Nontraditional Microfabrication Techniques

Other Micromachining Techniques

- Template replication
- Sealed cavity formation
- Surface modification
- Printing
- Stereolithography (3-D)
- Sharp tip formation
- Chemical-mechanical polishing
- Electric discharge machining
- Precision mechanical machining
- Thermomigration
- Photosensitive glass
- Focused ion beam
- SCREAM

Sealed Cavity Formation

- Form structure using sacrificial material and small access holes
- Cover holes using one of three methods
  - Simple application of glues, plastics, photoresist, etc
  - Thin-film application such as sputtered, evaporated, and CVD films
  - Reactive sealing, i.e. thermal oxidation, etc
- Gettering- collect gases in cavity

Surface Modification

- Used to change surface properties, especially in biomedical applications
- HMDS used to “methylate” surface and remove hydroxyl groups
- Self-assembled monolayers (SAMs) formed using RSiCl3 (R is alkyl group)
- Often used to reduce wear and adhesion forces
- Apply dendrimers (hyper-branched polymers) for molecule recognition

Printing

- Useful for non-planar substrates
- Very low-cost
- Screen printing
  - Resolution limit of about 100 mm
  - Alignment more difficult
  - Great for patterning polymer layers in biosensors
  - One step process
  - Requires liquid form
- Transfer printing
  - Raised bumps used to transfer ink, etc
- Powder loaded polymers
  - Material properties dependent on material in plastic liquid that can be rolled on and patterned
- Ink jet

Micromechanical Machining - An Option to Lithography

• Can produce extremely smooth, precise, highresolution structures
• Expensive, non-parallel, but handles much larger substrates
• Precision cutting on lathes produces miniature screws, etc with 12 mm accuracy
• Chip Processes
  – diamond machining, tools ~100 mm thermal surfaces, fluid microchannels
  – microdrilling, tools > 25 mm manifolds, fiber optics, molds
  – micromilling, tools ~22 mm, features < 8 mm molds, masks, thermal surfaces

Micromechanical Machining - An Option to Lithography

- Energy Processes

– microEDM, tools > 10 :m microturbines, toolselectrodes, stators

– focused ion beam (FIB), atomic-scale machining,
micromilling tools, probes, etc.

– laser, micron-scale spot ablate hard materials, polymerization

Micromechanical Machining Characteristics

- Relative tolerances are more typically 1/10 to 1/1000 of feature or part dimensions
- Absolute tolerances are typically similar to those for conventional precision machining (micrometer to sub-micrometer)
- Feature is often inaccessible by conventional metrology techniques (high aspect ratio boolean negative features)
- Like conventional machining, in-process, on-line metrology is preferred over post-process or off-line metrology

General Micromachining Metrology

- Tool location
  - Endmills 8 mm x 2 mm
  - 22 mm x 3 mm
  - Drills 25 mm x 4 mm
  - Diamond 100 mm x 2 mm
- Part/fixture location for multiple processes in multiple machines
- Post processing of lithographic molds
- Post processing of electroplated structures

Complementary Processes (Direct Removal Processes)

- Chip making (force processes)
  - Diamond machining
  - Microdrilling
  - Micromilling
  - Grinding and polishing
  - Microsawing
- Energy beam (forceless processes)
  - Focused ion beam
  - Micro electrical discharge
  - Laser ablative and photo polymerization

Microfabrication Using Polymers

Polymers for Microfabrication

- Examples diverse
  - PDMS
  - PMMA
  - Polyurethane
  - Polyimide
  - Polystyrene
- Disadvantages
  - Low thermal stability
  - Low thermal and electrical conductivity
  - Techniques for fabrication on microscale not as well developed

PDMS (Polydimethylsiloxane)

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

Soft Lithography

- Developed by Whitesides, et. al. at Harvard
- Microcontact printing
  - Elastomeric stamp
  - Patterns of self-assembled monolayers (SAMs) and proteins
  - SAMs allow a variety of surface modifications
- Thickness variation by changing tail length
- Modification of tail group changes surface properties
- Variety available for different substrate materials
    - Other SAM advantages
- Self healing and defect rejecting
- Ultrathin resists and seed layers
- Do not require clean room facilities
- Low cost
    - Fabricated using a PDMS mold of "photoresist" structure

High Aspect Ratio Molding

LIGA Process; typical Materials are Ni, NiCo

- Micromachining; typical Materials are Brass, Al alloys
- Si Micromachining; typical Materials are Si, Ni
- Combination of Various Techniques Followed by Electroplating: Ni, NiCo

Compound Abbrivation Glass Transition [ºC]

Polymethylmethacrylate PMMA 105
Polycarbonate PC 150
Polysuflone PSU 190
Polyoxymethylene POM 165
Polyethylethylketone PEEK 340
Polyvinylidenfluorid PVDF 170
Polyamide PA 12 180

Mold Inserts

Basic requirements

- Low mechanical stiction and friction
- No deviation from vertical sidewalls (no undercuts)
- Avoid surface oxidation

  Chemically inert

  Smooth surfaces

  Defect free sidewalls

  Homogeneous material properties

Common Molding Materials

PMMA
Poly(methyl methacrylate),
Tg 100°C, Tproc 170°C-210°C
Transparent, brittle, sensitive to crack
optics, lost mold for production of metallic microstructures

PC
Poly(carbonate),
Tg 148°C, Tproc 180°C-200°C
Transparent, good hardness and impact strength
optics, medical

POM
Poly(oxy methylene),
Tm = 156°C (Copolymer), Tproc 180°C
Tm = 175°C (Homopolymer)
Low friction, good impact strength, critical decomposition into formaldehyde, critical cavitation due to crystallization
mechanical applications (gear wheels)

PSU
Poly(sulfone),
Tg 190°C, Tproc 250°C
Transparent, high strength
for use at higher temperatures up to 180°C, microfluidic pump

Molding of Ceramic Microstructures

Why are we Interested in Ceramic Microstructures ?
But

- Attractive Material Properties (Mechanical, Chemical, Thermal,..
- Additional Functionality (PZT Effect, Conductivity, Shrink Compensated,..)
- More Compatible to other Materials used in MST than Polymers
- Can the Material be Processed on the Micrometer Scale ?
- Can the LIGA like Sidewall Quality be Maintained?
- Can the Microstructures be Mass Fabricated?
- Can the Overall Shrinkage due to Sintering be Compensated and the Dimensional Accuracy Ensured?

General Design Rules for Mold

- Round the corners where the polymer will shrink onto the metal
- Avoid patterning numerous aspect ratios in one sample (ie. Use AR that deviate +/- 2 from the average AR in the pattern)
- Centralize the patterns that are most critical.

