Introduction

Fabrication Process

PDMS Device Fabrication

This quick start guide is intended for researchers familiar with the equipment. A more detailed walkthrough is provided later on in the document, detailing every necessary step.

Preparing the Mold:

1. Place the silicon wafer mold into the silane deposition rig.
2. Deposit silane at -15 in Hg of pressure for 30 minutes.
3. Remove the silicon wafer with tweezers to avoid contamination.

Casting the Mold:

1. Mix the Sylgard 184 elastomer in a 10:1 ratio of base to curing agent using U-Line jars
2. Direct Casting on Wafer. Base Elastomer: 40 g, Curing Agent: 4 g
    1. Casting Parts in Plastic Petri Dish. Elastomer: 35 g, Curing Agent: 3.5 g
    2. Weigh the elastomer, jar, and thinky mixer adapter. Record mass and adjust counterweight in the thinky mixer (do not exceed 310 g!)
3. Run the thinky mixer in Standard (STD) mode with the following settings
    1. Mix Time: 60 seconds, Spin Speed: 2000 rpm
    2. Defoam Time: 60 seconds, Spin Speed: 2200 rpm
4. Pour degassed elastomer into vessel containing mold
5. Place vessel into vacuum chamber, perform the following steps:
    1. Degas for 15 minutes, then vent.
    2. Degas for 10 minutes, then vent.
    3. Degas for 5 minutes, then vent.
6. Place the degassed vessel onto a drip catch tray in the oven and bake at 80 C.
7. Bake for 3-4 hours or overnight
8. Remove the cured PDMS and let cool.

Preparing Device for Bonding:

1. Remove from the curing vessel. Scrape excess PDMS from the back of the wafer.
2. Prepare a clean vessel for holding the PDMS. This will be used for transporting the part to the ozone cleaner with minimal contamination.
3. Use clean tweezers to carefully lift off the cured PDMS. Place the side previously in contact with Silicon facing up in the clean vessel. Important: Do not let anything touch the silicon face of the PDMS. This will interfere with the bond.
4. Sonicate the backing material in Acetone for 2 minutes, IPA for 2 minutes, and DI Water for 1 minute each.
5. Dry the backing material using compressed N2 gas.
6. Punch the holes using a biopsy punch or dispensing needle tip.
7. Activate the PDMS and glass surfaces (a or b)
    1. Ozone Chamber: 10 minutes
    2. Plasma Chamber: 600 mTorr, expose for 30 seconds at RF level High

Bonding Device:

1. Using clean tweezers, bring the two ozone-exposed faces into contact with each other. Apply pressure to ensure even contact.
2. Bake the bonded device at 110 C for 20 minutes.

PDMS Membrane Fabrication

Troubleshooting

Detailed Operation Processes

Preparing Elastomer

Safety Considerations:

- Elastomer agents spill easily and leave a sticky residue. Prepare the work environment appropriately and promptly clean up any spills.
- Protective liners cover the bench in microfluidics. The lab staff replaces these weekly, but please replace any contaminated liners after large spills.

PPE Required:

- Gloves (Latex or Nitrile)
- Eye Protection
- Lab Coat

Materials Needed:

- Sylgard 184 elastomer
- 3 oz white U-Line Jar
- Plastic Spatula

Tools Needed:

- Unordered List ItemElectronic scale
- 3D printed Thinky Mixer adapter

Procedure:

1. Retrieve a 3 oz U-Line jar from the box above the PDMS bench.
2. Remove the lid, place the jar on the scale, and tare the scale.
3. Measure out Sylgard 184 in a 10:1 ratio of base to curing agent.
4. For a plastic petri dish: 60 g elastomer base, 6 g curing agent.
5. For spin-coating a Si wafer: 5 g elastomer base, 0.5 g curing agent.
6. Assume ~5% of prepared elastomer will remain in container.
7. Remove jar from scale and replace lid. Fit jar into 3D printed adapter for Thinky Mixer.

