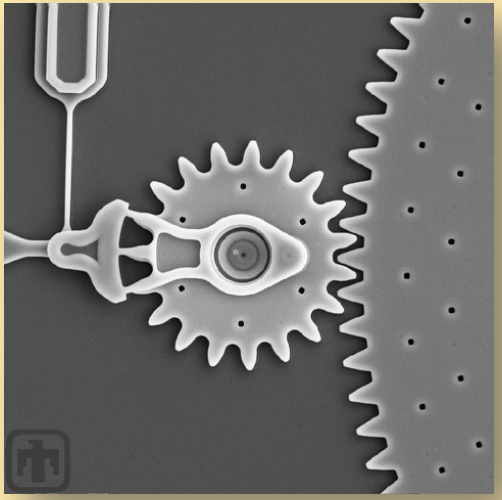
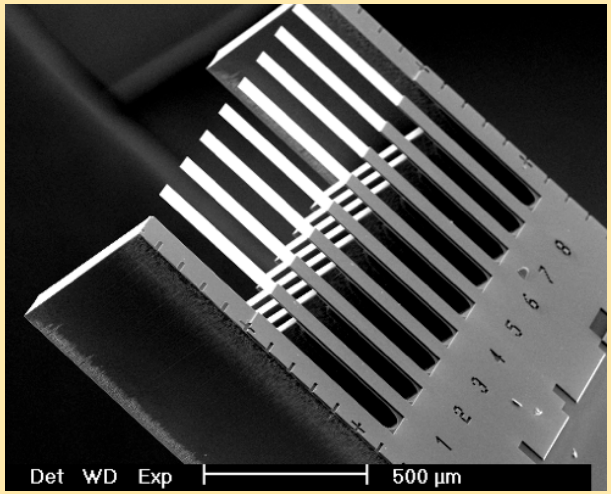
MEMS MICROMACHINING OVERVIEW

Surface



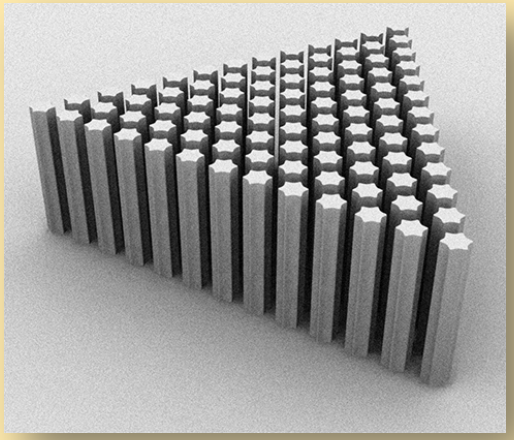
Microgears
[Image Courtesy of Sandia National Laboratories, SUMMiT V process]

Bulk



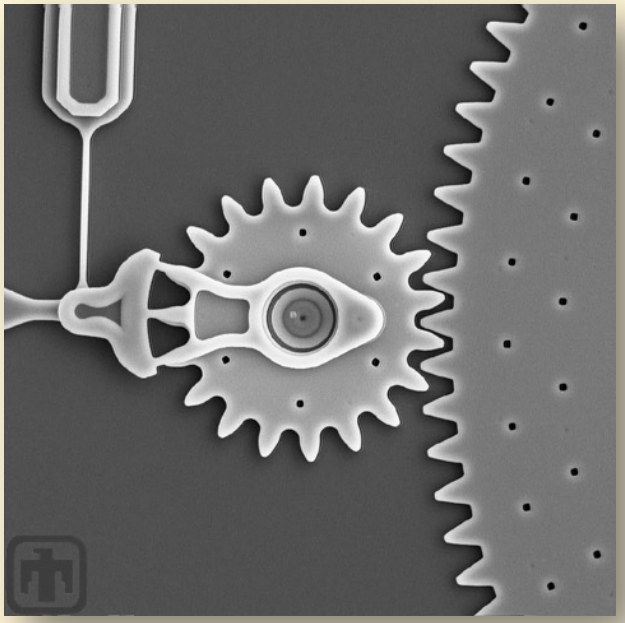
Microcantilever Chemical Sensor Array
[Image courtesy of Dr. Christoph Gerber, Institute of Physics, University of Basel]

LIGA



Graphic of High Aspect Ratio Rods

Surface Micromachining

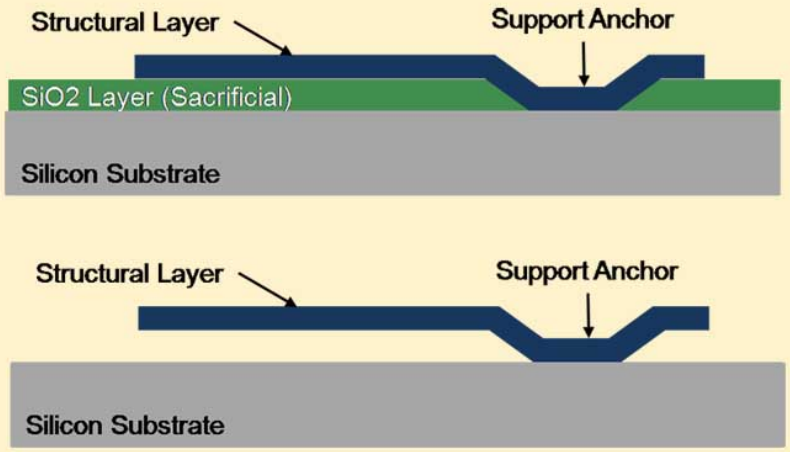


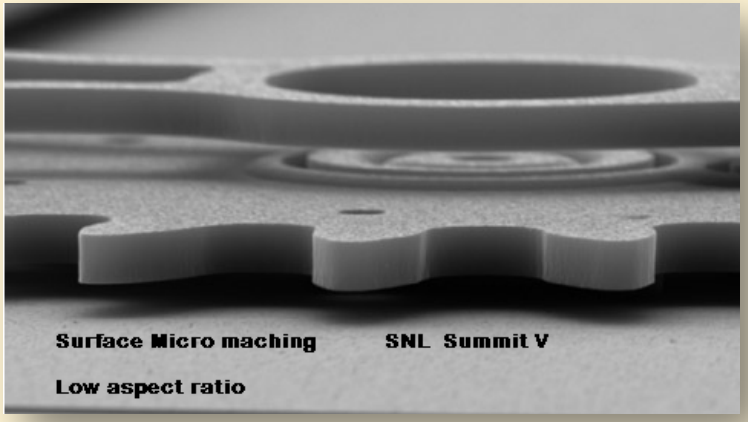
Microgears

[Image Courtesy of Sandia National Laboratories, SUMMiT V process]

Surface Micromachining

- Structural and sacrificial layers are deposited, patterned and etched on top of a substrate.
- Structures have low aspect ratios (short and wide)
- Based on CMOS manufacturing. *(CMOS – complementary metal oxide semiconductor)*





[Image courtesy of Sandia National Laboratories]

