

Manufacturing a PDMS microfluidic device via a Silicon Wafer Master

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Abstract



This document describes the manufacturing process for a general microfluidic device which uses either pipette tips, O-Ring or non O-Ring syringe reservoirs as a fluid delivery mechanism. The manufacturing process does not involve much labor but requires a lot of waiting. The entire process takes a minimum of 5 hours but optimally the process takes 9 hours. First the PDMS is mixed and degassed for approximate 1 hour. Then the activated PDMS is poured onto the master and baked in an oven. After a minimum of 4 hours of baking, the PDMS is unmolded from the master and processed further. Next a glass slide is cleaned and the PDMS layer containing the microfluidic features are bonded to the glass slide. Finally the device is completed by attaching either pipette tips or pre-cut syringe tubes.

Mixing the PDMS

In preparation for this stage obtain a some unpowdered disposable gloves, a disposable plastic knife and a disposable plastic cup.

PDMS should be mixed in a 1:10 ratio of curing agent and PDMS monomers. The PDMS monomers are much more viscous than the curing agents. For this example implementation, we will be using a mixture which consists of 7g of curing agent and 70g of monomer.

The PDMS can be mixed in a disposable plastic cup, not unlike the cups found near water coolers. Wider cups may be better because they expose a larger surface of the contained fluid to air, which will aid in degassing the PDMS later.

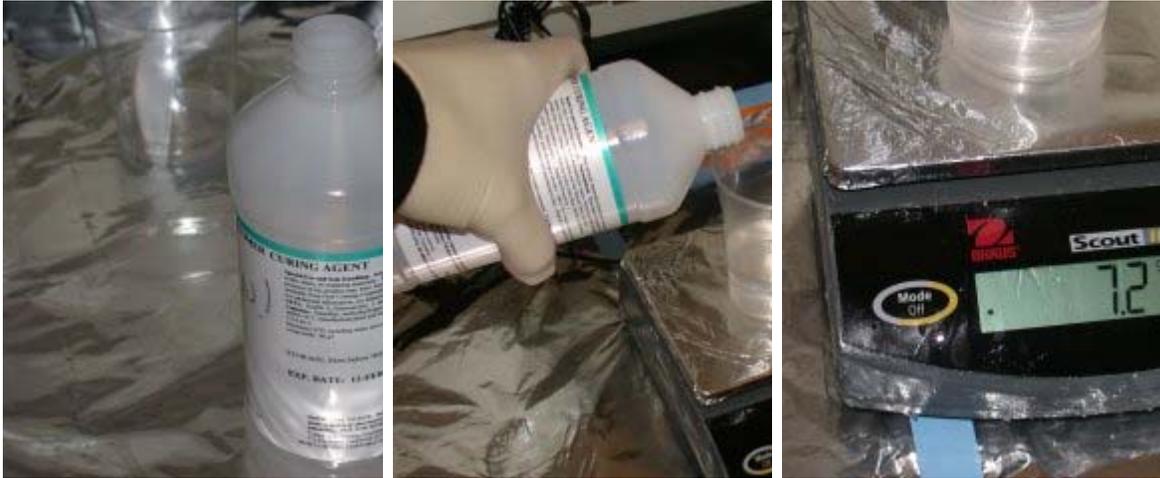
While PDMS is very safe, it is a sticky and messy substance to work with. You should put on some disposable gloves before touching the containers or tools which come into contact with uncured PDMS. Use unpowered gloves to prevent contaminating the PDMS. At this stage, you should not be too concerned with dust or other particles falling into the PDMS, they will be absorbed into the bulk of the device and will usually not affect the channels. However, powdered gloves should not be used the unmolding and bonding stages of fabrication.



Turn on the electronic scale and adjust the device so that it reads the correct units, in this case we adjust it to read in grams. Place the cup on the scale, and press the "Tare" button to rezero the scale.



Slowly pour 70g of PDMS (base) monomer into the cup.



Press the Tare button to rezero the scale. Then pour approximately 1/10 the amount of PDMS curing agent into the cup (7g), for a total mass of 77g for the entire mixture. You will not notice any immediate visible reactions when these two fluids come in contact. In actuality, the order in which the curing agent and PDMS base is added to the cup is not important since they will thoroughly be mixed anyway.



