MEMS
its methods and applications

CHE 384T – Graduate Student Presentation

11/14/17

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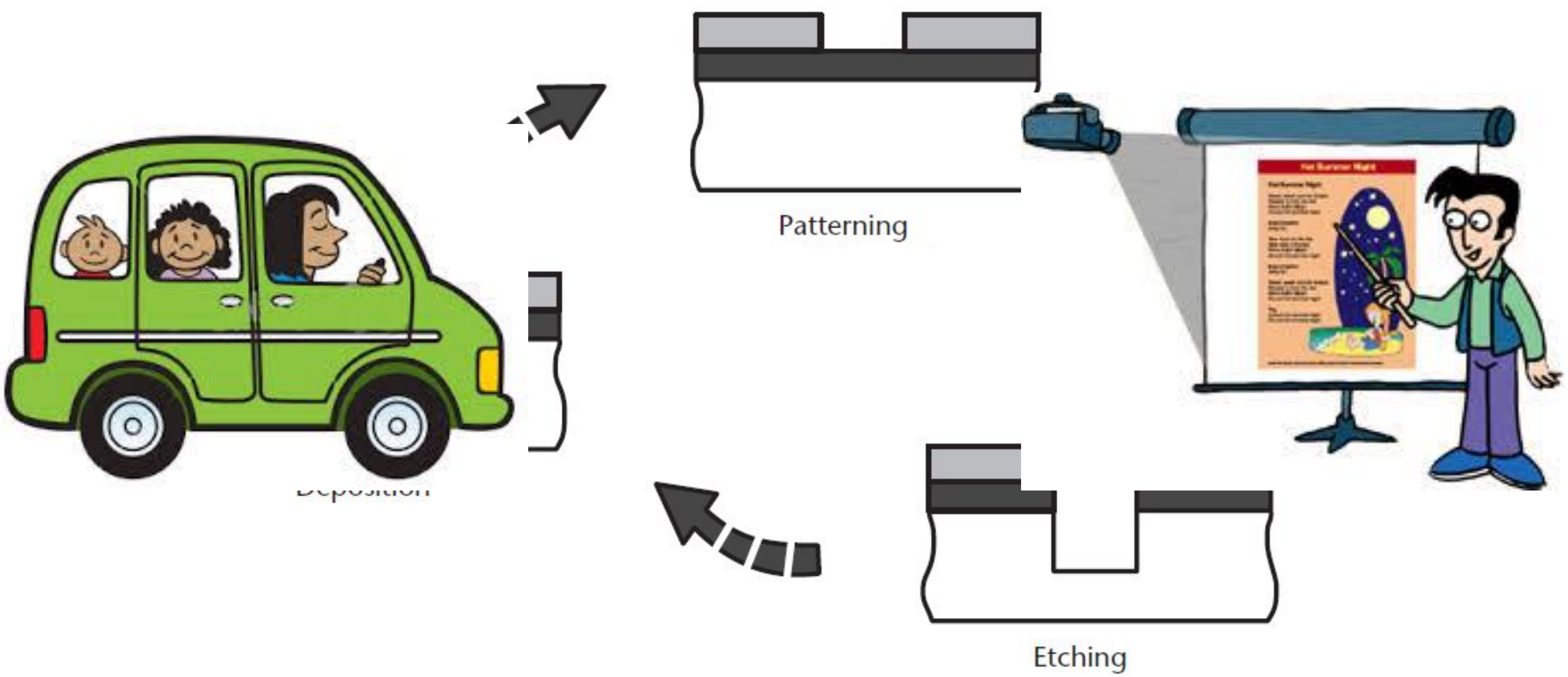
Contents

- MEMS
- Brief history
- Methods
  - Surface
  - Bulk
  - LIGA
- Applications
  - Industrial & automotive
  - Optical displays
- Outlook

MEMS - MicroElectroMechanical Systems

- A portfolio of various micromachining techniques & processes to create miniature systems at microscale
- MEMS devices are everywhere



http://clipart-library.com/clipart/903804.htm
https://www.bushfirepress.com/musicroom/support/multi_age.html

Early days of MEMS

- Discovery of the piezoresistive effect in silicon by C.S Smith (1954)
  - A change in the electrical resistivity when mechanical strain is applied
- “Silicon as a mechanical material” by Kurt Peterson at IBM (1980s)
  - Pressure sensors, accelerometers, nozzles

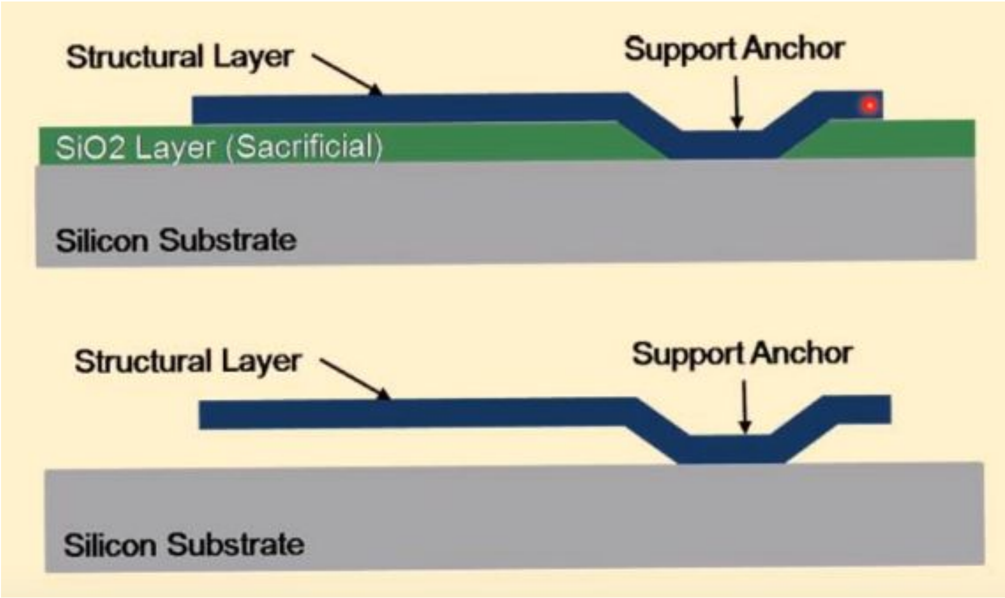
http://www.memsjournal.com/2010/07/mems-industry-overview-the-past-the-present-and-the-future.html