Surface Micromachining

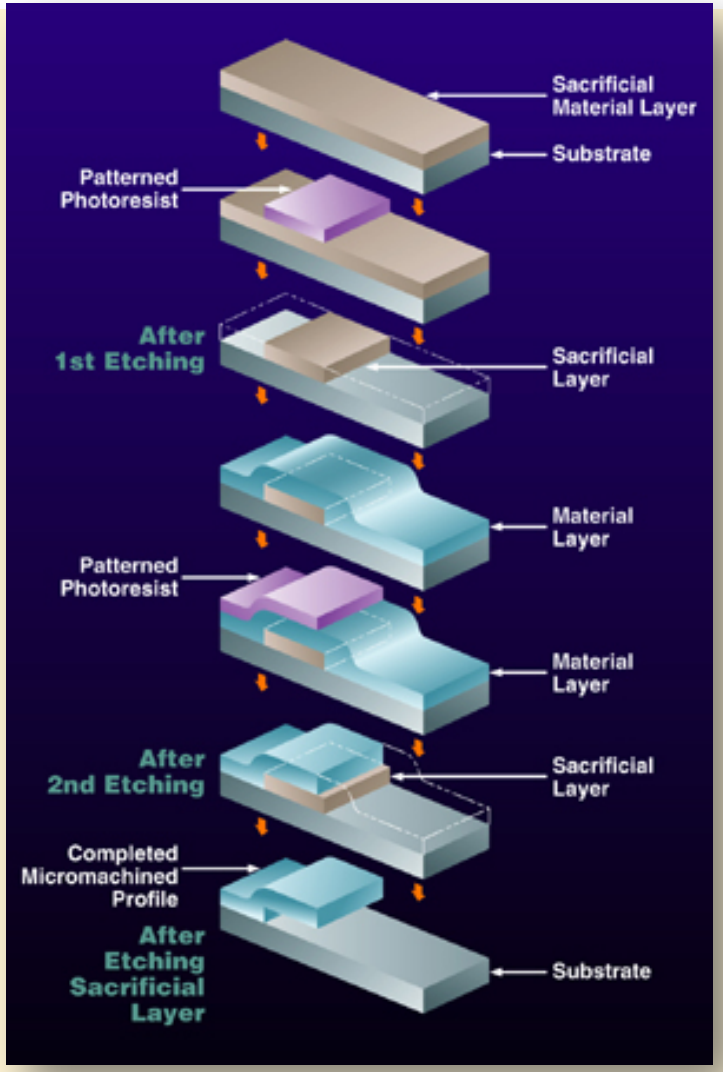
- A micromechanical part is formed out of deposited thin films
- At least one structural and at least one sacrificial layer.

Microcantilever Fabrication

1)A sacrificial layer is deposited, patterned and etched

2)A structural layer which is deposited, patterned, and etched

3)Sacrificial layer is removed.

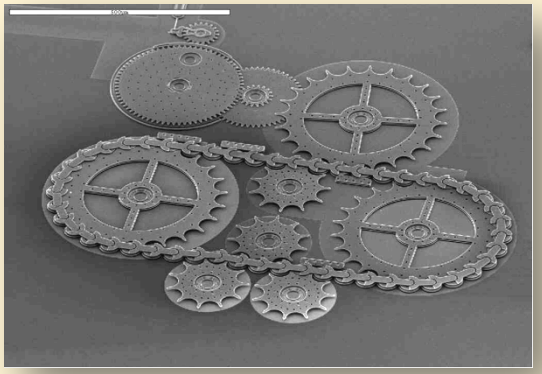


[Image courtesy of Southwest Research Institute. Copyright SwRI]

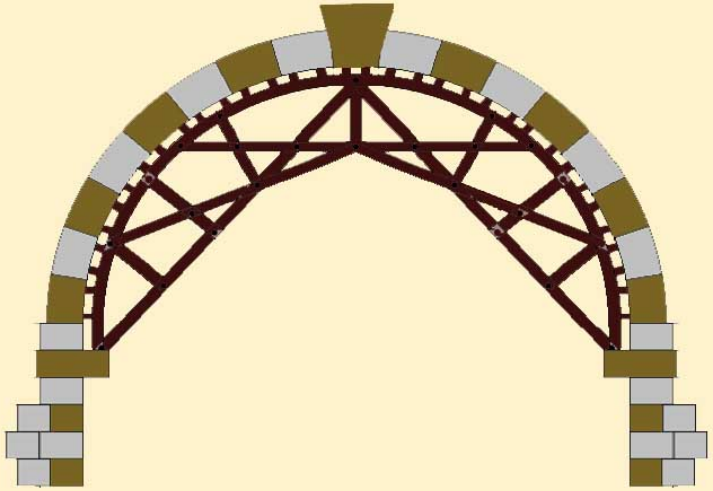
Surface Micromachining

What is a sacrificial layer?

- Needed when building complicated components, such as moveable parts.
- Used to separate layers as the structure is being constructed
- Dissolved away at the end to free the structural layers.

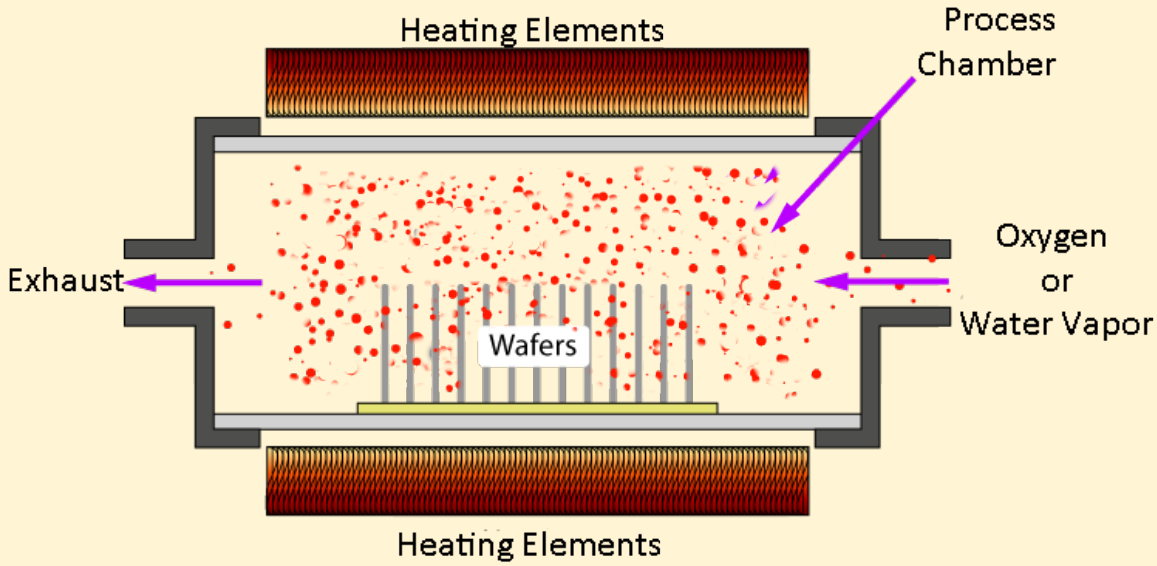


[Image Courtesy of Sandia National Laboratories]