Take the cup off the scale and begin to stir the PDMS mixture using the disposable plastic knife. Stir the mixture for approximately 3 minutes. A large stopwatch is useful for keeping time. In general, any stiff disposable rod can be used to stir the mixture and a plastic knife is low cost and works well. After the 3 minutes of stirring the mixture will have many air bubbles. These bubbles must be removed before the PDMS can be used to make a device. Throw away the knife, it is no longer needed.

Degassing the PDMS

To degas the PDMS, we expose the mixture to a vacuum. The vacuum causes the bubbles in the PDMS mixture to expand and rise to the surface where they pop. Although, the precise amount of time needed to fully degas the mixture will depend on the amount of PDMS being mixed and the width of the cup, 1 hour is a good estimate. However, most of this time is spent just waiting for the process to complete.



A desiccator connected to a vacuum line is used to apply a vacuum to the PDMS mixture. First place the plastic cup containing the mixture into a larger, heavier container, such as a Pyrex beaker or an aluminum foil boat. The larger container will catch any PDMS that spills out of the plastic cup during the degassing process and will keep the plastic cup from being knocked over when the vacuum is released. Place both the cup and its container into the desiccator. Multiple cups of PDMS can be degassed simultaneously as long as there is enough room inside the desiccator.



Close the lid of the dessicator and adjust the vaccuum valve on the dessicator to connect the vaccuum line.



Now turn on a relatively weak vacuum by opening the valve on the vacuum line by only a few turns. A vacuum that is too strong causes the PDMS to actually boil over the side of the cup. Leave the PDMS in the vacuum for 1-2 hours. The PDMS is ready to be taken out of the vacuum when there are nearly no bubbles in the liquid. Release the vacuum valve on the desiccator slowly since the sudden rush of air may knock over the cup. A few small bubbles are acceptable because they will float to the top when making the device. Do not leave the PDMS in the vacuum for too long because it will become more viscous and will prevent bubbles from rising to the surface when the PDMS is poured into the mold.

Pouring the PDMS

Once the PDMS has been degassed, remove it from the desiccator and place the cup containing it on a lab bench with plenty of space to work with. The pattern for the PDMS device is created by pouring the liquid PDMS onto a surface containing the negative of the pattern and then allowing the PDMS to harden. The solid PDMS now contains the desired pattern of channels and can be bonded to a glass slide or a slab of PDMS to seal the channels. In this project the pattern has been created using SU-8 that has been layered onto a silicon wafer. The SU-8 has been developed by exposing it to a UV light image of the desired pattern. The sections of the SU-8 that were not exposed to UV light are removed leaving a negative mold for the device. The wafer containing the pattern is coated with a thin layer of silane to make it easier to peel the solidified PDMS from the wafer. The completed wafer is known as a "master" for creating the PDMS device. Developing masters using silicon wafers allows the use of standard microfabrication techniques which provide for excellent resolution and pattern quality. The disadvantage is that the wafers take a long time to create and require the use of special clean room facilities. Additionally the wafers are very fragile and a small crack will easily propagate throughout the entire wafer.

Due to the fragile nature of silicon wafers, the masters are usually stored in a special box designed to hold wafers. The PDMS will be poured onto these wafers but we will need to create a container to prevent the PDMS from dripping off the sides of the wafer. To create this container we will create an aluminum foil "boat" around the wafer. It is best to use thin regular aluminum foil, not heavy duty, because it will be easier to remove the aluminum foil from the PDMS later.



Tear a sheet of aluminum foil that is large enough to hold the wafer with at least an additional 2 inches of clearance on all sides. Place the sheet on the lab bench near the stored wafers and the degassed PDMS. While wearing gloves, gently take the silicon master out of its storage box and center the master on the foil with the pattern face up. Now, gently, fold the edges of the foil up around the master and crimp the foil around the edge of the wafer with the intent of sealing the underside of the wafer from contact with PDMS. The foil should also form a wall around the wafer, preventing the PDMS from running off the wafer.



If the device requires O-Ring reservoir fittings, the O-Ring mold must be placed on the wafer before pouring the PDMS onto the master. The O-Ring mold consists of an array of capacitors glued onto a glass slide. Holding the mold with the glass slide on top and the capacitors on bottom, gently align the capacitors with the array of reservoir pads on the wafer.



