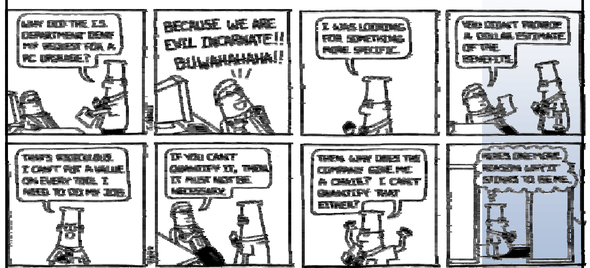
Microfabrication Using Polymers

Dr. Bruce K. Gale
Microsystems Principles
ENGR 494C and 594C

Can We Measure Everything?



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
- Advantages over silicon
  - Inexpensive
  - Flexible
  - Transparent to visible/ UV
  - Easily molded
  - Surface properties easily modified
  - Improved biocompatibility or bioactivity

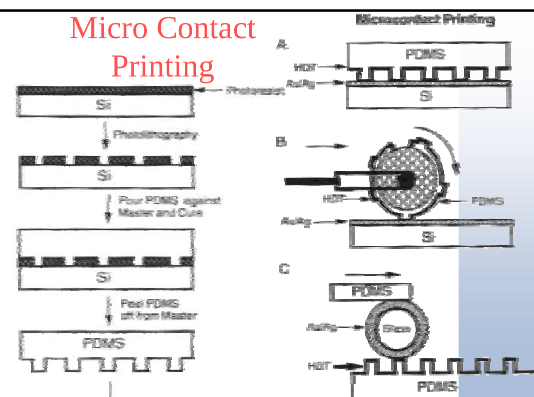
PDMS

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

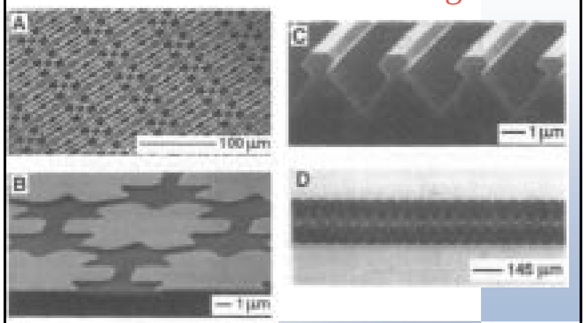
Soft Lithography

- 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

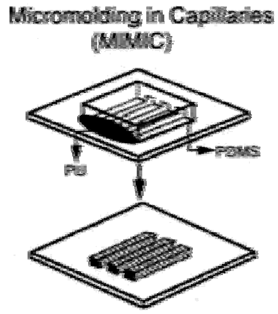
Micro Contact Printing



Micro Contact Printing

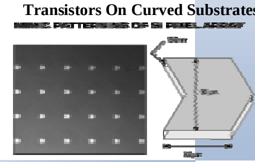


Soft Lithography: MIMIC



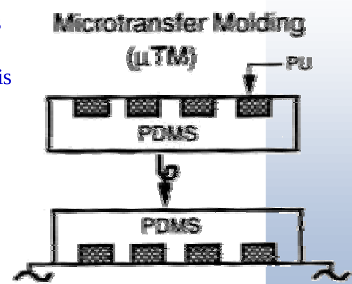
- Polyurethane or other material wicks into capillaries formed in PDMS stamp