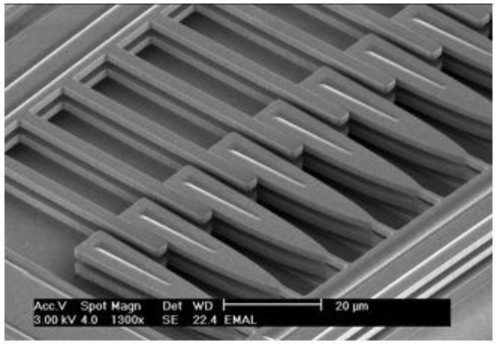
Various methods of MEMS

- Surface micromachining
- Bulk micromachining
- **LIGA**

1 / Surface micromachining

- Structural and sacrificial layers
- Low aspect ratio



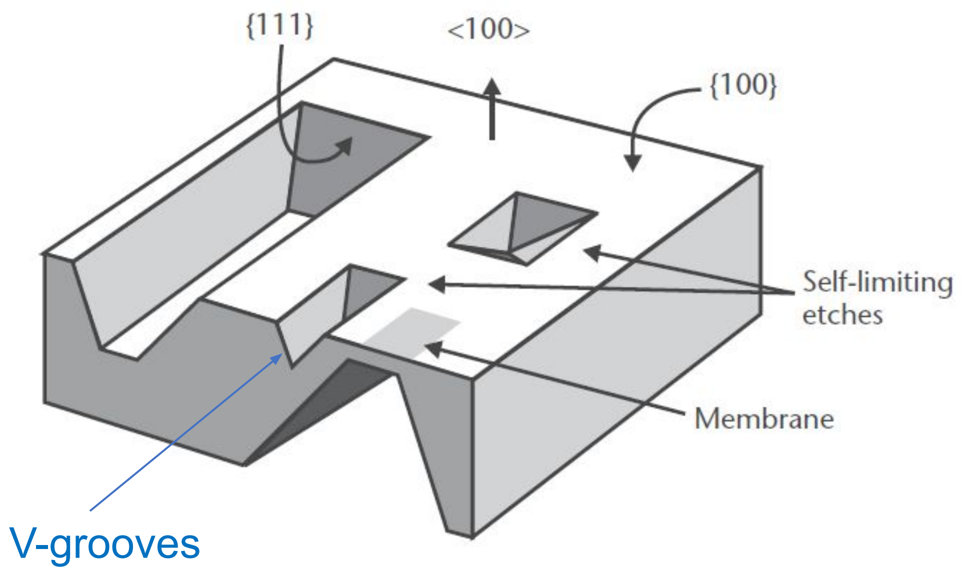


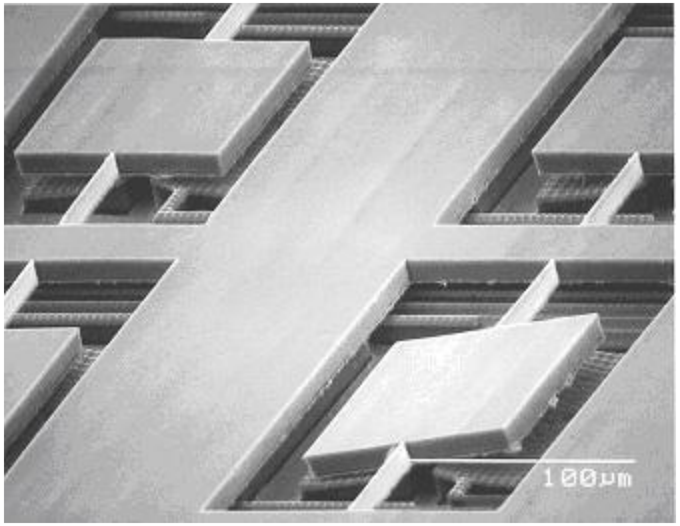
https://compliantmechanisms.byu.edu/content/introduction-microelectromechanical-systems-mems
https://www.youtube.com/watch?v=EALXTht-stg

2 / Bulk micromachining

- Subtractive process
- Selective (or anisotropic) etching
  - Wet chemical etching
  - Dry plasma etching
- Higher aspect ratio

Eg) KOH etch rate: {110} > {100} > {111}

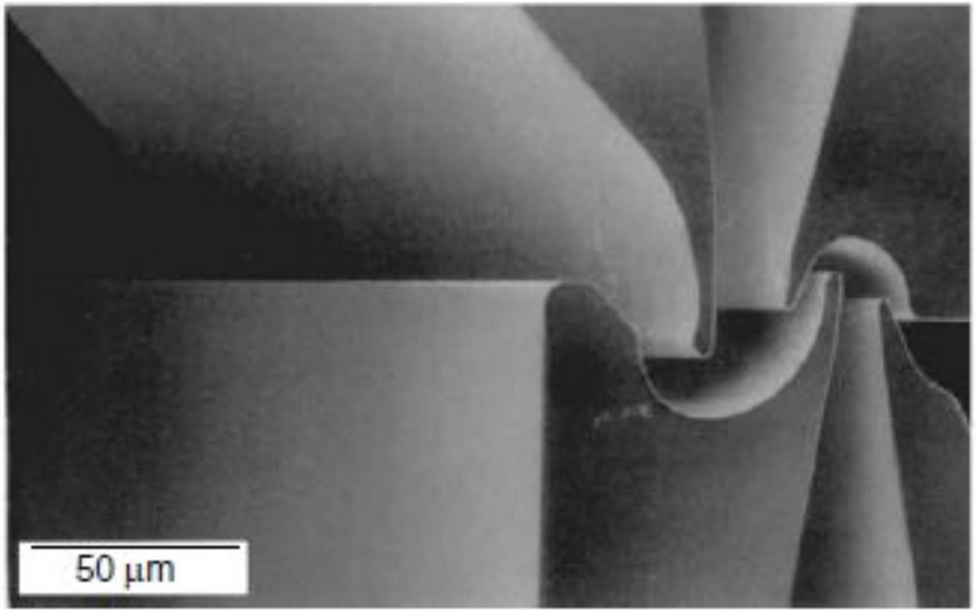


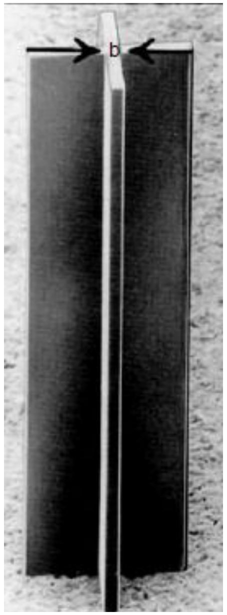


https://compliantmechanisms.byu.edu/content/introduction-microelectromechanical-systems-mems

3 / LIGA – Lithographie, Galvanoformung, Abformung

- Originally studied for the mass production of micron-sized nozzles for uranium isotopes
- Additive process
- Very high aspect ratio (~100)
- Vertical & smooth sidewalls

