Micro-Machining

ver. 1

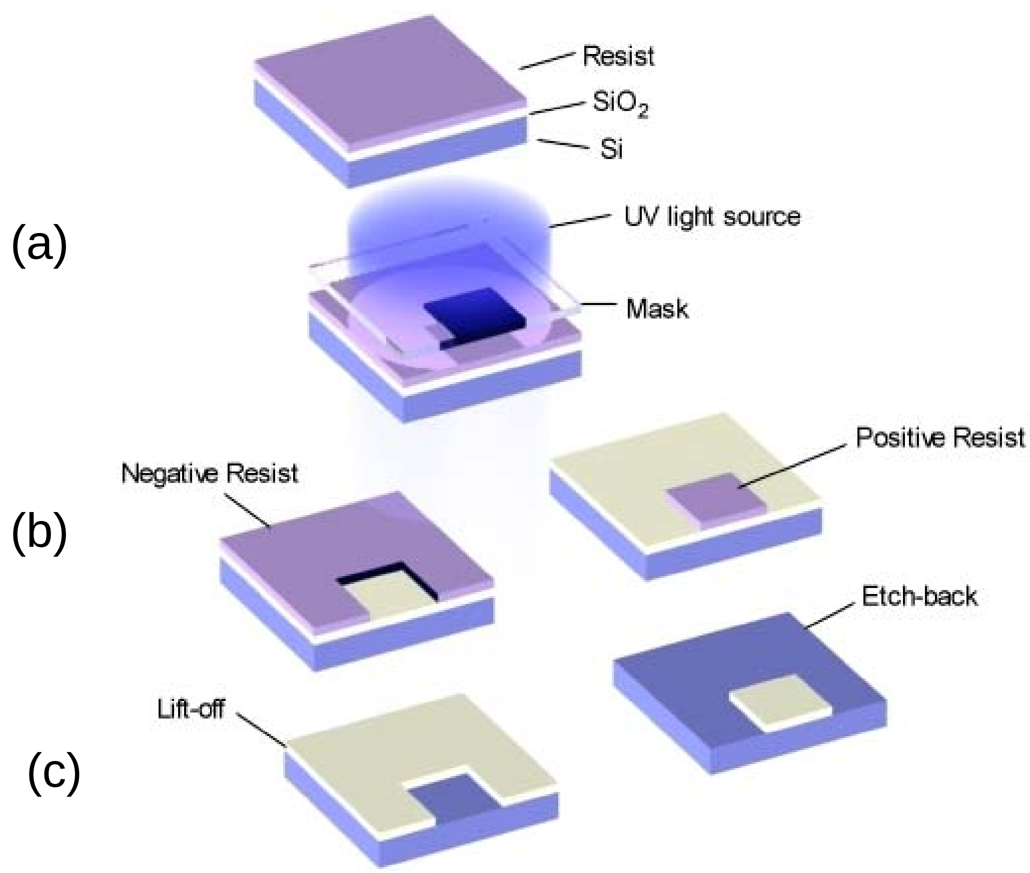
Micromachining

- 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

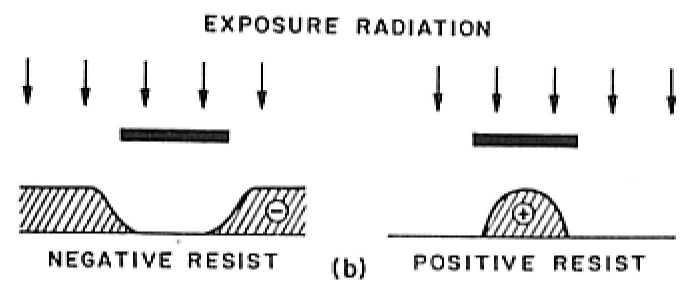
Photolithography



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

Photolithography Process Description

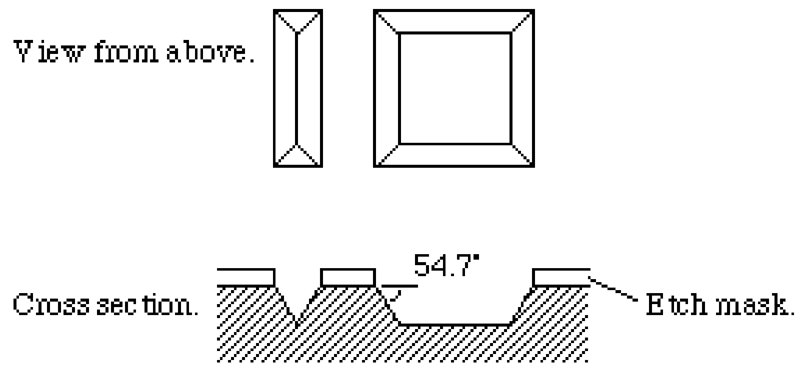
- The wafers are chemically cleaned to remove particulate matter, organic, ionic, and metallic impurities
- High-speed centrifugal whirling of silicon wafers known as "Spin Coating" produces a thin uniform layer of photoresist (a light sensitive polymer) on the wafers
- Photoresist is exposed to a set 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

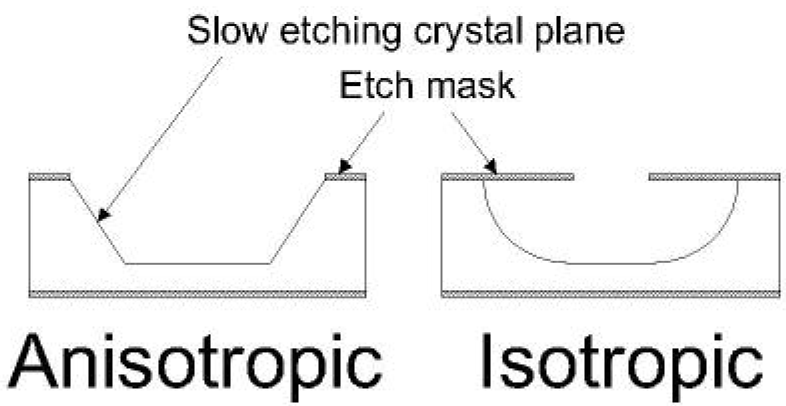


(a) Resist exposure characteristics.   (b) Resist after development.

