

Designing a Mechanism to Cleave Silicon Wafers

by

Victor Figueroa

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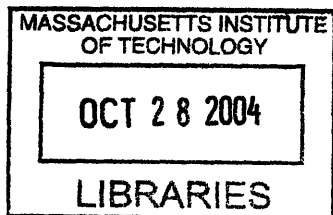
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Signature of Author: \_\_\_\_\_  
Department of Mechanical Engineering  
(September 8, 2004)

Certified by: \_\_\_\_\_  
Alexander Slocum  
Thesis Supervisor, Department of Mechanical Engineering

Accepted by: \_\_\_\_\_  
Professor Ernest G. Cravalho  
Senior Thesis Coordinator, Department of Mechanical Engineering



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### ABSTRACT

A device was designed and manufactured to precisely cleave silicon wafers. Two vacuum chucks were designed to support a 150 mm diameter silicon wafer and cleave it by providing a pure moment at a pre-etched v-notch while a vacuum was created on either side of the cut. The design of the vacuum chucks would also accommodate the smaller pieces of the wafer and would allow for the cleaving process to yield 19 mm x 34 mm die. The overall system consisted of three main components: the stationary vacuum chuck, and the pivoting vacuum chuck, and the base plate, which supported the two vacuum chucks. Hinges connected the two vacuum chucks and allowed one to cleave a silicon wafer resting atop the two chucks simply by applying a small load on the handle of the pivoting chuck. The system was manufactured, assembled, and tested to prove its functionality.

Thesis Supervisor: Alexander Slocum  
Title: Professor of Mechanical Engineering

## Acknowledgements

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## 1. Introduction

Silicon wafers have many applications in precision engineering and microsystems. Often times it is required that a wafer be cut, or cleaved, into smaller pieces, as a wafer by itself often holds dozens or more devices. In the case of growth of carbon nanotubes by chemical vapor deposition being performed on the wafer, it is necessary to cleave the wafer into die 19 mm x 34 mm. In a student laboratory, this may be performed by etching the desired pattern into the wafer and carefully fracturing the silicon along the etch by hand by scribing with a diamond tap. In more industrial settings, one may have an expensive, automated machine perform the task. The goal for this project was to design and manufacture a device to precisely cleave silicon wafers for use in a laboratory. What resulted was the design of a portable, customizable vacuum chuck that was able to cleave silicon wafers with little effort exhausted by the operator of the device.

This paper describes the design process, analytical methods, manufacturing process, and tests used to design a device to precisely cleave silicon wafers.

## 2. Design Analysis

The design process began with a study of the silicon wafer and bench-level experiments to determine what it would take to cleave the wafer and in what manner should it be performed. Once that was determined, detailed design of the individual components took place.

### 2.1 The Silicon Wafer

The silicon wafers that were to be used in the design of this mechanism were 150

mm in diameter and featured a grid-like pattern of v-groove trenches which dictate the boundary. These etches were cut 55  $\mu\text{m}$  deep into the silicon and created rectangular die 34 mm by 19 mm, as seen in Figures 1 and 2:

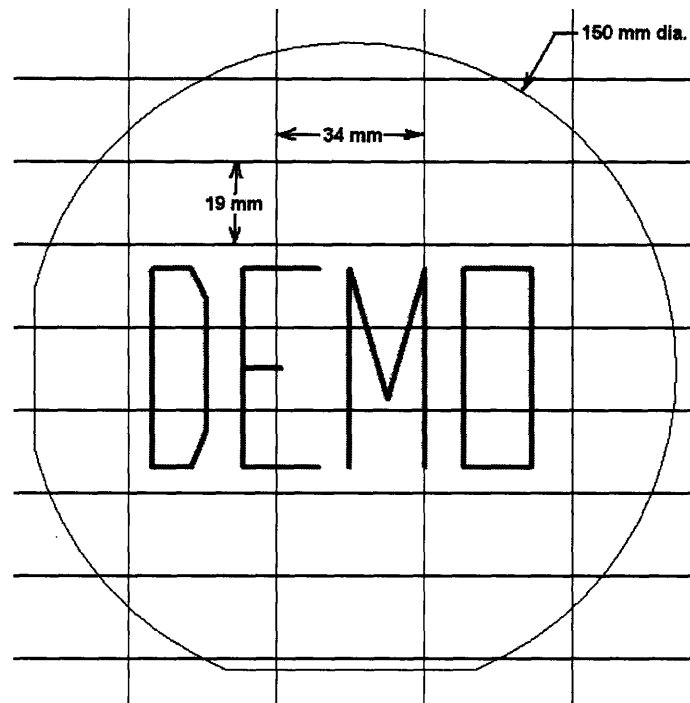


Fig.1. The dimensions of the silicon wafer and die used in designing the cleaving mechanism.

