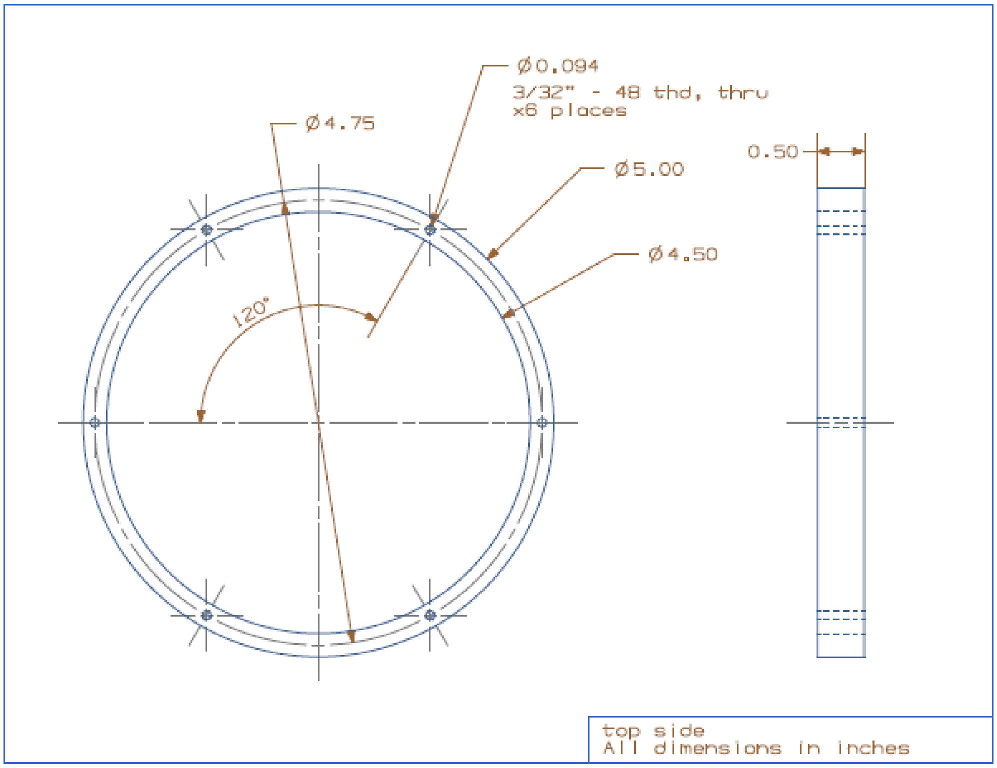
-Base Plate



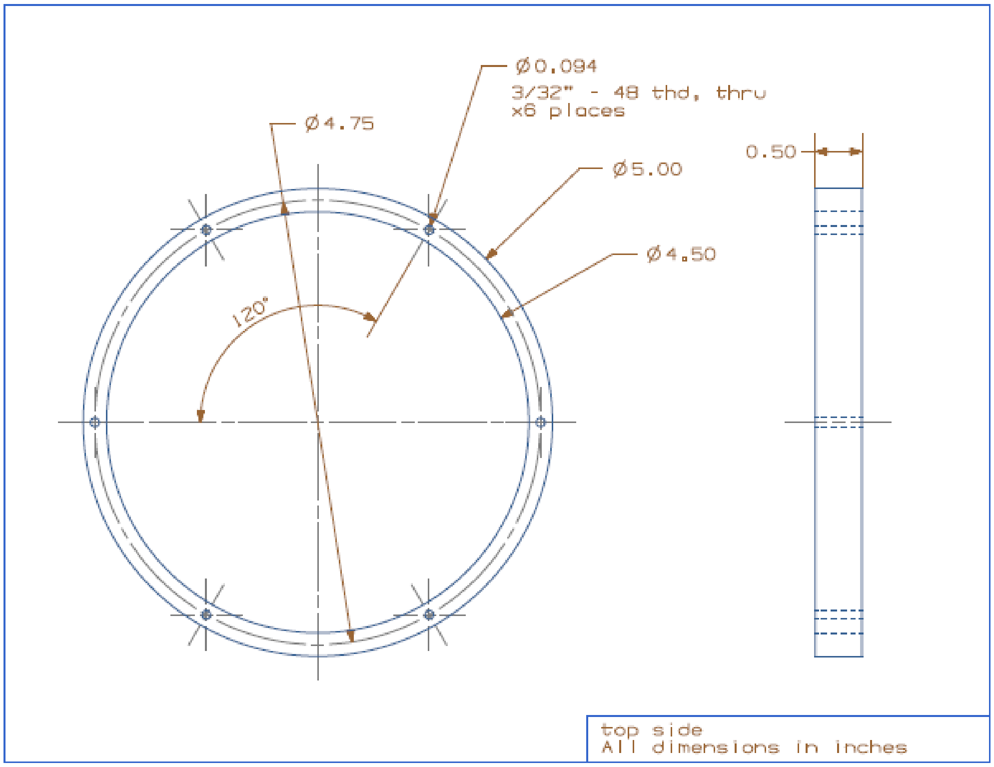
-Bottom Side


Ø0.375
0.788
1.00
Ø5.00
Ø4.50
Ø0.094
3/32" - 48 thd
thru hole
Ø4.75
120°
30°
2.469
1/32" shaved
off outer dia.
bottom side
All dimensions in inches

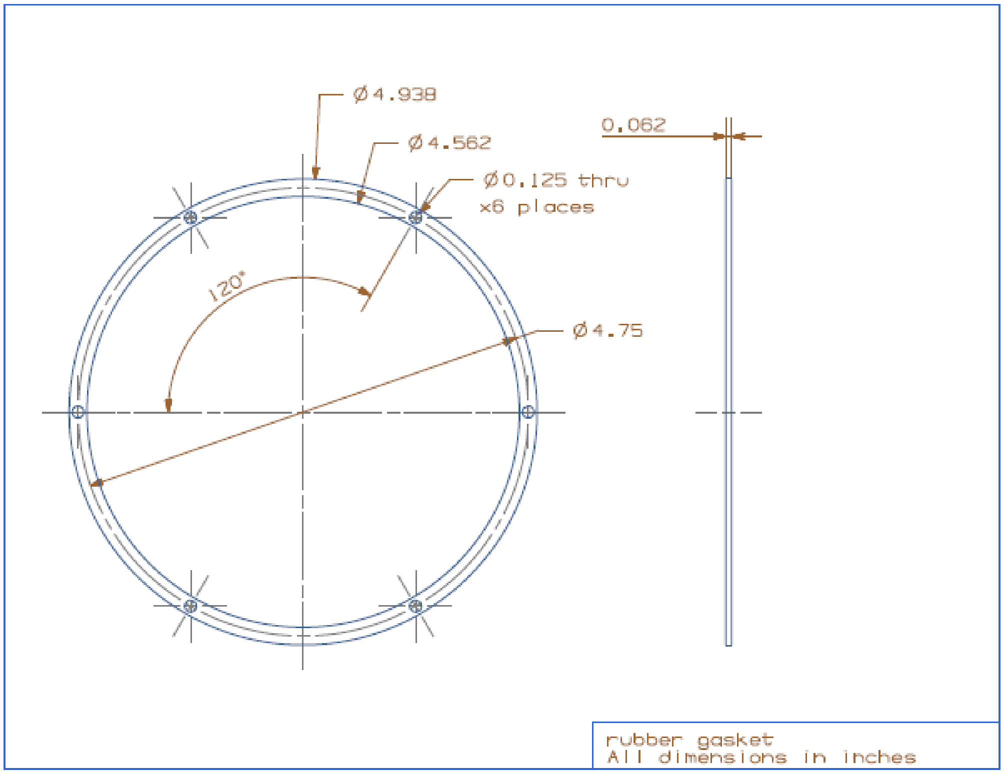
-Top Side


Ø0.094
3/32" - 48 thd, thru
x6 places
Ø4.75
0.50
Ø5.00
Ø4.50
120°
top side
All dimensions in inches

