Benchtop Photolithography and Microfluidics

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Abstract*– The concept of microfluidics involves the manipulation and control of fluids that are constrained to channels with dimensions in the micrometer scale or less where capillary action and diffusion are the dominant means of transport. This study has been used in many science and engineering industries for projects such as micromixers, cell biology research, drug delivery devices and labs on a chip. Microfluidics allows the analysis and use of less volume of samples, chemicals and reagents reducing the global fees of applications. Many operations can be executed at the same time thanks to their compact size, shortening the time of experiment. Using the concept of photolithography to design the microchannels, we have been able to conduct micromixing in polydimethylsiloxane(PDMS) microchannels. Our numerical results qualitatively agree with the already conducted micofluidics experimental results. We have done finite element simulation of fluid flow by implementing the equations that govern fluid flow in microchannels in low Reynolds number regime and where the only active way of mixing is through diffusion. This paper describes a procedure to fabricate microfluidic channels using photolithograpic methods without requiring expensive instruments and a short description of the process towards performing the numerical simulation of mixing in micro channels through COMSOL.

I. Introduction

Microfluidics deals with manipulation of small volumes of fluids through channels with dimensions of tens to hundreds of micrometers with precise dynamic control over the flow to study new phenomena occurring in fluids at the microscale to nanoscale. The concept of microfluidics involves the manipulation and control of fluids that are constrained to channels with dimensions in the micrometer scale or less where capillary action and diffusion are the dominant means of transport. Microfluidics has been used in many science and engineering applications such as low Reynold's number micro-mixing, cell biology research, drug delivery devices and lab-on-a-chip devices. Microfluidics allows analysis and use of less volume of samples, chemicals and reagents, reducing the cost of applications and increasing sustainability. Many operations can be executed simultaneously using parallel processing, thanks to their compact size, shortening the time of experiment. Using the concept of benchtop photolithography to design the micro-channels, our lab has been able to conduct micro-mixing in polydimethylsiloxane(PDMS). Our work consists of the experimental procedures to develop and test these micro-channels and the numerical simulation of fluid flow in the channels to back up these simple inexpensive experimental procedures.

II. CONCEPTS

Mixing devices are called mixers and they can be divided into passive micrometers and active mixers. In active mixers, there are many factors that influence mixing in the channels such as pressure and temperature

gradient, and could include pumps and valves. On the other hand, passive micromixers are only influenced by the concentration gradient which causes diffusion of the molecules of the fluids in the mixing chamber.

Constants that Govern Microfluidics

1. Reynold's Number: This is the ratio of a fluid's inertial force to its viscous force, where inertial force is the force due to the mass momentum of fluids in motion and viscous force is the force of friction of a flowing fluid. High Reynold's number implies that the flow is turbulent. Low Reynold's number implies that the flow is laminar, which means when two fluids are placed side-by-side, they do not mix turbulently. Hence, mixing occurs only through diffusion.

2. Peclet's Number: The Peclet number is defined as the ratio of the rate of advection of a physical quantity by the flow to the rate of diffusion (matter or heat) of the same quantity driven by an appropriate gradient. Equation:

$$Pe = N_{conv}/N_{diff}$$
$$Pe = LV/D$$

Where L is the length scale, V is the velocity magnitude and D is the diffusion coefficient. High Reynold's number implies that the flow is turbulent. Low Reynold's number implies that the the flow is laminar, which means when two fluids are placed side-by-side, they do not mix the conventional way. Hence, mixing occurs through diffusion.

B. Laws governing microfluidic

Navier-Stokes Equation is the equation of motion (Newton's Law) for fluids. Fick's Law states that molecules of fluids undergo vibrations which give rise to diffusion. In the presence of a concentration gradient, these molecules vibrate and move towards each other to even out the gradient.

III. EQUIPMENT

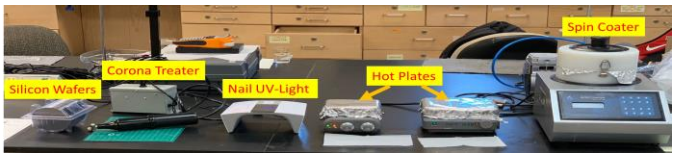

FIG. 1. Materials and equipment needed for benchtop photolithography.

• Silicon Wafer. University Wafers. • Spin Coater. MTI Corporation. • Hot Plate. Fischer Scientific. • Corona Treater. Electro-Technic Products, BD20AC Laboratory Corona Treater.

