Infinitesimal Machinery

Based on Feynman's 1983 speech

Feynman's award

Announced in 1959 speech titled 'There's Plenty of Room at the Bottom'

Perhaps this doesn't excite you to do it, and only economics will do so. Then I want to do something; but I can't do it at the present moment, because I haven't prepared the ground. I hereby offer a prize of $1000 to the first guy who can take the information on the page of a book and put it on an area 1/25 000 smaller in linear scale in such manner that it can be read by an electron microscope.

And I want to offer another prize—if I can figure out how to phrase it so that I don't get into a mess of arguments about definitions—of another $1000 to the first guy who makes an operating electric motor—a rotating electric motor which can be controlled from the outside and, not counting the lead-in wires, is only 1/64 inch cube.

I do not expect that such prizes will have to wait very long for claimants.[1]

1/64 inch ~ 390 µm cube

The McLellan Micromotor

William McLellan (1924-2011), a Caltech graduate, spent just 2½ months laboring on the project, using tools such as toothpick and a watchmaker's lathe. About the size of a speck of sand, it is mounted under a microscope so that the individual parts can be seen.

Motor diameter: 15/1000 inch ~ 375 µm

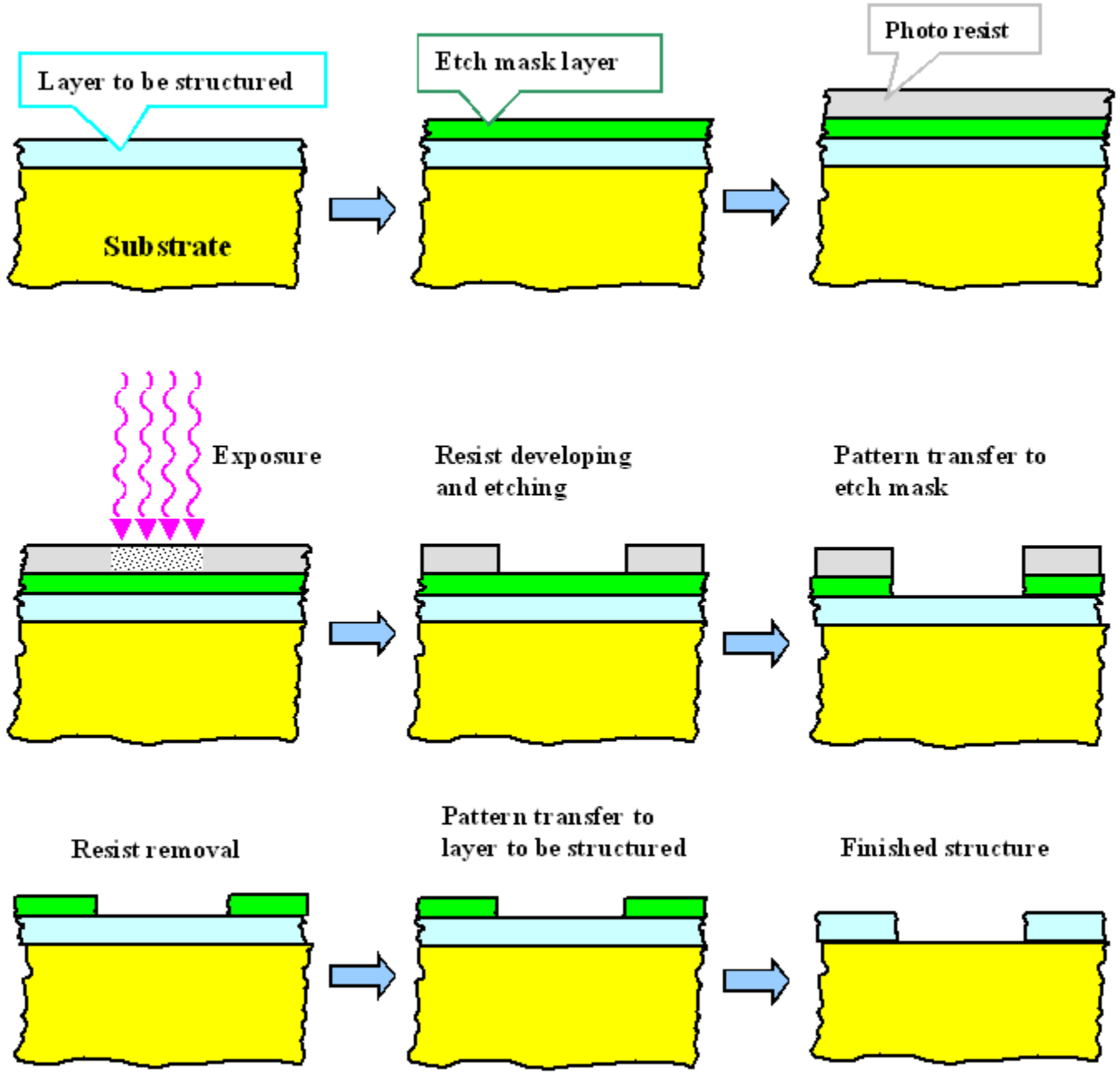
https://m.facebook.com/quantumphysics.mza/posts/richard-feynman-and-william-mclellanthe-worlds-smallest-motor-in-dec-1959-feynma/3764121993693485/
https://pasadenahistory.org/collections/micromotor/
https://www.theguardian.com/science/2004/jun/10/science.nanotechnology