-Top Lid

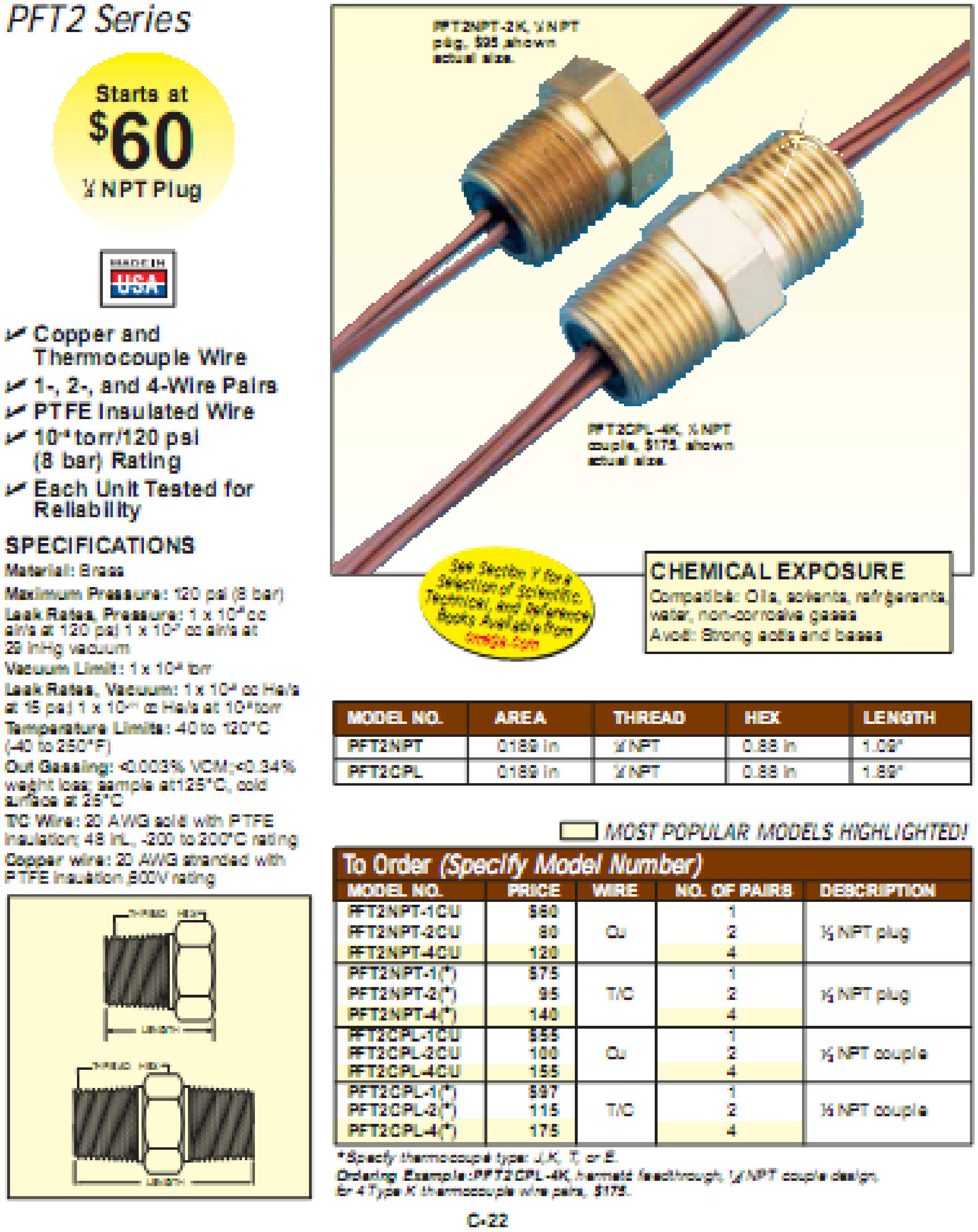


-Gasket



APPENDIX N: Parts and Components Data Sheet or CAD Drawings

-Electrical Wire Feed-thru Seal (Omega.com)



PFT2 Series

Starts at $60 ½ NPT Plug

MADE IN USA

- ✓ Copper and Thermocouple Wire
- ✓ 1-, 2-, and 4-Wire Pairs
- ✓ PTFE Insulated Wire
- ✓ 10^{-4} torr/120 psi (8 bar) Rating
- ✓ Each Unit Tested for Reliability

SPECIFICATIONS

Material: Brass

Maximum Pressure: 120 psi (8 bar)

Leak Rates, Pressure: 1 x 10^{-4} cc air/s at 120 psi; 1 x 10^{-7} cc air/s at 29 inHg vacuum

Vacuum Limit: 1 x 10^{-4} torr

Leak Rates, Vacuum: 1 x 10^{-4} cc He/s at 15 psi; 1 x 10^{-11} cc He/s at 10^{-4} torr

Temperature Limits: 40 to 120°C (-40 to 250°F)

Out Gassing: <0.003% VCM; <0.34% weight loss; sample at 125°C, cold surface at 25°C

T/C Wire: 20 AWG solid with PTFE insulation; 48 in L, -200 to 200°C rating

Copper wire: 20 AWG stranded with PTFE insulation, 600V rating

PFT2NPT-2K, ½ NPT plug, $95 shown actual size.

PFT2CPL-4K, ½ NPT couple, $175 shown actual size.

See Section Y for a Selection of Scientific, Technical, and Reference Books Available from omega.com

CHEMICAL EXPOSURE

Compatible: Oils, solvents, refrigerants, water, non-corrosive gases

Avoid: Strong acids and bases

MODEL NO.	AREA	THREAD	HEX	LENGTH
PFT2NPT	0.189 in	½ NPT	0.88 in	1.09"
PFT2CPL	0.189 in	½ NPT	0.88 in	1.89"

▭ *MOST POPULAR MODELS HIGHLIGHTED!*

To Order *(Specify Model Number)*

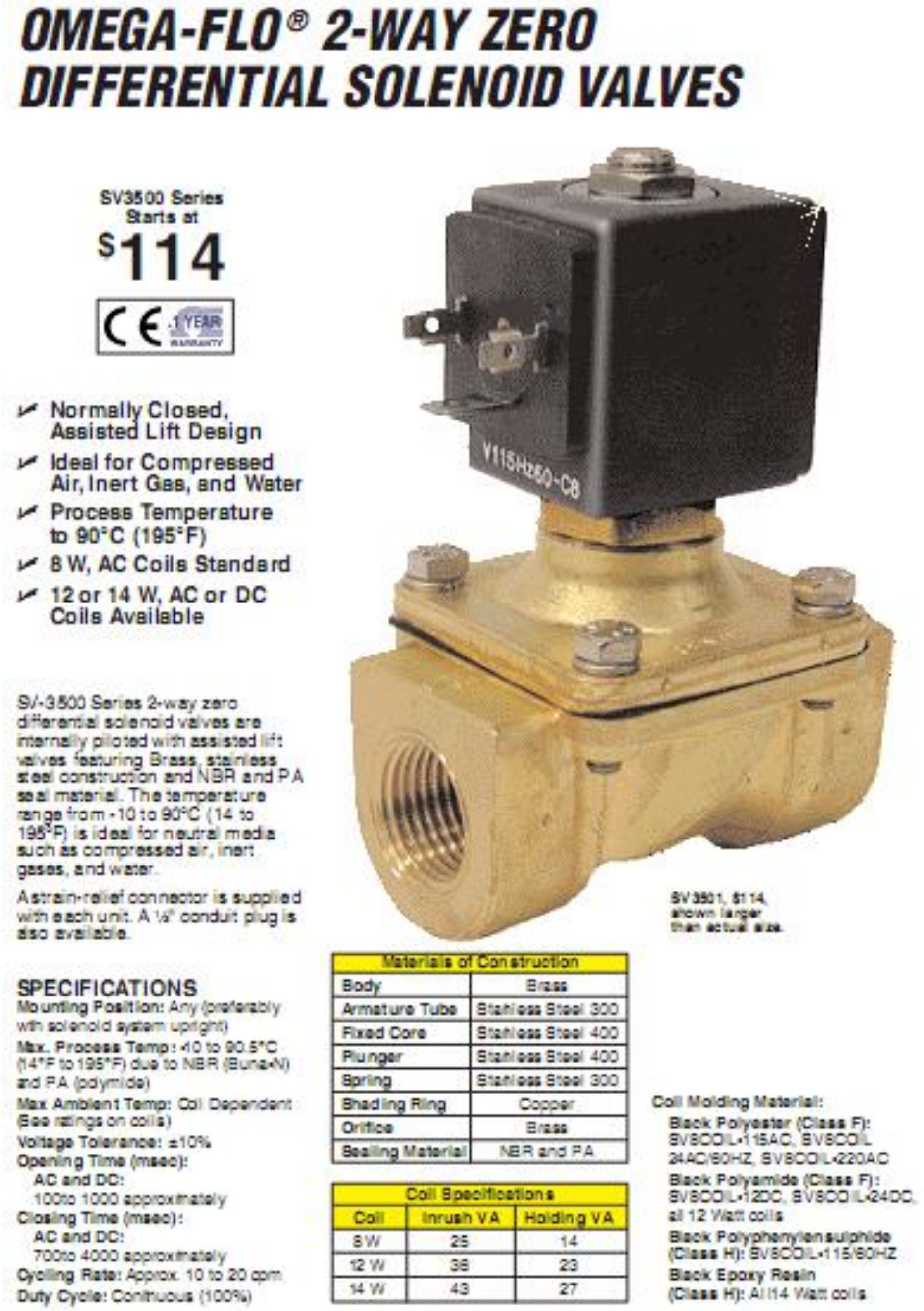
MODEL NO.	PRICE	WIRE	NO. OF PAIRS	DESCRIPTION
PFT2NPT-1CU	$60	Cu	1	½ NPT plug
PFT2NPT-2CU	80		2	
PFT2NPT-4CU	120		4	
PFT2NPT-1(*)	$75	T/C	1	½ NPT plug
PFT2NPT-2(*)	95		2	
PFT2NPT-4(*)	140		4	
PFT2CPL-1CU	$55	Cu	1	½ NPT couple
PFT2CPL-2CU	100		2	
PFT2CPL-4CU	155		4	
PFT2CPL-1(*)	$97	T/C	1	½ NPT couple
PFT2CPL-2(*)	115		2	
PFT2CPL-4(*)	175		4	

**Specify thermocouple type: J, K, T, or E.*

Ordering Example: PFT2CPL-4K, hermetic feedthrough, ½ NPT couple design, for 4 Type K thermocouple wire pairs, $175.

C-22

-Two-way Solenoid Valves (Omega.com)



OMEGA-FLO® 2-WAY ZERO DIFFERENTIAL SOLENOID VALVES

SV3500 Series
Starts at
$114

CE 1 YEAR WARRANTY

- Normally Closed, Assisted Lift Design
- Ideal for Compressed Air, Inert Gas, and Water
- Process Temperature to 90°C (195°F)
- 8 W, AC Coils Standard
- 12 or 14 W, AC or DC Coils Available

SV-3500 Series 2-way zero differential solenoid valves are internally piloted with assisted lift valves featuring Brass, stainless steel construction and NBR and PA seal material. The temperature range from -10 to 90°C (14 to 195°F) is ideal for neutral media such as compressed air, inert gases, and water.

