ME290R: Topics in Manufacturing
Fall 2017

Nanoscale manipulation of materials

Lecture 9: Lithography for MEMS and microfluidics
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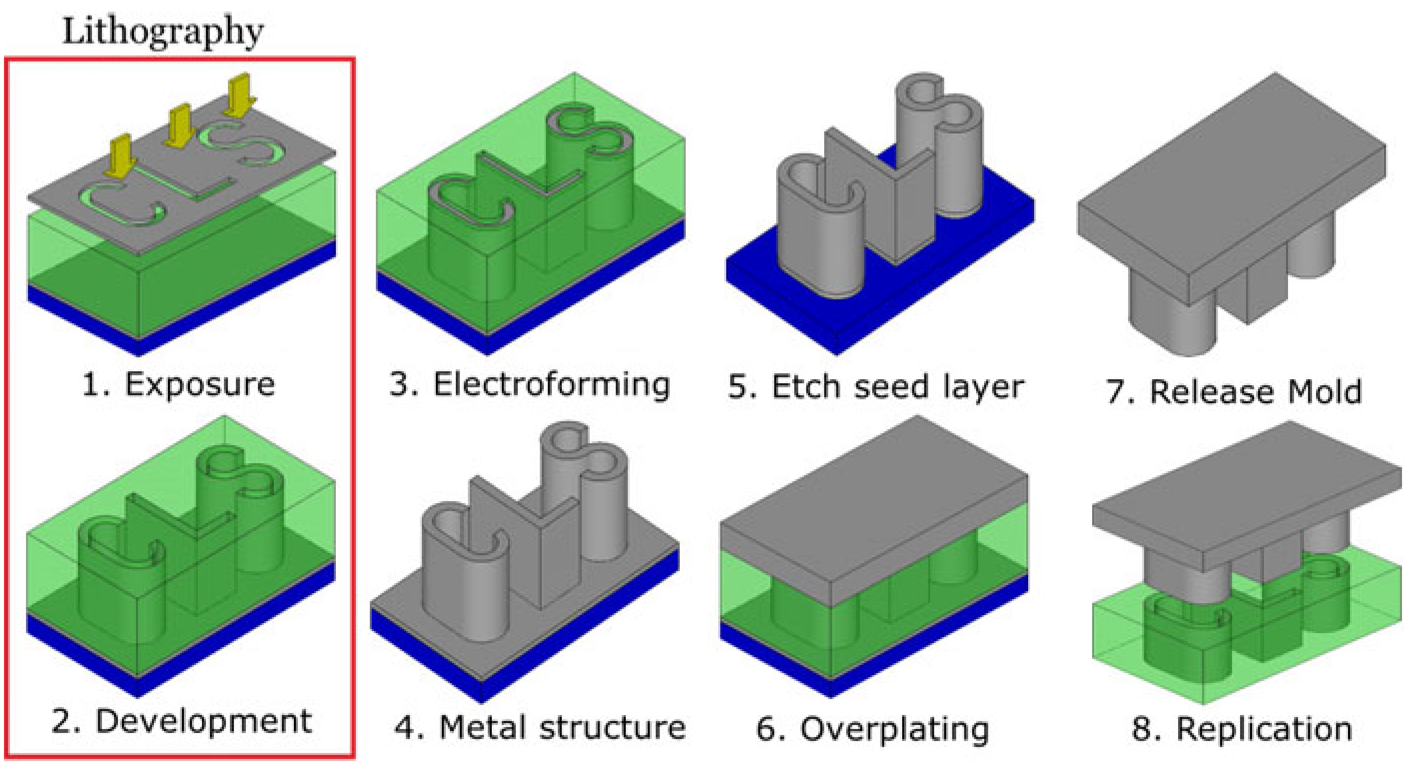
Lithography for MEMS and microfluidics

- Lithography for MEMS
  - LIGA (high-aspect ratio photolithography)

- Lithography for microfluidics
  - Glass and silicon
  - Injection molding
  - Soft lithography
    - Casting; plasma-activated bonding
    - Elastomeric valves; fluidic large-scale integration
  - Thermoplastic embossing

The LIGA process

- LIGA stands for: *Lithographie, Galvanoformung, Abformung* (Lithography, Electroplating, and Molding)

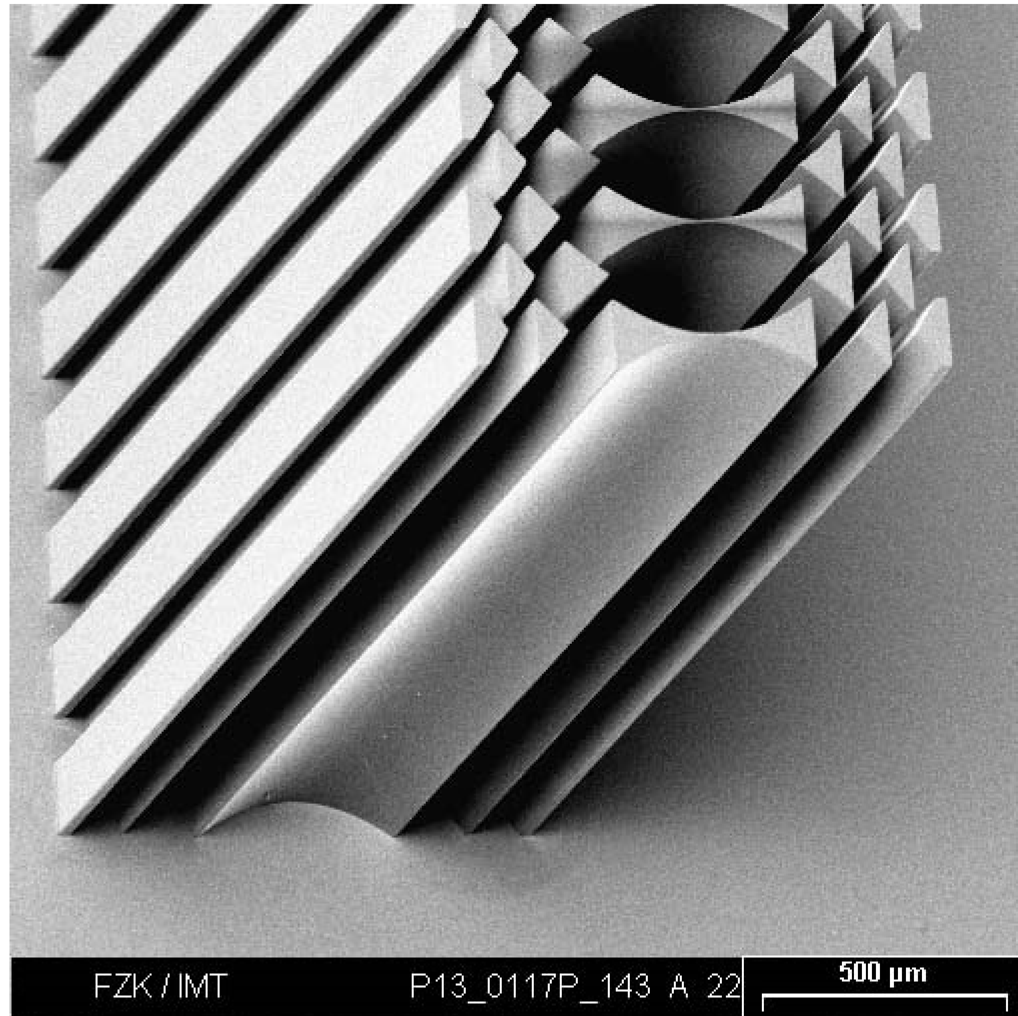


Variants of LIGA

- X-ray LIGA
  - Aspect ratios > 100
  - Parallel sidewalls
  - Sidewall roughness ~ 10 nm (*cf* deep reactive ion etch: hundreds of nm to micron-level scalloping)
  - But requires a synchrotron
- UV LIGA
  - Using UV light
  - Lower aspect ratios, but still > 10 possible