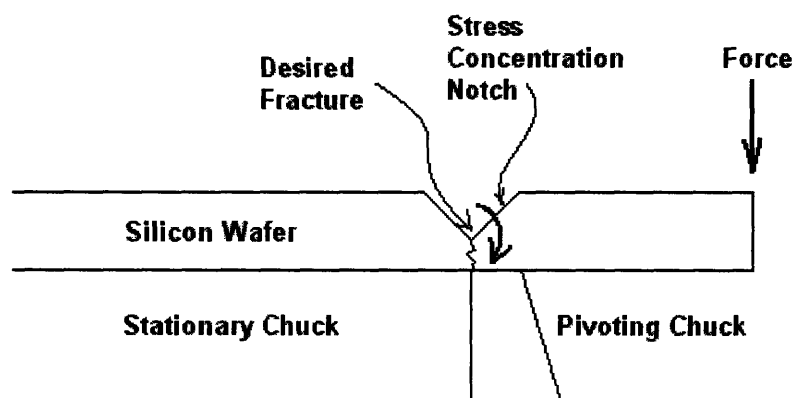


Fig. 2. The silicon wafer breaking strategy involves having a force provide a pure moment around the vertex of a stress concentration notch, thus cleaving the wafer along the axis of the trench.

## 2.2 Bench-Level Experiments

During the first bench-level experiment, a silicon wafer was placed across the porous graphite surface of two air bearings connected to a vacuum pump in an attempt to cleave the silicon wafer along the edge of one of the air bearings. This would be performed by keeping one of the air bearings static while rotating the other one downwards to make the cut. Although the wafer adhered to the surface of the air bearings when the vacuum pump was turned on, the suction force was not large enough to keep the wafer on the static air bearing while the other one rotated. What was needed was a stronger force.

A pair of larger air bearings were then obtained and the same bench-level experiment was performed again. Although the larger air bearings provided a stronger vacuum, the force was still insufficient to prevent the wafer from tearing away from the surface of the bearing. To temporarily remedy this problem, a second vacuum bearing was placed atop the silicon wafer, sandwiching it, and thus preventing the wafer from tearing away from the air bearing surface. The other bearing to which the wafer was attached was then rotated downwards and the wafer was cleaved along the edge of the static air bearing. This proved the hypothesis that with enough downward force pushing the wafer against the surface, two air bearings would be able to cleave a silicon wafer simply by rotating the wafer slightly along the axis of the desired cut, but precise application of force is essential for pure moment.. It was then decided that a vacuum chuck would need to be designed with larger holes than on the previous air bearings to provide a greater vacuum force.



### 2.3 Vacuum Chuck Design

The concept of the vacuum chuck design was simple: there would be two vacuum chucks nearly equal in size connected by a hinge or other linkage system that would allow one of the vacuum chucks to pivot, thus cleaving the silicon wafer. The design process began by analyzing the wafer die sizes and deciding how the wafer would be cut. Because of the pattern of the die, each cut across the wafer would result in two unique shapes, which would later need to be cut as well. The shapes would resemble semi-circles that would get progressively smaller until several long, rectangular strips of the silicon wafer were left. Figure 3 shows these shapes as they appeared in one of the designs of the vacuum chuck. Although this design was later modified to adapt new features and consist of more plates, the dimensions of the recessed area and hole pattern were preserved in the final design.

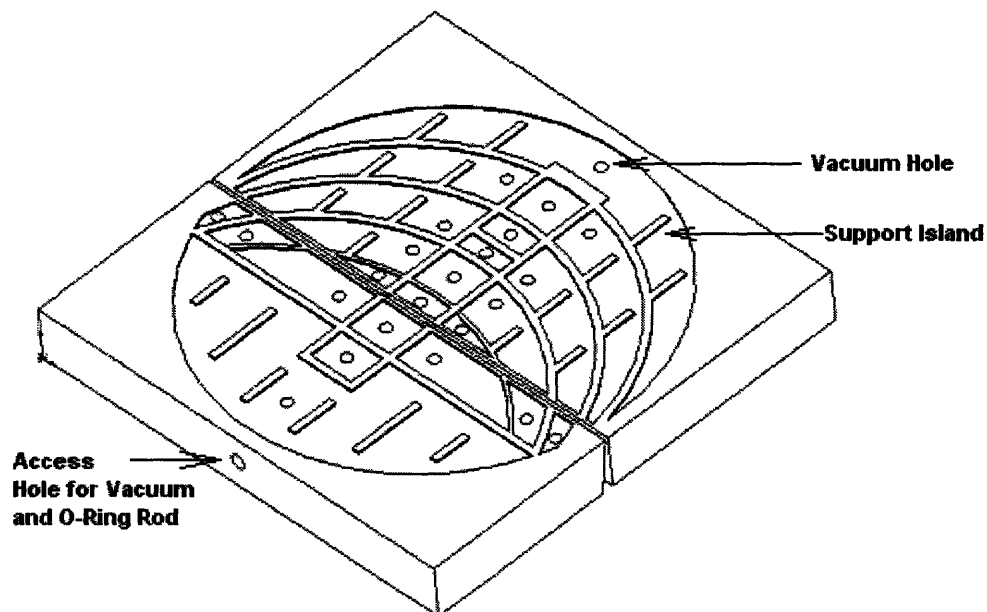


Fig. 3. An early vacuum chuck model shows the relationship between the vacuum hole pattern and design of the wafer support system.

The silicon wafer would be placed atop a cavity 5.7" in diameter for the initial cut. Underneath the wafer would lie extrusions 1/10" thick to support the wafer where the die have been etched. These supports were made to prevent the wafer from fracturing along an etched line away from where the cleaving was intended to be. Once the wafer was cut into two pieces, the new pieces would be placed atop the appropriate chamber pattern and holes that would be exposed to the atmosphere would be sealed in order to preserve the vacuum under the wafer.

