# 3D Printing using the Solidscape Studio for Rapid Prototyping of Optics and Microfluidic Devices

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## References

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## 1. Introduction

Emerging techniques for 3D printing have opened the door to several different applications requiring cheaper and faster prototyping abilities. Applications for 3D printing have continued to increase as 3D printers have become more accessible. A recent overview in innovations in 3D printing overviews applications from optics to organs and states that 3D printing has the potential to enable mass customization of components on a large scale [1]. Advantages of 3D printing include but are not limited to being able to conduct smaller production runs for competitive prices compared to traditional manufacturing, customization of devices, rapid prototyping, and the ability to use a variety of materials for biocompatible devices. In this paper we will provide an overview of 3D printing and the Solidscape Studio 3D printer in addition to two specific applications for 3D printing: custom optics and microfluidic channels.

## 2. 3D Printing and the Solidscape Studio

3D printing, or Additive Manufacturing (AM), allows for complex designs that would be difficult to machine while only requiring the ability to design using CAD software.

*3D Printing Resources*

For CAD software, Solidworks Student Edition is available for free through the Terman Library (https://library.stanford.edu/englib/technology/software) or Autodesk is available for free online (http://www.autodesk.com/education/free-software/academic-resource-center). There are also many open source and free CAD softwares, but Solidworks or Autodesk should be sufficient for most applications.

There are several 3D printers available for use on campus. The Product Realization Lab (PRL) has fused deposition modeling (FDM) printers for making large resolution plastic parts. The PRL also has a higher resolution multijet, ABS-like printer. Using these printers for research is discouraged. (https://productrealization.stanford.edu/resources/processes/3d-printing). The

Garner Lab has a FDM and a multi-jet printer available for on-campus researchers (https://sharedfacilities.stanford.edu/service_center/show_external/101/3-dimensional-printing-facility). Finally, there is the Solidscape Studio in the SNF, which is detailed in this report.

Additionally, there are many online resources for ordering 3D printed parts in many different resolutions and materials. The PRL website lists several such companies.

*The Solidscape Studio*


**Figure 1: The Solidscape Studio**

The Solidscape Studio is a high resolution wax 3D printer mainly marketed towards custom jewelers. The Studio has a 6.4 um minimum layer size, up to ~800 nm RMS surface finish and has a 6"x6"x2" build area. The wax Model Material melts at $100^0$ C and dissolves in IPA. The wax Support Material melts at $60^0$ C and dissolves in mineral oil. The 3ZWorks software takes .stl files and prepares proprietary .3zs job files for the Solidscape Studio.

*Summary for using Solidscape Studio*

1. Prepare CAD file of device and export as .STL format
2. Open .STL in 3ZWorks
    a. Rotate so that flattest part is on bottom
    b. Scale works okay, most adjustments should be made in CAD software
3. Append additional devices or copies as desired
4. Use WIZARD or FILL button to prepare .3zs file and
    a. WIZARD is an easy way to prepare multiple slice ranges
    b. FILL is for more advanced fill options
5. Enable on Badger
6. Transfer .3zs file using network transfer in lab or USB stick
    a. The Studio will choose newest .3zs file on USB root drive.
    b. Test USB stick when printer is not in use to make sure it is compatible
    c. Make sure your desired .3zs file is displayed on touch screen before starting
7. Make sure build plate is in place
    a. Press FINALIZE if previous printer forgot to do so
    b. Otherwise, pull latch to open lid.
    c. Replace build plate by lining the holes to the nubs and slide tabs forward.
8. Press START JOB

    a. Touch screen will have estimated start and finish times and progress bar
9. Press FINALIZE when print is finished
    a. Lid will open automatically
    b. Remove build plate by sliding tabs back and grabbing by the sides\
10. Place build plate on hot plate
    a. Turn on hot plate and make sure it is set to 100-1100C
    b. DO NOT GO OVER 1100C. THIS MAY BURN THE CALIBRATION BAR CODE
    c. Let heat for ~15-20 minutes.
11. While hot plate is heating, turn on dewaxing crock pot.
    a. Press power button
    b. Press probe
    c. If LCD shows HIGH, hit enter
    d. Use arrows to set temperature to 1400F, hit Enter
    e. Crock pot should beep and start warming up
12. Disable STUDIO but do not turn off the printer
13. Remove parts from build plate and transfer to dewaxing solution
    a. Use plastic scraper or other thin object to pry off pieces
    b. Be careful not to scratch build plate
    c. Turn off hot plate and allow build plate to cool down
14. Dewax for at least 2 hours
    a. Part will be done when there is no red or transparent goopy material
15. Retrieve parts in strainer and let dry on cleanroom wipes

**3. Custom Optics**

Custom optics is an interesting and exciting application of 3D printing. The basic idea is to make molds of the desired part, and use optical materials such as PDMS for transmissive optics or aluminum for reflective optics. The additive manufacturing process allows for complex designs that would be very difficult to create using traditional processes.

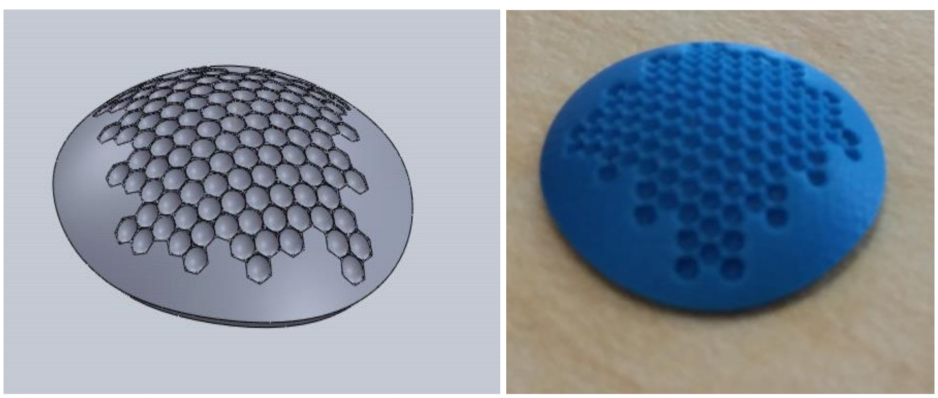


**Figure 2: CAD design and wax print of microlens spherical array mold**

Additionally, rare or unique optical devices can be very expensive even if they are relatively simple. A diamond turned axicon or a reflective parabolic mirror can cost thousands of dollars because demand for them is low and so cheap mass productive techniques are not employed. The goal then is to make these devices almost as good or better than a diamond turned device for an order of magnitude less cost and a bit of processing.

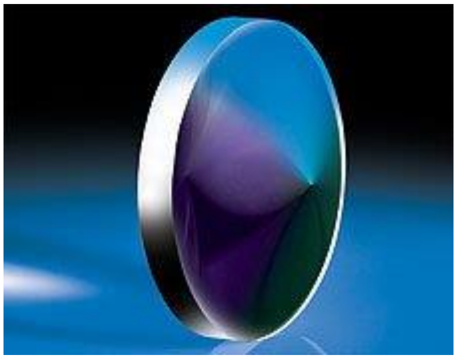


**Figure 3: CAD rendering of an Axicon**

The roughness of the wax surface directly out of the printer, quoted at about 800 nm RMS, is too large for optical quality devices. Additionally, we found that PDMS does not cure on the surface of the wax, leaving the device sticky and cloudy. A smoothing process and a barrier between the wax and the PDMS needed to be found.

*Summary for Preparing PDMS Optics*

1. CAD mold inverse of desired part
2. Print and dewax
    a. Let piece completely dry after dewaxing
    b. Make sure there are no defects or crumbs
3. Smooth wax surface before parylene deposition
    a. Suggested process: 15 min bath in 10% IPA-H2O
4. Parylene coating – parcoater (see Appendix A)
    a. Use at least 10g of parylene (measured in the dimer)
    b. Add 4 drops of A-174 Silane to chamber walls before pump down
5. Prepare 10:1 PDMS and bake at $60^{o}$C until set
    a. Enable thermoscientific-oven and set to $60^{o}$C
    b. Typically, 2 hours is enough. Use test PDMS to check.
    c. For firmer devices, use lower ratio or over cure
    d. DO NOT GO ABOVE 600C, WAX WILL DEFORM AND MELT
6. Extract piece using razor blade
    a. Cut off unwanted PDMS
    b. Remove any parylene from PDMS device
    c. If possible, remove parylene from wax mold to recoat and reuse.

*Smoothing Processes*

There are many options for surface finishing a 3D printed device. Polishing or chemical-mechanical planarization was not attempted but may prove sufficient. Heated acetone vapor baths are popular for smoothing ABS parts, so similarily IPA vapor may work well but is also dangerous.

Reflowing the surface of the wax using an IR lamp for uniform heating seemed like an ideal solution. However, the IR lamp is too powerful and causes the wax to melt too quickly. Using a culinary torch also seemed promising, but proved to be very finicky and would require a lot of trial and practice to perfect.

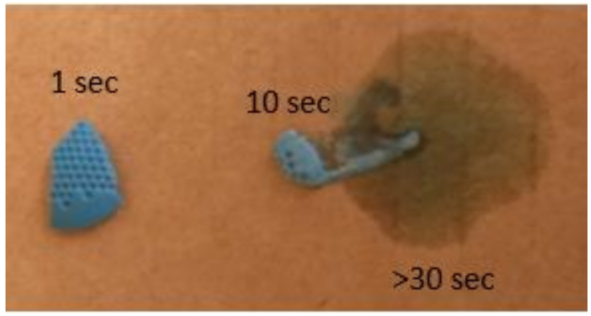



**Figure 4: Melted wax tests**

Along the same reasoning as the vapor bath, we decided to test a diluted 10% IPA-H20 solution, testing various times. A too short bath will have no effect, but too long will start to effect features as well as reveal undesired rough substructures. We found that a 15 minute bath in the 10% IPA works well.

We used AFM measurements to test the surface roughness of the wax pieces. The measurements were inspected using the Gwyddion free software.