Pour the PDMS on one edge of the wafer and as low as possible to prevent the creation of new air bubbles. The PDMS will eventually flow to a uniform height over the wafer. Some air bubbles will form on the surface of the wafer, especially near the turns of the serpentine channels. These small bubbles will float up to the surface after about 5 minutes. Bubbles on the surface of the PDMS will not affect the device's performance and will usually burst during the curing process. Dust and other small particles in the PDMS also will usually not affect the device's performance because they will be trapped in the bulk of the device. If pipette tips or non O-Ring reservoirs will be used as the delivery mechanism for the device, no additional work is needed and the aluminum boat containing the PDMS and wafer can be placed in the 60 degree Celsius curing oven. If the device uses O-Rings, you may notice some bubbles under the capacitors. These bubbles can be extracted by placing the entire wafer with PDMS into the vacuum desiccator for a few minutes before placing the wafer into the oven.



Other researchers may be baking PDMS so remember to write your name and the time you placed the PDMS into the oven on the board nearby. The curing process takes a minimum of 4 hours but optimally the PDMS should be left in the oven overnight for 8 hours.

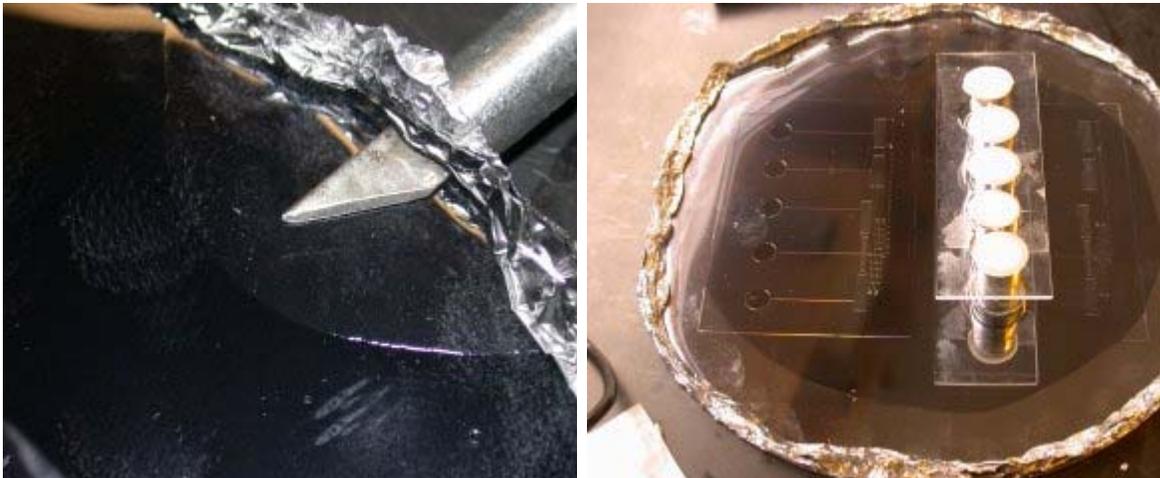
PDMS Unmolding



Remember to be very gentle with the wafer throughout the unmolding process. Most master breakages occur during this step. While wearing gloves, take the wafer out of the oven and place it on the lab bench. Wait a few minutes for the wafer to cool. To it easier to handle the wafer, remove the excess aluminum foil around the edges of the wafer.



Now use a small knife, i.e. an exactoknife, to completely remove the foil on the bottom of the wafer.



Now with the wafer again flat on the table, slide the knife's tip in between the wafer and the PDMS at the edge of the wafer. Slide the knife around the circumference of the wafer separating the PDMS from the wafer at the edges. Continue to unmold more of the PDMS by inserting the knife deeper but being careful not to touch the SU-8 pattern on the wafer. Continue to use the knife to move the unmolded "front" to the edge of the pattern.