Applications of LIGA

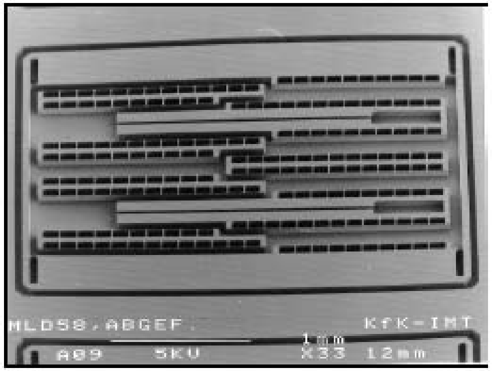
- X-ray optics
- Metallic MEMS – tougher alternative to silicon
  - Optical switches: optically smooth sidewalls
  - Supercapacitors: interdigitated electrodes
- As a mold for hot embossing



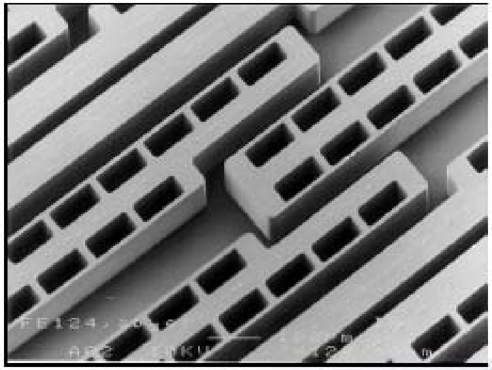
https://www.imt.kit.edu/english/236.php

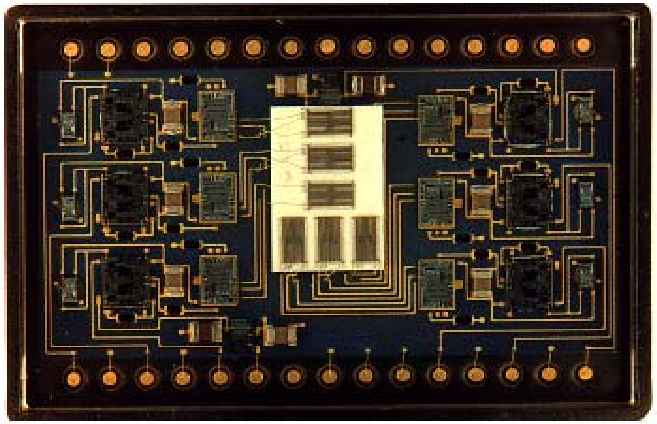
Applications of LIGA

PMMA structure



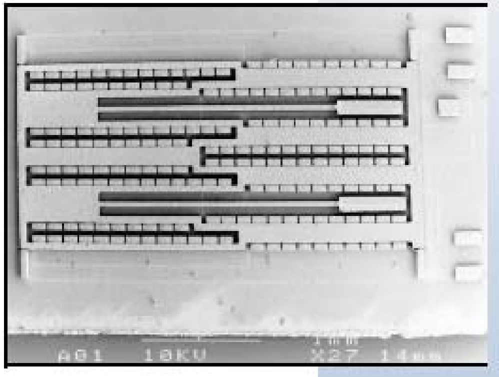
Detail

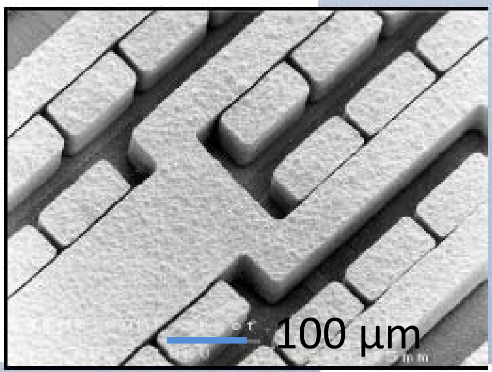




Redundant Sensor System

Ni - structures 120 µm high





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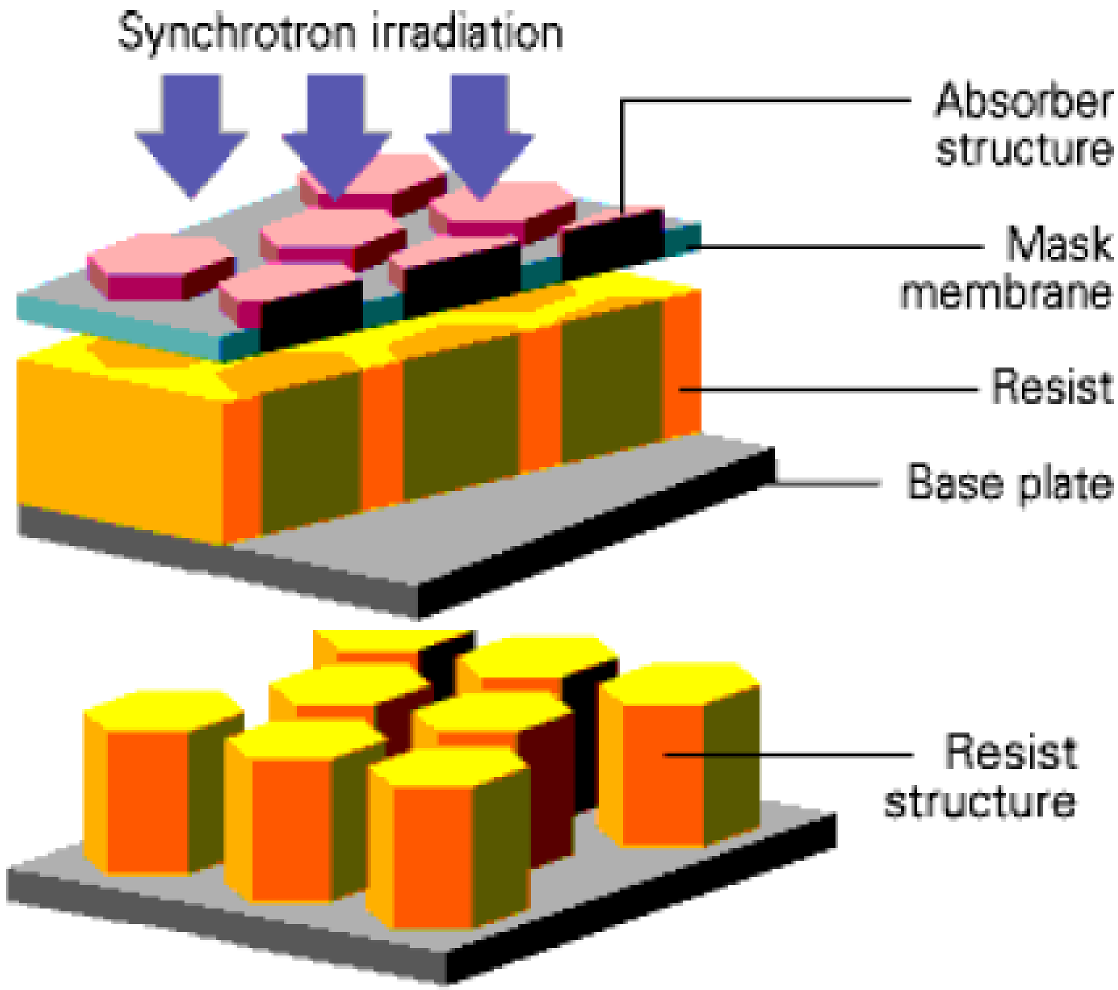
X-ray LIGA and examples of its use

- How is the mask made?



