LAB MODULE 1: PDMS Device Fabrication
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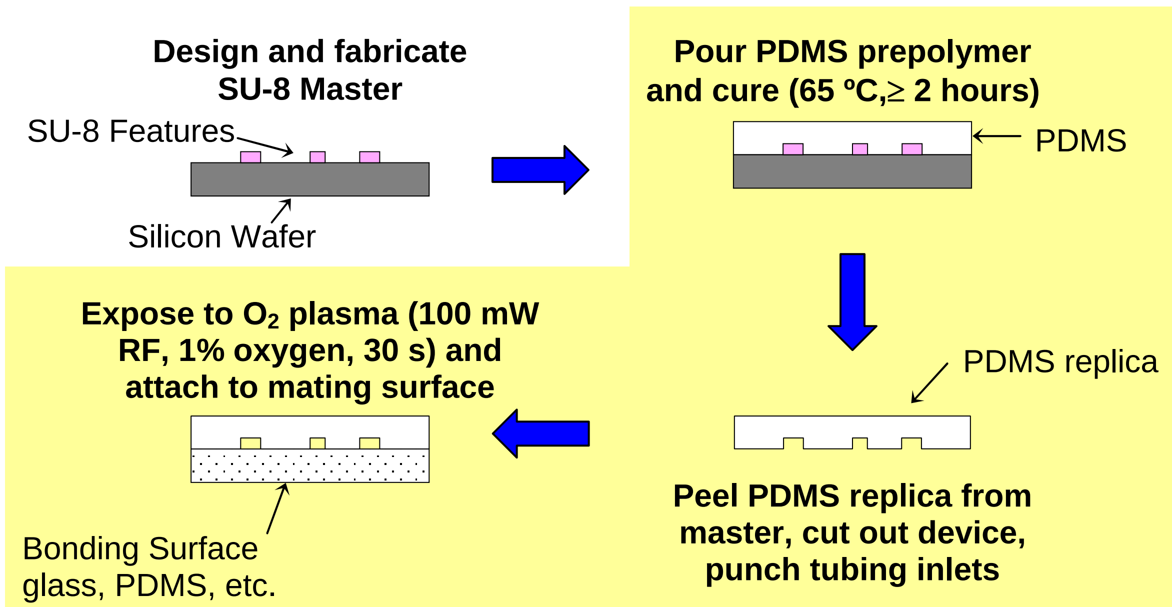
Purpose and Expected Outcome:
The purpose of this laboratory module is to provide an introduction and a hands-on demonstration of micro-fabrication of a PDMS device. We will start with a SU-8 master and fabricate devices in PDMS.

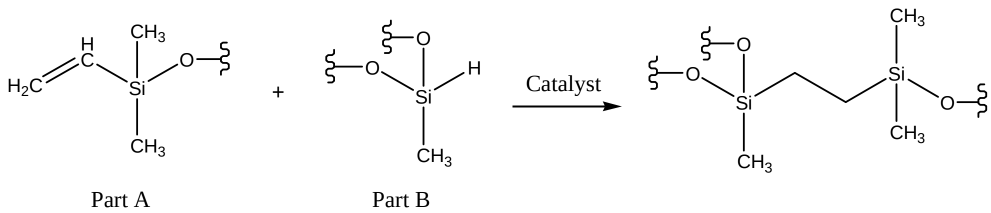
Overview of Polydimethyl Siloxane (PDMS) Device Fabrication:
PDMS device fabrication is one of the easiest methods for the rapid prototyping microfluidic devices. The main steps in fabricating are sketched in Scheme 1 below.



Scheme 1. Schematic overview of PDMS Device Fabrication.

In this experimental module, we will perform the steps outlined above in yellow. The general principles of microfabrication, including design and manufacture of positive resists, will be covered by ___ the first lecture entitled "Fundamentals of Microfabrication Technologies". The bonding of the elastomer device will be discussed and time permitting will be accomplished with an UV-ozone source. Post-bonding surface modification will be covered by ____ in the second lecture, "Surface Chemistry and Modification".

