Micro-Machining

ver. 1
Micromachining

- Photolithography
- Etching
- LIGA
- Laser Ablation
- Mechanical Micromachining
Micromachining Basics

• Refers to techniques for fabrication of 3D structures on the micrometer scale

• Applications include MEMS devices e.g. airbag sensor, medical devices, micro-dies and molds, etc.

• Most methods use silicon as substrate material
Photolithography

- Used in microelectronics fabrication
- Used to pattern oxide/nitride/polysilicon films on silicon substrate
- Basic steps
  - photoresist development
  - Etching
  - Resist removal
Photolithography Process Description

• The wafers are chemically cleaned to remove particulate matter, organic, ionic, and metallic impurities
• High-speed centrifugal whirling of silicon wafers known as "Spin Coating" produces a thin uniform layer of photoresist (a light sensitive polymer) on the wafers
• Photoresist is exposed to a set of lights through a mask often made of quartz
• Wavelength of light ranges from 300-500 nm (UV) and X-rays (wavelengths 4-50 Angstroms)
• Two types of photoresist are used:
  – Positive: whatever shows, goes
  – Negative: whatever shows, stays

(a) Resist exposure characteristics. (b) Resist after development.
Etching

Process Variations:
1. Wet etching
2. Dry etching

Variations of wet etching:
- Anisotropic
- Isotropic
Wet Etching Process Description

• The wet etching process involves:
  – Transport of reactants to the surface
  – Surface reaction
  – Transport of products from surfaces

• The key ingredients are:
  – Oxidizer (e.g. H₂O₂, HNO₃)
  – Acid or base to dissolve the oxidized surface (e.g. H₂SO₄, NH₄OH)
  – Dilutent media to transport the products through (e.g. H₂O)
Dry Etching

Process Variations:
1. Plasma based
2. Non plasma based

A typical parallel plate plasma etching
Bulk Micromachining

- Process for producing 3D MEMS structures – older process
- Uses anisotropic etching of single crystal silicon
- Example: silicon cantilever beam for atomic force microscope
Bulk Micromachining

(a) Diffused layer (e.g., p-type Si)

(b) Non-etching mask (e.g., silicon nitride)

(c) Freestanding cantilever

Substrate (e.g., n-type Si)

Dopant Diffusion

Masking

Anisotropic Etching
Surface Micromachining

• Newer process for producing MEMS structures

• Uses etching techniques to pattern micro-scale structures from polycrystalline (poly) silicon, or metal alloys

• Examples: accelerometers, pressure sensors, micro gears and transmissions, micro mirrors etc.
Surface Micromachining

(a) deposition of a phosphosilicate glass (PSG) spacer layer; (b) etching of the spacer layer; (C) deposition of polysilicon; (d) etching of polysilicon; (e) selective wet etching of PSG, leaving the silicon substrate and deposited polysilicon unaffected.
Comb Drives and Gears

Spider Mites on Ring (slow)  Spider Mite on Ring (faster)
Typical MEMS Parts

Six gear chain
Typical MEMS Parts

Silicon mirror assembly
Typical MEMS Parts

Motor
LIGA

German Acronym

LI thographie → Lithography
Galvanoformung → Electroforming
Abformung → Molding

Process Flow

1) Lithography
   - Irradiation
   - Development
   - Resist Structure

2) Electroforming
   - Electroforming
   - Removal of realat
   - Metal Structure (Mold Insert)

3) Molding
   - Plastic
   - Mold Insert

4) Ceramic Fabrication
   - Ceramic Slurry Casting
   - Sintering

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LIGA - Basic Steps

- X-ray Irradiation
- Resist Development
- Electroforming
- Resist Removal

(a)

Irradiation

Developing

Electroforming

Resist removal

Final product

Mold insert
LIGA Process Description

• Deep X-ray lithography and mask technology
  – Deep X-ray (0.01 – 1nm wavelength) lithography can produce high aspect ratios (1 mm high and a lateral resolution of 0.2 µm)
  – X-rays break chemical bonds in the resist; exposed resist is dissolved using wet-etching process

• Electroforming
  – The spaces generated by the removal of the irradiated plastic material are filled with metal (e.g. Ni) using electro-deposition process
  – Precision grinding with diamond slurry-based metal plate used to remove substrate layer/metal layer

• Resist Removal
  – PMMA resist exposed to X-ray and removed by exposure to oxygen plasma or through wet-etching

• Plastic Molding
  – Metal mold from LIGA used for injection molding of MEMS structures
LIGA Process Capability

- High aspect ratio structures: 10-50
  - Max. height 1-500 μm
- Surface roughness < 50 nm
- High accuracy < 1 μm

Any lateral shape

High accuracy

High aspect ratio
Laser Ablation Process Description

- High-power laser pulses are used to evaporate matter from a target surface.
- A supersonic jet of particles (plume) is ejected normal to the target surface which condenses on substrate opposite to target.
- The ablation process takes place in a vacuum chamber - either in vacuum or in the presence of some background gas.
Mechanical Micromachining

• Lithography and/or etching methods not capable of making true 3D structures e.g. free form surfaces
• Also, limited in range of materials
• Mechanical machining is capable of making free form surfaces in wide range of materials
• Can we scale conventional/non-traditional machining processes down to the micron level? Yes!
Mechanical Micromachining

• Two approaches used to machine micron and sub-micron scale features
  – Design ultra precision (nanometer positioning resolution) machine tools and cutting tools
    • Ultra precision diamond turning machines
  – Design miniature but precise machine tools
    • Micro-lathe, micro-mill, micro-EDM, etc
Ultra Precision Machine Tools

Mold for spheric/aspheric lenses

Source: www.toshiba-machine.com
Miniature Machine Tools

Source: MEL, AIST, Japan
Miniature Machine Tools

Micro Turning

Micro Milling

Source: MEL, AIST, Japan
Micro Cutting Tools

Cutting tools made by Focused Ion Beam (FIB) machining

A 25-μm end mill tool (right), with five cutting edges, was fabricated using focused ion beam machining. The end mill was used to make this 25-μm wide x 25-μm deep channel (above) in aluminum.

Source: http://www.sandia.gov

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Micro Cutting Tool

10 μm tool with human hair
Micro Injection Molds
Stencil Machining

\( \phi = 50 \, \mu \text{m}, N = 50,000 \, \text{rpm}, \text{feed} = 100 \, \text{mm/min}, \text{chip size} = 100 \, \text{nm} \)
Mechanical Micromachining Process Description

- Can produce extremely smooth, precise, high resolution true 3D structures
- Expensive, non-parallel, but handles much larger substrates
- Precision cutting on lathes produces miniature screws, etc. with 12 μm accuracy
- Relative tolerances are typically 1/10 to 1/1000 of feature
- Absolute tolerances are typically similar to those for conventional precision machining (micrometer to sub-micrometer)
Summary

• Micromachining methods
  – IC fabrication based processes
  – Mechanical machining based processes

• Applications in MEMS, medical device fabrication, etc.

• Still evolving field