A strain-relief connector is supplied with each unit. A ½" conduit plug is also available.

SV3501, $114, shown larger than actual size.

SPECIFICATIONS

Mounting Position: Any (preferably with solenoid system upright)

Max. Process Temp: -10 to 90.5°C (14°F to 195°F) due to NBR (Buna-N) and PA (polymide)

Max Ambient Temp: Coil Dependent (See ratings on coils)

Voltage Tolerance: ±10%

Opening Time (msec):
AC and DC:
100to 1000 approximately

Closing Time (msec):
AC and DC:
700to 4000 approximately

Cycling Rate: Approx. 10 to 20 cpm

Duty Cycle: Continuous (100%)

Materials of Construction	
Body	Brass
Armature Tube	Stainless Steel 300
Fixed Core	Stainless Steel 400
Plunger	Stainless Steel 400
Spring	Stainless Steel 300
Shading Ring	Copper
Orifice	Brass
Sealing Material	NBR and PA

Coil Specifications		
Coil	Inrush VA	Holding VA
8 W	25	14
12 W	36	23
14 W	43	27

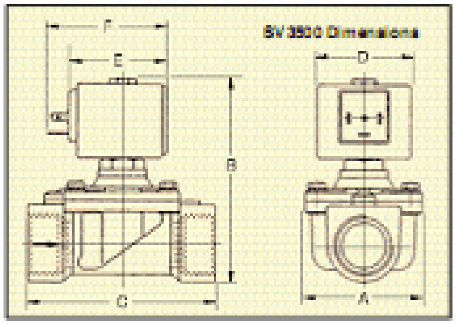
Coil Molding Material:

Black Polyester (Class F): SV8COIL-115AC, SV8COIL 24AC/60HZ, SV8COIL-220AC

Black Polyamide (Class F): SV8COIL-12DC, SV8COIL-24DC, all 12 Watt coils

Black Polyphenylensulphide (Class H): SV8COIL-115/60HZ

Black Epoxy Resin (Class H): All 14 Watt coils



Valve Dimensions			
Pipe Size	A	B	C
¼, ⅜ NPT	1³¹⁄₃₂"	3½"	2⅞"
½, ¾ NPT	1³¹⁄₃₂"	3¹⁵⁄₁₆"	2⅝"
1 NPT	2⁹⁄₁₆"	4¹³⁄₃₂"	4³⁄₃₂"

Coil Dimensions			
Coil	D	E	F
8 W	1⁵⁄₁₆"	1²¹⁄₃₂"	2¼"
12 W	1⁵⁄₁₆"	1²⁹⁄₃₂"	2¼"
14 W	2¹⁄₁₆"	5⁵⁄₃₂"	2¼"

▭ MOST POPULAR MODELS HIGHLIGHTED!

To Order *(Specify Model Number)*

Model No.	Price	Pipe Size	Orifice Size	Cv Flow Factor	Coils		Operating Pressure		
							Min psi	M.O.P.D.*	
					Standard	Optional		AC psi	DC psi
SV3501	$114	¼"	⁷⁄₁₆"	1.4	8 W		0	200	75
		¼"	⁷⁄₁₆"	1.4		12 or 14 W	0	200	200
SV3502	114	⅜"	⁷⁄₁₆"	1.4	8 W		0	200	75
		⅜"	⁷⁄₁₆"	1.4		12 or 14 W	0	200	200
SV3503	117	½"	⅝"	2.8	8 W		0	200	35
		½"	⅝"	2.8		12 or 14 W	0	200	160/200‡
SV3504	117	¾"	⅝"	2.8	8 W		0	200	35
		¾"	⅝"	2.8		12 or 14 W	0	200	160/200‡
SV3505	200	1"	1"	8.3	8 W		0	116	0
		1"	1"	8.3		12 or 14 W	0	200	22/85‡

** Maximum operational pressure differential.*

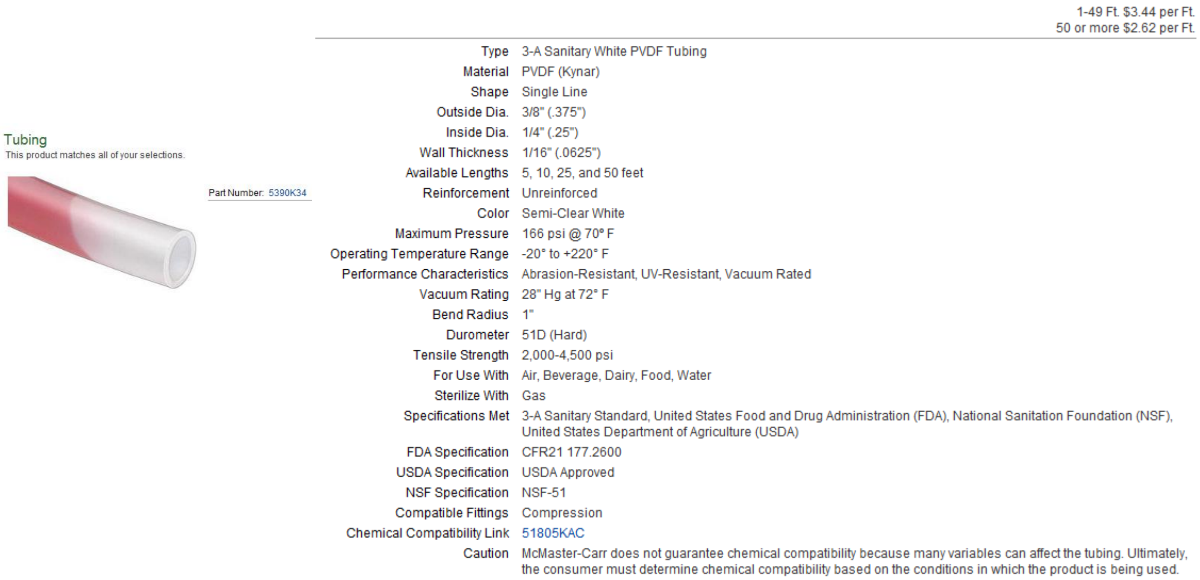
‡ Ratings for 12 W/14 W as shown.

Accessories

Model No.	Price	Description
Connectors		
SV-CGC	$8	Replacement cable grip connector
SV-CC	8	½" conduit connector
Coils		
SV8COIL-115AC	$16	Replacement 8 W coil for 110 to 120 Vac/50 to 60 Hz 154°C (310°F) (Class F)
SV8COIL-12DC	16	8 W coil for 12 Vdc154°C (310°F) (Class F)
SV8COIL-24DC	16	8 W coil for 24 Vdc 154°C (310°F) (Class F)
SV8COIL-24AC/60HZ	16	8 W coil for 24 Vac/60Hz 154°C (310°F) (Class F)
SV8COIL-220AC	16	8 W coil for 220to 240 Vac/50to 60 Hz154°C (310°F) (Class F)
SV8COIL-115/60HZ	23	8 W coil for 115 Vac/60 Hz 182°C (360°F) (Class H)
SV12COIL-120/60HZ	24	12 W coil for 120 Vac/60 Hz 154°C (310°F) (Class F)
SV12COIL-12DC	52	12 W coil for 12Vdc 154°C (310°F) (Class F)
SV12COIL-24DC	24	12 W coil for 24Vdc 154°C (310°F) (Class F)
SV14COIL-24DC	52	14 W coil for 24Vdc 182°C (360°F) (Class H)
SV14COIL-24/50-60HZ	52	14 W coil for 24Vdc/50 to 60Hz 182°C (360°F) (Class H)
SV14COIL-12DC	52	14 W coil for 12Vdc 182°C (360°F) (Class H)
Repair Kits (Include Diaphragm, Spring, Plunger, and O-rings)		
VRK-3512	$36	Repair kit for SV3501 and SV3502
VRK-3534	36	Repair kit for SV3503 and SV3504
VRK-3505	36	Repair kit for SV3505
FW-306	125	Reference Book: Valve Handbook

Comes complete with operator's manual, 8 W coil and cable grip connector.
***Ordering Examples:** SV3501, ¼" valve for ⁷⁄₁₆" orifice, $114.*
SV3503, ½" valve for ⅝" orifice, $117.

-Kynar Tubing (McMaster.com)



Tubing

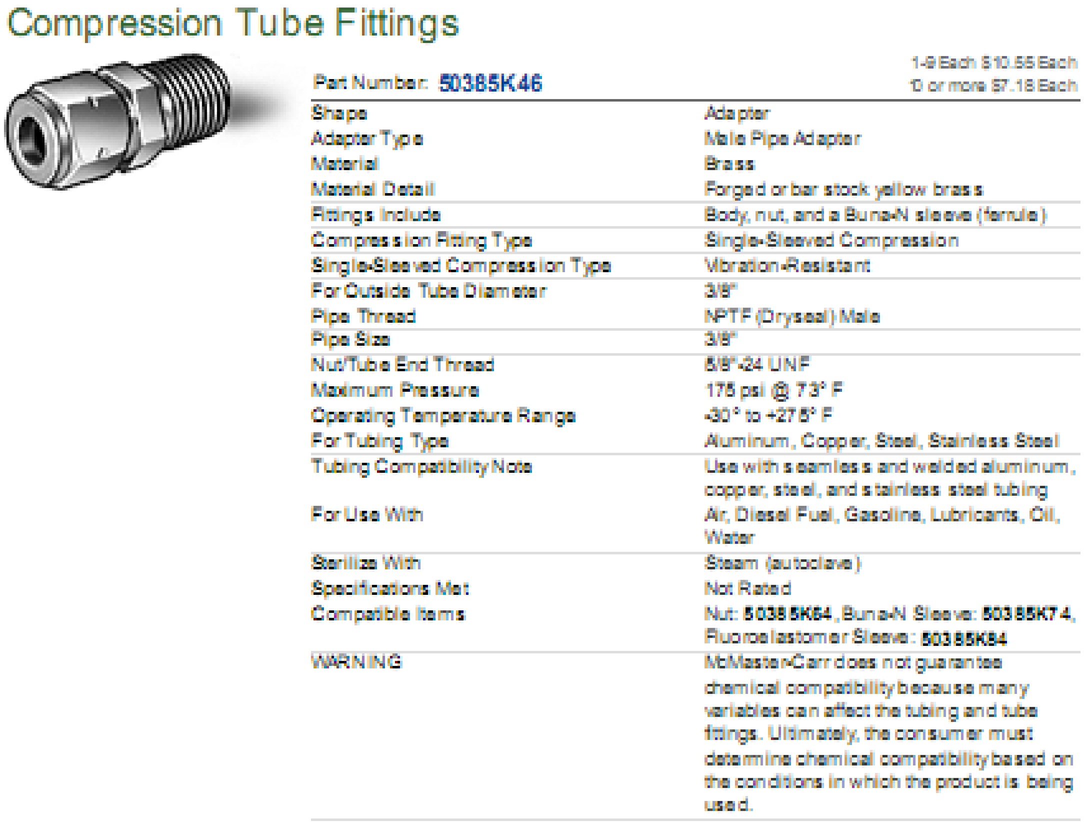
This product matches all of your selections.