8. Tare scale. Weigh jar+lid+adapter and record mass. This number is necessary for setting Thinky Mixer counterweight (see **Mixing Elastomer**)

Mixing Elastomer

Safety Considerations: The Thinky Mixer can support a maximum weight of 310 g. Anything heavier than this will cause an eccentric load that can seriously damage the machine. Confirm that container lid is tightly sealed before loading into the machine. Improperly sealed containers will eject elastomer into the machine and can seriously damage it.

PPE Required: Gloves (Latex or Nitrile) Eye Protection Lab Coat

Materials Needed: U-Line jar containing elastomer components (prepared in Preparing Elastomer)

Tools Needed: Thinky Mixer 3D printed Thinky Mixer adapter

Procedure:

1. Press “Open” on the Thinky Mixer to disengage the lock and open the machine.
2. Confirm that the jar+lid+adapter assembly weighs less than 310 grams.
3. Adjust the knob until the counterweight matches the jar+lid+adapter mass.
4. Align the adapter with the pegs in the mixer and insert the jar+lid+adapter into the machine. Close the mixer lid and confirm that “Lock” is illuminated.
5. Confirm Recipe. Use the “Memory” Button to cycle through options until “Memory 1” is illuminated. Similarly, Use the “Step” Button to cycle through the steps. Confirm the following checklist:
    1. Mode:
    2. Step 1: “Mix”, Time: 1 minute, Speed: 2000 rpm
    3. Step 2: “Defoam”, Time: 1 minute, Speed: 2000 rpm
    4. Step 3: N/A, Time: 0, Speed: 0 rpm
    5. Step 4: N/A, Time: 0, Speed: 0 rpm
    6. Step 5: N/A, Time: 0, Speed: 0 rpm
    7. If the system does not match this, see Appendix Programming Thinky Mixer for changing the settings.

Spinning Elastomer

Safety Considerations: Make sure the system lid is secured before starting the spinner.

PPE Required: Gloves (Latex or Nitrile) Eye Protection Lab Coat

Materials Needed: U-Line jar containing mixed and degassed elastomer Cleaned substrate Tools Needed: Laurel Spinner Substrate vacuum chuck adapter Substrate alignment jig

Procedure: Check paper towels lining the Laurel spinner. If they are saturated with elastomer, replace them with fresh paper towels. Retrieve the blue tray kept on the shelf above the Laurel spinner. This contains the necessary adapters and jigs for spinning membranes on a variety of parts.

Place the substrate on the vacuum chuck. Depending on the substrate, do one of the following things: 3” Silicon Wafer: Flip the alignment jig so that the smaller tangent bars are facing up. Place the alignment jig on the center post, and hold the face flush with the top of the center post. Place the wafer on the jig and push it up against the two tangent bars. Confirm that the silanated face is facing upwards. While holding the wafer in place, Press Vacuum on the control panel (the green light will be lit when the option is available)

6” Silicon Wafer: Flip the alignment jig so that the larger tangent bars are facing up. Place the alignment jig on the center post, and hold the face flush with the top of the center post. Place the wafer on the jig and push it up against the two tangent bars. Confirm that the silanated face is facing upwards. While holding the wafer in place, Press Vacuum on the control panel (the green light will be lit when the option is available). Microscope Slide: Place the slide alignment jig on top of the center post. Seat the microscope slide with the clean face facing upwards inside the rectangular groove. Small Substrate: Put the size adapter jig on top of the center post (round object with a smaller O-ring set in the center). Place the small substrate centered over the O-ring While holding the substrate in place, Press Vacuum on the control panel (the green light will be lit when the option is available).

Pour the degassed elastomer onto the substrate center until approximately 75% of the substrate is covered. Carefully pop any bubbles with a sharp implement, these will cause streaks in the membrane Consult the thickness-spin curve in the laminated sheet for the optimal settings. Press Start on the machine. Wait for the cycle to complete. Using tweezers, carefully remove the wafer. Bake at 80 C for 3-4 hours or overnight.