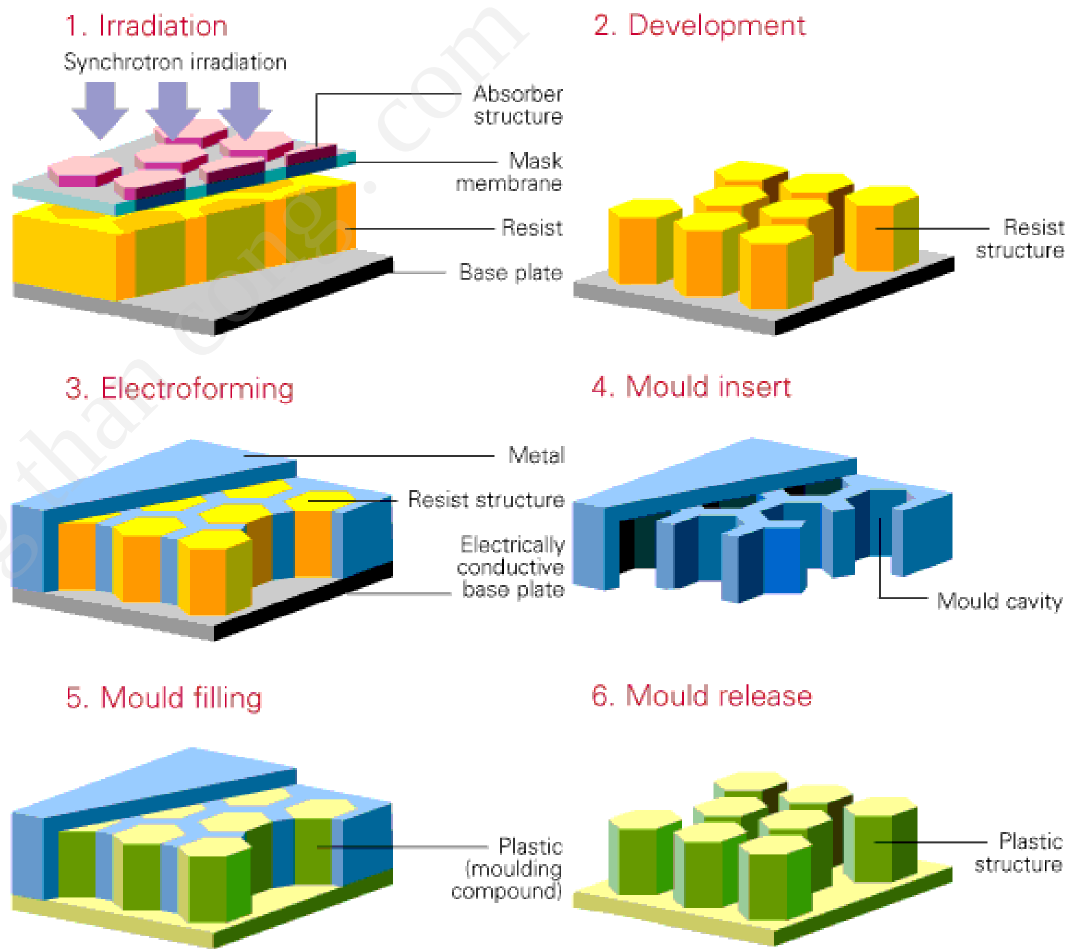
Deviation further from center are more difficult to emboss

General Design Rules for Mold

- Sidewall quality is critical
  - Surface roughness > 500 nm
  - Perpendicularity >85° with >2 ° center bowing
- Bottom surface quality less critical
  - Surface roughness > 10 mm

LIGA process

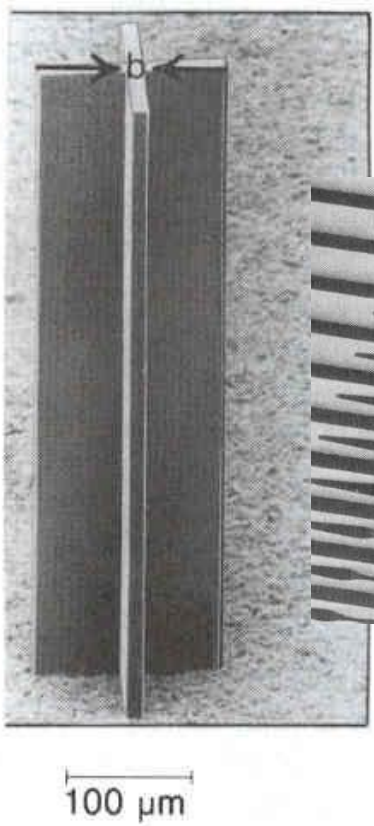
- LIGA
  - German term
    - Lithographie, Galvanoformung, Abformung ➔ Lithography, electroplating, molding
  - Also called DXRL (Deep X-ray lithography)
  - XRL
    - IC: small feature sizes using small wavelength of X-ray (many industry gave up)
    - MEMS: Very thick structures using high energy

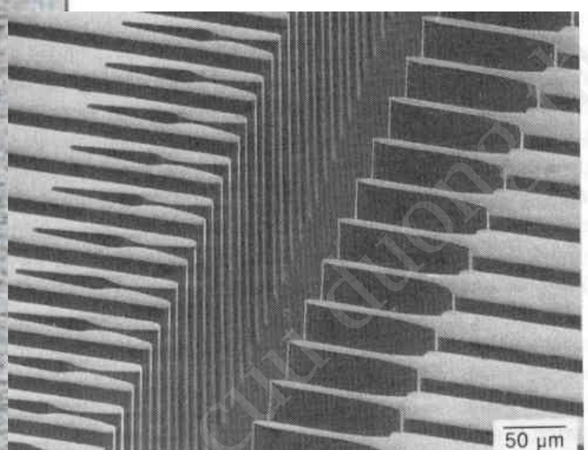


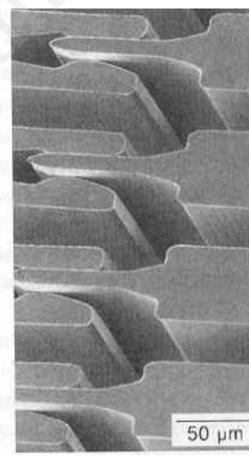
Source : IMM, Institut für Mikrotechnik mainz Gmbh

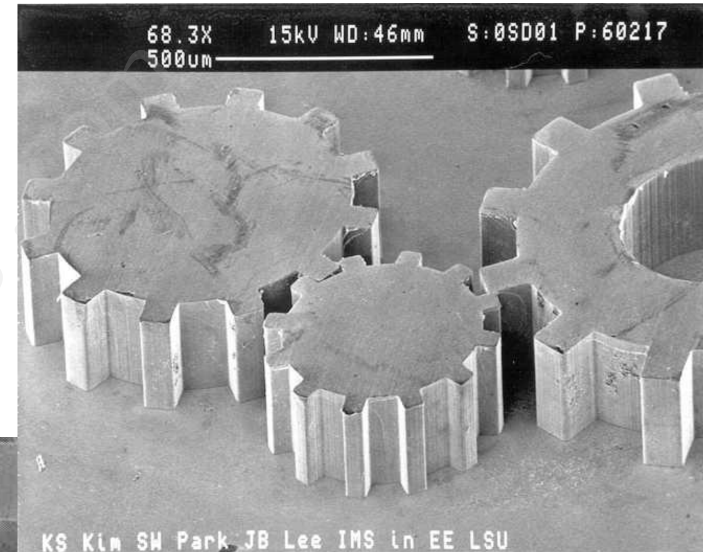
LIGA examples

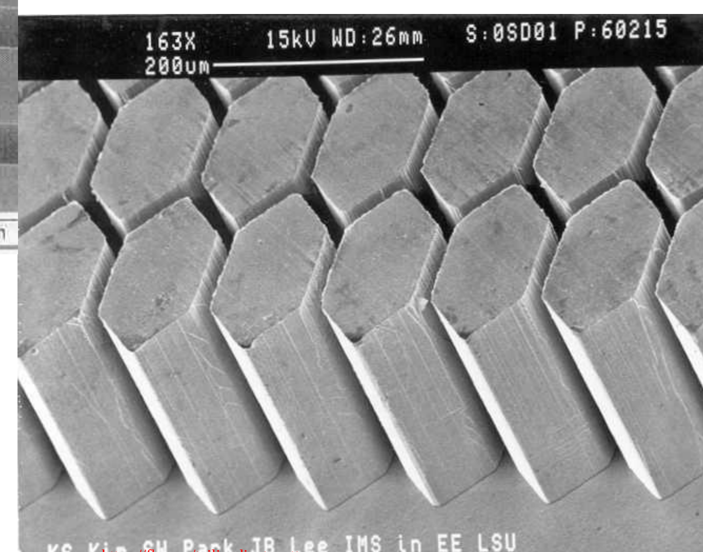
- High aspect ratio microstructures (HARMs)
  - Thickness: ~2 mm
  - Aspect ratio: > 10:1