Part Number: 5390K34

1-49 Ft. $3.44 per Ft.
50 or more $2.62 per Ft.

Type	3-A Sanitary White PVDF Tubing
Material	PVDF (Kynar)
Shape	Single Line
Outside Dia.	3/8" (.375")
Inside Dia.	1/4" (.25")
Wall Thickness	1/16" (.0625")
Available Lengths	5, 10, 25, and 50 feet
Reinforcement	Unreinforced
Color	Semi-Clear White
Maximum Pressure	166 psi @ 70° F
Operating Temperature Range	-20° to +220° F
Performance Characteristics	Abrasion-Resistant, UV-Resistant, Vacuum Rated
Vacuum Rating	28" Hg at 72° F
Bend Radius	1"
Durometer	51D (Hard)
Tensile Strength	2,000-4,500 psi
For Use With	Air, Beverage, Dairy, Food, Water
Sterilize With	Gas
Specifications Met	3-A Sanitary Standard, United States Food and Drug Administration (FDA), National Sanitation Foundation (NSF), United States Department of Agriculture (USDA)
FDA Specification	CFR21 177.2600
USDA Specification	USDA Approved
NSF Specification	NSF-51
Compatible Fittings	Compression
Chemical Compatibility Link	51805KAC
Caution	McMaster-Carr does not guarantee chemical compatibility because many variables can affect the tubing. Ultimately, the consumer must determine chemical compatibility based on the conditions in which the product is being used.

-Swagelok to Pipe thd. Adapter (McMaster.com)

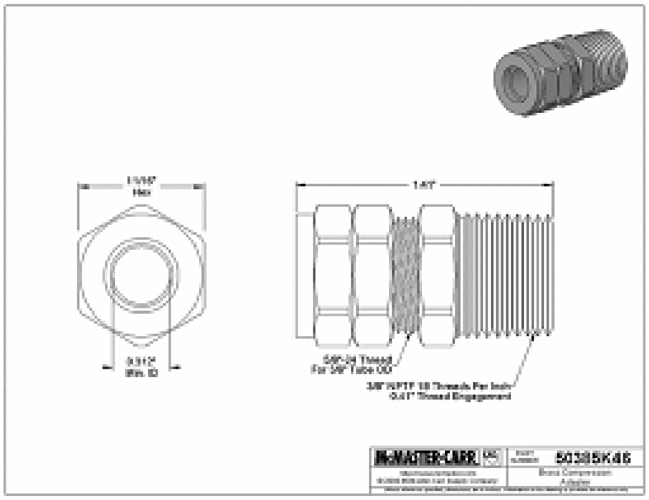


Compression Tube Fittings

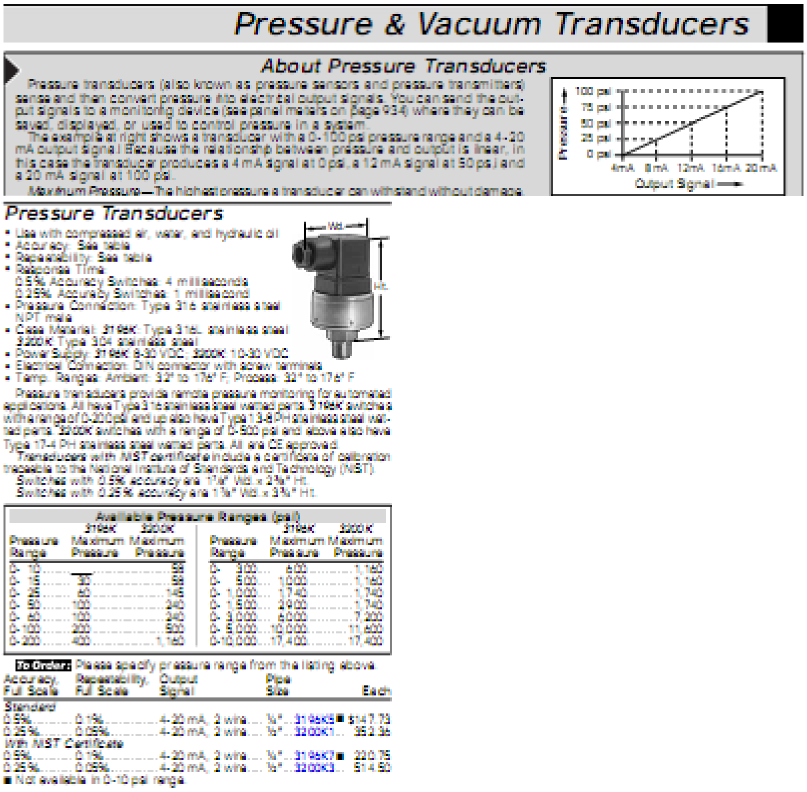
Part Number: 50385K46

1-9 Each $10.55 Each
10 or more $7.18 Each

Shape	Adapter
Adapter Type	Male Pipe Adapter
Material	Brass
Material Detail	Forged or bar stock yellow brass
Fittings Include	Body, nut, and a Buna-N sleeve (ferrule)
Compression Fitting Type	Single-Sleeved Compression
Single-Sleeved Compression Type	Vibration-Resistant
For Outside Tube Diameter	3/8"
Pipe Thread	NPTF (Dryseal) Male
Pipe Size	3/8"
Nut/Tube End Thread	5/8"-24 UNF
Maximum Pressure	175 psi @ 73° F
Operating Temperature Range	-30° to +275° F
For Tubing Type	Aluminum, Copper, Steel, Stainless Steel
Tubing Compatibility Note	Use with seamless and welded aluminum, copper, steel, and stainless steel tubing
For Use With	Air, Diesel Fuel, Gasoline, Lubricants, Oil, Water
Sterilize With	Steam (autoclave)
Specifications Met	Not Rated
Compatible Items	Nut: 50385K64, Buna-N Sleeve: 50385K74, Fluoroelastomer Sleeve: 50385K84
WARNING	McMaster-Carr does not guarantee chemical compatibility because many variables can affect the tubing and tube fittings. Ultimately, the consumer must determine chemical compatibility based on the conditions in which the product is being used.



-Pressure Gauge (McMaster.com)



Pressure & Vacuum Transducers

About Pressure Transducers

Pressure transducers (also known as pressure sensors and pressure transmitters) sense and then convert pressure into electrical output signals. You can send the output signals to a monitoring device (see panel meters on page 934) where they can be saved, displayed, or used to control pressure in a system.

The example at right shows a transducer with a 0-100 psi pressure range and a 4-20 mA output signal. Because the relationship between pressure and output is linear, in this case the transducer produces a 4 mA signal at 0 psi, a 12 mA signal at 50 psi, and a 20 mA signal at 100 psi.

Maximum Pressure—The highest pressure a transducer can withstand without damage

Pressure Transducers

- Use with compressed air, water, and hydraulic oil
- Accuracy: See table
- Repeatability: See table
- Response Time:
  0.5% Accuracy Switches: 4 milliseconds
  0.25% Accuracy Switches: 1 millisecond
- Pressure Connection: Type 316 stainless steel NPT male
- Case Material: 3196K: Type 316L stainless steel
  3200K: Type 304 stainless steel
- Power Supply: 3196K: 8-30 VDC; 3200K: 10-30 VDC
- Electrical Connection: DIN connector with screw terminals
- Temp. Ranges: Ambient: 32° to 176° F; Process: 32° to 176° F

Pressure transducers provide remote pressure monitoring for automated applications. All have Type 316 stainless steel wetted parts. 3196K switches with a range of 0-200 psi and up also have Type 13-8 PH stainless steel wetted parts. 3200K switches with a range of 0-500 psi and above also have Type 17-4 PH stainless steel wetted parts. All are CE approved.

Transducers with NIST certificate include a certificate of calibration traceable to the National Institute of Standards and Technology (NIST).

Switches with 0.5% accuracy are 1⅞" Wd. x 2⅝" Ht.
Switches with 0.25% accuracy are 1⅞" Wd. x 3⅝" Ht.

