



MECH&AE M183B

Lab Report:
**Analysis of the Fabrication Process and Device
Functionality**

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Date: December 6, 2019

Table of Contents

1 Introduction (Jose)	3
Major Process Technologies	3
2 Module 1 (Michael)	4
2.1 Monitoring Residual Stresses in Thin Film Devices	4
2.2 Fabrication	6
2.3 Results and Discussion	7
3 Module 2 (Ho-ting)	11
3.1 Introduction	11
3.2 Device Fabrication	12
3.3 Results and Discussion	16
4 Module 3 (Audrey)	20
4.1 UV Nanoimprint Lithography Overview	20
4.2 Fabrication	21
4.3 Results and Discussion	23
5 Conclusion (Jose)	24
6 References	26

1 Introduction (Jose)

In this laboratory, students were given hands-on experience in a variety of MEM/NEMS fabrication processes through three separate learning modules. The three modules consisted of fabricating: 1) microstructures to monitor the stress state in thin films, 2) microfluidic channels through a mold and replica, and 3) an array of nanodots using nanoimprint lithography. Each of these modules introduced major microfabrication processing steps such as substrate solvent washing, baking, photoresist application for UV exposure, UV mask exposure to chemically modify photoresist solubility, and development to remove UV-exposed positive photoresist for the final end product. Additional steps are applied for desired applications, such as creating a Polydimethylsiloxane (PDMS) mixture for microfluidic fabrication as used in Module 2 and nano-imprinting for nanoscale pattern etching as used in Module 3.

The body of the report is divided by module. For each module, a brief background is provided, followed by the fabrication process, and analysis of device results. Analysis includes data tabulation along with showcasing relevant images of functioning devices. In addition, assessments on successfully functioning devices are given alongside assessments of fabrication errors.

Major Process Technologies

The laboratory modules consisted of utilizing several processing technologies that have already been established in the silicon wafer industry. The following Table 1.1 lists some of the technologies with their respective purpose:

Table 1.1: Major Technology Processes

Process	Purpose
Adhesion Coat	Promote adhesion of PR to surface
Dehydration bake	Dives out solvents to improve photoresist-wafer adhesion
Descum	Removes residual photoresist that remained after development
Development	Remove UV exposed or unexposed photoresist
Hard Baking	Hardens the photoresist
LPCVD	Low-pressure, high temperature CVD method
Mask Aligner	Aligns the photomask with existing features and patterns
Nanoimprint	Mechanical imprinting to fabricate nanoscale patterns
Oxide Etch (BOE)	A wet etchant used to remove layers from the surface of a wafer
Photolithography (Contact)	Creates the image from the photomask by direct contact with photoresist layer
Piranha Bath	Removes organic material from wafer by submerging in an oxidation agent solution
Polysilicon Etch	Remove polysilicon using HNO_3 , HF, H_2O mixture
Soft Bake	Drive out remaining solvent from the photoresist film
Solvent Wash	Removes unwanted residues from the substrate
Spincoat	Coats the wafer in a uniform layer of photoresist
Thermal Oxidation	Create a thin oxidation layer on the wafer surface
UV Exposure	Prints the image from the photomask to the photoresist layer

2 Module 1 (Michael)

2.1 Monitoring Residual Stresses in Thin Film Devices

Residual stresses can develop due to thermal effects or nonequilibrium growth in the thin films and can be detrimental to the reliability of thin film electronic devices [1]. Therefore,

incorporating in-situ monitoring of key parameters such as residual stresses into the design can be very beneficial ensuring the technology processing is consistent from run to run [2].

Test structures that can be used to monitor the stress include: fixed-fixed beam, and ring and beam. Other structures can be used to monitor the stress gradient: cantilever beam and archimedes spiral beam [2]. The shapes of residual stress test structures and residual stress gradient test structures are shown in Figures 2.1 and 2.2.

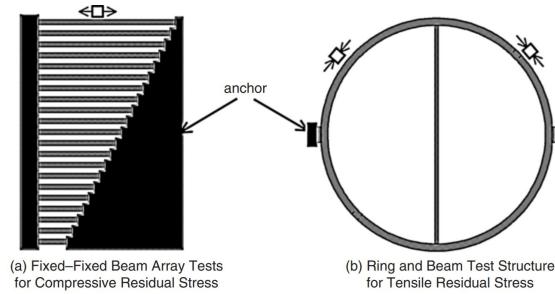


Figure 2.1: Residual stress test structures. [2]

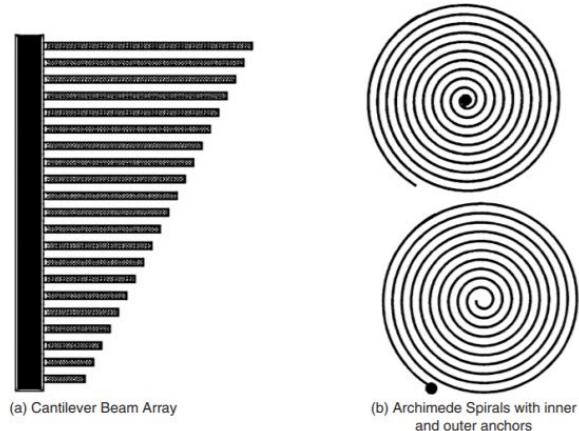


Figure 2.2: Residual stress gradient test structures. [2]

Fixed-fixed beams (Figure 2.1a) can be used to determine the residual compressive stresses in the thin film. When the underlying sacrificial layer is removed, the compressive residual stress in the material will cause expansion and buckling in beams greater than the critical length defined by Euler column theory [2].

Ring and beam structures (Figure 2.1b) can be used to determine the residual tensile stresses in the thin film. After removing the sacrificial layer, the tensile residual stress of the material causes the ring structure to contract, which produces a compressive force on the beam structure. The compressive force will cause expansion and buckling in beams greater than the critical length [2].

The residual stress gradient is due to an internal bending moment of the film. Cantilever beams (Figure 2.2a) are the simplest test structures to measure the residual stress gradient of the thin film. The deflection of the beam after removing the sacrificial layer depends on the stress gradient [2]. Another test structure that can be used to measure the stress gradient is the Archimedes spiral (Figure 2.2b). The spiral will expand or contract after releasing and cause the spiral to curl up or down. The average strain gradients in thin films can be measured from optical micrographs before and after their release from the substrates [3].

2.2 Fabrication

Beam-based thin-film stress-sensing monitoring microstructures are fabricated for Module 1. These structures include stress-sensing. The process flow is outlined in Figure 2.3 and starts with a 525 μm thick single-crystal silicon wafer (Figure 2.3a).

First, a 1.5 μm silicon oxide layer is grown on a single-crystal silicon wafer in a wet furnace at 1050°C (Figure 2.3b), followed by a 1 μm polysilicon layer using LPCVD at 600°C (Figure 2.3c). After washing and a dehydration bake, an HMDS coat is applied to promote adhesion. A 1 μm AZ5214 photoresist layer is spin-coated on at 500 RPM with a 100 RPM/sec ramp for 5 seconds, followed by 4000 RPM with 1000 RPM/sec ramp for 30 seconds (Figure 2.3d). After soft baking at 105°C for 60 seconds, the mask pattern is transferred using a Quintel Mask Aligner with 20 seconds exposure.

For development, 1:6 dilution of AZ 400K and DI water is used to remove the exposed PR (Figure 2.3e). After DI rinsing and drying, the wafer is hard baked at 120°C for 2 minutes. The wafer is then descummed using TeGal Plasline Asher at 200 W and 0.5 mtorr for 2 minutes. The exposed polysilicon is etched using a 10:1:10 $\text{HNO}_3:\text{HF}:\text{H}_2\text{O}$ solution (Figure 2.3f). For 10 minutes, a 10:1 $\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2$ piranha bath is used to remove the remaining PR (Figure 2.3g).

Finally, the oxide layer is etched to release the cantilevers using 6:1 BOE for 100 minutes (Figure 2.3h). The top view for a fixed-fixed beam structure is shown in Figure 2.3i.