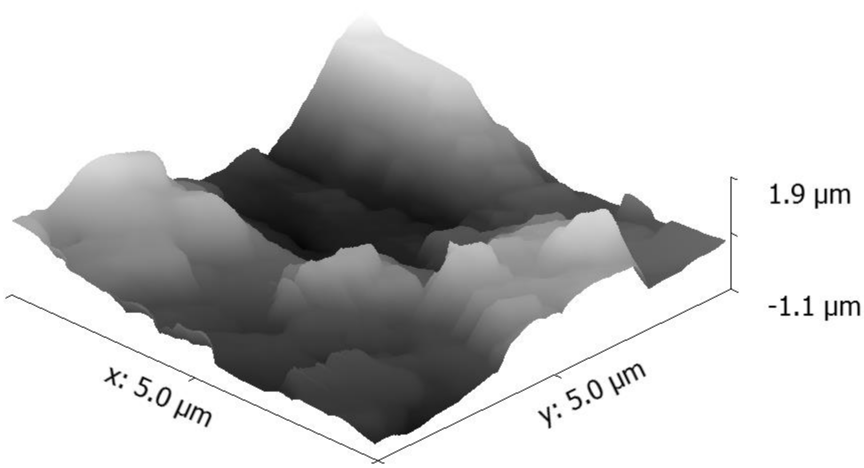



**Figure 5: Untreated Wax Surface, RMS: .5777 um**

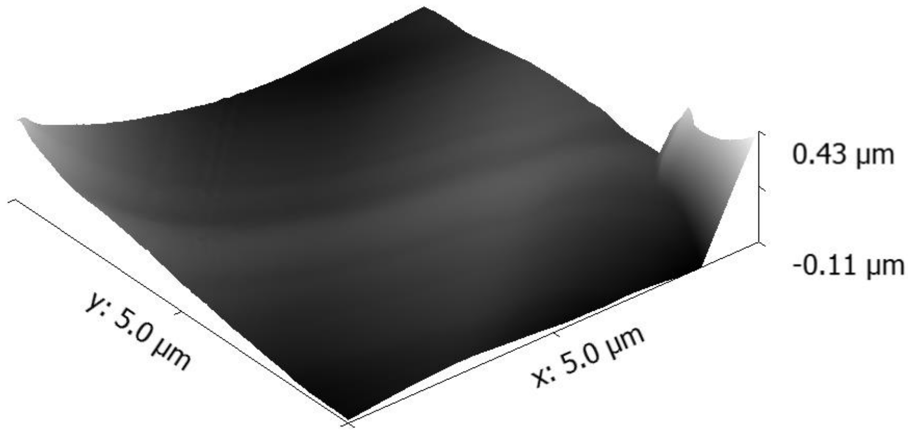



**Figure 6: 15 Minute 10% IPA Wax Surface, RMS: 1.02 nm**

1 nm RMS roughness seems too optimistic, but in general we saw that the high frequency noisy roughness was severely reduced. In the corners we can see that it begins to sharply increase, so there is still some low frequency macro roughness from the printing process. However, the 15 minute bath is obviously better than no treatment.

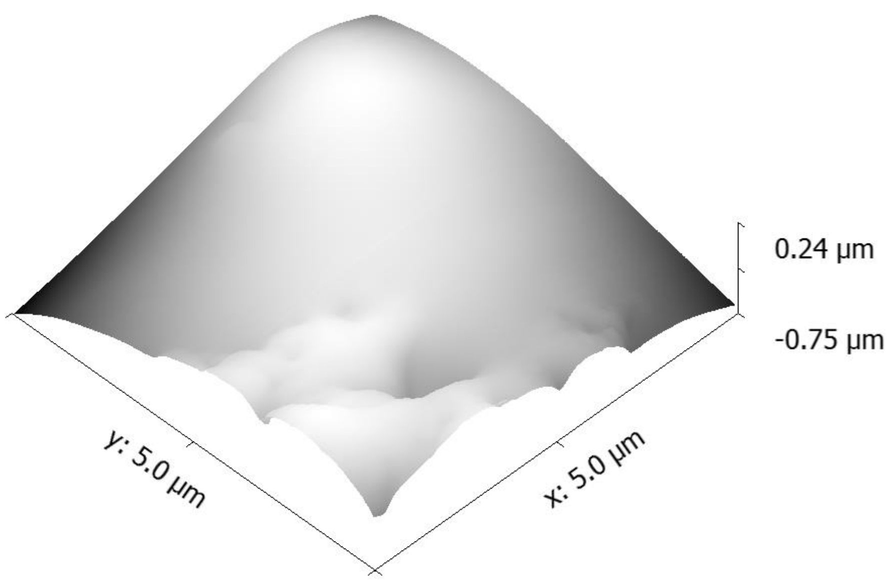



**Figure 7: 30 Minute 10% IPA Wax Surface, RMS: 186.35 nm**

We believe that the parylene coating may also help reduce the roughness as the conformal coating does not necessarily replicate the submicron structures. However, this coating's main purpose is to protect the PDMS from the wax so that it will fully cure.

Using the SNEOX confocal mode, we are able to measure the surface of the PDMS devices after extraction from the wax mold.

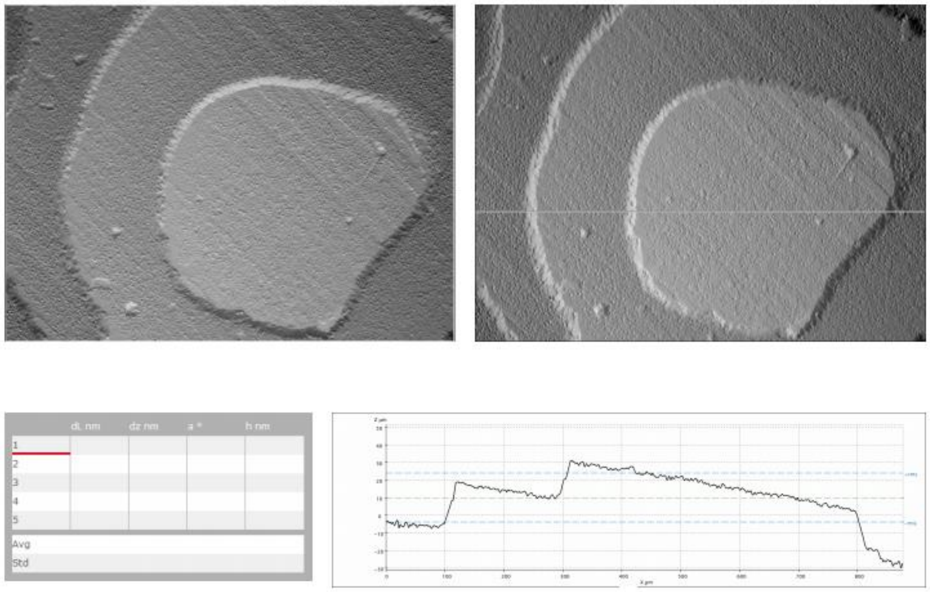


**Figure 9: 20x Confocal measurement of PDMS Lens without smoothing treatment**

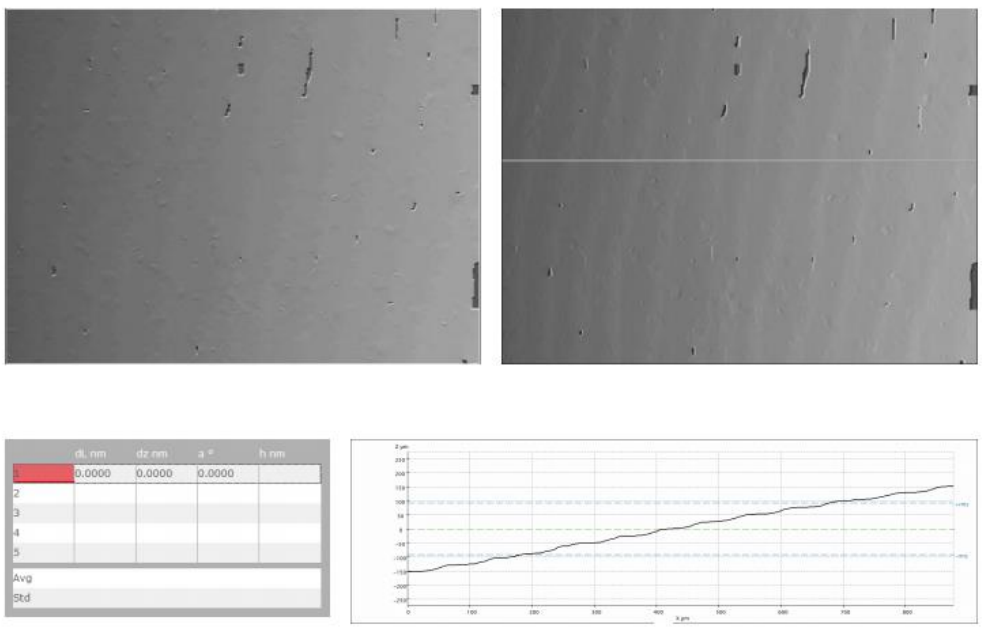


**Figure 10: 20x Confocal measurement of PDMS Parabola with 15 minute 10% IPA**

We can see from these measurements that the high frequency roughness is definitely worse in the non IPA treated device. Additionally the process ridges are damped in the treated device, but still noticeable.

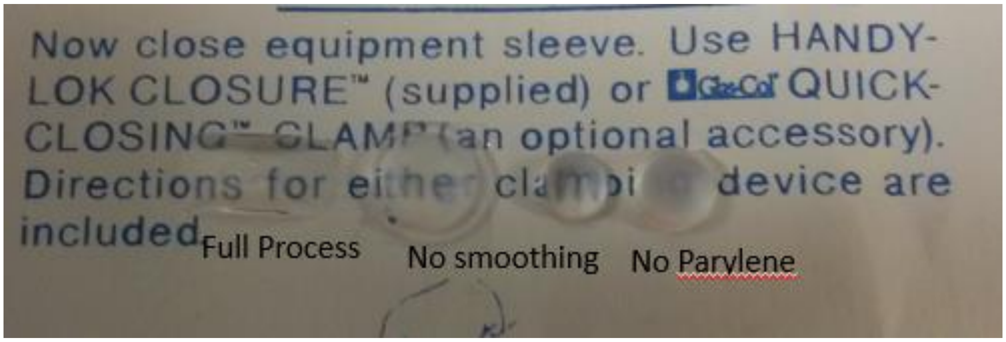


**Figure 11: Optical clarity comparison of PDMS devices with various process parameters**

The finished products shows that our process definitely improves the quality of the PDMS surface. We can see through the pieces using the full process with no haziness, unlike the non-smoothed devices. However, a close inspection will still show some low frequency (~10um) ridges. As such, the clarity of the device will depend somewhat on its shape and size, and the smoothing process can be further refined. The lenses from molds without parylene are uncured on the surface and are barely transparent.