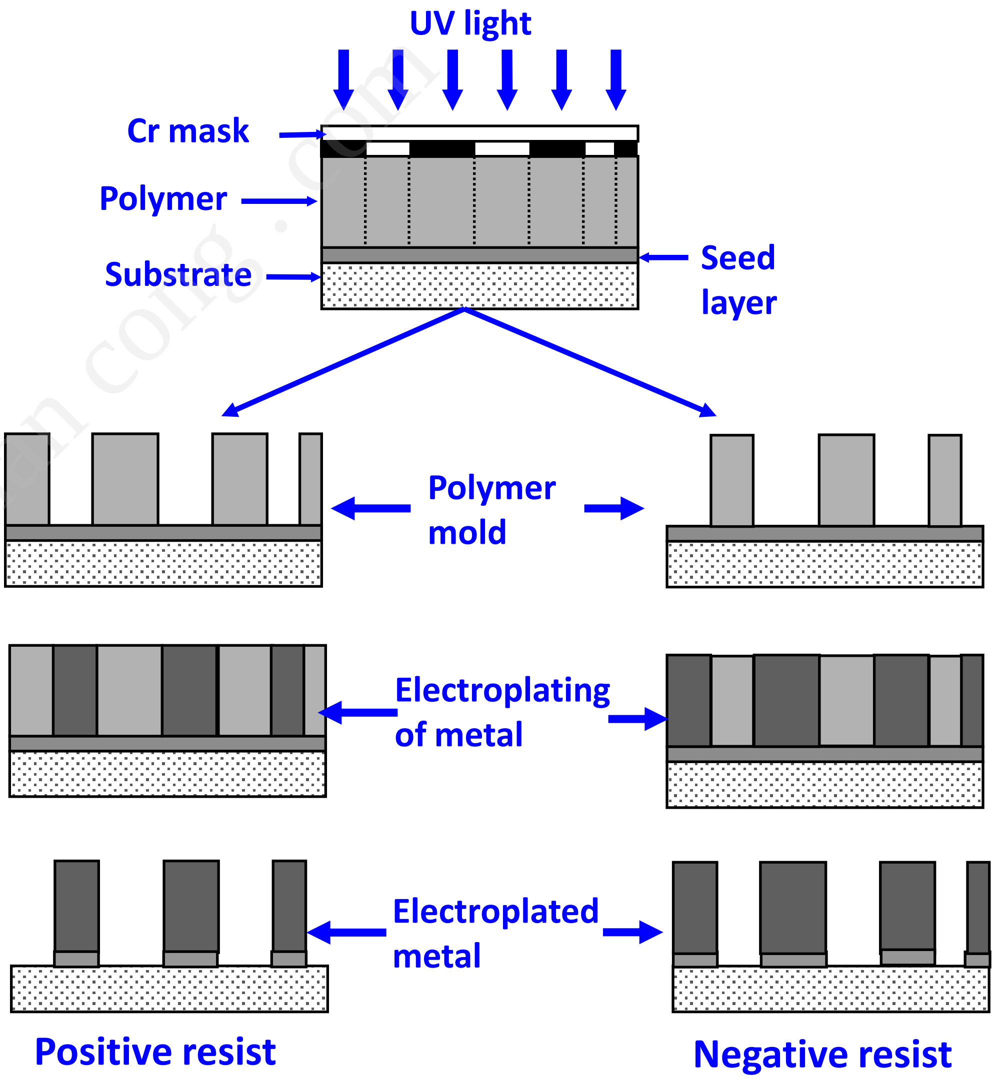




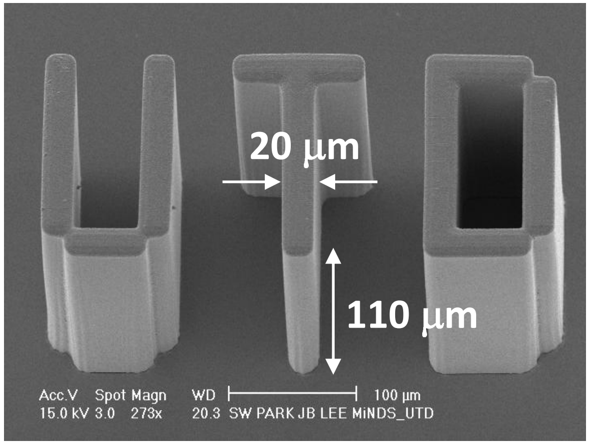


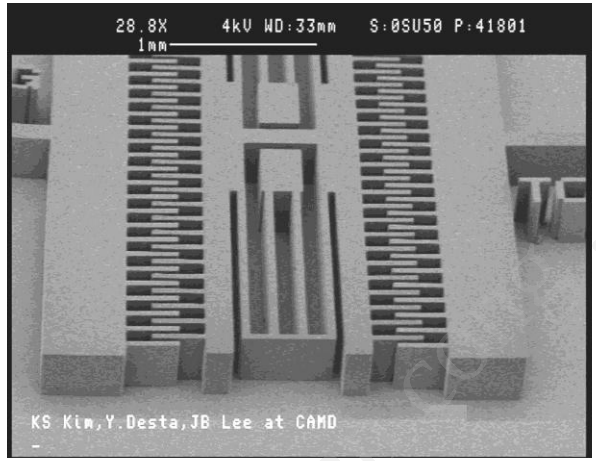
UV-LIGA process

- UV-LIGA
  - Standard UV lithography
  - UV-sensitive polymeric resists: +ve PR, -ve PR (SU-8 epoxy, polyimide, thick photoresist)
  - Multi-layer possible
  - Cost-effective compared to LIGA (Also called LIGA-like or poor man's LIGA)
- Polymer as electroplating mold
  - PR
    - Low aspect ratio (< 1:1)
    - ~40 μm thick
  - Polyimide
    - Low aspect ratio (< 3:1)
    - ~80 μm thick
  - SU-8 epoxy
    - High aspect ratio (~10:1)
    - ~ 500 μm thick

