Motivation

- The height-to-width ratio capability is critical to the fabrication of miniature components that can withstand high pressure and temperature, and can generate/transfer useful forces or torques.
- Vertical dimensions from hundreds of microns to millimeters and horizontal dimensions as small as microns.
- Superior to current precision machining techniques.
- Material flexibility.
Electrostatic Actuators

Rely on the attractive force between two conductive plates or elements carrying opposite charges

**LIGA**

- A micromachining technology originated in the early 1980s at the Karlsruhe Nuclear Research Center, Germany
- German acronym for
  - Lithographie, Galvanoformung, and Abformung
- X-ray Lithography and Mask Technology
- Electroforming
- Plastics Molding
X-ray Lithography and Mask Technology

- **Deep** X-ray lithography allows structures of any lateral design with high aspect ratios to be produced.
- The walls of these structures are **smooth** and **parallel** to each other.
- The very sophisticated structures of this type can be produced lithographically only by a highly penetrating, intense, and parallel X-radiation supplied by a **synchrotron**.
X-ray Lithography

\[ \lambda \approx 10 \text{ Angstroms} \]

X-ray Lithography and Mask Technology

- The transparent carrier of the mask is a very thin metal foil (e.g. titanium, beryllium), while the absorbers consist of a comparatively thick layer of gold.
- The lateral structural information is transferred into a plastics layer, normally polymethylmethacrylate (PMMA).
- Exposure to radiation modifies the plastic material in such a way that it can be removed with a suitable solvent, leaving behind the unirradiated plastics as the primary structure (positive PR).
Electroforming

- The spaces generated by the removal of the irradiated plastic material can be filled with metal by electroforming processes
- This technique is used to produce microstructures for direct use, but also tools made of nickel and nickel alloys for plastics molding
- The negative pattern of the plastics structure is generated as a secondary structure out of a molding tool

Plastics Molding

- The metal microstructures produced by deep X-ray lithography and electro-forming are used as molding tools for the production of replicas in large quantities and at low cost
- The molding technique allows micro-structures of metals or plastics to be made directly on top of the appropriate electronic evaluation circuit, i.e., to be integrated in a quasi-monolith without changing their electronic properties
Characteristics

• High accuracy
  – Structure of a reflection grating, 0.25 µm step height, 125 µm structural height

Characteristics

• Any lateral shape
  – Separation nozzle as an example of arbitrary lateral shaping
Characteristics

- High aspect ratio
  - Bar structure 400 µm high, with parallel sidewalls

Applications

- Any lateral geometry of structures
- Structural height above 1 mm
- Smallest lateral dimension down to 0.2 µm
- Aspect ratios of free-standing individual structures and details above 50 and 500, respectively
- Surface quality in the submicron range with roughness, Ra, of 30 nm
- Various materials: polymers, metals, and alloys
Thick Resist Technology

• AZ 9200 series photoresists

Soft Bake (°C/sec) 110/120
Post-Exposure Bake (°C/sec) 110/60
Developer AZ® 300 MIF
Develop Temperature (°C) 23

Features

<table>
<thead>
<tr>
<th>Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior resolution with high aspect ratios</td>
<td>• Achieve sub-micron critical dimensions with aspect ratios of 6:1 in broadband exposure and 8:1 in i-line exposure</td>
</tr>
<tr>
<td>Excellent focus and exposure latitude</td>
<td>• Improved process yields</td>
</tr>
<tr>
<td></td>
<td>• Reduced rework</td>
</tr>
<tr>
<td>Available in viscosities that allow coating thicknesses up to 24 μm</td>
<td>• Single resist series that applies to wide range of applications</td>
</tr>
<tr>
<td>Formulated from AZ Electronic Materials’ extensive photoresist chemistries</td>
<td>• Coat, bake, and develop using AZ® P4000 photoresist-type processes</td>
</tr>
<tr>
<td></td>
<td>• Provides stable films with excellent adhesion for plating and wet etch applications</td>
</tr>
<tr>
<td>Cast in PGMEA “safer” solvent with no co-solvent</td>
<td>• Toxicity hazard is extremely low</td>
</tr>
<tr>
<td></td>
<td>• Provides excellent coating properties</td>
</tr>
</tbody>
</table>
SU-8 PhotoResists

- Epoxy based negative resists with high optical transparency and are sensitive to near UV radiation
- Cured topography are highly resistant to solvents, acids and bases and have excellent thermal stability

Electroplating

- The deposition of a metallic coating onto an object by putting a negative charge onto the object and immersing it into a solution which contains a salt of the metal to be deposited
- Important process parameters are pH, current density, temperature, agitation, and solution composition
Electroplating