The initial plan for sealing the holes was to thread each one and insert removable set screws so that one would be able to change the pattern of open holes by simply adding and removing the screws. This was deemed impractical, as it would be a painstakingly long process to unscrew several screws for each new cut of the wafer. It would also result in the having 25 small set screws that could easily be lost when not used for closing holes. A much simpler idea was developed in the form of rods with O-rings attached to them which would fit into the holes already designed for the middle plate's vacuum channel system. One would be able to insert a rod into one of the long horizontal tubes and seal one or more of the holes that would connect the horizontal tube to the vacuum cavity of the top plate. Only five rods would be needed as opposed to 25 set screws, and the process of opening and closing holes would be much quicker.

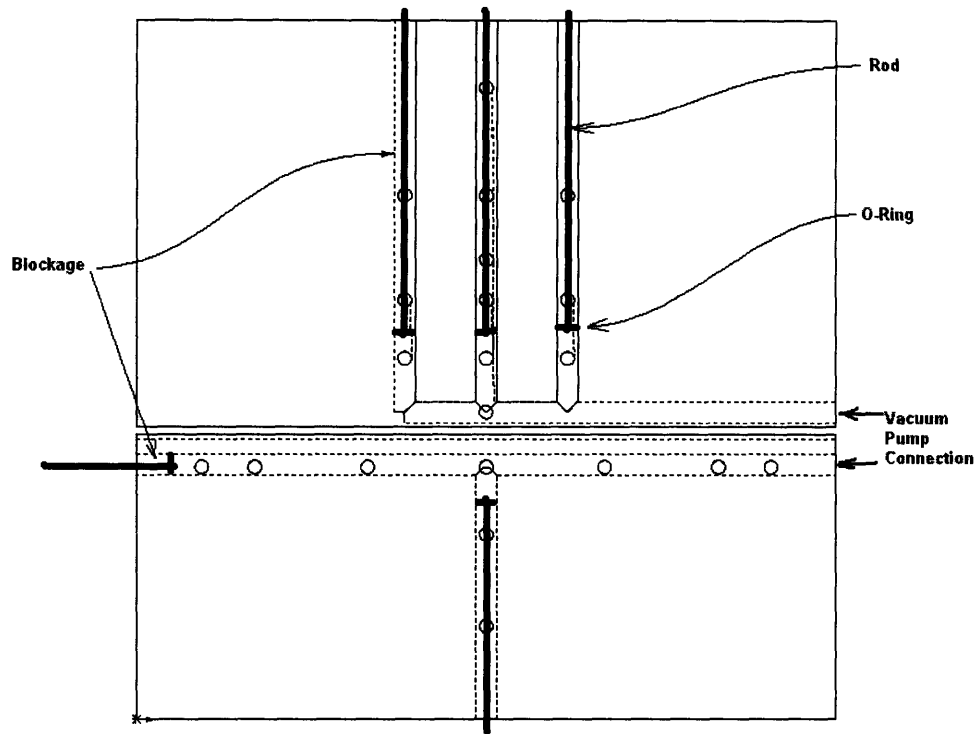


Fig. 4. Schematic of the vacuum holes and O-rings that would block air from escaping through unwanted holes.

After learning that the vacuum chuck design portrayed in Figure 2 would be too difficult and time-consuming to machine because it would have to be performed on the mill, the design was changed to allow for machining the intricate vacuum chamber system on the waterjet. The waterjet method of manufacturing would be much more efficient than the mill, but would require that the cuts made to create the cavity in the aluminum would need to go through the entire piece of stock. This called for splitting the design in Figure 2 into two plates: the top plate would serve as the support structure for the wafer and the chamber system for the vacuum (see Figure 5); and the bottom plate (which from here on will be referred to as the middle plate) would provide the channels and holes necessary for the vacuum system (see Figure 6). In order to prevent air leakage

between the two metal plates, a thin piece of rubber would be placed between them to act as a gasket.

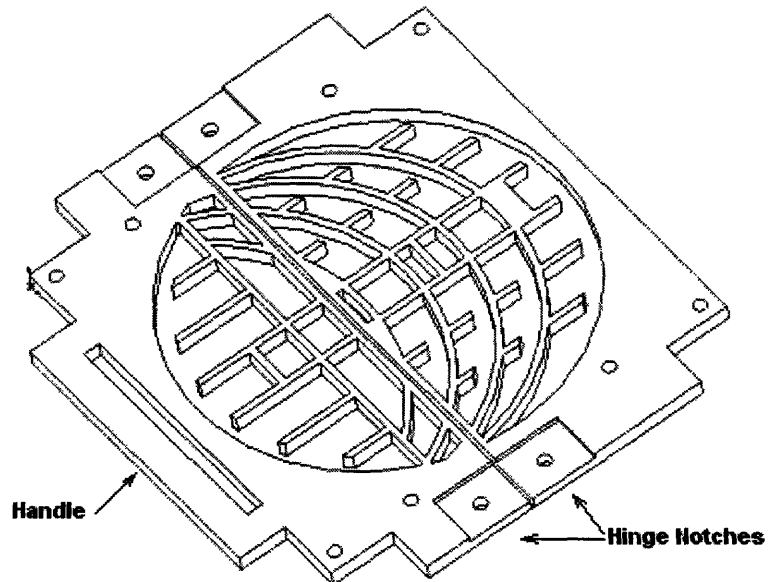


Fig. 5. The top plates of the vacuum chuck, showing the support structure for the silicon wafer, vacuum chamber cavities, screw hole locations, and handle.