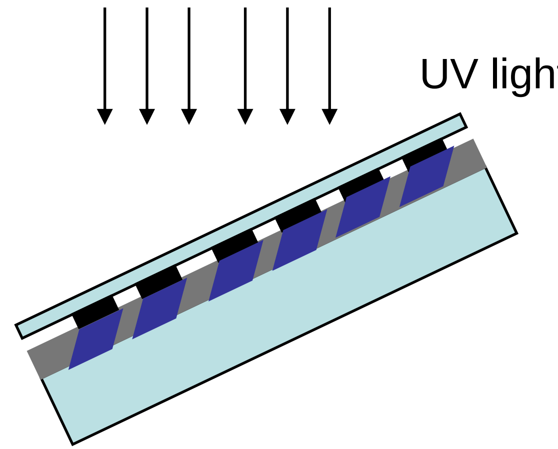


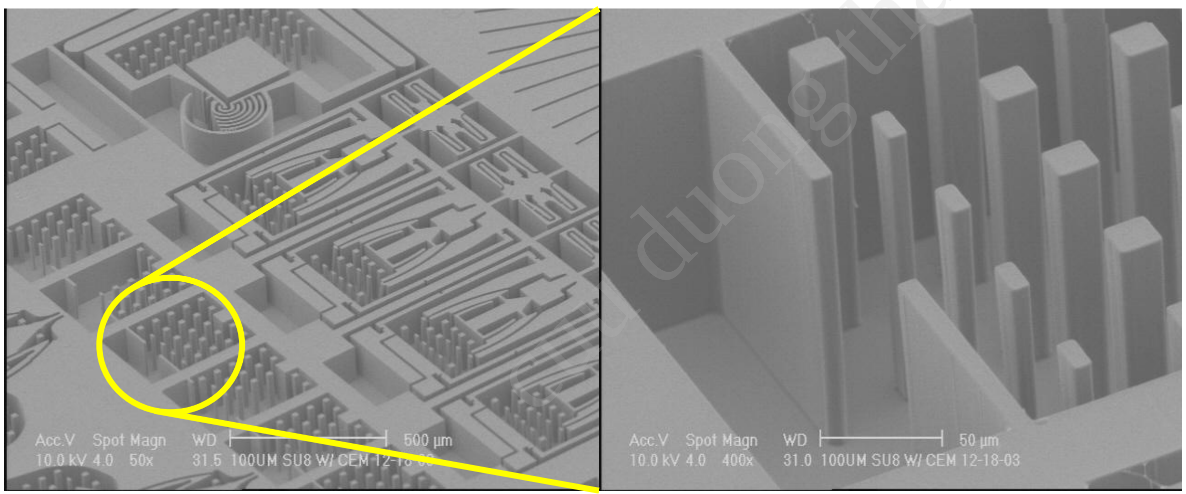
Examples of UV-LIGA processed SU-8

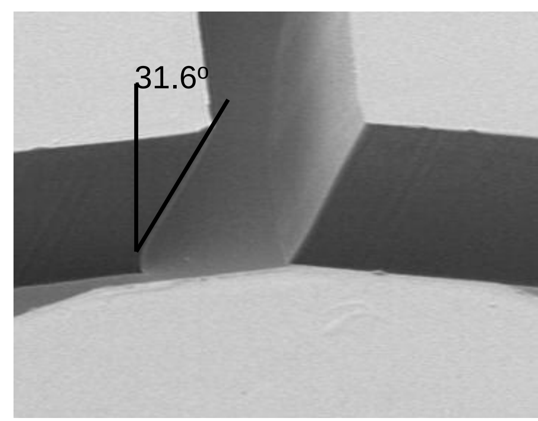




Tilted SU-8 exposure

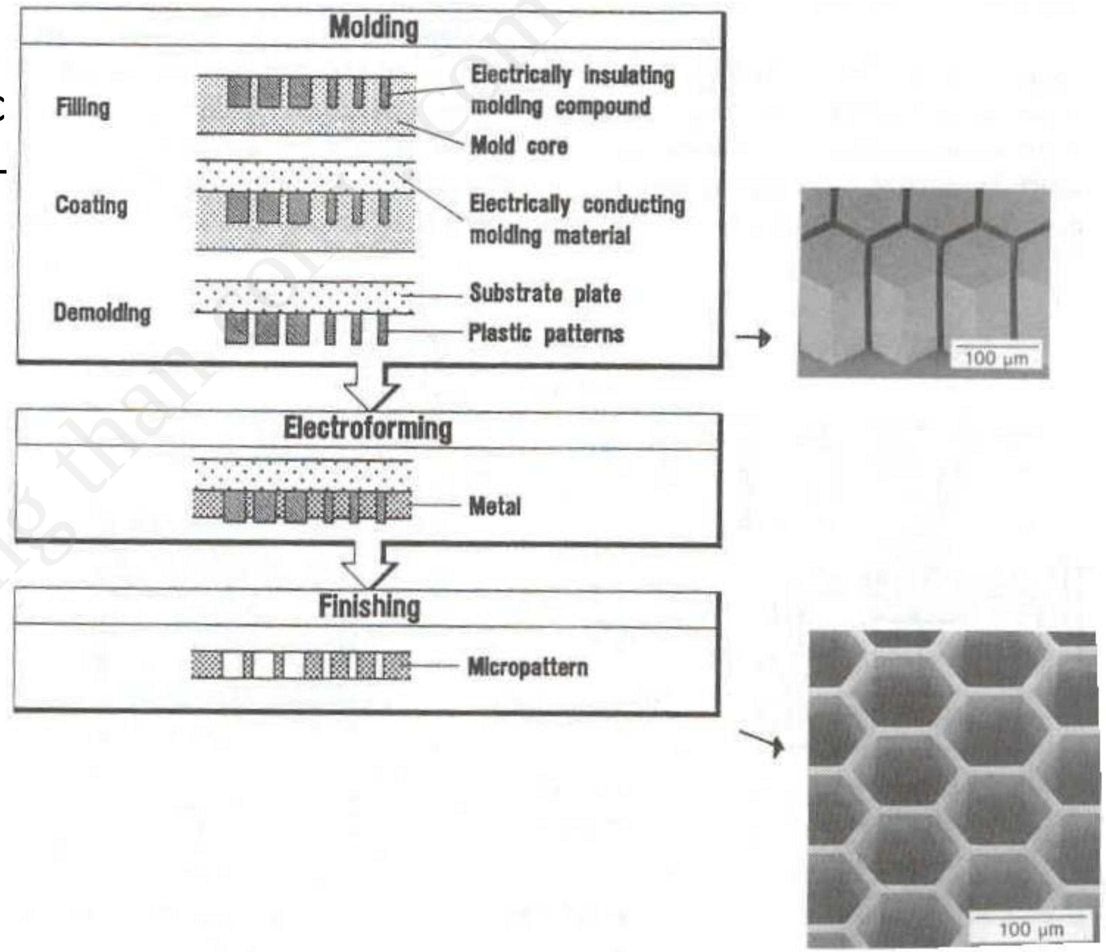




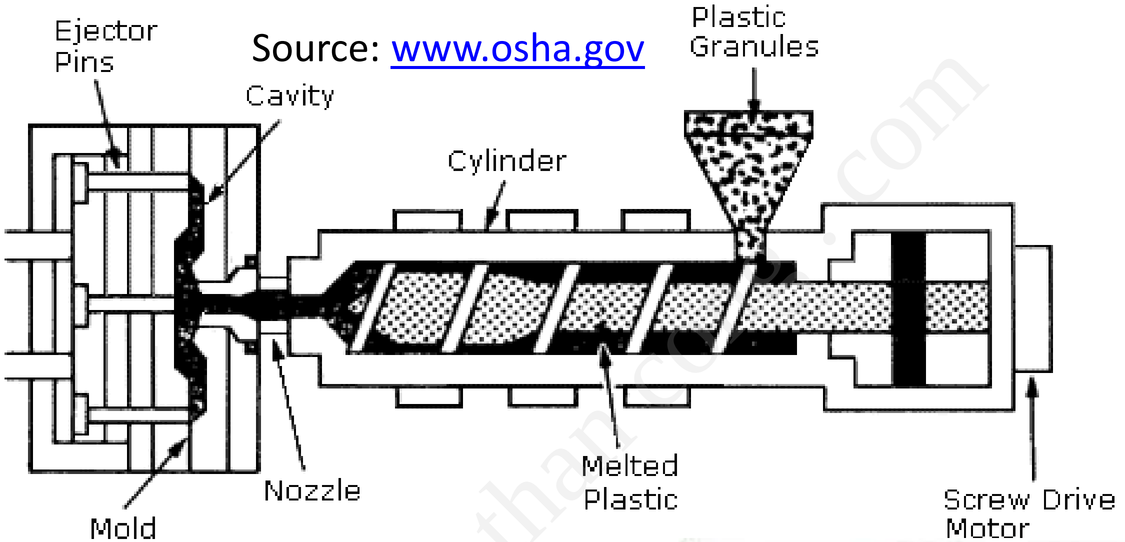


Molding

- Molding
  - Low cost massive production of precise plastic parts using LIGA or UV-LIGA-processed metallic mold inserts
- Injection molding
  - Molten plastic is injected onto a metallic mold insert
  - Heated above glass transition temperature (T_g) of the plastic
  - Polymers
    - PE, PP, PC, PMMA, COC, or biodegradable polymers (e.g. RESOMER®)