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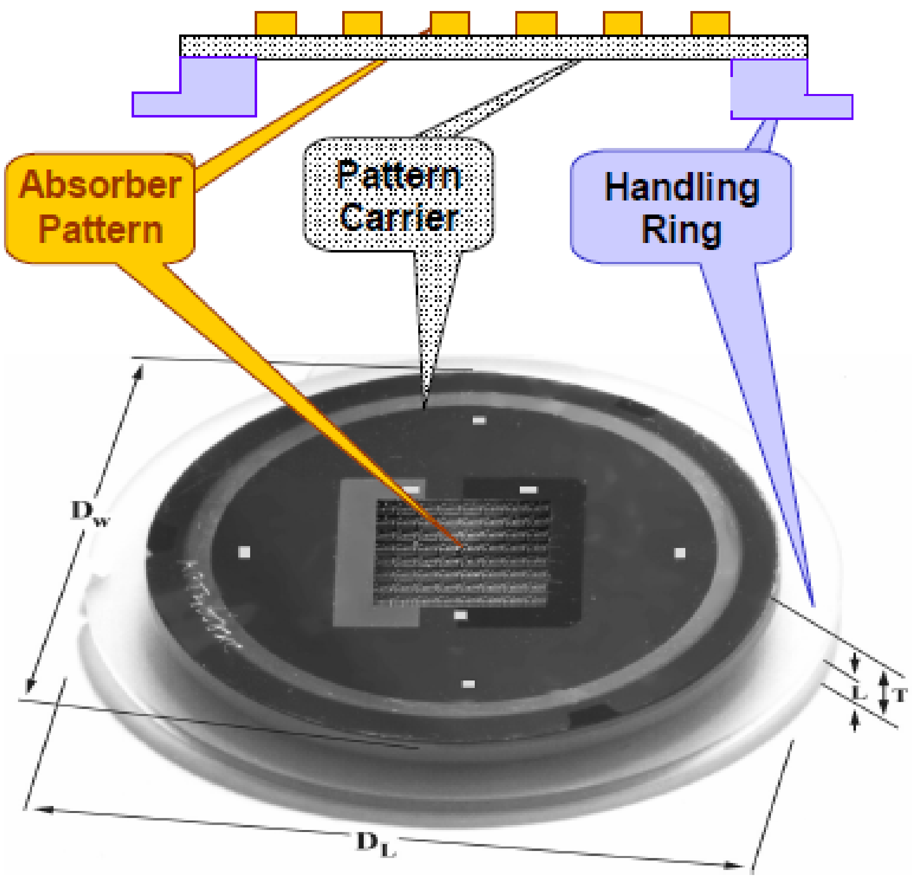
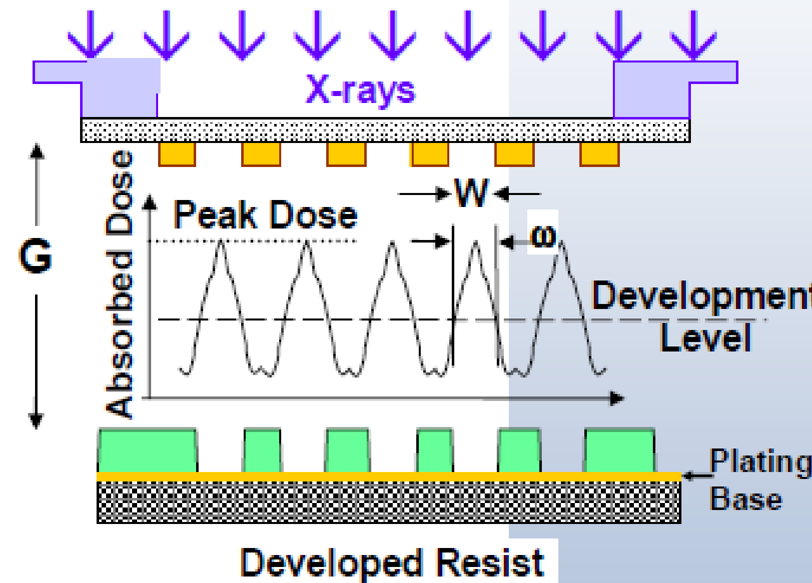
X-Ray Mask