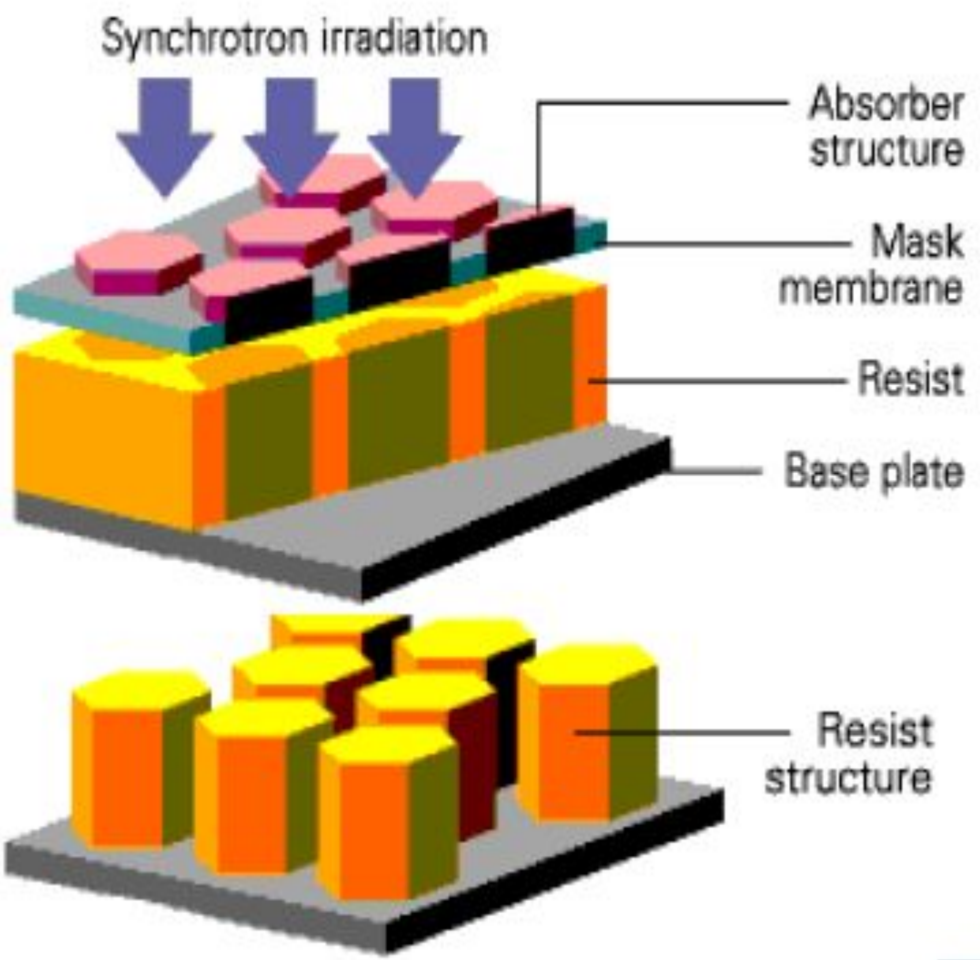




Early 1980s – Karlsruhe nuclear research center in Germany

3 / LIGA – Lithography Step

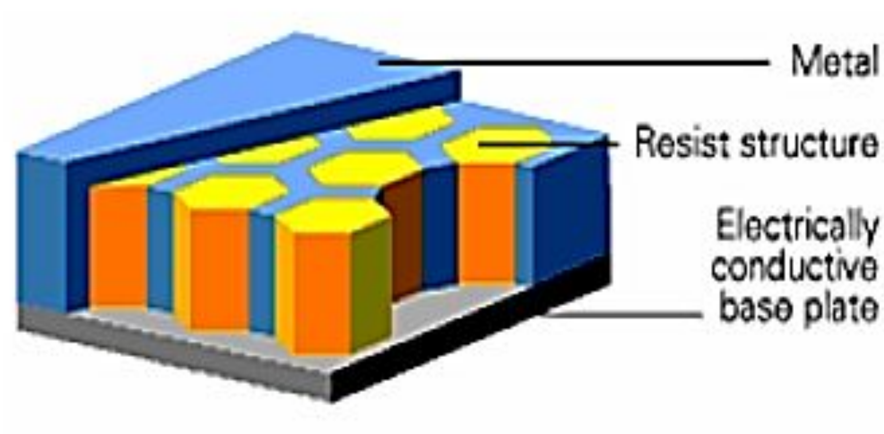
- X-ray proximity printing

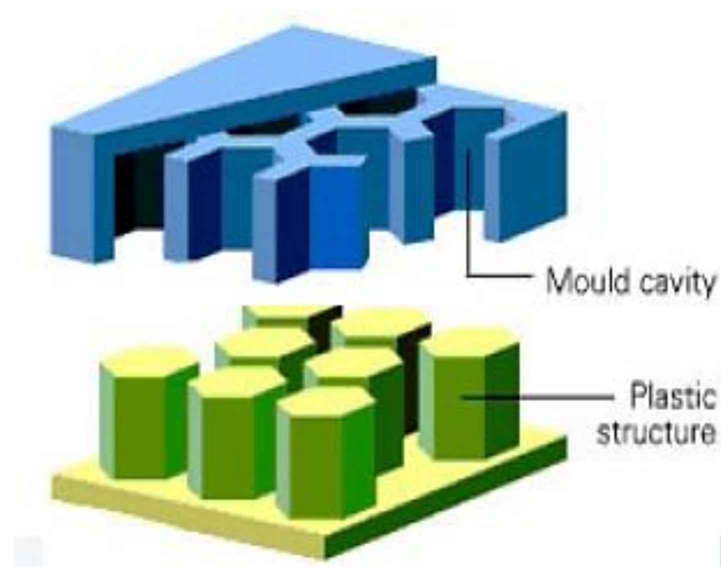


- X-ray mask
  - Thick absorber patterns and thin membrane layer
- Resist
  - PMMA
- Base plate
  - Conducting seed layer (gold/nickel)

3 / LIGA – Electroplating & Molding Step

- Immersing in electrolyte baths (e.g. Ni-sulfamate bath)
- Hot embossing/Injection molding
- Demolding with the help of mold release agents (e.g. 3-6 wt% PAT 665) & design shapes