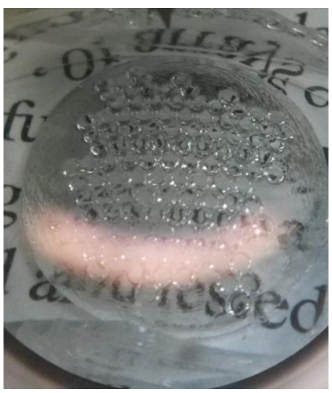


**Figure 12: Spherical Microlens**

The microlens array turned out especially well because of the small size of the microlens. This design would be exceedingly difficult if not impossible to create using other methods.

Nina Vaidya of the Solgaard group has devised an alternate process using a curable varnish. This method has proven acceptable for reflective optics and full details will be coming soon for the SNF Wiki. Additionally, there are certainly plenty of other techniques that can be explored, depending on the application.

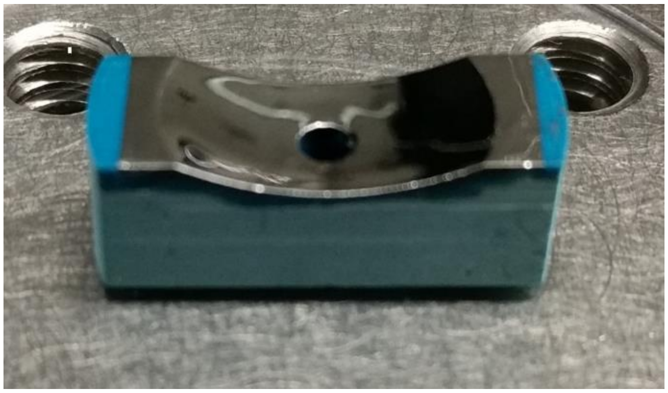


**Figure 13: Reflective Parabolic Mirror**

**4. Microfluidic Channels**

Another application for rapid prototyping of microfluidic devices is using 3D printed devices to replace standard photolithography clean room techniques. We detail two techniques using 3D printing that aimed to meet the following requirements: (1) Channels are clear so clear imaging into the device channel is possible, (2) Channel dimensions of 500-µm and below are used to match standard microfluidic size requirements, (3) Edges are straight with the goal of edge roughness being between 10-20-µm. Large edge variation may be acceptable based on the application and user requirements.

The first technique we propose (flipped channel without coating) is using 3D printed molds (material is wax) directly out of the printer described previously. We have found that the wax and the PDMS results in a semi-dull plastic finish that requires channels to be made with a flipped-channel orientation for clear imaging into the device. Edge variation is found to be on average greater than 50-µm. The second technique we propose (standard channel with parylene coating) follows the standard lithography process for microfluidic fabrication more closely. Channels are clear and the edges have a variation of ~10-µm. For both techniques we assessed channel widths of 500- and 250-µm. The 3D printer has shown the ability to achieve much smaller channels which can also be further tested in the future.

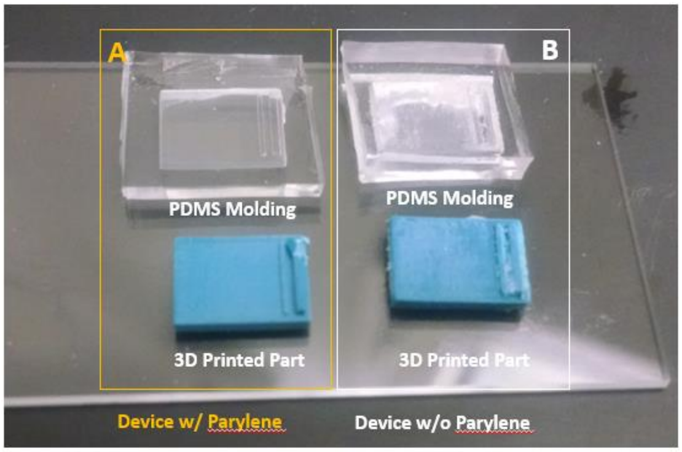



**Figure 24: (A) Channels and PDMS become very clear with Parylene Coating, (B) PDMS becomes cloudy when devices are cured without any coating. This results in the need to conduct a reverse channel fabrication.**

*Microfluidic Channels made from 3D Printed Molds without Coating*

The first technique that we propose is making microfluidic channels without any type of coating. The 3D printed devices are taken directly from the printer without any additional processing. It is recommended that this technique be used for an early stage rapid prototyping technique as the edge variation is large (> 50-µm). The fabrication flow diagram for this technique is shown in Fig 2 and detailed step-by-step fabrication details are found in Table 1.

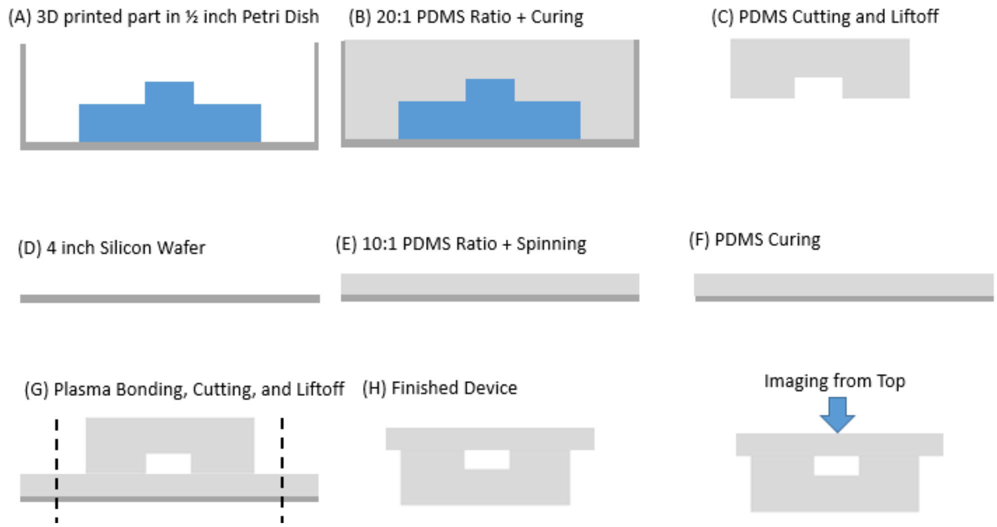



**Figure 15: Fabrication procedure for 3D molds without coating**

**Table 1: Fabrication details for microfluidic channel fabrication with 3D devices (without coating on 3D printed device)**

| | |
|---|---|
| **10:1 PDMS spun on 4 inch wafer** | |
| | 10g base + 1g cure mix and degas for 1 hour |
| | Spin 4 inch wafer, 10 s @ 500 rpm, 50 s @ 3000 rpm w/ PDMS |
| | Cure for 2 hours at 60C |
| **20:1 PDMS for 3D Printed Devices** | |
| | 20g base + 1g cure mix and degas for 1 hour |
| | Pour PDMS onto device in a ½ inch dish |
| | Cure for 2 hours at 60C |
| | Cut and peel device off of 3D printed part |
| | Spin device in glass dish w/ magnetic spinner in 10% IPA for 1 hour |
| | Let device air dry for 15 minutes |
| **Plasma Process Parameters** | |
| | Load samples |
| | Perform plasma exposure for 60 seconds |
| | Vent chamber |
| **Bonding** | |
| | Place PDMS device in conformal contact with PDMS on wafer |
| | Apply uniform pressure to PDMS for 10s |
| | Incubate the PDMS on PDMS at 60C for 15-30 minutes |
| | |

(A) Place the 3D printed part into a Petri Dish that fits the piece. It is essential that the edges of the dish are taller than the device when it is sitting at the bottom of the dish. If the 3D printed device is not flat, it is recommended that the device is mounted to the bottom of the dish using double sided tape. This ensures that PDMS will not come underneath the device and cause it to float upwards during the curing procedure.

(B) Use a 20:1 PDMS Ratio of the base and the curing agent. The ratio can be changed based on the properties the user desires for the PDMS. For example, using a larger quantity of the curing agent will result in the PDMS material (post-curing) to be more rigid. On the other hand, using a smaller quantity of the curing agent will result in the PDMS material to be stretcher. However, suing a smaller quantity of the curing agent will result in a longer curing time for the plastic to become solid.

(C) After the PDMS has cured, cut around the feature of interest on the 3D printed device and carefully peel the cured PDMS off of the printed device. If the device is not damaged during this process it can be reused based on the users' needs. At this point, take a microfluidic hole punch and make 2 holes in the locations in the channel that you'd like as "inlet" and "outlets." Place this device aside in another petri dish for temporary standby.

(D) Separately, take a 4 inch silicon wafer and clean it using standard cleaning processes

(E) Use a 10:1 PDMS Ratio and Spin the PDMS using the details in Table 1 to create a thin film coating on the device.

(F) Cure the wafer with the thin film of PDMS on it

(G) Take the device from part (C) and the wafer with the thin film of PDMS and activate both surfaces with plasma. Within 5 minutes of activating both surfaces with plasma, make sure to place the device onto the thin film of PDMS (if bonding is not done within 5 minutes, repeat the plasma. Gently press down the device onto the thin film for 60 seconds to ensure bonding between the two PDMS surfaces has been made. Cut around the device and carefully peel it off the silicon surface.

(H) Flip the device over and you have a finish channel! Imaging should be conducted from the top of the device and looking into the microfluidic channel.