Casting Elastomer

Safety Considerations: PPE Required: Gloves (Latex or Nitrile) Eye Protection Lab Coat Materials Needed: Aluminum foil Plastic petri dish Mixed elastomer Tools Needed: Vacuum chamber Wafer-shaped form for foil boat making Procedure: Place item in bottom of vessel If casting directly on silicon wafer, make a boat from aluminum foil. Use a form to shape the foil and check foil for any holes. If casting small items (like MiiCraft prints), place them in a plastic petri dish. Pour elastomer directly into the vessel. Do not overfill. Place the vessel containing the elastomer and the mold into the vacuum chamber. Turn the vacuum valve to the on position and degas the elastomer for 15 minutes. Turn the vacuum valve to the off position and vent the chamber. Turn the vacuum valve to the on position and degas the elastomer for 10 minutes. Turn the vacuum valve to the off position and vent the chamber. Turn the vacuum valve to the on position and degas the elastomer for 5 minutes. Turn the vacuum valve to the off position and vent the chamber. Remove the vessel from the vacuum chamber.

Curing Elastomer

Safety Considerations: Ovens and trays pose a potential burn hazard. Wear insulated gloves while handling oven and trays. Do not remove trays from the oven. There is no visual indication of their temperature and left unattended or forgotten the hot trays can injure others. Material dripped onto the bottom surface of the oven burns and damages the equipment. Do not bake items without a drip tray underneath. Required PPE: Insulated gloves. Gloves (Latex or Nitrile) Eye Protection Lab Coat

Materials Needed: Foil for lining drip tray (optional) Degassed elastomer Tools Needed: Oven Heat resistant drip tray Procedure: Confirm that the oven is set to 80 C. Either oven in the Microfluidics Lab is acceptable. Identify an empty oven tray to use for spill protection. Carefully transport degassed elastomer to the ovens. Place the part to be cured on the tray. The tray will collect any spilled elastomer and prevent it from burning on the oven source. Bake for at least 3-4 hours. Overnight is also acceptable. Leave a note on the oven with your name, contact information, and expected return date/time. Unmarked items are subject to removal from the oven. Use the insulated gloves to remove your part from the oven, and let cool on the bench Leave the oven on. (This may be subject to change as lab staff investigate the energy consumption of leaving the oven on versus turning the oven on/off).

Ozone Activation

Safety Considerations: Ozone is a toxic molecule, so this process requires proper ventilation. Perform all operations in a fume hood. If a fume hood is not available, the scrubber must be attached and used. Leave the scrubber on for a minimum of 10 minutes after usage before opening. Do not open the lid during operation. If necessary, use a metal implement to push back the rubber seal and confirm that the bulb is functioning. The bulb (~$3000) is extremely fragile, and can be broken by overextending the base height. Use the ruler to confirm the top of the sample is at a safe height (below 10 cm) to prevent damage. This process is only approved for activating PDMS and glass. Check with lab staff before using the equipment for any other purpose. PPE Required: Gloves (Latex or Nitrile) Eye Protection Lab Coat Materials Needed: PDMS device (to be bonded) Glass device backing (to be bonded). Solvent clean glass before exposure (see Solvent Cleaning) Tools Needed: Ozone lamp station Scrubber (if using outside the fume hood) Special ruler (flag marked at max height of 10 cm) Procedure: Open the lid of the ozone machine, place the samples inside. Place the samples such that the bonding surfaces are facing up IMPORTANT: Use the ruler to confirm that the top of the specimen is below 10 cm. Failure to do so will break the bulb (~$3000!) To raise/lower the stage, hold the stage with one hand and loosen the knob on the right side of the machine. Lift/lower the stage to the new height (It is unsupported and will drop when the knob is loosened), and then tighten the knob to secure it. Close the lid, and confirm that the lid clicks into place If the lid does not click, use an allen key to adjust the screws underneath the handle. These adjust the springs that control the resistance of the engagement. Press the Clock button to confirm that the timer is set to 10 minutes. Use the Plus and Minus buttons to adjust the time. Press On to start the machine. To check that the machine is running, use the metal ruler to slightly depress the rubber gasket and check that light is emanating. IMPORTANT: Do not open the machine during operation. The machine displays Idle when finished. Remove the samples and close the lid.