• UV lamp. Piano Series 007, UV LED Nail Lamp (Adjustable 48W/ 60W)

• Incubator. Quincy Lab, Inc. , Model 10-140 Incubator, 140 Series

• Microfluidic pump. New Era Pump Systems, Inc. Model No. NE-300

• Biopsy Puncher. Electron Microscopy Science Rapid-Core 0.75,

• L-shaped metal connector, TE NEEDLE 20 GA, BENT 90 DEG

• Tubing. 1.6mm OD, 0.8mm ID.

CHEMICALS USED

• MicroChem SU-8 2050 photoresist • MicroChem SU-8 Developer • Acetone • Isopropyl Alcohol • Deionized WaterIV. SOME COMMON MISTAKES

PRE-PROCESSING AND SETUP

Approximate time to complete the process: 2 hours (Note: Use the polished face of the wafer in the whole process). Turn on two hot plates, one at 65◦C and the other at 95◦C. Fill a plastic disposable glass with 10mL of Micro-Chem SU-8 developer. Clean properly all tabletop apparatus used with Isopropyl Alcohol (IPA). Avoid dust and contamination on the wafer throughout the process.

CLEANING

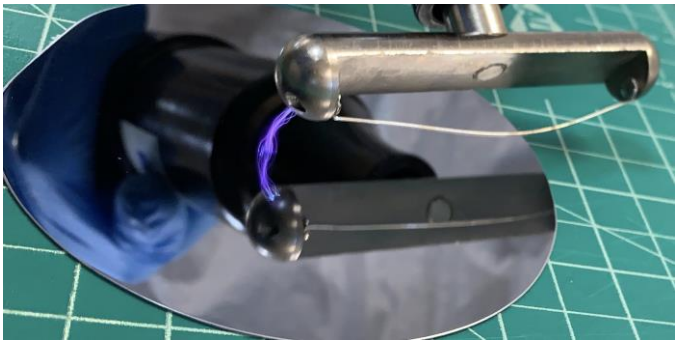

FIG. 2. Treating the silicon substrate with corona.

Clean the Silicon Wafer with Acetone followed with Isopropyl Alcohol (IPA). Rinse properly the whole wafer with Deionized (DI) water. Dry the wafer with the compressed air (use low air speed to avoid breaking the wafer). Use the hot plate to bake the wafer at 95◦C for 10 min (This step is to evaporate the wafer on the surface of the wafer). Remove the wafer from the hot plate and let it cool down to room temperature for 5 min. Use the handheld corona treater to treat the whole surface of the wafer for 20 seconds. Immediately after treatment with the corona treater, spin coat the photoresist (PR) on the wafer.

SPIN COATING OF THE NEGATIVE PHOTORESIST

(SU-8 2050 photoresist is used for the fabrication of the microchannels). Load the wafer on the vacuum chuck of the spin coater. Alternatively, we can use a homemade spin coater with a recycled computer fan [1]. Align the wafer properly so that the center of the wafer rests on the middle of the chuck. Then, pour 2-4mL of the PR, depending on the wafer size (usually bigger diameter wafer requires more PR to coat its surface) on the middle of the wafer. Avoid having trapped air bubbles. Use the following coating recipe to coat the wafer with the PR.

Step 1: Speed (500 rpm); Acceleration/Deceleration: 300rpm/s; Duration:10 sec, followed by

Step 2: Speed: 2000 rpm; Acceleration/Deceleration: 500rpm/s; Duration: 30sec.

SOFT PRE-EXPOSURE-BAKING

The following steps are set to gradually heat up the PR to avoid rapid heating that will cause stresses and cracks in the PR. Remove the wafer from the Spin coater and place on the hot plate at 65◦C for 10 min. Place the wafer on the second hot plate at 95◦C for 30 min. After this last step, avoid direct light on the coated wafer. After baking, let the wafer cool down to room temperature for 5 min.

EXPOSURE TO UV LIGHT

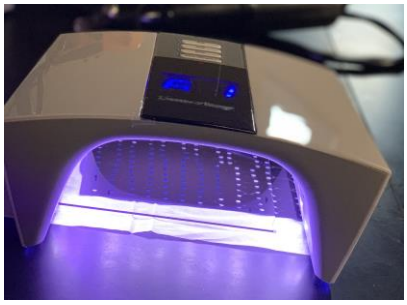

FIG. 3. UV treatment using a nail curer.