Fig 3 shows an image of a completed channel edge with healthy RBC being flowed through the channel. Channel is successful since cells can be clearly imaged and the channel is fully sealed.

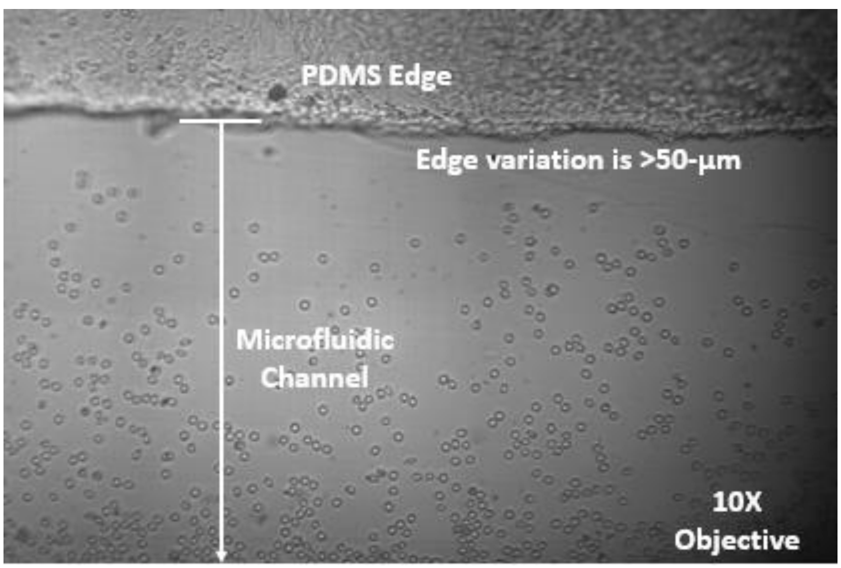



**Figure 17: Microfluidic channel edge with healthy red blood cells being flowed in channel**

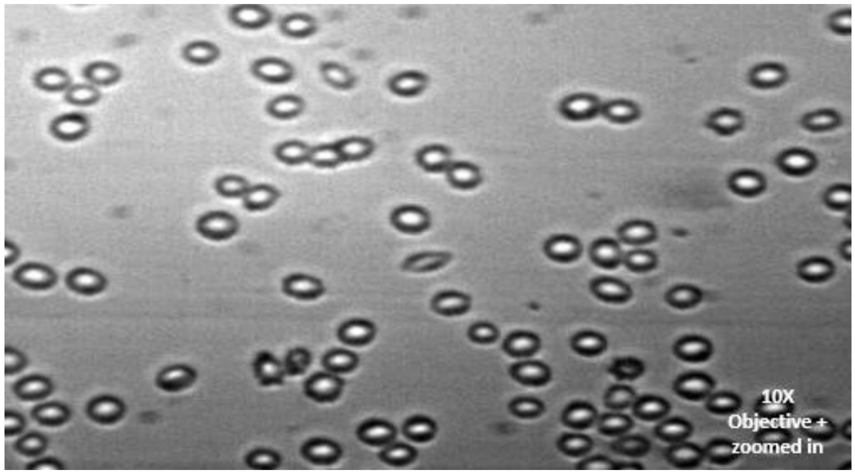



**Figure 18: Red Blood Cells can be clearly viewed in the channel**

*Microfluidic Channels made from 3D Printed Molds with Parylene Coating*

The second technique that we propose is making microfluidic channels with a thin layer of parylene deposited on the 3D printed part. This technique results in high quality microfluidic devices similar to those that arise from methods using photolithography. The edge variation is ~10-µm and the PDMS comes off clear from the mold. The fabrication flow diagram for this technique is shown in Fig 5 and detailed step-by-step fabrication details are found in Table 2.

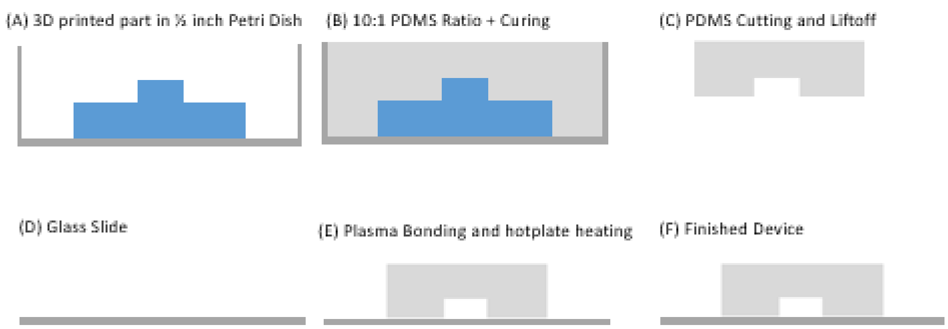



**Figure 19: Fabrication diagram for 3D printed devices with parylene coating**

(A) Place the 3D printed part (**that has parylene already deposited on it)** into a Petri Dish that fits the piece. It is essential that the edges of the dish are taller than the device when it is sitting at the bottom of the dish. If the 3D printed device is not flat, it is recommended that the device is mounted to the bottom of the dish using double sided tape. This ensures that PDMS will not come underneath the device and cause it to float upwards during the curing procedure.

(B) Use a 10:1 PDMS Ratio of the base and the curing agent. The ratio can be changed based on the properties the user desires for the PDMS. For example, using a larger quantity of the curing agent will result in the PDMS material (post-curing) to be more rigid. On the other hand, using a smaller quantity of the curing agent will result in the PDMS material to be stretcher. However, suing a smaller quantity of the curing agent will result in a longer curing time for the plastic to become solid.

(C) After the PDMS has cured, cut around the feature of interest on the 3D printed device and carefully peel the cured PDMS off of the printed device. Make sure to very carefully peel the PDMS off of the device. Parylene coating may be damaged during the peeling procedure. If the device is not damaged during this process it can be reused based on the users' needs. At this point, take a microfluidic hole punch and make 2 holes in the locations in the channel that you'd like as "inlet" and "outlets." Place this device aside in another petri dish for temporary standby.

(D) Prepare a glass slide for bonding by using compressed air to clean the surface (a silicon wafer can also be used if desired).

(E) Take the device from part (C) and the glass slide and activate both surfaces with plasma. Within 5 minutes of activating both surfaces with plasma, make sure to place the device onto the glass slide (if bonding is not done within 5 minutes, repeat the plasma. Gently press down the device onto the thin film for 60 seconds to ensure bonding between both surfaces.

(F) Microfluidic channel is ready for use!

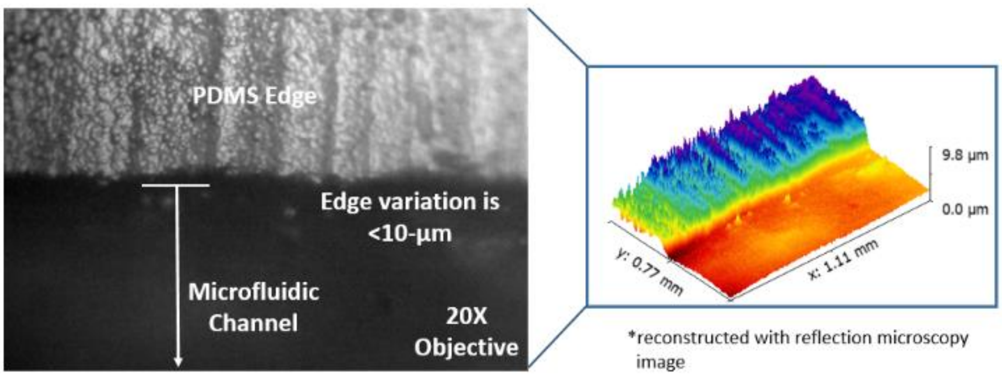



**Figure 20: PDMS Channel Edge viewed with Reflection Microscopy**

Fig 6 shows an image of a completed channel edge with a 20X objective lens using reflection microscopy. AFM results of a flat 3D printed device (shown in Fig 7) is calibrated with the flat top of the PDMS seen in Fig 6. This is conducted to help reconstruct a large area RMS roughness on the PDMS. The AFM RMS roughness of the flat 3D printed device was found to ~570 nm. Using the AFM←→Reflection Microscopy calibration we estimate the roughness of a large area of PDMS is ~1.3-µm. We did not find this roughness to be an issue during the PDMS and glass slide bonding process. The channel remained sealed for several uses (tested up to 10 uses) for imaging red blood cells. Red blood cells in channel are found in Figure 8 and show that the channel is able to achieve clear imaging of the cells.

