Microfluid Mixer

Kelsey Ganzon[1]

[1]*Department of Mechanical Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801*

May 2, 2024

1 Introduction

1.1 Design

The purpose of the lab was to fabricate a device that is able to mix fluids from PDMS. Figure 1 shows the device design. Two liquids of different dye enter their respective inlets and meet at point A. They combine to form a laminar flow towards point B. The liquids travel parallel with respect to each other. After the liquid hits point B, the corner forces their flow to change direction towards point C. The disruption from the corner causes turbulence within the fluid which induces mixing of the fluids. The process repeats at each corner, which further mixes the fluids together. Finally, the fluid reaches point D where they are analyzed on how well they were mixed. The fluids then exit the device through the outlet.

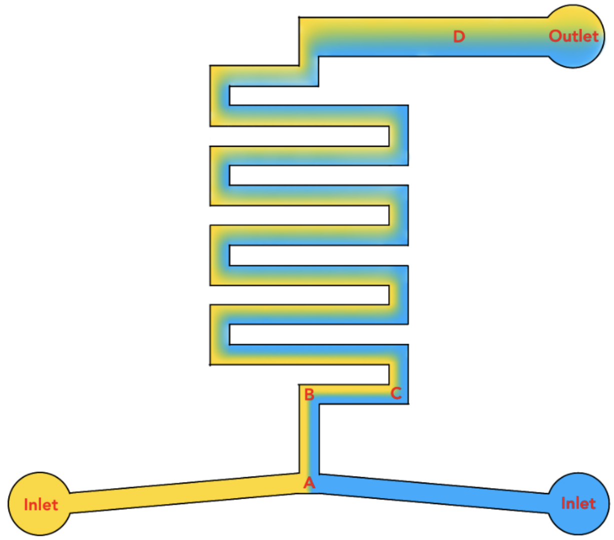

Figure 1: Caption

1.2 Figures and Schematics

The first part of the fabrication process is the KMPR photoresist layer that is deposited onto the surface of the wafer. This is done through spin coating and is shown in Figure 2

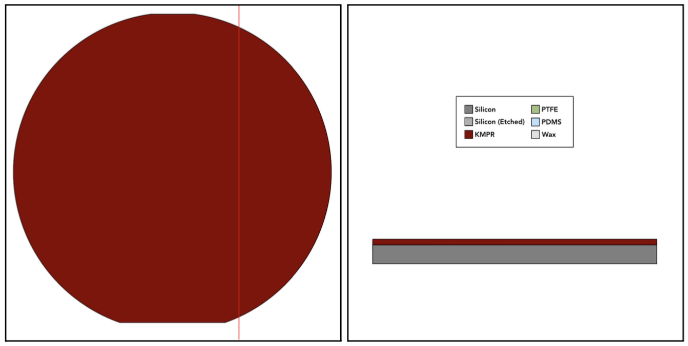

Figure 2: top view on the left and side view on the right of the photoresist layer

After the photoresist layer was deposited, the wafer was flood-exposed under the mask and developed using AZ 917. The exposure created a patterned device outline as shown in Figure 3

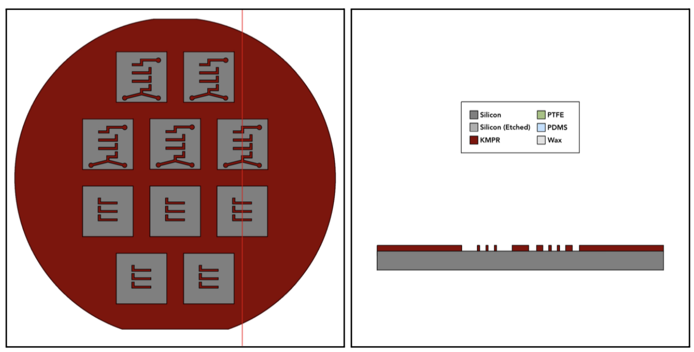

Figure 3: top view on the left and side view on the right of the flood-exposed mask on the wafer

After the wafer was exposed, the exposed silicon was then etched using DRIE to form then channels. The KMPR residue was removed using an O_2 descum. The resulting waver is shown in Figure 4

