PARALLEL

MANUFACTURING BASICS

for microfluidic devices

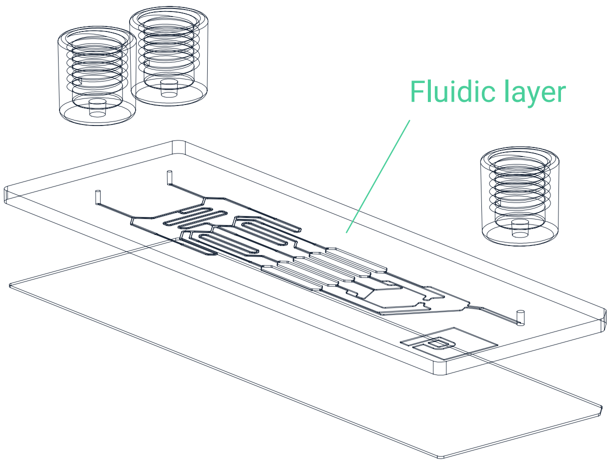

Figure 1: Device layout

Manufacturing basics for microfluidic devices

Microfluidic technologies have led to game-changing advances in drug discovery, genomics, precision medicine, and diagnostics. However, a major hurdle in microfluidic development lies in the manufacturing of micro-scale devices. There are several different processes available with different strengths, weaknesses, and underlying principles that should be considered before choosing a strategy.

Microfeature forming methods

One of the core elements in microfluidic manufacturing is the process of forming the fluidic layer (Figure 1), or the body of the device, which contains the channels and microfeatures used to manipulate fluids. There are several manufacturing techniques to fabricate fluidic layers that can be broadly classified into **Prototype** processes and **Production** processes.

Prototype processes

Polydimethylsiloxane (PDMS) casting

The most common prototyping technique used in academic research is to fabricate fluidic layers by casting uncured polydimethylsiloxane (PDMS), a clear silicone rubber, onto a mold. The cured rubber can then be removed, leaving the imprint of the microfeatures in the silicone rubber body. This technique is relatively low cost and can yield devices with impressive microfeature geometry and accuracy by using photolithography techniques to create the mold. Much of the early microfluidic research focused on PDMS devices, and thus it has become one of the most prolific prototyping methods in the industry. However, PDMS is a material with a few potentially problematic properties, including high gas permeability and absorption of small molecules. Also, it is a difficult manufacturing technique to transition to high volume production.

Subtractive manufacturing

Alternatively, subtractive techniques can be used to form microfeatures in thermoplastics by removing material from a starting block or blank. Some examples of subtractive methods include micromilling and laser machining. Both techniques allow the use of thermoplastic materials, which are generally much more appropriate for high volume manufacturing, but each has its own limitations. Milling channels and features below 200 microns in cross section becomes quite difficult, and the rough surface finish and burrs leftover from the machining process can create challenges with flow and imaging properties. Laser machining is only compatible with a small subset of thermoplastics, and can suffer from batch to batch repeatability issues and lack of control in microfeature cross section.

Additive manufacturing

Additive manufacturing via 3D printing has become extremely useful in many product development processes. But, in microfluidic projects, 3D printed prototypes are generally limited in resolution, have poor control over surfaces, and are made from materials with chemistries that can compromise assays and imaging methods. Like PDMS casting, 3D printing is also not a technique that effectively scales for high volume manufacturing.

Production processes

Production techniques are typically designed to maximize part to part repeatability. Typically these methods require expensive tooling and process optimization, with lead times that are generally measured in months.

Etched glass

Glass is a useful material for microfluidic applications because of its excellent optical properties and solvent compatibility. In this process, photolithography is used to place a very accurate mask on a glass wafer, then the wafer is exposed to a process that removes material from the unmasked areas of the substrate. “Wet etching” typically uses hydrofluoric acid (nasty stuff) to etch away the unmasked regions. Since the acid eats away at the glass isotropically, the etching effect removes material in all directions at a similar rate, including underneath the masked layer. High aspect ratio features are not possible to form by this method.

Alternatively, “dry etching” uses a plasma to anisotropically remove material, allowing for high aspect ratio features. Both processes can be good choices when maximum accuracy or glass is required, but they suffer from long lead times and expensive unit costs compared to other processes.

Hot embossing

In hot embossing, a heated tool consisting of proud microfeatures is pressed into the thermoplastic at high pressures, transferring the features into the surface of the part. The tool can be created by a variety of processes such as milling or photolithography-based processes. While embossing can produce accurate microfeatures cost effectively at scale, it can only create a limited set of microfeatures. It generally isn’t possible to create features with larger cross sections, non-planar geometries, or through holes.

Microinjection molding

Microinjection molding is the most widely adopted and successful process for producing accurate microfluidic features at high volumes. The incredibly low cycle times, functional thermoplastic materials, and high part-to-part accuracy makes it a desirable process to create features in microfluidic products. The main drawback of microinjection molding is that the mold tooling can easily cost more than $50,000 and take a few months for fabrication and process optimization. It’s a wonderful technique for high volume production, but it’s critical to make sure that a design is functional before scaling up to the injection molding process.

Current prototyping techniques are not representative of micro injection molding!

The problem

The design parameters for existing prototyping methods are wildly different from those of injection molding. This can lead to outcomes where a device design might be functional in a prototype process, but will fail when transitioned to production. Or, alternatively a device that would work in a production environment is discounted because it's not feasible in existing prototype processes.

