Fabrication of Polymeric Microfluidic Devices

Mateusz L. Hupert,† W. Jason Guy,† Proyag Datta,‡ and Steven A. Soper†

†Center for Bio-Modular Multi-Scale Systems and Department of Chemistry

‡Center for Advanced Microstructures and Devices

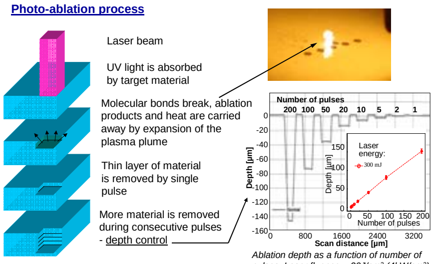
Louisiana State University, Baton Rouge, LA 70803

Miniaturization of laboratory processes to form micro total analysis systems (µTAS) has recently gained a great deal of attention in academic and industrial research laboratories. In principle, µTAS offers multiple advantages over bench-top instruments, such as increased speed of analysis, high-throughput, multiplexing capabilities, portability and significantly lower cost of operation through reduction in sample, reagent, and solvent volumes. All of these features are especially appealing to such areas as genetic analyses, clinical testing, drug discovery, food control, and environmental monitoring. In order to make microfluidic devices more widely available for bioanalytical testing, especially for assays where cross-contamination of the samples is unacceptable, µTASs need to be produced in high volumes at low unit costs so disposability can be realized. These requirements point toward polymers as highly attractive materials for microdevice fabrication. Polymers are generally inexpensive and low-cost fabrication techniques are available for both rapid prototyping and mass production. Polymers also posses a wide range of physical, chemical, and surface properties, which allow for fine tailoring of the chip material to a specific application. Center for Bio-Modular Multi-Scale Systems (CBM^2) and Center for Advanced Microstructures and Devices (CAMD), both located on LSU campus, posses the necessary equipment and technical knowledge for rapid prototyping (laser ablation, high-precision micromilling) and mid-volume production of polymeric microfluidic devices via replication (hot-embossing, injection molding, and casting) from metal masters fabricated through LiGA or high-precision micromilling. Some of our manufacturing capabilities are outlined and discussed below.

Laser Ablation

Laser beam of specific wavelength is used to cut microchannels and drill holes in polymeric material through photo-ablation process

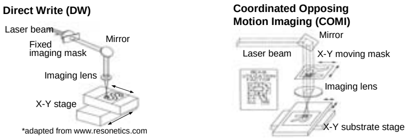
Photo-ablation process



Ablation depth as a function of number of pulses. Laser fluence = 20J/cm² (4kW/cm²)

Beam Delivery Techniques

Direct Write (DW) — **Coordinated Opposing Motion Imaging (COMI)**



Universal mask holder for DW — *Design-specific mask for COMI*

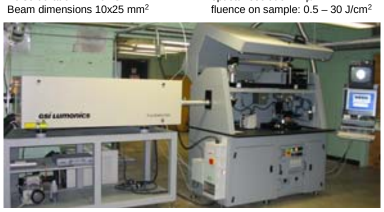
- Ideal for simple curvilinear features and drilling
- Design-specific mask is not required - universal mask holder
- Work area not limited by demagnification
- Faster prototyping – only CAD drawing needed

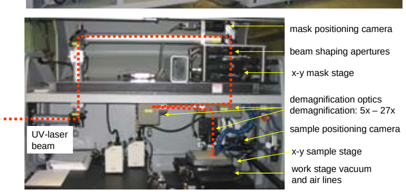
- Most efficient utilization of a beam – shorter machining time
- Best for complicated designs (eg.: crossing lines, lines with continuously changing widths)

Resonetics RapidX 1000 Series laser system

Lumonics PM-848 UV excimer laser
KrF (248 nm, 80W), **ArF** (193 nm, 30W)
Max. repetition rate 200 Hz
Pulse duration 12-20 ns
Beam dimensions 10x25 mm²