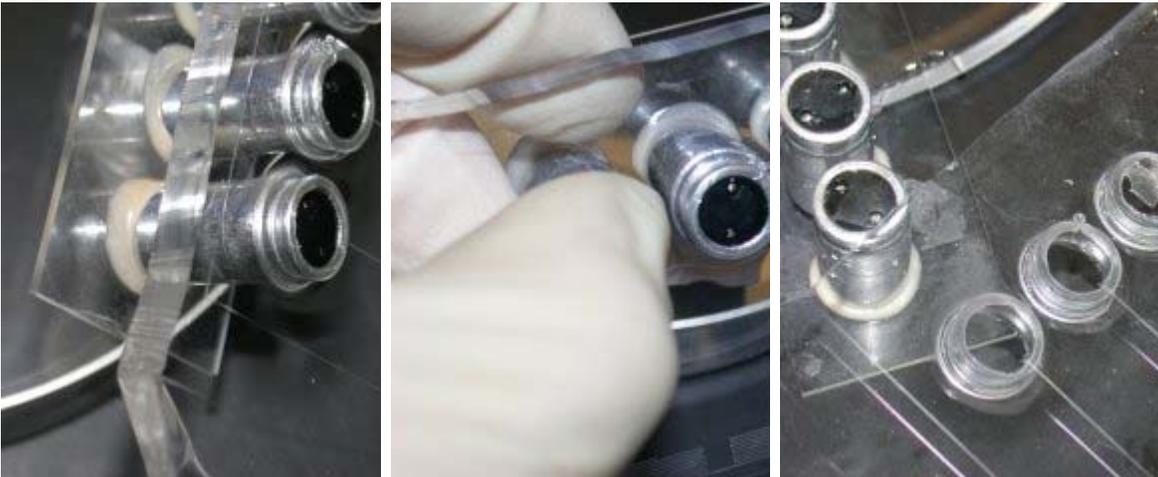
At this point use your hands to grip the PDMS and slowly peel it away from the wafer.



If the device uses O-Ring molds, these must be gently pried off the surface of the wafer along with the surrounding PDMS. You can pry the O-Ring mold off by tilting the glass slide gently causing the capacitors to separate from the wafer. Do this slowly as this process can place a lot of stress on the wafer. Place the peeled off PDMS on the lab bench with the side containing the channels face up.



Now place the wafer into its protective box.



If we are making O-Ring devices we must remove the O-Ring mold from the PDMS. Generally, we wish to avoid touching the side of the PDMS containing the channels because this surface will be bonded to glass and any oil on our gloves may affect the quality of the bonding. However, an exception can be made if we are making O-Ring devices because it is very difficult to properly remove the O-Ring mold without touching this surface. Loosen the capacitors from the surrounding PDMS using your fingers until they are finally completely removed. It is very easy to crack the PDMS around the capacitors during this procedure. The crack will create a leak which will usually cause the device to fail because the reservoir will be unable to deliver fluid properly.

Post Processing of PDMS device



After the O-Ring mold is removed, there may still be a thin film of PDMS left over. This thin film will prevent the reservoir from feeding the delivery channel. Using a small knife, i.e. exactoknife, remove the film to bring the large reservoir in contact with the tiny delivery channel.



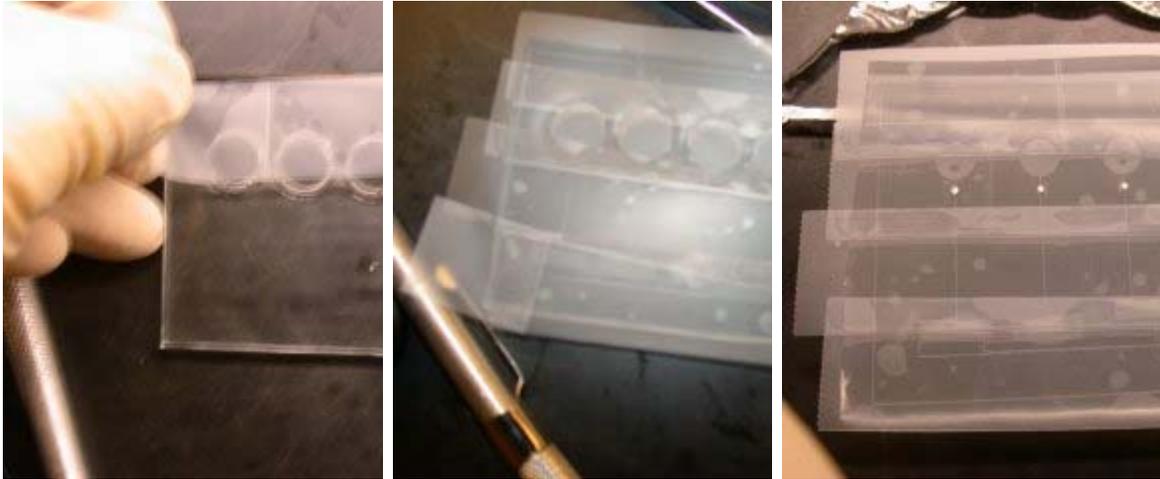
After the O-Ring mold has been removed or if the device uses pipettes or non-O-Ring reservoirs, take a box cutter and cut out the devices from the PDMS. If we are making O-Ring devices no additional post processing is required.