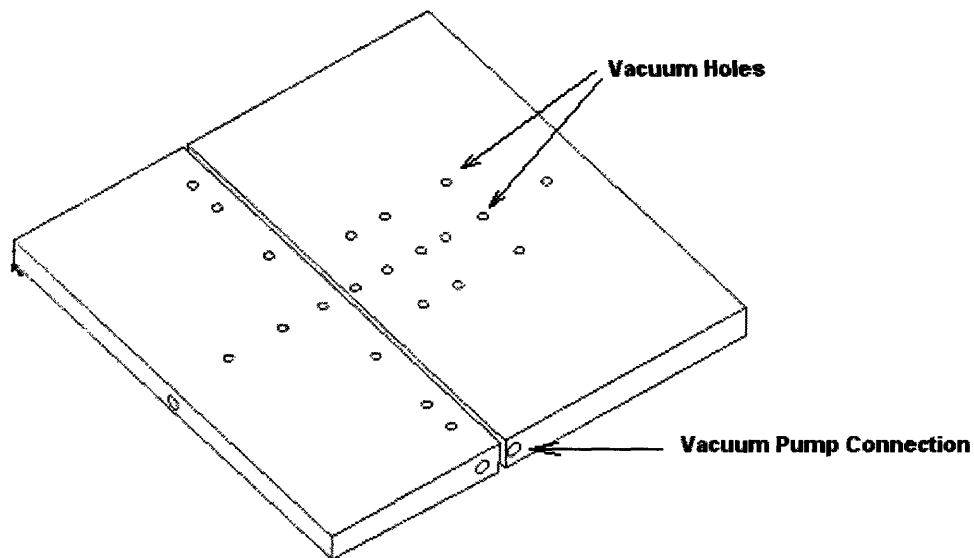


Fig. 6. The middle plates of the vacuum chuck, showing the hole locations for the vacuum system.

It was decided to use flat hinges to attach the static top plate to the pivoting top plate. The hinges would have to be positioned so that the center of the shaft would line up

directly with the axis of rotation about the surface edge of the top plate. This would provide a pure moment about the notch where the wafer would be cleaved. If the axis of rotation were not along this edge, bending the assembly would introduce forces that could cause a break in the seal of the vacuum or perhaps cause the wafer to fracture away from the cutting edge. To ensure that the center of the hinge shaft would be in line with the surface edge of the top plate, the areas in which the hinges would be placed would be recessed 0.08”.

Now with a design for the attachment of the top and middle plates secured, the newly designed vacuum chucks needed a base plate to rest on. Functional requirements of the base plate were that it would support the static vacuum chuck, provide ample room for the pivoting vacuum chuck to rotate, support the pivoting vacuum chuck, and would support attachment to an optical table. The base plate connects to the static plate using 1” 10-32 screws. A recessed area would be present in the vacuum chuck to provide a large range of movement for the pivoting plate, and would also support the pivoting plate using springs. 0.265” diameter clearance holes at the corners of the base plate would allow for the attachment of the device to an optical table with ¼-20 bolt holes spaced 1” apart.

Figure 7 shows the overall design of the base plate:

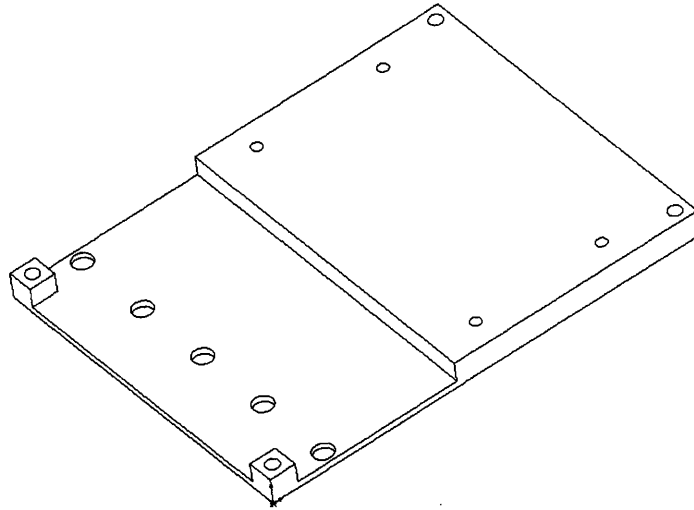


Fig. 7. The base plate, serving as support for the vacuum chucks, and securing the system to the optical table.

### 3. Manufacturing Process

The manufacturing process began by obtaining  $\frac{1}{2}$ "-thick aluminum jig plate that would serve as the middle plate of the vacuum chuck. Jig plate was used because its flat finished surface would minimize the effect of air leakage between the middle and top plates. The size of the original jig plate stock used was approximately 7"x15" and was cut to a 7" square on the bandsaw. A larger, slower saw was then used to bring the stock closer to the desired 6.5" square. Once finished with the rough cutting, the middle plate was placed in the CNC mill and precisely squared off at 6.5". With the middle plate already in the vice of the mill and its zero's set, a program was created on the mill to find the hole locations on the top surface of the plate. With a center drill in place, the program was run and 27 punctures were made where the holes would soon be. The holes that were to be part of the vacuum system were bored with a  $\frac{1}{8}$ " drill, while a #17 drill was used to create the holes that would support the 10-32 screws. Running the program lead to an error in one of the hole locations, as a typographical error put one of the vacuum holes at

0.461” in the y-axis rather than at 0.641”. The resulting hole did not prove to be problematic, and a second hole was drilled in its proper location adjacent to the first hole.

