

## SOFT LITHOGRAPHY

This area of micro and nanofabrication is what most consider being “unconventional” because it is not necessarily well tested, but it offers promise because of its relative ease of use and financial relief. It is termed soft lithography because organic materials are used to transfer molds and patterns onto other materials and these organic materials are usually “soft.” Amazingly, this technique allows for < 100nm fabrication. Making the pattern on these soft materials consists of three main steps: 1) Forming a master surface with the characteristics desired for fabrication, 2) Pouring in a mold to create a “stamp” to be used for fabrication, and 3) The stamp is then used to create a replica of itself for other applications. Soft lithography is usually divided into three main categories: 1) Microcontact Printing, and 2) Micromolding.

### **Making the Masters:**

The masters used for soft lithography can be formed using the techniques already established for common microfabrication methods. Imagine a flat surface with a certain pattern protruding up from it like a 3-D maze. An elastomeric polymer is then poured into that certain design and used to fabricate materials. The most commonly used soft material is polydimethylsiloxane (PDMS), basically silicon rubber. This material has incredible properties such as: toughness, flexibility, unreactive to most of the materials being fabricated, and it is optically transparent down to 300nm which allows UV lithography to be used as well. PDMS overcomes most of the distortions that occur at the nanoscale such as: shrinkage of polymer, expansion of polymer due to heat, and adhesive forces during stamping that might pull the polymer from itself onto the substance being stamped.

### **MICROCONTACT PRINTING ( $\mu$ CP)**

This style of fabrication is very versatile. But before we discuss  $\mu$ CP, another concept must be defined: Self-Assembled Monolayers, or SAM. This is the crucial element in  $\mu$ CP. This uses the laws of molecular attraction and organization to form efficient patterns of organic molecules onto certain substrates. The most common SAMs are alkanethiolates,  $\text{CH}_3(\text{CH}_2)_n\text{S}^-$ , because of their ability to form almost perfectly on substrates such as gold and silver. These SAMs must exhibit certain qualities in order to be desirable, these qualities include: simple preparation, low amount of defects, stable under normal laboratory conditions, and sensibility in applications. The following is the basic process of  $\mu$ CP: 1) Dip a PDMS mold into a solution of a specific material, or ink, and this material sticks to the PDMS master surface, 2) Place the PDMS master (with the material-coated surface downward) on a metal-coated substrate such as gold or silver and consequently only the surface protruding from the PDMS has contact with the substrate, 3) The ink will form a chemical bond with the metal and only the ink on the protruding surface will form a SAM (this is the where the SAM protrudes approximately one to two nanometers from the metal surface just as ink on a piece of paper), and 4) The PDMS mold is removed from the substrate and the “ink” remains on the metal surface (i.e., the material does not go away from the substrate with the PDMS) since the chemical bond between the ink and the metal/substrate is much stronger than the adhesion force between the ink and the PDMS. This causes the ink/material to stay on the metal in the form of the original PDMS pattern. This is a

fairly obvious process because it can be compared to stamping a surface on the macroscopic level.

**Advantages:**

- The physical dimensions of the PDMS mold determine the dimensions of the fabricated material.
- The flexibility of PDMS allows for custom design outside a flat plane, perhaps a curved surface.
- There are a variety of different materials to act as “inks” on many different types of surfaces.
- Ease of preparation and non-demanding conditions of fabrication.

**Disadvantages:**

- The ink can spread just as a stamp we are all familiar with (just on the molecular level).
- Any kind of deformation in the stamp will not allow any pattern it creates to function as desired.
- The possible number of defects in the metallic substrates.

**MICRO MOLDING**

This method is based on the same concept of microcontact printing where a PDMS mold is used to accomplish various tasks. There are four distinct methods within this category that will be discussed: 1) Step-and-Flash Lithography, 2) Replica Molding, 3) Microtransfer molding, 4) Micromolding in Capillaries, and 5) Solvent Assisted Micromolding.

**Step-and-Flash Lithography:**

This method is as follows: 1) A liquid polymer is poured onto a metal substrate, 2) instead of PDMS, a quartz mold is used to press down onto the polymer to mold it into a desired shape, and 3) then everything is UV cured and the mold is removed from the substrate, leaving a patterned polymer on the substrate.

**Replica Molding:**

This process is by far the most simplistic. Basically, pour a polymer substance onto a PDMS mold and allow the polymer to cure. Then remove the polymer from the PDMS mold, and a desired polymer mold is left.

**Microtransfer Molding:**

This method is as follows: 1) A liquid polymer is poured onto a PDMS mold and the excess is removed, 2) then the PDMS which is filled with the polymer is placed on a metal substrate, and 3) the PDMS mold is removed and the polymer pattern is left on the substrate due to strong molecular forces.

**Micromolding in Capillaries (MIMIC):**

This technique relies on the filling of capillaries formed by placing a mold with open channels in it on a metal substrate. The basic process is as follows: 1) this technique commonly uses a polydimethylsiloxane or PDMS mold to accomplish its objectives because the PDMS mold can be placed completely on a metal substrate and has very little reactivity with the surface which allows the PDMS mold to be pulled off of the metal substrate with ease. By doing this, open square channels are formed between the PDMS and the metal substrate where three sides are from the PDMS and the bottom side is the substrate. 2) Then a liquid such as a prepolymer or a mixture of the materials to be formed are commonly used to fill the capillaries. Fluids with low surface tension and low viscosity (they are thin and free flowing) are most ideal for this process. Because solvents have low viscosity, they are commonly used to carry materials into the capillaries to be deposited in desired areas. This part relies on a concept called surface free energy. This basically describes how much a material put into a closed region wants to attach to a certain surface mainly due to molecular forces. Most materials in the liquid phase have certain forces and opposing forces that keep the liquid in equilibrium; but when a surface of the liquid is exposed to another type of surface such as a solid, the forces change on that surface and cause the liquid to change accordingly. The lower the free energy, the less likely a material will want to stick to it and spread across it. Because the surface free energy of the PDMS is lower than that of the substrate, the material being molded wants to spread across the surface of the substrate more than the surface of the PDMS. The dominant wetting of the capillaries comes from the wetting of the substrate because of the difference in the free energies. 3) Once the capillaries have been filled and the liquid used has either cross-linked, crystallized, cured, adhered, or deposited onto the surface of the substrate, the PDMS mold is removed and free standing structures of organic or inorganic materials are left where they filled the capillaries. These structures can then be removed to become independent structures by processes including chemical and mechanical means. For example some chemical means include glass and silicon dioxide substrates being dissolved in hydrofluoric acid or silicon substrates being oxidized in potassium hydroxide; and some mechanical means include removing the structures with Scotch tape or tweezers.

MIMIC has been shown to fabricate microstructures or organic polymers, inorganic and organic solids, ceramics, metals, and crystalline microparticles on the surfaces of various substrates. Applications of this process include MEMS (micro-electro-mechanical systems), fracture mechanics, microanalytical and microchemical devices, sensors, and others.

**Solvent Assisted Micromolding (SAMIM):**

This is almost the same technique as MIMIC: 1) Place the PDMS mold onto a substrate with nothing in it where the molded side is face down on the substrate, 2) pour a solvent into the open areas of the molded side of the PDMS, 3) place all of this onto a polymer film, 4) allow the solvent to dissolve the desired parts of the polymer film, and 5) evaporate the solvent and remove the PDMS.

## References

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