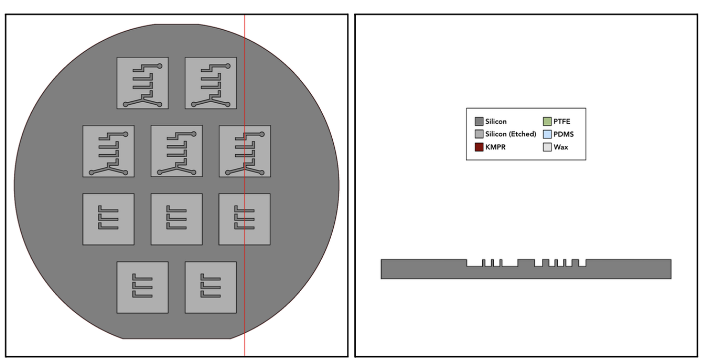

Figure 4: top view on the left , side view on the right of the etched wafer and KMPR removed

A layer of PTFE was spin-coated onto the wafer in order to reduce the stiction between the wafer and the PDMS. Figure 5 shows the added layer.

A wax strip is then added to the wafer around the patterned devices. The PDMS is then prepared and put into a pressure chamber to get rid of any air bubbles. After the PDMS is settled, it was then

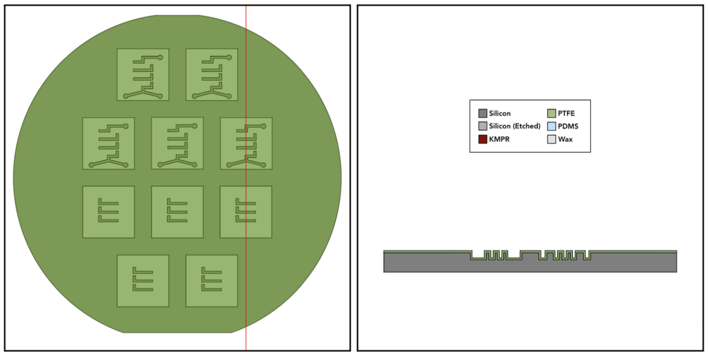

Figure 5: top view on the left and side view on the right of the PTFE spin-coat on the wafer

poured on the top of the wafer, covering all the devices. The wax barrier prevented any spillage. The resulting wafer is shown in Figure 6

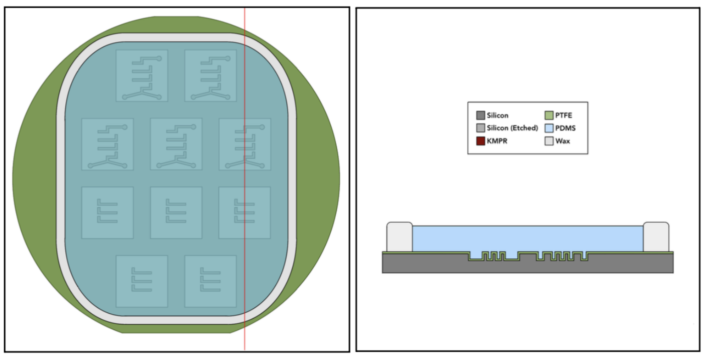

Figure 6: top view on the left and side view on the right of the wax boarder on the wafer with PDMS layer

After the elastomer was cured, the PDMS layer was carefully removed. Each device was diced using a razor blade and a 1 mm biopsy hole was made for the inlet and outlet. The two halves were then descumed with an activation layer. The top and the bottom halves were placed on top of each other and aligned with a microscope. Figure 7 shows the top half of the PDMS layer.

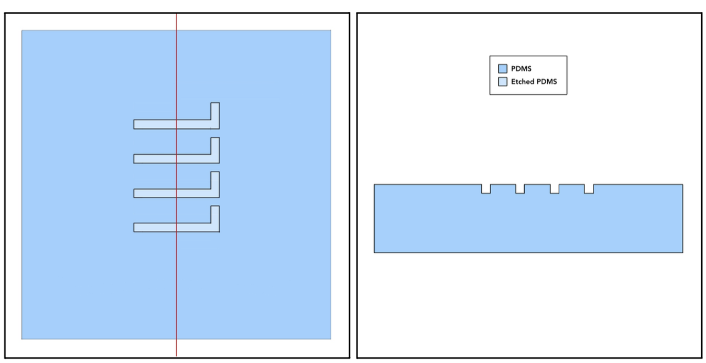

Figure 7: Top view on the left and side view on the right of the top half of the PDMS layer

Figure 8 shows the bottom half of the layer. When aligning the two halves, it is important to note that there is a two minute window before the activator sets. This caused the alignment to be time sensitive. Figure 9 shows the inlet and outlet holes that were biopsied.