Etching

Process Variations:
1. Wet etching
2. Dry etching





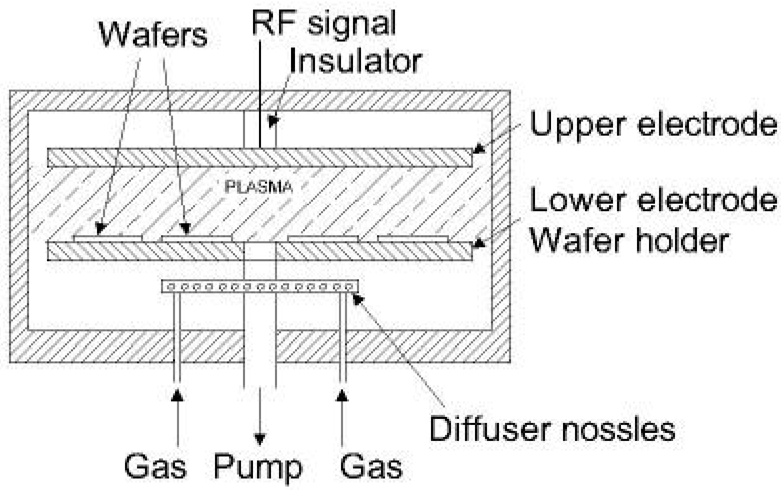
Variations of wet etching

Wet Etching Process Description

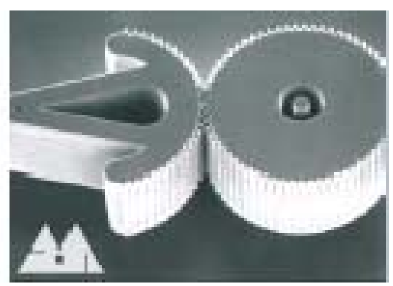
- The wet etching process involves:
  – Transport of reactants to the surface
  – Surface reaction
  – Transport of products from surfaces
- The key ingredients are:
  – Oxidizer (e.g. H_2O_2, HNO_3)
  – Acid or base to dissolve the oxidized surface (e.g. H_2SO_4, NH_4OH)
  – Dilutent media to transport the products through (e.g. H_2O)