- Diffusion-limited reactions
  - Species in the electrolyte must be transported to and from the electrode before electrode reactions can occur

$$\frac{dC}{dx} = \frac{C_{x=\infty} - C_{x=0}}{\delta}$$

Overpotential:

$$\eta_c = \frac{RT}{nF} \ln \frac{C_{x=0}}{C_{x=\infty}}$$

Faraday’s law:

$$i = nFD_0 \frac{C_{x=\infty} - C_{x=0}}{\delta}$$

$$i_I = nFD_0 \frac{C_{x=\infty}}{\delta}$$

$$i = i_I (1 - e^{-\frac{nF \eta_c}{RT}})$$

Electroplating

- Temperature and flow control
- Filter and power supply capable of accurately controlling low currents
- Computer-based diagnostic and control system that allows special waveform generation and control for electrical input, and provides continuous monitoring and off-normal alarms
Planarization

- lap to the final thickness and polish
Motivation

• Glass and silicon has been the dominant substrate materials
  – Fabrication methods for Si and glass are easy to adapt from the semi-conductor fabrication technology
• Polymer-based micro-devices
  – Reduced cost of substrate
  – Simple manufacturing procedures
  – Does not require routine access to cleanroom
  – Diverse surface modification methods
Polymers

• -M-M-M-M-M-M-M- or -(M)_n-

• Examples
  – Ethylene -(CH₂)₂-
  – Propylene -(CH₂)-CH(CH₃)-
  – Styrene -(CH₂)-CH(C₆H₆)-

Definition

• **Polymer**: a large molecule made up of small building blocks
• **Monomer**: the building block of a polymer
• **Copolymer**: a polymer made up of different monomers
• **Blend**: a mixture of different polymers
Definition

• **Thermoplastics**: linear or branched polymers which can be melted repeatedly upon the application of heat
• **Thermosets**: normally crosslinked and rigid, intractable once formed and degrade rather than melt upon the application of heat
• **Elastomers**: crosslinked rubbery polymers that can be stretched easily to high extensions and rapidly recover once the applied stress released

Polymers for Microfluidic Devices

• SU-8 (Epoxy)
• PMMA
• PC (PolyCarbonate)
• PDMS (PolyDiMethylSiloxane)
• Parylene
• Teflon
• COC (Cyclic Olefin Copolymers)
• BCB (BenzoCycloButene)
Polymer Microfabrication

- Lithography
- Molding techniques
  - Embossing
  - Injection molding
  - Casting
- Serial patterning techniques
  - Laser photoablation
  - Printing
  - Stereolithography

Lithography

- Deposition
  - Coating
  - Vapor deposition
  - Electrodeposition
- Photo-patterning
- Etching
  - Plasma etching
  - Ion milling
Parylene

- Conformal coating, vapor deposition
- Vaporization
- Pyrolysis
- Deposition

SU-8 Photoresist

- High aspect ratio imaging with near vertical side walls
- Near UV (350-400nm) processing
- Film thicknesses from 1 to >200 µm with single spin coat processes
- Superb chemical and temperature resistance
Process Flow

- Substrate Pretreat
- Coat
- Soft Bake
- Expose
- Post Expose Bake
- Develop
- Rinse & Dry
- Hard Bake
- Imaged Material
- Remove

SU-8 Photoresist

- Cracking
- Hard to remove
### Table 1. Basic physical properties of molding polymer materials

<table>
<thead>
<tr>
<th>Thermoplastic materials for micromolding</th>
<th>Density ($\times 10^3$ kg/m$^3$)$^{(c)}$</th>
<th>Glass temperature $T_g$ (°C)</th>
<th>Permanent temperature of use (°C)</th>
<th>Thermal conductivity $\lambda$ (W m$^{-1}$ K$^{-1}$)</th>
<th>Linear expansion coefficient $x$ (10$^{-6}$ K$^{-1}$)</th>
<th>Heat distortion temperature measurement method: Vicat Method B (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyamide 6 (PA 6)</td>
<td>1.13</td>
<td>60</td>
<td>80–100</td>
<td>0.29</td>
<td>80</td>
<td>180</td>
</tr>
<tr>
<td>Polyamide 66 (PA 66)</td>
<td>1.14</td>
<td>70</td>
<td>80–120</td>
<td>0.23</td>
<td>80</td>
<td>200</td>
</tr>
<tr>
<td>Polycarbonate (PC)</td>
<td>1.2</td>
<td>150</td>
<td>115–130</td>
<td>0.21</td>
<td>65</td>
<td>148–150</td>
</tr>
<tr>
<td>Polyoxymethylene (POM)</td>
<td>1.41–1.42</td>
<td>–60</td>
<td>90–110</td>
<td>0.23–0.31</td>
<td>90–110</td>
<td>154–160</td>
</tr>
<tr>
<td>Cycloolefin copolymer (COC)</td>
<td>1.01$^{(c)}$</td>
<td>138$^{(c)}$</td>
<td>Not available</td>
<td>Not available</td>
<td>60$^{(c)}$</td>
<td>123$^{(c)}$</td>
</tr>
</tbody>
</table>