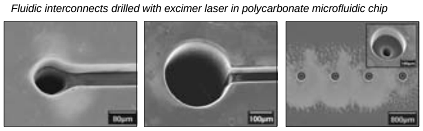
Workstation:
software controlled (except demag.)
demagnification: 5x – 27x
optical resolution: 2 µm
fluence on sample: 0.5 – 30 J/cm²



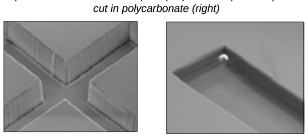


Examples of fabricated microstructures

Fluidic interconnects drilled with excimer laser in polycarbonate microfluidic chip



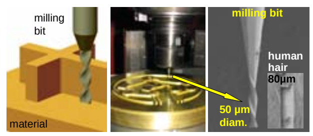
10 µm x 10 µm microchannel cut in Kapton (left) and 100 µm x 30 µm microchannel cut in polycarbonate (right)



*adapted from www.resonetics.com

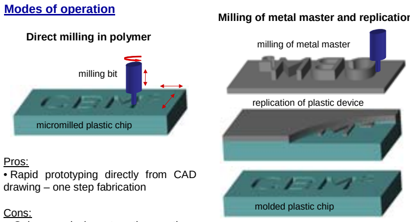
High-Precision Micromilling

Computer Numerically Controlled (CNC) Milling Machine using very small milling bits (down to 25 µm diameter) rotated at very high speed (40,000 – 200,000 rpm) is used to directly cut polymeric material or to cut metal substrate to form master which is consecutively used for replication of microchannels into polymeric material through hot-embossing, injection molding or casting



Modes of operation

Direct milling in polymer — **Milling of metal master and replication**



Pros:
- Rapid prototyping directly from CAD drawing – one step fabrication

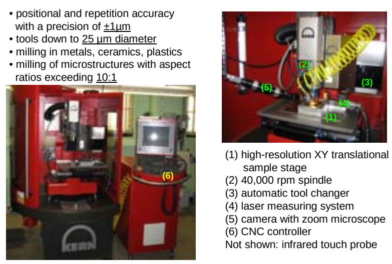
Cons:
- Only one device at a time – time-consuming milling process has to be repeated for every device
- Size and aspect ratio of the channel is dependent on size and aspect ratio of milling bit
- Quality of the micro-structures is strongly dependent on machinability of polymeric material - burr formation, wall roughness
- Roughness of the bottom of the channel can not be very well controlled

- Fast and inexpensive replication of the microstructures into polymers through hot-embossing, injection molding, and casting
- Metals with good machining properties (e.g., brass) can be used to achieve best surface finish
- Size and aspect ratio of microchannels not limited by milling bit characteristics

Cons:
- multi-step fabrication,
- round corners of crossing microchannels

KERN MMP micromilling machine

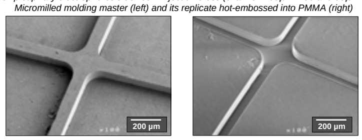
- positional and repetition accuracy with a precision of ±1µm
- tools down to 25 µm diameter
- milling in metals, ceramics, plastics
- milling of microstructures with aspect ratios exceeding 10:1



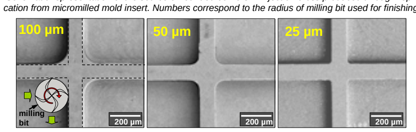
(1) high-resolution XY translational sample stage
(2) 40,000 rpm spindle
(3) automatic tool changer
(4) laser measuring system
(5) camera with zoom microscope
(6) CNC controller
Not shown: infrared touch probe

Examples of fabricated microstructures

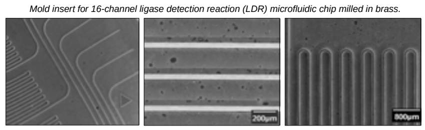
Microchip capillary electrophoresis device – injection cross (channel: 100µm wide and 90µm deep). Micromilled molding master (left) and its replicate hot-embossed into PMMA (right)



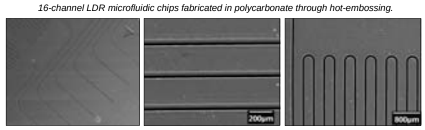
Schematic representation of the source of rounded corners in injection cross produced through replication from micromilled mold insert. Numbers correspond to the radius of milling bit used for finishing.



