Polymer-based Microfabrication

- PDMS
- SU-8
- PMMA
- Hydrogel
Soft Lithography

Developed by Whitesides, et. al
A set of techniques for microfabrication based on the use of lithography, soft substrate materials (PDMS) as a substrate, and molding of polymers

Simple and cheap fabrication
Rapid process for prototyping

Micromolding
  - Microtransfer molding
  - Replica molding

Microcontact Printing
Monolayer (protein, cells, etc.)
Micromolding

Why micromolding?

Lithography
- Spin coat photoresist
- Expose to UV light through a mask and then expose to a solution of developer

Soft materials (PDMS)
- Cast PDMS
- Remove PDMS from master
- Features: ~500 nm - 500 μm
  100 μm - 1 cm
  1 μm - 500 μm

Molding
Microcontact Printing

Printing on a planar substrate with a rolling stamp

Printing on a planar substrate with a planar PDMS stamp

- Print and pattern a layer of molecules
- Print and pattern probes on microarray

Printing on a curved substrate with a planar stamp
Microtransfer molding (µTM)

Figure 24. SEM images of polymeric microstructures fabricated by µTM: A) patterned, isolated microstructures of PU on silver (one layer); B) isolated microcylinders of epoxy on 5-µm lines of epoxy supported on a glass slide (two layers); C) a continuous web of epoxy over a layer of 5-µm lines of epoxy supported on a glass slide (two layers); D) a three-layer structures on a glass slide made from a thermally curable epoxy.
Micromolding in Capillaries (MIMIC)

Figure 27. SEM images of polymeric microstructures fabricated by MIMIC from prepolymer of polyacrylate (A, C) and polyurethane (B, D) without solvents.\textsuperscript{[37, 179]} The structures in B and D are freestanding; the buckling occurred during sample preparation and demonstrated their strength.
Solvent Assisted Micromolding (SAMIM)

- PDMS mold is wetted a solvent that can swell the polymer
- Solvent swells/dissolves a thin layer of polymer
- The resulting fluid (gellike Polymer/solvent) conforms the mold pattern
- Solvent evaporates and pattern solidifies
Technical Problems in Soft Lithography

a) **Pairing**
- Occurs at high aspect ratio
- Caused by weight and surface tension

b) **Sagging**
- Occurs at low aspect ratio
- Caused by compression force while inking

c) **Shrinking / swelling**
- Shrinking during curing
- Swelling by nonpolar solvents
PDMS (Polydimethylsiloxane)

- Deforms reversibly
- Can be molded with high fidelity
- Optically transparent down to ~300nm
- Durable and chemically inert
- Non-toxic
- Inexpensive

Upon treatment in oxygen plasma, PDMS seals to itself, glass, silicon, silicon nitride, and some plastic materials.
Rapid Prototyping Procedure for Soft-lithography

1. **idea**
2. **CAD pattern**
3. **image printing**
4. **mask**
5. **photolithography**
6. **structures**
7. **24 hours**
8. **master**
9. **soft lithography**
10. **stamp or mold**
11. **REM**
Thick Resist (e.g. Su-8) Lithography

SU-8 is a negative photoresist based on EPON SU-8 epoxy resin for the near-UV wavelengths from 365 nm to 436 nm. At these wavelengths the photoresist has very low optical absorption, which makes photolithography of thick films with high aspect ratios possible.

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Steps

- Substrate Pretreat
- Coat
- Soft Bake
- Expose
- Post Expose Bake (PEB)
- Develop
- Rinse & Dry
- Hard Bake (optional)

Spin speed:

65-95 °C
365-436 nm
65-95 °C
150-200 °C

Figure 1. Spin speed vs. thickness curves for selected SU-8 resists.

Baking times (min):

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<th>Product Name</th>
<th>Thickness (µm)</th>
<th>Pre-bake @ 65°C</th>
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(Microchem, Inc.)
PMMA (Poly methyl methacrylate)

1. Initial Setup

2. Nanoimprinting

3. Mold Removal

FIG. 1. Schematic of nanoimprint lithography process. (Renstrom)

Dot pattern imprinted into PMMA (poly-methymethacrylate). The dots have a 25 nm diameter and 120 nm period.

Ti/Au dot pattern on a silicon substrate fabricated using nano-imprinting and a lift-off process. The dots have a 25 nm diameter and 120 nm period.
Hydrogel Based Microfabrication

Hydrogel Fabrication

- Photosensitive (polarity like negative PR)
- Liquid-phase photo-polymerization
- Laminar flow-aided patterning
- Functional (stimuli-responsive) and non-functional materials
- Fabrication of fluidic channels, actuators, valves, pumps
- Typical polymerization time: 5-40 sec (UV light)
- Minimal Total fabrication time of a system (<10 min)

A hydrogel jacket valve in a T channel

(D. Beebe)
Fabrication of a valve in a Hydrogel Microchannel

2-D and 3-D micro fluidic network
Geometry Control during Fabrication by Using Laminar Flows
Rigid Materials vs. Soft (Elastomeric) Materials

**Rigid materials**

Crystalline silicon, amorphous silicon, glass, quartz, metals

**Advantages:**

- Fabrication process is mature and well developed
- Bulk-etching for forming two- and three-dimensional shapes
- Batch process – compatible with IC process
- Silicon dioxide: good quality, stable chemically and thermally

**Disadvantages:**

- Expensive
- Brittle
- Opaque (for silicon) in the UV/Vis regions
- Low dielectric strength (Si)
- Surface chemistry is difficult to manipulate

**Packaging/Bonding:**

- Anodic bonding
- Fusion bonding
- Polymer bonding

**Good and Bad!**
Rigid Materials vs. Soft (Elastomeric) Materials

**Soft materials**

PDMS, PMMA, Polyimide, Hydrogel, etc..

**Advantages:**
- Quick
- Inexpensive
- Flexible (for actuation such as valuing)
- Transparent to visible/UV
- Durable and chemical insert
- Surface property easily modified
- Improved biocompatibility and bioactivity

**Disadvantages:**
- Limited to simple structure
- Low thermal stability
- Low thermal and electrical conductivity
- Techniques for microfabrication not as well developed

**Packaging/Bonding:**
- Through surface modification – easy but not robust