Deposition

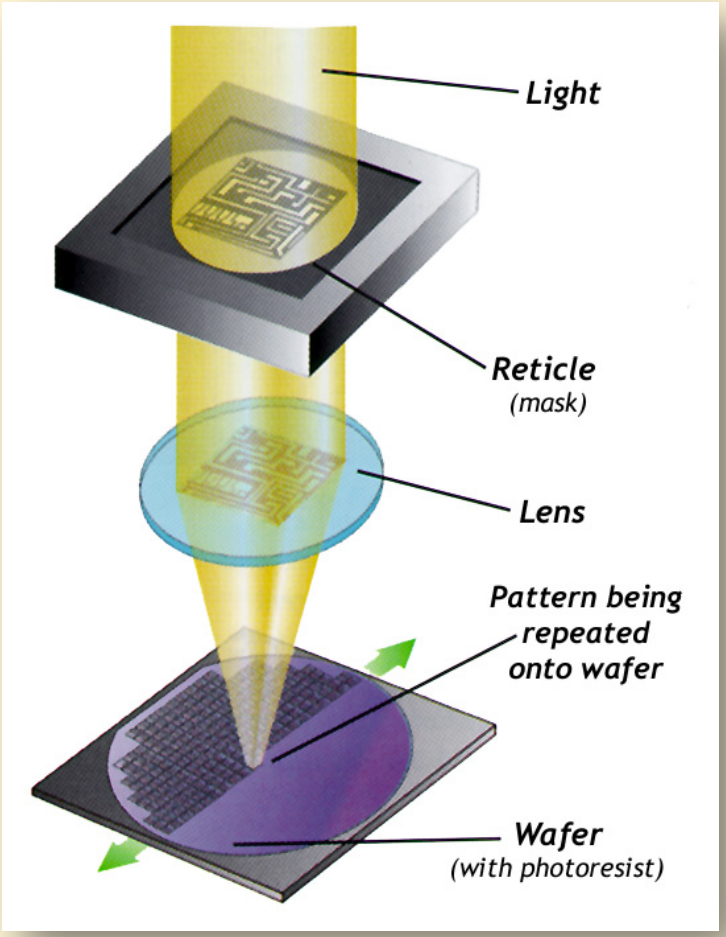
- First layer could be an insulator, isolator or sacrificial layer.
- First layer is “usually” a thermally grown silicon dioxide layer (SiO_2 or oxide).



- Other thin films and subsequent layers of oxide and other thin films use a type of Chemical Vapor Deposition (CVD).

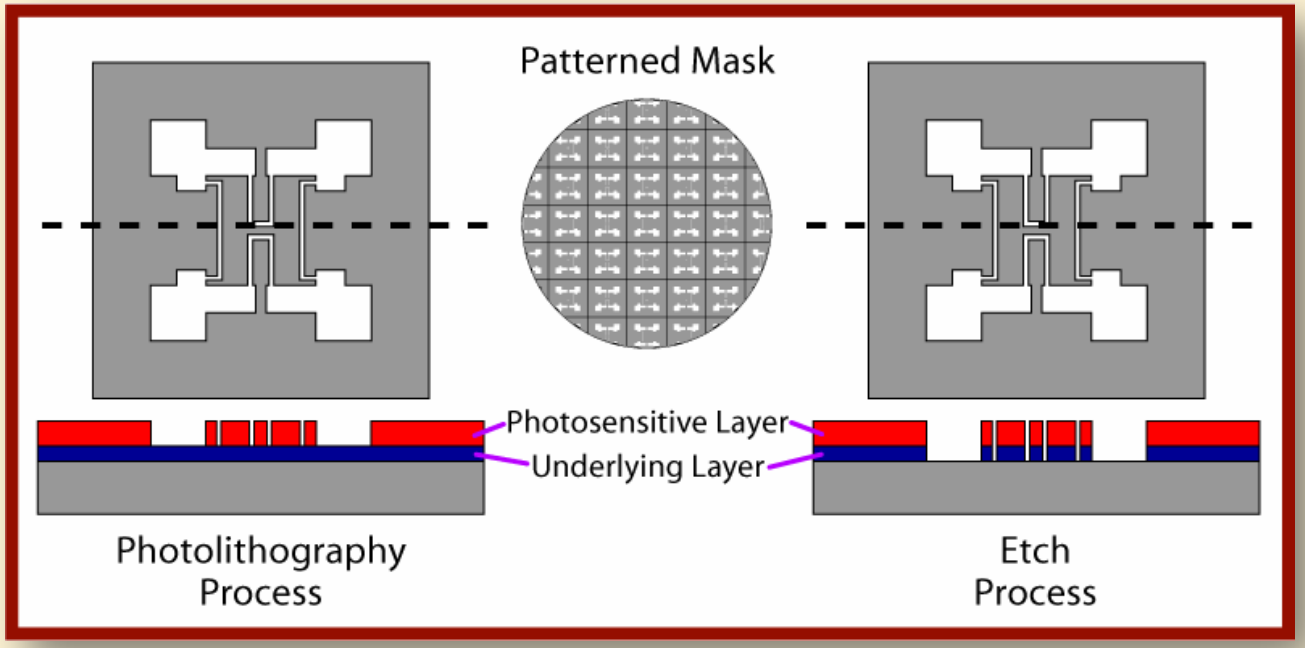
Photolithography

- Pattern (Photolithography)
  - Coat wafer with photoresist
  - Align and expose resist to a pattern
  - Develop resist
  - Bake to harden resist



[Image Courtesy of MATEC]

Photolithography and Etch

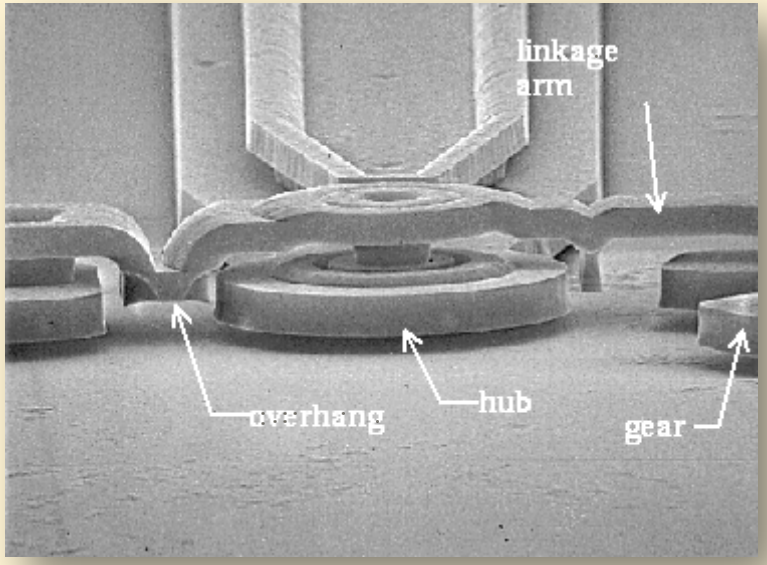


- Pattern from mask is transferred into photoresist.
- Photoresist pattern is transferred into underlying layer using an etch process.
- After etch, the photoresist is removed.

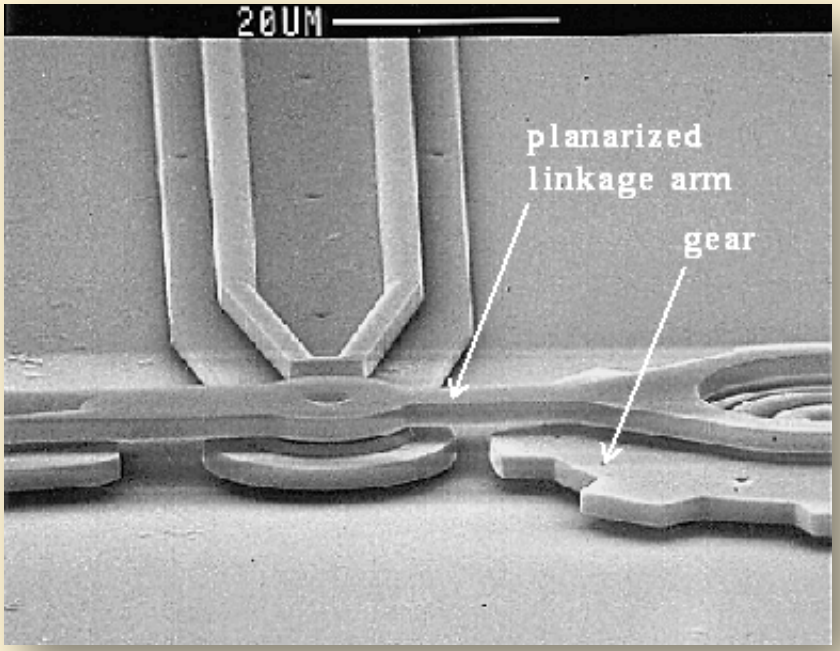
Surface Micromachining - CMP

CMP or Chemical Mechanical Polishing is used after one or two structural layers to flatten the bumpiness in the topography of the wafer's surface.