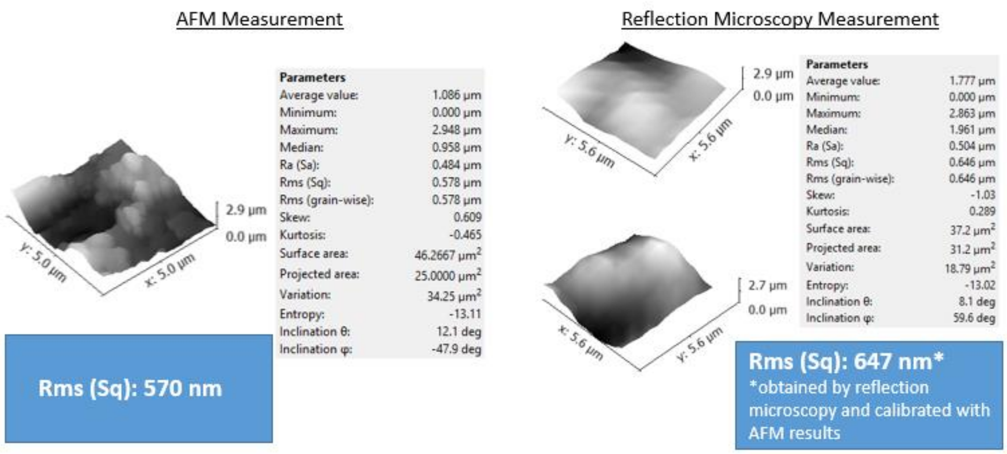



**Figure 21: AFM to Reflection Microscopy Measurement Calibration for RMS surface roughness**

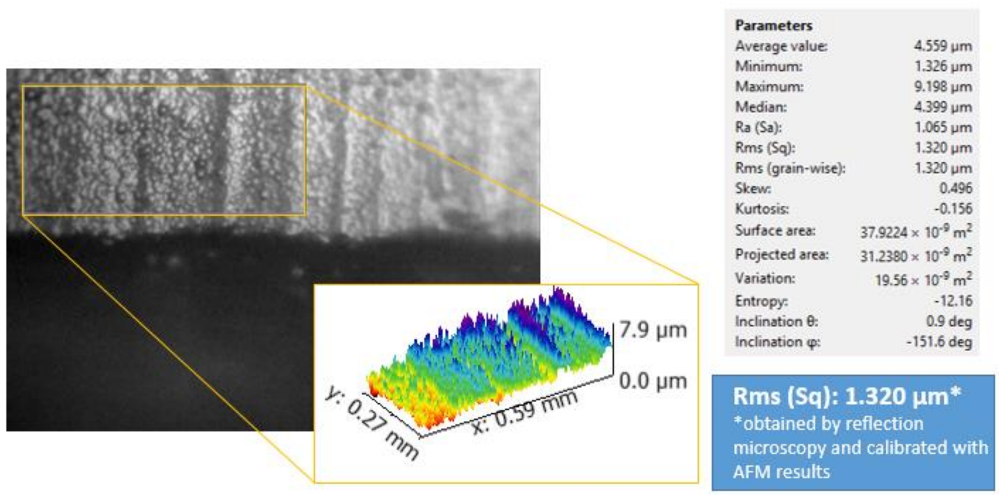



**Figure 22: Large area RMS roughness estimation using reflection microscopy**

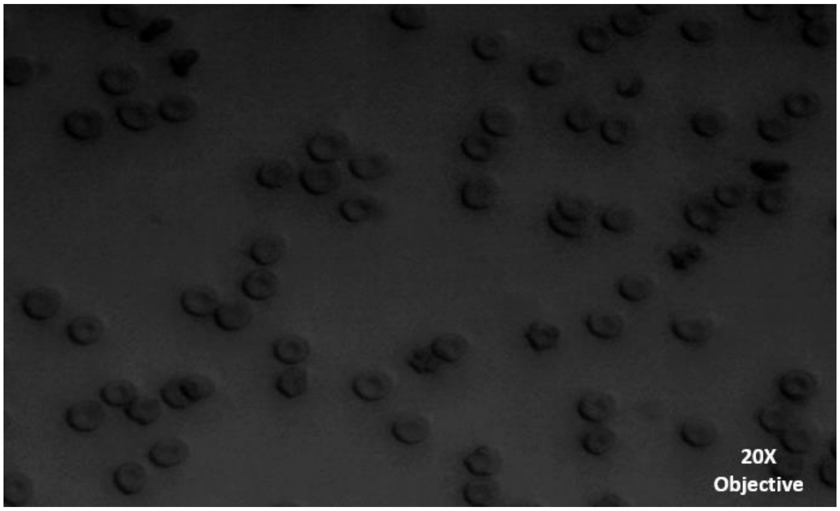



**Figure 23: Red Blood Cells viewed clearly in the microfluidic channel**

| | |
|---|---|
| **Parylene Coating on 3D Printed Devices** | PDS 2010 LABCOTER™ 2 Parylene Deposition System |
| | 5g of Parylene Dimer is used for the thin film deposition (step 3 in instructions) |
| | For complete instructions, please refer to SNF website on the Parylene Coater: https://snf.stanford.edu/SNF/equipment/nSiL/Parylene_Coater/PDS_2010_LABCOTER_Parylene |
| | We have also included the short version of the instructions in Appendix A |
| **10:1 PDMS for 3D Printed Devices** | |
| | 10g base + 1g cure mix and degas for 1 hour |
| | Pour PDMS onto device in a ½ inch dish |
| | Cure for 2 hours at 60C |
| | Cut and peel device off of 3D printed device |
| | Let device air dry for 15 minutes |
| **Glass Slide** | |
| | Use compressed air to remove any residue on glass slide |
| | Silicon wafer can also be used, do necessary cleaning procedures to clean the wafer to remove residue |
| **Plasma Process Parameters** | |
| | Adjust vacuum to read 2.16 ± 0.02 Torr |
| | Power set to 30 W (0.030 kW) |
| | Plasma distributing plate in place |
| **Plasma Protocol** | |
| | Prior to loading samples, perform run on an empty vacuum chamber to properly set power supply knob position for desired process parameters |
| | Load samples (PDMS mold and glass slide) |
| | Perform plasma exposure for 60 seconds |
| | Vent chamber |
| **Bonding** | |
| | Place PDMS device in conformal contact with glass slide |
| | Apply gentle but uniform pressure to PDMS for 10s |
| | Incubate PDMS on glass at 60C overnight for best bonding results (quick incubations for 2 hours can be done as well) |

## 5. Future Work

In this work we have outlined the capabilities of 3D printing and the Solidscape Studio. In addition, we have showed two specific applications where rapid and cheap prototyping of 3D printing can benefit the field. Future work is necessary to further advance both custom optics design and microfluidic channels. Further smoothing processes are required for 3D devices to be used a molds for high quality optical devices. In addition, for microfluidics it is necessary to further push the printer resolution to achieve channels below 250-μm in addition to translating the printer to 3D microfluidic designs. There are further applications to be investigated with the Solidscape Studio as well. Such applications may lie in reflective optics, inductors, and MEMs.

# Appendix A:

## PDS 2010 LABCOATER 2 Parylene Deposition System

***For 3D Printed Parts, 5-15g of Parylene dimer was used (step 3), 4 drops A-174 Silane was applied to chamber walls after putting in the parts and before pumping down.***

Reference:
https://snf.stanford.edu/SNF/equipment/nSiL/Parylene_Coater/PDS_2010_LABCOTER_Parylene

1. Enable equipment in the badger and fill out the log book.

2. Vent chamber (Vacuum to **VENT**), inspect the cleanness of the chamber and cold trap. Follow section 8.5.9 and 9.2 to clean the old trap and chamber if necessary.

3. Prepare an aluminum foil boat and fill with appropriate quantity of Parylene dimer. Record final parylene weight in logbook.

    a. Cut foil into a rectangle about 3.5 x 6 inches;

    b. Curl the foil around the cylindrical former to form a "boat".

4. Load Parylene dimer/boat. Close vaporizer door. The Parylene dimer/boat should be just inside the vaporizer, not close to the furnace.

    o Load samples with a bare silicon wafer or piece for thickness characterization.

5. While holding cold trap thimble, turn Vacuum to **VACUUM.**

6. Wait for pressure going below 200 mT. then turn on the chiller.

7. **Wait 10-15 minutes** for chiller pump to warm up if starting from cold; you should see the green light is on near the chiller switch.

8. Verify all the setpoints are in correct values.

9. Press the green **Process START/STEOP button** to start the PLC program in auto mode

10. Turn Furnace/Chamber Gauge control switch from **DISABLE** to **ENABLE.**

11. Turn Vaporizer control switch form **DISABLE** to **ENABLE**.

12. The deposition process takes at least 30mins or several hours to complete, depending on the dimer weight put in the boat. You should make sure the furnace temp is approaching the setpoint before you leave for a long run.

13. Once completed, the green **Process Start/Stop light** will **flash** and all the heaters are turned off automatically. Press Process Start/Stop button and green light will turn off.

14. Toggle Furnace/Chamber Gauge to **DISABLE** and Vaporizer to **DISABLE**. **Turn OFF Chiller** and **WAIT 60 MINUTES** (for heaters to cool down and cold trap to warm up).

15. To vent chamber, set Vacuum to VENT. Verify tool at atmosphere by checking cold trap thimble. Lift Lid, unload Samples and remove the dimer aluminum foil boat.

16. Inspect and clean the tool, particularly the cold trap thimble, chamber lid and O-ring with steps below:

    a. Put on a second pair of gloves over the first pair;

    b. Rinse the cold trap with Micro90 2% in DI Water;

    c. Scrape off the Parylene deposit with a Soft Scrub pad;

    d. Wipe lightly with a lint free cloth - leaving the trap slightly moist;

e. Gently wipe off visible particles inside the chamber, lid and o-ring with cleanroom wipes and slight IPA solution;

f. Change gloves after this operation to prevent tool or clean room contamination from electrostatic Parylene particles. (i.e. Pull of the second pair of gloves).

17. Replace the Lid. Set Vacuum to VACUUM to pump down.

18. Shutdown. Verify Chiller Off, Furnace/Chamber Gauge to DISABLE, Vaporizer to DISABLE, process START/Stop light is Off; when the chamber pressure is below 100mT, you can turn the Vacuum position to HOLD.

19. Characterize the deposited film thickness, and fill out logbook completely.

20. Disable the badger, report in the badger and notify SNF Lab Staff of any tool or process issues or the chamber inside wall is starting to peel off.