Plasma Activation

This process is counterintuitive. Increased exposure time decreases the surface bonding. If the recipe is not working, try increasing the gas pressure or decreasing the exposure time. This process is sensitive to humidity, and bonding decreases with severe humidity. Safety Considerations: Do not open the hatch while the machine is in operation. The system is set up to generate plasma from air or nitrogen. Do not use any other gases to generate plasma, they have additional pump and exhaust requirements. Do not turn the pump off while the chamber is under vacuum. This can pull oil from the pump and damage the system. PPE Required: Gloves (Latex or Nitrile) Eye Protection Lab Coat

Materials Needed: PDMS device (cleaned, to be bonded) Glass slide (cleaned, to be bonded) Tools Needed: Plasma cleaning station Procedure: Air Plasma: Place PDMS and glass slide on the foil tray inside the plasma chamber. Ensure that the bonding faces are facing up. Inspect the hatch o-ring for cleanliness. Wipe debris using a clean cloth. Switch the hatch valve to Pump. Confirm that the RF Level dial is turned to Off. Turn the power switch on both units to On. (the left unit should warm up for at least a minute before powering on the plasma) Align the hatch with the chamber opening and hold in place with one hand. Flip the Pump toggle switch to On and hold in place. When the pressure drops below atmospheric (see vacuum gauge on right unit), the hatch will vacuum seal. When the chamber reaches 200 mTorr, slightly open the hatch valve towards Vent until the chamber reads a pressure of 600 mTorr (~⅛ of a turn) The chamber pressure is extremely sensitive to valve position. Adjust slowly and do not let chamber pressure come to atmospheric. After the chamber pressure equilibrates at 600 mTorr, turn the RF Level dial to High. Look through the holes in the left unit casing for a purple glow. The purple glow is a result of the plasma generation. Expose the surfaces for 30 seconds, then turn the RF Level dial to Off. Time this process using an external timer. Hold the hatch in place. With the pump still running, turn the hatch valve to Vent. Let the chamber come to atmospheric pressure, turn the Pump toggle switch to Off. Remove the hatch and return to its storage place. Turn the power switch on both units to Off. Remove activated surfaces. The activation is temporary and will decrease with time.

Nitrogen Plasma: Open the nitrogen valve on the fume hood 1 turn. Set the rotameters on the right plasma unit to 0 flow rate. Place PDMS and glass slide on the foil tray inside the plasma chamber. Ensure that the bonding faces are facing up. Inspect the hatch o-ring for cleanliness. Wipe debris using a clean cloth. Switch the hatch valve to Pump. Confirm that the RF Level dial is turned to Off. Turn the power switch on both units to On. (The left unit should warm up for at least a minute before powering on the plasma). Align the hatch with the chamber opening and hold in place with one hand. Flip the Pump toggle switch to On and hold in place. WHen the pressure drops below atmospheric (see vacuum gauge on right unit), the hatch will vacuum seal. When the chamber reaches 200 mTorr, slowly bleed nitrogen into the chamber until the chamber pressure reads 1800-2000 mTorr. (use the valve on the left rotameter). The chamber pressure is extremely sensitive to valve position, Adjust slowly and do not let chamber pressure come to atmospheric. After the chamber pressure equilibrates at 1800-2000 mTorr, turn the RF Level dial to High. Look through the holes in the left unit casing for a bright pink glow. This light results from the plasma generation. (The optimal pressure fluctuates, but a strong pink glow is a sign of correct operating conditions). Expose the surfaces for 30 seconds, then turn the RF Level dial to Off. Time this process using an external timer. Hold the hatch in place. With the pump still running, turn the hatch valve to Vent. Let the chamber come to atmospheric pressure, then turn the Pump toggle switch to Off. Remove the hatch and return to its storage place. Turn the power switch on both units to off. Adjust the rotameter so that the flow rate is 0. Close the fume hood nitrogen valve. Remove activated surfaces. The activation is temporary and the effects will decrease with time.

