3D Printing Methods in Microfluidics

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Introduction

Microfluidics are valuable to biochemical research, broadly used in drug testing, individual cell assays, synthetic tissue research, and much more. Microfluidics utilize microfluidic devices, which have networks of small channels and tubes that enable controlled mixing, splitting, and manipulation of nanoliter volumes of liquids. Their appeal lies in the ability to observe cellular behavior on an individual scale while conserving resources. As the field advances, such devices can make many laboratory procedures easier and more efficient.

The current manufacturing process for microfluidic devices is exhaustive, prone to failure, and time and resource-consuming. The typical timeline for a lab such as ours to make a microfluidic device takes weeks and is costly in terms of time, labor, and funding: an expense many labs simply cannot afford.

We aim to create a manufacturing process that combines 3D printing and traditional techniques to create products that cost less in time and resources while opening the doors to more novel device designs that have typically been restricted to planar and rigidly nodal layouts.

The preliminary process of our research was composed of a thorough review of several relevant studies concerning the calibration and modification of 3D printers for the use of microfluidic device manufacturing. This study is ongoing, and we are currently prototyping a manufacturing process for a cell trap that would require the unique structuring afforded by 3D printing and the precision that can be achieved through traditional methods. The results we have collected so far indicate 3D printing as a viable manufacturing method to include in traditional techniques, as every print comes closer to the level of precision PDMS offers.

Issues we have encountered so far have been linked to the unfavorable thermal properties of the material we have been using for most prototyping, where the melting point is far too low to be effective for further research and application. The material solubility is also incompatible with our cleaning and sanitization processes.

Future exploration of this research will expand into high-complexity designs that are unlikely with solely current production methods, and manufacturing process optimization based on the methods of this research.

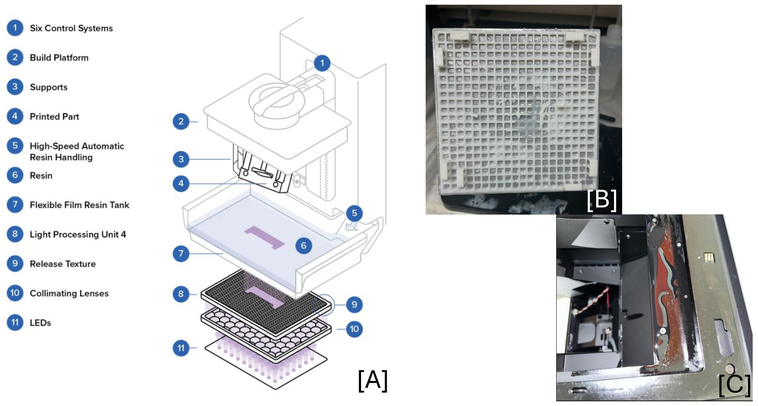
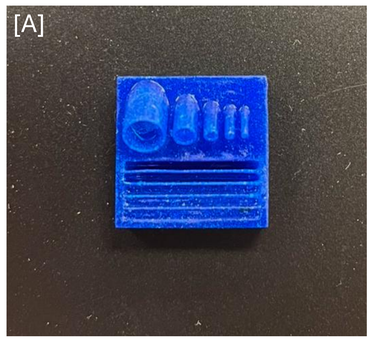


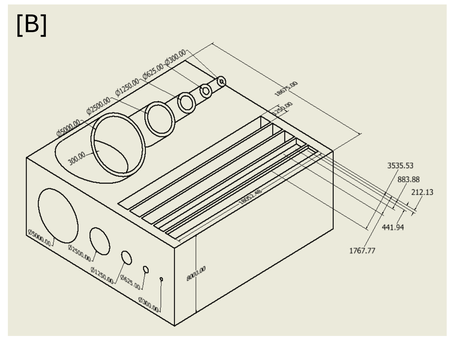
Figure 1 details the process of troubleshooting our printer and finding optimization opportunities. [A] is an image taken from FormLabs of the anatomy of an SLA printer. [B] is an image of a lattice with overhangs we had printed to see which areas were still problematic after thoroughly cleaning. [C] is an image of where the optical window sits, where we can see resin has collected.

References

Methods and Materials

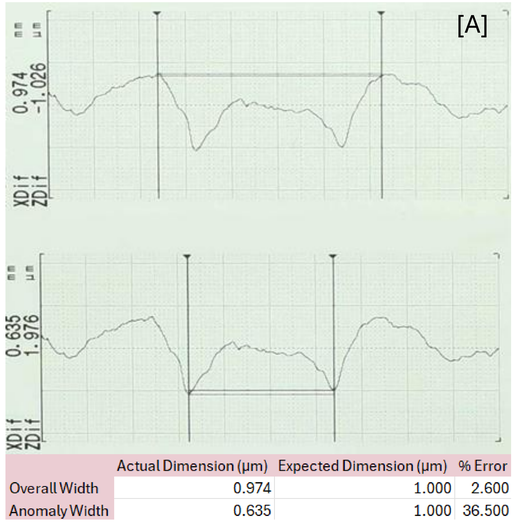
- Formlabs 2 SLA printer
- Formlabs Clear Cast Resin
- Formlabs Castable Wax 40 Resin
- Formlabs Tough 1500 Resin
- Profilometer
- Autodesk Inventor Professional 2024
- polydimethylsiloxane (PDMS) microfluidic device
- Light microscope