With the top surface of the middle plate finished, the aluminum was placed upright in the vice to allow for the drilling of the vacuum pump connector holes and holes for the insertion of the O-ring rods. The middle plate was zeroed again and after finding the location of the holes with the center drill, the holes were created with an 1/8” drill, as seen in Figure 8:



Fig. 8. Drilling the holes in the middle plate for the O-ring rods.

The holes that were to be used to connect the mid plate to the vacuum pump were tapped for the 10-32 threads used on the vacuum pump tube adapter (see Figure 16 in Appendix). Once all of the milling of the middle plate was finished, the plate was cut into two pieces using the bandsaw, in accordance with the design of having one static plate and one pivoting plate.

Each of the O-ring rods that were used to restrict the passage of air to different holes in the middle plates were cut from a 6' stainless steel rod 1/16" in diameter. A band saw was used to cut five sections of rod approximately 4" in length and an O-ring was attached to the end of each rod using epoxy.



Fig. 9. One of the O-ring rods used to plug the vacuum lines in the middle plates.

The top plate of the vacuum chuck was also constructed out of aluminum jig plate in an attempt to keep the surface that would be in contact with the silicon wafer as even and as free of blemishes as possible. The original stock of aluminum obtained was 1/4"-thick and 12"x12". Much of the machining of the top plate was performed by the OMAX<sup>™</sup> waterjet. This involved converting the SolidWorks solid model of the top plate into a DXF drawing file so that the waterjet's software would be able to read it. With the jig plate mounted in the waterjet, a tool path was run to cut out the areas that would become the vacuum cavity and screw holes. The holes meant for securing the top plate to the middle plate were clearance holes for 10-32 screws, while the holes intended to attach the hinges to the top plate were tapped for 1/4"-20 screws. The waterjet also cut the top plate into two halves, as seen in Figure 8:





Fig. 10. One half of the top plate comes out of the waterjet.

After threading the  $\frac{1}{4}$ -20 holes, the areas for the hinges to rest in were cut on the CNC mill. One of the top plates was placed in the vice, zeroed, and a tool path was created to mill out a notch 0.08" deep, 1.025" long, and .8" wide using a 0.25" end mill. Two of these notches were made on each top plate, with the notch on the smaller plate being 0.975" long rather than 1.025" long. This was done to allow for the center of the hinge shaft to be in line with the edge where the wafer was to be cleaved.



Fig. 11. Milling a notch in one of the top plates for a hinge to rest in.

The base plate of the system was formed from a  $\frac{3}{4}$ "-thick sheet of milled aluminum. The band saw was used to cut the large piece of stock down to the desired dimensions of 8.5" x 6.5". The rectangular piece of aluminum was then set in the vice of the mill and zeroed in preparation for clearance holes to be drilled. The first four holes, which would serve to connect the base plate to the optical table, were clearance holes for 1"  $\frac{1}{4}$ -20 bolts. Four other holes would serve as clearance holes for  $\frac{3}{4}$ " 10-32 screws that would connect the base plate to the stationary middle plate. With the holes drilled, the recessed area of the base plate design was then milled out. The process began by using a  $\frac{1}{2}$ " end mill to shave off approximately 0.05" off of the top surface of the plate on each pass. Several passes were made until the desired depth of 0.4" was reached. Once the milling process was complete, five holes were made approximately  $\frac{1}{8}$ " deep with a  $\frac{3}{8}$ " end mill where the springs to support the dynamic top plate would reside.

The hinges for the vacuum chuck originated from a 6" piece of unfinished steel piano hinge, 0.35" thick with a 2" open width (see Figure 12). Two sections of hinge were mostly cut out on the band saw, each one  $\frac{3}{4}$ " wide to include three  $\frac{1}{4}$ " knuckles. The only part not cut on the band saw was the shaft of the hinge, which was later cut using a hacksaw.

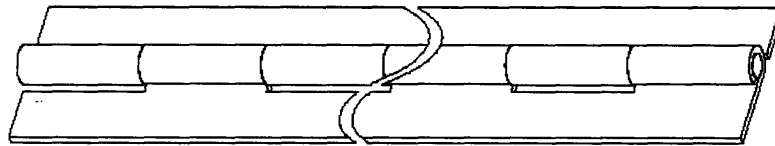


Fig. 12. An example of the flat hinge used to join the two top plates [1].

The corners of the hinge sections were then filleted using a belt sander to allow for a proper fit into the notches milled on the top plates. A "J" drill was then used to make clearance holes in the hinges that would bind them to the top plates.

In order to minimize air leakage between the top and middle plates in the vacuum, a sheet of  $\frac{1}{32}$ " rubber was placed between the plates. Holes were punched into the rubber so as not to impede the passage of air between middle and top plates through the vacuum holes. Holes were also punched into the rubber at the locations of the screw holes so as not to disrupt the function of those holes, either.

