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**TECHNICAL INNOVATION**

# Low-cost BioMEMS Photomask Alignment Technique

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**Abstract**

Microelectromechanical Systems (MEMS), devices with components generally measuring less than 100 µm, are often used to study biological interactions such as cell activity monitoring or biocompatibility testing. When performing photolithography for MEMS, consecutive layers of photoresist are added to create three-dimensional structures where a typical device has two or three layers; each layer must be precisely aligned with the layer previously formed underneath. An aligner has been made to complete this alignment task for less than $40 by utilizing the flats of the wafers to consistently position them. Photomasks are cut with laser cutter technology so they can be placed over tight fitting alignment pins on the device. The aligner resulted in a two-layer accuracy of 238.2 ± 10.55µm (n=5). Such an aligner allows students to more easily learn the photolithography process by reducing time for mask alignment thereby accelerating master fabrication time.

## Introduction

When completing the photolithography process in the MEMS or BioMEMS fields, the fabrication of a master can be tedious and laborious. The time and investments spent by laboratories on achieving high levels of accuracy between multiple layer masters are inefficient. With low-technology aligners, significant time is spent in the efforts to adequately align multiple layers with limited success. Higher levels of accuracy are attainable but often at the cost of extremely high cost digital aligners upwards of $30,000. A low-cost and faster aligner was desired which would still yield satisfactory accuracy between multiple layers.

In order to address this need, our senior biomedical design team at the University of Wisconsin – Madison was able to fabricate a device that provides advantages over other aligners: (1) significantly lower cost (<$40); (2) extremely repeatable and easy to construct with minimal tooling; (3) precise accuracy (238.2 ± 10.55µm for a two-layer master); (4) low manufacturing time of the alignment device (approximately four hours from start to finish). In addition, our device can be created using materials that are available from any local hardware store.

This article reports the materials, detailed fabrication process, and accuracy testing results for our aligner including the theory behind our design, assembly of the aligner, and visual test results acquired via Leica DFC480 stereo microscope.

## Structure and Fabrication

### Design Theory

The alignment technique is heavily based upon the Miller index of silicon wafers. Whether the index (indicative of the crystalline structure orientation) is [100], [110], or [111], the geometrical shape of any silicon wafer has at least one flat of 0.875 inch length. The approach for this design was to position this flat against an edge and restrict movement of the wafer with a lock bar on the opposing side of the wafer. Since this method theoretically ensures consistent placement of the wafer on the aligner, overall accuracy of the device is dependent upon the consistent placement of photomasks. To accomplish this two alignment pins are added to the base which will correspond with holes in the photomask transparency. Each mask layer can then be placed over the alignment pins and no further adjustments are necessary.

To ensure proper placement of the alignment holes for each layer, all photomasks for a given master are printed on the same transparency and cut by laser cutting technology. We used a 40 Watt Epilog® Mini Laser which has a listed accuracy of 12,000 dpi (2.12 µm per dot). However any laser cutting system capable of reading vector files and with a similar accuracy can be used. The laser cut is designed to accomplish two things; cut the mask out of the transparency so as not to interfere with the lock bar, and cut two alignment holes which fit snugly over the alignment pins and lock the mask in position with the base. The size and spacing of the alignment holes can be found by trial and error using measurements of the alignment pins on the base taken with digital calipers. Proper sizing and spacing of alignment should ensure that the mask is unable to translate when placed over the pins, but not fit too tightly that the transparency is distorted. When designing photomasks it is essential that the printed photomask layout and the file which is sent to the laser for cutting are in agreement. It is helpful to include the lines which will be cut by the laser in the photomask print. This way a test run can be done on paper and compared with the photomask to ensure everything is in the right spot before the more expensive mask is cut.

