Laser Processing for Microfluidic Device Fabrication

Microfluidics is the technology for moving, mixing, processing and analyzing fluids on a microscale. The minimum feature size on a microfluidic device is typically between 50 and 100µm, but can be as small as 5µm. The most commercially-successful application of microfluidic technology to date is the ink jet print head. Microfluidic devices that integrate assay functions are now revolutionizing the fields of microbiology and clinical pathology by providing inexpensive lab-on-a-chip devices that deliver test results much more quickly than traditional techniques. There are three basic types of microfluidic devices; those that are fabricated from silicon or glass, those that are fabricated from polymers and those that are fabricated from laminates of several different materials.

Microfluidic Device Fabrication with Silicon and Glass

The earliest microfluidic devices were fabricated from silicon or glass using processes that were develop for integrated circuit manufacturing. These processes are complex and expensive, but they yield very precise results. First the silicon or glass substrate is coated with a light sensitive photoresist layer. The photoresist is then exposed to ultraviolet light through a metallic mask. After exposure the photoresist is developed and baked to transfer the micro-pattern from the mask to the photoresist layer. The coated substrate is then etched to create microfluidic channels. This set of process steps is known as photolithography (see Figure 1 for a schematic description).

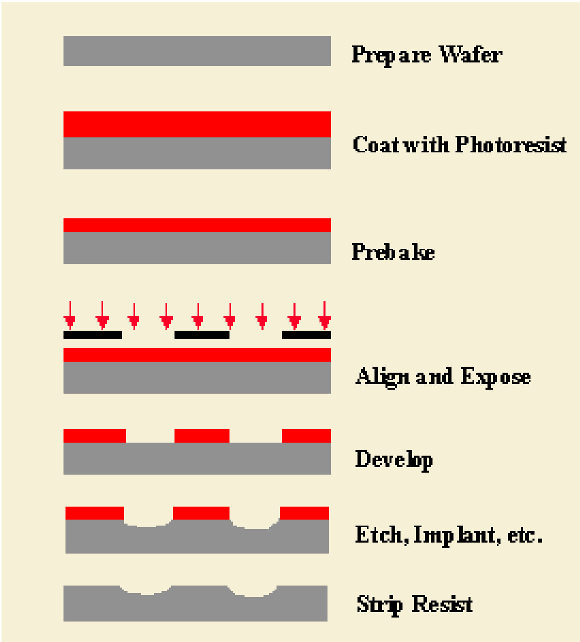

Figure 1. Creating microfluidic channels in silicon or glass using photolithography.

Photolithography is a complex and time-consuming process. It also relies on very expensive equipment, however this process is capable of producing extremely complex patterns with channels as narrow as 5µm.

Microfluidic Device Fabrication with Polymers

Polymer-based microfluidic devices offer a range benefits over silicon and glass devices. These materials are flexible, they are relatively inexpensive and they do not require expensive photolithography for device fabrication. Microfluidic channels can be formed in polymers by laser engraving, by micro-machining or by molding.

Polymers fall into three basic categories based on their physical properties – elastomers, thermosetting plastics and thermoforming plastics. The polymers that are most commonly used for microfluidic devices are:

- Elastomers
    - Silicone
- Thermosetting Plastics
    - Novolac
    - Polyimide
- Thermoforming Plastics
    - Acrylic
    - Polycarbonate
    - Teflon

Elastomers can stretch or compress in response to applied forces, and then return to their original shape. The most common elastomer used for microfluidic devices is silicone (aka PDMS). The channel patterning process is done by casting silicone resin over a mold, and then curing the resin. This process is shown schematically in Figure 2. The molds can be made by laser engraving or by micromachining. Molds can also be made using photolithography, but this increases fabrication time and cost.

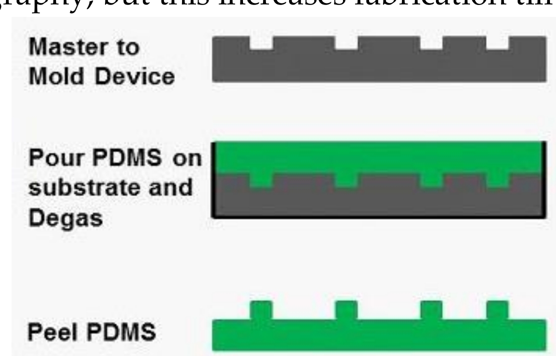

Figure 2. Steps for creating microfluidic channels using cast silicone (PDMS).