Finally, with all of the machining nearly complete, the top and middle plate of the pivoting portion of the vacuum chuck was assembled in order to taper the face of the part that was only 0.05" from the face of the static portion of the vacuum chuck. An angle of approximately 5-degrees was desired to allow for the pivoting chuck to rotate freely without coming into contact with the static piece prematurely and disrupting the range of movement. The two plates were screwed together and placed in the vice of the CNC mill

atop 5-degree parallels. A ¼” end mill was then used to shave off the face of the aluminum from the bottom of the middle plate to very near the surface of the top plate.

Before the device was ready to be tested, the device had to be assembled and the springs had to be inserted between the base plate and the pivoting vacuum chuck to determine how long the springs needed to be to keep the surface of the pivoting chuck level with the stationary chuck. Once this was determined, the springs were placed into a vice and compressed until the desired length was met. Epoxy was then used to secure the springs to the base plate and the system was ready for testing.

#### 4. Assembly and Testing

With all of the components of the vacuum chuck system designed and machined, the system was assembled and ready to be tested. A vacuum pump was connected to the newly manufactured chuck, a wafer was positioned to cover all of the vacuum chambers on the side of the chuck to be tested, and the pump was turned on.

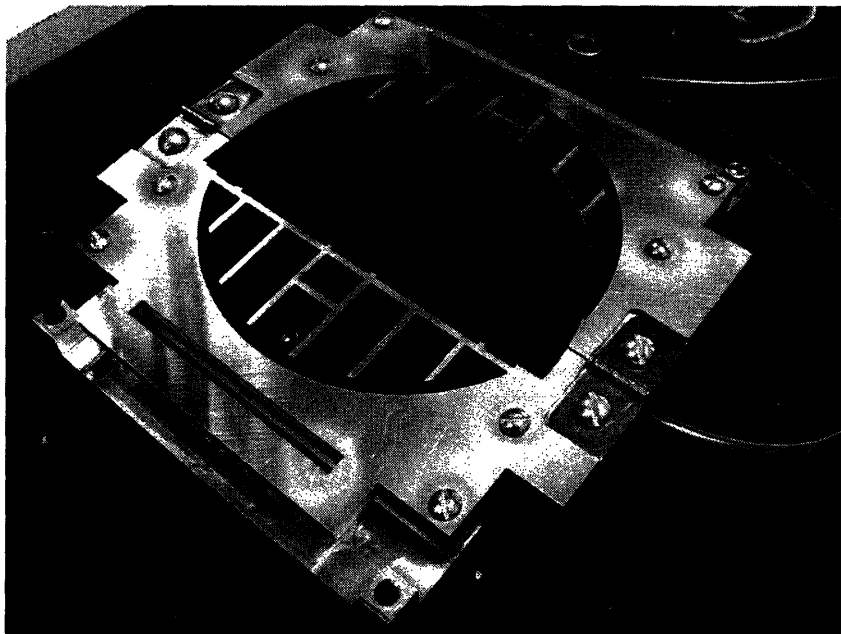


Fig. 13. A silicon wafer is used to test the pressure of the vacuum inside the chucks shortly after being assembled for the first time.

A gauge on the pump displayed the vacuum pressure to be approximately 10 inches of mercury (Hg), which was far from the pump's optimal operating capacity (30 in. Hg being perfect vacuum). The pressure improved when the screws that connected the top plate to the middle plate were adjusted. It turned out that some of the screws were too tight, causing the top plate to deform and bend, allowing air to escape between the top plate's bottom surface and the rubber gasket. Making the proper tightness adjustments yielded a new pressure of 19 in. Hg, which turned out to be plenty strong enough to support cleaving of the wafer. This process was repeated on the other vacuum chuck and produced similar results.

It was noticed, however, that by placing pressure near the center of the top plate along the cleaving edge, the pressure increased to approximately 24 in. Hg. This showed that air was leaking between the top and middle plates at the center of the vacuum chuck, away from the screws. Because of the geometry of the top plate, screws were not able to be positioned near the center of the cleaving edge, thus allowing some space between the plates for air to escape. This was remedied in the laboratory by placing electrical tape across the top plate, rubber gasket, and bottom plate on the side which face the leakage problem. This quick fix brought the vacuum pressure up to approximately 24 in. Hg, providing more than enough pressure to keep the silicon wafer firmly attached to the surface of the vacuum chuck.

When it came time to place a wafer over both vacuum chucks to try to cleave it, it was observed that the top plates were slightly uneven, as seen in Figure 14:



Fig. 14. The flat silicon wafer shows the imperfection in the level of the top plates.

Although the two plates were off by small fractions of an inch, their failure to be perfectly level resulted in a leakage of air when the silicon wafer was placed over the two plates. This problem was also quickly fixed; this time by inserting three pieces of 0.002" shim stock beneath the hinge of the stationary chuck in order to raise the top plate of the pivoting chuck by approximately 0.006".

With all of the air leaks accounted for, a silicon wafer was ready to be cleaved. A wafer was placed over the top of the two vacuum chucks, the vacuum pump was turned on, and with a small downward force on the handle of the pivoting chuck, the wafer was properly fractured along the etch.