Data for the cycopentadien-norbornen copolymer Zeonex

Poly(methylmethacrylate) (PMMA) 1.18–1.19 106 82–98 0.186 70–90 80–110

Polyethylene low density (PE-LD) ≤ 0.92 ≤ 10 70$^{(i)}$ 0.349 140 40

Polyethylene high density (PE-HD) ≤ 0.954 ≤ 90$^{(i)}$ 0.465 200 60–65

Polypropylene (PP) 0.896–0.915 0–10 100 0.22 100–200 90–100

Polystyrene (PS) 1.05 80–100 70$^{(i)}$ 0.18 70 78–99

### Table 2. Basic chemical properties of molding polymer materials

<table>
<thead>
<tr>
<th>Thermoplastic materials for micromolding</th>
<th>Solvent resistance</th>
<th>Acid and alkaline resistance</th>
<th>Trade name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyamide 6 (PA 6)</td>
<td>Resistant against: ethanol, benzene, aromatic and aliphatic hydrocarbons, mineral oils, fats, ether, ester, ketones</td>
<td>Not resistant against: dilute and concentrated mineral acids, formic acid</td>
<td>Perlon (Bayer) Ultradur (BASF)</td>
</tr>
<tr>
<td>Polyamide 66 (PA 66)</td>
<td>Same as above</td>
<td>Same as above</td>
<td>Nyfril (Du Pont) Celanese (Ticona) Ultramid (BASF)</td>
</tr>
<tr>
<td>Polycarbonate (PC)</td>
<td>Resistant against: water, benzene, mineral oils</td>
<td>Conditionally resistant against: alcohols, ether, ester</td>
<td>Makrolon (Bayer)</td>
</tr>
<tr>
<td>Polyoxymethylene (POM)</td>
<td>Resistant against: fuels, mineral oils, usual solvents</td>
<td>Not resistant against: aromatic acids, acetic acid, oxidizing solvents</td>
<td>Hostaflex ( Hoechst)</td>
</tr>
<tr>
<td>Cycloolefin copolymer (COC)$^{(c)}$</td>
<td>Resistant against: acetone, methylmethacrylate, methylal, methanol, isopropanol</td>
<td>Not resistant against: dilute and concentrated mineral acids and alkalis, 30% H$_2$O+40% formaldehyde, detergents in water</td>
<td>Topas (Ticona) Zeonex (Nippon Zeon)</td>
</tr>
<tr>
<td>Cycopentadien-norbornen copolymer Zeonex</td>
<td>Not resistant against: ether, aromatic and aliphatic hydrocarbons, methylethyketone</td>
<td>Not resistant against: concentrated HNO$_3$</td>
<td></td>
</tr>
<tr>
<td>Poly(methylmethacrylate) (PMMA)</td>
<td>Resistant against: water, mineral oils, fuel, fatty oils</td>
<td>Resistant against: up to 20%, dilute acids, dilute alkanes, NH$_3$</td>
<td>Plexiglass (Rhône) Lucryl (BASF) Perspex (ICI)</td>
</tr>
<tr>
<td>Polyethylene (PE)</td>
<td>Resistant against: alcohols, benzene, toluene, xylene</td>
<td>Resistant against: NH$_3$, dilute HNO$_3$, H$_2$SO$_4$, HCL, KOH, NaOH</td>
<td>Lupolen (BASF)</td>
</tr>
<tr>
<td>Polypropylene (PP)</td>
<td>Resistant against: dilute solutions of salts, lubricating oils, chlorinated hydrocarbons and alcohols</td>
<td>Resistant against: most dilute acids and alkalis</td>
<td>Hostalan (Hoechst)</td>
</tr>
<tr>
<td>Polystyrene (PS)</td>
<td>Resistant against: alcohols, polar solvents</td>
<td>Not or hardly resistant against: ether, benzene, toluene, chlorinated hydrocarbons, acetone, ether, oils</td>
<td>Resistant against: dilute and concentrated acids (except HNO$_3$) Hostalan (BASF) Polystyrol (BASF)</td>
</tr>
</tbody>
</table>
Embossing