Tom Van Sant’s ‘eyes’ paintings

- https://vimeo.com/52267509
- https://landsat.gsfc.nasa.gov/article/a-big-eye-in-the-mojave-desert/

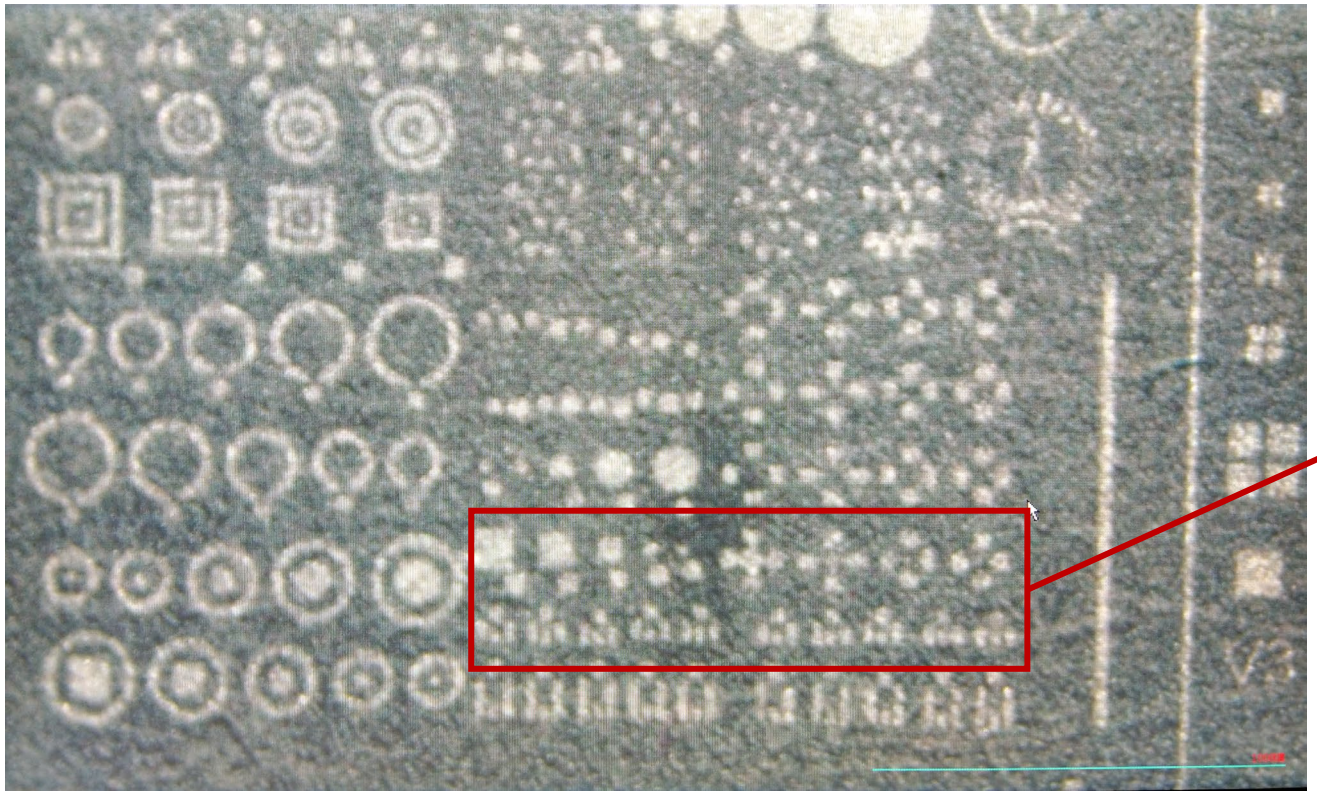
Micromachining

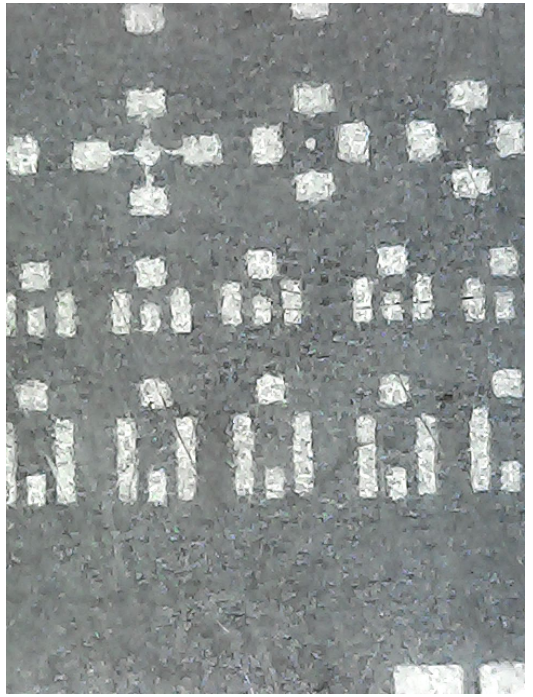
- Manufacturing at macroscale
- 3 basics steps for translating it to microscale
  - Deposition
  - Patterning
  - Etching