21. Clean the area. Enjoy your work!

# Appendix B:

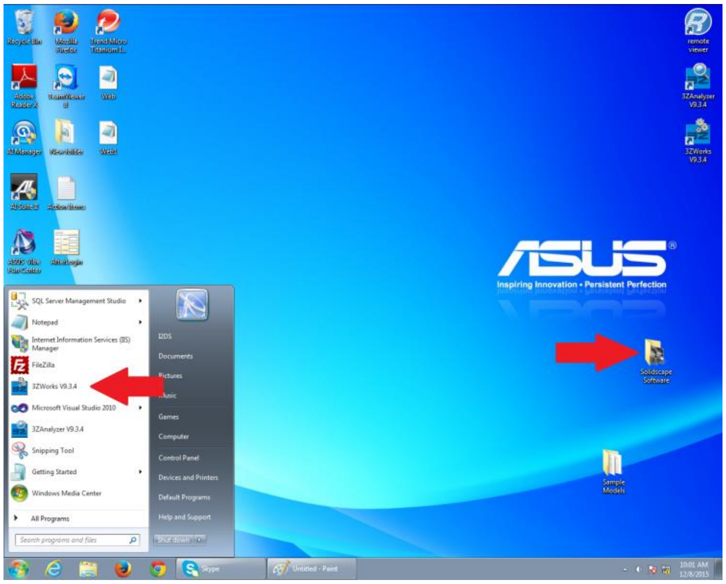
## INSTRUCTIONS FOR USING THE SOLIDSCAPE STUDIO AND 3ZWORKS SOFTWARE

*Summary for using Solidscape Studio*

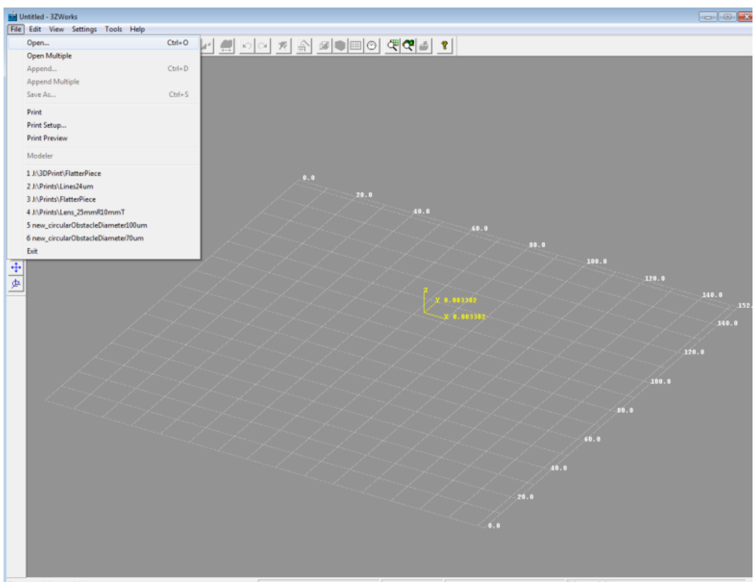
1. Prepare CAD file of device and export as .STL format
2. Open .STL in 3ZWorks
    a. Rotate so that flattest part is on bottom
    b. Scale works okay, most adjustments should be made in CAD software
3. Append additional devices or copies as desired
4. Use WIZARD or FILL button to prepare .3zs file and
    a. WIZARD is an easy way to prepare multiple slice ranges
    b. FILL is for more advanced fill options
5. Enable on Badger
6. Transfer .3zs file using network transfer in lab or USB stick
    a. The Studio will choose newest .3zs file on USB root drive.
    b. Test USB stick when printer is not in use to make sure it is compatible
    c. Make sure your desired .3zs file is displayed on touch screen before starting
7. Make sure build plate is in place
    a. Press FINALIZE if previous printer forgot to do so
    b. Otherwise, pull latch to open lid.
    c. Replace build plate by lining the holes to the nubs and slide tabs forward.
8. Press START JOB
    a. Touch screen will have estimated start and finish times and progress bar
9. Press FINALIZE when print is finished
    a. Lid will open automatically
    b. Remove build plate by sliding tabs back and grabbing by the sides\
10. Place build plate on hot plate
    a. Turn on hot plate and make sure it is set to 100-1100C
    b. DO NOT GO OVER 1100C. THIS MAY BURN THE CALIBRATION BAR CODE
    c. Let heat for ~15-20 minutes.
11. While hot plate is heating, turn on dewaxing crock pot.
    a. Press power button
    b. Press probe
    c. If LCD shows HIGH, hit enter
    d. Use arrows to set temperature to 1400F, hit Enter
    e. Crock pot should beep and start warming up
12. Disable STUDIO but do not turn off the printer
13. Remove parts from build plate and transfer to dewaxing solution
    a. Use plastic scraper or other thin object to pry off pieces
    b. Be careful not to scratch build plate
    c. Turn off hot plate and allow build plate to cool down
14. Dewax for at least 2 hours
    a. Part will be done when there is no red or transparent goopy material
15. Retrieve parts in strainer and let dry on cleanroom wipes

*Preparing a .3zs file in 3ZWorks*

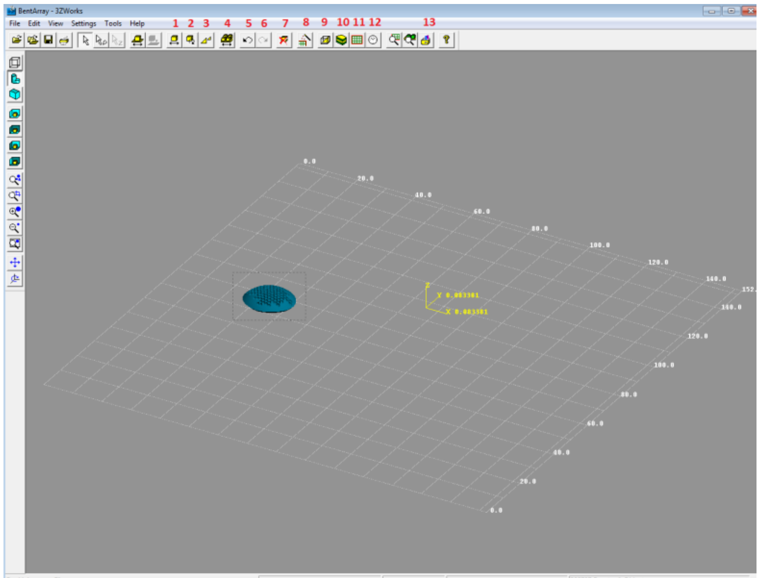
Log on to the computer next to the Solidscape Studio.



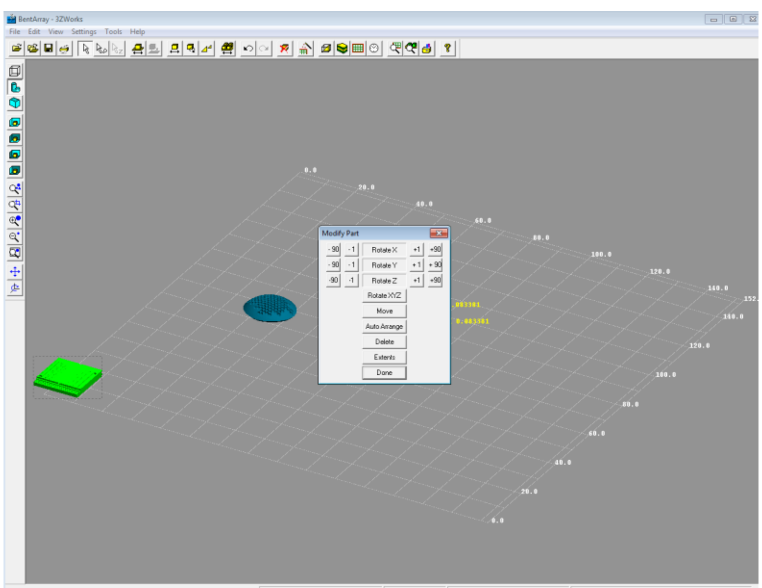

Copy the Solidworks Software folder (right) onto a USB stick if you wish to install the 3ZWorks and 3ZAnalyzer software on a home computer. Otherwise, open 3ZWorks (left).



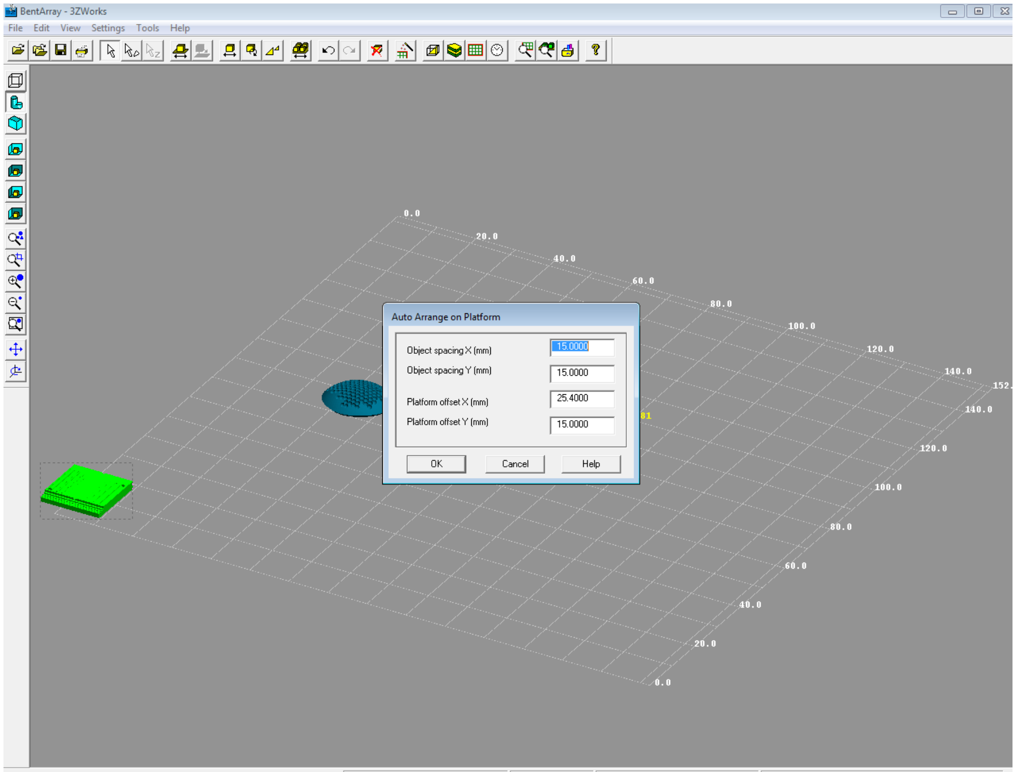

Select Open to add an .stl file to the build area. Open Multiple will open multiple copies of the same .stl file. If there are already pieces in the build area, Append or Append multiple will add additional, different .stl files.