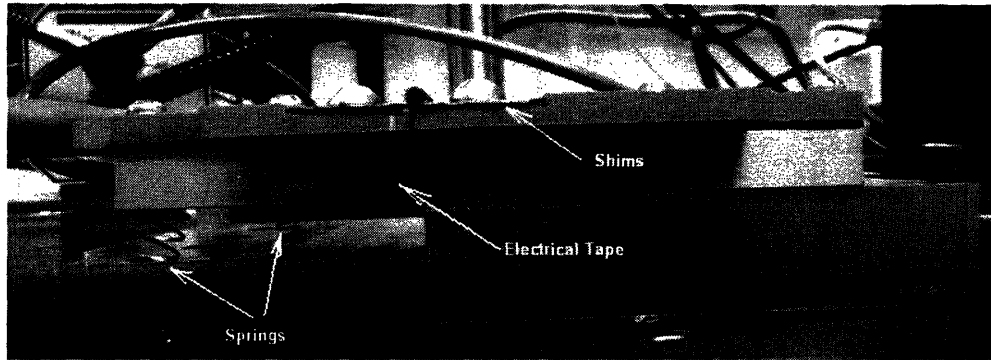


Fig. 15. The view from the side as a test is conducted to cleave a silicon wafer.

## 5. Future Work

Although the vacuum chuck worked as it was intended to, there are still improvements that could be made to the system. For future work, it would be helpful to fit a straight edge above the surface of the top plate so that one would be able to line up the etch on the silicon wafer to the edge of the stationary chuck with more precision. Perhaps the straight edge could accommodate a slide for holding a diamond scribe, allowing for cleavage lines to be made on the silicon wafer on the spot.

It would also be interesting to explore the concept of a single-piece top plate design. That is, rather than having two separate top plates connected by hinges, one could waterjet the top plate to be one piece, with thin strips of aluminum connecting what is currently the two top plates in place of the hinges. The elasticity of the thin strip would allow the one half of the vacuum chuck system to bend and thus cleave the silicon wafer using a cantilever beam as the hinge.

One advantage of two-plate design of the vacuum chuck is that the top plate is easily removable and may be able to be replaced by a top plate of a different design, which would be easy to produce using the waterjet. This would allow for silicon wafers of different sizes and die patterns to be cleaved, making the device customizable. This, of

course, assumes that the new vacuum cavity and wafer support structure complies with the existing vacuum hole pattern on the middle plates.

## Conclusions

The mechanism to cleave silicon wafers performed as expected, with the exception of a few unforeseen circumstances. Issues such as air leaking between the top and middle plates were quickly remedied, in this case by applying electrical tape to restore a high vacuum pressure in the chuck. The problem of having uneven top plates was solved by inserting shim stock under the hinges connected to the stationary chuck in order to raise the level of the pivoting chuck. Once these issues were resolved, the vacuum chuck served its purpose and made a neat cleave of a silicon wafer. The device is suitable for laboratory use, and can be customized to accommodate silicon wafers of varying size and die patterns.



## References

- [1] McMaster-Carr, [Online document], [6 Sept. 2004], Available HTTP:  
<http://www.mcmaster.com/library/9/933881/15665A162L.GIF>

Appendix

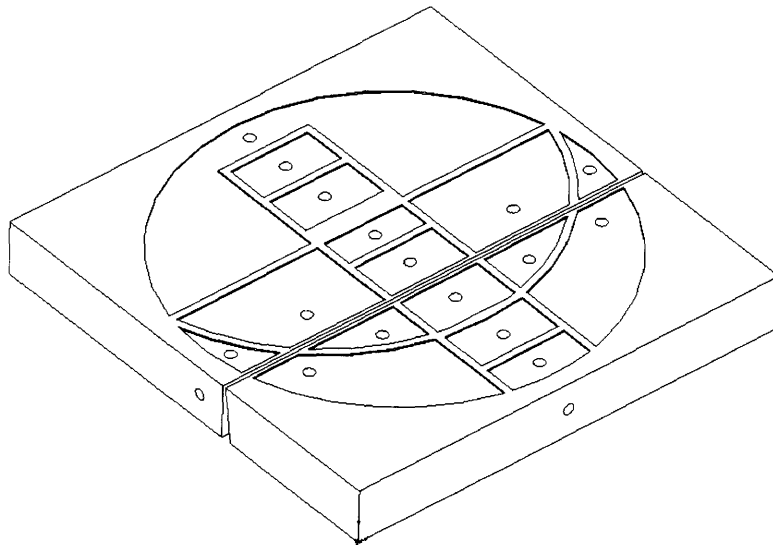


Fig. 16. One of the original designs for the vacuum chuck system.

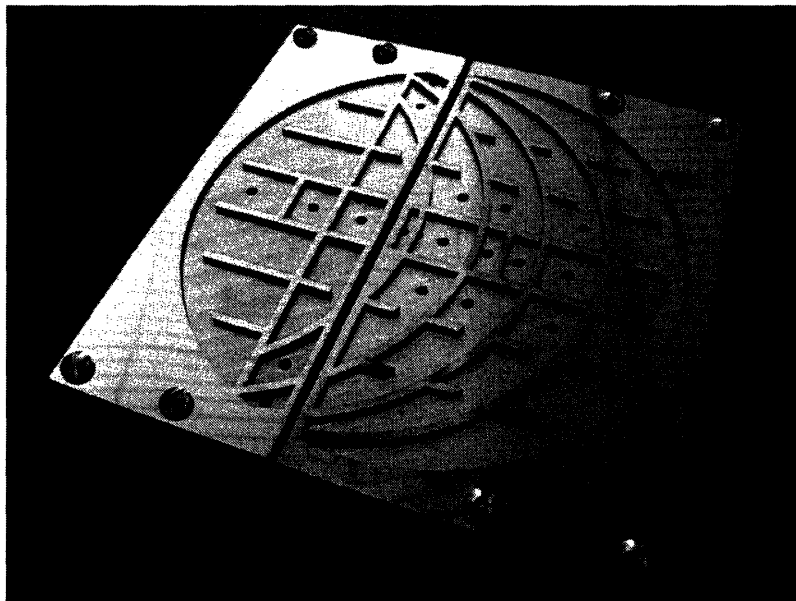


Fig. 17. 1/16"-thick top plates were first machined to fit atop the middle plates, but were too thin to adequately seal the vacuum cavity, so they were replaced with the current 1/4"-thick top plates.