Place the wafer under the UV light (365 nm wavelength). Properly align the Photomask (PM, the design of the microchannels) on the wafer. Place a wide glass slide on the Photomask to promote better contact of the Photomask with the Photoresist coated wafer. Expose the wafer to the UV light at maximum power for 5 min and let the set up stand for 5 min. Carefully remove the glass slide and the Photomask.

SOFT POST-EXPOSURE-BAKING

We placed the wafer on the hot plate at 65◦C for 5 min. Then, place the wafer on the hot plate at 95◦C for 10 min. Let the wafer cool down to room temperature for 5 min.

DEVELOPMENT

We placed the wafer in the MicroChem SU-8 developer solution and swirl the developer solution smoothly for 110 min or until the unexposed Photoresist dissolves in the developer solution. Remove immediately the wafer from the developer after the channels totally appeared and rinse with IPA. Remember, if there are white traces on the wafer, the PR was not totally developed. Reimmerse the wafer into the developer for 30s or 1 min and repeat if necessary until there are no more white traces when rinsing with the IPA. Finally, rinse the channels with Deionized water and dry slowly with compressed air. Bake the wafer on the 65◦C hot plate for 5 min. The microchannel (molds) are now ready.

PDMS MOLD FOR MICROFLUIDIC CHIP

SYLGARD 184 elastomer is used to create microchannels. Open the SYLGARD 184 kit containing two plastic bottles (the large bottle contains the PDMS base and the small bottle contains the PDMS curing agent). Place a disposable plastic container on a scale. Pour first the PDMS base in the container Pour second the PDMS curing agent in the container at a weighing ratio of 1 to 10. For example, if the PDMS base is 10g, the weight of the PDMS curing agent needed is 1g. Mix thoroughly the mixture in the container. Place the silicon wafer with the microchannels molds in a plastic container Pour the PDMS mixture over the silicon wafer. Make sure to have enough PDM covering the silicon wafer (at least 0.5 cm of PDMS covering the silicon wafer).

DEGASSING OF PDMS (GETTING RID OF THE AIR BUBBLES)

It is important to get rid of the air bubbles in the PDMS mixture. There are two methods to get rid of the air bubbles: - Degassing using the vacuum pump for 2 hours or more if needed. (This is the quickest way to take out the air bubbles) - Leaving the PDMS mix uncovered for 24 hours at room temperature. For this process, the second method is used. Leave the container containing the silicon wafer and PDMS in the lab without covering and at room temperature for 24 hours. After the 24 hours, there will be no more air bubbles in the PDMS mix. The PDMS will still soft and sticky to touch. Place the container in the incubator at 40◦C for 1 hour or more until the PDMS is no more sticky to touch.

CUTTING THE PDMS MICROCHANNELS

Carefully peel the PDMS off the silicon wafer and place the PDMS on a clean surface.

CREATING INLETS AND OUTLETS HOLES ON THE PDMS MICROCHANNELS

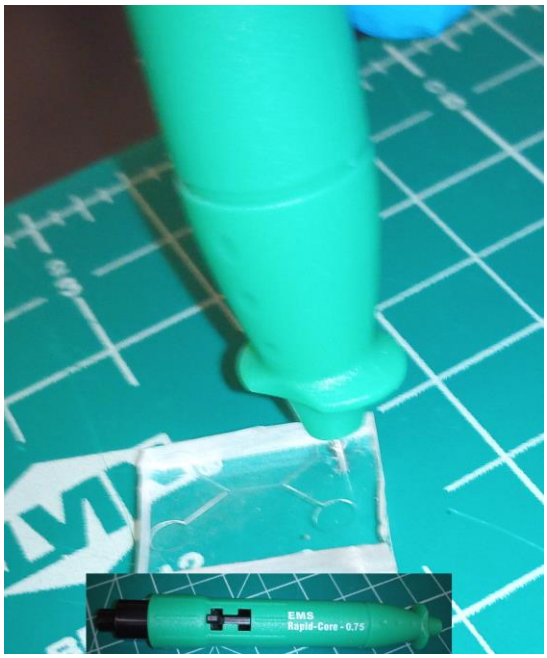

FIG. 4. Hole punching in the microchip using a biopsy punch.

Place the PDMS on a clean and hard surface (preferably a cutting mat). Use the Biopsy puncher with 0.75mm diameter to punch four holes in the microchannels reservoirs.