Soft Lithography Used To Fabricate Transistors On Curved Substrates



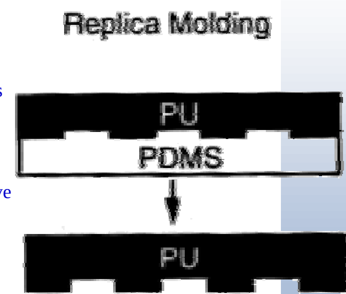
Microtransfer Molding

- A filled mold is reversed and liquid material is cured

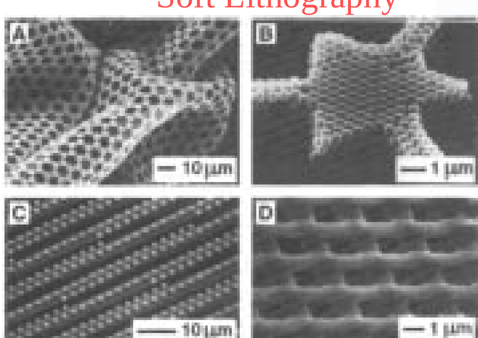


Soft Lithography: Replica Molding

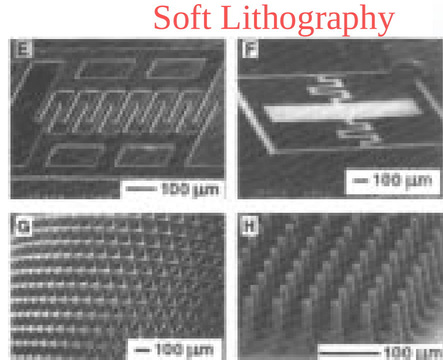
- Similar to fabrication of PDMS stamp, but another material is used
- Flexible mold easily removed
- PDMS non reactive and low surface energy



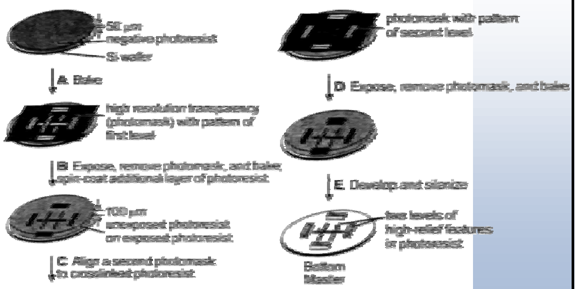
Soft Lithography



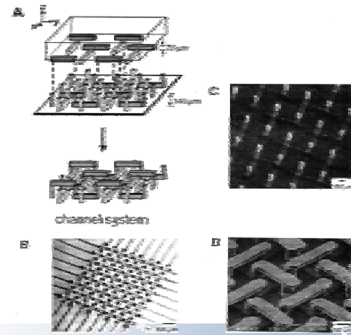
Soft Lithography



Multilevel Structures



Multilevel Microfluidic Systems



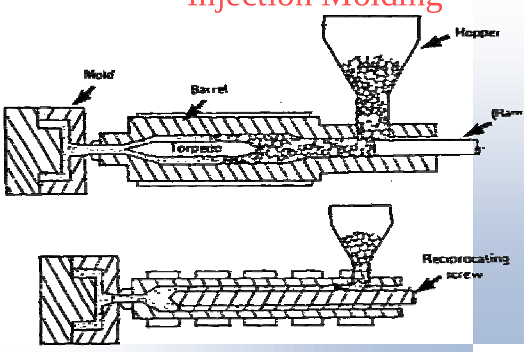
Rapid Prototyping

- How do we get around turn-around times associated with MEMS?
- Chrome masks are expensive >$400 (the more detailed, the more expensive)
- The answer: high resolution printing on polymer films (overheads)
- Idea to prototype time can be reduced to 1 day
- Typical cost about $10
- Other advantages
  - Polymer masks can be used for non-planar substrates
  - Multiple masks can be stacked to achieve modular patterns
- Disadvantages
  - Limited use
  - Limited to about 10 micrometer resolution

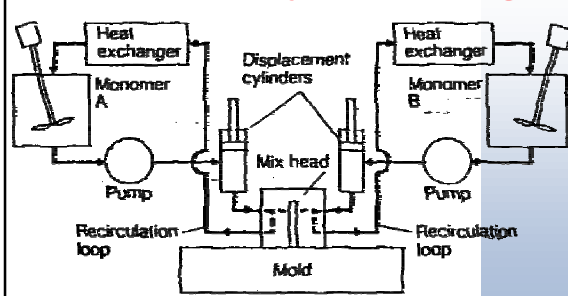
Other Polymer Techniques

- Embossing
  - Low cost
  - High throughput
  - Structures as small as 25 nm
- Injection molding
  - Features less than 500 nm
  - Useful for metals, ceramics, etc
- Laser ablation
  - Removes material
  - Resolution down to 6 microns
- X-ray lithography
- LIGA