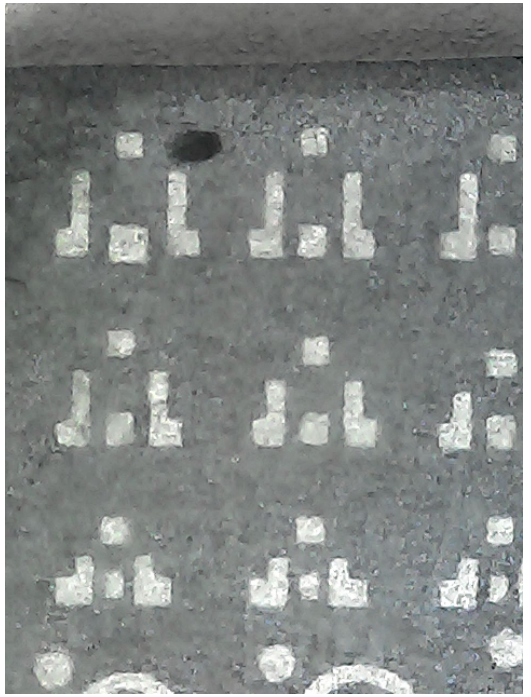


https://www.tf.uni-kiel.de/matwis/amat/elmat_en/kap_6/backbone/r6_6_1.html

Microfabricated patterns

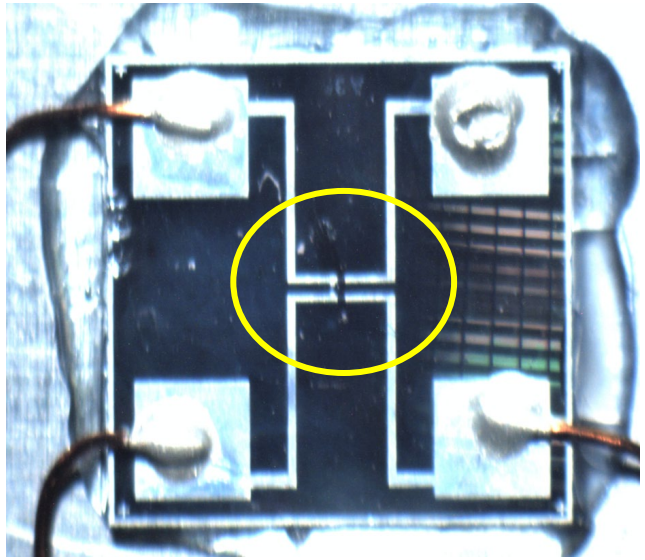




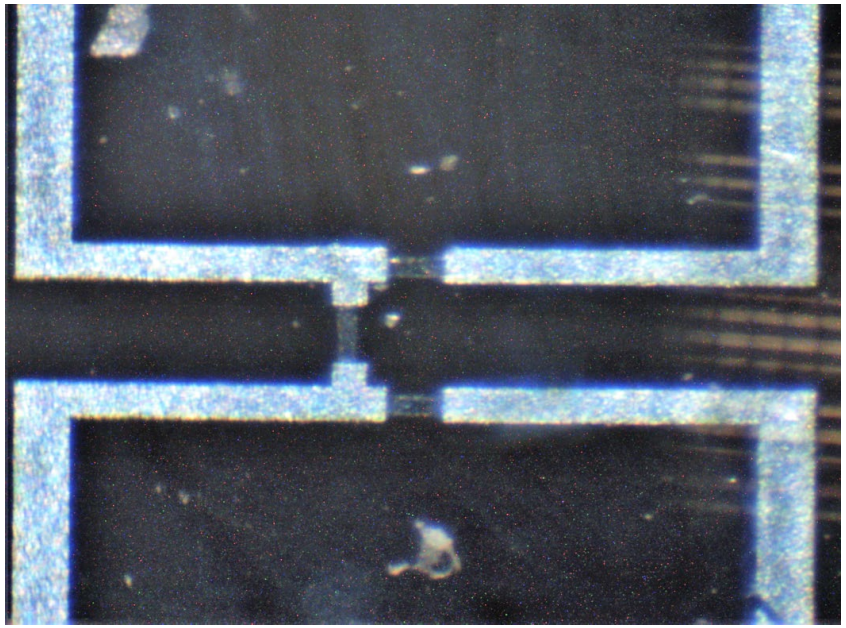


Courtesy: CeNSE, IISc

MEMS strain sensor



6 mm



100 μm

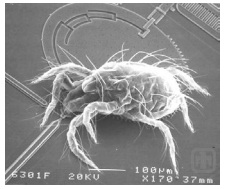
Device and image by Shiva Karthik

MEMS Gallery | Sandia Labs

https://www.sandia.gov/mesa/mems-video-image-gallery/

The Scale of Things – Nanometers and More

Things Natural



Dust mite

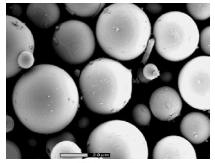
200 μm

Ant

~ 5 mm

Human hair

~ 60-120 μm wide

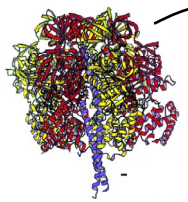


Fly ash

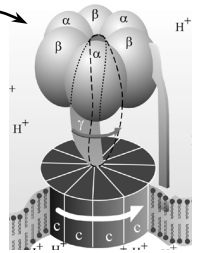
~ 10-20 μm

Red blood cells

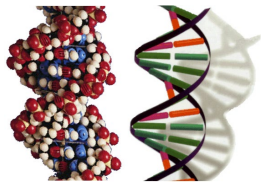
(~7-8 μm)