Injection molding system



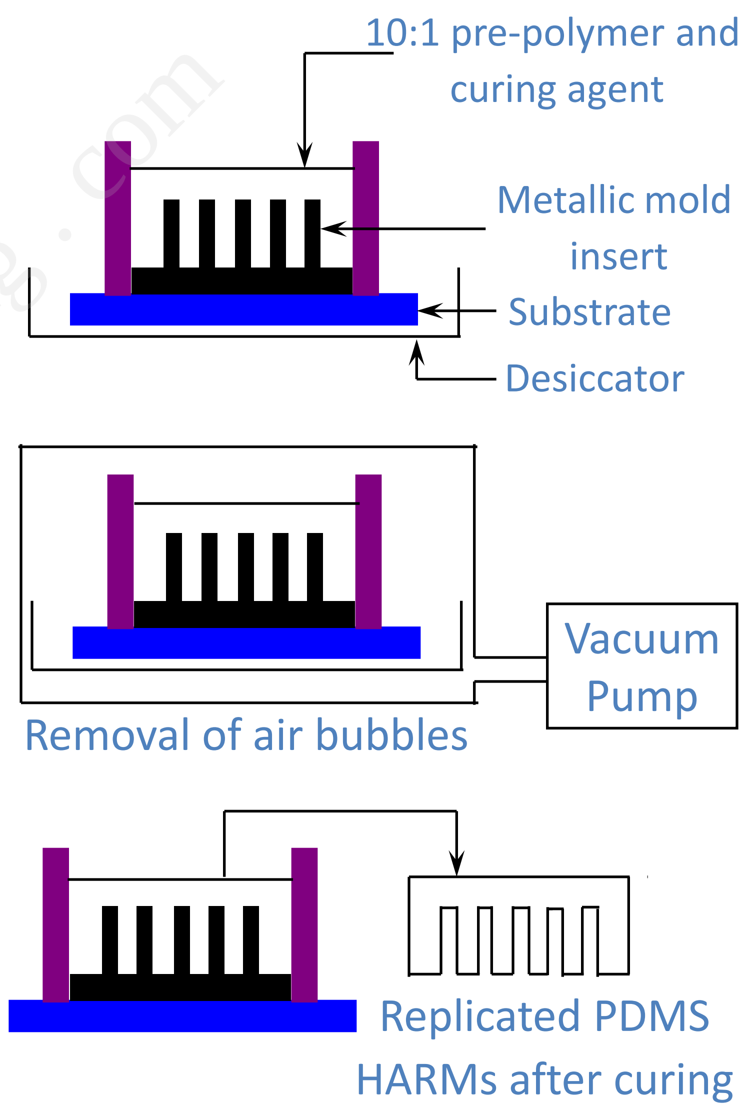
Source: www.osha.gov

Injection molded plastic toys

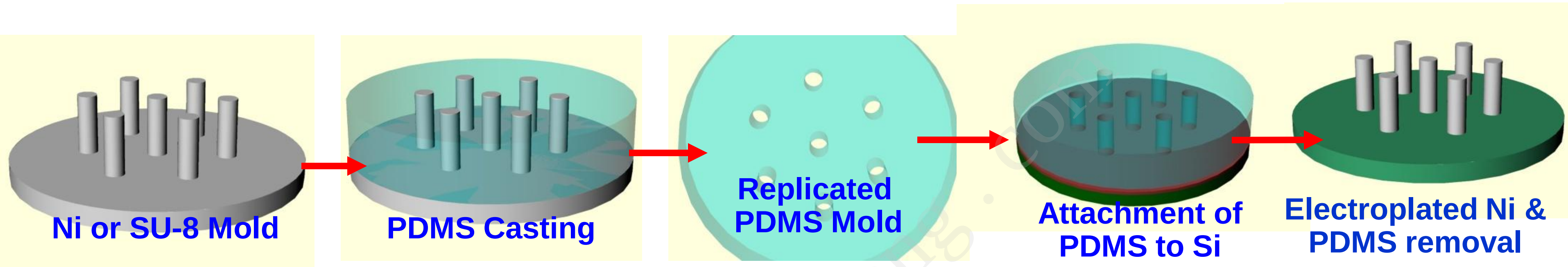
www.toysrgus.com

PDMS molding process

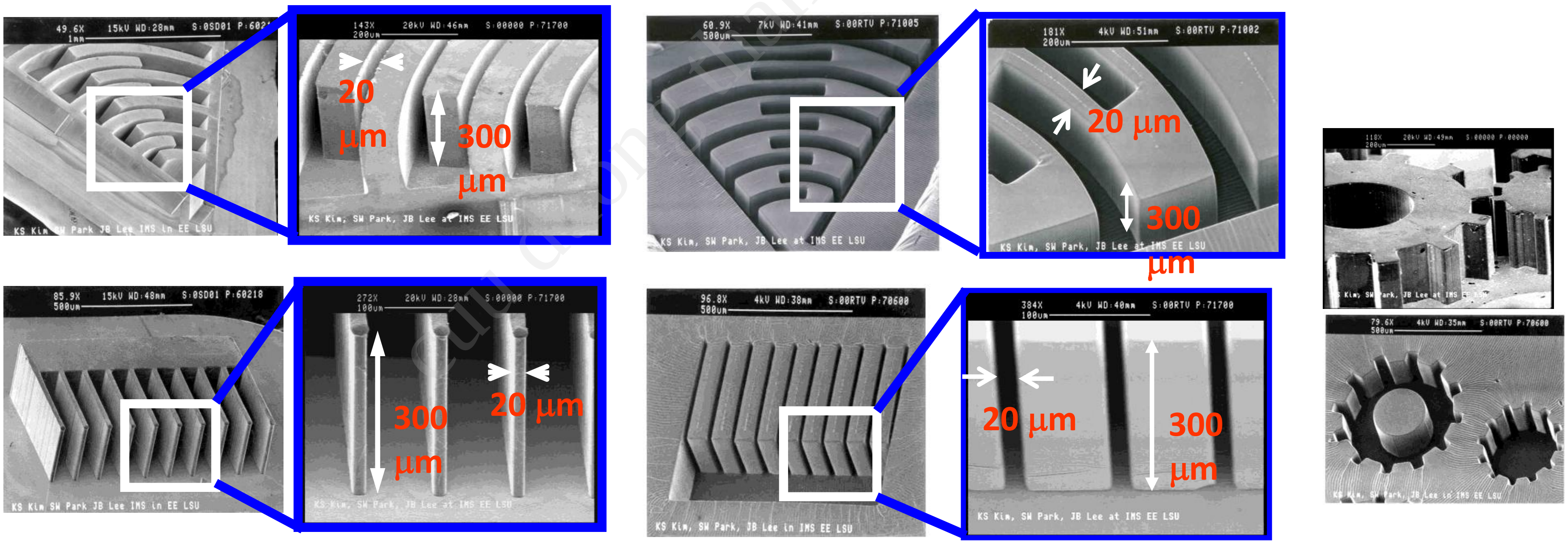
- PDMS (polydimethyl siloxane)
  - Microelectronics compatible silicone elastomer, durable, optically transparent, and inexpensive
- Process
  - A mixture of PDMS pre-polymer and a curing agent cast or spin-coated onto master molds
  - Cured at 100 °C for ~1 hour (65 °C for 4 hours)
  - Replicated PDMS peeled off from master molds
- Advantages
  - No need of expensive equipment such as injection molding and hot embossing machines for polymer replication
  - Low temperature processing for curing PDMS (65 °C)



PDMS replication and pattern transfer process



Application : massive replication of precision PDMS microstructures, pattern transfer of MEMS components on circuit