3 / LIGA – Making a mold insert for plastic molding

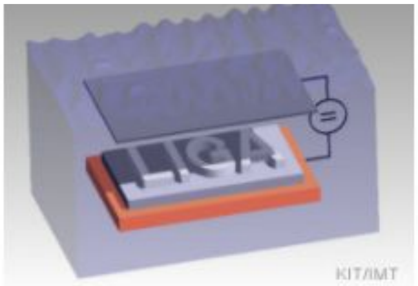


Fig. 29: Nickel electroplating in process

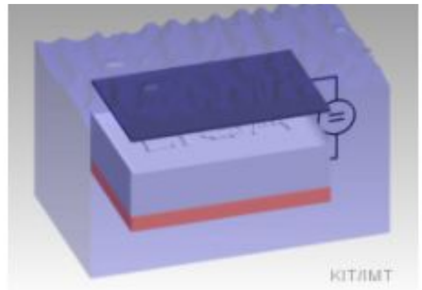


Fig. 30: Nickel electroplating finished

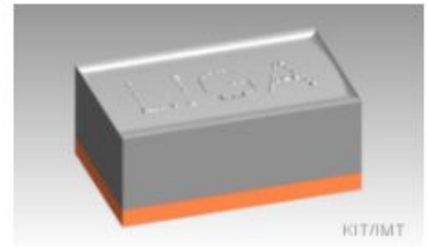


Fig. 31: Nickel mould after electroplating

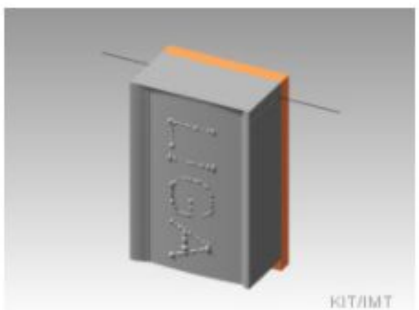


Fig. 32: Wire eroding of the mould, step 1

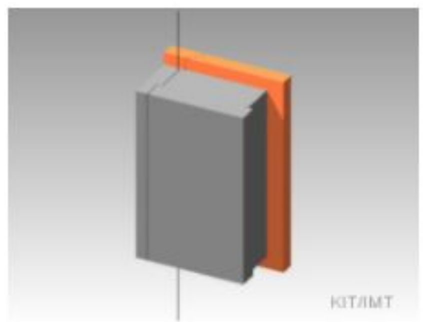


Fig. 33: Wire eroding of the mould, step 2

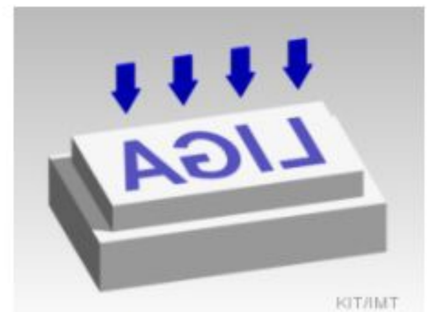


Fig. 34: Flood exposure before resist removing

Fig. 35: Finished nickel mould

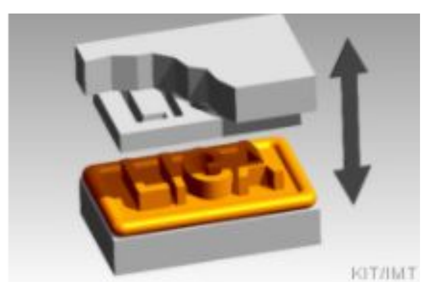


Fig. 36: Moulding for mass replication

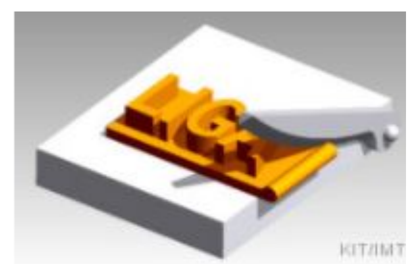
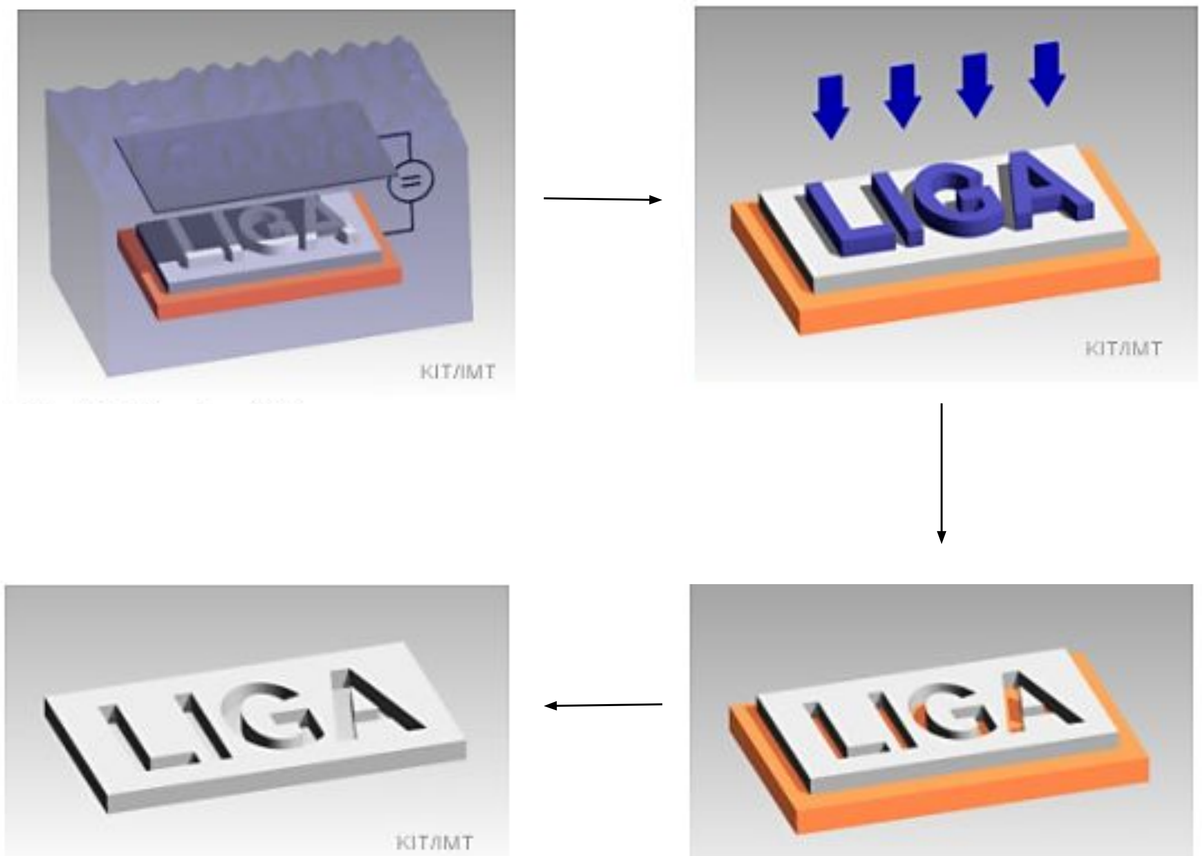