Thermosetting plastics like polyimide can be cast using molds, but unlike elastomers they become rigid after curing. Thus they can be formed into freestanding microfluidic devices with high aspect ratio channels. Microfluidic channels can be formed in thermosets like polyimide by casting the polymer resin onto a mold, and then curing the resin (basically the same process as shown in Figure 2). Alternatively the microfluidic channels can be formed directly in the surface of the cured plastic by laser engraving or by micro-machining. This method avoids the need to create a mold altogether.

Thermoforming plastics are rigid solids at room temperature, but they soften at higher temperatures. Thermoforming plastics like acrylic, polycarbonate and even Teflon are shaped by heating and then pressing into a mold. This process is known as thermoplastic embossing and is shown schematically in Figure 3. These molds can be created either by photolithography or by micro-machining. Alternatively the microfluidic channels can be formed directly in the surface of the plastic, as with the thermosets. This method avoids the need to create a mold altogether.

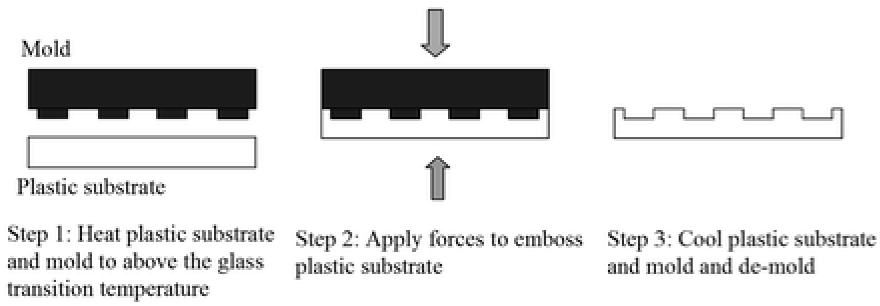

Figure 3. Steps for forming microfluidic channels by thermoplastic embossing

Laser Processing Opportunities

Laser engraving can be used to form a microfluidic channel directly in all of materials mentioned above. Laser engraving Silicon or Glass requires a UV laser. Laser engraving for any of the polymer materials can be done using a CO_2 laser. Laser engraving is especially well-suited to rapid prototyping and low volume production because the time and expense creating molds by photolithography are eliminated. Any pattern that can be designed with readily-available graphic design software (Solid Works, AutoCAD, Rhino, etc.) can be directly uploaded to the laser system and used to engrave the microfluidic channel directly into the polymer. With laser engraving a microfluidic device can be completed in just a few minutes, compared to several days necessary for photolithography.

Unique Universal Advantages for Fabricating Microfluidic Devices

A Universal Laser System (ULS) XLS platform is ideal for fabricating microfluidic devices. The accuracy provided by the motion system can reliably engrave channels as small as 50µm. Camera registration provides precise alignment to the substrate material. Gas Assist provides a jet of air or inert gas to keep the channels clean during the laser engraving process. MultiWave Hybrid™ technology provides additional laser wavelengths for use with composite or hybrid materials. The Standard Materials Database provides optimized laser process settings for hundreds of materials including acrylic, polycarbonate, Teflon and silicone. These unique capabilities make ULS laser processing solutions ideal for microfluidic device fabrication.

Other Benefits of ULS Laser Processing Solutions

ULS Laser System Manager software allows for up to 16 settings, color-coded for easy recognition. This allows several processes to be run in a single pass through the laser system, such as:

- engraving patterns with different depths
- texturing a surface with patterns of dots, lines, or 3D shapes such as pyramids or conical projections
- focusing at different depths to accommodate surface height variations
- perforating, drilling or trepanning holes
- marking with logo, part number or unique identifier matrix code
- full-penetration cutting through the substrate material
- processing parts that consist of multiple materials

Laser System Manager (LSM) software has a time estimator function built in to allow virtual testing for throughput without actually running the laser system. This aids in planning for production and in determining job costing.

The LSM software has an array capability to run rows and columns of duplicate parts without opening the design software. This duplication function can be quickly set up in the LSM control screens.

In addition, the XLS can be equipped with a plug-and-play rotary fixture to allow surface modification on cylindrical or faceted components.