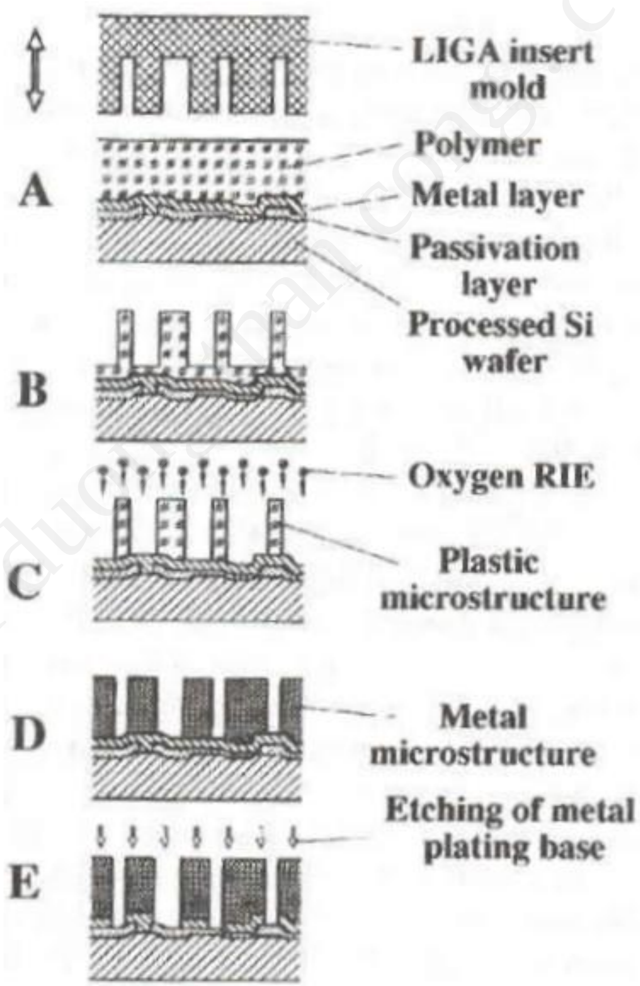


Ni mold

Replicated PDMS

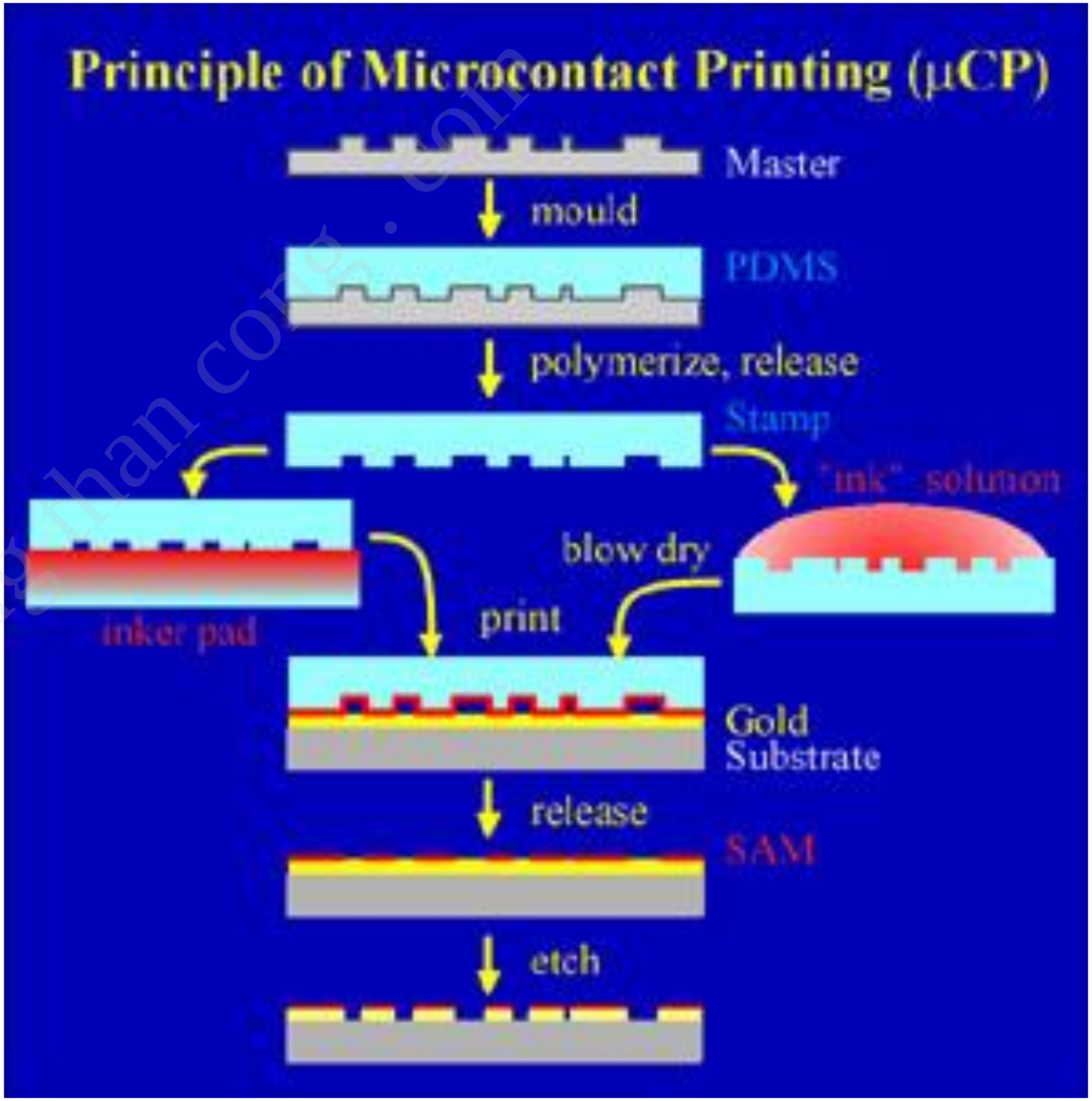
Hot embossing

- Hot embossing
  - Plastic is heated above T_g and a mold insert is pressed into the plastic



Micro contact printing (μCP)