Mold insert for 16-channel ligase detection reaction (LDR) microfluidic chip milled in brass.



16-channel LDR microfluidic chips fabricated in polycarbonate through hot-embossing.

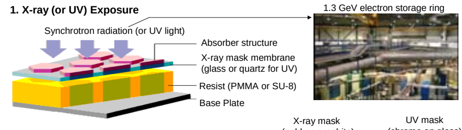


LiGA

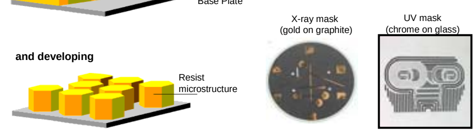
LiGA (Lithographie, Galvanoformung, Abformung) is a German acronym for a three step process: lithography, electroplating and forming. In the first step the desired pattern is transferred into photoresist using either UV or X-ray lithography. In the second step, metal (typically nickel) is electroplated to fill out the voids between the microstructures and produce metal molding master (a negative of patterned resist). In the last step metal molding master is used to reproduce microstructures into polymeric material via hot-embossing or injection molding processesss.

LiGA process

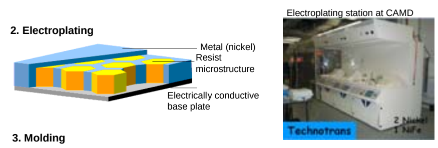
1. X-ray (or UV) Exposure



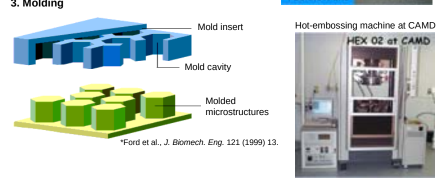
and developing



2. Electroplating



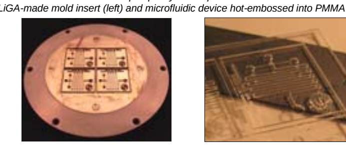
3. Molding



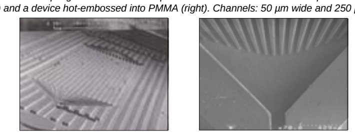
*Ford et al., *J. Biomech. Eng.* 121 (1999) 13.

Examples of fabricated microstructures

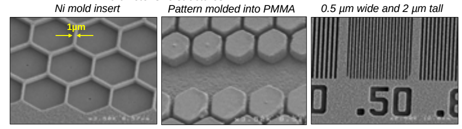
Microchip capillary electrophoresis device. LiGA-made mold insert (left) and microfluidic device hot-embossed into PMMA (right)



17-channel sampling unit for selective capture of tumor cells from blood sample. Ni mold insert (left) and a device hot-embossed into PMMA (right). Channels: 50 µm wide and 250 µm deep.



Micrometer size structures — *Ni mold insert* — *Pattern molded into PMMA* — *Sub-micrometer Ni structures 0.5 µm wide and 2 µm tall*



Comparison between different fabrication techniques

	Min. channel width [µm]	Max. aspect ratio	Wall	Avg. wall roughness [nm]	Time from design to 1st chip	cost/chip <10 chips
Laser ablation	> 5	5:1	sloped (~7°)	> 100	hours	low 1)
Direct micromilling	> 25	2:1 – 4:1	vertical	> 300	hours	low1)
Micromilling + replication	>10	10:1	vertical	> 200	1 day	moderate2)
X-ray LiGA	< 1	> 20:1	vertical	10-20	2-3 weeks	very high2)
UV LiGA	~ 5	10:1	sloped (2-10°)	10-20	2-3 weeks	high2)

1) – cost/chip is independent of the number of manufactured devices
2) – cost/chip drops dramatically with the number of manufactured devices

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