Embossing Machine

- Vacuum
- Temperature
- Pressure
- Alignment
- De-embossing
Nanoimprint

**a** Contact mould and substrate ($t = 0$)
- Quartz
- Si

**b** Excimer laser irradiation ($t > 0$)
- Molten Si

**c** Silicon embossing ($0 < t < 250$ ns)

**d** Silicon solidification ($t > 250$ ns)

**e** Mould and substrate separation

---

Nanoimprint

**a** SEM image of nanoimprinted quartz with a feature size of 10 nm and a gap of 140 nm.

**b** SEM image of nanoimprinted silicon with a feature size of 110 nm and a gap of 10 nm.
Injection Molding

• Melting of the plastics
• Injection of the melt into the mold
• Cooling of the mold
• Removal of the part
Soft Lithography

- An alternate strategy for the fabrication and manufacture of nanostructures
- Can generate patterns with critical dimensions as small as 30 nm
- Use transparent, elastomeric PDMS stamps with patterned relief on the surface to generate features
- The stamps can be prepared by casting prepolymer against masters patterned by conventional lithographic techniques, as well as against other masters of interest
PDMS Casting

1. fabricate and silanize master
2. pour PDMS prepolymer over master
3. cure, peel off PDMS

- Representative ranges of values
  - $h$: 0.2~20, $d$: 0.5~200, $l$: 0.5~200 microns

Contact Printing

1. Mold
2. Prepolymer
3. Polymerize, release
4. Stamp
5. "Ink" solution
6. Blow dry
7. Print
8. Gold substrate
9. Release
10. SAW
11. End

Images (a), (b), (c), (d)
Layered Hybrid Stamp

Curved Surface
Large-Scale Integration

Science

Large-Scale Integration
Functional Hydrogel Structures
Stereolithography
期中考注意事項

‧佔學期成績的百分之二十五
‧範圍
‧題型
‧可攜帶計算機與一頁A4大小的參考資料
‧考試時間
   – 十一月十五日星期一晚上六點三十分起

範圍

‧期中考前各週所介紹的各項製程
‧本週所介紹的製程不考
‧實驗部分期中考不考
題型

• 簡答題
• 申論題
• 計算題
• 是非題或多選題
• 請以中文做答
Lab 3: Evaporation and Bulk micromachining

Part A
Dry etch

Part B
wet etch

Si

Cr/Ni

Lab 2-2:
1. Break wafer into A, B
2. BOE wet etching B, RIE dry etch A
3. PR strip, wafer cleaning

Lab 3:
1. E-beam evaporate Cr/Ni 0.05/0.15μm on A
2. TMAH bulk etch B

Lab 3 RIE Dry Etching, E-beam Evaporation and Bulk Micromachining

<table>
<thead>
<tr>
<th>Step#</th>
<th>Process description</th>
<th>Parameters</th>
<th>Signature</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>CF4O2 dry etch</td>
<td>CF4O2=10-5, 150 W, ~ 18 mins</td>
<td>take pictures</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>PR prestrip</td>
<td>acetone strip PR, IPA rinse, DI rinse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Piranha clean</td>
<td>Piranha bath: H2SO4:H2O2: 7:1, 90 °C 10 mins, DI rinse 5 mins, N2 blow/spin dry</td>
<td>take pictures</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>E-beam deposition</td>
<td>E-beam deposition Cr:Ni 0.05 and 0.15 μm continuously</td>
<td>Thickness of Cr: /Ni</td>
<td></td>
</tr>
</tbody>
</table>

Process for Part B:

<table>
<thead>
<tr>
<th>Step#</th>
<th>Process description</th>
<th>Parameters</th>
<th>Signature</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>HF dip</td>
<td>HF(49%):DI=1:20, dip for 20 seconds until surface hydrophobic (note: HF can etch Cr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>KOH bulk etching</td>
<td>KOH at 70 °C for 2 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>DI rinse</td>
<td>DI rinse for at least 10 mins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Wafer dry</td>
<td>DI-IPA exchange until wafer in full 99.5% alcohol solution place wafer on hotplate (120°C) to dry</td>
<td>Bulk etching depth:</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Wafer inspection</td>
<td>Inspect micro structures under microscope</td>
<td>take pictures</td>
<td></td>
</tr>
</tbody>
</table>