Fig. 37: Final machine finishing

http://www.x-ray-optics.de/index.php/en/10-hauptkategorie-en/208-liga-process

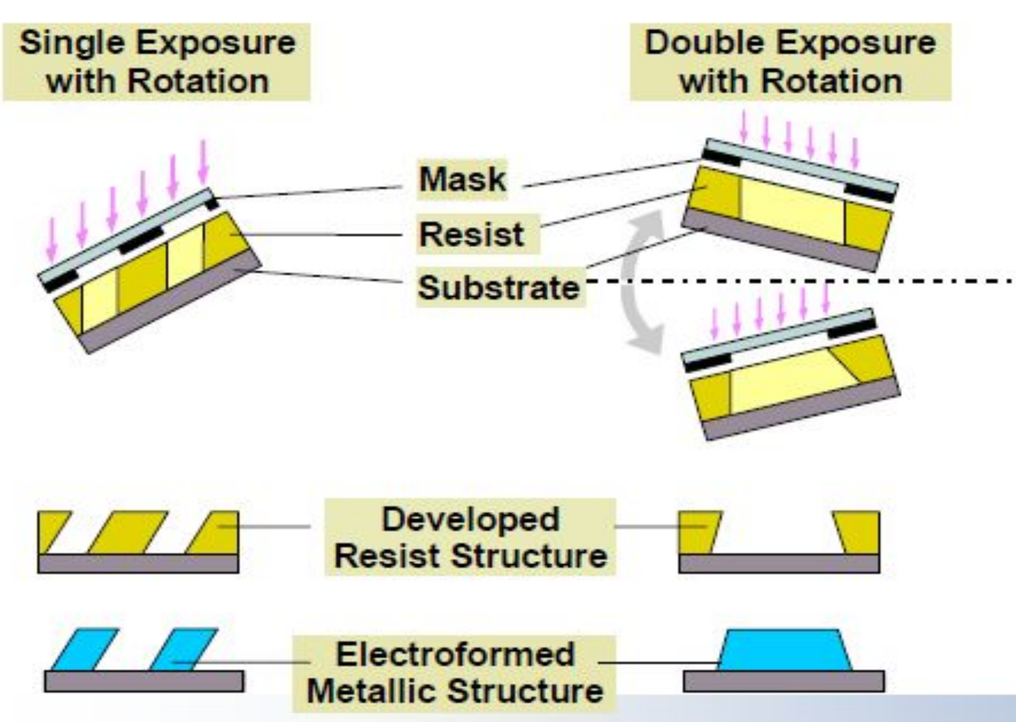
3 / LIGA – Making a microstructure

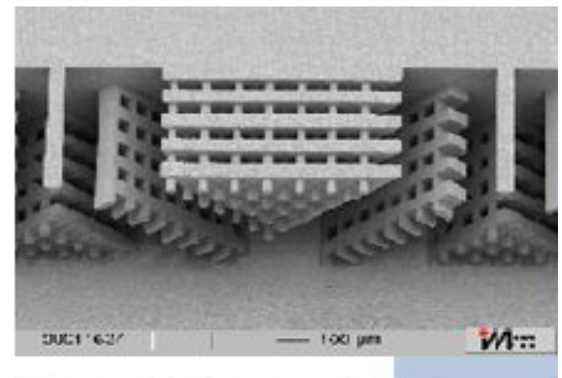


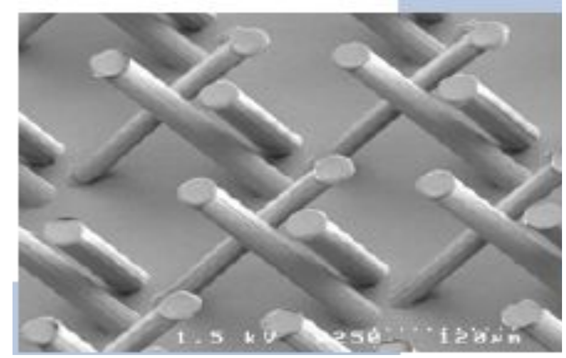
http://www.x-ray-optics.de/index.php/en/10-hauptkategorie-en/208-liga-process

3 / LIGA – Slanted Microstructures

- Complex structures can be fabricated by multiple oblique irradiation





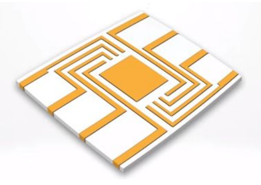


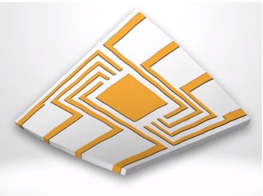
Various applications of MEMS

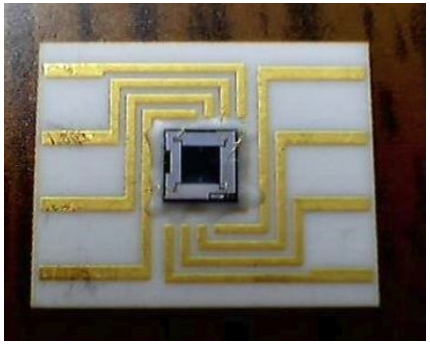
- Industrial & automotive
  - Pressure sensors
  - Accelerometers
  - Nozzles
  - Safety devices for nuclear weapons
- Optical displays
  - Digital micromirrors

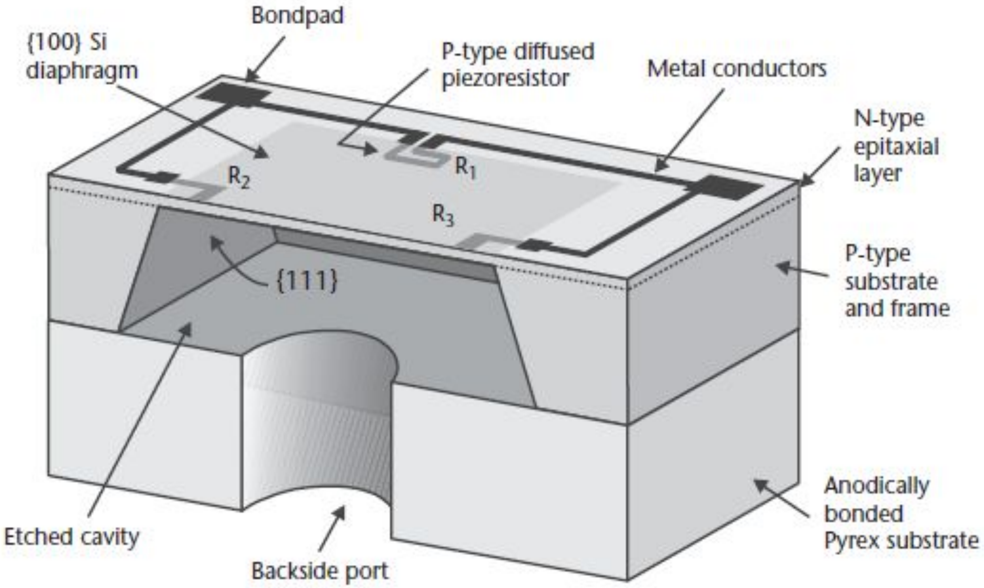
1 / Industrial & automotive

- **Piezoresistive pressure sensors**
  - Thin silicon diaphragm
  - Mechanical stress causes changes in crystal lattice structure electrical resistance changes