Available Pressure Ranges (psi)

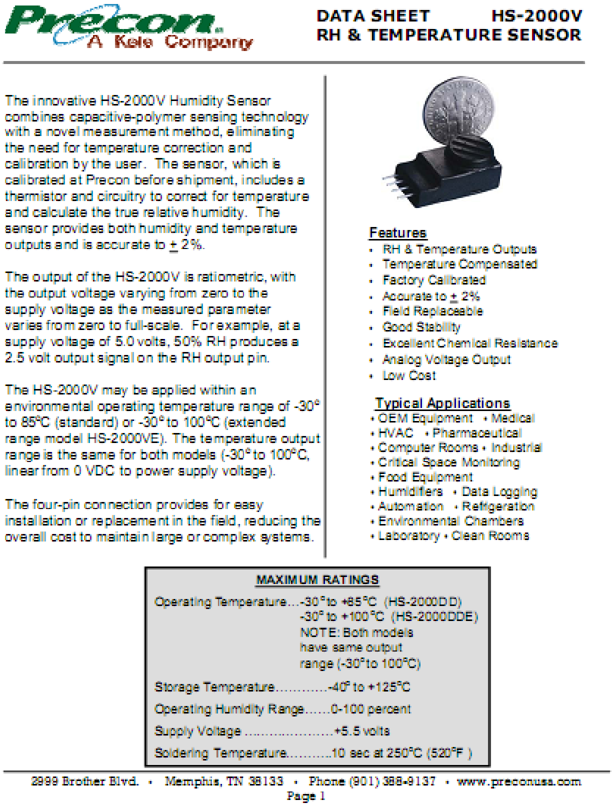
Pressure Range	3196K Maximum Pressure	3200K Maximum Pressure
0- 10	—	58
0- 15	30	58
0- 25	60	145
0- 50	100	240
0- 60	100	240
0- 100	200	500
0- 200	400	1,160
0- 300	600	1,160
0- 500	1,000	1,160
0- 1,000	1,740	1,740
0- 1,500	2,900	1,740
0- 3,000	6,000	7,200
0- 5,000	10,000	11,600
0-10,000	17,400	17,400

To Order: Please specify pressure range from the listing above.

Accuracy, Full Scale	Repeatability, Full Scale	Output Signal	Pipe Size		Each
Standard					
0.5%	0.1%	4-20 mA, 2 wire	¼"	3196K5■	$147.73
0.25%	0.05%	4-20 mA, 2 wire	¼"	3200K1	352.36
With NIST Certificate					
0.5%	0.1%	4-20 mA, 2 wire	¼"	3196K7■	220.75
0.25%	0.05%	4-20 mA, 2 wire	¼"	3200K3	514.50

■ Not available in 0-10 psi range.

-Humidy Sensor (Precon.com)



Precon
A Kele Company

DATA SHEET HS-2000V
RH & TEMPERATURE SENSOR

The innovative HS-2000V Humidity Sensor combines capacitive-polymer sensing technology with a novel measurement method, eliminating the need for temperature correction and calibration by the user. The sensor, which is calibrated at Precon before shipment, includes a thermistor and circuitry to correct for temperature and calculate the true relative humidity. The sensor provides both humidity and temperature outputs and is accurate to ± 2%.

The output of the HS-2000V is ratiometric, with the output voltage varying from zero to the supply voltage as the measured parameter varies from zero to full-scale. For example, at a supply voltage of 5.0 volts, 50% RH produces a 2.5 volt output signal on the RH output pin.

The HS-2000V may be applied within an environmental operating temperature range of -30° to 85°C (standard) or -30° to 100°C (extended range model HS-2000VE). The temperature output range is the same for both models (-30° to 100°C, linear from 0 VDC to power supply voltage).

The four-pin connection provides for easy installation or replacement in the field, reducing the overall cost to maintain large or complex systems.

Features

- RH & Temperature Outputs
- Temperature Compensated
- Factory Calibrated
- Accurate to ± 2%
- Field Replaceable
- Good Stability
- Excellent Chemical Resistance
- Analog Voltage Output
- Low Cost

Typical Applications

- OEM Equipment • Medical
- HVAC • Pharmaceutical
- Computer Rooms • Industrial
- Critical Space Monitoring
- Food Equipment
- Humidifiers • Data Logging
- Automation • Refrigeration
- Environmental Chambers
- Laboratory • Clean Rooms

MAXIMUM RATINGS

Operating Temperature…-30°to +85°C (HS-2000DD)
-30° to +100°C (HS-2000DDE)
NOTE: Both models
have same output
range (-30°to 100°C)

Storage Temperature…………-40° to +125°C

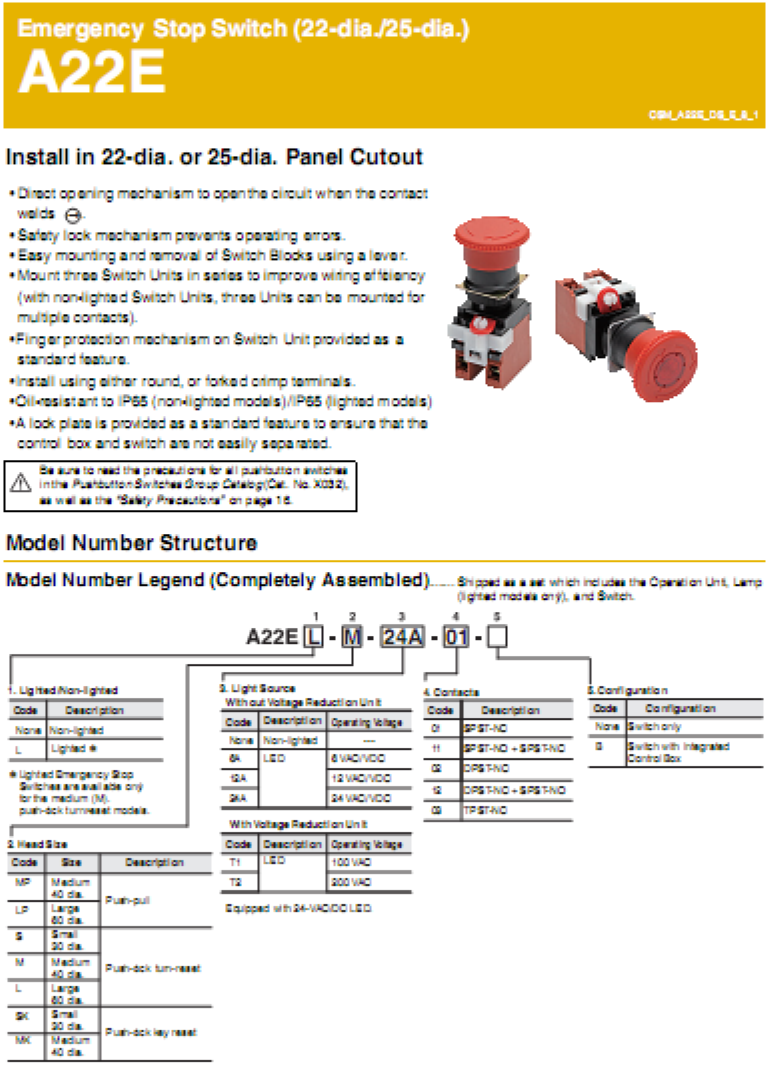
Operating Humidity Range……0-100 percent

Supply Voltage …………………+5.5 volts

Soldering Temperature……….10 sec at 250°C (520°F)

2999 Brother Blvd. • Memphis, TN 38133 • Phone (901) 388-9137 • www.preconusa.com
Page 1

-Emergency Stop Button (Omron.com)



Emergency Stop Switch (22-dia./25-dia.)

A22E

CSM_A22E_DS_E_6_1

Install in 22-dia. or 25-dia. Panel Cutout

- Direct opening mechanism to open the circuit when the contact welds ⊖.
- Safety lock mechanism prevents operating errors.
- Easy mounting and removal of Switch Blocks using a lever.
- Mount three Switch Units in series to improve wiring efficiency (with non-lighted Switch Units, three Units can be mounted for multiple contacts).
- Finger protection mechanism on Switch Unit provided as a standard feature.
- Install using either round, or forked crimp terminals.
- Oil-resistant to IP65 (non-lighted models)/IP65 (lighted models)
- A lock plate is provided as a standard feature to ensure that the control box and switch are not easily separated.

⚠ Be sure to read the precautions for all pushbutton switches in the *Pushbutton Switches Group Catalog* (Cat. No. X032), as well as the "*Safety Precautions*" on page 16.

Model Number Structure

Model Number Legend (Completely Assembled)

...... Shipped as a set which includes the Operation Unit, Lamp (lighted models only), and Switch.

1 2 3 4 5

A22E L - M - 24A - 01 - □

1. Lighted/Non-lighted

Code	Description
None	Non-lighted
L	Lighted *

* Lighted Emergency Stop Switches are available only for the medium (M), push-lock turn-reset models.

2. Head Size

Code	Size	Description
MP	Medium 40 dia.	Push-pull
LP	Large 60 dia.	
S	Small 30 dia.	Push-lock turn-reset
M	Medium 40 dia.	
L	Large 60 dia.	
SK	Small 30 dia.	Push-lock key reset
MK	Medium 40 dia.	

3. Light Source

Without Voltage Reduction Unit

Code	Description	Operating Voltage
None	Non-lighted	---
6A	LED	6 VAC/VDC
12A		12 VAC/VDC
24A		24 VAC/VDC

With Voltage Reduction Unit

Code	Description	Operating Voltage
T1	LED	100 VAC
T2		200 VAC

Equipped with 24-VAC/DC LED.