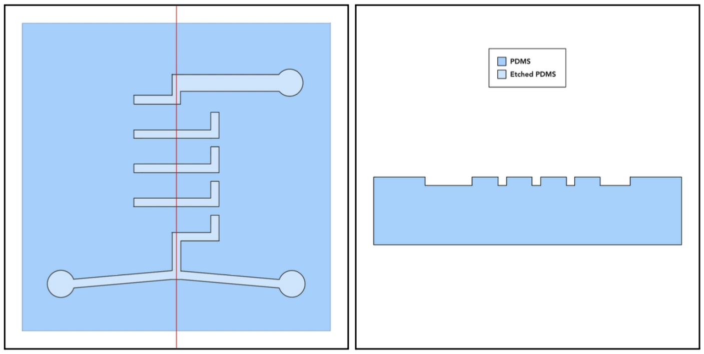

Figure 8: Top view on the left and side view on the right of the bottom half of the PDMS layer

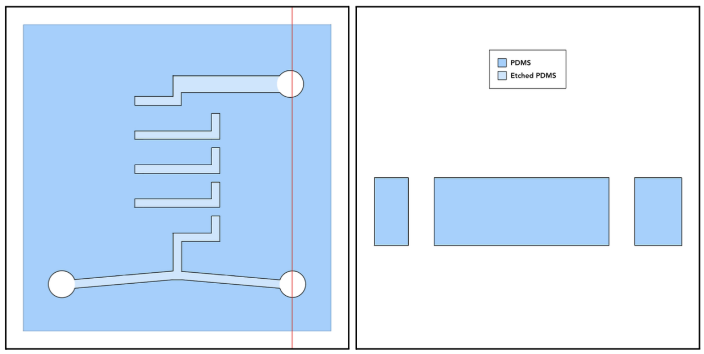

Figure 9: top view on the left and side view on the right of the biopsied holes of the inlet and outlets

2 Literature review

A literature review was done on Marcel Workamp where he produced a microfluidic mixer. The mixer features a single mixing chamber in which the particles are driven by a moving magnet. [1]. The experiment involved the probing the frequency of motion of the magnetic stirrer as well as the addition of glass particles. The device schematic is shown in Figure 10

The functionality of our device differs from Workamps device. Our device uses a passive mixing mechanism by passing fluids through sharp turns. In Workamps device, it features an active mixing design where the magnetic stirrer can be controlled by an external controller. This device was only tested at low flow rates (0.02 and 0.04 mL/min), so the optimal flow regime is indeterminate. Since a smaller magnet was used in order to reduce the drag, the mixing rates were limited. The article hypothesized that using a larger magnet may increase the mixing rates which can achieve higher flow rates. This hypothesis was not tested however.

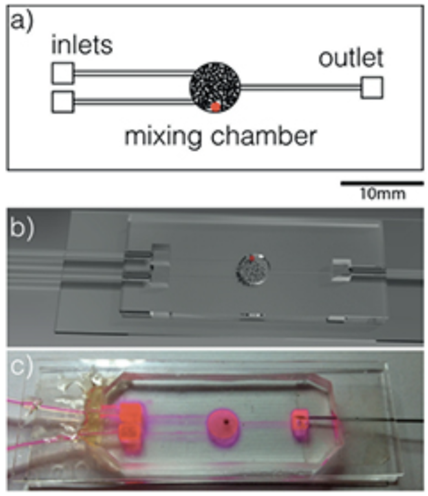

Figure 10: Workamp's device design and schematic of the microfluidic mixer

3 Results and Analysis

3.1 :

The channel heights were measured and are given in Table 1 along with the average. The fluid that

Trial	Channel Heights (μm)
1	153
2	152.6
3	148.4
Average	151.33

Table 1: Channel Heights of the devices and the average

was used in this lab was dyed water. We can neglect the affects of the dye on the water, so the density and viscosity will be the same as water. Thus the density of water is $\rho = 997kg/m^3$, and the viscosity of the water is $\mu = 8.9x10^-4Pa * s$. The Velocity of the fluid can be calculation using Equation 1.

$$V = \frac{\Phi}{A} \tag{1}$$

where Φ is the flow rate and A is the cross sectional area. The Area is calculated by multiplying the Channel height and the channel base which is 200 μm. The characteristic Length of the channel can be calculated by Equation 2

$$L = D_h = \frac{4A}{P} = \frac{4bh}{2 * (b + h)} \tag{2}$$

Where A is the cross sectional area and P is the wetted perimeter. The Reynolds number for at different flow rates for the device can be calculation using Equation 3

$$Re = \frac{\rho V L}{\mu} \tag{3}$$

where ρ is the density of the fluid, V is the velocity of the fluid, L is the channel Length, and μ is the viscosity of the fluid. The Reynolds numbers were and velocities calculated and are shown in Table 2 for each flow rate measured.