BONDING THE PDMS MICROCHANNELS WITH GLASS

Rinse the face of the PDMS with the microchannels with acetone, IPA and DI water. Dry the PDMS with clean compressed air. Place the PDMS on a clean surface. Take a clean glass slide and place it near the PDMS. Take out the corona treater, assemble and use it as defined in the instruction's manual. Treat with the corona treater for 30-60 seconds the PDMS face with the open microchannels. Treat one side of the glass slide with the corona treater for 30-60 seconds. Immediately bind both treated surfaces of the PDMS and glass slide. Apply gently some pressure on the PDMS and glass slide to bond

FIG. 5. Bonding the PDMS channel with glass.

them. Put the bonded PDMS and glass slide in the incubator at 40C for 30min (this will strengthen the bond). The microchannel chip is now ready.

FITTING THE MICROCHANNEL CHIP WITH THE MICROFLUIDIC SYSTEM L-SHAPE CONNECTORS

FIG. 6. Final fitting of the connectors and the tubes.

Take the L-shape connector and clip out the plastic connector. Connect one end of the L-shape connector to the tube connected to the syringe. Insert the other end of the L-shape connector inside the holes in the PDMS. Check that the L-shape connector is well-fitted inside the hole to avoid leaks.

5

CLEANUP

After the process, it is important to clean up the equipment used. Use acetone to wash off the Photoresist splashes on the spin coater. Use IPA to clean the tabletops used. Use the lab cleaning procedure to clean the glassware used and the tweezers.

IV. NUMERICAL SIMULATION OF MICROFLUIDICS

Create the geometry in SolidWorks and define the boundary conditions

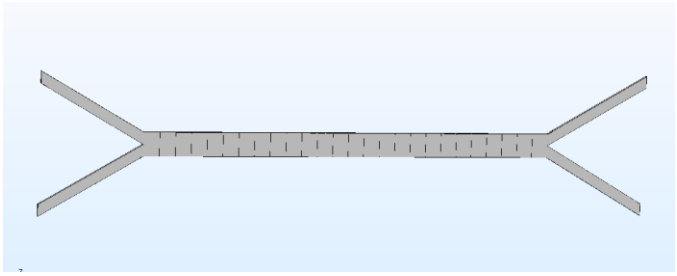

FIG. 7. Creating the geometry.

Run the Analysis

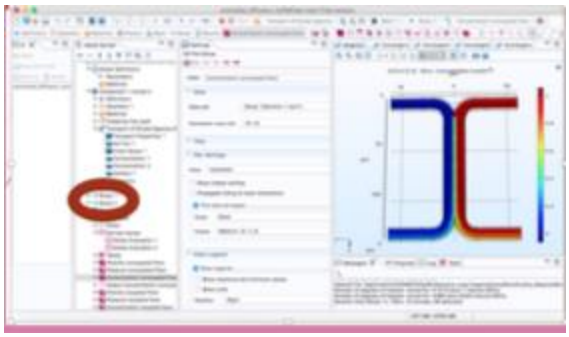

FIG. 8. Computing the studies

Postprocess the Analysis

1. Open the results section and view the velocity profile of the flow

2. View and analyze the concentration profile

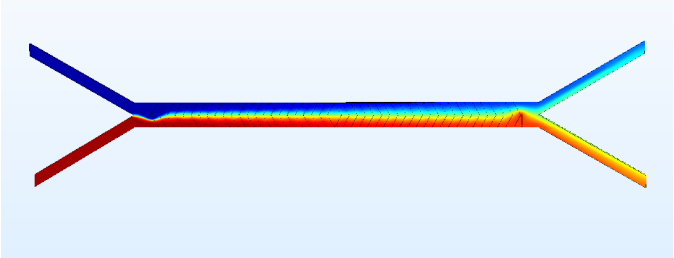

FIG. 10. Computing the studies

REFERENCES

[1] D. Mark, S. Haeberle, G. Roth, F. Von Stetten, and R. Zengerle, in Microfluidics Based Microsystem (Springer, 2010), pp. 305–376

[2] S.-Y. Teh, R. Lin, L.-H. Hung, and A. P. Lee, Lab on a Chip 8, 198 (2008).

[3] T.P. Burg, M. Godin, S.M. Knudsen, W. Shen, G. Carlson, J. S. Foster, K. Babcock, and S. R. Manalis, Nature 446, 1066(2007)

[4] D. J. Collins, R. ORorke, C. Devendran, Z. Ma, J. Han,A. Neild, and Y. Ai, Physical Review Letters 120, 074502 (2018).

[5] A. W. Martinez, S. T. Phillips, G. M. Whitesides, and E. Carrilho, Analytical Chemistry 82, 3 (2010).