For pipette tip style devices, a hole must be punched on the delivery channels to interface with the pipette. Place the device with the channel surface face up on a slab of PDMS to prevent the cutting edge of the hole puncher from dulling. The hole puncher consists of a large needle with an inner diameter of about 2mm and a rod to remove the PDMS inside the needle. Insert the needle perpendicular to the surface of the device into the delivery channel about 5mm away from the junction between the delivery channel and the large circular reservoir pad.

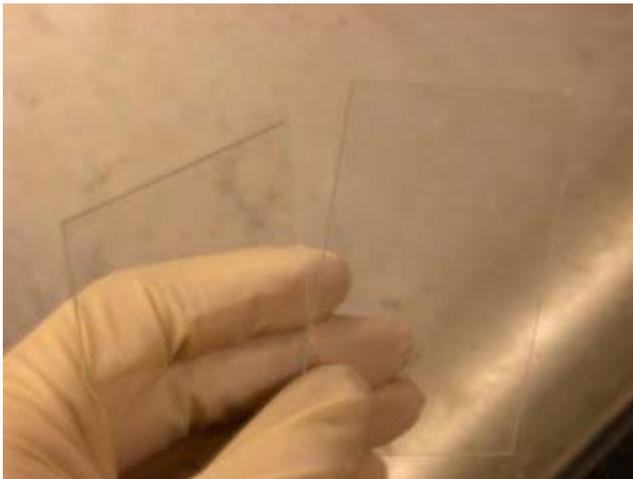


Push the needle completely through the device and use the thin rod to punch out the PDMS inside the needle before removing the the needle. For non O-Ring reservoir devices, place PDMS on a Teflon block and use a number 6 cork borer to punch a hold where the reservoir pads are located. Again try to punch the hole perpendicular to the device.



Once the necessary holes have been created, completely cover the side of the device containing the channels with scotch tape. Use an excess amount of tape because it will be peeled away later when the device is bonded to glass. The tape serves the dual purpose of prevent dust from accumulating on the bonding surface as well as removing the debris of the hole punching process from the surface. At this point the devices can be stored for bonding later.

Slide Cleaning



The channels of the device can be closed by bonding a glass slide to the surface containing the channels. To ensure a good bond and to prevent small particles from clogging the channels, the glass slides are cleaned prior to bonding. Only the side of the slide to be bonded needs to be cleaned but as it is sometimes difficult to know which side of the slide is which, both sides can be washed just in case. Gloves should be worn throughout the cleaning process to prevent skin oils from transferring onto the slides.



First the slides are rinsed under running water. Then clean the surface using dish detergent and rinse the soap off completely. Next rinse the surface with distilled water. Finally rinse the surface with isopropyl alcohol.



Dry off the isopropyl alcohol completely using the nitrogen gun. The cleaned glass slides should be stored in a petri dish to prevent dust in the air from accumulating on them.

Device Bonding



The cleaned glass slide will be bonded to the PDMS device using a plasma bonder. Inside the plasma bonder, the bonding surfaces of the slide and the PDMS device are subjected to high energy plasma which strips away electrons on the surface. This causes the surfaces to become hydrophilic. When these two hydrophilic surfaces come into contact they form a strong bond. In this project a plasma is created from air but a stronger bond may be created if a pure oxygen plasma is used instead.



Take the PDMS device and peel off the protective tape. Now use this tape to remove any particles on the bonding surface. Pay extra care to remove particles around the fluid delivery holes as these may clog the channels if they enter the device.