The Characteristic length for a circular channel is determined by the following Equation 4

$$L = \frac{4A}{P} = \frac{4\pi r^2}{2\pi r} = 2r = D \tag{4}$$

which means that the characteristic length is the same as the cross sectional diameter of $200\mu m$. Using Equation 1 and 3, the Velocity and Reynolds number are calculated and shown in Table 3

Flow rate (mL/min)	Velocity(m/s)	Reynolds Number
0.005	2.723	531.415
0.05	27.233	5314.159
0.1	54.466	10628.318
0.25	136.165	26570.795
0.5	272.331	53141.590
1.0	544.662	106283.180

Table 2: Velocity of the fluid and Reynolds Number for each flow rate measured

Flow rate (mL/min)	Velocity(m/s)	Reynolds Number
0.005	2.652	594.298
0.05	26.525	5942.981
0.1	53.051	11885.963
0.25	132.629	29714.908
0.5	265.258	59429.817
1.0	530.516	118859.634

Table 3: Velocity of the fluid and Reynolds Number for each flow rate measured for a circular channel

3.2 :

The Reynolds number is calculated to determine whether or not the fluid has laminar or turbulent flow. Typically for water, a Reynolds number 2300¡ indicates laminar flow and R_e ¿ 4000 indicates turbulent flow [2]. According to Tables 2 and 3, the 0.005 mL/min flow rate was the only one that caused laminar flow since 531.415 and 594.298 is less than 2300. The rest of the flow rates indicated turbulent flow. This makes sense because as the fluid moves past the corners, the fluid starts to mix due to hitting the sides. This turbulent force causes the fluid to mix.

3.3 :

Figure 11 maps the concentration of the dye and the position across the channel. This helps visualize how well the fluid was mixed. Table 4 gives the standard deviations of the brightest value across the channel. The least efficient mixing is the one that corresponds to the highest standard deviation.

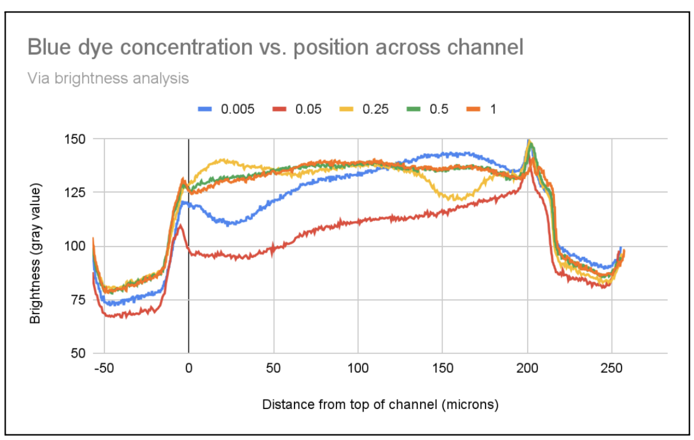

Figure 11: The degree of mixing for flow rates across different points of the channel

The least efficient is the lowest flow rate which is 0.005 mL/min. The most efficient mixing, or the lowest standard deviation, was the flow rate of 0.5 mL/min which was not the highest flow rate. This demonstrates that there is a certain regime in which the most optimal mixing occurs. Since the turbulence as the fluid passes through the corners causes the mixing to occur, it may not have a direct linear relationship to the flow rate.

Flow Rate (mL/min	Brightness Standard Deviation
0.005	10.60094
0.05	10.0758
0.25	4.78599
0.5	2.8314
1.0	3.7438

Table 4: Standard Deviations of Brightness across channels at different points

There are many ways to optimize these results and better visualize the mixing. One of the ways is to use colorimetry techniques to better visualize how well the mixing occurs and will provide better data and images. Another way to determine the dependence of flow rate is to take more measurements in between the interval of 0.005 and 1.0 mL/min to better understand if there is a trend in flow rates. All the calculations in this report was done using python and can be found in the appendix below.