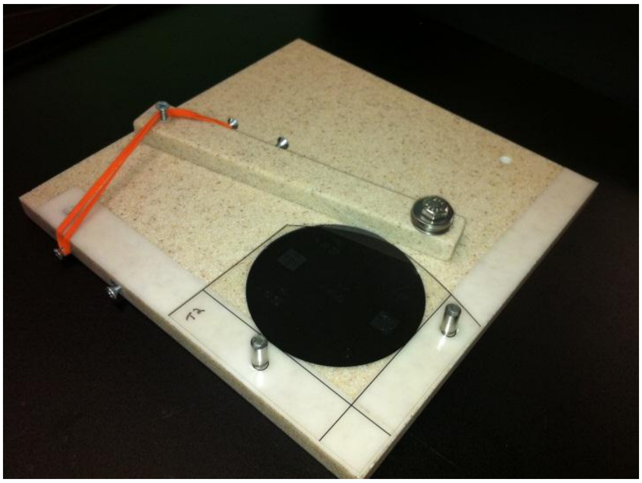

**Fig.1: The final prototype of the low-cost aligner in use with wafer constrained and photomask placed over alignment pins.**

## Materials

The designed photomask aligner was manufactured using commonplace components. The base for our design was cut from a ½-inch thick Corinthian™ 100% solid surface acrylic cutting board with original dimensions 11 3/8" x 11 3/8". The smooth polished surface finish of the acrylic base aids in keeping the silicon wafers flat during the photolithography process. Cut-offs of the acrylic base were used to also fabricate the lock bar which is pulled against the wafer via tension bands. To constrain the wafer, two lips were made into a corner using 0.030-inch thick Delrin (DuPont's® acetalpolyoxymethylene) material. The pieces used were cut from a sample obtained from CS Hyde Company in Lake Villa, IL. The Delrin is backed with 3M® 300LSE adhesive backing-chosen for its bonding strength to low-surface energy polymers such as the polished surface of the acrylic base. 3M® 300LSE adhesive also is unaffected by water or UV exposure which is a critical requirement given the shearing load placed against the lip under high-intensity UV light.

Other materials used in the aligner prototype are standard hardware components that have been modified to perform their desired intention to aid in photomask alignment. The modified hardware was purchased as ¼-28 UNF x 1½" stainless steel hex cap screws. Fine ¼-28 UNF threads were selected in place of more readily available ¼-20 UNC course threads for increased thread engagement and rigidity of the alignment components. Stainless steel hardware offers better hardness and therefore better retains its concentricity when used as cylindrical alignment rods in the design. Other materials are simply ¼-inch flat washers and a tension band (standard size 33 rubber band). The small screws used in coordination with the tension band to apply appropriate load to the lock bar against the wafer are simply #8-32 x 5/8-inch flat Phillips head screws (quantity=5).

## Fabrication

The construction process for our device began with cutting out a base for the aligner. We used a drop saw to cut out the 8 1/8" x 8 1/8" base from the 11 3/8" x 11 3/8" acrylic solid surface cutting board. A mitre saw, hand saw, or table saw would also suffice for this task. We then cut out the lock bar for the device using the same saw and scraps from the acrylic material that were not used for the base. Dimensions for the lock bar were 6 ¾" x 7/8" x ½". The strips of Delrin were cut 7/8" wide with an industrial paper cutter. The bolts and screws used with our device were sawed off to a desirable length with a band saw. Thread-shortening cuts were cleaned up via belt-sander to ensure proper thread function. Alignment pins were tapered with the belt sander to reduce wear on the photomask alignment holes. The exact dimensions are not entirely important for the bolts and screws since washers are used to ensure a snug fit. Alignment holes were drilled at 2 ¼" and 2 7/8" from the base corner. After the parts were cut out, we began to assemble the prototype. Screws were placed on the sides of the lock bar and base. Finally the holes for the pivoting bolts to contain the lock bar was drilled and tapped. Delrin strips were added to edges of the base with the adhesive 3M® 300LSE backing already on the Delrin. Alignment pins tapered slightly at the top and were placed into their respective holes. Finally, we attached the lockbar to the device with a screw and washers. The complete fabricated prototype can be seen in Figure 1. For fabrication prints, see the appendix.†