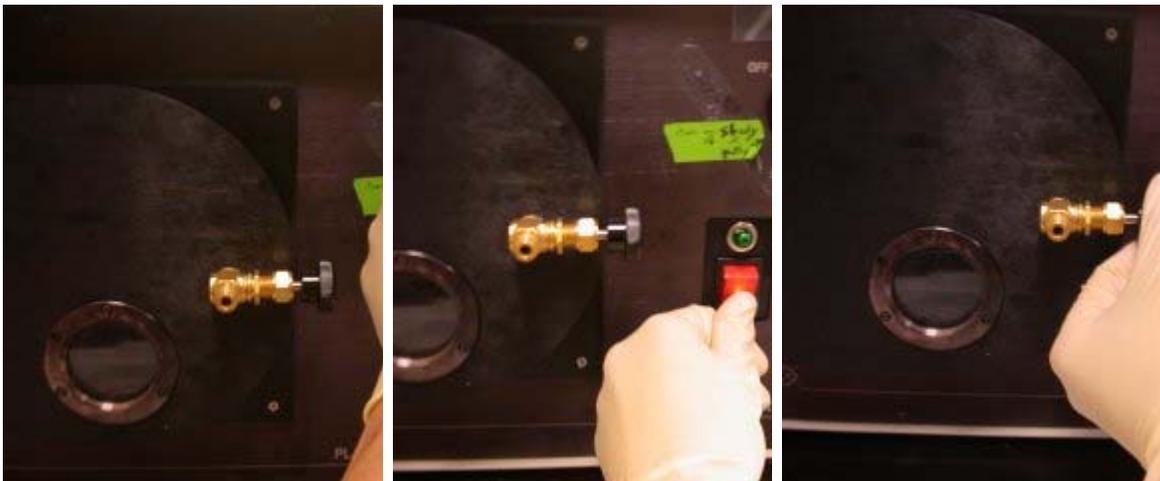
Once the surface is clean place the PDMS on a glass slide with the bonding surface face up and place the slide and PDMS into the plasma bonder. Take the cleaned glass slide and place it on another glass slide, again with the bonding surface face up and put both into the plasma bonder.



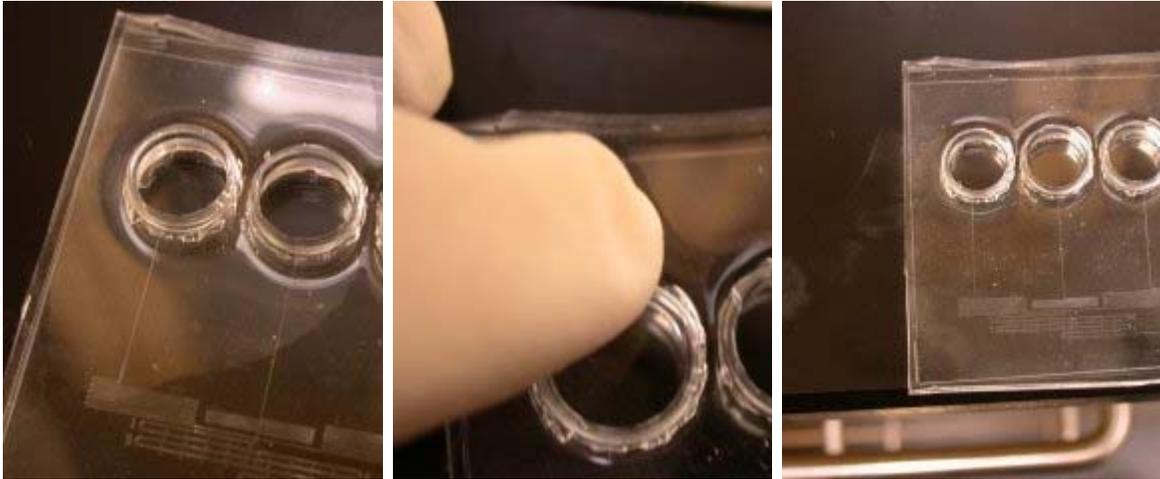
Close the door and close the venting valve on the door. Turn on the vacuum and switch on the RF generator but leave the dial for the RF strength in the off position. Wait 3 minutes to ensure a good vacuum is created in the chamber.