Without CMP



With CMP

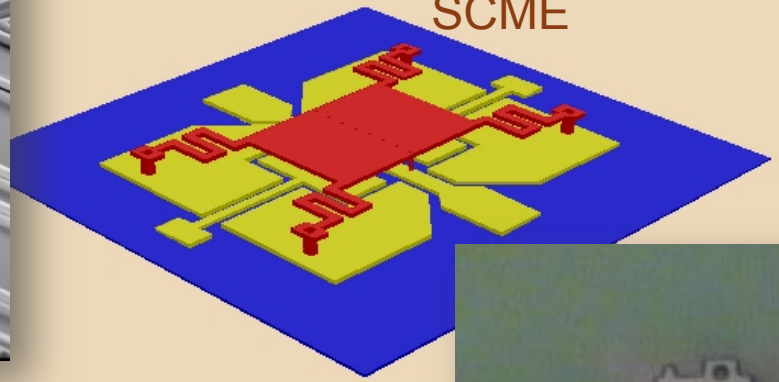


[Scanning Electron Microscope (SEM) images courtesy of Sandia National Laboratories]

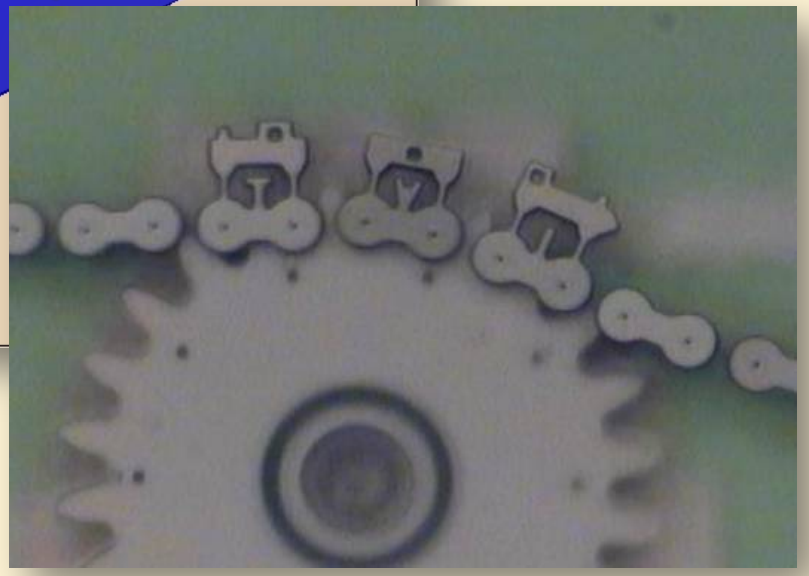
Surface Micromachining – Components

Comb Drive
Sandia National Labs

RF Switch
SCME

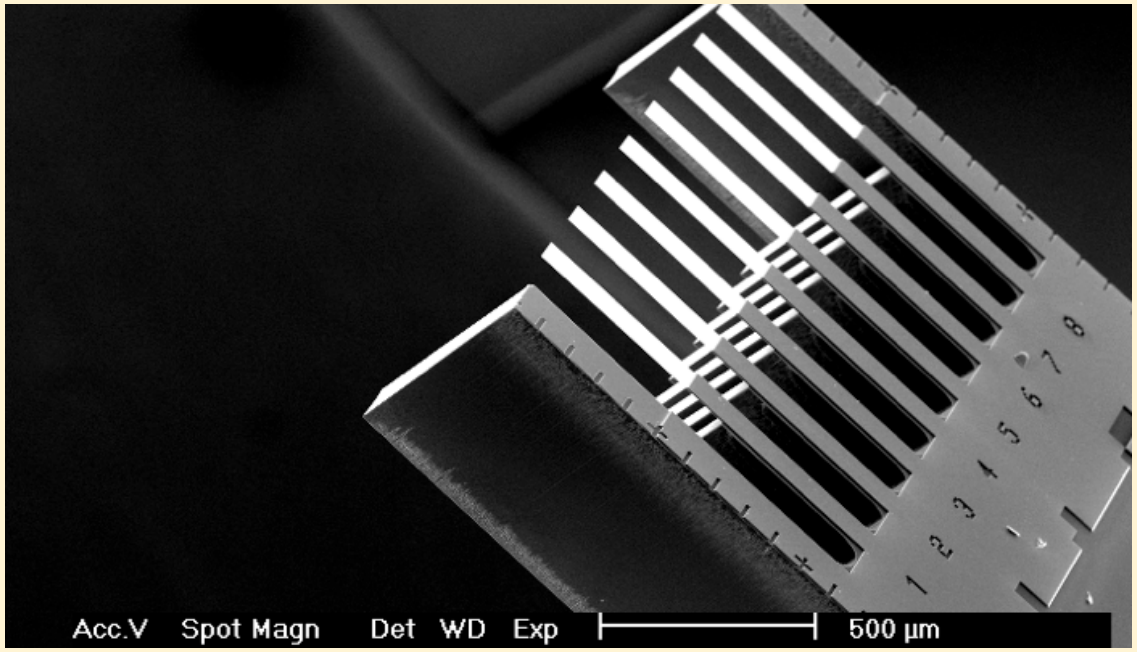


- SAW Sensors
- Actuators
- RF Switches
- Inertial Sensors
- Cantilevers
- TRA's



Chain
Paul Tafoya

Bulk Micromachining



Microcantilever Chemical Sensor Array
[Image courtesy of Dr. Christoph Gerber, Institute of Physics, University of Basel]

Bulk Micromachining

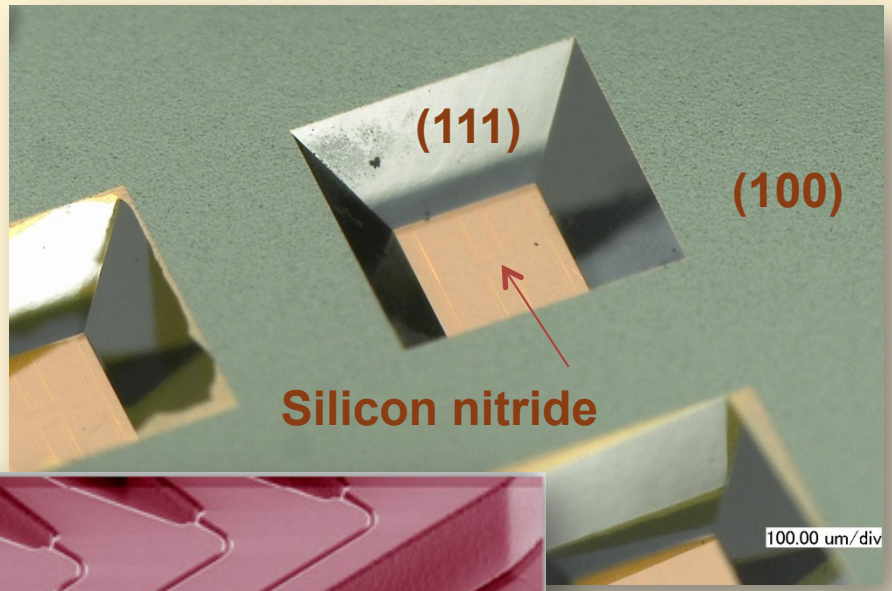
- Removes the “bulk” of a material
- Subtractive process
- Cliff dwellings at Mesa Verde – an example of bulk etching
- Micro-machined structures formed into the wafer substrate