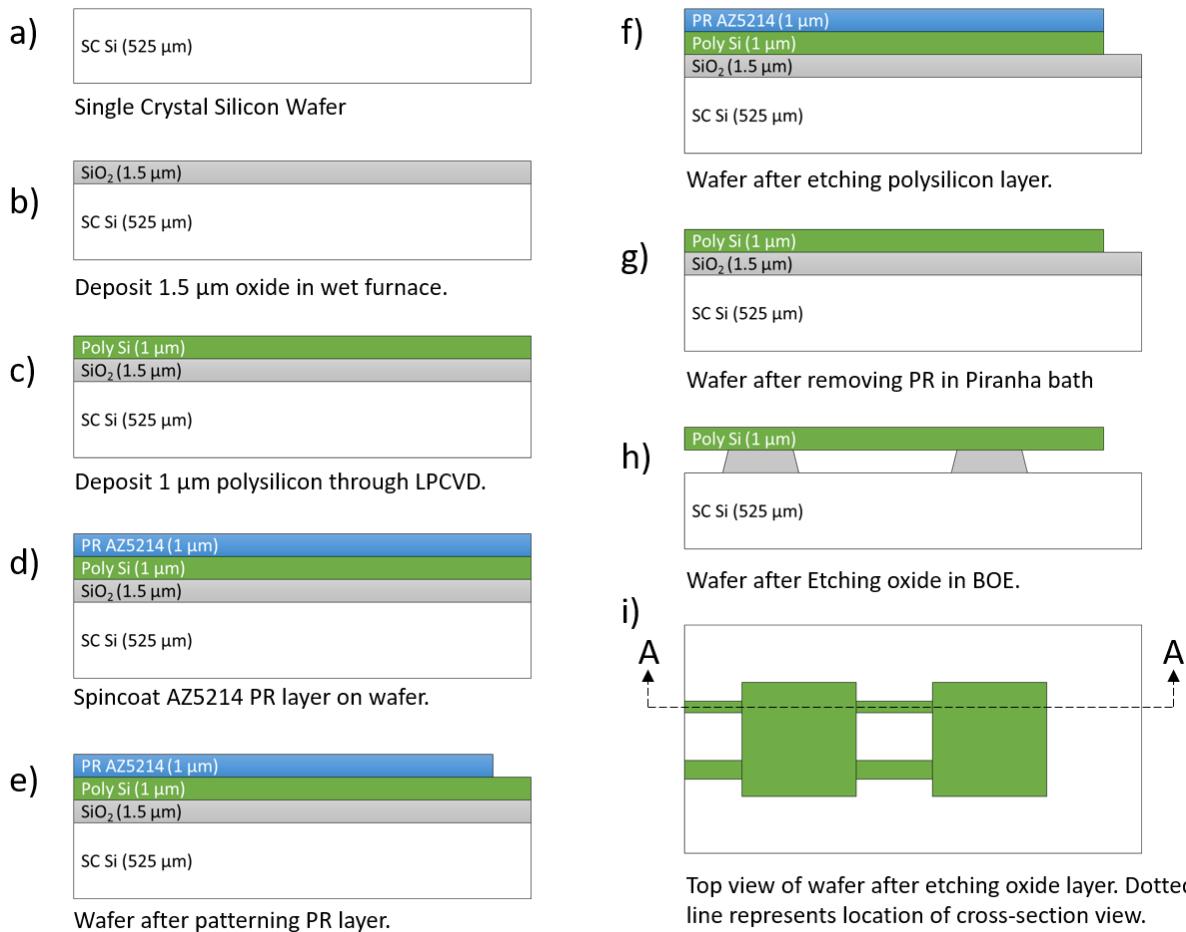


Figure 2.3: Process flow for fabricating microstructures in Module 1.

2.3 Results and Discussion

The microstructures were visually inspected at two stages: first, after PR development and before removing the sacrificial layer; and second, after removing the sacrificial layer. Figure 2.4 shows the patterned wafer after development.

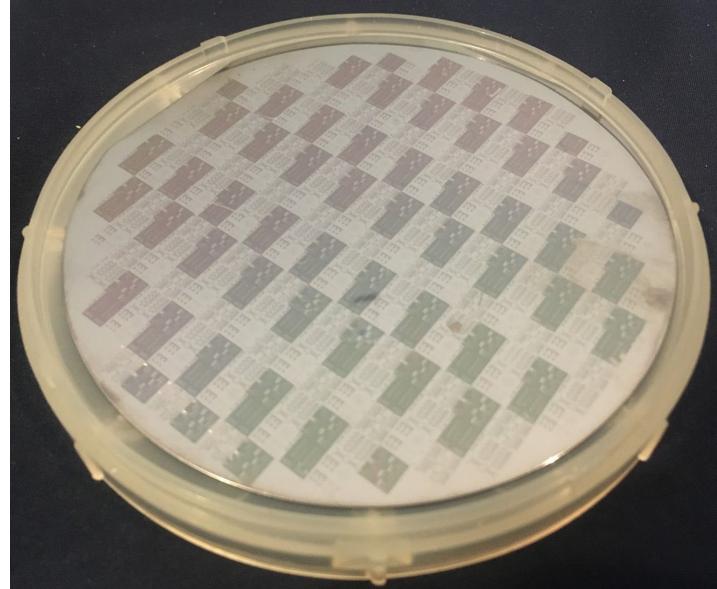


Figure 2.4: Patterned wafer after development.

An array of structures with incrementing feature sizes and the same shape allows a way to quickly assess the wafer's resolution after development through visual inspection. Figure 2.5 is an image of such an array after development. The structures associated with 2 μm and 3 μm resolutions are not present and have been completely etched away, while the structure with 4 μm features is partially missing. The smallest structure that is completely intact has 5 μm features. Thus, the polysilicon layer has a resolution of 5 μm . The resolution is not what is expected for Module 1, because the sample was overdeveloped during fabrication. The wafer was initially dried using N₂ instead of DI rinsing, giving time for the residual developer to overdevelop.

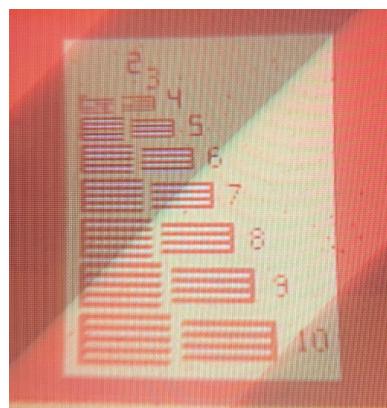


Figure 2.5: Array of microstructures used to assess device resolution.

Figure 2.6 shows an array of cantilever beam structures that can be used to evaluate the stress gradient in the thin film after the sacrificial layer is released. Figure 2.7 are structure arrays that can be used to assess the extent of the undercut after BOE.

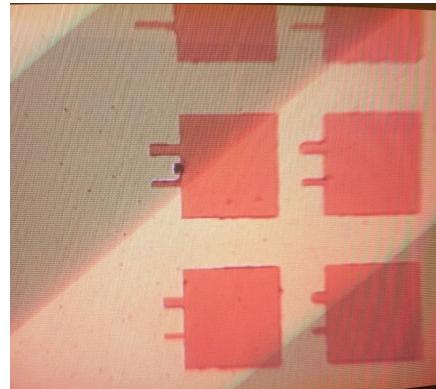


Figure 2.6: Array of cantilever beam structures that can be used to gauge the stress gradient.

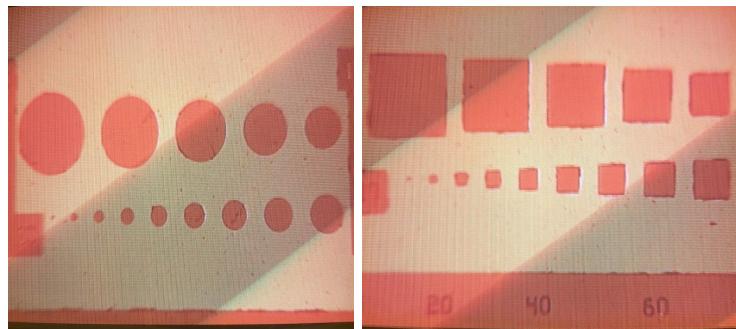


Figure 2.7: Array of circular and square structures that can be used to assess BOE undercut.

After etching the oxide layer using BOE, the beams are no longer anchored. The residual stresses in the layer will cause the beams to warp as described in Section 2.1. Figures 2.8 to 2.11 are selected microscope images of the wafer after BOE.