Injection Molding



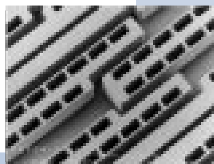
Reaction Injection Molding



Molding of High-Aspect Ratio Microstructures

Acceleration Sensor Made using LIGA

Typical Dimensions
Height: 150 µm
Min. Width: 3.3 µm
Min. Detail: 0.2 µm
Aspect Ratio: 45



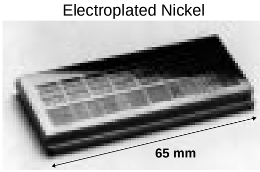
3D Acceleration Sensor System
Forschungszentrum Karlsruhe (IMT)
microParts, Jenoptik, Rieger, Bosch,

Optical Lithography and Etching

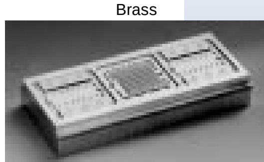
- SU-8 Approach
  - Low AR (>5) capable
  - Structure height limited to 25 µm (to prevent bowing of sidewall)
  - Difficult to remove SU-8 after plating Ni
- DRIE Approach
  - Silicon used as mold insert Surface conditioning to prevent stiction of polymer to Si is critical
  - Mold my not last many cycles
  - Si needs bead of epoxy around edge to prevent mold from being ripped apart during demolding

High Aspect Ratio Mold Inserts

LIGA Mold Insert
Made from
Electroplated Nickel



Micromachined Mold
Insert Made from
Brass



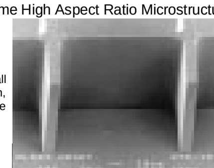
Institut für Materialforschung III

Hot Embossing

An Alternative Molding Process?

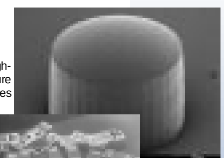
Extreme High Aspect Ratio Microstructures

Sidewall
100 µm High,
2.3 µm Wide



High Performance Material Properties

High-
Aperture
Microlenses



Ni Testpattern
on a CMOS
Wafer

Integration of CMOS Electronics

Mass Production
of Micro-
Spectrometers

Prototype Production in
Medium Numbers

Source: Dr. M. Heckele; Forschungszentrum Karlsruhe (IMT)

High Aspect Ratio Molding

Mold Insert:
- 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

Examples of Molding Compounds:

Compound	Abbrivation	Glass Transition [°C]
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

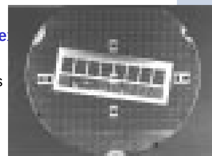
⇒ Chemically inert
Smooth surfaces
Defect free sidewalls
Homogeneous material properties

Possible Applications for Molding Techniques

- **Mass production of HARM**
  - ⇒ Onto substrates up to 6 inch
  - ⇒ Self supported structures

Mass Production of Micro-Spectrometers

- **Process integration enables construction of more complex μ-systems**
  - ⇒ Molding onto CMOS - wafers



Molding Process Options

- **Accepted industrial process**
  - ⇒ Reliable, repeatable, reproducable
- **Batch processing**
  - ⇒ Parallel using of several mold inserts
- **Tailoring of structural properties due to flexible material choice**
- **Other than polymer materials are possible**
  - ⇒ Filled polymers e.g. conductive materials (particles, powder and fibers)
  - ⇒ Metals
  - ⇒ Ceramics

Common Molding Materials

PMMA

Poly(methyl methacrylate),
T_g 100°C, T_{proc} 170°C-210°C

Transparent, brittle, sensitive to crack
optics, lost mold for production of metallic microstructures

POM

Poly(oxy methylene),
T_m = 156°C (Copolymer), T_{proc} 180°C
T_m = 175°C (Homopolymer)

Low friction, good impact strength, critical decomposition into formaldehyde, critical cavitation due to crystallization
mechanical applications (gear wheels)

PSU

Poly(sulfone),
T_g 190°C, T_{proc} 250°C

Transparent, high strength
for use at higher temperatures up to 180°C
microfluidic pump

PC

Poly(carbonate),
T_g 148°C, T_{proc} 180°C-200°C

Transparent, good hardness and impact strength
optics, medical

Micro Metal Injection Molding (MIM)

Metal Microstructures are of Interest Because of

- Mechanical Properties (Hardness, E-Modulus,…)
- Electrical and Magnetic Properties
- Low Thermal Expansion Coefficient Compared with Polymers

But

- Can other than Electroplating Techniques be Used ? (Electroplating is Limited to some Noble Metals and only Few Binary Alloys)
- Can they be Replicated from Molded (Polymer) Forms ?