NIST Standard MEMS X-Ray Mask

D_A=100 mm, D_w=100 mm, T=7 mm, L=3 mm, patterned area up to D_l=80 mm

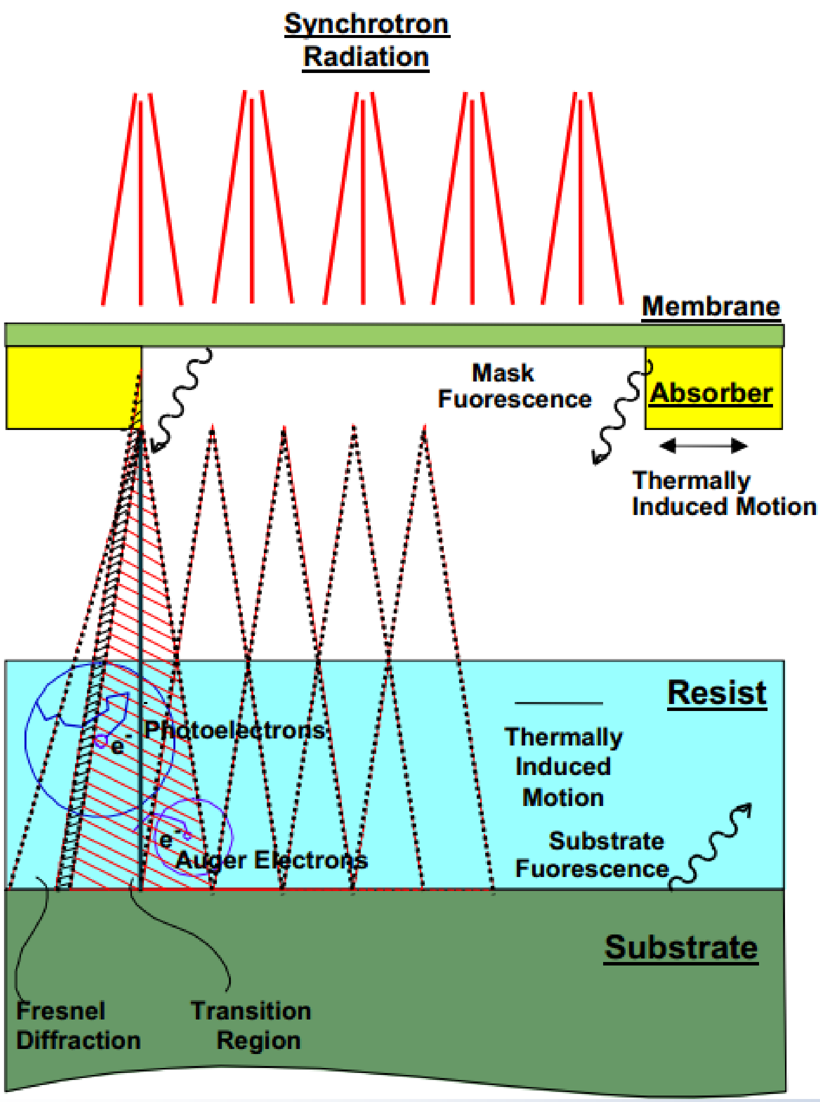
Exposure

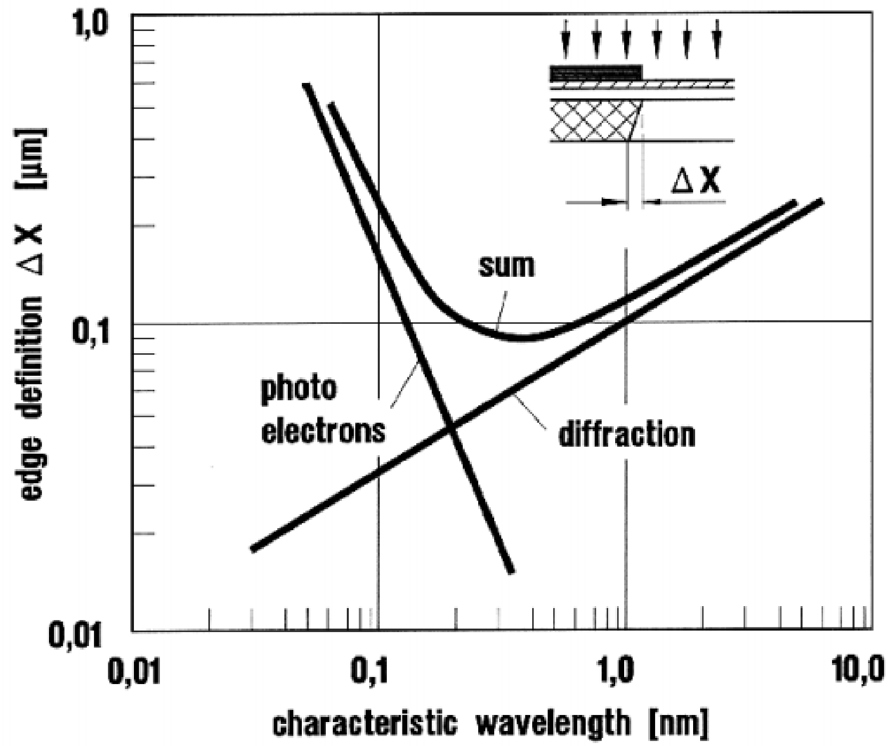


Mask Materials:

- Handling ring – Pyrex, glass, metal …
- Carrier – Si(B), SiC, SiN, Si, Be, Ti, C …
  thickness – from ~2-5μm up to 200μm
- Absorber – Au, W(Si,N), Ta(Si,N)
  thickness – from ~0.5-1μm up to 50 μm

Edge definition in X-ray LIGA





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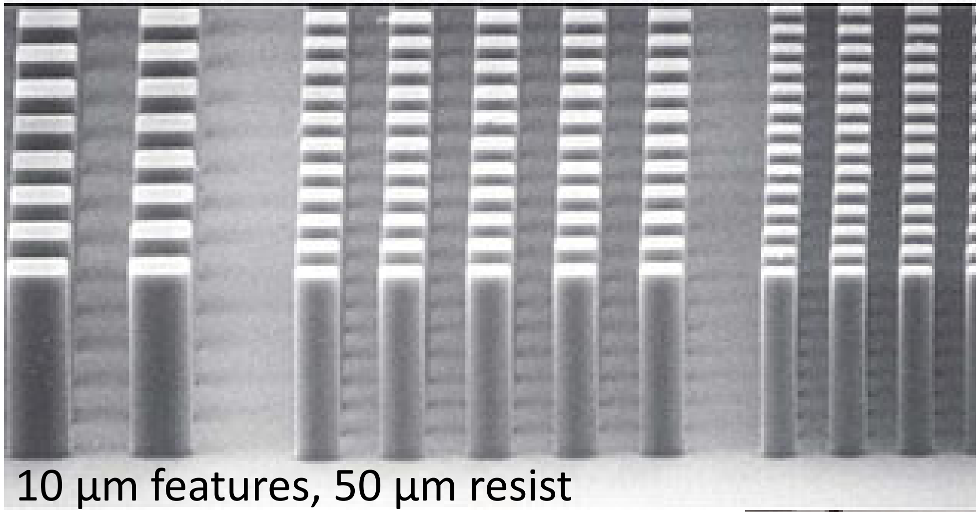
X-ray LIGA needs a synchrotron light source

- Electrons have ~GeV energy when leaving the source (cf about 3.4 eV at 365 nm)