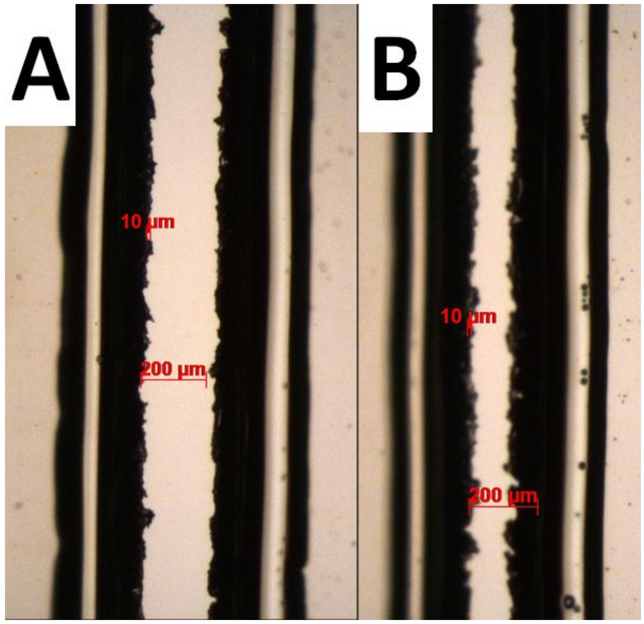


**Fig 2: Transparency laser cuts with settings at (A) 50% speed/20% power (B) 50% speed/10% power. (A) shows optimal settings to reduce cut variance.**

## Budget

A major component of this design project and photolithography processes in general is cost. As mentioned earlier, high-tech, very accurate aligners can cost more than $30,000. Because the main purpose of the aligner was for teaching purposes and so that other labs and universities can make similar devices, significant importance was placed on keeping the cost of the alignment device as low as possible. We were able to fabricate the entire aligner for less than $15. If unable to obtain a free sample of the Delrin material, the cost of the entire device would be about $40.

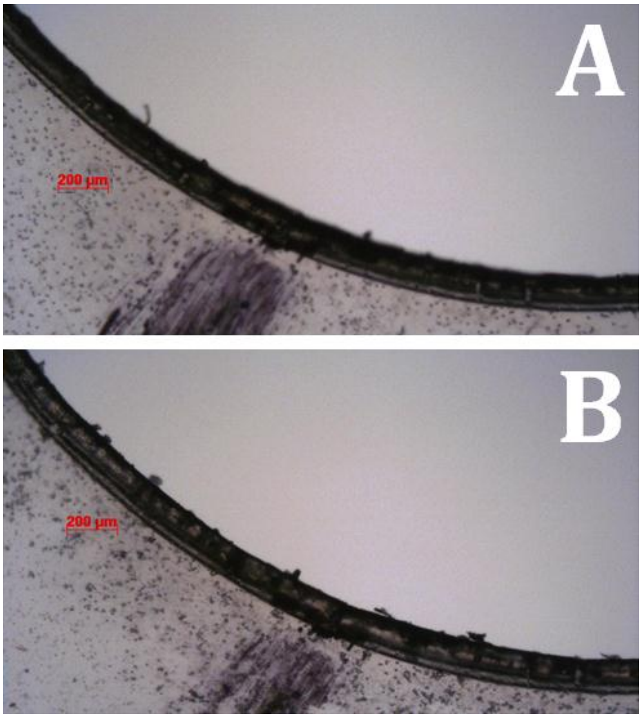


**Fig 3: (A) Microscopic image of photomask alignment hole before use. (B) Microscopic image of same alignment hole after placement over rods 100 times.**