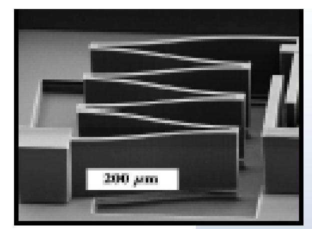
Dry Etching

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



A typical parallel plate plasma etching



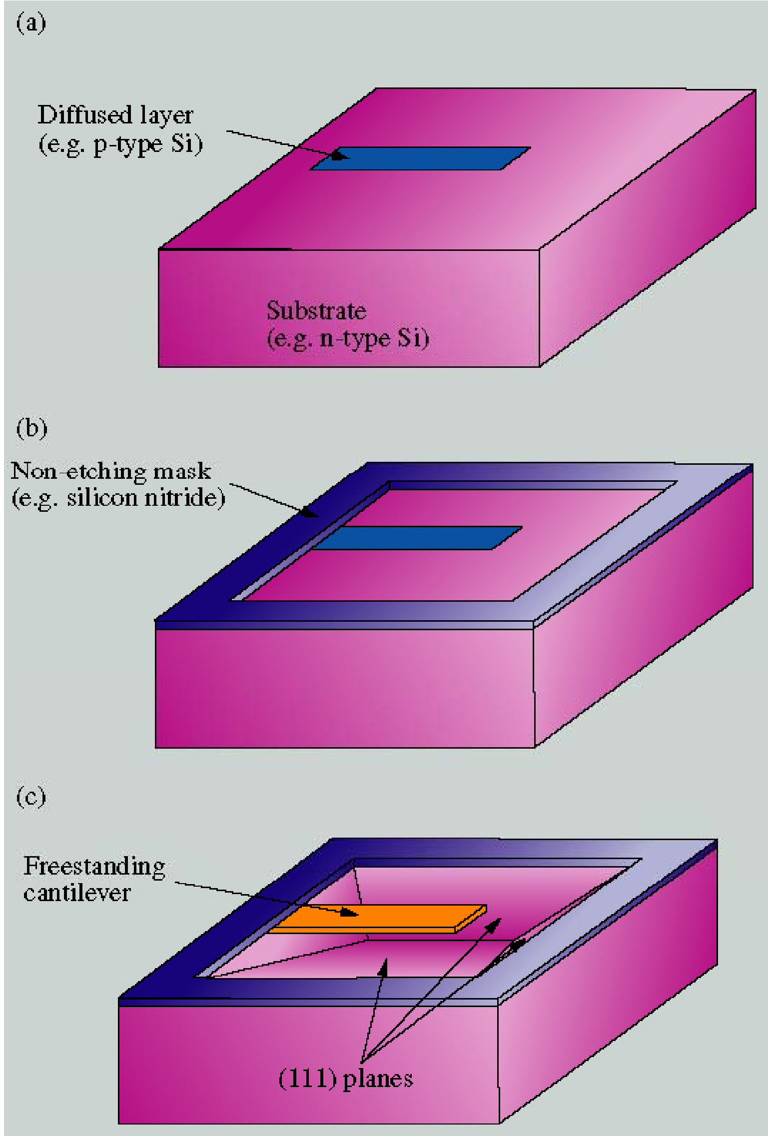


Source: LucasNova

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



Dopant Diffusion

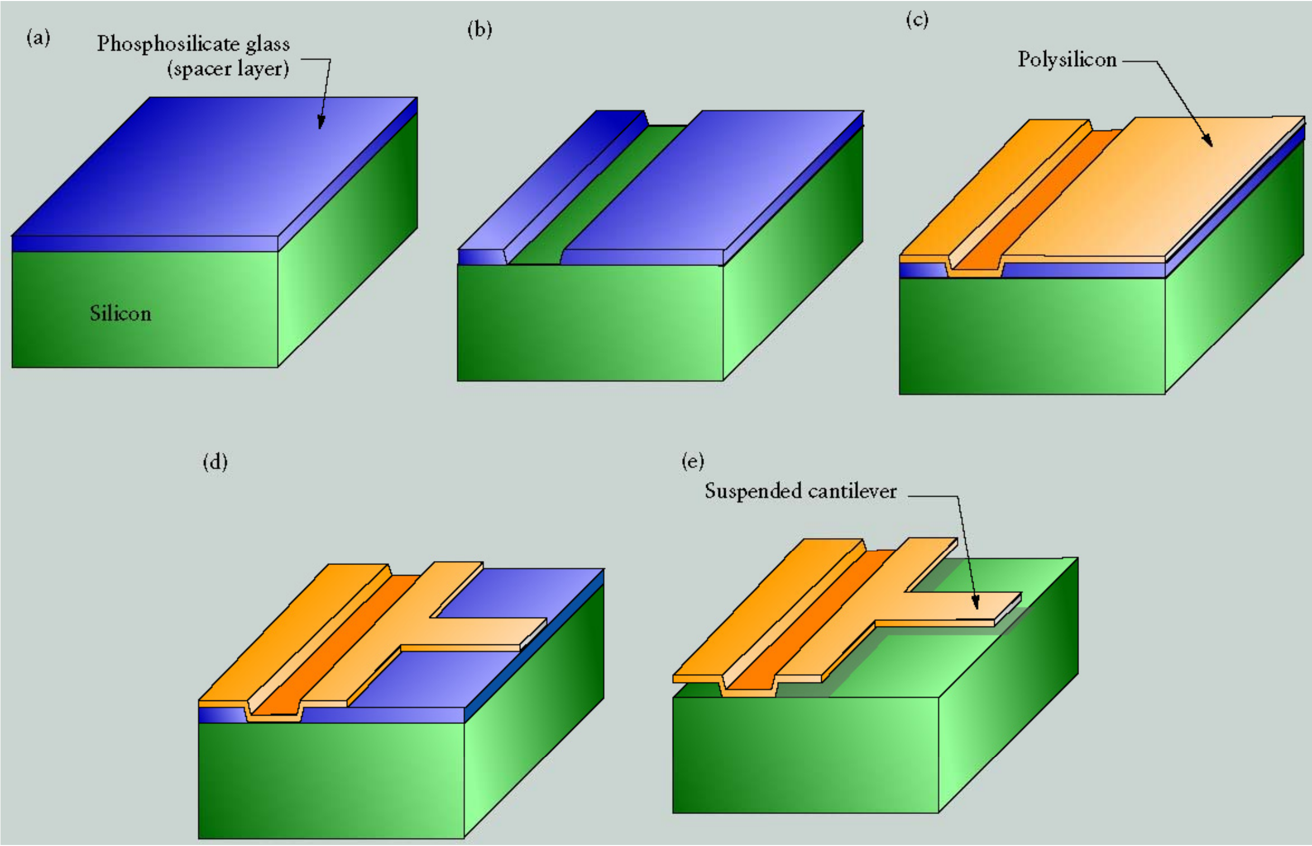
Masking

Anisotropic Etching

Surface Micromachining

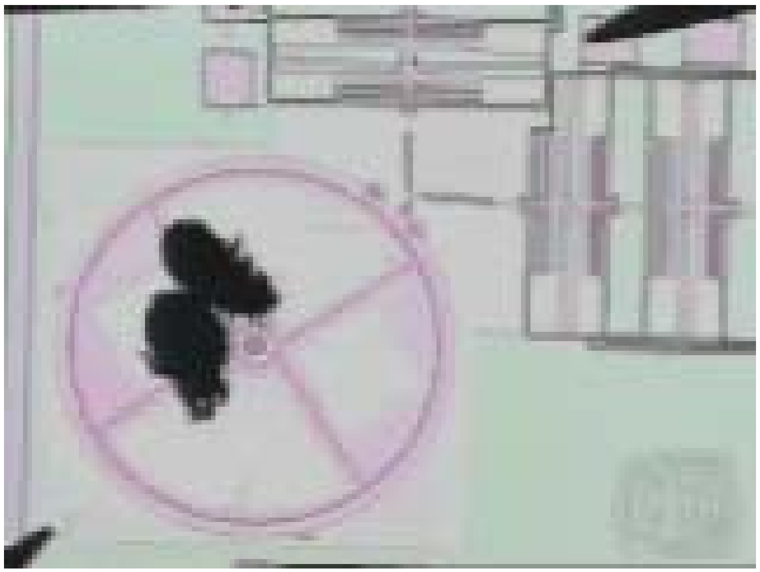
- Newer process for producing MEMS structures
- Uses etching techniques to pattern micro-scale structures from polycrystalline (poly) silicon, or metal alloys