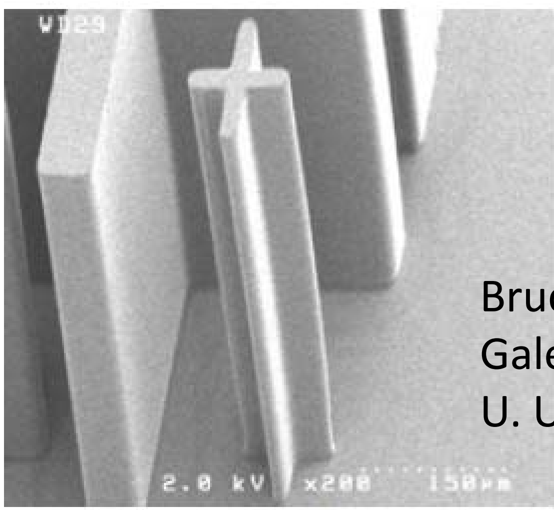
Canadian Light Source

Examples of UV LIGA using SU-8 as the resist



10 µm features, 50 µm resist
MicroResist Technology

http://www.microresist.de/projects/mikrostruk_en.htm



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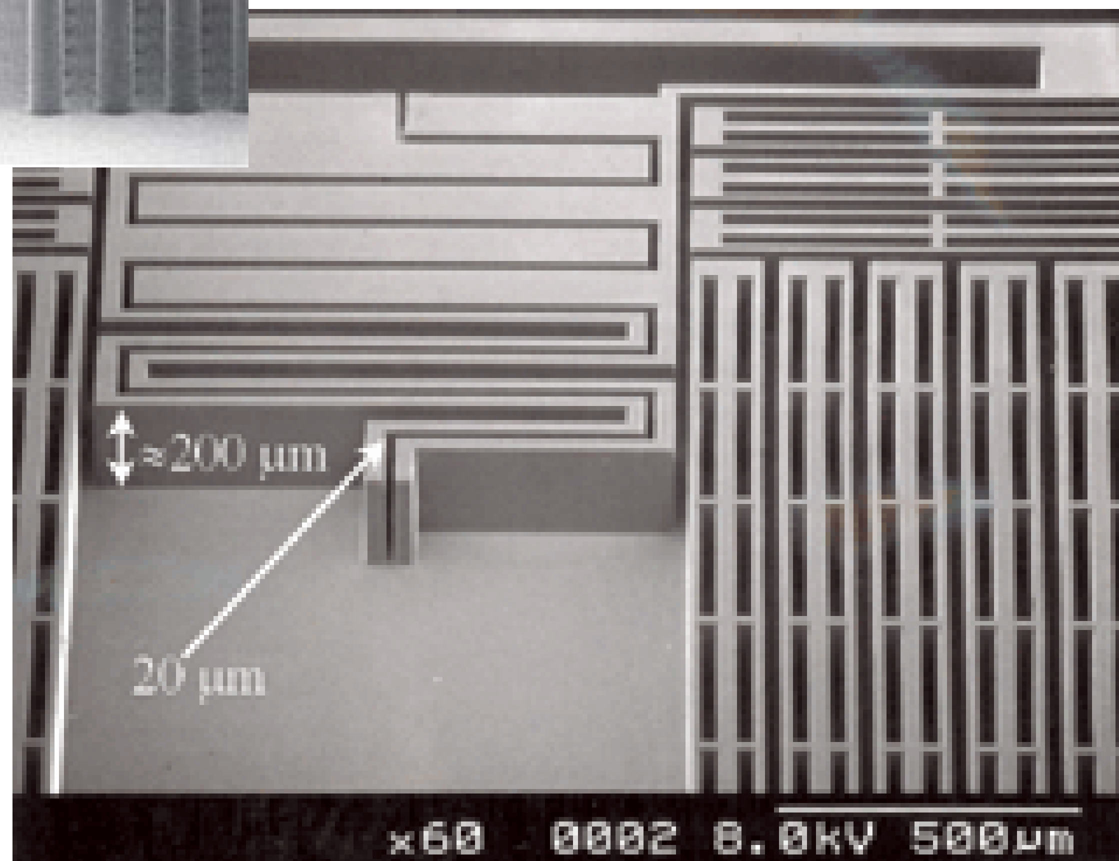
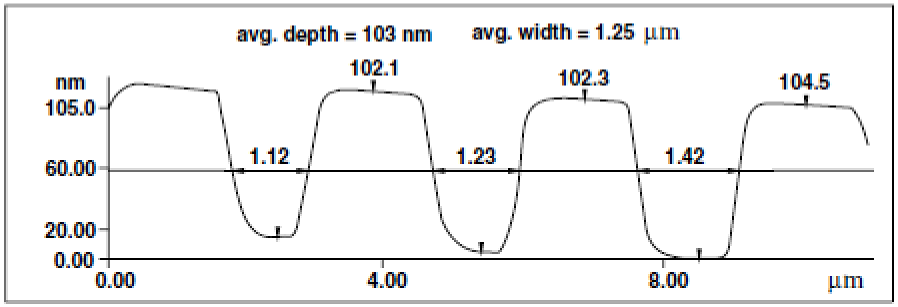
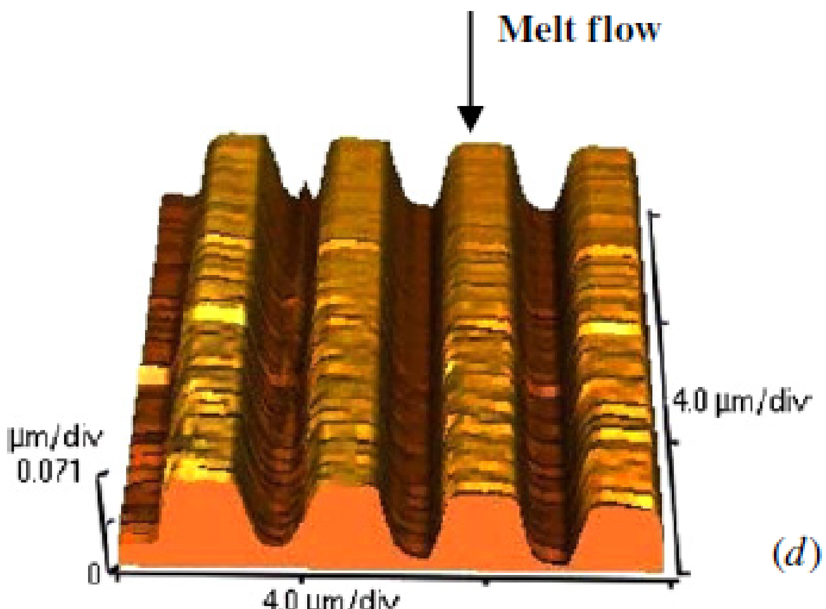
Height: ~360µm
Width: ~ 14 µm