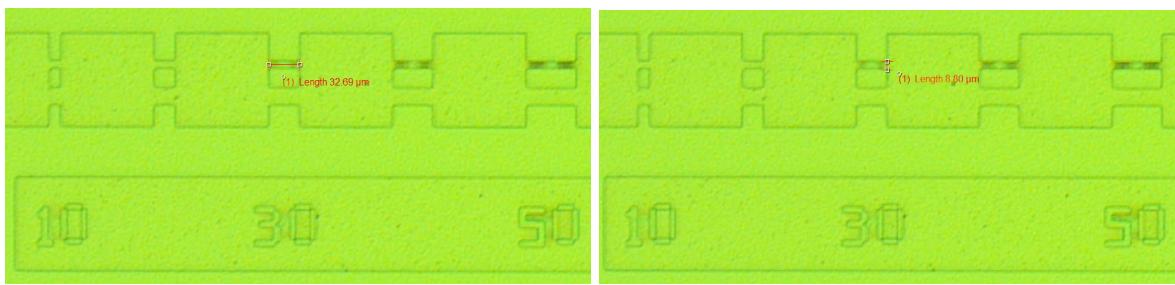


Figure 2.8: Dimensions of shortest buckled fixed-fixed beam.

The warping in the sample can be seen through contrasting light and dark regions. Based on Figure 2.8, the critical length is nominally 30 μm and measured to be 32.69 μm . For a fixed-fixed beam structure, the thin film residual strain can be calculated using the critical length.

$$\epsilon = \frac{4\pi^2 I}{AL_c^2} = \frac{\pi^2 h^2}{3L_c^2}$$

where I is the moment of inertia, A is the cross-sectional area, L_c is the critical beam length, and h is the beam thickness. Assuming $h = 1 \mu\text{m}$ for the beam height and using the measured critical length $L_c = 32.69 \mu\text{m}$, the compressive residual strain in the thin film is $\epsilon = 0.0031$.

Figure 2.9 shows a partially released Archimedes Spiral. The stress gradient can be determined using the method developed by Fan [3] by comparing the spirals before and after the release.

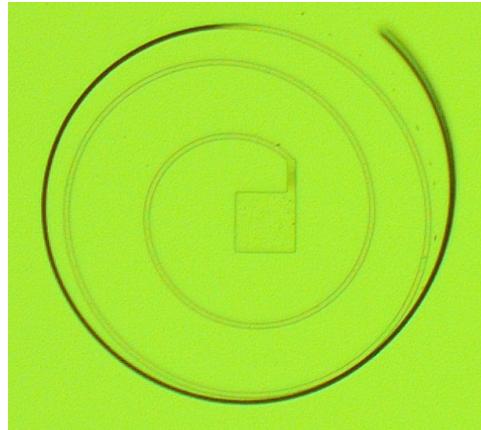


Figure 2.9: Partially released Archimedes spiral.

Figure 2.10 shows a ring and beam structure. As explained in Section 2.1, this structure is supposed to measure tensile stresses. The fact that buckling seems to occur in both this and the fixed-fixed structure suggests that there may be inhomogeneous stresses within the film.

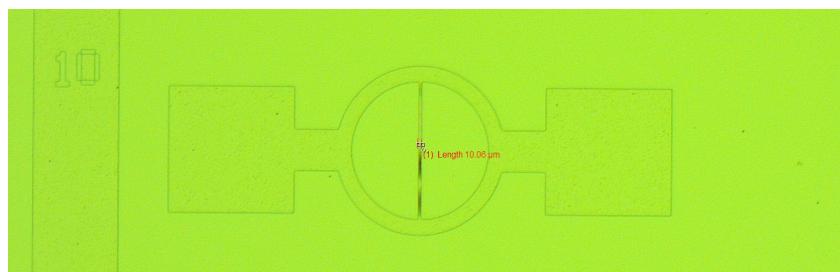


Figure 2.10: Released ring and beam structure.

Although the circular and rectangular structure arrays that are typically used to evaluate the extent of the undercut were not measured, by using the measurements found in Figure 2.10 and Figure 2.11, the undercut is probably between 10.06 μm and 17.80 μm .

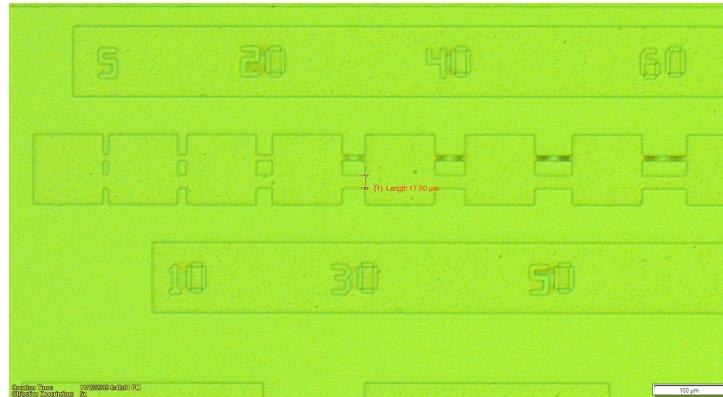


Figure 2.11: Measured width of unreleased the 30 μm fixed-fixed beam is 17.80 μm .

3 Module 2 (Ho-ting)

3.1 Introduction

Microfluid is known for addressing fluid motion within microscale chambers or channels, which can be very different from their behavior in macroscale since the capillary forces becomes dominant in microscale. The technique of controlling microfluid can be applied to fields such as chemistry, biochemistry, and biotechnology, and usually comes in the form of a microfluidic chip that enables lab-on-a-chip for cell culture, molecules sensing, and autoselection. The advantages of a microfluidic chip over traditional methods are the small size, fast reaction time, and low energy consumption capabilities of the chip. The following picture is an example of such a chip, which is similar in structure to the chip that will be created in this module.

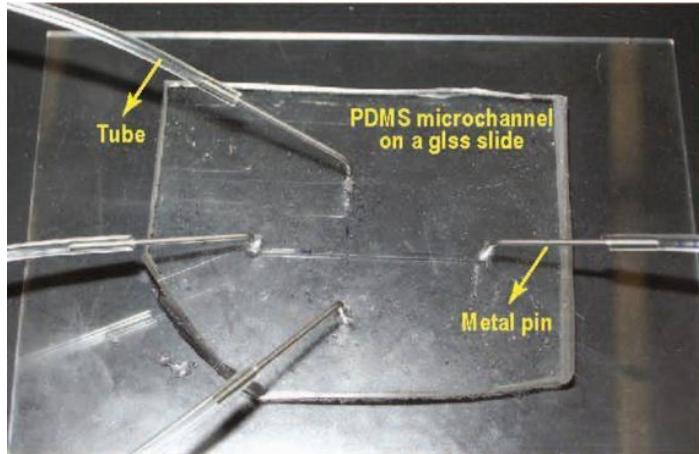


Figure 3.1: Microfluidic device with water tubes attached

3.2 Device Fabrication

Fabricating a microfluidic device involves two separate processes. The first process involves application of photolithography. A 3-inch single-sided silicon wafer is solvent washed with the AMI method. The wafer then undergoes rinsing with deionized water and is N₂ dried. The wafer then underwent a 5 minute 150°C dehydration bake on a hotplate, to remove any organic materials or metals. Photoresist is then applied by coating the wafer surface in SU-8 2075 PR. It was observed that the SU-8 2075 PR was a relatively thick photoresist. The wafer is then uniformly coated with SU-8 2075 by spin coating until a ~100μm thick coating was achieved. The wafer then underwent soft baking at 60°C for 5 minutes, and another round at 95°C for 20 minutes to remove any remaining solvents. Next, the wafer is put under UV exposure at an intensity of $I = 6.5 \frac{mW}{cm^2}$ for 40 seconds. A post exposure bake is then applied to the wafer for 10 minutes at 95°C. The wafer is then submerged in an SU-8 developer for approximately 5 minutes, while continuously swirling the development solution. The wafer is then rinsed with IPA for 10 seconds and N₂ dried. The wafer was then inspected using a Dektak Profilometer, to measure its thickness. A microscope was then utilized to measure its widthness. The last step in the first process is a hard bake at 150°C for 10 minutes.