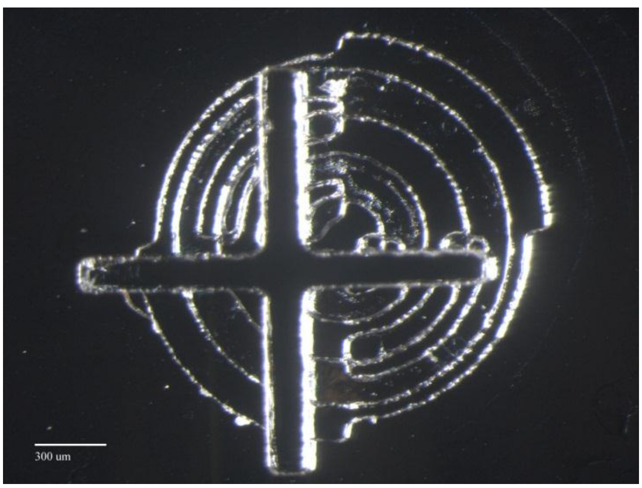


**Fig 4: One of five images obtained from stereo microscope showing 2nd layer crosshairs on 1st layer target used to evaluate accuracy of prototype. A final alignment accuracy of 238.2 ± 10.55µm (n=5).**

## Results and Discussion

### Laser Optimization

Numerous tests were done to test the efficacy of the aligner and the various components of the process. In order to cut precise holes to fit over the alignment pins, we used a 40 Watt Epson Laser Cutter available in a campus teaching lab. In conjunction with the laser cutter, we adjusted specific settings through CorelDRAW®. Because our team was initially unfamiliar with the laser cutter, an assortment of tests was done using the laser cutter's settings to cut different shapes from transparency film. By varying the power and speed of the program we were able to alter the photomask transparency melting involved and the variance along the cut. Since the settings allowed for 1%-100% for both power and speed, we tested several combinations of these settings. As Figure 2 shows, the settings of 50% speed and 20% power showed the least amount of variance along the cutting line. We were also curious to see how accurate the cutting platform of the laser cutter was. In order to do this, we programmed a straight line cut vertically down the transparency film. By measuring the distance from the edge of the film to the cut at the top and bottom, we determined that was approximately 0.1% off square when testing for alignment of the cutting platform. Finally we had to determine the exact dimensions of our aligner as fabricated. Since the laser cutter has the ability to cut circles with a diameter down to the thousandth of an inch, we cut several holes at diameters above and below the diameter of the alignment pins as measured with digital callipers. A final diameter of 0.230in was chosen for the two holes because it fit snugly on the pins without too much resistance to put on or remove. Additionally, measurements were taken to determine the exact distance between the centres of the two pins. This was measured to be 2.800in.

### Alignment Hole Wear Testing

Because the photomasks have the possibility for reuse we wanted to find out how much repeated use of one photomask affected the integrity of the alignment holes. To look at this problem, we took microscopic photographs of each of the two holes after zero uses, five uses, 25 uses and 100 uses. As shown in Figure 3, we saw minimal difference in wear between the holes after zero uses and after 100 uses.

### Accuracy of the Aligner

In order to determine the accuracy of the aligner, we made a master wafer with targets of various sizes with exact measurements. As discussed earlier, this wafer was made with circular targets on the first layer and a crosshair design on the second layer. After the basic photolithography steps were completed, we used a stereo microscope to take photographs of the master wafer. Specifically we looked at the smallest target-crosshair size on the wafer (see Figure 4).From these targets, we were able to conclude that of the five identical targets on the wafer, the average accuracy was 238.2 ± 10.55µm (n=5).

### Spring-Constant Testing

Determination of the spring constant was conducted as a means to quantify loads applied upon the wafer. Since there are two screw positions on both the acrylic base and lock bar, the tension can apply variable loads. Additionally, since the band is in three-point loading (as opposed to linear stretch), an additional variable is introduced. Furthermore, the design is made for use with 3in and 6in wafers --- changing the displacement of the band accordingly. Since a low-resolution force gauge couldn't be acquired, spring-constant was found by measuring the displacement of the band from equilibrium under known loads (container with various amounts of liquid). By graphing the results of known force against displacement and setting the y-intercept to 0, the spring constant $k$ was found as 21.556 N/m (as seen in Figure 5).