~10 nm diameter



ATP synthase

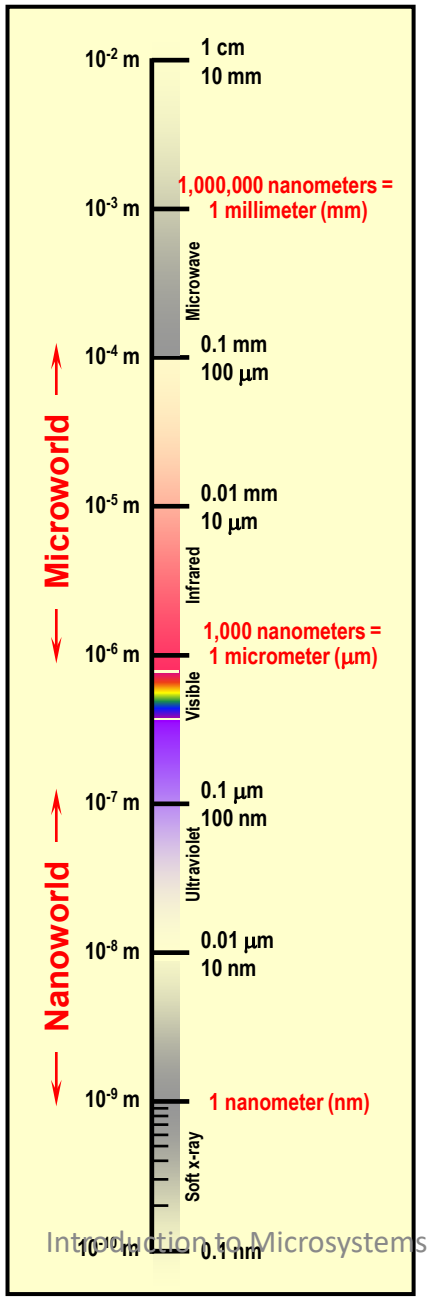


DNA

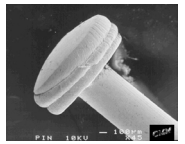
~2-1/2 nm diameter

Atoms of silicon

spacing 0.078 nm

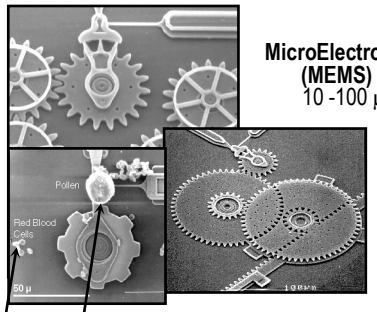


Things Manmade



Head of a pin

1-2 mm

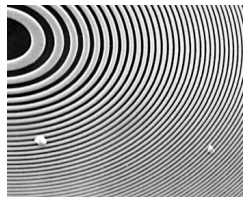


MicroElectroMechanical (MEMS) devices

10 -100 μm wide

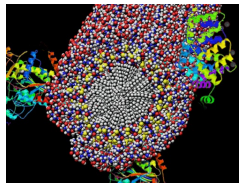
Pollen grain

Red blood cells



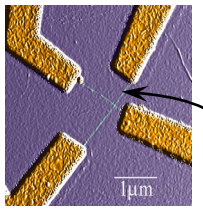
Zone plate x-ray "lens"

Outer ring spacing ~35 nm

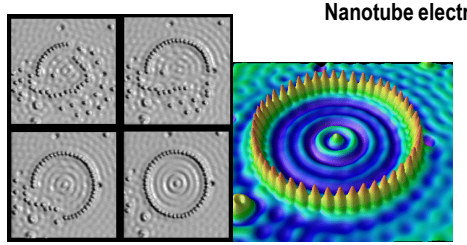


Self-assembled, Nature-inspired structure

Many 10s of nm



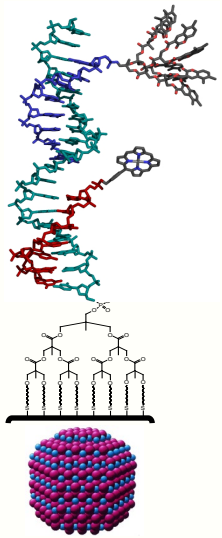
Nanotube electrode



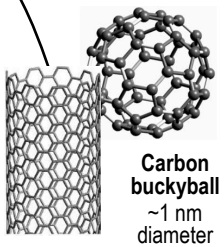
Quantum corral of 48 iron atoms on copper surface positioned one at a time with an STM tip

Corral diameter 14 nm

The Challenge



Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.