The second process involves creating the material that will house the microfluidic channel. The pattern of interest in this module, is two separate microfluidic channels as seen in Figure 3.2. The schematic depicts the two structure droplet generator (upper pattern) and the

fluid steering system (lower pattern). The fabrication of the pattern, as explained in the previous paragraph, essentially creates a photoresist mold that will be used to create a physical microfluidic structure. Such a technique is commonly used to prototype microfluidic channels due to its simple process [4]. The first step in this process is to create a PDMS and curing agent mixture with a ratio of 10:1. This was done by mixing 20 grams of PDMS with 2 grams of the curing agent. The PDMS mixture was then degassed by exposing the PDMS to a vacuum. The purpose of the vacuum is to have air bubbles trapped in the mixture rise to the surface and pop, effectively degassing it. The PDMS is left inside the vacuum for approximately 1-2 hours.

Once degassed, the PDMS is poured onto the wafer mold. The PDMS covered wafer is then placed in a vacuum chamber for 30-60 minutes to remove any remaining air bubbles that rise to the surface. Next, the PDMS covered wafer is baked in an oven at 65°C for 50 minutes. After baking the polymer will harden into a gel-like substance. The PDMS is carefully cut into a rectangular shape, and the PDMS is detached from the wafer mold and placed on a glass slide. A simplified process is visualized in Figure 3.3. The final PDMS-glass apparatus was placed in the following configuration, as seen in

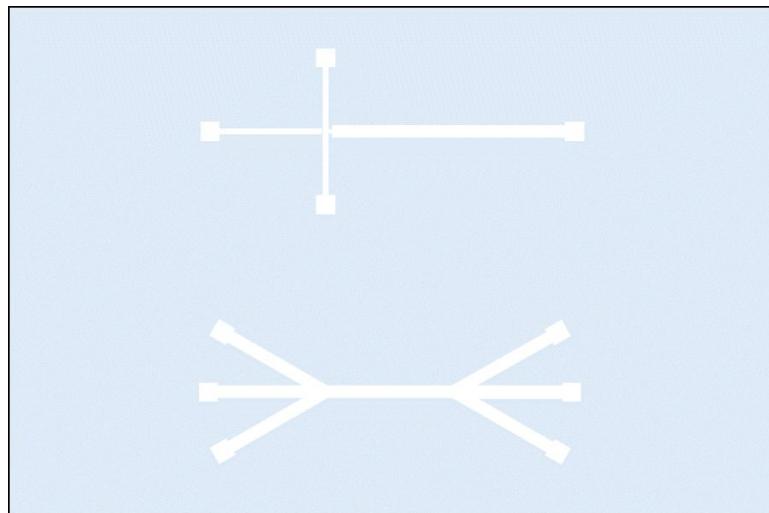


Figure 3.2: Microfluidic channel pattern

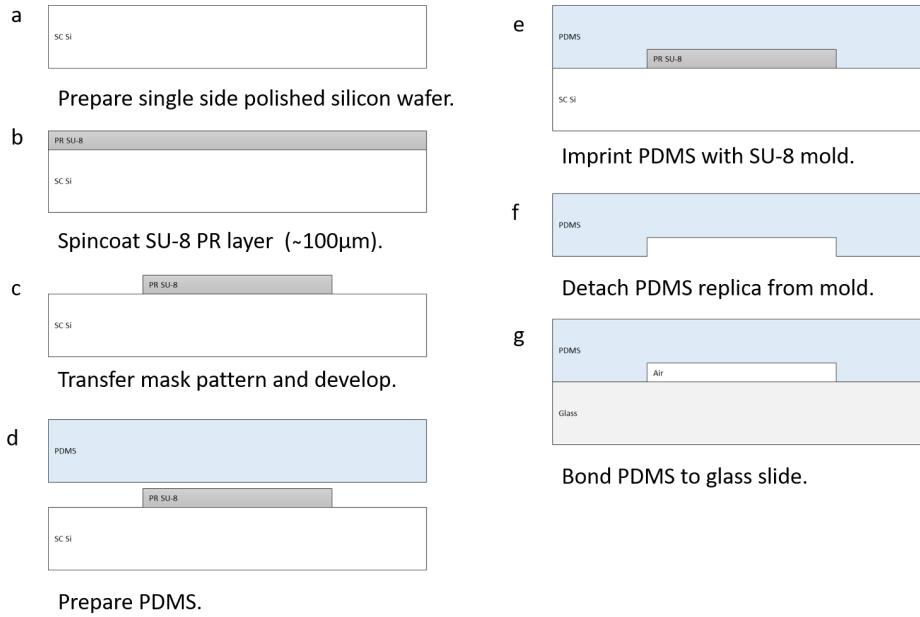


Figure 3.3: Process of creating a SU-8 PR mold (a-c), along with PDMS structure (d-g)

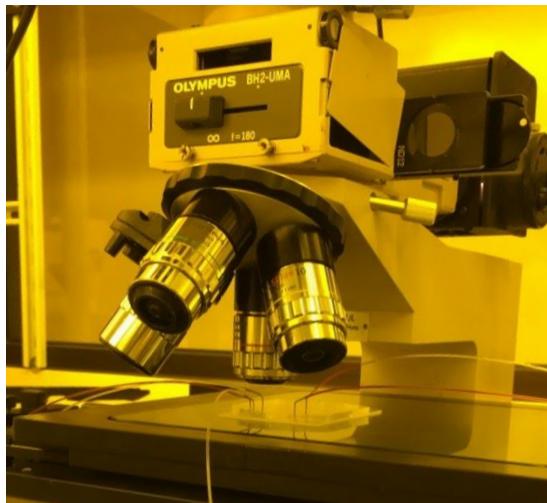


Figure 3.4: Microfluidic apparatus in testing

In this module, there are two different microfluidic channels on the chip. The droplet generator is shown in the upper side of Figure 3.2. The droplet generator is a tool to generate and manipulate micron sized droplets by controlling the flow rate of two fluid in different phases. In our case, they are water and oil. The droplet generator fabricated here is a flow focusing droplet generator. In a flow focusing design, water is introduced directly into the main channel while oil

phase is injected by two branches that is perpendicular to the main channel. The water stream is then pinched on both sides by the oil, and a droplet is formed due to the competition between the viscous force and the surface tension at the interface between the two phases [5].

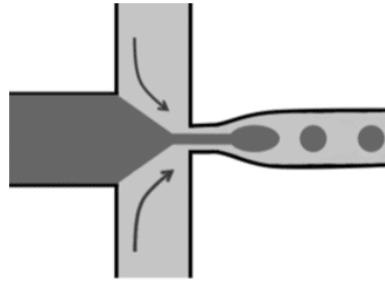


Figure 3.5 Flow focusing droplet generator

Depending on the experimental conditions, several kinds of droplet formation process can be observed:

1. The squeezing regime: where flat droplets that occupy the full width of the channel forms. The droplets form due to the pressure drop in the main channel introduced by the oil.
2. The dripping regime: spherical droplets form due to the viscous shear forces.
3. The jetting regime: droplet sizes are much smaller than channel width, and generated at very high frequency.
4. Stable co-flow regime: no droplets generated.

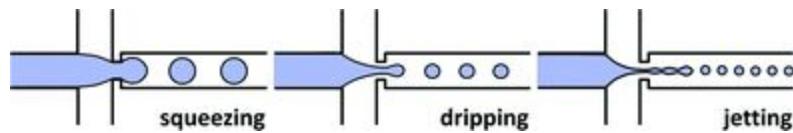


Figure 3.6 Modes of droplet formation [6]

The lower pattern in Figure 3.2 is the flow steering system. In the microfluid channels, the fluids are laminar flows, so the stream from the three inputs do not mix with each other. Instead, the top and bottom flow are there to guide the central stream. In Figure 3.7, when the flow rate of the bottom water flow is faster than the top water flow, the central water flow can be guided to the upper channel in the downstream.