### Safety Factor Calculations

Safety factor of loading is required to ensure the wafer isn't overloaded or compressed near its fracture limit. Various methods were used to calculate multiple safety factors including yield stress, axial load, and ultimate stress while comparing to values of various studies and reports. Equation 1 was used to compute yield stress from the spring constant.

$$\sigma_y = \frac{k}{A} \cdot L \qquad (1)$$

For the computation, $\sigma_y$=3440[1], k=21.556 N/m, L=0.0762m (wafer diameter), A=9.6774x$10^{-9}$ $m^2$ (wafer height x lock bar contact length). This yields a safety factor of 40.5344. If approximating stress by F/A (instead of using spring constant), a stress of 0.31 MPa is estimated on the wafer. In comparing this to the reported failure stress for Silicon wafers in the literature of 208.911 MPa[2] a safety factor of 673.904 was computed. Alternatively, the safety factor was compared to a die breaking load of 70 N for silicon of 0.38mm thickness. [3] For a 3in wafer, the observed maximum load on the prototype was 3.06 N, yielding a safety factor of 22.88 (70 N/3.06 N). The same study also found a failure stress for wafers of thickness 0.38mm at 400 MPa.[3] The safety factor then is 1290.32. Clearly the aligner has been designed so as to avoid fracture of the silicon wafer although calculated safety factors range from 22.88 to 1290.32 depending on the assumptions made in calculations and which previous studies those calculations are compared to.

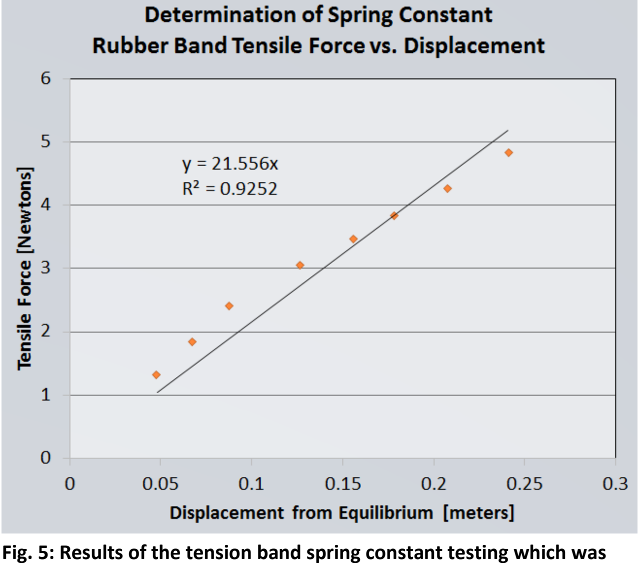


**Fig. 5: Results of the tension band spring constant testing which was completed by measuring displacement of the tension band from equilibrium (in meters) under known loads (in Newtons).**

## Conclusions

Current photomask alignment devices are difficult to manufacture and expensive to purchase. The aligner designed by our team at the University of Wisconsin-Madison provides a low-cost, easy to manufacture alternative with accuracy sufficient for use in a student teaching lab. The materials used in the fabrication process of our device were easy to obtain and can be purchased for under $40. After only four hours of assembly, our device was fully functional and provided a precise accuracy of 238.2 ± 10.55μm for a two-layer master. Our results demonstrated efficiency and consistency and eliminated the majority of human error. Our photomask aligner is appropriate for any lab in need of an affordable, easy-to-fabricate, accurate device for photolithography purposes. The skill needed to gather and assemble necessary materials for our device is minimal, which encourages labs everywhere to utilize our device.

## Notes and references

1 ECOGEHR® Bio-Polymers, *Professional Plastics Mechanical Properties Database*, 2012.

2 Steinzi M., Band tests of silicon ladders to determine ultimate strength. *Hytech Inc.*, 8.3.2000.

3 Chong DR, Lee WE, Lim BK, Pang JL, and Low TH. Mechanical characterization in failure strength of silicon dice. *Packaging Analysis and Design*, 2012.

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† Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/b000000x/ (APPENDIX)