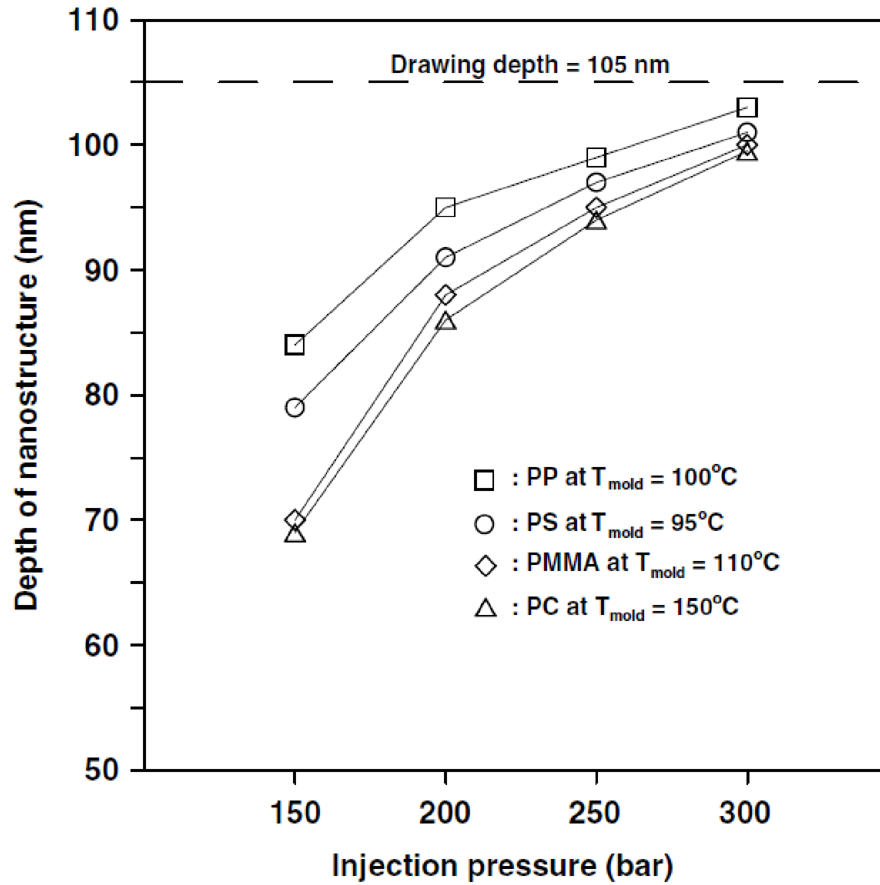


Injection molding for micron-scale pattern replication

PP, 100 C, 300 bar

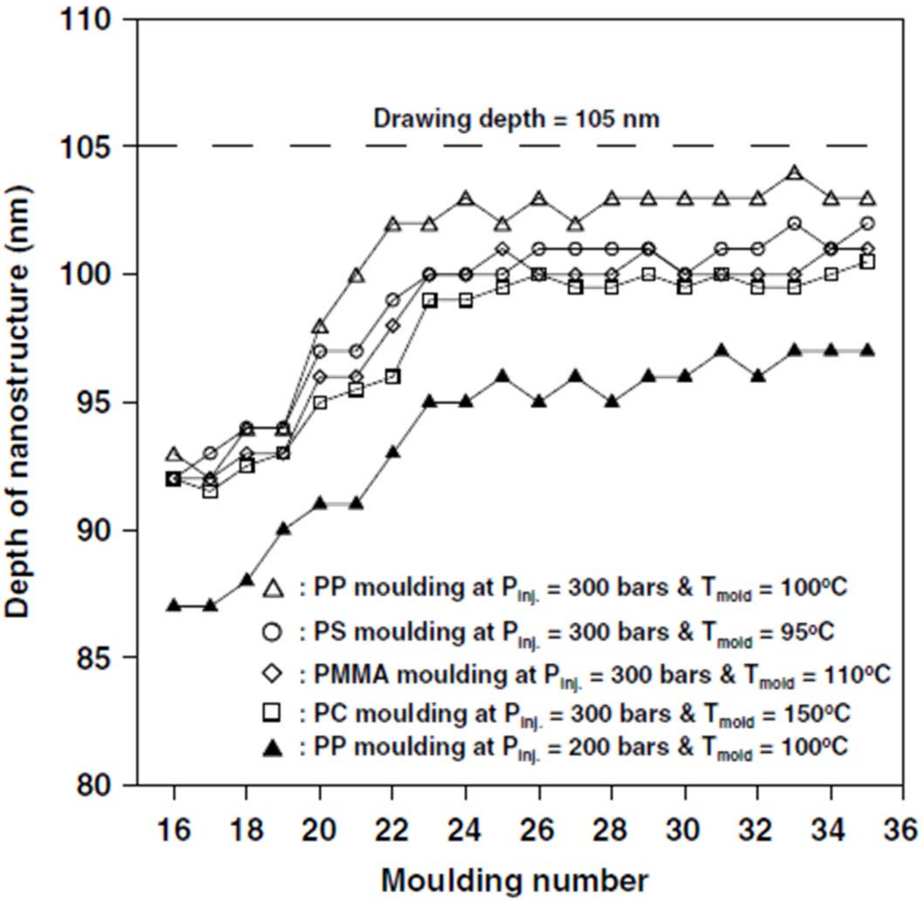


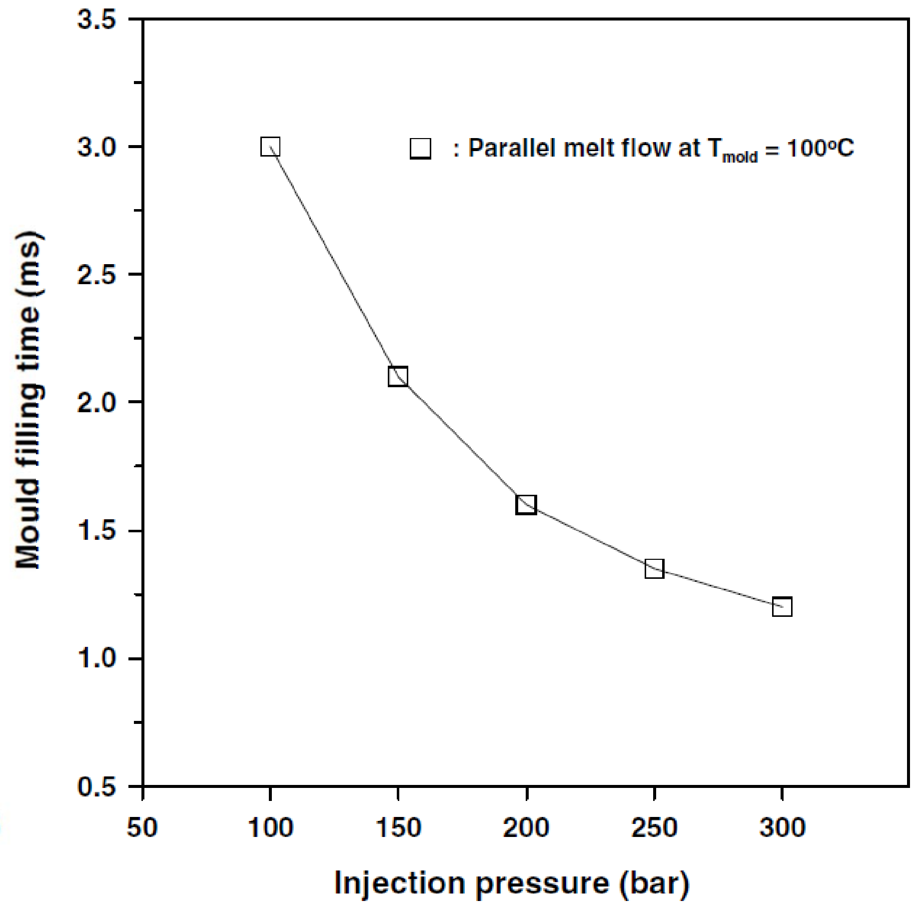




Huang, J. Micromech. Microeng. **17** (2007) 1518–1526

Injection molding for micron-scale pattern replication





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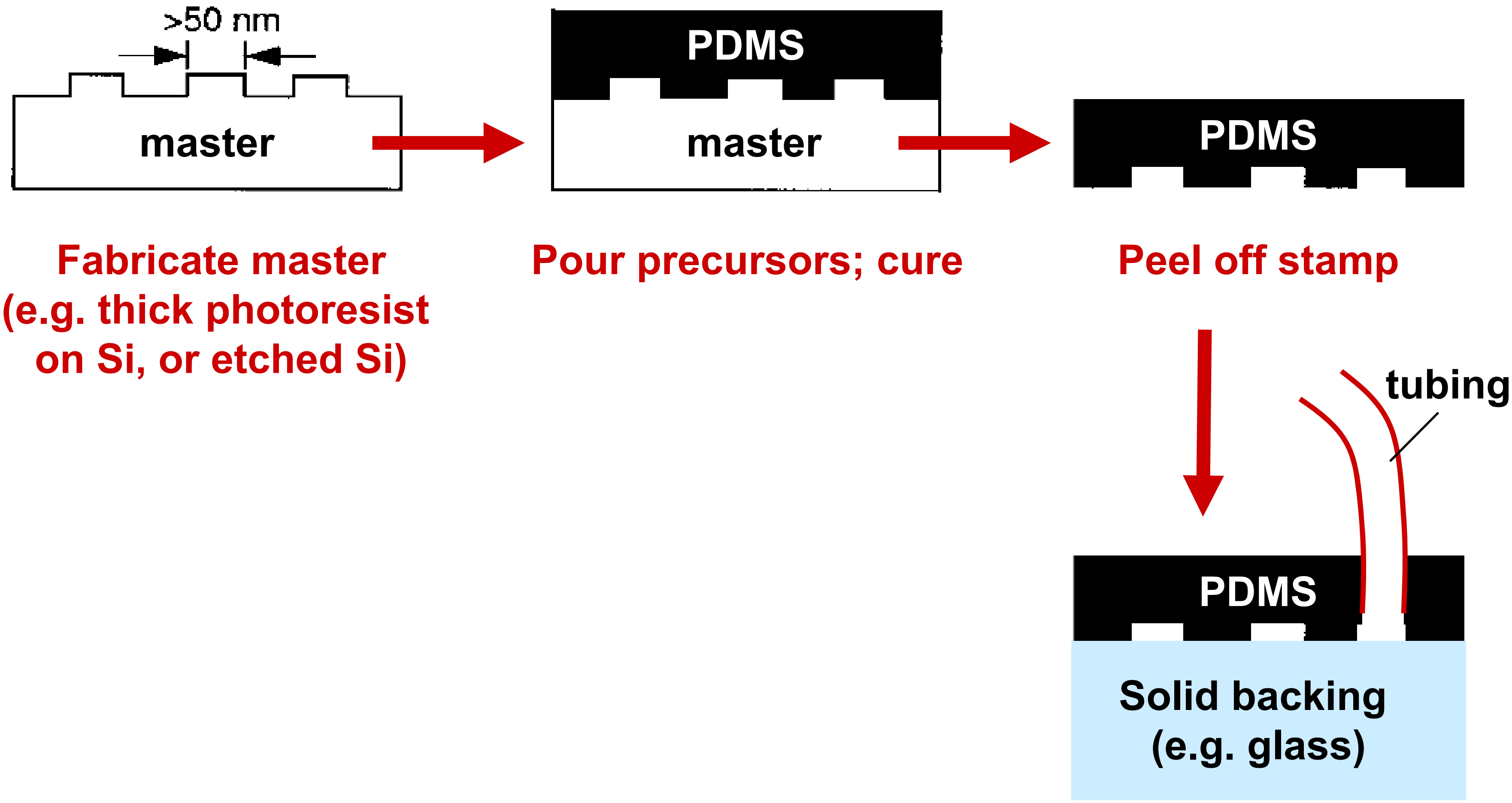
Micro-casting for device fabrication