- Examples: accelerometers, pressure sensors, micro gears and transmissions, micro mirrors etc.

Surface Micromachining

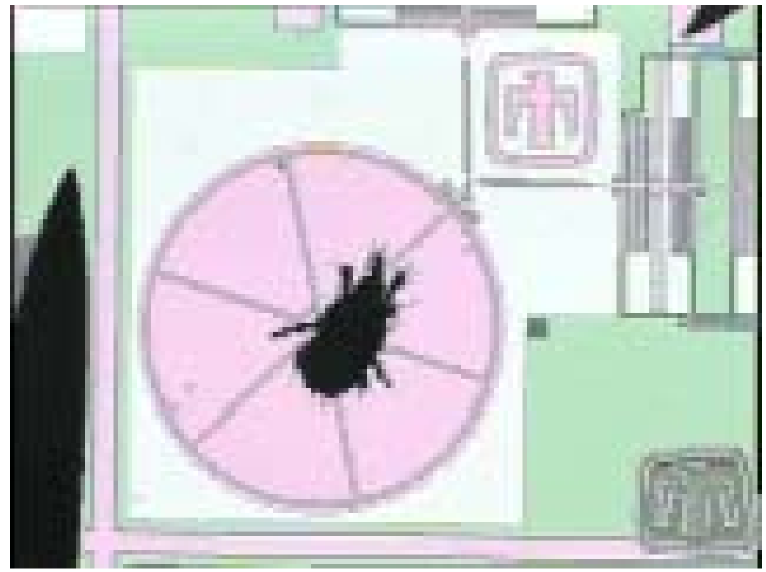


(a) deposition of a phosphosilicate glass (PSG) spacer later; (b) etching of the spacer layer; (C) deposition of polysilicon; (d) etching of polysilicon; (e) selective wet etching of PSG, leaving the silicon substrate and deposited polysilicon unaffected

Comb Drives and Gears

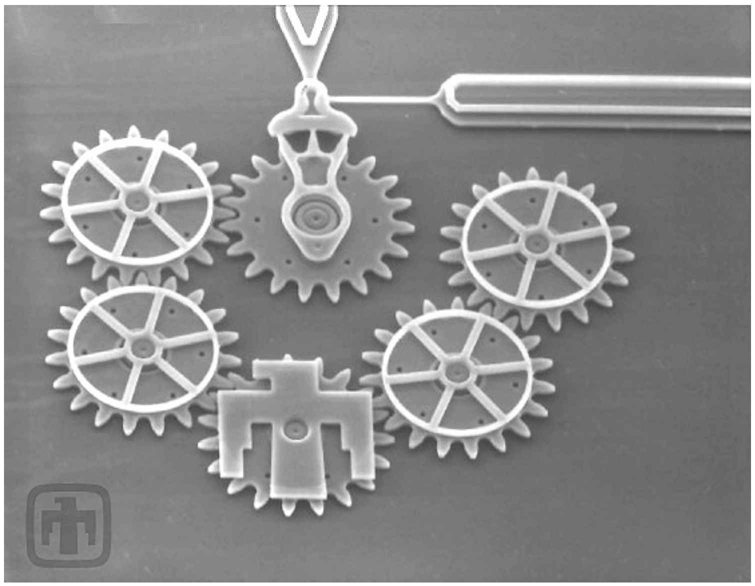


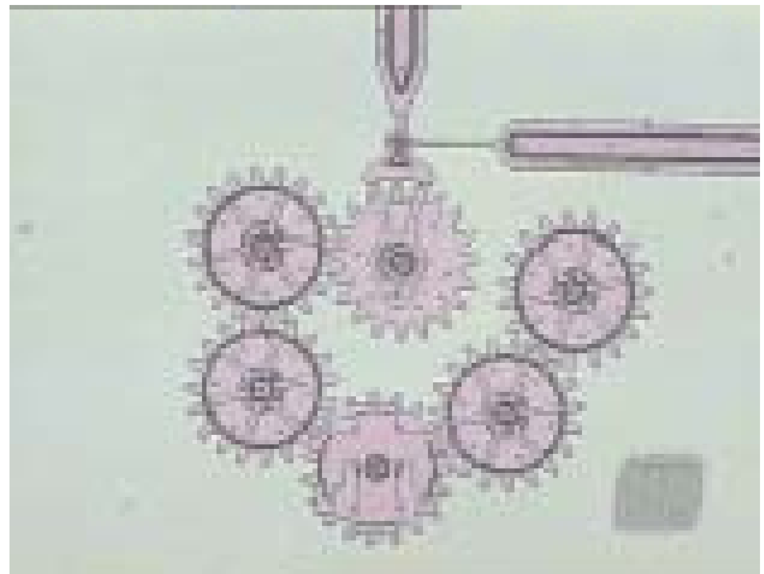
Spider Mites on Ring (slow)