Corona Activation

Safety Considerations: The corona discharge wand ionizes the surrounding air, producing molecules like ozone. Open the closest fume hood sash to promote air flow during use. If using the wand for more than 10 minutes of operation, perform all work inside a fume hood to prevent excess accumulation of ionized byproducts. The wand presents a shocking hazard. Keep hands away during operation. Metal tools are forbidden when using the corona discharge wand. Use plastic tweezers and

other implements. PPE Required: Nitrile gloves, not latex, must be worn. Materials Needed: PDMS device (to be bonded) Glass slide (to be bonded) Scrap PDMS - for dialing in wand settings Tools Needed: Corona discharge wand Plastic tweezers / handling implements (no metal) Plastic or insulated work surface Procedure: Prepare the workspace. Remove metal implements and other shocking hazards Lay out samples. Confirm that the bonding faces are facing upwards. Plug in the corona discharge wand. Hold the wand over the piece of scrap PDMS. Position the wand between ⅛" and ¼" away from the surface of the material. Turn on the wand and increase the distance between the wand and surface until there is minimal sparking.

Silane Deposition

Safety Considerations: Trimethylsilyl chloride is an extremely reactive compound that forms HCl upon contact with water, including water vapor in the air. This process can only be performed in a fume hood, and the process requires an inert nitrogen environment. Do not raise the fume hood sash above recommended levels. The system should be supervised at all times. If leaving the lab while in use, leave a note with your name, contact information, and your return time. PPE Required: Gloves (Latex or Nitrile) Eye Protection Lab Coat All work must be completed inside the fume hood. TMSC is extremely toxic. Materials Needed: Substrate Tools Needed: Tweezers Silane Deposition Rig Vacuum Pump Procedure: Make sure the vacuum pump is turned on. Open the nitrogen valve 2-3 turns. Set gas Selector Valve to Off. Remove the acrylic lid from the silane deposition rig. Carefully place item to be silanated inside the chamber using tweezers. Position item away from the silane nozzle. Inspect the O-ring for any dirt or obstructions. This will compromise the seal. Replace the acrylic lid on the rig. Confirm that the item being silanated is not underneath the silane nozzle. Switch the Selector Valve to Vacuum. When the pressure gauge reaches - 20 in Hg, switch the Selector Valve to Off. Note the exact reading of the pressure gauge. Wait 2 minutes, and inspect the pressure gauge again. Confirm that the pressure has not changed. A change in pressure indicates an imperfect seal. Clean the O-ring and test again. Open the Isolation Valve. The Silane Valve must remain closed. Slowly turn the Selector Valve to Nitrogen. (Opening the valve too quickly will cause an influx of gas and blow small parts around the chamber). When the pressure reaches - 3 in Hg, turn the Selector Valve to Vacuum. When the pressure reaches -25 in Hg, turn the Selector Valve to Nitrogen. Repeat Steps 11 and 12 four times. When the pressure reaches -3 in Hg on the last run, turn the Selector Valve to Off. Turn the Selector Valve to Vacuum. Just before the internal pressure reaches - 15 in Hg, open the Silane Valve. Turn the Selector Valve to Off when the internal pressure reaches - 15 in Hg. Let the system run for 30-60 minutes. Record start/end times in the log for tracking TMSC consumption. Close the Silane Valve. Turn the Selector Valve to Vacuum. When the pressure reaches -25 in Hg, turn the Selector Valve to Nitrogen. Repeat Steps 17 and 18 four times, switching the Selector Valve to Vacuum when the pressure reaches - 3 in Hg. While still at negative pressure, close the Isolation Valve. With the Selector Valve set to Nitrogen, let the system come to positive pressure. When the seal breaks, turn the Selector Valve to Off. Using carefully remove the part. Reseat the acrylic lid on the rig. Turn off the vacuum pump and close the nitrogen line.