Fabricate master (e.g. thick photoresist on Si, or etched Si)

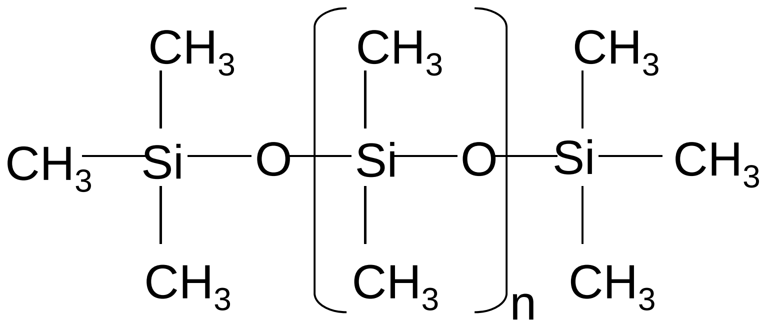
Pour precursors; cure

Peel off stamp

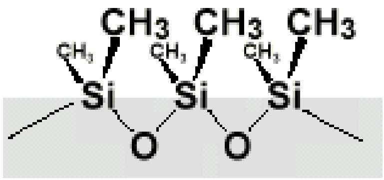
Bond channels closed

See, for example, Duffy and Whitesides, *Anal. Chem.*, vol. 70, pp. 4974-4984, 1998, and McDonald and Whitesides, *Acc. Chem. Res.*, vol. 35, pp. 491-499, 2002.

Plasma-activated bonding for PDMS



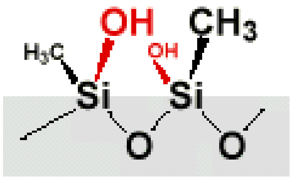
Upon treatment in oxygen plasma, PDMS seals to itself, glass, silicon, silicon nitride, and some plastic materials.



HYDROPHOBIC

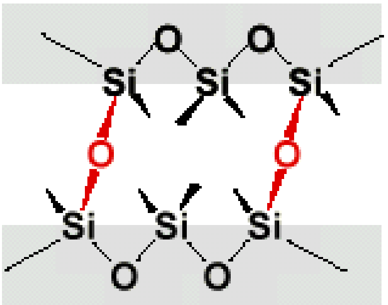
Expose to oxygen plasma (~ 1 min)

Air (~ 10 min??)

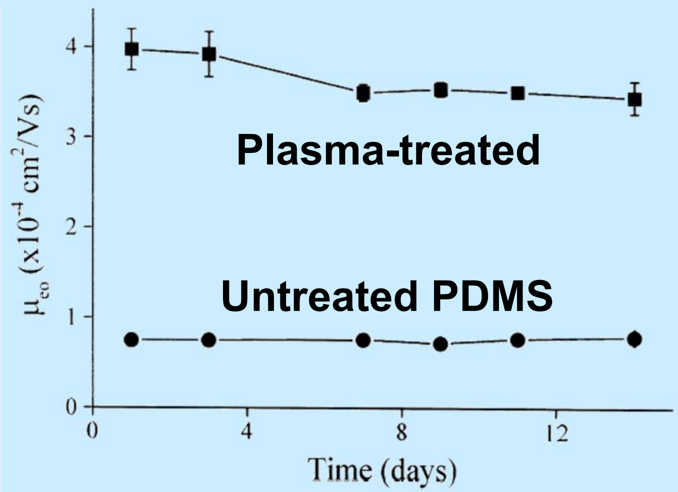


HYDROPHILIC

contact PDMS surfaces



irreversible seal: formation of covalent bonds



Electroosmotic mobility decays after plasma surface treatment: Ren *et al.*, *J. Chromat. B*, vol. 762, pp 117-125, 2001

Advantages of PDMS for microfluidics fabrication

- UV transparency down to ~ 240 nm: useful for sensing
- Ability to be made hydrophilic (plasma treatment)
  - But lifetime of hydrophilicity an open question [e.g. 1, 2]
- Useful gas permeability
  - Artificial lungs, cell culture chambers, etc [e.g. 3, 4]
- Ease of bonding; bonding tolerant to particles
  - Therefore don't necessarily need a clean-room
- Non-toxic to living cells
- Low stiffness useful for engineering multi-layer pump/valve microsystems [e.g. 5]

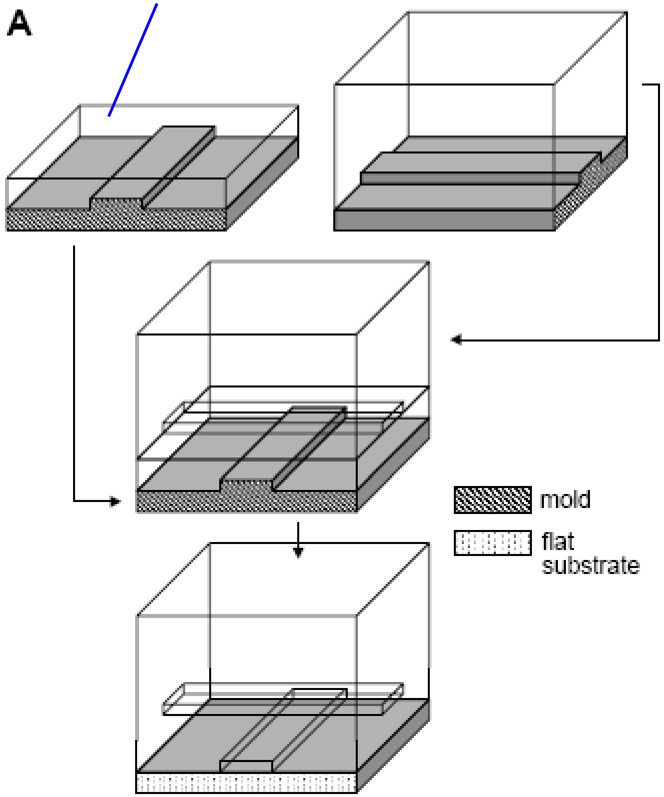
1. Ren *et al.*, *J. Chromat. B*, vol. 762, pp 117-125, 2001
2. Ro *et al.*, *Electrophoresis*, vol. 23, pp. 1129-1137, 2002
3. Thangawng *et al.*, *Biomed Microdevices,* vol. 9, pp. 587-595, 2007
4. Zanotto, Jensen *et al.*, *Biotech. Bioeng.*, vol. 87, pp. 243-254, 2004
5. Unger, Quake *et al.*, *Science*, vol. 288, pp. 113-116, 2000