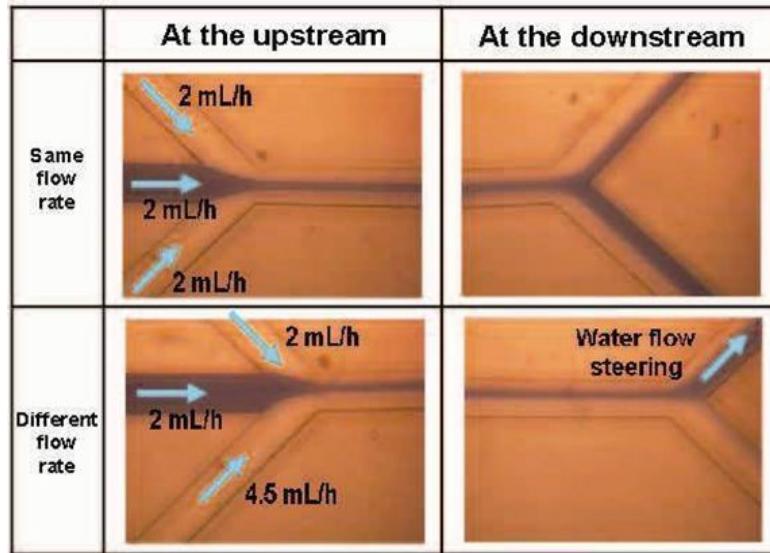


Figure 3.7: Flow steering system

3.3 Results and Discussion

Examining the sample under profilometer allowed for measurements to be taken of the patterned photoresist. The measurements are displayed in the following figures.

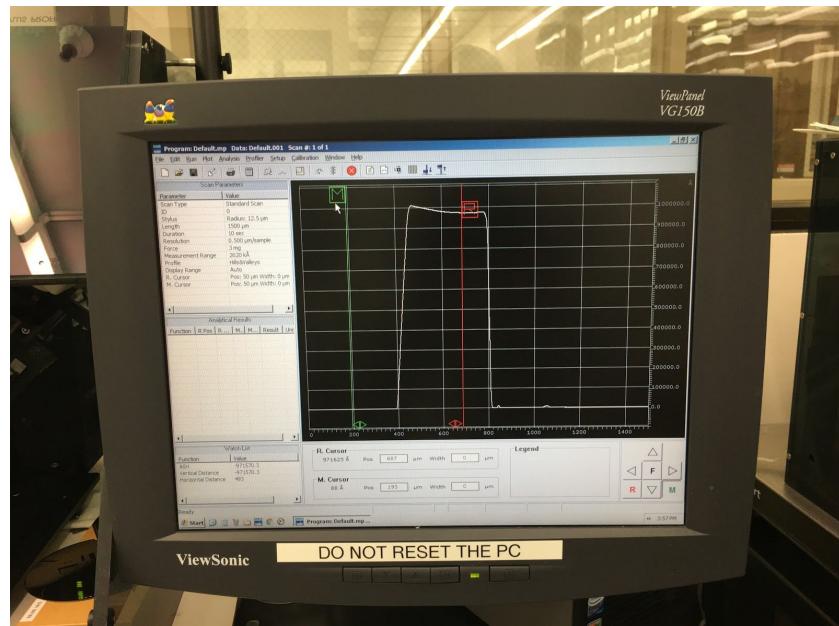


Figure 3.8: Data from profilometer at location 1 on patterned photoresist

Figure 3.8 shows the step height and width of the pattern on the photoresist. The step height is 100um, and the step width is 400um.

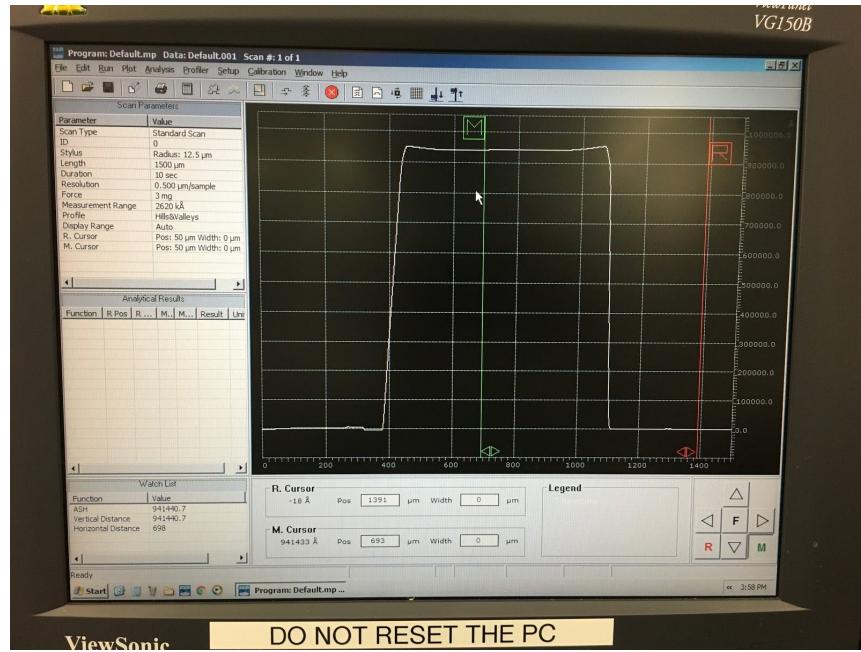


Figure 3.9: Data from profilometer at location 2 on patterned photoresist

Figure 3.9 shows the surface profile of another location on the photoresist. The step height is 95um, and the width is 700um.

Table 2.1: Results of droplet generation experiment.

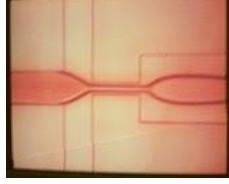
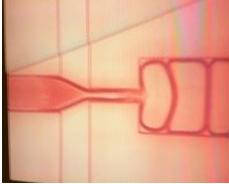
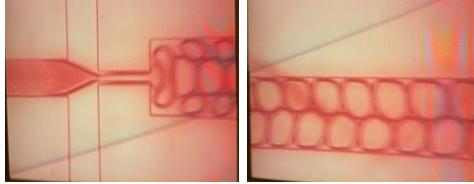
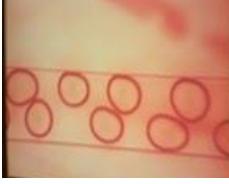
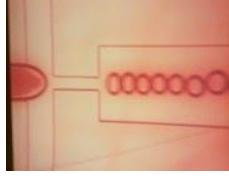
Water: 3.0 mL/hr Oil: 0.1 mL/hr	
Water: 1.5 mL/hr Oil: 0.1 mL/hr	
Water: 0.1 mL/hr Oil: 0.1 mL/hr	
Water: 0.1 mL/hr Oil: 1.0 mL/hr	
Water: 0.1 mL/hr Oil: 2.0 mL/hr	
Water: 0.1 mL/hr Oil: 3.0 mL/hr	

Table 2.1 contains the photos of droplet generation. In the photo in the first row of table 2.1, there is no water droplet generated. The flow rate of water is way larger than the flow rate of the oil, so the oil is incapable to chop the water stream. In the second row, the water flow rate is half of the one in the first row, and the oil flow rate remains the same. Big water droplet starts to form in the tube. In the third row, the water flow rate is further reduced, the water droplets become significantly smaller than those in the second row, since less amount of water can flow through the neck between two chops. In the fourth row, the water flow rate maintains the same as in the third row, but the oil flow rate is increased. The resulting water droplets have about the same size comparing to the third row, but are less dense. This happens when the water flow rate is lower than the oil flow rate. In the fifth row, the oil flow rate is doubled, and the radius of the water droplet is nearly reduced by half. The same trend can be observed in the sixth row. When the oil flow rate is increased, the water stream is chopped more frequently by the oil, resulting in a smaller droplet.

In row 1, the system is in stable co-flow regime. In row 2 and row 3 it is in the squeezing regime, and it transfers to dripping regime in row 4, 5, and 6.

Table 2.2: Results of flow steering experiment.