Molding of Ceramic Microstructures

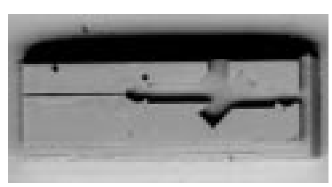
Why are we Interested in Ceramic Microstructures ?

- Attractive Material Properties (Mechanical, Chemical, Thermal,..
- Additional Functionality (PZT Effect, Conductivity, Shrink Compensated,..)
- More Compatible to other Materials used in MST than Polymers

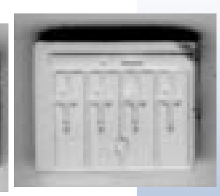
But

- 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?

Ceramics FZK - IMF



Green Compact



Sintered Al_2O_3 Bench

Open: shrink control to better than 1 μm in all critical dimensions achievable?

Aligned Molding of LIGA Microstructures

IfM Hot Embossing machine

Benefits

- Fully programmable process
- Data acquisition (force, temperature, position and pressure)
- Short process time due to electrical heating and oil cooling

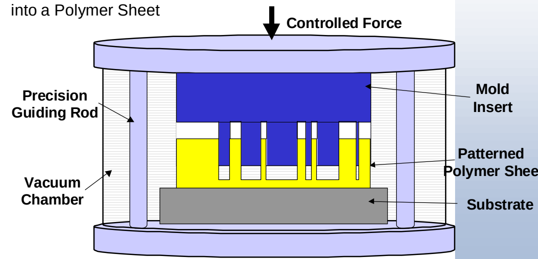
Limitation

- Manual substrate handling only

October 9, 2001 Microsystems Principles

Hot Embossing Process

Pattern Transfer by 'Controlled' Stamping of a Mold Insert into a Polymer Sheet



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Hot Embossing Process Cycle

- Phase 1
  - Closing and evacuation of process chamber
  - Heating of mold insert and substrate
  - Plastification of the polymer sheet
- Phase 2
  - Maximum temperature
  - Molding tool is pressed into the polymer
  - Applying the max. molding pressure
- Phase 3
  - Cooling of mold insert and substrate
  - Venting of the chamber
  - Demolding and taking out the molded micro parts

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Hot Embossing - State-of-the-art

Key Features

- Extremely Precise and Simple Process
- Well Controlled Embossing Force
- 'Gentle' Process due to Low Embossing and Demolding Velocity
- Uniform and Homogeneous Material Properties and Low Internal Stress Microstructures
- Compatible with other Technologies
- Simple Process Integration Allows the Fabrication of Complex Systems with Reduced Assembly Efforts
- Cost-effective Small Scale Series Fabrication Demonstrates Performance and Reproducibility of Microsystems

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Hot Embossing Process

⇒ A "perfect" μ-fab technology for

- **University R&D environment**
- **Small scale series**
  (prototyping, demonstration of manufacturing capability)

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Applications

Plastic microstructures as

Semi finished structures

onto substrates (e.g. Si, ceramics)

- Fabrication of metal microstructures e.g. movable

Finished structures

self supported

- Separated structures like micromechanical devices e.g. gear wheels
- Optical structures like lenses, spectrometers
- Microfluidic devices like micro- and nanochannels

onto substrates (e.g. Si, ceramics)

- Optical benches
- Optical structures like lenses, spectrometers
- Microfluidic devices like micro- and nanochannels

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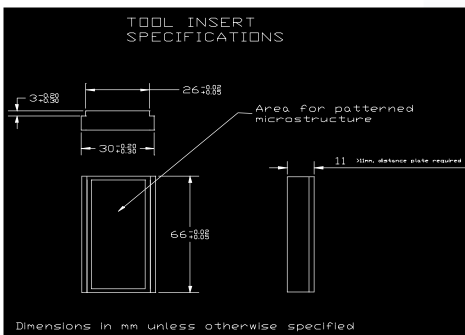
General Design Rules for Mold

- 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

Metal - Tool Insert



Silicon Wafer Used As Tool Insert