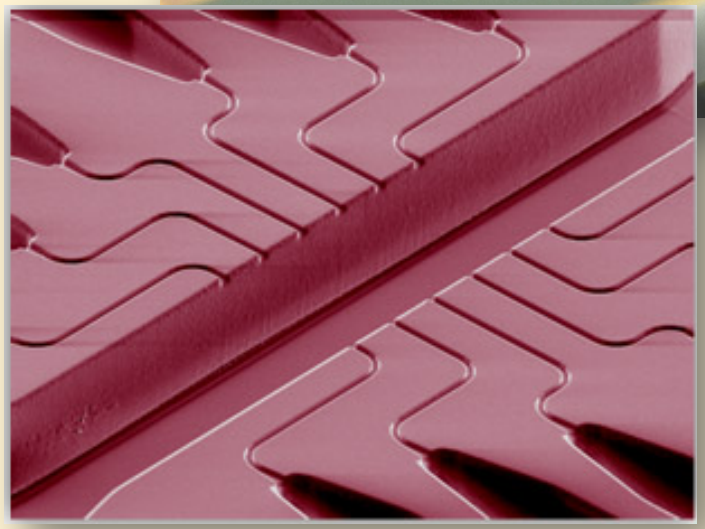
[Image printed with permission from Barb Lopez]

Bulk Micromachining

- Three-dimensional MEMS device within substrate
- Selective anisotropic etch
- High volume manufacturing such as sensors
- Bulk micromachined devices typically have high aspect ratios.

Backside of MTTC Pressure Sensor

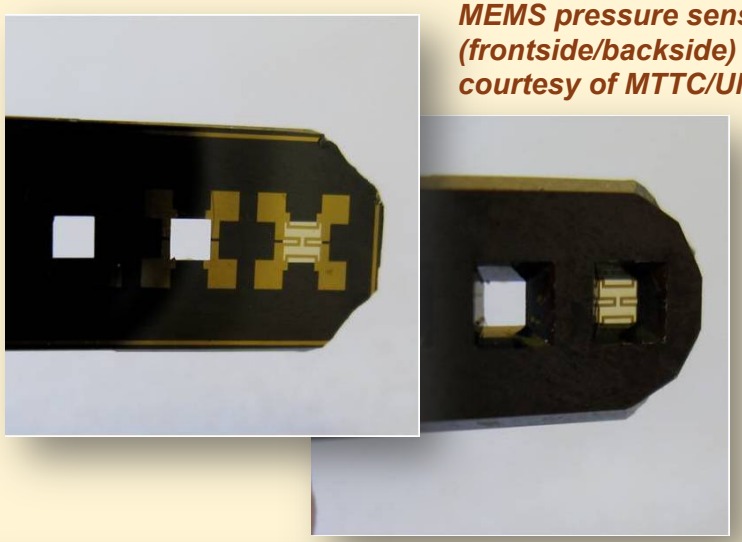




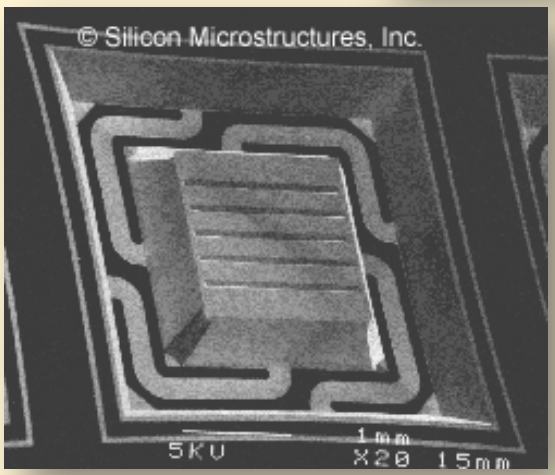
Microfluidic channels with high aspect ratio fluidic chambers [C. Ionescu-Zanetti, R.M. Shar, J. Seo, Y.Jan, and L.P.Lee (PNAS, 2005). Printed with permission by Luke Lee, Dept. of Bioengineering, UC-Berkeley)]

Bulk Micromachining Processing

- Deposition
- Photolithography
- Etch
  - structural layers
  - sacrificial layers
- Bulk dry or wet etching of relatively large amounts of silicon substrate



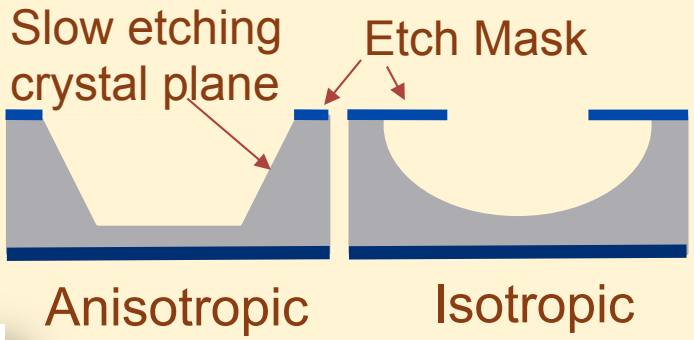
MEMS pressure sensor (frontside/backside) [Images courtesy of MTTC/UNM]

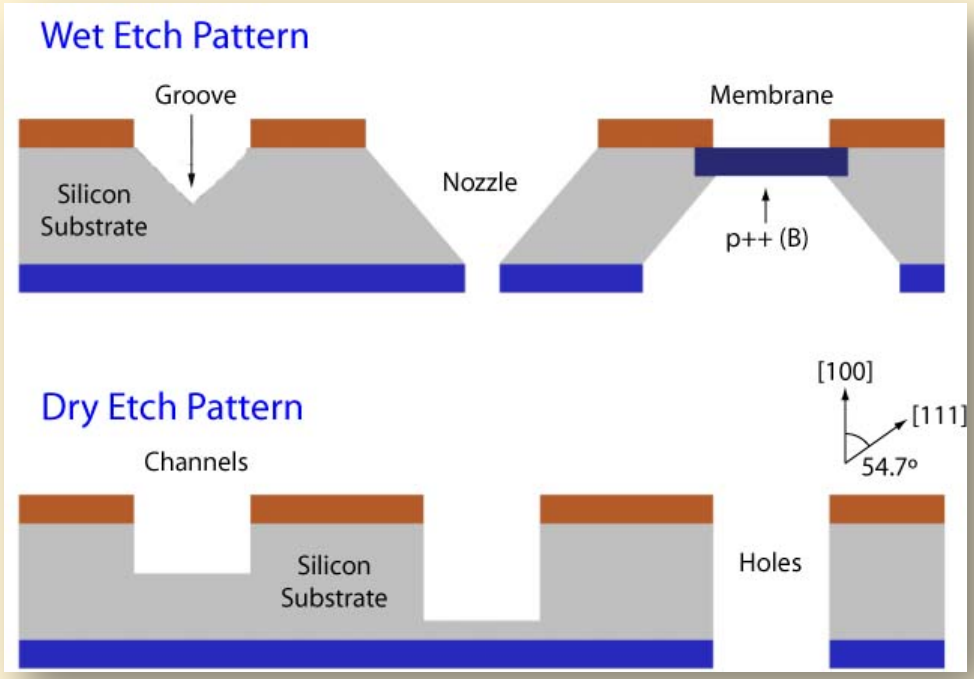


[Image courtesy of Khalil Najafi, University of Michigan]