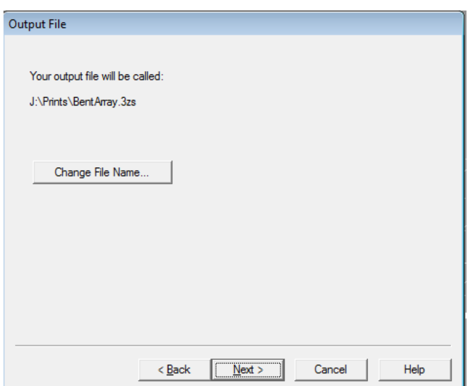

1. Move XYZ: Move selected objects in XYZ
2. Rotate: Rotate selected objects in XYZ
3. Scale: Scales selected objects in XYZ
4. Auto Arrange: Automatically arrange objects on grid
5. Undo
6. Redo
7. Delete: Removes selected objects
8. Wizard: Prepare .3zs file with slice ranges and option of adding extra support
9. Extents: How big your stuff is
10. Slice Ranges: Print ranges of layers with different resolutions.
11. Fill: Options for changing behavior of support material.
12. Time Estimate
13. Remote Monitor



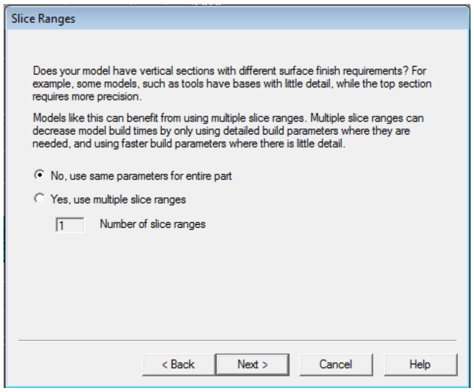
Double clicking an object will bring up this menu for that specific object. Useful for quickly rotating pieces that have alternate front plane designations by 90 degrees.



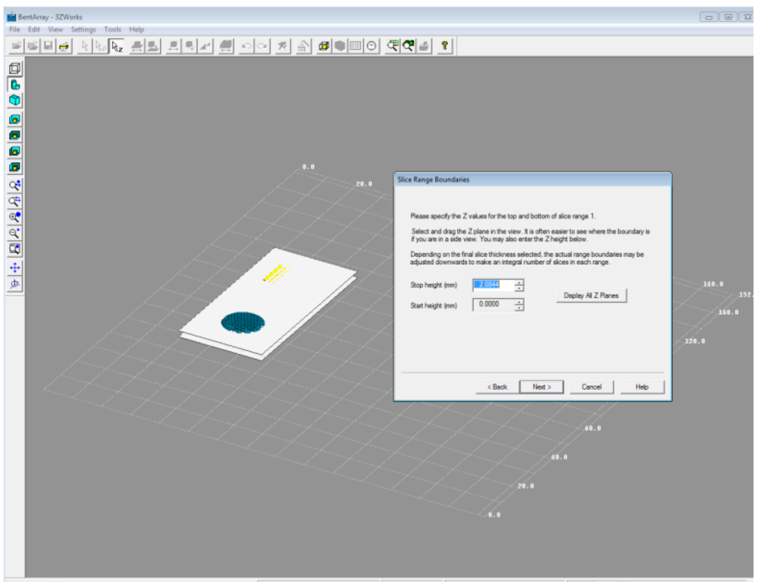

Make sure to auto arrange if you have multiple pieces in the build area. Spacing X-Y will dictate how far apart objects are from each other, while Offset X-Y will move objects away from edges. Do not overfill the build area.



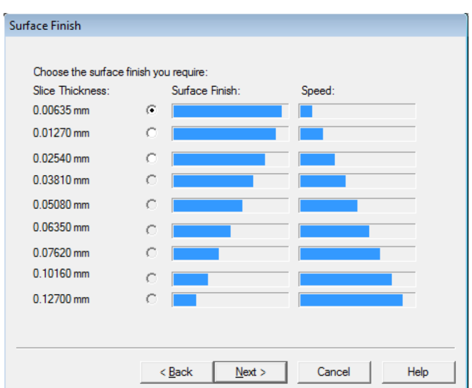

When creating a .3zs file, such as through the Wizard button, the file name will automatically be the name of the first .stl file opened, and it will save to the same directory.



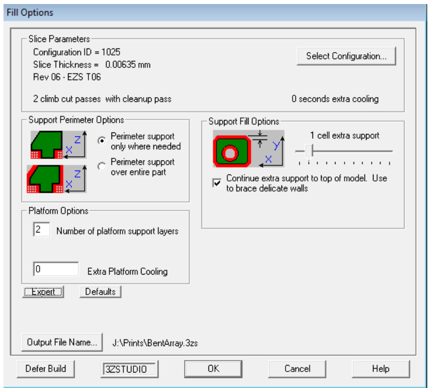

Selecting Yes, use multiple slice ranges while using the Wizard (or pressing the Slice Ranges buton), will begin process of creating multiple ranges over which layers will be printed at different resolutions (6,12 or 24 um).



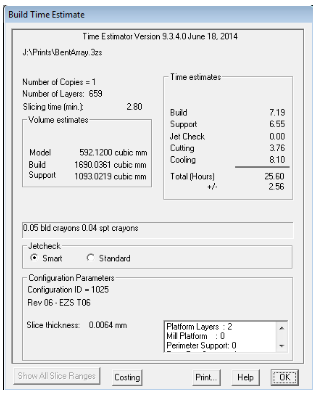

Choosing a slice range height can be done by looking at your CAD design or using the white sheets to eyeball your desired ranges.



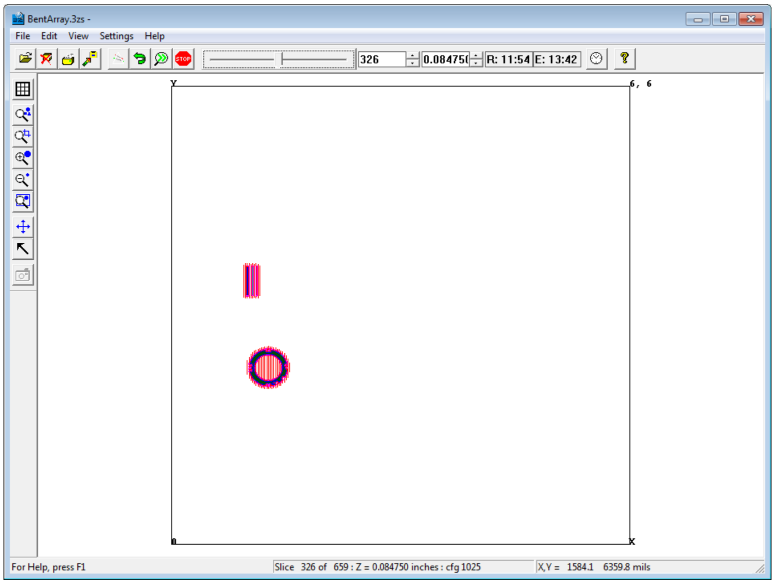
For any range, choose a layer thickness using any of the radial buttons. Only the first 3 should be selectable. Build time increases approximately linearly with decreasing resolution (6um will take 4x as long as 24 um).



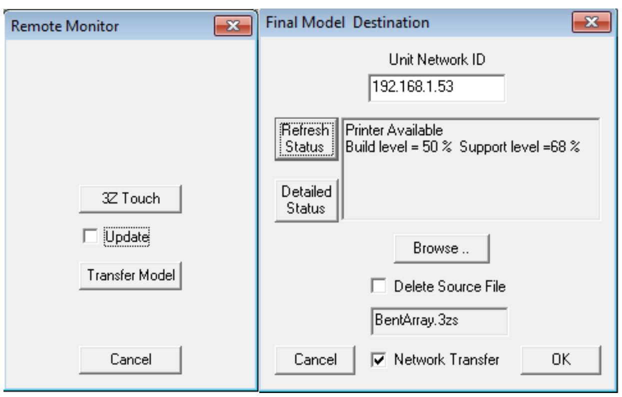

The Fill button allows options for the support material not available using the Wizard. Use additional platform support layers for very thin pieces.




Hitting the time estimate button or finishing the fill or wizard will bring up an estimate for how long the build will take. Calibrations and warming up the wax tanks can cause the build to take longer than estimated. Hitting ok again will bring up a 3ZAnalyzer of the .3zs file generated.

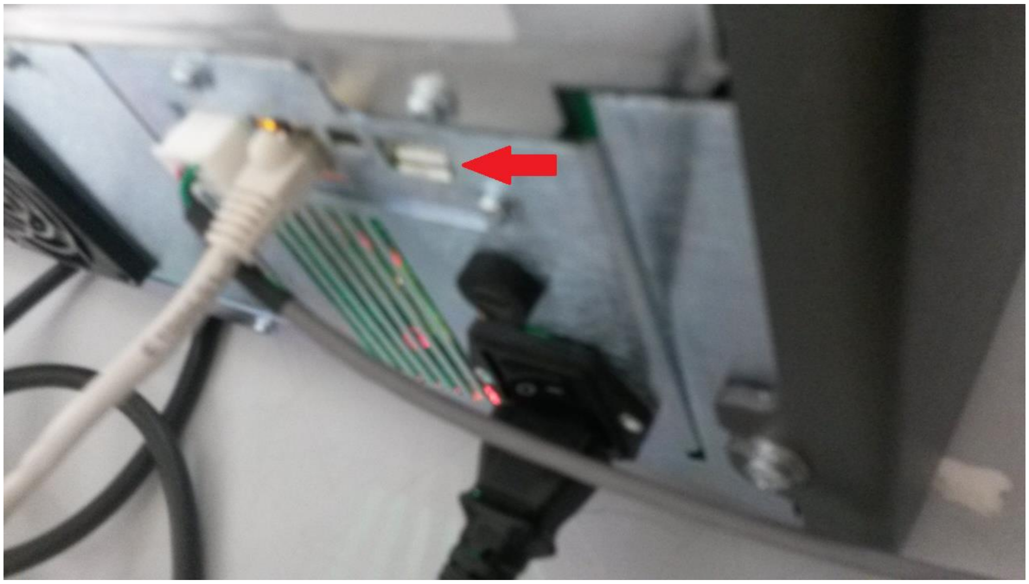



The 3ZAnalyzer software allows you to look at support (red) and model (green/blue) material used for each layer individually. Take a quick look through to make sure there are no horrible, obvious errors.