Spider Mite on Ring (faster)

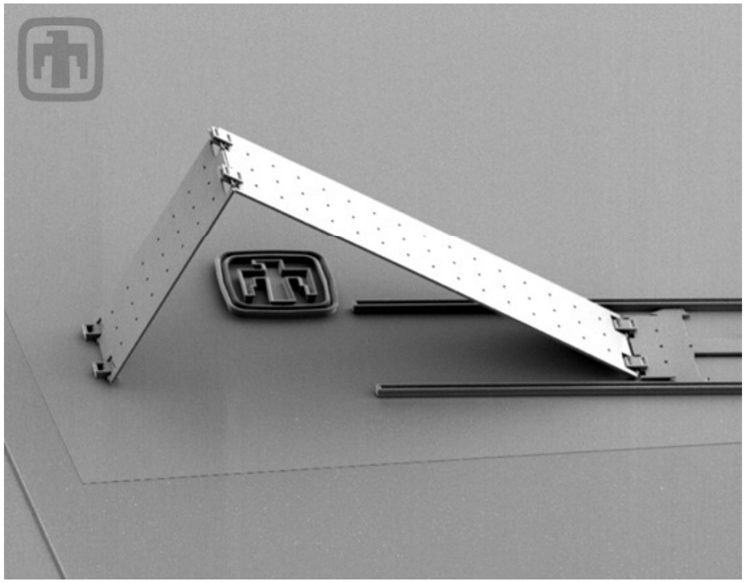
Typical MEMS Parts



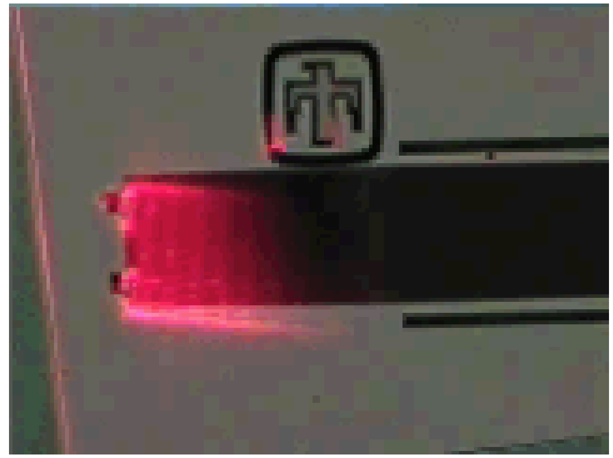


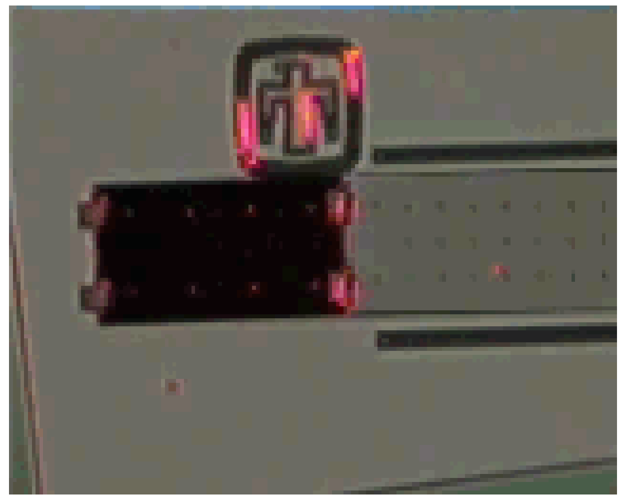
Six gear chain

Typical MEMS Parts

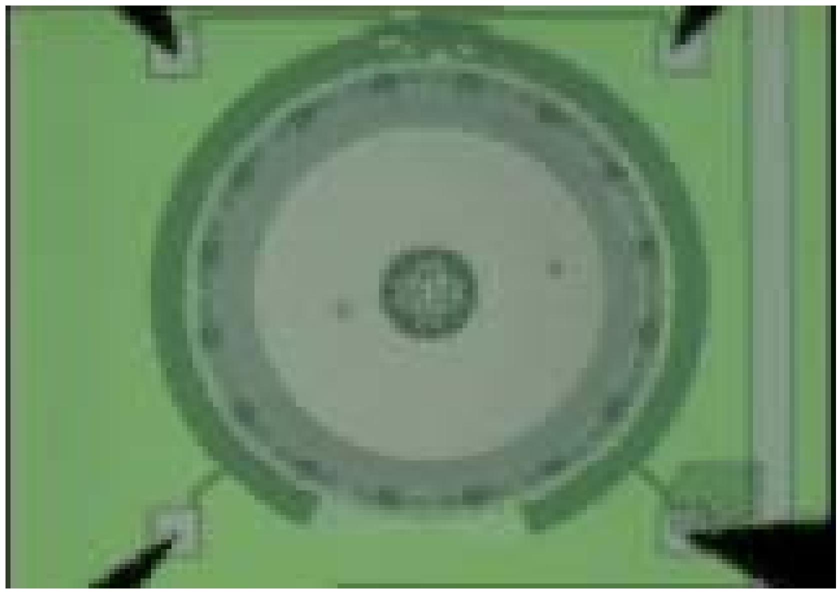


Silicon mirror assembly





Typical MEMS Parts

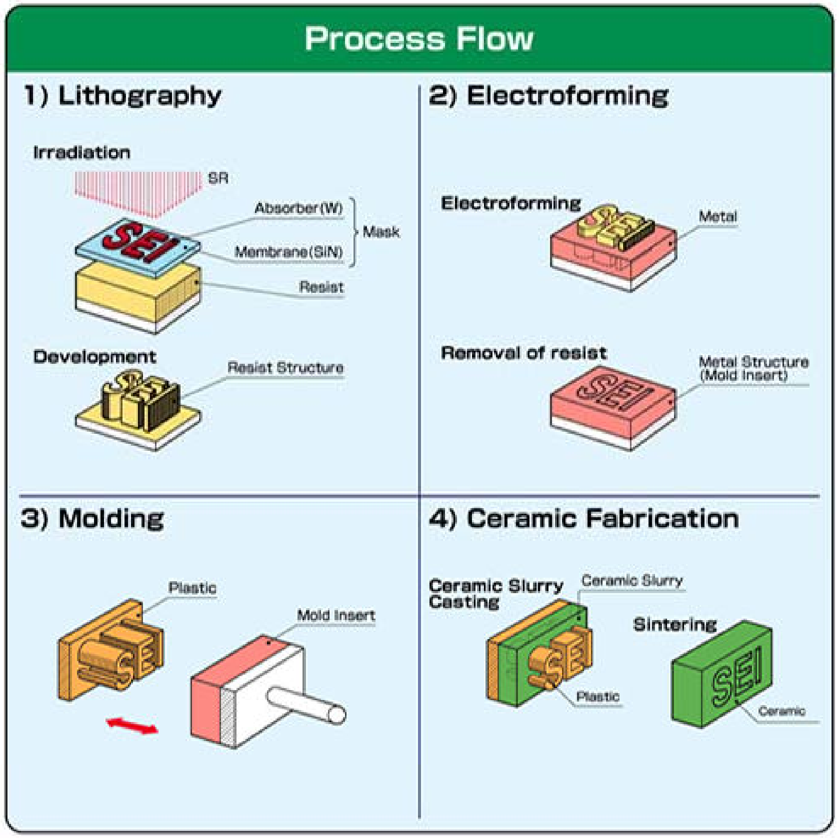


Motor

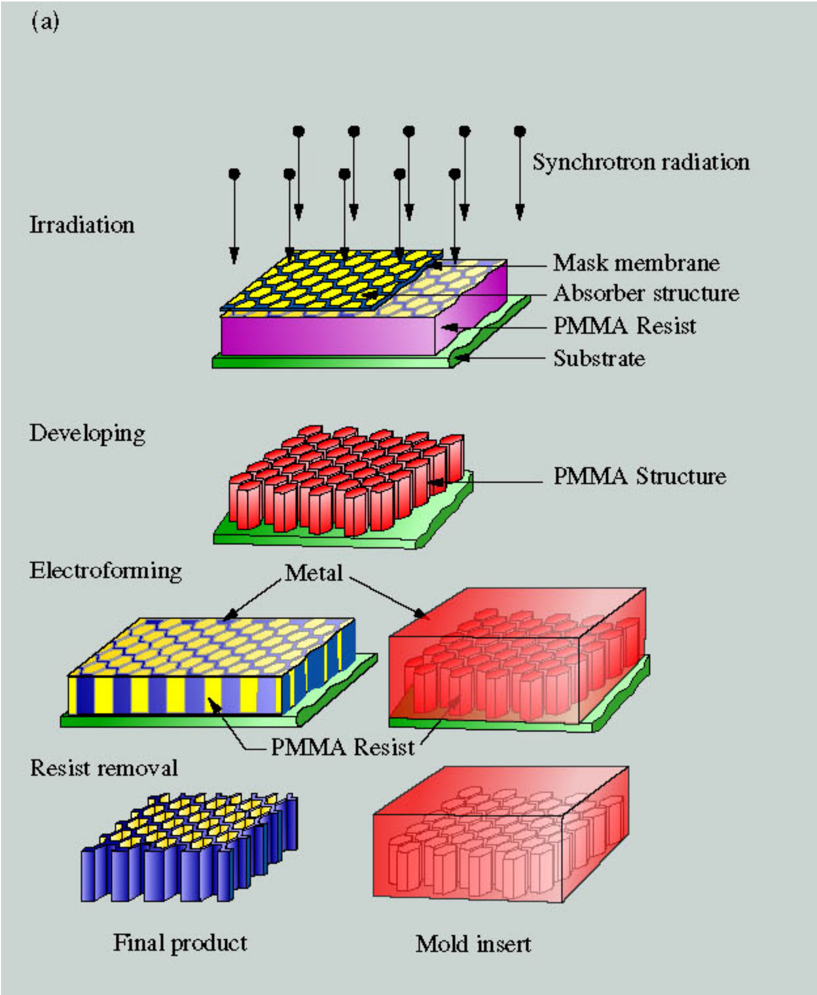
LIGA

German Acronym

- LI thographie → Lithography
- Galvanoformung → Electroforming
- A bformung → Molding



LIGA - Basic Steps



X-ray Irradiation

Resist Development

Electroforming

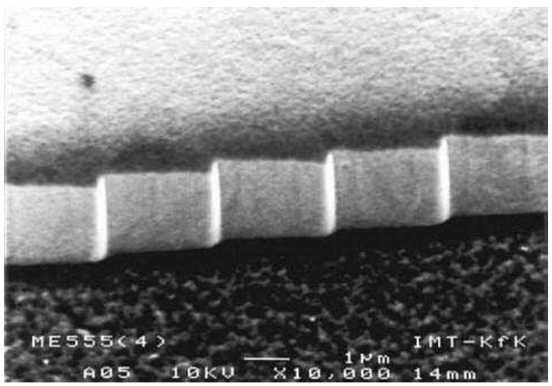
Resist Removal

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

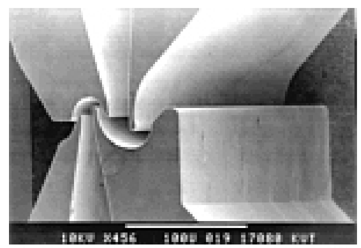
LIGA Process Capability

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

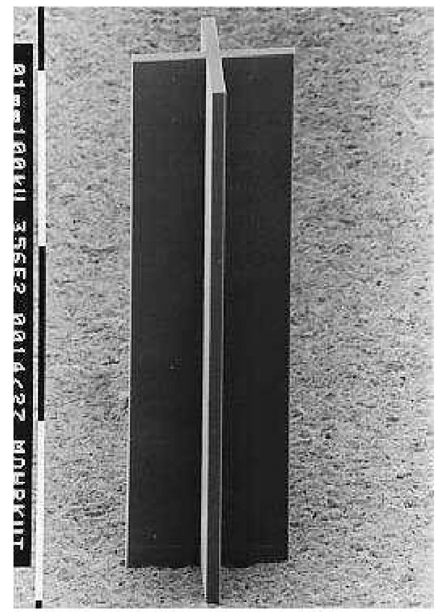


Resist structure of a reflection grating, 0.25 μm height, 125 μm structural height.