Disadvantages of PDMS for microfluidics fabrication

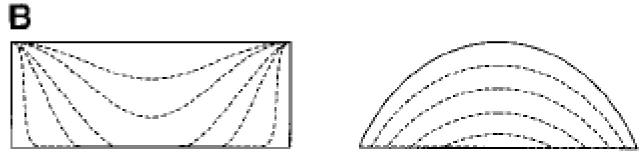
- Permeability – parasitic absorption of molecules
- Variability of material parameters
- Irreversibility of bond – makes multilayer alignment challenging
- Difficulty of automating handling of highly flexible polymers

Valves and pumps made with multilayer soft lithography

This layer of PDMS is spun on: ~30 µm-thick valve membrane

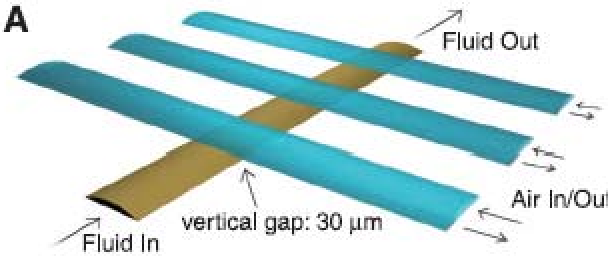


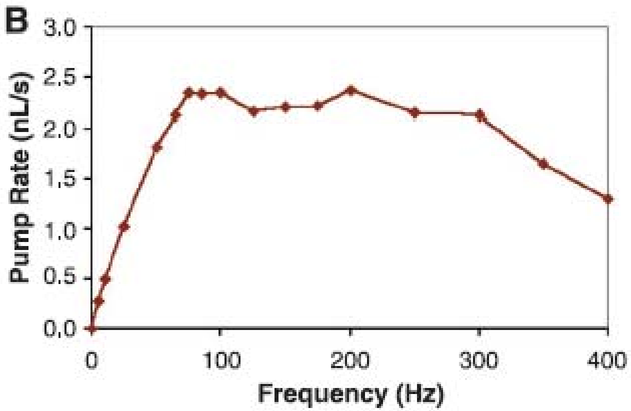
Pneumatic microvalve fabrication



Pneumatic microvalve actuation

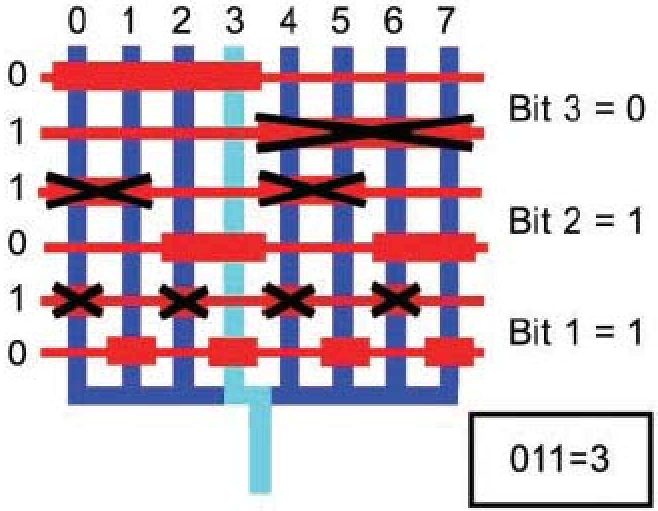
Elastomeric peristaltic pump



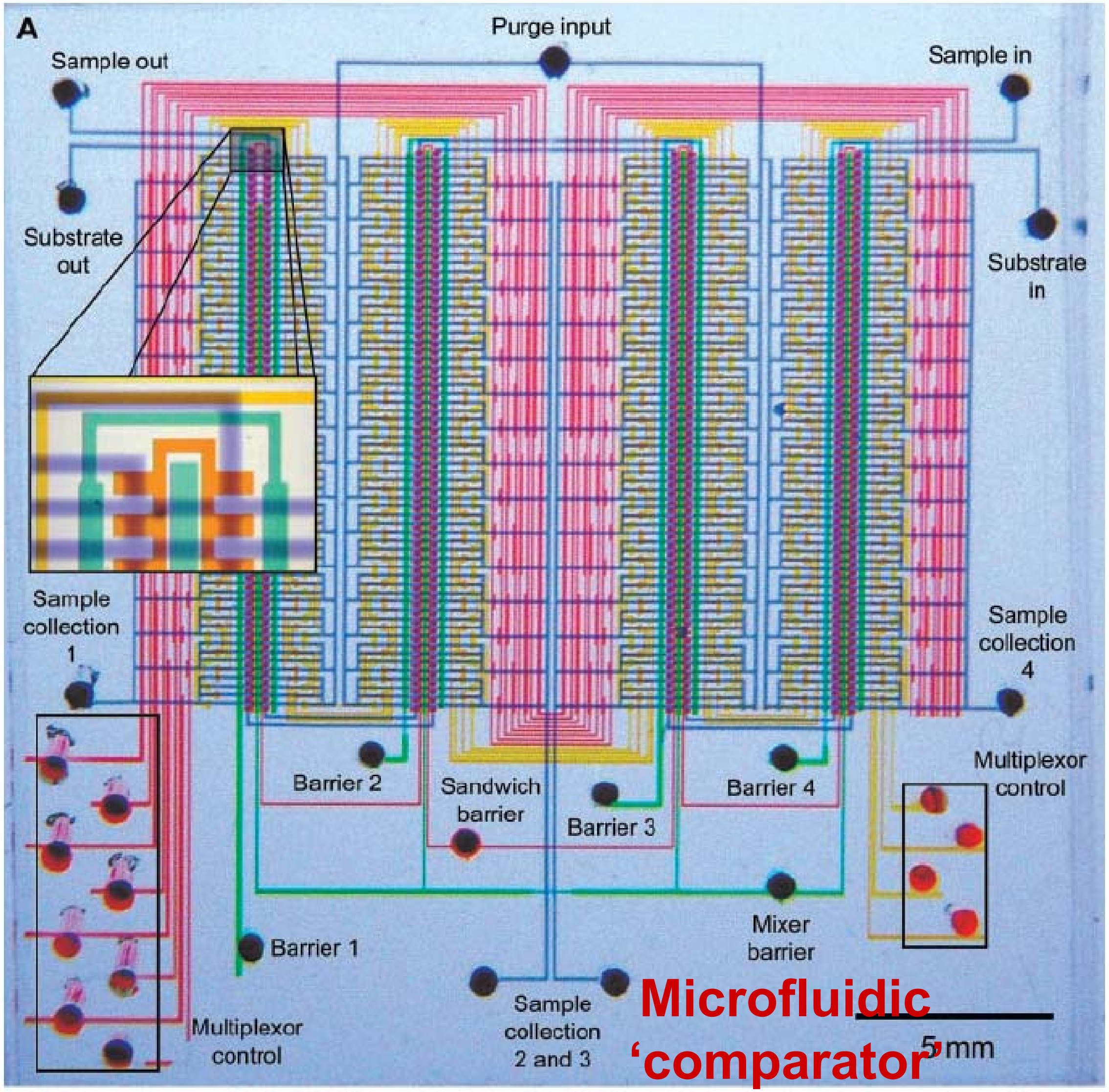


Unger, Quake *et al.*, *Science*, vol. 288, pp. 113-116, 2000

Microfluidic large-scale integration



Example of binary decoder



Microfluidic 'comparator'

Thorsen, Quake *et al.*, *Science*, vol. 298, pp. 580-583, 2002