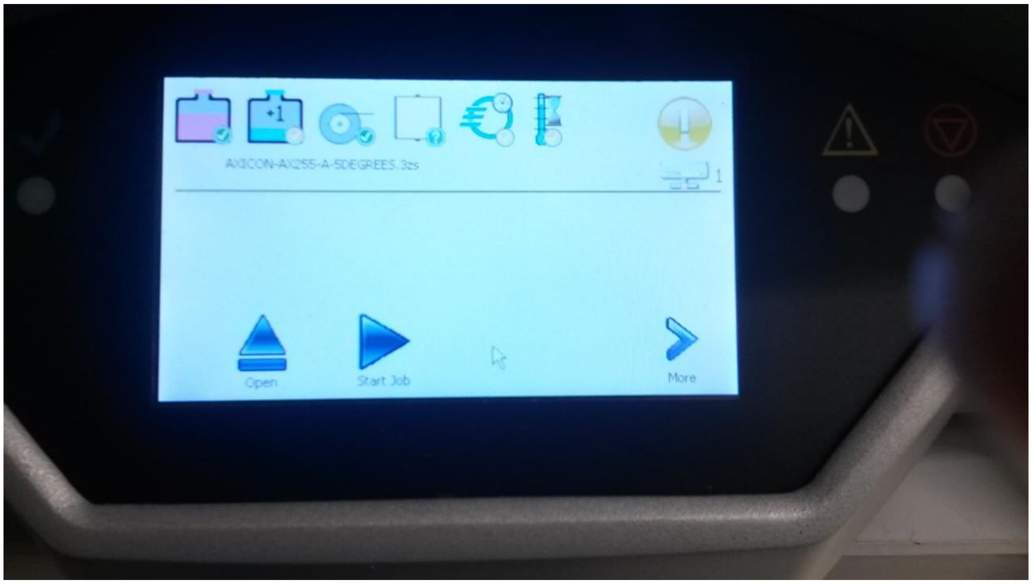



Selecting Transfer Model in the remote monitor screen will give you the option of saving a .3zs file or transferring it over the network. If working at home or the network in lab is not working, make sure a copy of the .3zs file you want to use is the most recent .3zs file in the root directory of your USB stick.

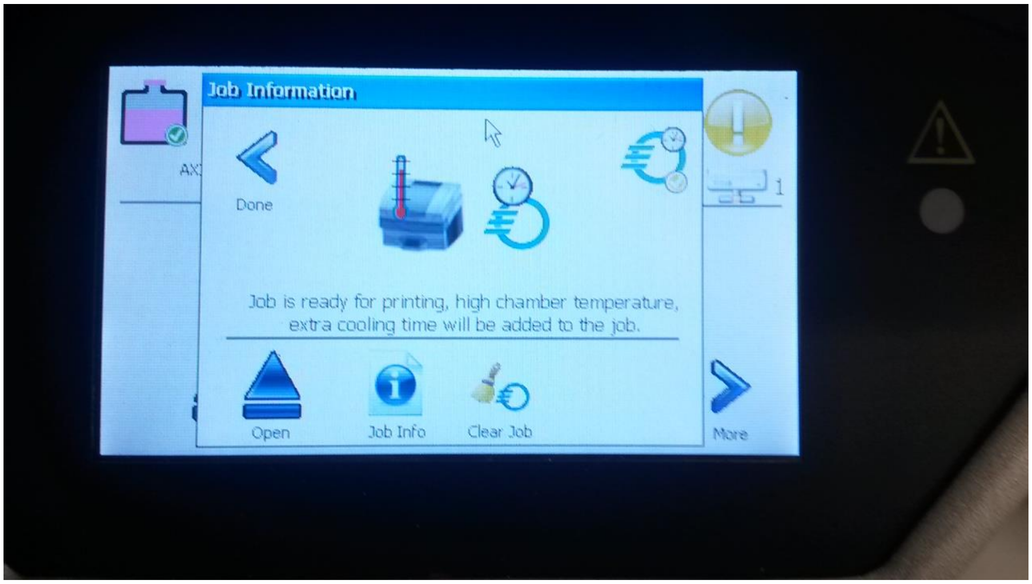
*Using the Solidscape Studio*



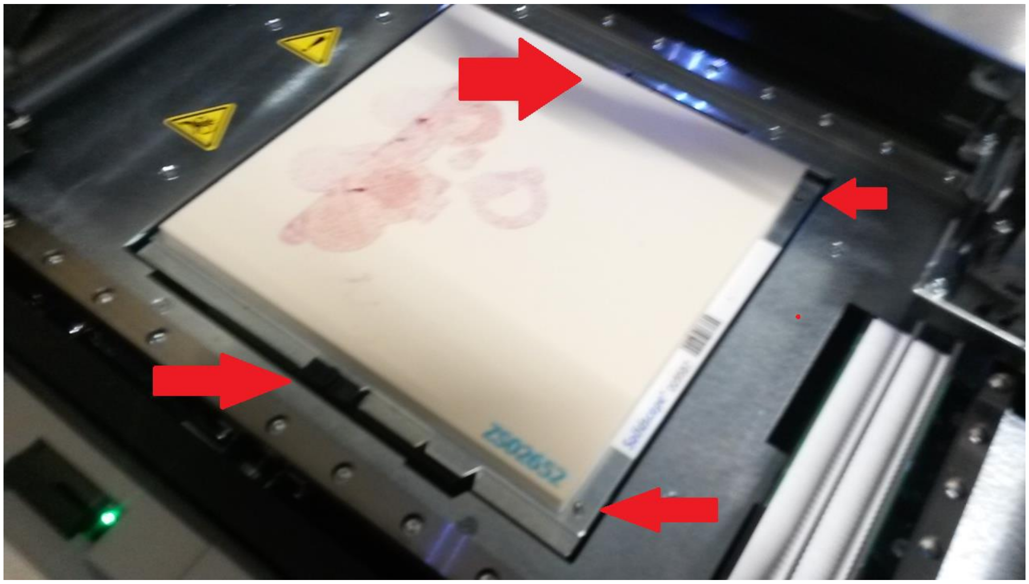
The USB slot is on the back of the printer above the power switch if there is no extension to the front of the printer.  Upon inserting a USB stick, the printer should automatically download the newest .3zs file on the root directory.  If it does not, it may be necessary to clear whatever current job is displayed.



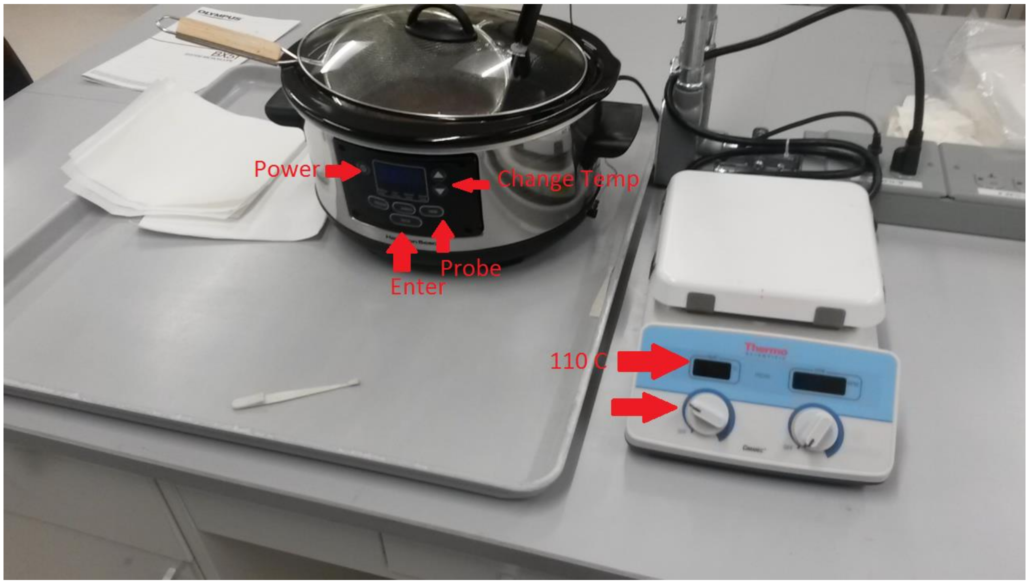

3Z Touch, the printers touch screen.  For basic users, the three important buttons are Open, which opens the lid, Start Job, which will start whatever .3zs job file that is listed at the top, and the Blue Circle with Three Stripes (Solidscape Icon) button opens the Job Information screen.  When done printing, the Start Job button will become Finalize.  Pressing this button will open the lid, move the head off to the side, and ready the printer for the next job file.




The Job Information screen will give information about the job, including any additional time for tank heating and chamber cooling. The Clear Job button will delete the currently loaded .3zs file and load the newest one on any inserted USB sticks.



When your job is finished, press the Finalize button and remove the build plate by sliding the two tabs left as in the picture (left arrows). When replacing the build plate, use the holes on the build plate by the barcode to align to the nubs in the printer (right arrows) and then sliding the black tabs to the right.




Put the build plate on the hot plate. Turn the hot plate on and make sure it is set to no more than $110^{o}$C and no less than $100^{0}$C. While the hot plate is warming the build plate, turn the crock pot on by pressing the power button. Press Prove, then hit enter when it says HIGH, set the temperature to $140^{o}$F and hit enter again. The crock pot should beep and then begin heating the mineral oil bath to the desired temperature. After about 20 minutes the build plate should be warm enough to extract the devices. Plop the devices into the strainer in the mineral oil and come back a couple hours later. Turn off the hot plate and allow the build plate to cool. Devices with small holes may take longer, shake the strainer once in a while to agitate the material in the holes. When there is no red material or transparent goopy residue left, shake the strainer in the oil and then remove it and allow it to drip a little. Place your devices onto a cleanroom sheet and turn off the crock pot. Your parts should quickly dry and be ready to use.