High accuracy



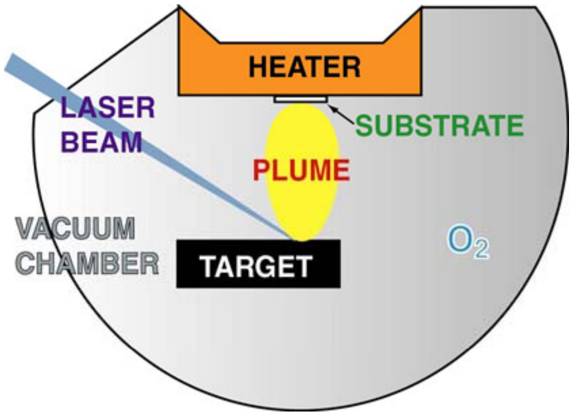
Any lateral shape

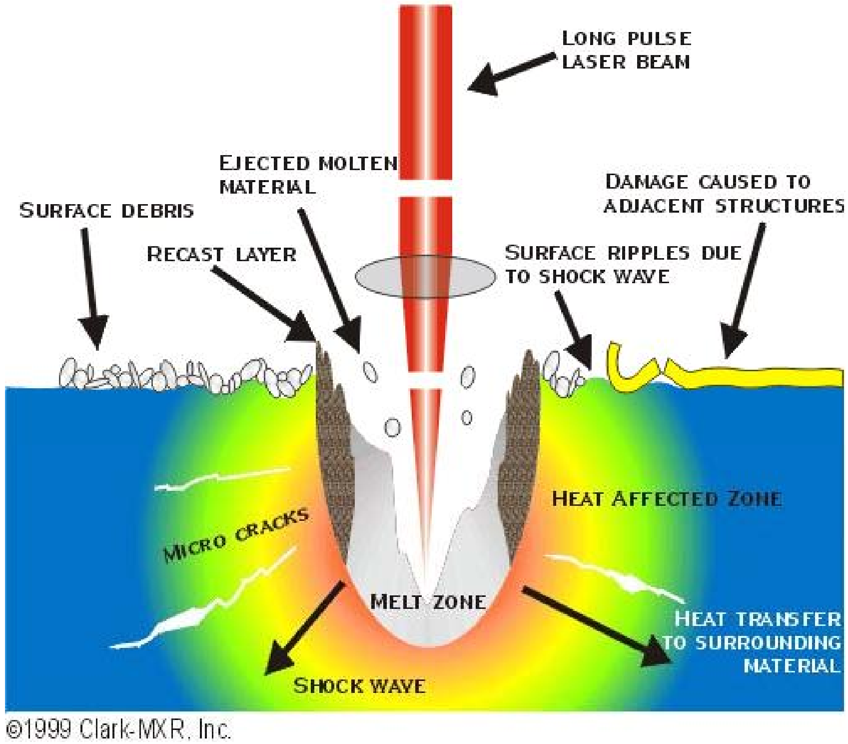


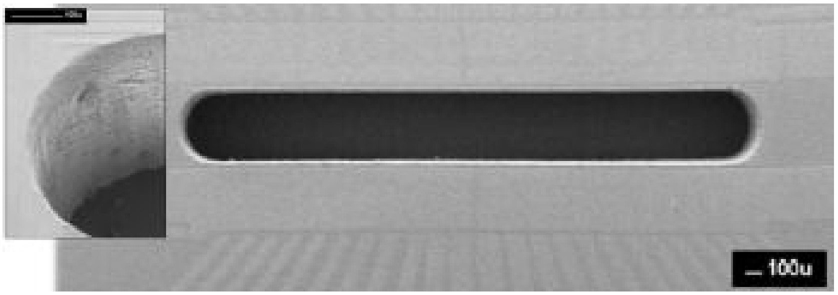
Bar structure 400 μm high, with parallel sidewalls.