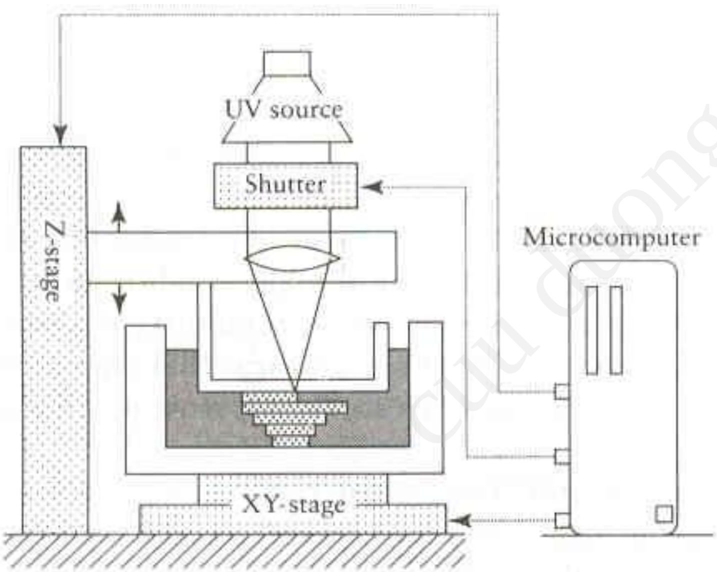
Stamping picture

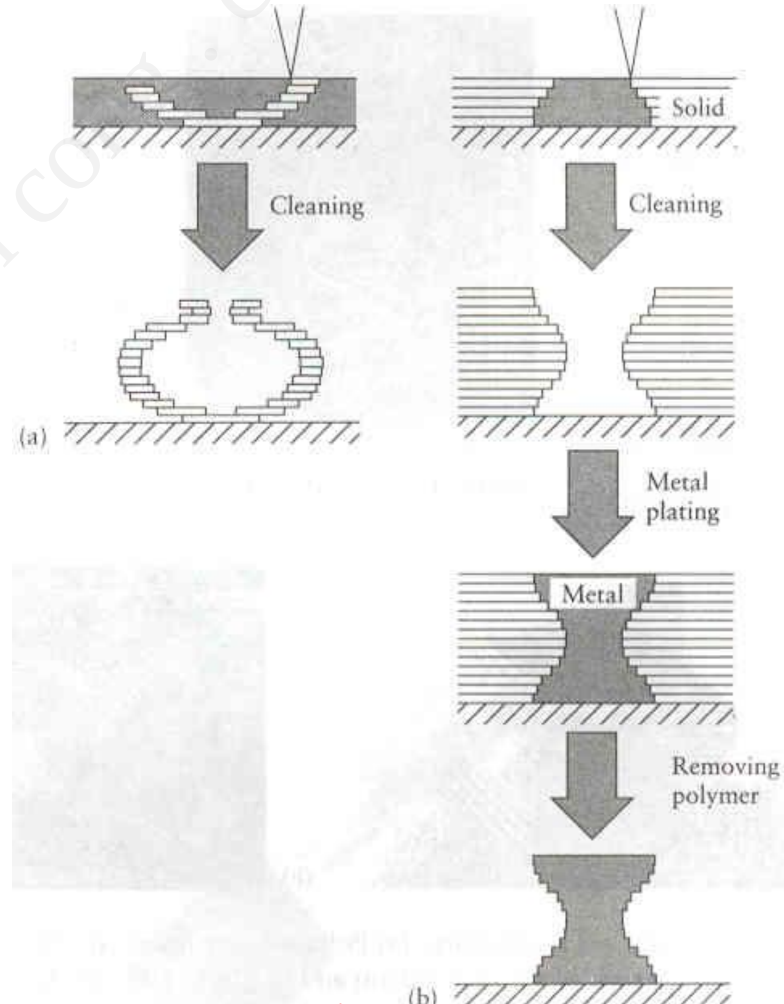


Source: http://www.zurich.ibm.com/st/microcontact/highres/mucp.html

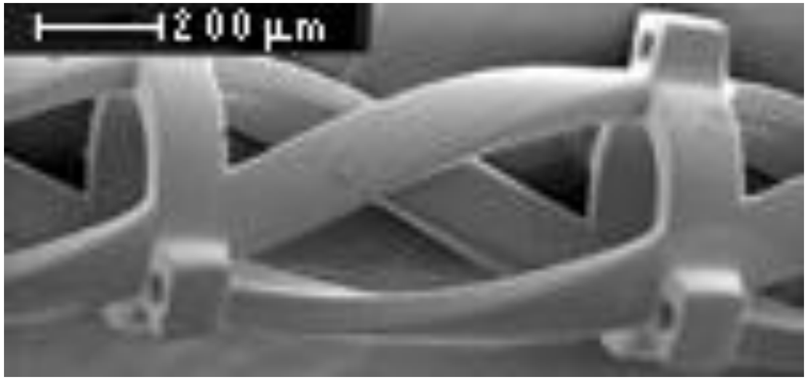
Stereolithography (SL)

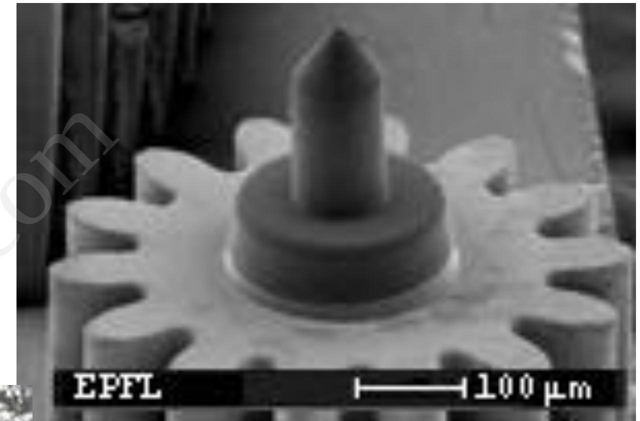
- Stereolithography
  - Repeatedly print layers that become part of a final microstructures
  - Freeform 3D structures made of polymers
    - Optical energy is focused and locally hardens a photopolymer
  - Rapid prototyping
  - Low cost
  - No integration w/ electronics

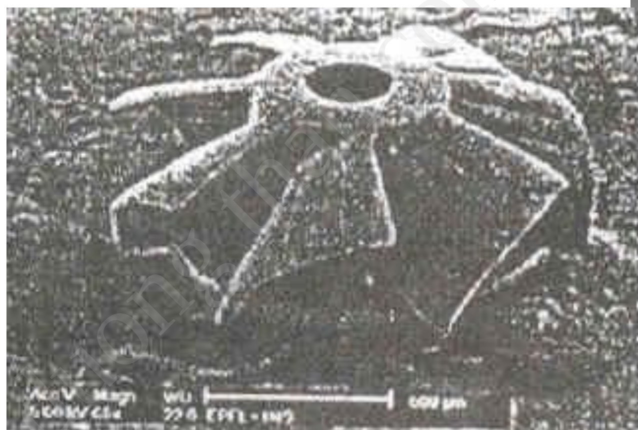


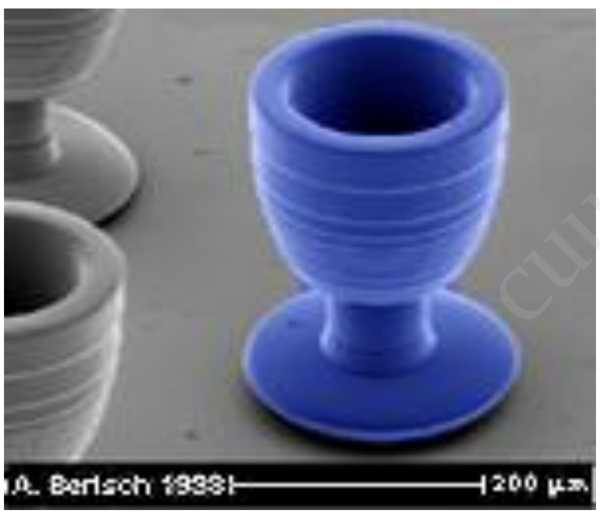


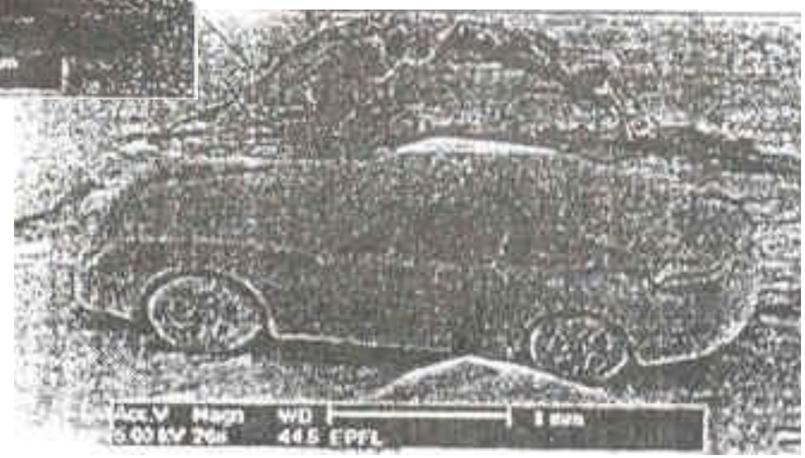
Micro SL examples











Source: http://dmtwww.epfl.ch/ims/micsys/

Miscellaneous micromachining techniques

- EDM (Electro-discharge machining)
  - Also called spark machining
    - Metal is locally removed by high frequency electrical sparks
  - Used for unusual designs in hard, brittle metals

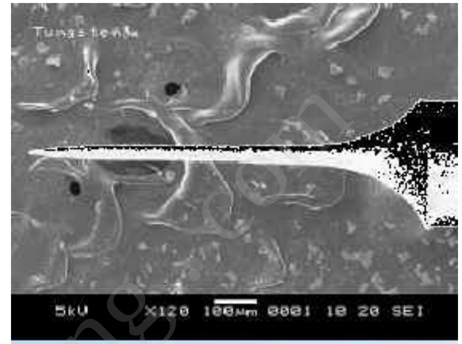
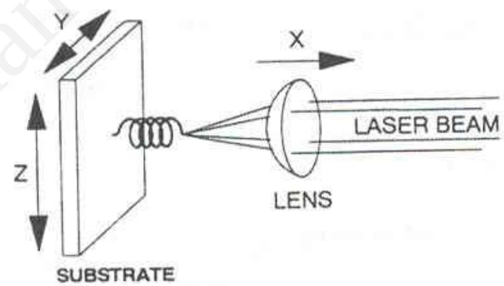
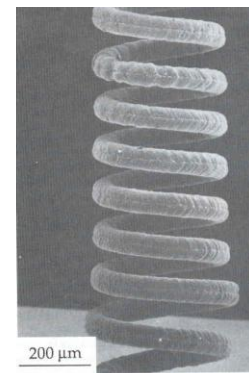


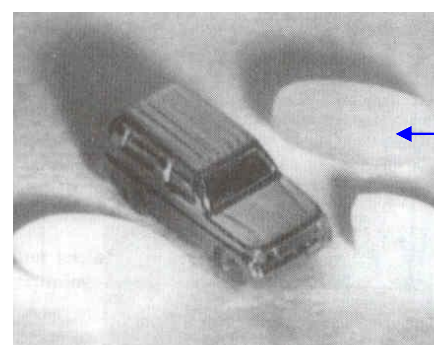
Figure 1: Cylindrical electrode (Φ30µm). The scale of the picture is as indicated.