4. Contacts

Code	Description
01	SPST-NO
11	SPST-NO + SPST-NC
02	DPST-NO
12	DPST-NO + SPST-NC
03	TPST-NO

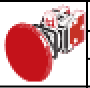
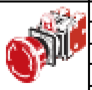
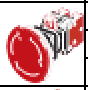
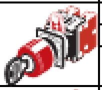
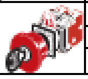
5. Configuration

Code	Configuration
None	Switch only
B	Switch with Integrated Control Box

Ordering Information

List of Models (Completely Assembled)

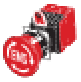
Non-lighted Models

Operating		Set Model	Color of cap
Appearance	Contact Configuration		
40-dia. head Medium Push-pull A22E-MP 	SPST-NC	A22E-MP-01	Red
	SPST-NO/SPST-NC	A22E-MP-11	
	DPST-NC	A22E-MP-02	
60-dia. head Large Push-pull A22E-LP 	SPST-NC	A22E-LP-01	
	SPST-NO/SPST-NC	A22E-LP-11	
	DPST-NC	A22E-LP-02	
30-dia. head Small Push-lock Turn-reset A22E-S 	SPST-NC	A22E-S-01 ●	
	SPST-NO/SPST-NC	A22E-S-11 ●	
	DPST-NC	A22E-S-02 ●	
	DPST-NC + SPST-NO	A22E-S12 ●	
	TPST-NC	A22E-S-03 ●	
40-dia. head Medium Push-lock Turn-reset A22E-M 	SPST-NC	A22E-M-01 ●	
	SPST-NO/SPST-NC	A22E-M-11 ●	
	DPST-NC	A22E-M-02 ●	
	DPST-NC + SPST-NO	A22E-M-12 ●	
	TPST-NC	A22E-M-03 ●	
60-dia. head Large Push-lock Turn-reset A22E-L 	SPST-NC	A22E-L-01 ●	
	SPST-NO/SPST-NC	A22E-L-11 ●	
	DPST-NC	A22E-L-02 ●	
30-dia. head Small Push-lock Key-reset A22E-SK 	SPST-NC	A22E-SK-01	
	SPST-NO/SPST-NC	A22E-SK-11	
	DPST-NC	A22E-SK-02	
40-dia. head Medium Push-lock Key-reset A22E-MK 	SPST-NC	A22E-MK-01	
	SPST-NO/SPST-NC	A22E-MK-11	
	DPST-NC	A22E-MK-02	

● Models with Korean S-mark certification.

Note: 1. Yellow cap models are also available (not for emergency stop use). Contact your OMRON representative.
2. The Operation Unit of A22E exept models with EMO/EMS indication is red. (The engraved mark is not white.)

With EMO/EMS Indication (non-lighted)

Operating		Set Model	Color of cap
Appearance	Contact Configuration		
40-dia. head Medium Push-lock Turn-reset With EMO Indication 	SPST-NC	A22E-M-01-EMO ●	Red
	SPST-NO/SPST-NC	A22E-M-11-EMO ●	
	DPST-NC	A22E-M-02-EMO ●	
	DPST-NC + SPST-NO	A22E-M-12-EMO ●	
	TPST-NC	A22E-M-03-EMO ●	
40-dia. head Medium Push-lock Turn-reset With EMS Indication 	SPST-NC	A22E-M-01-EMS ●	
	SPST-NO/SPST-NC	A22E-M-11-EMS ●	
	DPST-NC	A22E-M-02-EMS ●	
	DPST-NC + SPST-NO	A22E-M-12-EMS ●	
	TPST-NC	A22E-M-03-EMS ●	

● Models with Korean S-mark certification.

Lamp

LED

Appearance	LED light		Rated voltage	Model
	Red	Standard	6 VAC/VDC	A22-6AR
			12 VAC/VDC	A22-12AR
			24 VAC/VDC	A22-24AR

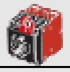
Note: For voltage-reduction lighting, use the A22-24AR.

Incandescent

Appearance	Rated voltage	Model
	6 VDC	A22-5
	14 VAC	A22-12
	28 VAC	A22-24
	130 VAC	A22-H1

Switch (Standard Load)

Without Voltage Reduction Unit

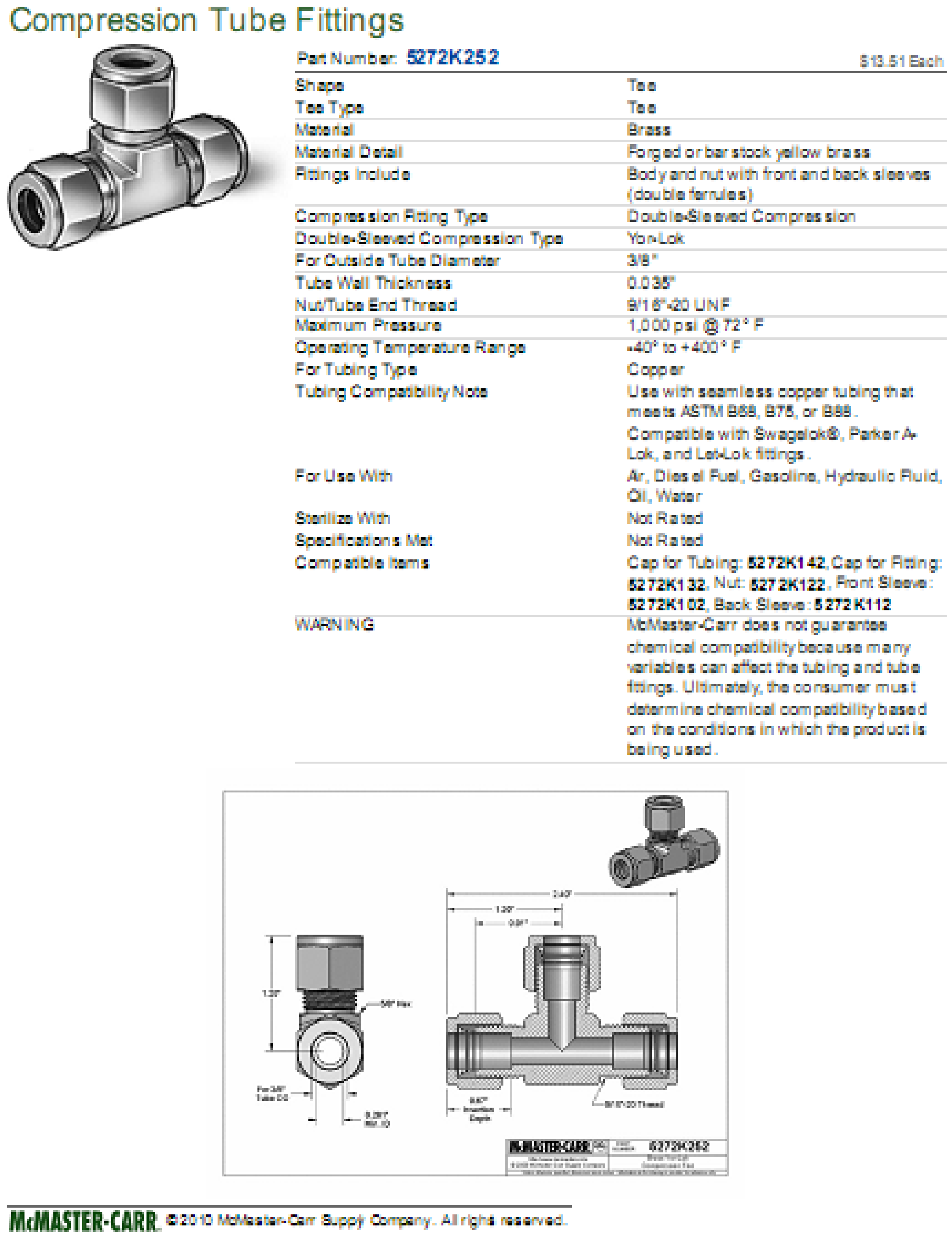
	Classification	Non-lighted	Lighted
	Appearance		
	Switch Action	Momentary	Momentary
Contacts		Model	Model
For standard loads	SPST-NC	A22-01M	A22L-01M
	SPST-NO + SPST-NC	A22-11M	A22L-11M
	DPST-NC	A22-02M	A22L-02M

With Voltage Reduction Unit

	Classification	Lighted (110 VAC)	Lighted (220 VAC)
	Appearance		
	Switch Action	Momentary	Momentary
Contacts		Model	Model
For standard loads	SPST-NC	A22L-01M-T1	A22L-01M-T2
	SPST-NO + SPST-NC	A22L-11M-T1	A22L-11M-T2
	DPST-NC	A22L-02M-T1	A22L-02M-T2

Note: When using with a Voltage Reduction Unit, use the A22-24AR.

-Swagelok “Tee” Fitting



Compression Tube Fittings

Part Number: **5272K252**	$13.51 Each
Shape	Tee
Tee Type	Tee
Material	Brass
Material Detail	Forged or bar stock yellow brass
Fittings Include	Body and nut with front and back sleeves (double ferrules)
Compression Fitting Type	Double-Sleeved Compression
Double-Sleeved Compression Type	Yor-Lok
For Outside Tube Diameter	3/8"
Tube Wall Thickness	0.035"
Nut/Tube End Thread	9/16"-20 UNF
Maximum Pressure	1,000 psi @ 72° F
Operating Temperature Range	-40° to +400° F
For Tubing Type	Copper
Tubing Compatibility Note	Use with seamless copper tubing that meets ASTM B68, B75, or B88. Compatible with Swagelok®, Parker A-Lok, and Let-Lok fittings.
For Use With	Air, Diesel Fuel, Gasoline, Hydraulic Fluid, Oil, Water
Sterilize With	Not Rated
Specifications Met	Not Rated
Compatible Items	Cap for Tubing: **5272K142**, Cap for Fitting: **5272K132**, Nut: **5272K122**, Front Sleeve: **5272K102**, Back Sleeve: **5272K112**
WARNING	McMaster-Carr does not guarantee chemical compatibility because many variables can affect the tubing and tube fittings. Ultimately, the consumer must determine chemical compatibility based on the conditions in which the product is being used.