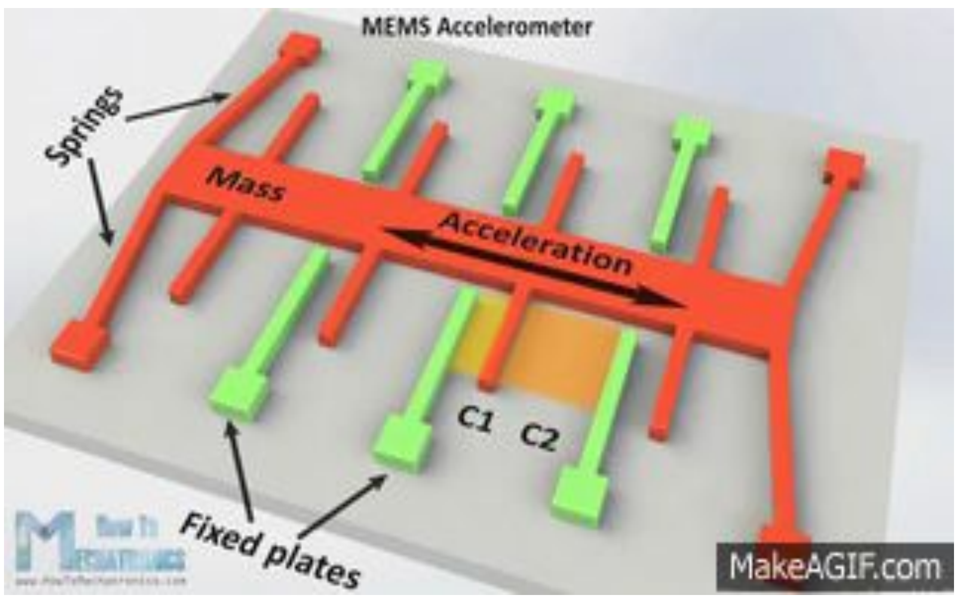


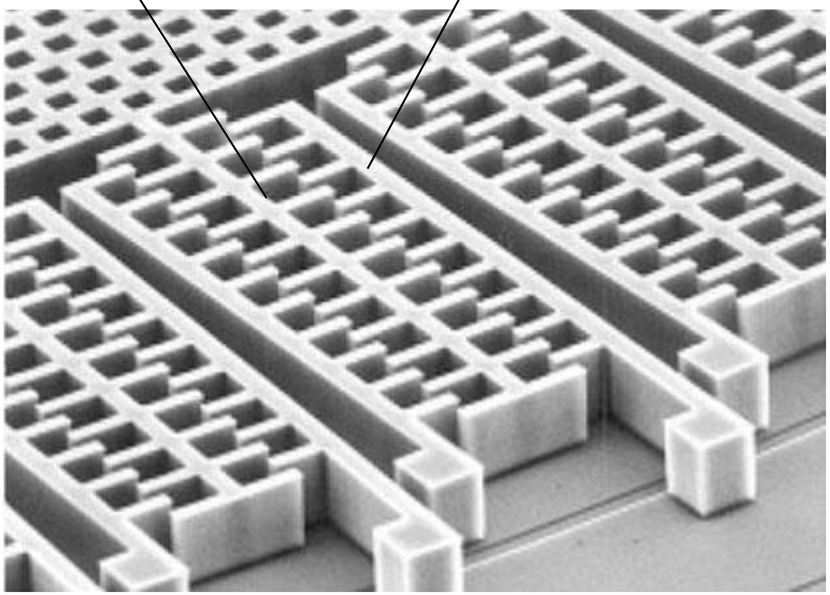




1 / Industrial & automotive

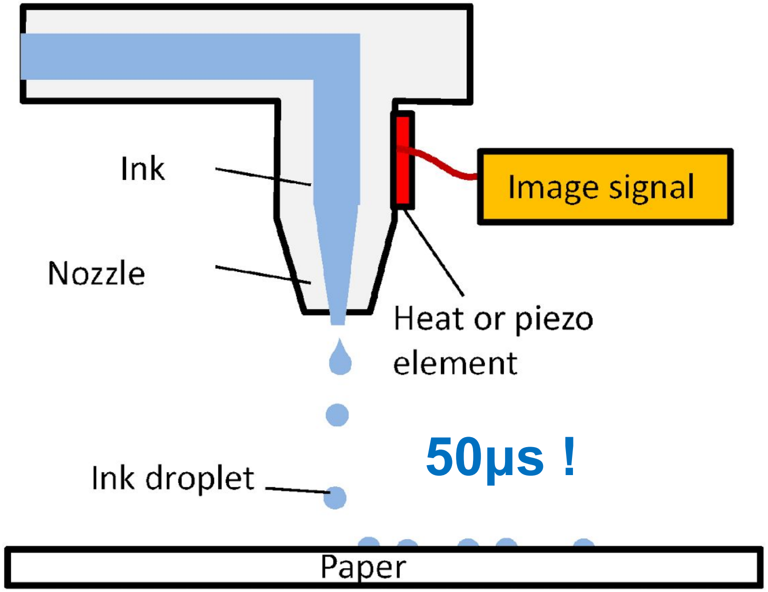
- **Accelerometers**
  - Displacement of the inertial mass





1 / Industrial & automotive

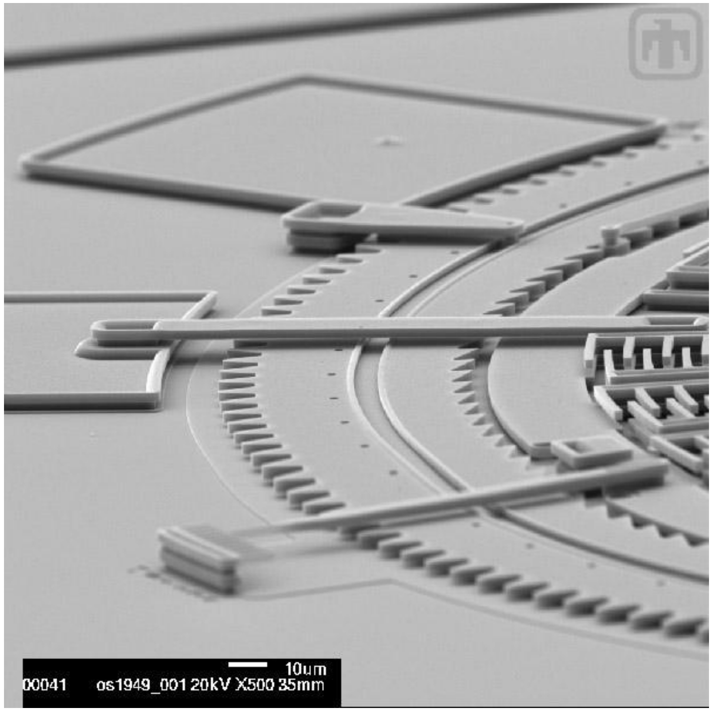
- **Nozzles**
  - Hewlett-Packard (HP)'s thermal inkjet technology (TIT)
  - MicroParts' drug-inhaling device for asthma patients by LIGA process



1 / Industrial & automotive

- **Nuclear weapons**
  - Safety devices – stronglinks – have pattern gear discriminators that are fabricated by LIGA process

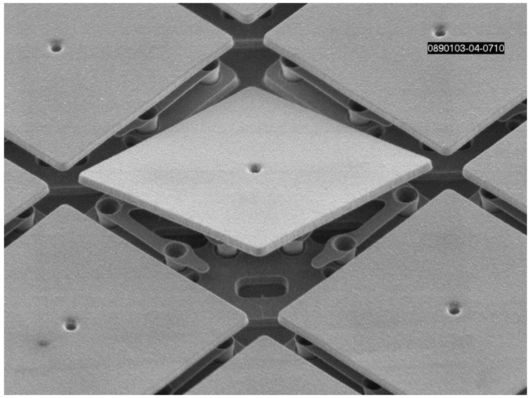
Detonator pellet



https://str.llnl.gov/Mar12/obrien.html
http://www.sandia.gov/mstc/mems_info/movie_gallery.html