Top Water: 3.0 mL/hr Middle Water: 3 mL/hr Bottom Water: 3.0 mL/hr	
Top Water: 1.0 mL/hr Middle Water: 3 mL/hr Bottom Water: 3 mL/hr	
Top Water: 0.5 mL/hr Middle Water: 3 mL/hr Bottom Water: 3 mL/hr	
Top Water: 0.5 mL/hr Middle Water: 3 mL/hr Bottom Water: 5 mL/hr	
Top Water: 0.5 mL/hr Middle Water: 3 mL/hr Bottom Water: 10 mL/hr	

Table 2.2 displays the results of the flow steering experiment. In the first row, since the top and bottom oil flow rate is the same, the water stream should be separated equally to the two branches. However, due to some defects in the microfluid chip, the water tends not to flow into the upper channel, but favors the lower channel instead. The same phenomenon can be observed in the following photos as well. In the second and third row, the top water flow rate is lowered, leading to less water in the lower channel, but the flow rate difference between the top and bottom water is still insufficient to fully steer the central flow to the upper channel. In the fourth and fifth row, we tried to raise the bottom flow rate to see if it can direct the central flow to the upper channel. The large flow rate difference did result in less dye in the lower channel, but when the bottom flow rate is above 10mL/hr, the central flow will be completely blocked from both channels. It is obvious that the central flow is already biased even when the top and bottom flow rate are the same. This error might stem from fabrication defects that cause the upper and the lower wall of the channel to have different characteristics (for instance, having different surface roughness), and further affects the real flow rate of the top and bottom stream.

4 Module 3 (Audrey)

4.1 UV Nanoimprint Lithography Overview

Nanoimprint lithography (NIL) is an emerging fabrication methodology that has shown high potential to enhance the performance of many different devices. Since its emergence in 1996, NIL has greatly shaped the production of solar cells, laser diodes, LEDs, and wafer-level optics. [7] NIL is a 3D patterning process that utilizes mechanical deformation to imprint a pattern from a mold onto a resist layer of a substrate. In UV NIL, the resist is often a monomer or polymer that is cured by UV light exposure.

This patterning process has the capability to create high resolution products of 10 nm or below. Soft UV NIL best applications are for large scale prints and non-ideal surfaces. [7] The resolution of NIL products are limited by only the mold, providing high resolution dense pattern capabilities. [8] In the past two decades, the NIL method has been praised for not only its performance quality but also its economical impact. Since the fabrication process is quite fast,

NIL can be used for large scale commercial manufacturing. The molds are often low cost to manufacture and are reusable, increasing product throughput. Nanoimprint lithography also has few disadvantages due to the nature of the fabrication process. Since the mold and the substrate need complete contact, patterns and mold can be broken during the application and release of the mold. [6] Complete contact also increases the chance of transferring impurities onto the substrate. Moreover, any changes to the desired pattern must result to remanufacturing the existing mold or creating a brand new mold. [8] With this being said, the goal of Module 3 is to explore the advantages and disadvantages of nanoimprint lithography and create imprints onto a glass substrate with a UV-curable resist. Quality of the fabrication process will be inspected afterwards using light microscopy.

4.2 Fabrication

The process flow can be sectioned into three main sections: substrate preparation, nanoimprinting and exposure, and inspection. The description of the process flow will be sectioned off similarly in this report.

For the substrate preparation, the substrate glass was washed using AMI, rinsed with DI water, and dried with N₂ gas. Once clean, a ULP adhesion layer coating was applied, and spun at 500rpm with 100rpm/s ramp for 5 seconds and then 4000rpm with 1000rpm/s for 45 seconds. This layer is to promote adhesion for the UV imprint resist coating. The substrate was then placed on a 180°C hotplate for 2 minutes to soft bake the ULP. The UV resist coating is then applied and spun at 2000rpm with 1000rpm/s ramp speed for 7 seconds.

For nanoimprinting, the glass substrate is loaded onto the chuck in the imprinting chamber. It is important to fix the wafer with the chuck vacuum turned on to prevent the substrate from moving during the imprinting process. Then, the substrate is aligned with the mold to ensure maximum contact. The substrate and mold is purged with N₂ for 15 seconds. The O-ring surrounding the substrate and mold is then inflated to seal the imprinting chamber. The chamber is pumped to become a vacuum and pressure will be applied to set the mold onto the resist. The substrate and mold is then exposed with UV for 2 minutes. After exposure, the vacuum, pressure, and O-ring will be released to reveal the newly exposed substrate and mold.

The mold is manually removed and the substrate can go through the inspection process. The important features to look for in Module 3 are the parallel line pattern. The pitch of the lines quantified the performance and success of the experiment. Figure 4.1 illustrates the cross sectional view of the process flow of Module 3.

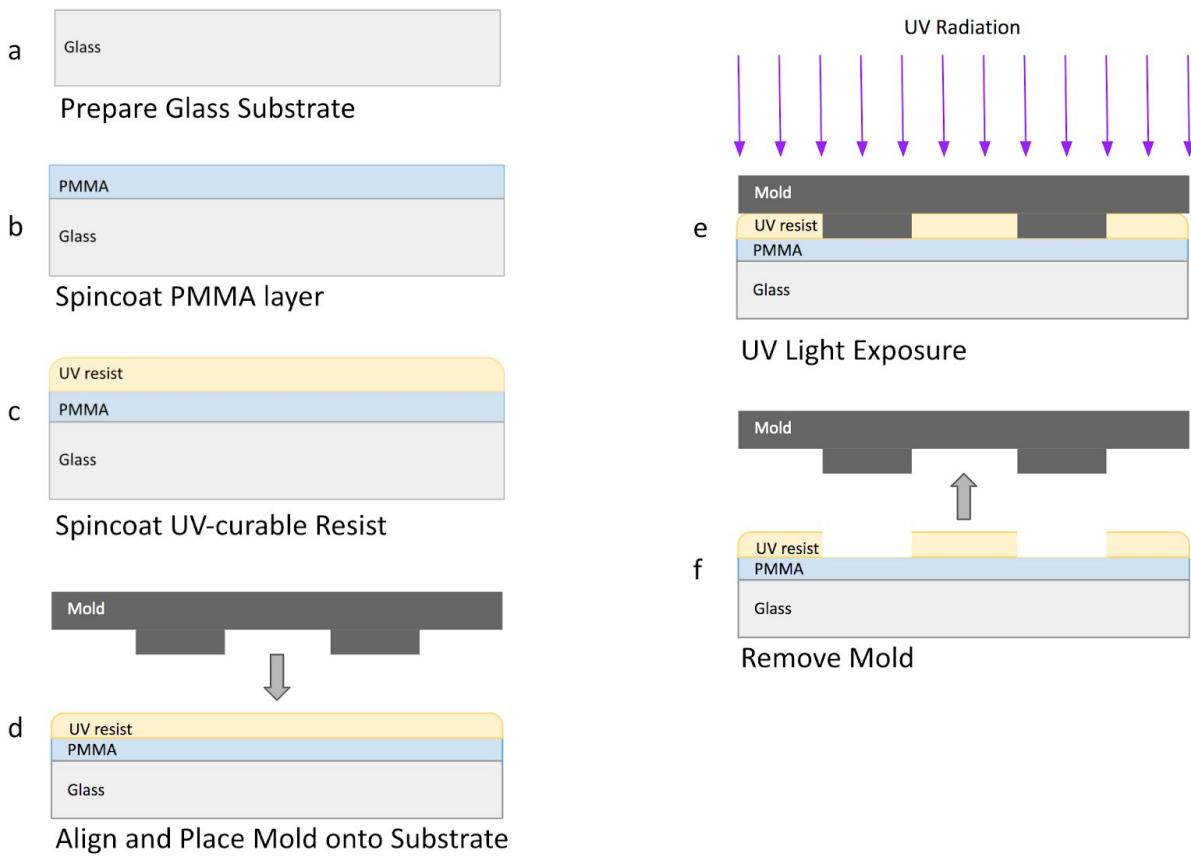


Figure 4.1: Process flow for fabricating pattern using UV Nanoimprint Lithography in Module 3.

4.3 Results and Discussion

The parallel line pattern was visible using a light microscope and images of the magnified line patterns were taken to calculate pitch length. The length of one pitch is equal to the length of one line and one space width. An image of the finished glass can be found below in Figure 4.2. The imprinted pattern is indicated by the holographic dots that shift colors under light.