APPENDIX O: Vacuum Pump Information and Data Sheet

Vacuum pump specs

Model #:	IDP3B11
Serial #:	LP1002L809
Pump len? #:	LPB002593
Op. Voltage:	121V
Base Pressure:	0.08 T
Retention Pressure:	3.00 T

Varian IDP-3 Dry Scroll Pump

IDP-3 Scroll Pump

TECHNICAL SPECIFICATIONS

Peak pumping speed	60 Hz – 60 l/m, 3.6 m³/hr, 2.1 cfm 50 Hz – 50 l/m, 3.0 m³/hr, 1.8 cfm
Ultimate pressure	2.5 x 10-1 torr (3.3 x 10-1 mbar)
Maximum inlet pressure	1 atmosphere (0 psig)
Maximum outlet pressure	1.4 atmospheres (6.5 psig)
Inlet connection	NW16 KF flange
Exhaust connection	Female ¼" NPT (10 mm hose barb provided)
Exhaust connection adapter	NW16 KF adapter provided
Gas ballast connection	Female ⅛" NPT
Ambient operating temperature	5 to 40°C (41 to 104°F)
Storage temperature	-20 to 60 °C (-4 to 140°F)
Motor rating	0.16 horsepower (0.12 kW)
Supply power	1 phase – 100 VAC, 50-60 Hz, 115 VAC, 60 Hz 220-240 VAC, 50-60 Hz
Motor thermal protection	Automatic
Rotation speed	3200 RPM at 60 Hz 2600 RPM at 50 Hz
Cooling	Air-cooled
Weight	9.5 kg (21 lbs.)
Shipping weight	10.5 kg (23 lbs.)
Restrictions	No corrosive, explosive, or particulate-forming gases
Leak rate	<1 x 10-6 std-cc/sec helium
Noise level (per ISO 11201)	55 dB(A)
Vibration level at inlet (per ISO 10816-1)	1.5 mm/sec
Compliances	Conforms with CE, CSA, CSA/CUS, Semi S2-200, and RoHS

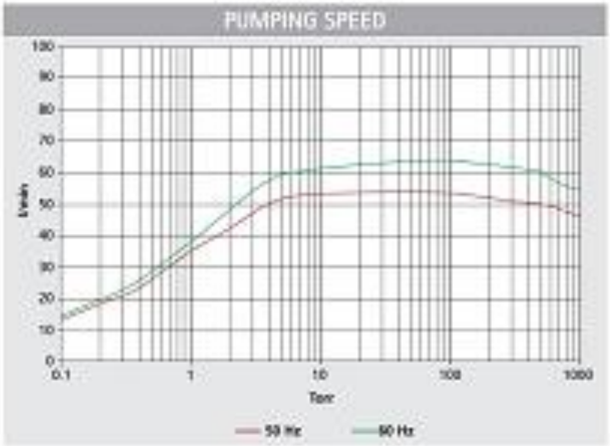
IDP-3 Scroll Pump vs. Rotary Vane

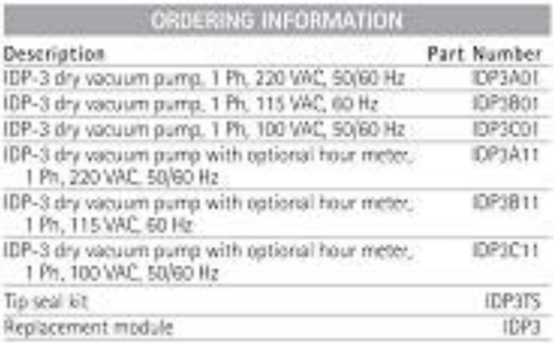
- The oil-free technology of the IDP-3 eliminates the possibility of oil contamination in the vacuum system or of oil spills or leaks into the work environment.
- Maintenance of the IDP-3 Dry Scroll Pump requires only a simple, infrequent tip seal change as compared to oil checks, changes, and disposal.
- The IDP-3 Dry Scroll Pump does not depend on the presence of sufficient oil to prevent seizing.

The IDP-3 is a compact, high performance dry pump that provides affordable oil-free vacuum and easy system integration, and is suitable for a wide variety of applications. The IDP-3 employs an innovative hermetic design in which the motor and bearings are outside the vacuum space, allowing full isolation of all pumped gases. Delivering a robust pumping speed of 60 l/m and a very low base pressure of less than 250 milliTorr, the IDP-3 provides all the advantages of Varian's patented scrol pump technology in a compact, lightweight, cost-effective package.

To Our Website
www.idealvac.com

Ideal Vacuum Products, LLC
2401B Phoenix Ave. NE
Albuquerque, NM 87107
Phone: (505) 872-0037
idealvac.com or pchemlabs.com





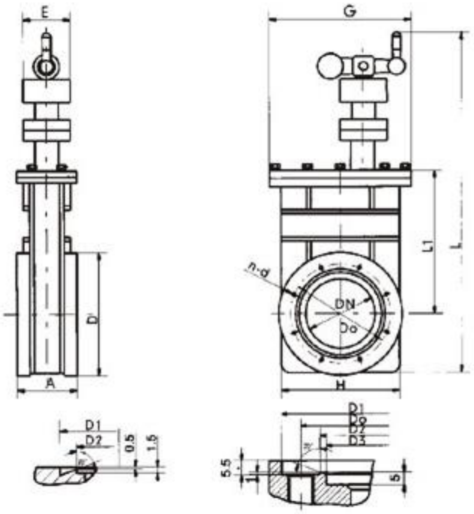
ORDERING INFORMATION

Description	Part Number
IDP-3 dry vacuum pump, 1 Ph, 220 VAC, 50/60 Hz	IDP3A01
IDP-3 dry vacuum pump, 1 Ph, 115 VAC, 60 Hz	IDP3B01
IDP-3 dry vacuum pump, 1 Ph, 100 VAC, 50/60 Hz	IDP3C01
IDP-3 dry vacuum pump with optional hour meter, 1 Ph, 220 VAC, 50/60 Hz	IDP3A11
IDP-3 dry vacuum pump with optional hour meter, 1 Ph, 115 VAC, 60 Hz	IDP3B11
IDP-3 dry vacuum pump with optional hour meter, 1 Ph, 100 VAC, 50/60 Hz	IDP3C11
Tip seal kit	IDP3TS
Replacement module	IDP3

APPENDIX P: Sliding Gate/Knife Valves

Company	Part Number	Description	Price (if available)
HTvavle (China)	PZ973 [1]	Electric sliding knife valve	$674.41
VAT (USA, Switzerland)	09140-PE44 [2]	Sliding, high vacuum	$2160.00
	10840-PE44 [3]	Sliding, ultra high vacuum	$2493.00
	16240-PA41 [4]	Rotary pendulum valve	$3082.75
ITT (USA)			
	XS150-DN100 [5]	Pneumativ, precission high vacuum	