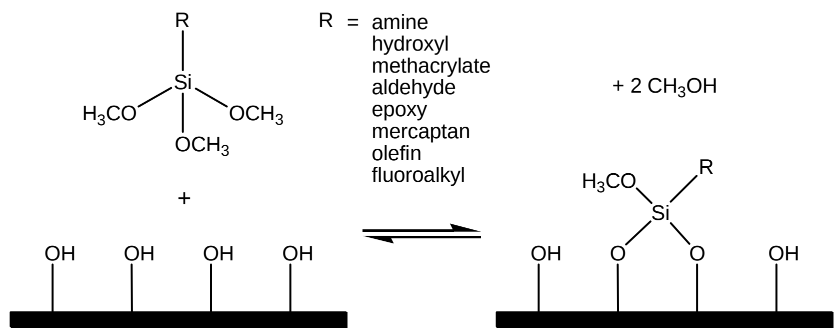
PDMS is a flexible elastomeric polymer that is an excellent material for microfluidic device fabrication.[1] In this lab module, we will use one of the most common PDMS elastomers, Sylgard® 184 from Dow Corning®. Sylgard is a two part resin system containing vinyl groups (part A) and hydrosiloxane groups (part B) shown in Scheme 2 below. Mixing the two resin components together leads to a cross-linked network of dimethyl siloxane groups. Because this material is flexible, it can be unmolded (peeled) from the SU-8 master, leaving the master intact and ready to produce another device.



Scheme 2. PDMS Crosslinking

Once the device is peeled from the mold, it is prepared for assembly into a final device. Devices are cut to size with standard surgical steel blades and access holes are punched for tubing and other device inputs. For tubing inputs, a needle hole is drilled slightly smaller than the outer diameter of the tubing being used. This provides adequate sealing for typical fluidic pressures.

Another useful property of PDMS is that its surface can be chemically modified in order to obtain the interfacial properties of interest.[2] The most reliable method to covalently functionalize PDMS is to expose it to an oxygen plasma, whereby surface Si-CH_3 groups along the PDMS backbone are transformed into Si-OH groups by the reactive oxygen species in the plasma. These silanol surfaces are easily transformed with alkoxysilanes to yield many different chemistries as shown below in Scheme 3.[3, 4]



Scheme 3. Silanization of plasma-exposed PDMS.

Equipment, Materials, and Supplies:

- Lab coats, gloves, hair nets, face masks
- SU-8 Silicon wafer masters - 32
- PDMS Resin - Dow Corning Sylgard 184 Part A, Part B
- Balance
- Weigh boats
- Stirring forks
- Vacuum jar (desiccator) with vacuum pump (or house vacuum)
- Surgical knives with blades
- Cutting surface
- Sharpened blunt needles to punch holes (See chart at end of document)
- Plasma (oxygen, water, air) source for non-reversible bonding

Module Outline and Workflow:

In this lab module, participants will get hands-on experience casting (pouring) PDMS over a silicon master device. Because PDMS takes > 2 hours to cure, another set of devices will be prepared ahead of time for cutting.

Protocol

1. PDMS pouring
   1.1. Put on a clean pair of gloves, lab coat, and face mask.
   1.2. Remove the master mold from its protective case and place it in a Petri dish secured by a tape. Blow with the nitrogen gun to remove any dust that may have accumulated.
   1.3. On the coarse scale, weigh out and mix 55 g of 1:10 PDMS per master mold into a small hexagonal weigh boat. Do this by first weighing out 5 g of curing agent, and then 50 g of polymer base.
   1.4. Mix the pre-cured PDMS with a mixing fork. Be sure to both swirl and fold the mixture to ensure that the curing agent is evenly distributed.
   1.5. Pour the PDMS into the SU-8 master mold placed in a Petri dish.
   1.6. Degas the PDMS by placing the mixed pre-cured PDMS in the vacuum desiccator and evacuating the chamber. Bubbles will appear, rise to the surface of the mixture, and pop. Degas the mixture for a minimum of 30 min. Vent the chamber as bubbles come close to the surface. Do this 2–3 times for the first 15 min. Degassing is complete when there are no longer bubbles visible in the mixture. Once all bubbles have been removed, cover the Petri dish and place in an oven at 65-80 °C for 3-6 hrs to cure the PDMS.
2. PDMS release
   2.1. Remove the PDMS casting from the oven and place on a clean bench top.
   2.2. Using an X-acto knife with a new blade, make straight cuts about 1 cm from the edge of the master mold. To make each cut, sink the point of the knife vertically into the PDMS until it reaches the silicon substrate. Angle the knife approximately 30° to the vertical and drag it in the direction of the cut. Make sure to maintain pressure on the knife such that the tip is always in contact with the silicon substrate. At the end of each cut, continue through the casting tray. Repeat this for each edge of the master mold.
   2.3. Once all the edges have been liberated, lift the mold up off the bench-top and carefully peel away the remaining portions of the casting tray from the underside of the mold. Discard this and any excess PDMS.
   2.4. Place the released PDMS layer in a clean Petri dish with it feature side up.
3. Fluidic port punching
   3.1. Wipe off the tip of the hole puncher with the ethanol soaked Kimwipe and bring it into alignment with the first port you will punch.
   3.2. Adjust the puncher so that it is as vertical as possible. Push the puncher through the PDMS until you hit the bottom.
   3.3. Push the plunger into punched hole to drive out the cored section of PDMS.
   3.4. Retrieve and discard the cored section from the under side of the device using a pair of forceps.
   3.5. Repeat steps 3.1 to 3.4 for each port.
   3.6. Place the punched PDMS device onto a Petri dish with feature side UP.