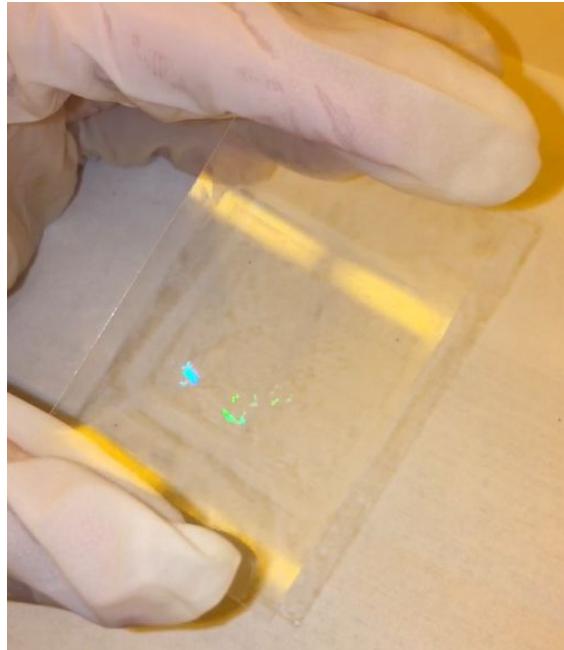


Figure 4.2: Finished product displaying the holographic imprinted pattern.

The lines were found using a series of different magnifications on the sample. Once found, using the microscope's program dimensioning tool, the length of a desired area could be found. A magnified top view of the sample can be seen in Figure 4.3.



Figure 4.3: Top view at 50x magnification with L indicating the length of the specified area.

The pitch size can be determined by taking the measured length and dividing the value by the number of lines it crosses. The pitch size in Module 3's sample is determined in the calculation below with the measuring tool covering a total of 11 lines.

$$\text{Pitch Size} = \frac{7.09\mu m}{11} = 0.645\mu m$$

The precision error can be taken as half of the last digit measured in the program. Thus, the pitch size of the sample is $0.645 \pm 0.05\mu\text{m}$.

5 Conclusion (Jose)

The overall goals for this laboratory were to apply the major microfabrication processes in a small team environment, with single silicon wafers, in order to gain introductory knowledge of the many manufacturing steps. Coupled with complementary lectures, diverse microfabrication technologies were implemented. Analysis of the physical devices, such as measurements and visual inspections under microscopes enabled investigations into the operation of devices. Working with single silicon wafers, errors or failures were produced and thus also analyzed in order to provide an in-depth perspective of the sensitive requirements of microfabrication.

In Module 1, a silicon wafer was produced for the objective of analyzing the mechanical integrity of the wafer and image resolution. This included the application of photolithography to imprint stress calibration patterns, which were then visually analyzed. Measurements were then taken for relevant stress calculations. After visually inspecting the finished wafer, a resolution of $5\mu\text{m}$ was measured due to the $5\mu\text{m}$ microstructures being the smallest structures to survive the etching process. Additionally, it was observed that the cause of the extinction of structures smaller than $5\mu\text{m}$ structures was due to possible overdevelopment due to a process flow error. The error consisted of a minor oversight, where the wafer was not cleaned using DI water leaving behind minor traces of developer that continued to etch beyond a desirable state. The residual strain ϵ was then calculated using the visual measurements taken, which was calculated to be $\epsilon = 0.0031$. Lastly, a deeper analysis using lab microscopes was undertaken, in which beam widths and spiral depth was measured.

Module 2 introduced an ambitious application of the photolithographic process by creating two microfluidic devices through a wafer molding process. The mold was designed through basic lithography as seen in Module 1, however one difference was the application of a thicker photoresist known as SU-8 2075. The reason for using SU-8 2075 is that it allows for better molding results as opposed to other photoresists from the other modules. The microfluidic

devices were created on a polymer substance known as PDMS. The PDMS was prepared and then applied to the finished SU-8 2075 wafer mold. The dried pattern was then detached from the wafer and put on a similarly shaped glass slide. The device design process was relatively simple, with time being the only constraint as many of the steps required for preparation of PDMS were considerably lengthy, on the order of hours.

The objectives of Module 2 consisted of investigating the behavior of microfluidic devices, specifically the effects entering water flow rates have on the exiting flow of liquids. The objective of the first device was to examine the effects of water-oil droplets as they formed when water and oil were inputted at different flow rates. Many different droplet configurations were observed and explained by physical effects such as pressure drops caused by oil and viscous shear forces. The objective of the second device was to analyze various iterations of a flow steering device. It was found that inserted flow rates have a direct effect on the exiting flow of liquid as seen in the bi-directional exit of the device hence the name ‘flow-steering’.

In Module 3, nano-imprint lithography was applied for the objective of creating nanoscale patterns on a silicon wafer through contact etching. The interesting aspect of this process is that it happens to be the most fast and economic lithographic process when compared to the previous two modules. The process involved physically stamping a pattern onto a resist coated wafer, however due to the rough nature of the process, it tends to generate more defects as opposed to other methods as was observed in visual inspections under a microscope.

Valuable knowledge of photolithography process flow, mold and microfluidic channel design, and nanoimprint technology was covered through physical experiments. In summary, the main objective of learning the steps necessary to carry out basic silicon wafer microfabrication was successful as demonstrated in the results of the three modules.

6 References

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Members:			Lab Section:			Wafer #
Week 1, Sep. 30th, MEMS Fab-Lab Process: (Safety Orientation)						
Type	Step	Name	Description	Purpose	Initials	Observations
Safety Orientatio	1	Microlab Safety Orientation	Microlab Safety Orientation (in class) in preparation for safety test to be given next week in lab. Always practice good lab habits throughout the quarter.	Microlab Safety Orientation	student	Microlab Safety Orientation
Week 2, Oct. 7th, MEMS Fab-Lab Process: (Orientation, Safety, Photolithography Demo), ~ 3 hrs						
Type	Step	Name	Description	Purpose	Initials	Observations
Safety Orientatio	0	Microlab Safety Walkthrough	Microlab Safety Walkthrough in preparation for safety test and to promote good lab habits throughout the quarter.	Microlab Safety Walkthrough	student	Microlab Safety Walkthrough
Training	1	Training	Safety Exam		Wilson	
	2	Training	Nanolab introduction and walkthrough; showcase PVD/CVD systems (time permitting)		Wilson	
Clean	3	Training	Wafer handling		TA	
	4	Training	Chemical Usage		TA	
Lithography	5	Solvent Wash	Wash wafers with acetone, methanol, and then isopropanol (perform AMI)	clean wafer	TA	
	6	Rinse	Rinse with DI then N2 blow dry	remove solvent residue	TA	
	7	Dehydration bake	Hotplate, 150 °C, t > 5 min		TA	
	8	Adhesion coat	HMDS tank, immerse for 10 min	Improve adhesion	TA	
	9	Photoresist coat	AZ5214, 4 droppers, spin right away, 500 RPM, 100 RPM/sec, 5 sec, 4000 RPM, 1000 RPM/sec, 30 sec	Deposit PR	TA	
	10	Soft Bake	Hotplate, 105 °C, 60 sec	Drive out solvents	TA	
	11	Mask Aligner	Quintel, visual alignment, 20 sec exposure	Transfer mask pattern	TA	Actual Exposure Time:
	12	Development	AZ400K + DI (1:6 ratio), 60 sec, DI rinse	Remove exposed PR	TA	Actual Development Time:
	13	Dry Wafer	N2 blow dry	Remove water	TA	
	14	Inspection	Eye/Microscope		TA	
Week 3, Oct. 14th, MODULE 1: MEMS Fab-Lab Process: (Photolithography, Cantilevers), ~ 4 hrs						
Type	Step	Name	Description	Purpose	Initials	Observations
Photolithography #1: Module 1	1	Solvent Wash	Wash wafers with acetone, methanol, and then isopropanol (perform AMI)	clean wafer	Student	
	2	Dehydration bake	Hotplate, 150 °C, t > 5 min	Drive off moisture	Student	
	3	Adhesion coat	HMDS tank, immerse wafer for 10 min	Improve adhesion	Student	
	4	Photoresist coat	AZ5214, 4 droppers, spin right away, 500 RPM, 100 RPM/sec, 5 sec, 4000 RPM, 1000 RPM/sec, 30 sec	Coat PR onto wafer	Student	
	5	Soft Bake	Hotplate, 105 °C, 60 sec	Drive out solvents	Student	Actual Soft Bake Time:
	6	Mask Aligner	Quintel, visual alignment, 20 sec exposure	Transfer mask pattern	Student	Actual Exposure Time:
	7	Development	AZ400K + DI (1:6 ratio), 60 sec, DI rinse	Remove exposed PR	Student	Actual Development Time:
	8	Dry Wafer	N2 blow dry	Remove water	Student	
	9	Inspection	Microscope	Quantify Photoresist Feature Sizes	Student	T: min line: period: C: min line: period: B: min line: period: L: min line: period: R: min line: period: Δ Line Width: μ : a
	10	Hard bake	Hotplate, 120 °C, 2 min	Strengthen resist	Student	
	11	Descum	Tegal plasma ash, 200 W, 0.5 mtorr, 2 min	Remove PR scum	TA	Actual Descum Time =
Etch	12	Polysilicon etch for Lab 2 wafers	10 HNO3 : 1 HF : 10H2O ~45s (use plastic beakers)	Etch polysilicon	TA	
	14	Piranha bath	Quartz beaker, mix H2SO4 + H2O2 (10:1), immerse wafer for 10 min	Remove PR	TA	
	15	Oxide etch	BOE (6:1), immerse wafer for 100 min	Etch oxide and release cantilever	TA	