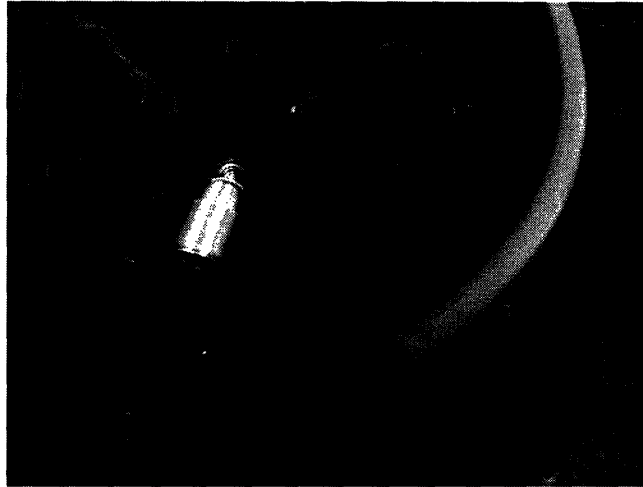


Fig. 18. The vacuum pump tube and connector that fit into the 10-32 holes tapped into the middle plates of the vacuum chucks.



Fig. 19. The overall vacuum chuck system.

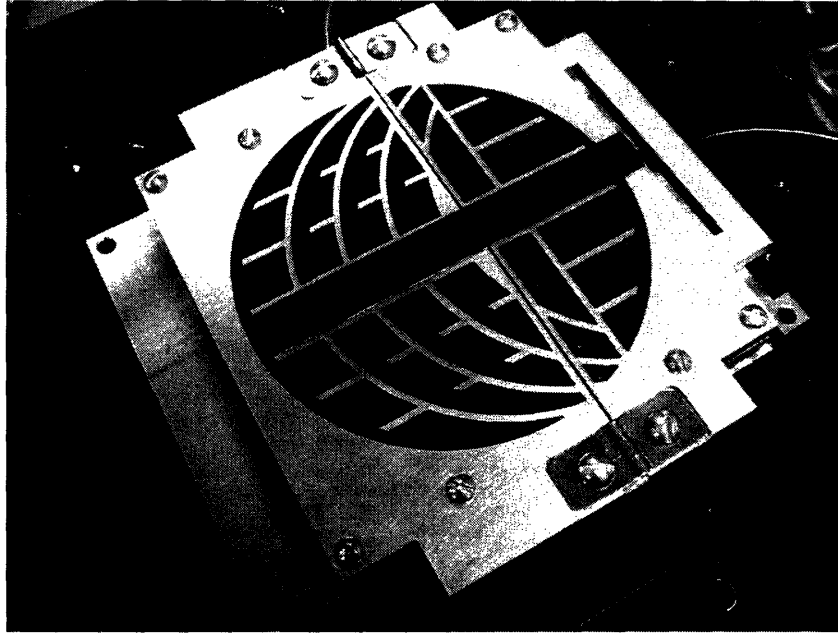


Fig. 20. Cleaving a rectangular strip of the silicon wafer.

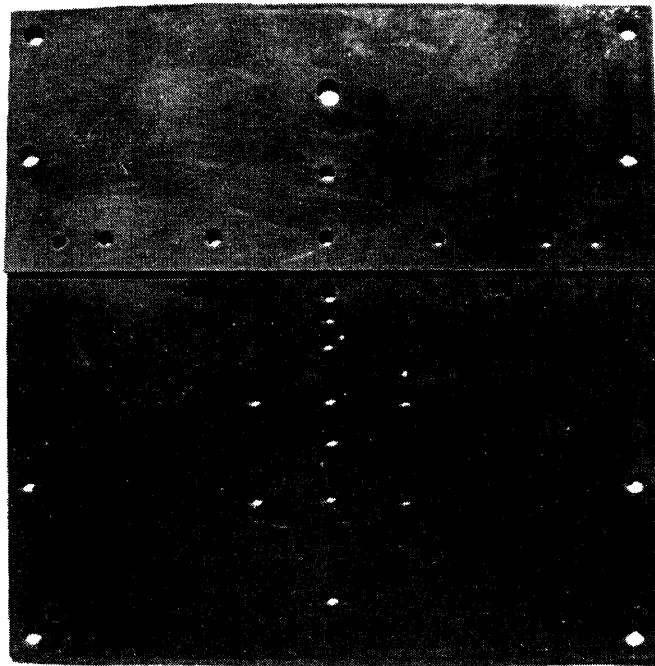


Fig. 21. A top view of the middle plates showing the hole pattern of the vacuum system.