Carbon buckyball

~1 nm diameter

Carbon nanotube

~1.3 nm diameter

Office of Basic Energy Sciences
Office of Science, U.S. DOE
Version 05-26-06, pmd

Methods of making MEMS

Surface micromachining

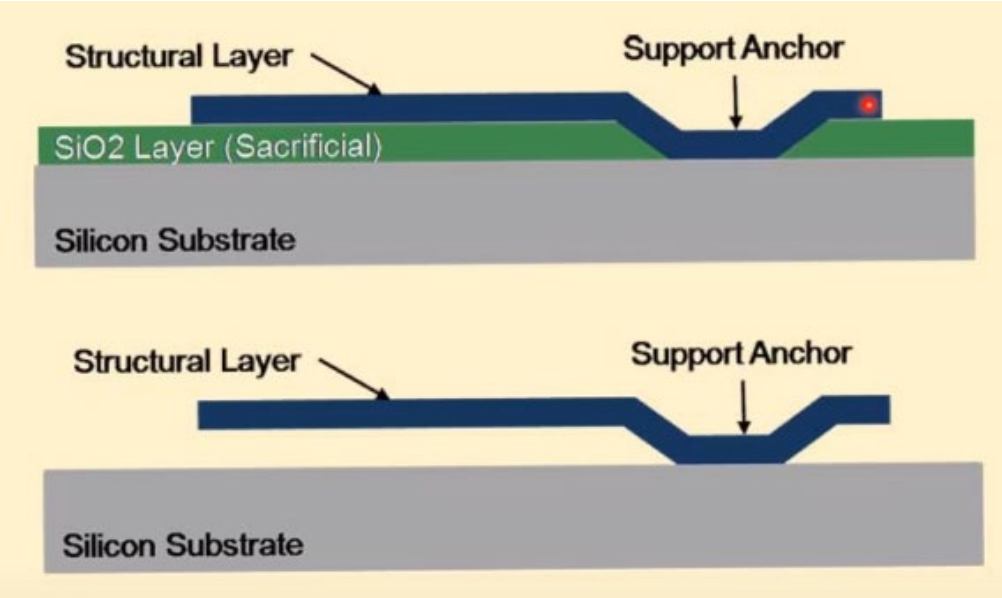
Bulk micromachining

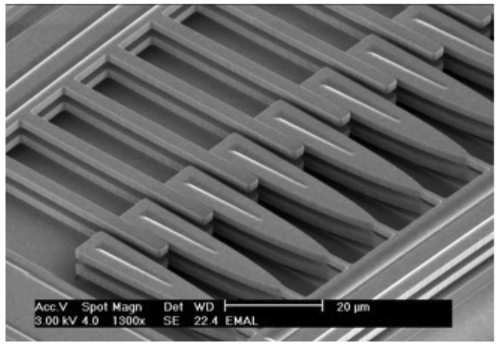
LIGA

Contents adapted from: “MEMS its methods and applications”, CHE 384T – Graduate Student Presentation, Ji Yeon Kim, The Department of Chemical Engineering, The University of Texas at Austin