High aspect ratio

Laser Ablation







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

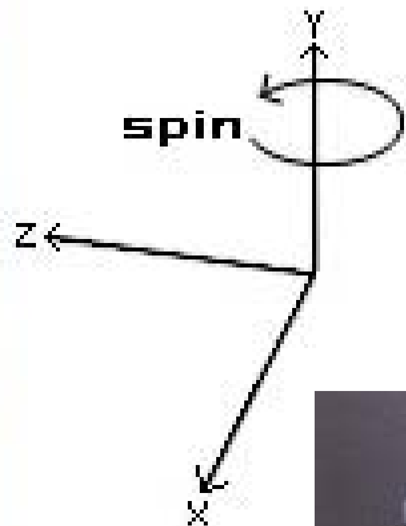
Mechanical Micromachining

- 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

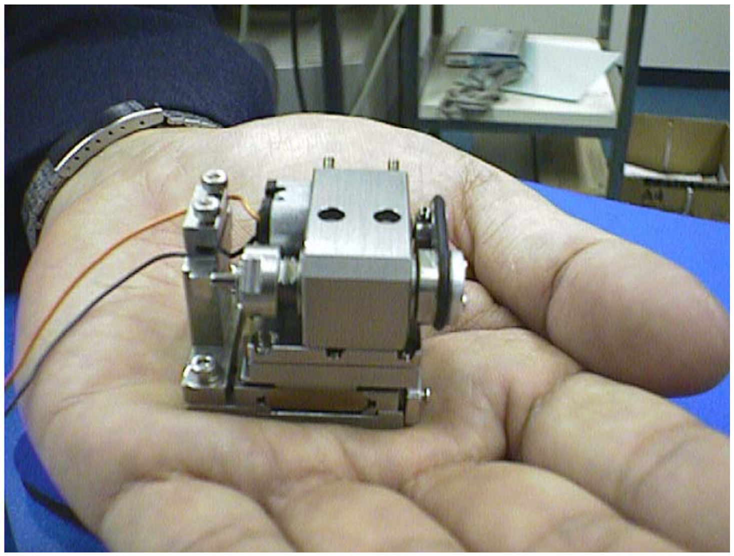
Ultra Precision Machine Tools



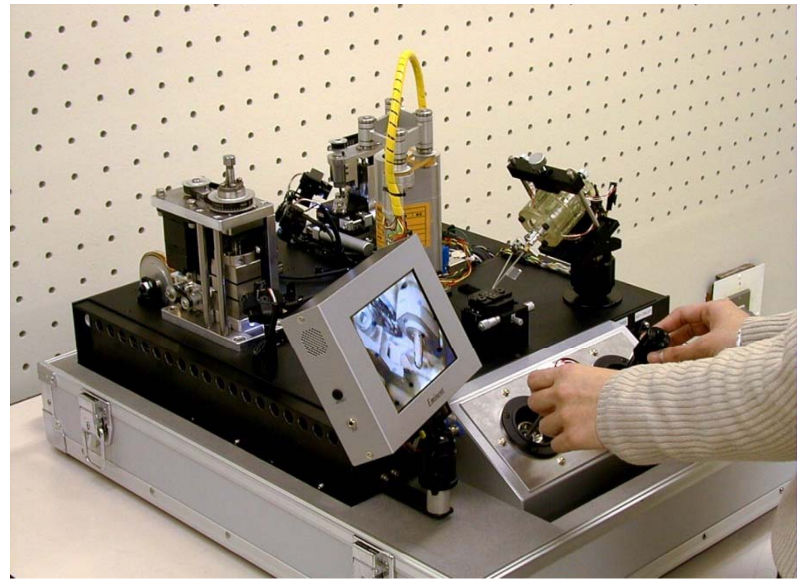
Mold for spheric/aspheric lenses

Source: www.toshiba-machine.com

Miniature Machine Tools

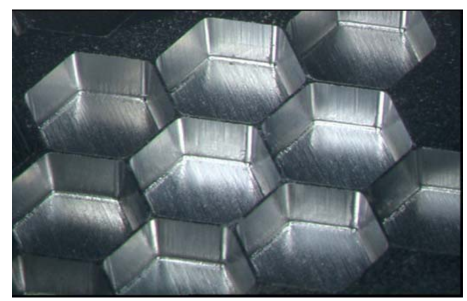


Micro Lathe

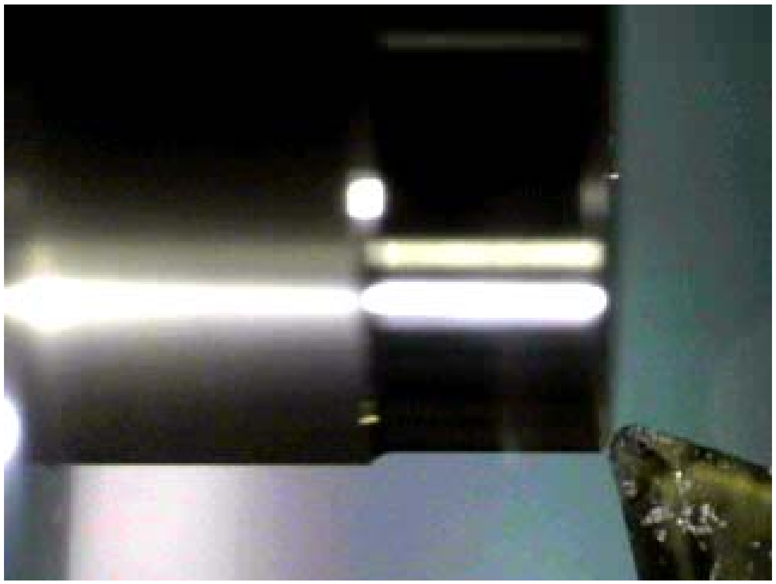


Micro Factory

Source: MEL, AIST, Japan



Miniature Machine Tools

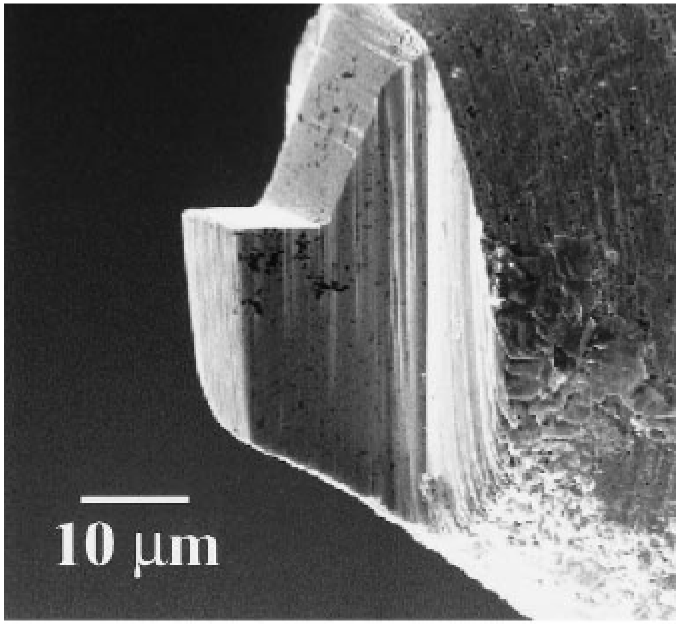


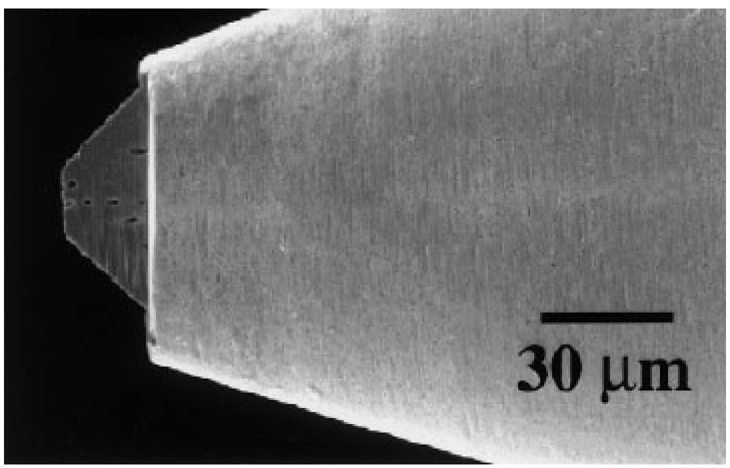
Micro Turning

Micro Milling

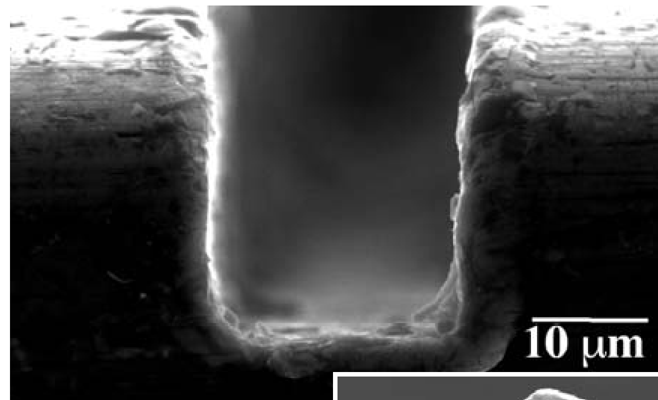
Source: MEL, AIST, Japan

Micro Cutting Tools

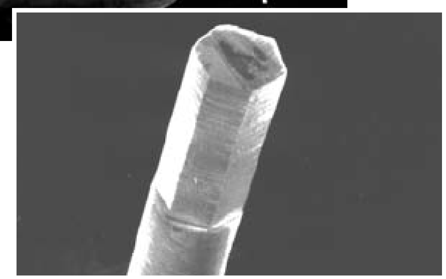




Cutting tools made by Focused Ion Beam (FIB) machining



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.