1. **HTvalve PZ Series**

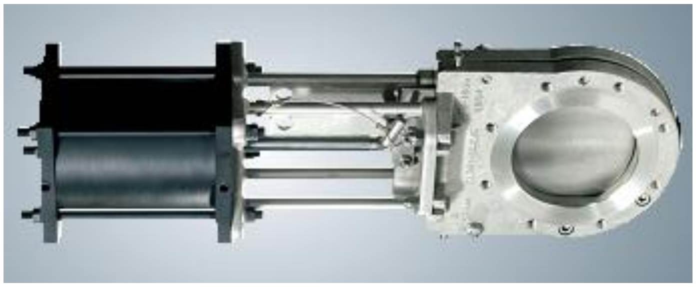


2. **VAT Series 091**

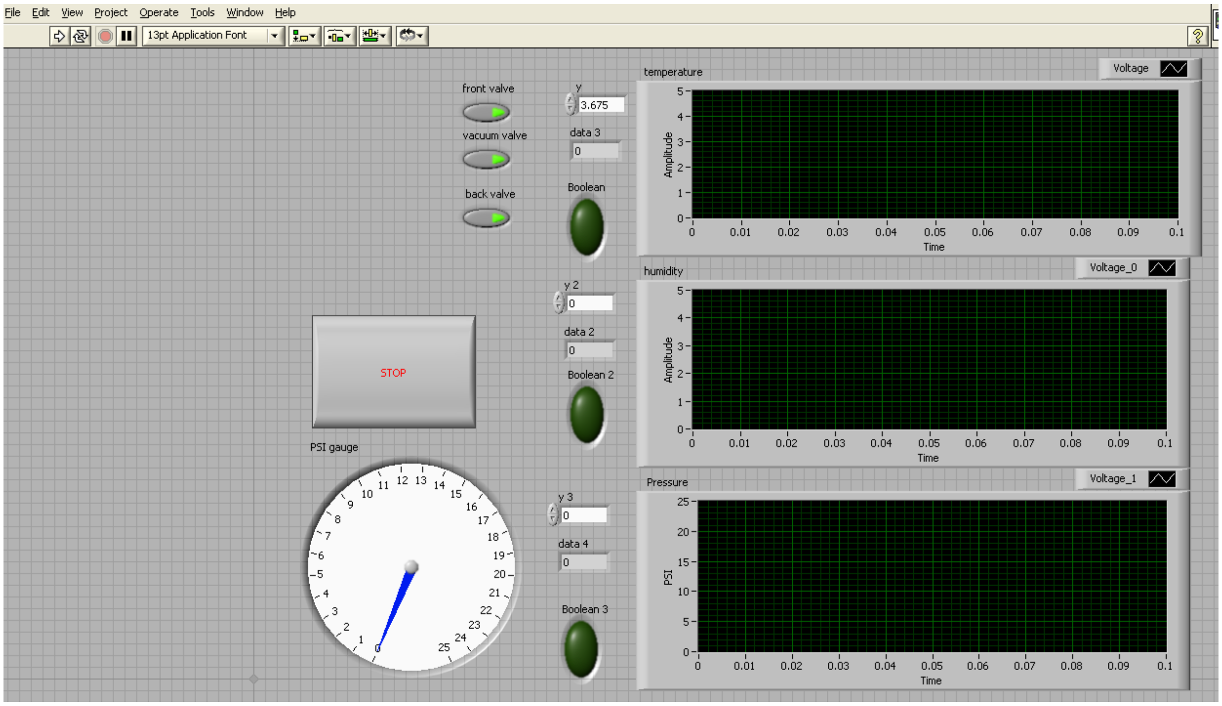
3. **VAT Series 108**

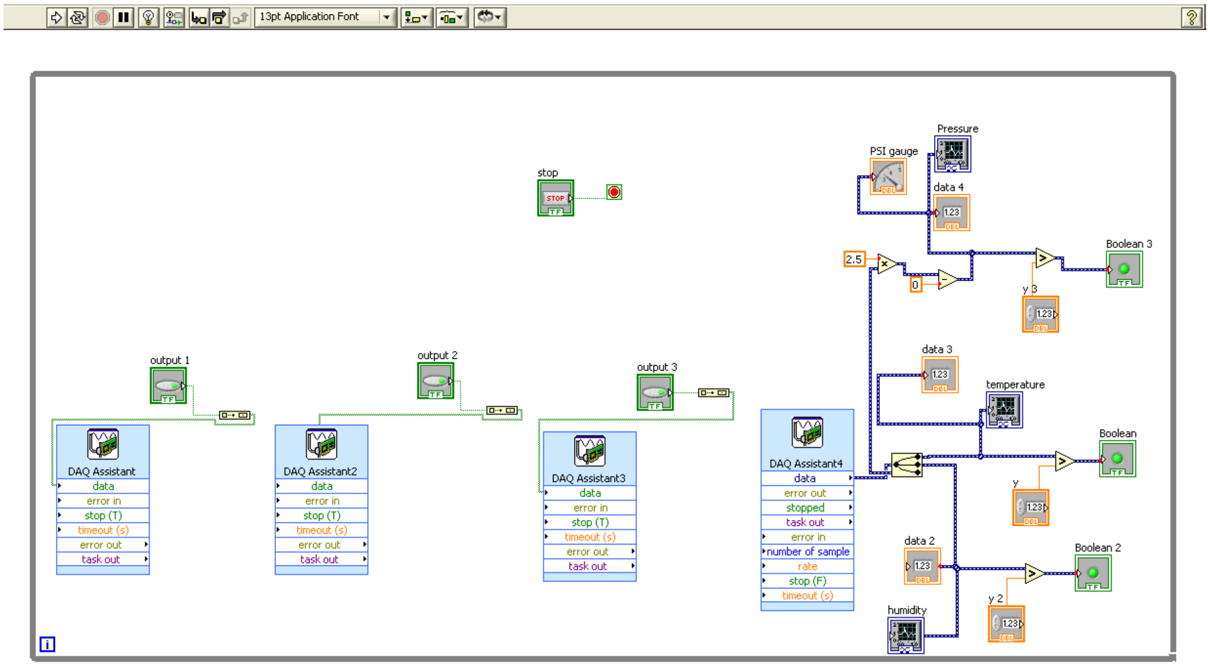
4. **VAT Series 162**

5. ITT XS150

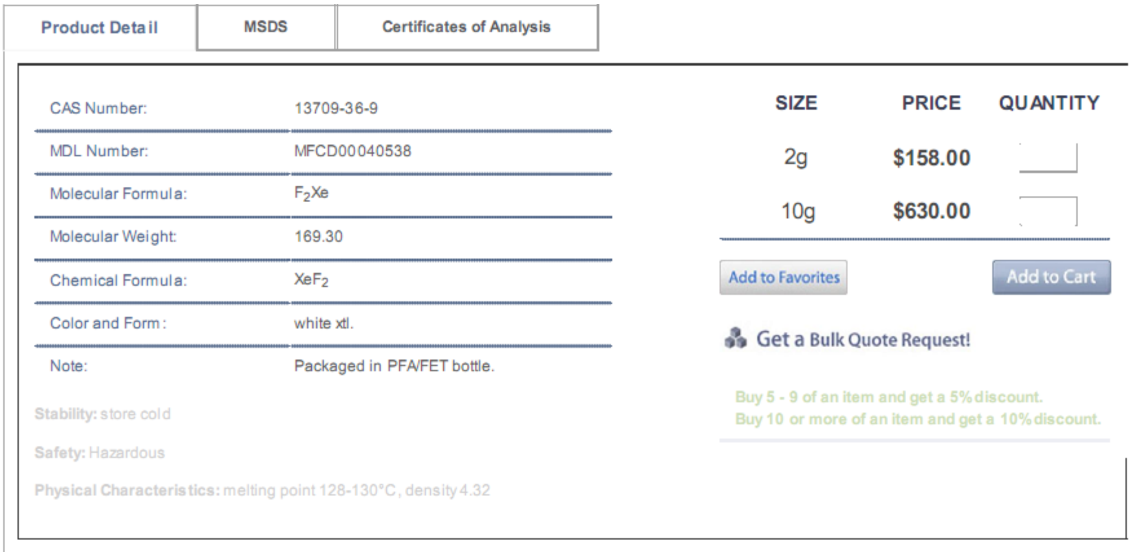


APPENDIX Q: LabVIEW Diagram





APPENDIX R: XeF_2 Purchasing and Containers



CAS Number:	13709-36-9
MDL Number:	MFCD00040538
Molecular Formula:	F_2Xe
Molecular Weight:	169.30
Chemical Formula:	XeF_2
Color and Form:	white xtl.
Note:	Packaged in PFA/FET bottle.

Stability: store cold

Safety: Hazardous

Physical Characteristics: melting point 128-130°C, density 4.32

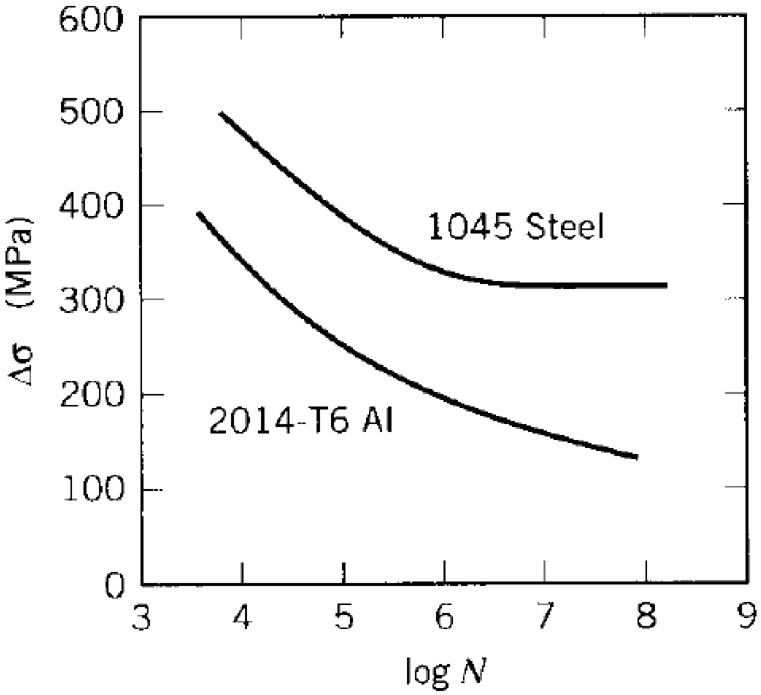
SIZE	PRICE	QUANTITY
2g	$158.00	☐
10g	$630.00	☐

Buy 5 - 9 of an item and get a 5% discount.
Buy 10 or more of an item and get a 10% discount.

XeF_2: PTFE bottles

XeF_2: 0.3L and 1.0L cylinders

APPENDIX S: Chamber Material Properties



H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials,* Vol. III, John Wiley & Sons, 1965.

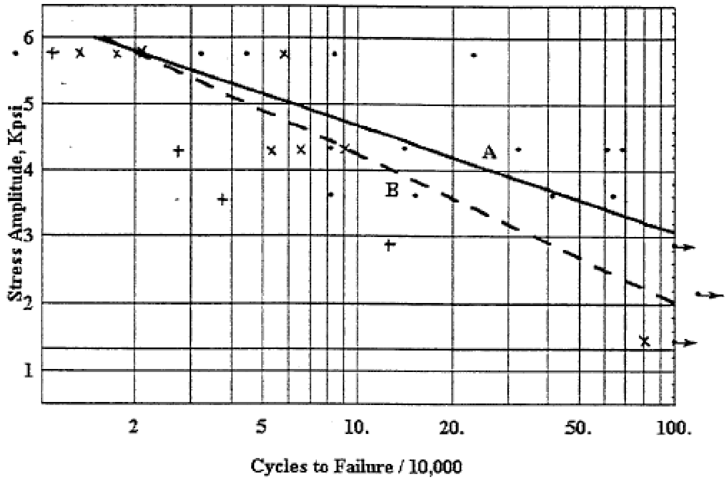


Figure 7. S-N Diagram for the Solid Polycarbonate Specimens

Kin, Y.B., *Fatigue Failure Analysis of Polycarbonate Transparencies in Different Environamental Conditions,* Purdue Research Foundation, Department of Engineering, December, 1994.