Then gently turn the dial controlling the RF strength to its maximum power. The venting valve may need to be opened very slightly to allow more air into the plasma. Look into the chamber via the window on the door to know how much to adjust the venting valve. The plasma in the chamber should be a bright pink color. Too much air in the chamber will prevent the plasma from forming, and too little will produce a weak plasma. Expose the device and glass slide to the plasma for 50 secs to one minute. This duration was found optimal for the bonding process and shorter or longer durations may result in a weaker bond.



Switch off the RF generator, vacuum pump and turn the RF dial to the off position. The surfaces quickly become less hydrophilic when exposed to air so try to bond the glass and PDMS as quickly possible. Open the venting valve to release the vacuum in the chamber.



After opening the chamber door, take the glass slide and place it on the table with the bonding surface upwards. Now take the PDMS device, flip it over and place it on top of the glass slide so that the two bonding surfaces contact. You should be able to see the bonding process occur. Apply gentle pressure to the regions of the device that have difficulty bonding. After 5 minutes the device should be finished bonding.

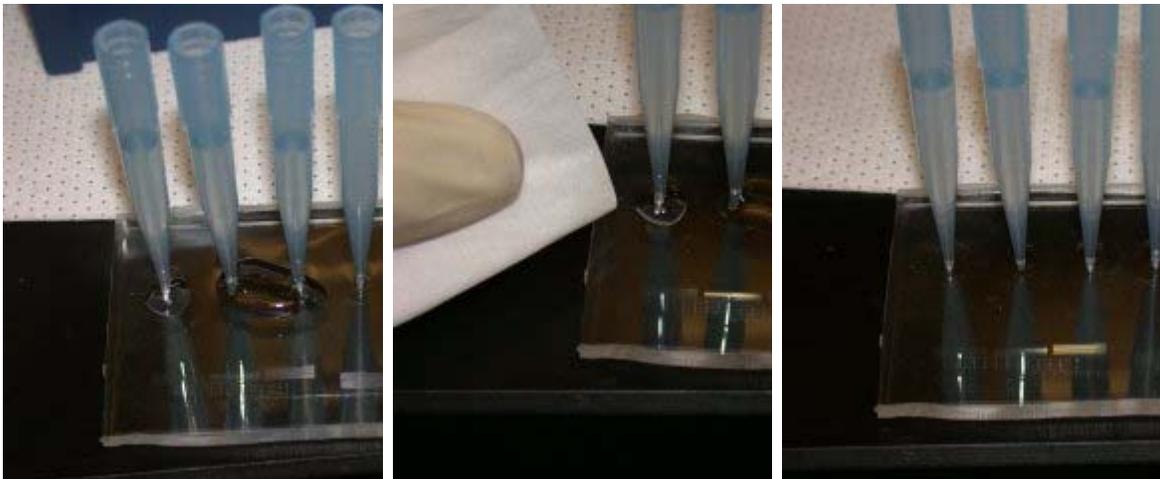


The device should be filled immediately with distilled water after the bonding process. After bonding, the channels are still very hydrophilic and makes it very easy to fill. Place a bead of water in one of the reservoir or punched pipette holes. You should be able to see the water from the single delivery channel fill the entire device.

Attaching Pipettes or Syringe Reservoirs



To complete a pipette tip device, pipette tips are inserted into the small punched holes. Try not to introduce air bubbles into the device throughout this process. Air bubbles will impede or block flow and are sometimes difficult to remove. Use a micro-pipette to fill a 1000 ml pipette tip with approximately 600 ml of distilled water. Place a bead of water on one of the device's input pipette holes. Using the micro-pipette, insert the pipette tip into the hole ensuring that no air is in the tip of the pipette. Finally, release the pipette from the micro-pipette leaving the pipette implanted in the device.



Repeat this process for the other pipette inputs. The residual liquid from the initial bead of water can be wiped away using a kimwipe or some other low lint material. Pipette tips for the outputs can simply be inserted into the hole since fluid will be entering the outputs.



For the reservoir type devices, precut syringe tubes are inserted into the reservoir holes. When you insert the syringe tubes, be very careful not to crack the PDMS around the reservoir holes. These cracks can easily propagate through the PDMS and cause a leak.