Week 4, Oct 21st, MODULE 1: Characterization / MODULE 2: SU-8 mold and PDMS replica fabrications, ~ 4 hrs						
Type	Step	Name	Description	Purpose	Initials	Observations
Cleaning	1	Wafer type	Single-side polished, 3" silicon wafer		Student	
	2	Solvent cleaning	Acetone, methanol, IPA (perform AMI)	Remove organics and metals	Student	
	3	Rinse	DI water, N2 dry		Student	
	4	Dehydration	Hotplate, 150 °C t > 5 min	Remove moisture	Student	
	5	SU-8 coat	SU-8 2075, 500 rpm for 5s with 100rpm/s and 2000rpm for 30s with 300rpm/s	Deposit ~100μm SU-8	Student	
SU-8 mold	6	Soft baking	Hotplate, 60 °C 5 min, then 95 °C 20 min.	Remove solvents	Student	
	7	UV exposure	Quintel, I=6.5mW/cm², exposure for 40s	Transfer mask pattern	Student	
	8	Post-exposure bake	95 °C for 10 min		Student	
	9	Development	SU-8 developer, > 5 min, agitate continuously	Remove unexposed SU-8	Student	SU-8 mold pattern
	10	Rinse and Dry	IPA for 10s		Student	
	11	Inspection	Dektak Profilometer, thickness, Microscope: widthness	Measurement of profiles	TA	t w: Resolution:
	12	Hard baking	150 °C for 10 min		Student	
	13	PDMS	PDMS (20g): Curing agent (2g) in the ratio of 10:1	Mixing with curing agent	Student	
	14	Pouring	PDMS onto the SU-8 mold		Student	
	15	Vacuum	Vacuum chamber for 30 ~ 60 min	Remove air bubbles	Student	
	16	Baking	Oven at 65 °C for 50 min	Curing PDMS on the mold	Student	

Members:			Lab Section:			Wafer #
Week 5, Oct 28th MODULE 2: MEMS Fab-Lab Process: (PDMS bonding and Characterization), ~ 4 hrs						
Type	Step	Name	Description	Purpose	Initials	Observations
Cleaning	1	Solvent cleaning	Clean glass slide using AMI	Remove organics and metals	Student	
	2	Rinse	Rinse with DI water, N2 dry		Student	
	3	Dehydration	Hotplate, 150 °C t > 5 min	Remove moisture	Student	
PDMS bonding	4	Detachment	PDMS replica detachment from the SU-8 mold		Student	
	5	Clean PDMS	Perform AMI		Student	
	6	Punching	Punching holes onto PDMS using pins	Inlet and outlet tube	Student	
	7	Oxygen plasma	Both glass and PDMS bonding surfaces face up for 2min. Be very careful when	PDMS bonding on a glass	TA	
	8	Bonding	PDMS bonding surface facing that of glass. Press down PDMS to be in contact with glass sufficiently for 2min		Student	
	9	Insert Metal pins	Insert the metal pins		Student	
	10	Oven	for 1 hr at 65°C	Enhance bonding	Student	
Tests	13	Microfluidic tests	1. Dye flow steering, 2. Droplet size generation speed control		Student	

Members:			Lab Section:			Wafer #
Week 6, Nov. 4th, Wildfire (no class this week)						
Type	Step	Name	Description	Purpose	Initials	Observations

Week 7 (Tue, Wed, Thur sessions), Nov.11th, MODULE 3: MEMS Fab-Lab Process: (Nanoimprint), ~ 3hrs						
Type	Step	Name	Description	Purpose	Initials	Observations
Resist coating	1	ULP adhesion layer coating	500rpm for 5s with 100rpm/s and 4000rpm for 45s with 1000rpm/s. Use 0.2µm filter to filter out particles from solution.	to provide adhesion for UV imprint resist coating	Student	
	2	Soft bake ULP	Hotplate, 180C for 2 min	drive out solvents	Student	
	3	UV resist coating	2000rpm for 7s with 1000rpm/s. Use 0.2µm filter		Student	
Nanoprinting and exposure	4	Load glass substrate	Place resist coated glass substrate onto chuck of the pneumatically controlled system.		Student	
	5	Fix wafer	This will turn on chuck vacuum to secure the substrate. Fix substrate with top chamber off to prevent premature imprinting.		Student	
	6	Alignment	Place the top chamber on the substrate chuck, and roughly align the mold and substrate to ensure maximum contact. Purge with N2 for >15 sec.		Student	
	7	Imprinting	The inflatable o-ring will inflate to seal the chamber. The chamber will pump down to vacuum. Pressure will be applied to the mold to press it into the resist.	deforms resist to pattern it	Student	
	8	Exposure	Expose with UV for 2 min.	crosslinks UV resist	Student	
	9	Release	After exposure, pressing "Release" will turn off the imprint pressure while maintaining vacuum.		Student	
Inspect	10	Microscope Inspection	Inspect the imprinted features under the microscope; bulk features should be visible. Measure the pitch of the lines and spaces.		Student	
Inspect	0	Microscope Inspections & Data Collection	Inspect MODULE 1's etched features under microscope and record with images. Examine for the BOE undercut dimensions, the micro-rings, the spiral features, and the cantilever beams. Record the critical buckling length of the clamped clamped beam. This can also be done in the make-up lab during Week 6 where attendance is not mandatory.	Determine the critical length and calculate film stress	Student	L _c =
						s =

Week 8 (Monday session only), Nov.18th, MODULE 3: MEMS Fab-Lab Process: (Nanoimprint), ~ 3hrs						
Type	Step	Name	Description	Purpose	Initials	Observations
Resist coating	1	ULP adhesion layer coating	500rpm for 5s with 100rpm/s and 4000rpm for 45s with 1000rpm/s. Use 0.2µm filter to filter out particles from solution.	to provide adhesion for UV imprint resist coating	Student	
	2	Soft bake ULP	Hotplate, 180C for 2 min	drive out solvents	Student	
	3	UV resist coating	2000rpm for 7s with 1000rpm/s. Use 0.2µm filter		Student	
Nanoprinting and exposure	4	Load glass substrate	Place resist coated glass substrate onto chuck of the pneumatically controlled system.		Student	
	5	Fix wafer	This will turn on chuck vacuum to secure the substrate. Fix substrate with top chamber off to prevent premature imprinting.		Student	
	6	Alignment	Place the top chamber on the substrate chuck, and roughly align the mold and substrate to ensure maximum contact. Purge with N2 for >15 sec.		Student	
	7	Imprinting	The inflatable o-ring will inflate to seal the chamber. The chamber will pump down to vacuum. Pressure will be applied to the mold to press it into the resist.	deforms resist to pattern it	Student	
	8	Exposure	Expose with UV for 2 min.	crosslinks UV resist	Student	
	9	Release	After exposure, pressing "Release" will turn off the imprint pressure while maintaining vacuum.		Student	
Inspect	10	Microscope Inspection	Inspect the imprinted features under the microscope; bulk features should be visible. Measure the pitch of the lines and spaces.		Student	
Inspect	0	Microscope Inspections & Data Collection	Inspect MODULE 1's etched features under microscope and record with images. Examine for the BOE undercut dimensions, the micro-rings, the spiral features, and the cantilever beams. Record the critical buckling length of the clamped clamped beam. This can also be done in the make-up lab during Week 6 where attendance is not mandatory.	Determine the critical length and calculate film stress	Student	L _c =
						s =

LAB REPORT 2 [MODULE 3] DUE AT NOON ON DECEMBER 06, 2019