Bulk Micromachining – Etch Profiles

- Isotropic Etch
- Anisotropic Etch
- Wet Etch vs. Dry Etch patterns

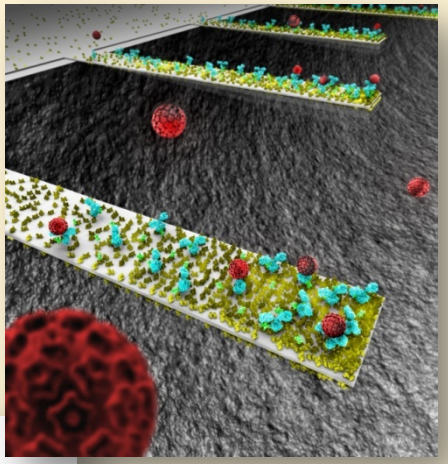


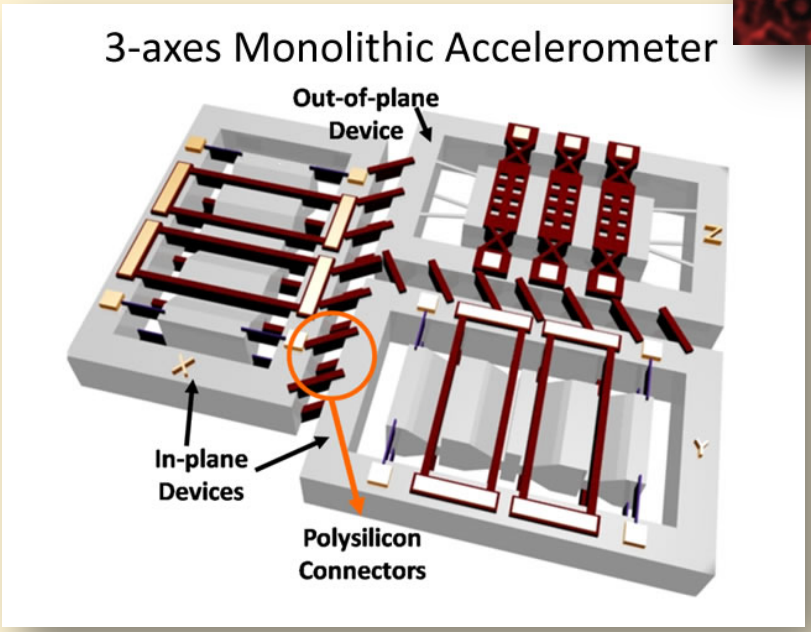


Bulk Micromachining – Components

- Cantilever Arrays
- Nozzles
- Microfluidic channels
- Needle arrays
- AFM Probes
- Membranes
- Chambers
- Through Wafer connections

Cantilever array
[Image courtesy of Seyet, Inc.]

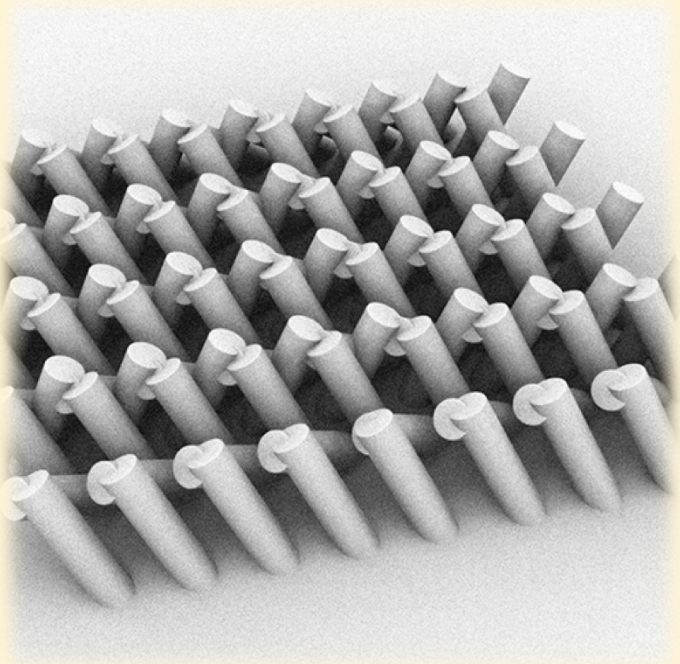




[Image courtesy of Khalil Najafi, University of Michigan]

LIGA

Lithographie (Lithography), **G**alvanoformung (electroforming), and **A**bformung (molding)



[Graphic representing angled structures possible through LIGA processing]

LIGA

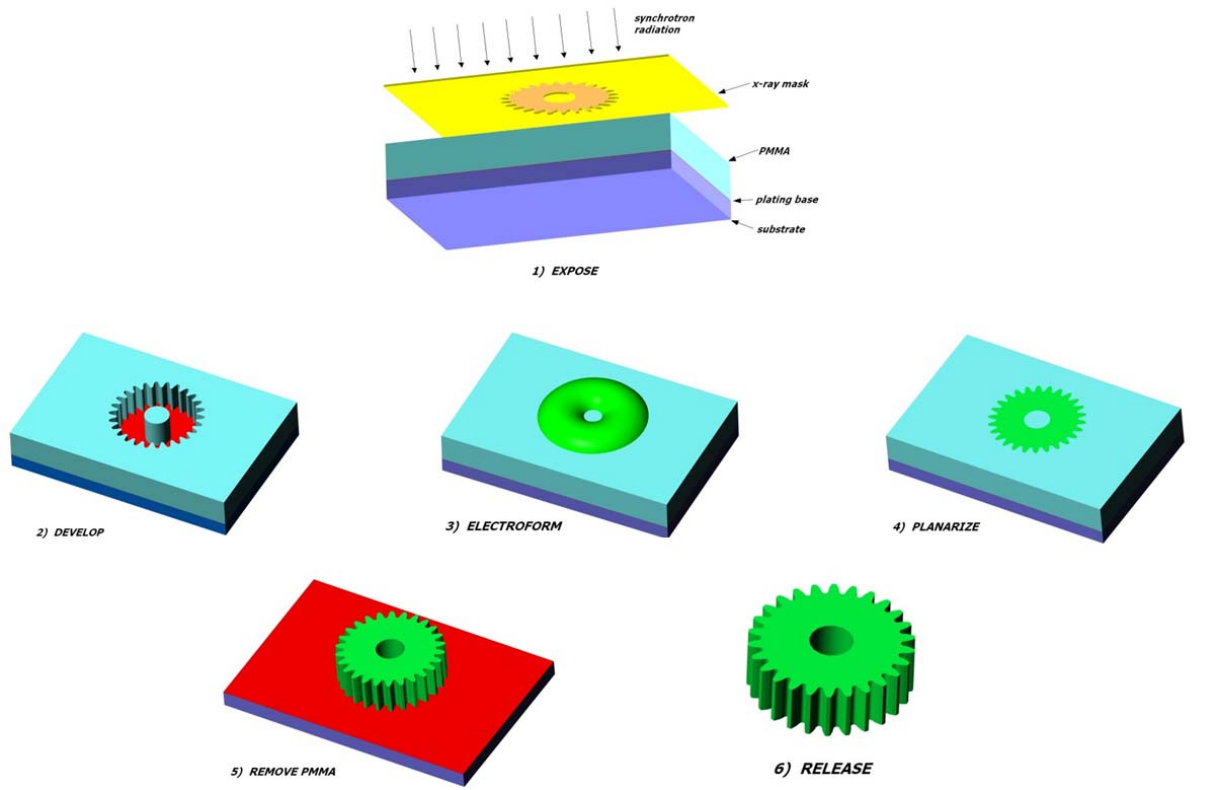
- Additive process
- HARMST – High Aspect Ratio Microstructure Technology
- Structures have precise dimensions and good surface roughness
- Output - Finished parts, molds, or stamps