Our Solution

At Parallel, we offer a new option for prototyping microfluidic devices with a process we call **transition molding**. Transition molding is similar to injection molding but optimized for the lower volumes and higher turnaround times required during the development process. That means when you design your devices for transition molding, you're also designing for injection molding!

Fundamental challenges in molding processes

At their most basic, all mold-based processes consist of a similar workflow. First, a tool or master is manufactured with the inverse geometry of the desired microfeatures, i.e. a channel in the finished part will require a raised feature in the mold. There are a variety of different processes to produce tools or masters, including nanolithography, laser machining, electrode-discharge-machining (EDM) or micromilling. Since it is the most commonly used technique, this guide will focus on micromilling. (Figure 2)

After the tool is fabricated, it is placed into automated equipment where the molding process can be carried out. The mold is closed, and thermoplastic resin is heated beyond its glass transition temperature and packed into the mold. Then, the plastic is cooled until it reaches a glassy state where it can be safely ejected or stripped from the mold.

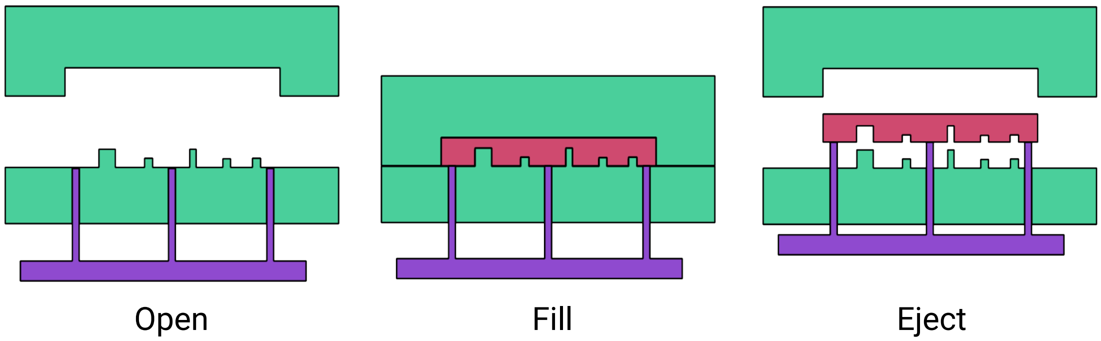

Figure 2: Molding process

Challenge 1: Cutting tool diameter

Most tools used in molding based processes are produced via micromilling, and considerations need to be made for the minimum practical tooling diameters that can be used in the milling process. In our process here at Parallel, the smallest standard tool we can run in our CNC machining centers is 100 microns (Figure 3) in diameter with a maximum aspect ratio of 3:1. This hard requirement is the driving factor in many of the specific transition molding design guidelines.

A principle of the tooling fabrication process is that as the end mill diameter decreases, machine time (and consequently, cost) increases. A great way to reduce cost and improve accuracy of the mold fabrication is to reduce the number of features that require small diameter end mills. Perhaps the most common area where this comes into play is in the corners and transitions of channels. If the radii of corners and space between channels can be increased, tooling production time can be drastically shortened.

Figure 3: End mill comparison

Challenge 2: Friction

An important phenomenon in the molding process is that as a thermoplastic material cools, it will shrink onto the mold. The shrinking effect creates friction between the finished part and the mold, which must be overcome to successfully remove the part during ejection. Typically, pins are placed in the mold that will be used to physically push the finished part off of the surface, creating the microfeatures.

A great way to ensure success in molding is to reduce this friction between the part and the mold with the mold by adding a draft angle to all vertical surfaces. For instance, instead of having channel walls be perfectly perpendicular to the face of the part, they can have a slight angle (2 degrees is a common choice). This angle will help to ensure that the part releases immediately from the mold surface during ejection instead of dragging along vertical walls, which can lead to feature damage, surface defect, or worse, broken parts.

A related principle is to make sure there is enough space between features to fit ejector pins. Typically, the exact pin placement will be left up to the manufacturer. However, it is important to make sure that there is some free area to accommodate ejectors, especially near areas with a high density of microfeatures. The standard pin diameters stocked at Parallel are 1.5mm and .75mm, and ideally there would be at least 500 microns of space between the ejector pin and nearby microfeatures.

Design guidelines

Nearly all of the specific design guidelines for the transition molding process are based on the two challenges listed above. During the design process, if you can answer the two questions “Can I cut the tooling?” and “Can I eject my part” then you are well on the road to a solid, manufacturable design for a microfluidic device. To learn more about the exact guidelines and details for a variety of different microfeatures, please head to our design guide. There we have best practices and tips for how to design individual microfeatures for success.

Design feedback

Providing feedback is a core part of our process here at Parallel. We’ll check your device to make sure that it complies with best practices and suggest changes that may be necessary to ensure success of your design. Upload your design today to receive a configurable quote that will allow you to adjust materials, configuration, quantities, and lead time on the fly.

Reach out to info@parallelfluidics.com to connect

About Parallel Fluidics

Parallel Fluidics is a rapid manufacturer of microfluidic devices. Upload a design now to get a quote for high quality prototypes in as little as three days.

Visit parallelfluidics.com for more design resources, embeddable components, and accessories to help accelerate the microfluidic dev`elopment process.