Solvent Cleaning

Safety Considerations: Isopropyl Alcohol and Acetone are both flammable materials and cannot be placed directly in the sonicator bath. They must be contained within a separate vessel placed inside the bath. Large chemical spills are a possibility. Pour all chemicals inside the fume hood. Keep fume

hood sash at or below maximum opening level to ensure adequate air flow. PPE Required: Gloves (Latex or Nitrile) Eye Protection Lab Coat Materials Needed: Polypropylene (PP) bags Acetone Isopropyl Alcohol (IPA) Tools Needed: Sonicator Bath (Filled with DI Water) Beakers (if not using PP bags) Tweezers Plastic boards with beaker shaped cutouts (if using beakers) Rail with PP bag clips Procedure: Beakers Remove the metal lid of the sonicator bath. Check that the bath is filled to the operating level (if not, fill to the line with DI). Place the plastic cutouts across the bath, resting it on the ledges that seat the lid. One cutout has 2 openings, the other has only 1. Retrieve the appropriate beakers from the drying rack above the sink in the microfluidics lab. Select the beakers labeled Acetone, IPA, and DI Water. Confirm that each beaker has a plastic tube / zip tie ring around it to act as a cushion. Fill each beaker with the corresponding chemical using the solvent bottles in the cabinet underneath the fume hood. Carefully seat each beaker in one of the cutouts. Confirm that the base of the container rests below the water level. Using tweezers, Place the parts in the IPA beaker first. Sonicate for 5 minutes. Transfer the parts to the Acetone beaker. Sonicate for 5 additional minutes. Transfer the parts to the DI Water beaker. Sonicate for 5 additional minutes. Remove parts and dry with compressed air. Place into clean travel case and close lid to reduce contamination. Discard solvent in the solvent waste bottle found in the cabinet underneath the fume hood. Pour chemicals inside the fume hood and use the funnel (found next to the waste bottle) to minimize spills. Rinse beakers with DI water hang on the drying rack. Return the plastic cutouts to their storage place. If needed, replenish the DI water in the sonicator bath to the fill line. Replace the bath lid.

Polypropylene (PP) Bags Remove the metal lid of the sonicator bath. Check that the bath is filled to the operating level (if not, fill to the line with DI). Retrieve 3 PP bags from the blue container adjacent to the sonicator. Using a sharpie, label the bags Acetone, IPA, and DI Water. Using compressed air, gently pressurize the bags before releasing the pressure. This will break the static adhesion of the inside layers. Failure to do so may cause the solvents to overflow during filling. Fill each bag halfway with the corresponding solvent. Carefully pour the solvents to avoid spills, use the provided rack to keep the bag upright. Using tweezers, place the parts inside the IPA bag. Seal the bag and clip the filled bag to the rail. Hang the rail across the sonicator bath, resting it on the ledges that seat the lid. Sonicate the part in the IPA bag for 5 minutes. Unclip the IPA bag from the rail, transfer the part to the Acetone bag, and seal. Clip the filled bag to the rail. Sonicate the part in the Acetone bag for 5 minutes. Unclip the Acetone bag from the rail, transfer the part to the DI Water bag, and seal. Clip the filled bag to the rail. Sonicate the part in the DI Water bag for 5 minutes. Unclip the DI Water bag from the rail. Remove the parts, blow dry with compressed air, and place in a clean transport case. Dispose of remaining solvents into the solvent waste jug (found in the cabinet underneath the fume hood). Pour all chemicals inside the fume hood and use the provided funnel to minimize spills. Discard empty bags in the trash. Return clip rail to its storage position. If needed, replenish the DI water in the sonicator bath to the fill line. Replace the bath lid.

Device Bonding

Safety Considerations: The oven poses a burn hazard. Use protective gloves when handling. PPE Required: Insulated gloves. Gloves (Latex or Nitrile) Eye Protection Lab Coat Materials Needed: Activated PDMS surface (for bonding) Activated glass surface (for bonding) Aluminum foil Tools Needed: Oven Tweezers Procedure: The hydrophilicity of activated surfaces decreases rapidly with time. Perform this procedure immediately after surface activation. Use clean implements. Any dirt or contamination will negatively impact the device bonding. Using clean tweezers, carefully pick up the two pieces to be activated. Bring the activated surfaces in contact with each other. Work from one

corner of the device to the other, gently pressing the surface to eliminate bubbles. Create a tray from aluminum foil, and place the device on it. This will facilitate baking the device. Bake the joined device at 120 C for 20 minutes. This will create a permanent bond between the glass and the PDMS. (A drip tray is not necessary) Remove the device and let cool.

Port Alignment Fixture