LIGA-micromachined gear for a mini electromagnetic motor

[Courtesy of Sandia National Laboratories]

LIGA Process

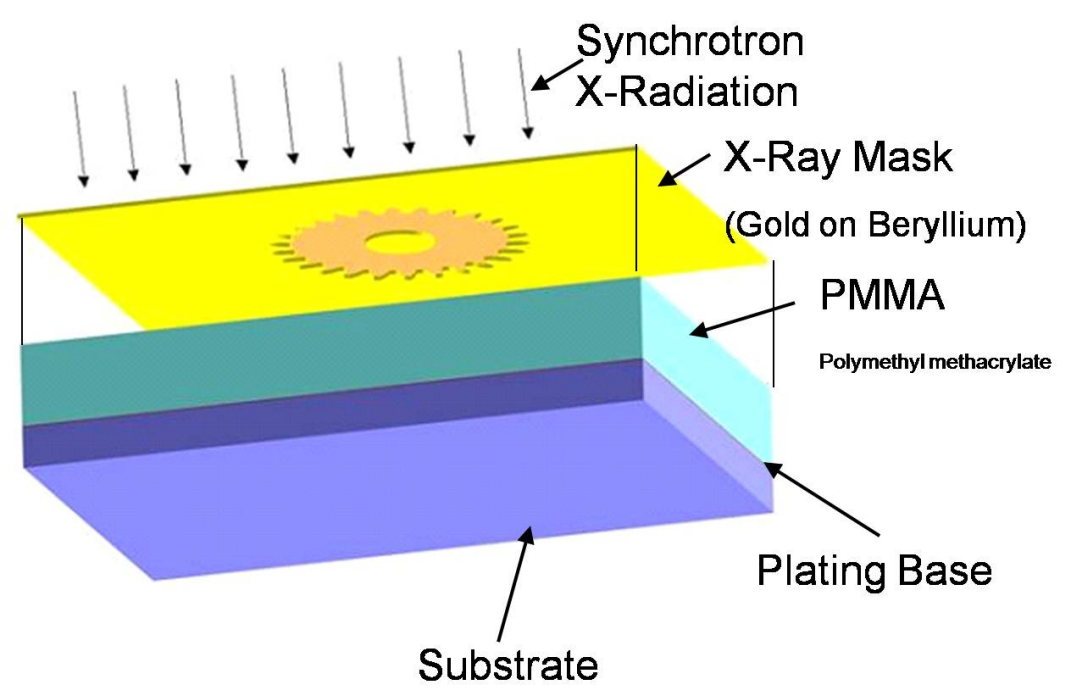
- Deposit
- Expose
- Develop
- Electroform
- Planarize
- Strip
- Release



[Image courtesy of HT MicroAnalytical, Inc.]

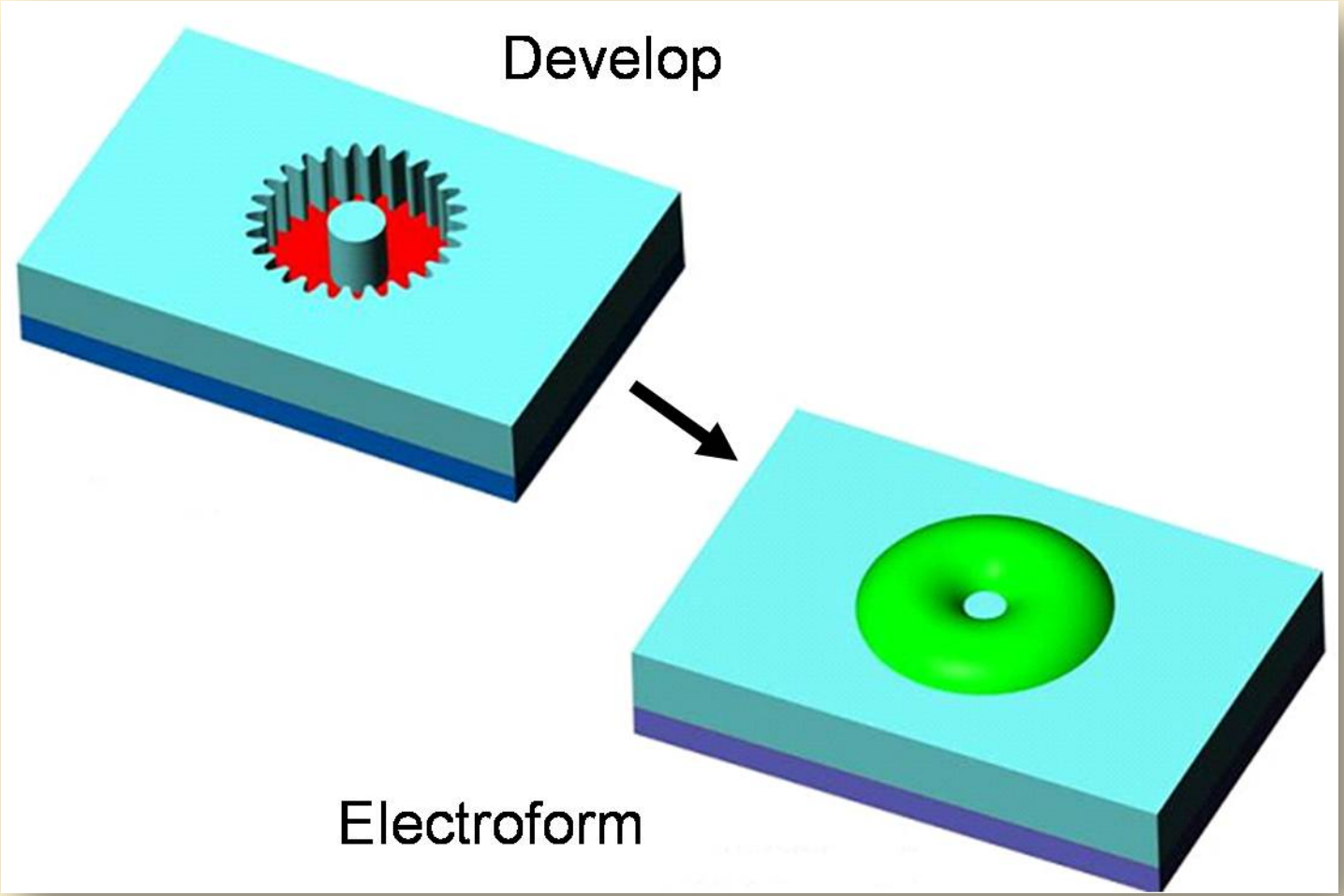
LIGA Lithography

- Photosensitive Material: PMMA *(polymethyl methacrylate)* or Plexiglass
- Light Source: Colimated Synchrotron radiation (x-ray)



[Image courtesy of HT MicroAnalytical, Inc.]