Source: http://www.eng.nus.edu.sg/EResnews/0601/sf/sf_4.html

- LCVD (Laser-assisted chemical vapor deposition)
  - Energy needed for deposition is provided by photons
  - Complex 3D structures
    - Adjusting the focal point of the laser continuously







rice

A 7-mm car fabricated by precision machining

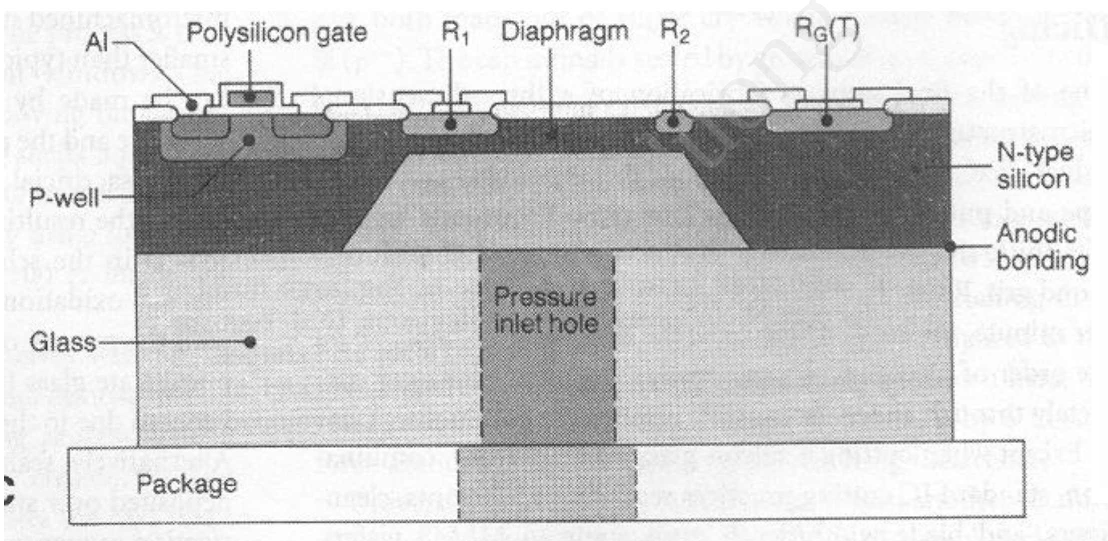
Packaging Technology

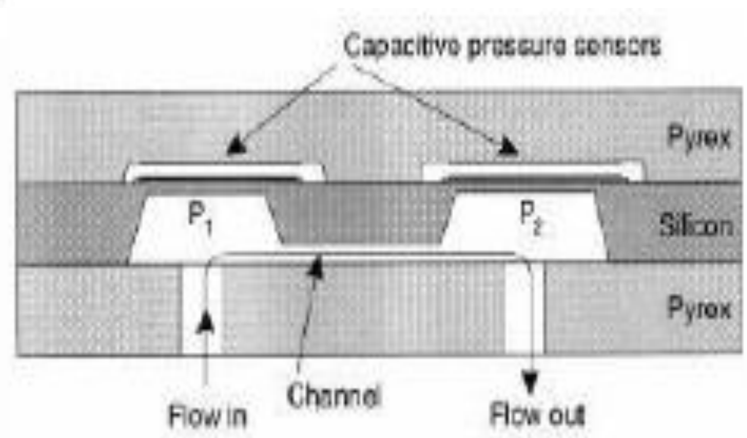
Bonding techniques

- Wafer bonding
- Plasma bonding
- Anodic bonding
- Adhesive bonding

Wafer bonding

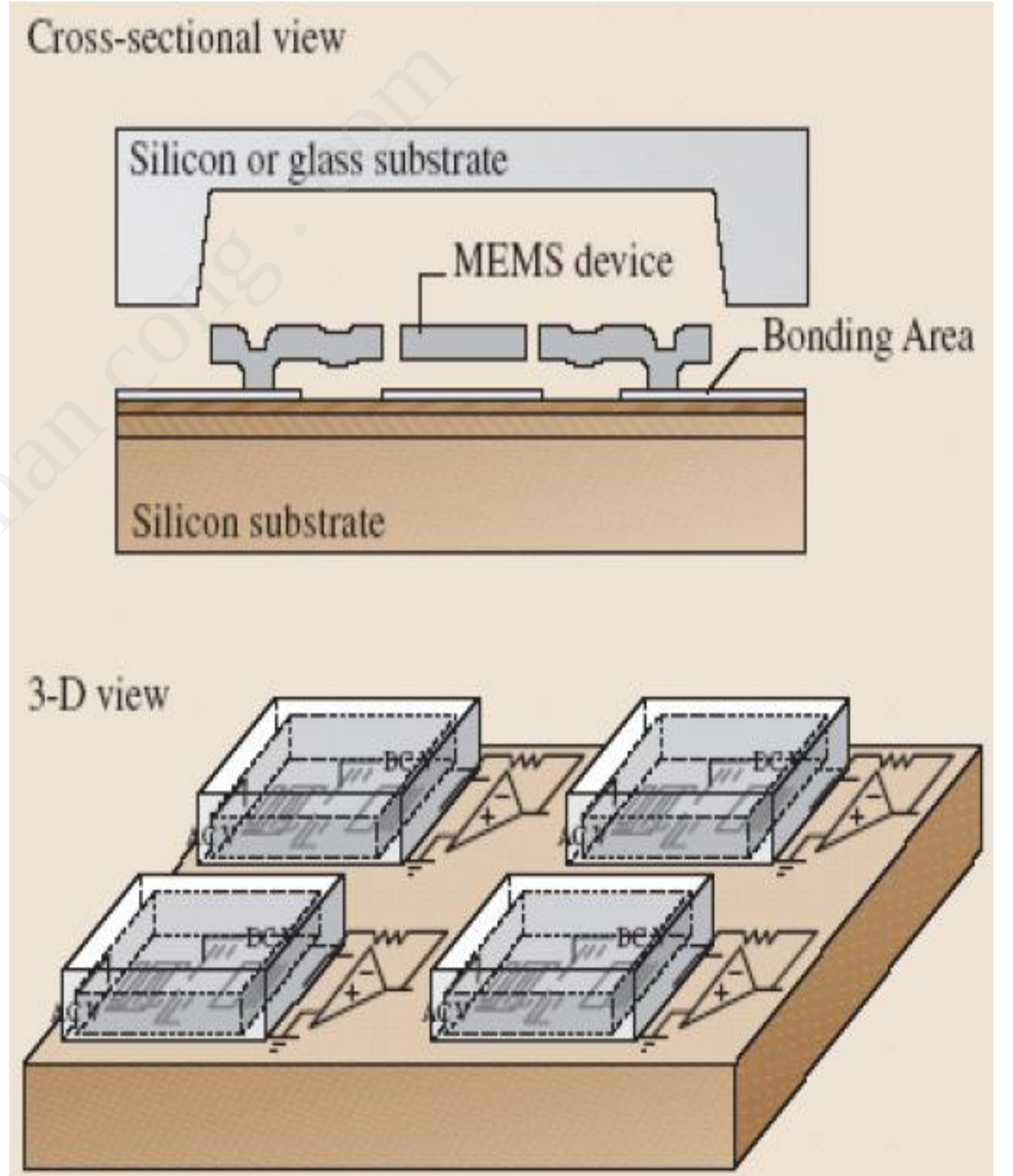
- Wafer bonding technique
  - A technique to create cavities or channels
  - Joint wafers together to provide hermetic sealing
  - Bond similar or dissimilar substrates permanently
  - Various bonding techniques are used
    - Anodic bonding, fusion bonding, eutectic bonding, glass frit bonding, ….





IC vs. MEMS packaging

- IC packaging
  - ICs are 2D planar devices and immoveable
  - Standardized process
  - Well established mass production technology
  - 1/3 ~2/3 of the total manufacturing cost
- MEMS packaging
  - MEMS devices are mostly freestanding and moveable
  - Non-standardized process
    - Packaging requirement different from one MEMS device to another
  - Easily takes up 2/3 or more of the manufacturing cost for initial commercialization



TI DLP packaging process