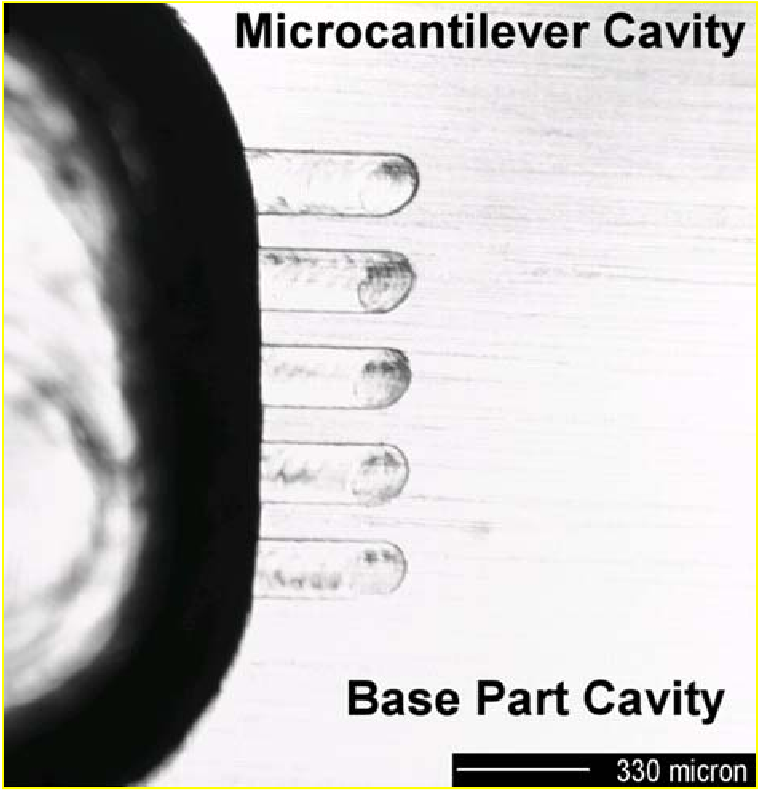
Source: http://www.sandia.gov

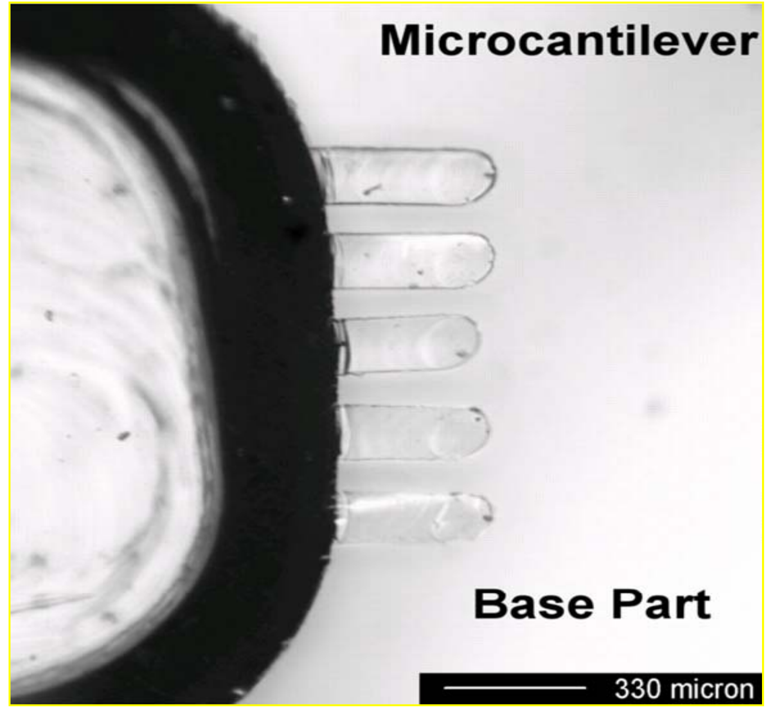
Source: Adams et al, Prec. Eng., 24 (2000) 347-356

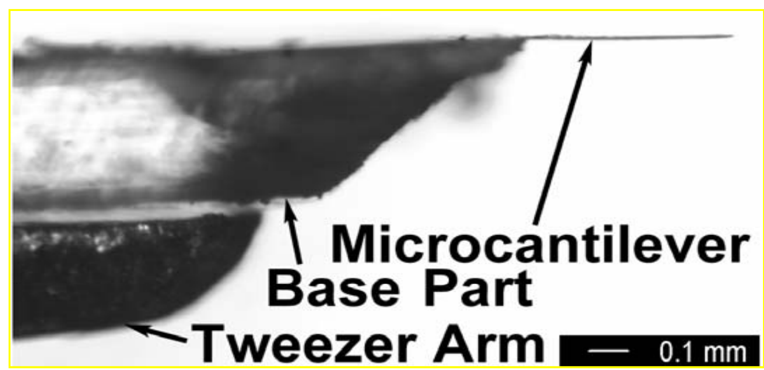
Micro Cutting Tool

10 μm tool with human hair

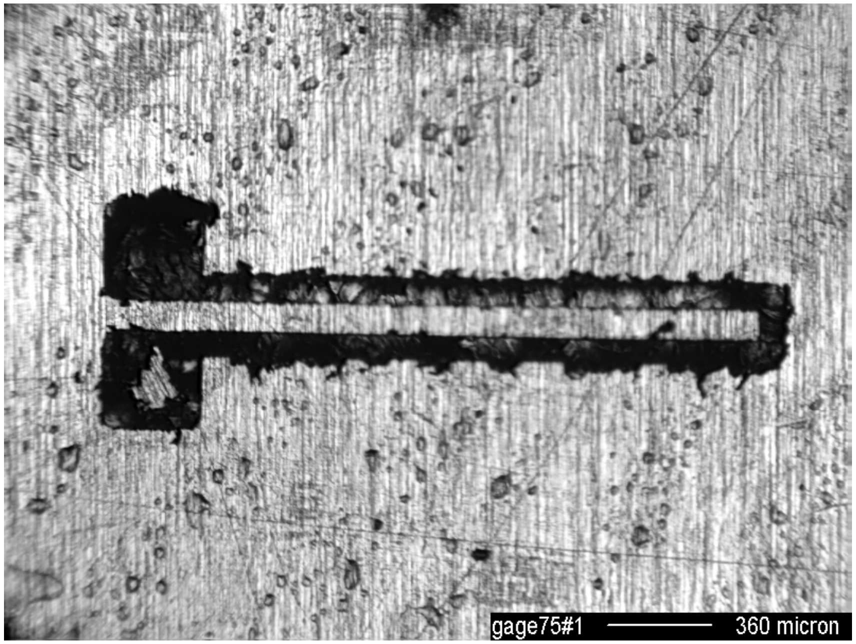
Micro Injection Molds

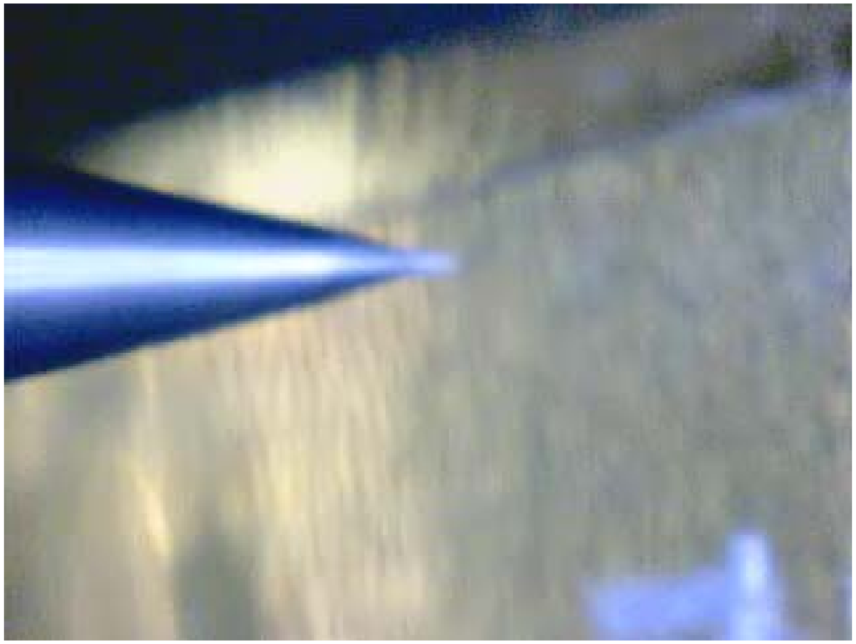






Stencil Machining





ϕ = 50 μm, N = 50,000 rpm, feed = 100 mm/min, chip size = 100 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