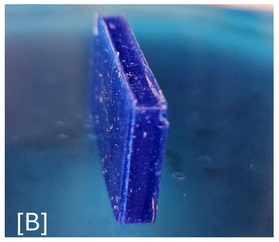


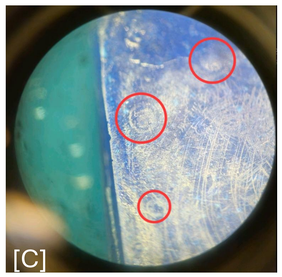
The Channel Optimizing Print

- **Goals:** Initially, we reviewed several relevant papers to find trends among optimal conditions for prototyping, including print orientation, material selection or fabrication, printer settings, testing software, etcetera (Figure 2A). We wanted to test the findings for print angle precision (Figure 2B). Several factors were tested using this print:
  - Ability to print increasingly smaller channels at an angle
  - Ability to print increasingly smaller channels through a structure
  - Precision of channel depth
  - Limits of thin structures extruded at varying heights
- **Methods:** Visual analysis of the larger features and use of several gauges of needles through channels to find if they were fully formed.
- **Observations:** The 300-micron channel was not fully formed at an angle, and the 625-micron channel was not fully formed through the structure. The channels were all successfully developed, but we noticed upon further observation that the border between the deepest channels in Figure 3A warped. We attributed this to the thermal properties of the material.



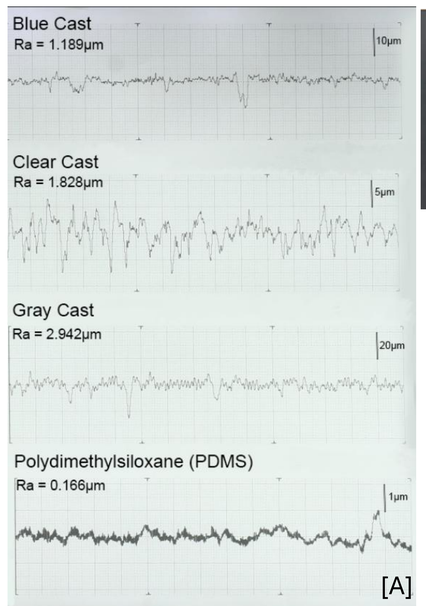
	Actual Dimension (µm)	Expected Dimension (µm)	% Error
Overall Width	0.974	1.000	2.600
Anomaly Width	0.635	1.000	36.500

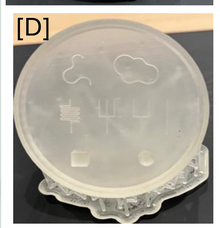


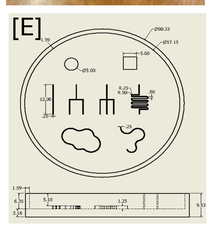


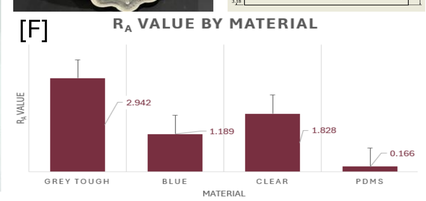
The Extrusion Print

- **Goals:** We wanted to find the accuracy of extremely small extruded features that push the limits of the 3D printer's capabilities.
- **Methods:** We used a microscope to identify visible features (Figure 3C) and used a profilometer on these areas to observe the recess depths on a micron scale. We then compared this to the schematics of the print (Figure 3A).
- **Observations:** There were some interesting anomalies in the print, which we have attributed to the thermal properties of the material we were working with (Figure 3A). We also noticed a film that had formed over the surface of the print, which had slightly warped the shape (Figure 3B).







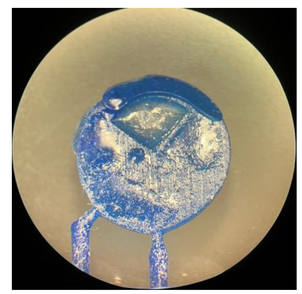


The "Petri Dish" Print

- **Goals:** Named after its similar appearance to a cell culture petri dish, this print tests two characteristics:
  - The ability of the printer to accurately print common designs used in microfluidic devices (Figure 4E).
  - The capabilities of the three available materials in terms of print clarity, material roughness, and tendency to warp.
- **Methods:** The R_a value (roughness) of the materials was assessed by a profilometer (Figure 4A) where we compared the R_a value between the blue resin at 0.025 mm layer thickness (Figure 4C), clear resin at 0.025 mm layer thickness (Figure 4D), the gray tough resin at 0.05 mm layer thickness (Figure 4B), and a Polydimethylsiloxane (PDMS) sample as a control.
- **Observations:** The blue material had the lowest R_a value, but we have discarded it as a viable material due to its tendency to warp features and difficulty to clean. The clear and gray resins had much higher clarity compared to the blue resin and had a reasonably low R_a value (Figure 4F).
  - Note that the R_a values of the materials are significantly different from that of the PDMS; however, previous studies[5] have found such differences to still work as needed.

Future Considerations

- Our next steps will be to apply our findings in prototyping a cell trap based on the proposed designs of FSU alum Dr. Cindy Duong[3] optimized for the housing of free fatty acids.
- **Goals:** Explore the 3D capabilities of the printer when creating features on more than one plane.
- **Methods:** Using COMSOL, we will simulate the fluid dynamics of the device to see if they are still optimal. It should be noted that we scaled her design to the abilities of our printer.



Conclusions

- This is an ongoing project, and the clear resin printed at a 25µm layer thickness has been most successful so far. The blue resin has been problematic due to its thermal properties, and its use in our research will be discontinued.
- Prototyping has been successful due to the investigation of previous studies and their strategies. Any errors have been attributed to material properties.
- Progress in biochemical research would be propelled by easy access to microfluidic devices that have been manufactured using methods that are less costly and labor-intensive. This also opens the door for more complex and novel designs.
- In terms of progress, we have high hopes for viable prototypes that are compatible with materials used in traditional manufacturing methods.