4 Conclusion

In conclusion, my mixer design worked during the initial test where we used the syringes to manually initiate the water flow. Both of the inlets supplied water, however it was hard the supply the fluid at the same rate. We then hooked up my fluid mixer to the testing device and unfortunately it did not mix properly. Under further investigating, it was determined that the channels were way too rigid and was not able to supply the fluid evenly. This caused a build up of fluid at one side since one inlet had greater force than the other inlet. When comparing to the TA sample, under the microscope, the channels appeared to be smooth and perfectly straight. This is due to the mask that was engineered that was able to expose the pattern perfectly. The masks that were printed from our designs were not of good quality which resulted in rigid lines as well as poor resolution. This shows how important it is to have a very good mask since you are limited by how well the mask is engineered. Another source of error also could have been the alignment part since we had to use our eyesight and microscope for judgement.

For future labs, I would say to specify more parameters when designing the fluid mixer such as how large we need to make the channels. I would also try and see if there is a way to print the masks a bit better to hopefully increase the yield of devices. The rigid channels prevented a lot of devices from working.

References

[1] A simple low pressure drop suspension-based microfluidic mixer. https://iopscience.iop.org/article/10.1088/0960-1317/25/9/094003/metaml. [Online; accessed May 1, 2024].

[2] Water flow in tubes. https://www.engineeringtoolbox.com/reynold-number-water-flow-pipes-d$_5$74.$html.[Online; accessedMay1, 2024]$.

5 appendix

The following code was used to calculate the Velocity along side the appropriate conversion:

```
    #calculating Velocity
def Velocity():
    phi=[5e-06,50e-06,100e-06,250e-06,500e-06,1000e-06]
    A=[3.06e-08,3.06e-08,3.06e-08,3.06e-08,3.06e-08,3.06e-08]
    V=[]
    for i in range(6):
        V.append(phi[i]/A[i])
```

```
    print(V)

    def velocityconvert():
    v=[163.3986928104575, 1633.986928104575, 3267.97385620915, 8169.934640522875, 16339.8
    c= [60,60,60,60,60,60]
    vc=[]
    for i in range(6):
        vc.append(v[i]/c[i])
    print(vc)
```

The following code was used to calculate the channel length:

```
    #calculating the length
def channelLength():
    A=[3.06e-08,3.06e-08,3.06e-08,3.06e-08,3.06e-08]
    h=[0.0001513333333,0.000151333333,0.000151333333,0.00015133333,0.00015133333]
    b=[200e-06,200e-06,200e-06,200e-06,200e-06]
    L=[]
    for i in range(5):
        L.append((4*A[i])/(2*(b[i]+h[i])))
    print(L)
```

The following code was used to calculate the Reynolds numbers:

```
    #Calculating the reynolds number
def Reynolds():

    p=[997,997,997,997,997,997]
    V=[2.7233115468409586, 27.233115468409586, 54.46623093681917, 136.16557734204792, 27
    mu=[8.9e-04,8.9e-04,8.9e-04,8.9e-04,8.9e-04,8.9e-04]
    L=[0.00017419354838709678, 0.00017419354838709678, 0.00017419354838709678, 0.0001741
    R=[]
    for i in range(6):
        R.append((p[i]*V[i]*L[i])/mu[i])
    print(R)
```

The following code was used to calculate velocity with a circular diameter and convert to the proper units:

```
    def velocityconvertcir():
    v=[159.1550775244383, 1591.550775244383, 3183.101550488766, 7957.753876221915, 15915
    c= [60,60,60,60,60,60]
    vc=[]
    for i in range(6):
        vc.append(v[i]/c[i])
    print(vc)

    def velocityconvertcir():
    v=[159.1550775244383, 1591.550775244383, 3183.101550488766, 7957.753876221915, 15915
    c= [60,60,60,60,60,60]
    vc=[]
    for i in range(6):
        vc.append(v[i]/c[i])
    print(vc)
```

The following code was used to calculate the Reynolds number for the circular diameter:

```
    #Calculating the reynolds number for circular diameter
def ReynoldsCirc():

    p=[997,997,997,997,997,997]
```

```
V=[2.652584625407305, 26.52584625407305, 53.0516925081461, 132.62923127036524, 265.25
mu=[8.9e-4,8.9e-4,8.9e-4,8.9e-4,8.9e-4,8.9e-04]
L=[200e-6,200e-6,200e-6,200e-6,200e-6,200e-06]
R=[]
for i in range(6):
    R.append((p[i]*V[i]*L[i])/mu[i])
print(R)
```