Once the devices have been poured, cut, and punched, we will discuss the process of bonding and surface chemical modification. In our labs, PDMS replicas and glass slides are cleaned with an oxygen plasma (100 mW, 2% oxygen, 35 s) in a PX-250 plasma chamber (March Instruments, Concord,MA) and then immediately placed in contact to bond the surfaces irreversibly. Chambers are then baked at 70 °C for 10 min following bonding. If there is time, laboratory participants will be encouraged to bond devices using a commercial UV-ozone source following the procedure outlined below.

4. Device bonding (with UV-ozone surface treatment)
   4.1. Lift cover off of UV-ozone machine and wipe metal platform with a cloth wetted with 2-propanol (isopropyl alcohol or IPA).
   4.2. Using tweezers, place the PDMS device with the feature side facing upwards on the metal platform from step 4.1.
   4.3. Using tweezers, place clean glass slides next to the device to be bonded.
   4.4. If there is any visible dust particles on the device or slide, wipe with a clean lint-free cloth soaked in IPA.
   4.5. Place cover on the UV-ozone source making sure that the device are approximately 3-5 mm from the UV lamp, which is housed in the cover.
   4.6. Expose device to UV for 3-5 minutes.
   4.7. Remove cover and using tweezers, grasp PDMS slab from its side and flip device over onto the glass side so that the features are bonded against the glass.
   4.8. Place the devices on a hotplate at 70 °C for 5-10 minutes.

The reactive silanol bonds at the surface of the PDMS will slowly diffuse back into the bulk of the PDMS elastomer. Therfore, chemical modification of the PDMS surface should immediately follow the oxygen plasma/ozone bonding.

References:

1. McDonald, J. C.; Duffy, D. C.; Anderson, J. R.; Chiu, D. T.; Wu, H.; Schueller, O. J.; Whitesides, G. M., Fabrication of microfluidic systems in poly(dimethylsiloxane). *Electrophoresis* **2000,** 21, (1), 27-40.
2. Makamba, H.; Kim, J. H.; Lim, K.; Park, N.; Hahn, J. H., Surface modification of poly(dimethylsiloxane) microchannels. *Electrophoresis* **2003,** 24, (21), 3607-19.
3. *Silicon Compounds: Silanes and Silicones*. Gelest, Inc.: Morrisville, PA, 2004; p 560.
4. Hermanson, G. T.; Mallia, A. K.; Smith, P. K., *Immobilized Affinity Ligand Techniques*. Academic Press: San Diego, CA, 1992; p 454.

Sources:
Small Parts, Inc.
13980 N.W. 58th Court
P.O. Box 4650
Miami Lakes, FL 33014-0650
http://www.smallparts.com

Part Description	Usage	Inner Diameter	Outer Diameter	Small Parts Part #
20G x ½" Stainless Steel Blunt Needles	Needles for cutting holes	0.023"	0.036"	NE-201PL-C
22G x ½" Stainless Steel Blunt Needles	Needles for direct injecting	0.016"	0.028"	NE-221PL-C
30G x ½" Stainless Steel Blunt Needles	Needles for tubing	0.006"	0.012"	NE-301PL-C
Tygon Tubing	Connect needles to device	0.01"	0.03"	TGY-010-5C

PDMS – Dow Corning Sylgard 184
UV-Ozone source – PSD-UV, Novascan Technologies

Add passive pumping, microspheres, and food coloring dye for flow illustration. Discussion group on results.