2 / Optical displays

- **Texas Instruments' Digital Light Processing (DLP) Technology**
  - Digital micromirror device (DMD)
  - Spatial light modulator/switch



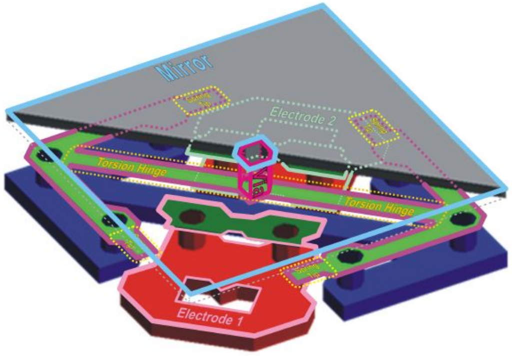
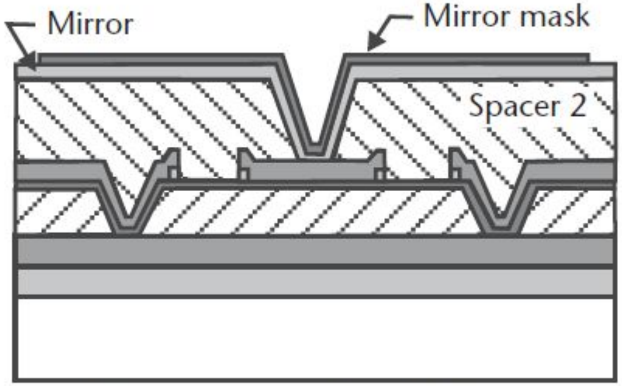
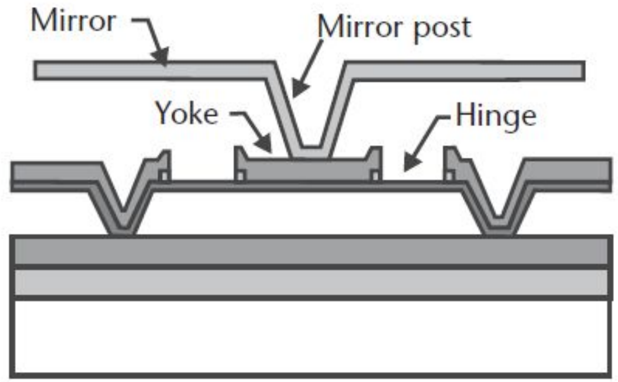


Figure 2. Pixel with Labeled Parts



5. Deposit spacer 2 and mirror



6. Pattern mirror and etch sacrificial spacers

2 / Optical displays

- Video – how does it work?
- http://www.ti.com/general/docs/video/watch.tsp?entryid=5157963226001

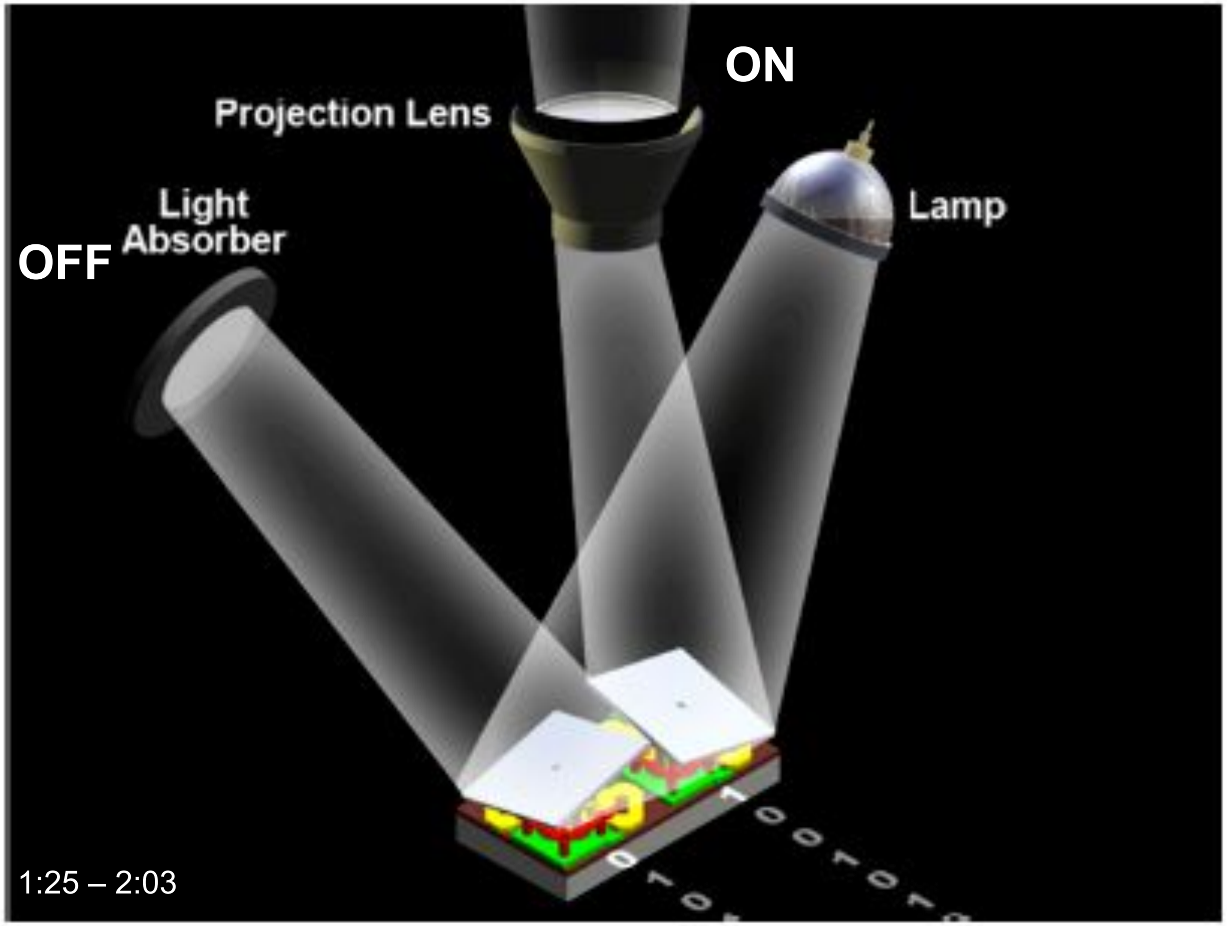


Figure 1. Pixels in On and Off State

15 μs – movement of DMD
150 ms – limit of human eye detection

2 / Optical displays

- Reliability
  - Hinge fatigue
  - Shock & vibration failure

Outlook for MEMS

Strength

- Provides a customized technical solution for a particular application
- Many tools to choose from

Limitation

- Doesn't have any standards
- Not many high-volume manufacturing applications
  - Absence of "the killer app"
- Diverging demands & fragmentation
- Poor forecasting & investments

To MEMS or not to MEMS?