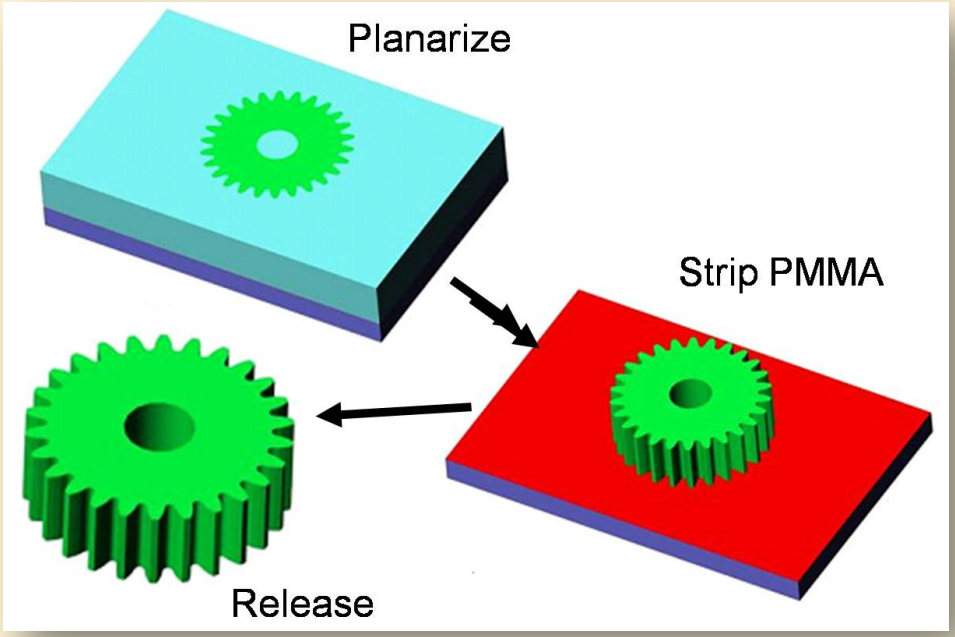
The LIGA Process



[Images courtesy of HT MicroAnalytical, Inc.]

The LIGA Post Process

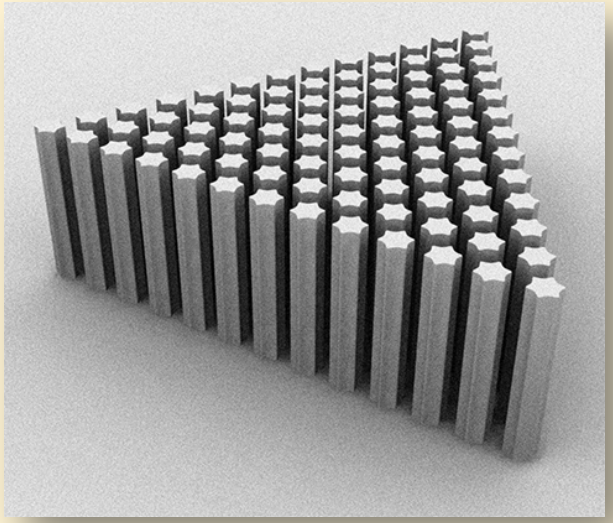
- Planarize, Strip PMMA, Release
- Stamping or molding
- Component level OR wafer scale assembly
- Wafer scale bonding
  - Multi-layer structures
  - Packaging
- Requires extensive, unique metrology



[Images courtesy of HT MicroAnalytical, Inc.]

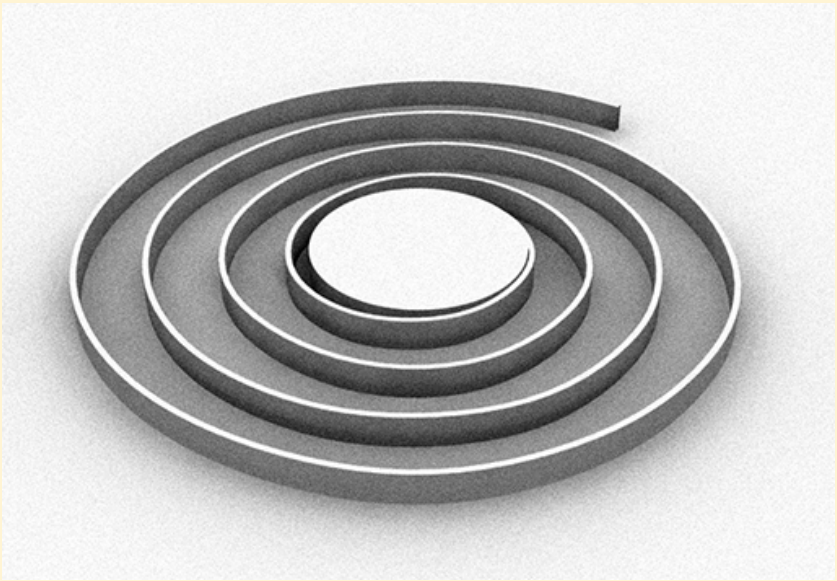
To view this animated process, go here: https://youtu.be/CbN7h3o51Zo

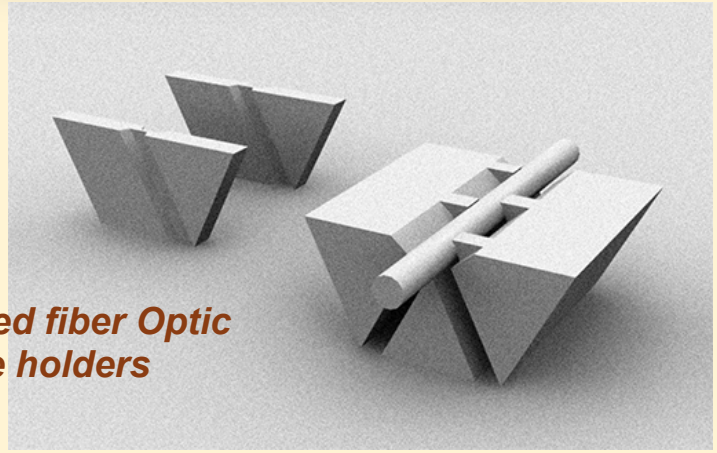
LIGA Structures



PMMA 30μm posts, 3μm spacing, 300μm tall

Precision miniature spring





Molded fiber Optic Cable holders

LIGA – Components

HARMST

- Turbines
- Gears
- Springs
- Clips
- Needle Arrays
- Shutters
- Gratings
- Packaging

Ant with a LIGA micro-gear.
Image courtesy of Rorschungzentrum Karlsruhe, Germany

Summary

MEMS fabrication (also called micromachining) has allowed for the manufacturing of micro-sized devices that can be fabricated on top of substrates, within substrates, or molded and bonded.

Three widely used micromachining processes are

- surface micromachining
- bulk micromachining, and
- LIGA (**Li**thography**, G**alvanoformung, and **A**bformung).

Acknowledgements

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