- Enabling a new function, cost reduction, reliability

Cover of Scientific American Magazine in November 1992 (G. Stix, Scientific American 267, 5 (1992)). https://en.wikipedia.org/wiki/LIGA

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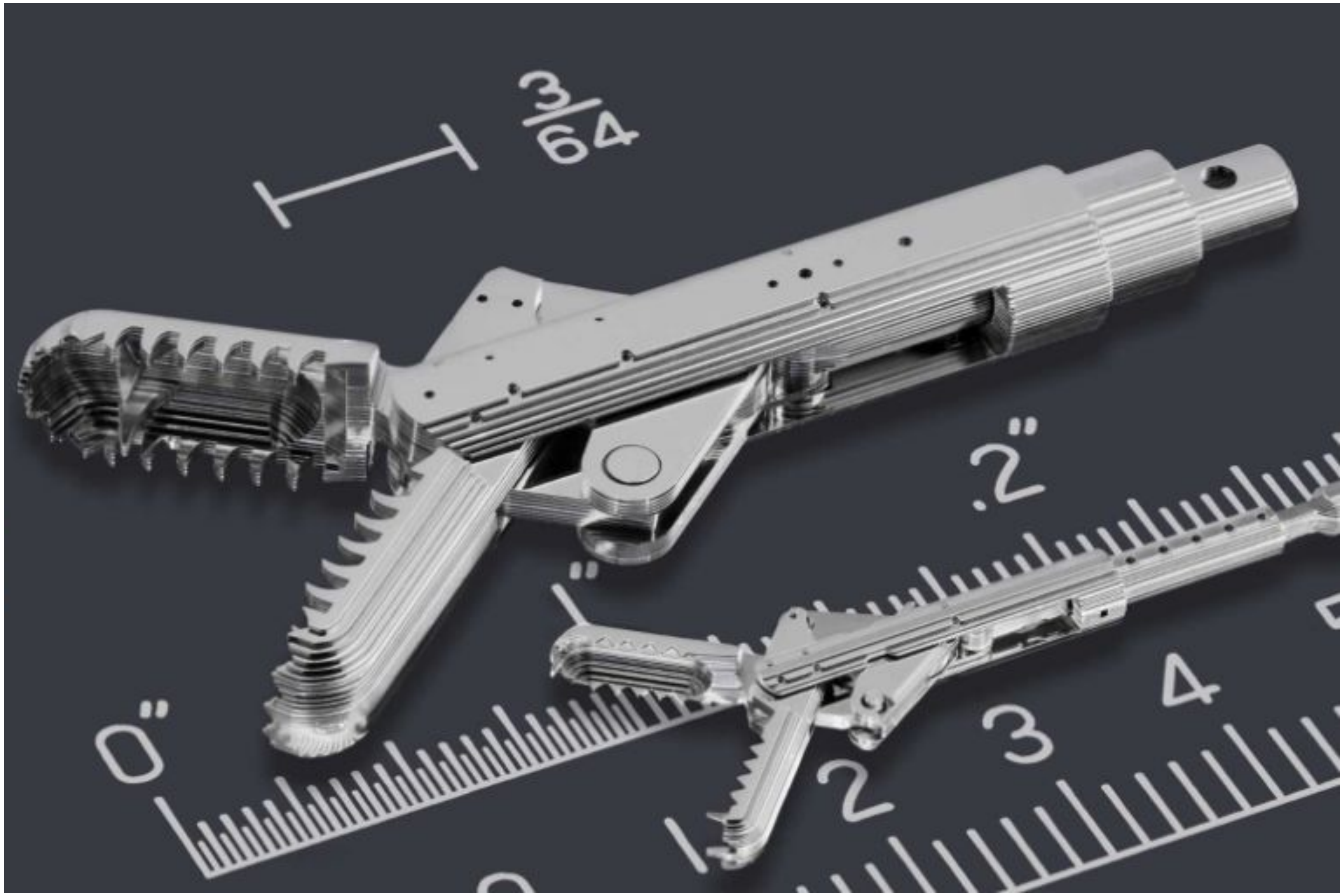
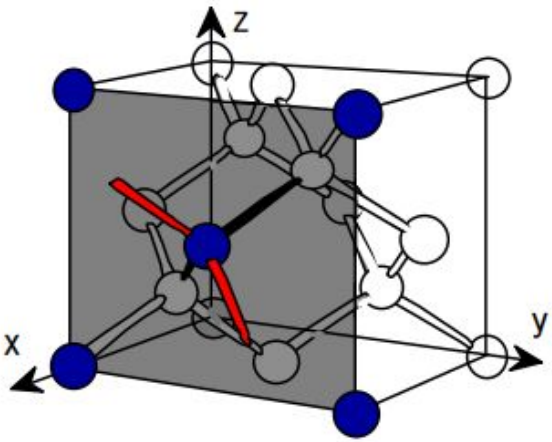
MEMS is evolving …



Microfabrica

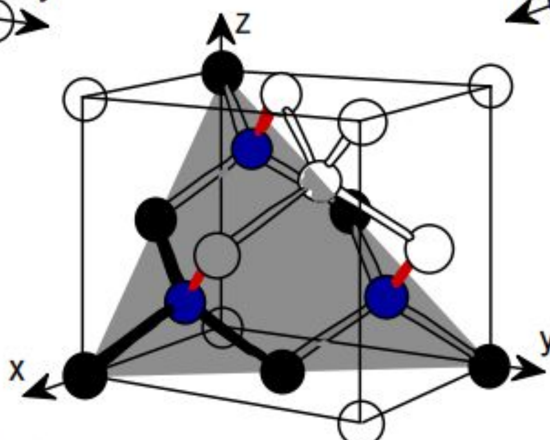
Miller indices of Silicon

Hypothesis: Number of dangling bond appearing on the silicon surface determines the etching rate



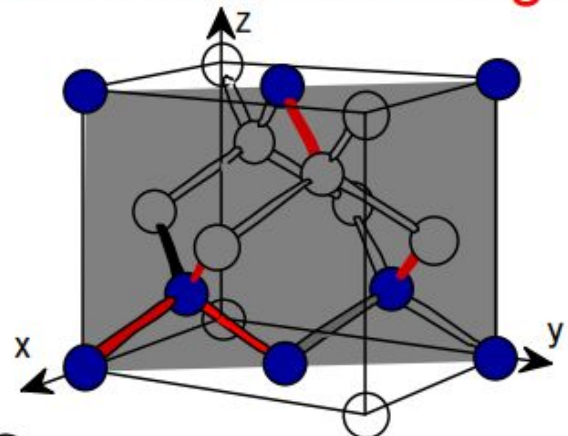
(100)面

Dangling bond : **2**
Back bond : **2**



(111)面

Dangling bond : **1**
Back bond : **3**



(110)面

Dangling bond : **1 +(2)**
(Exposed back bond : **2**)
Back bond : **3**

K. Sato. *Basic 2 Basic 2 Anisotropic Wet-etching of Silicon: Characterization and Modeling of Changeable Modeling of Changeable Anisotropy.*