Surface micromachining

- Structural and sacrificial layers
- Low aspect ratio

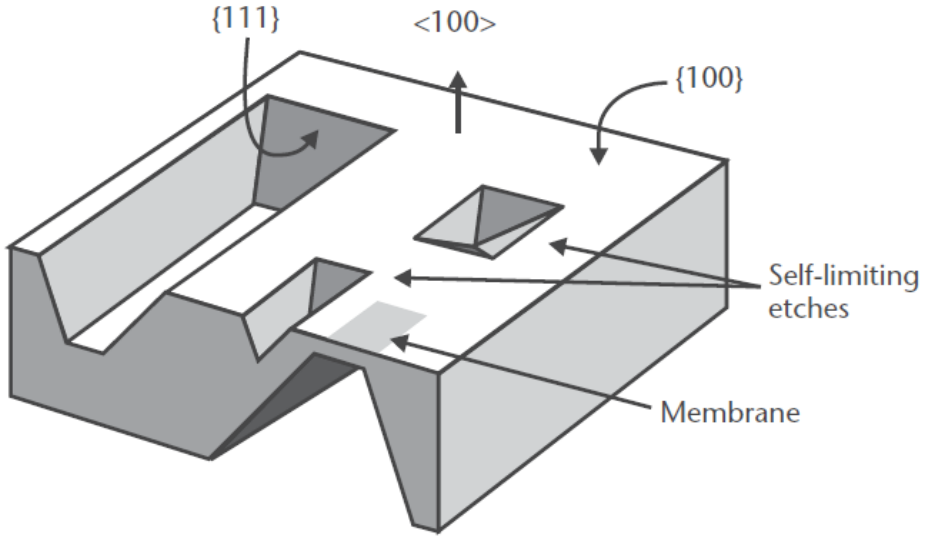


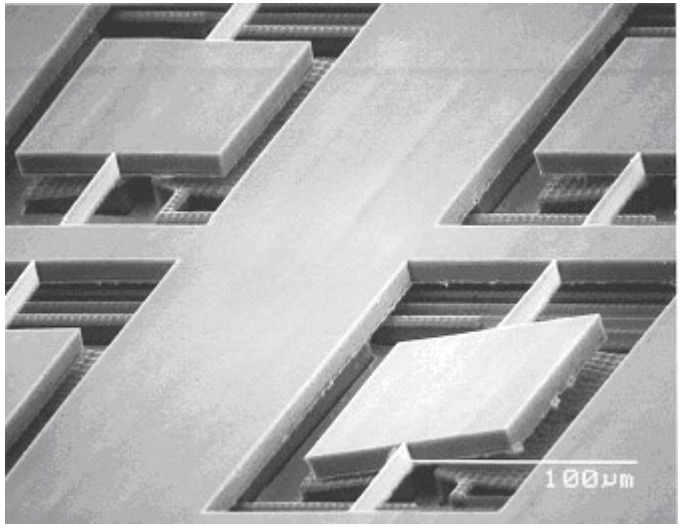


Bulk micromachining

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

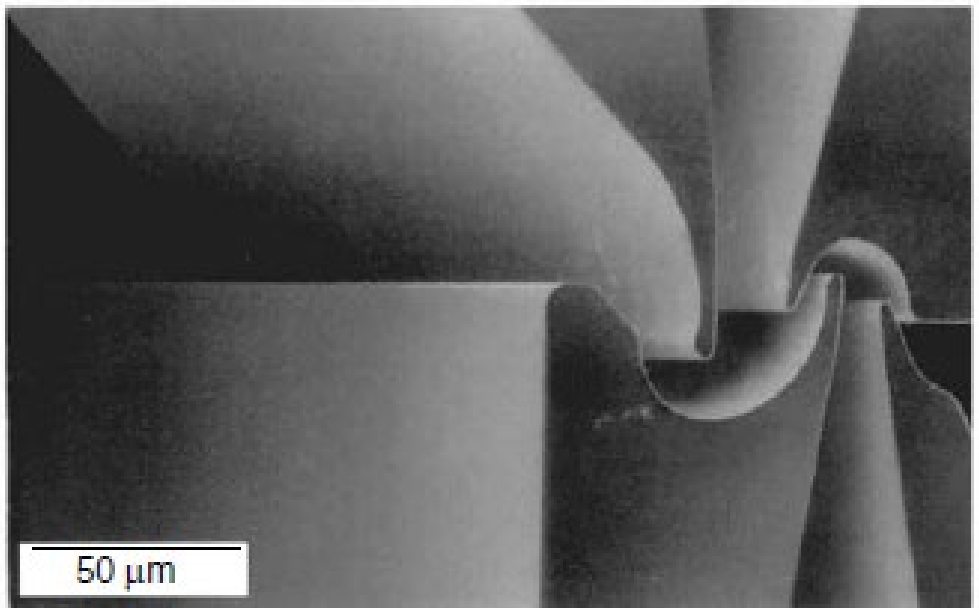
Eg) KOH etch rate: {110} > {100} > {111}

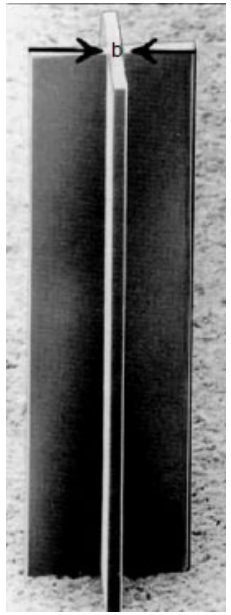




LIGA – Lithographie, Galvanoformung, Abformung

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

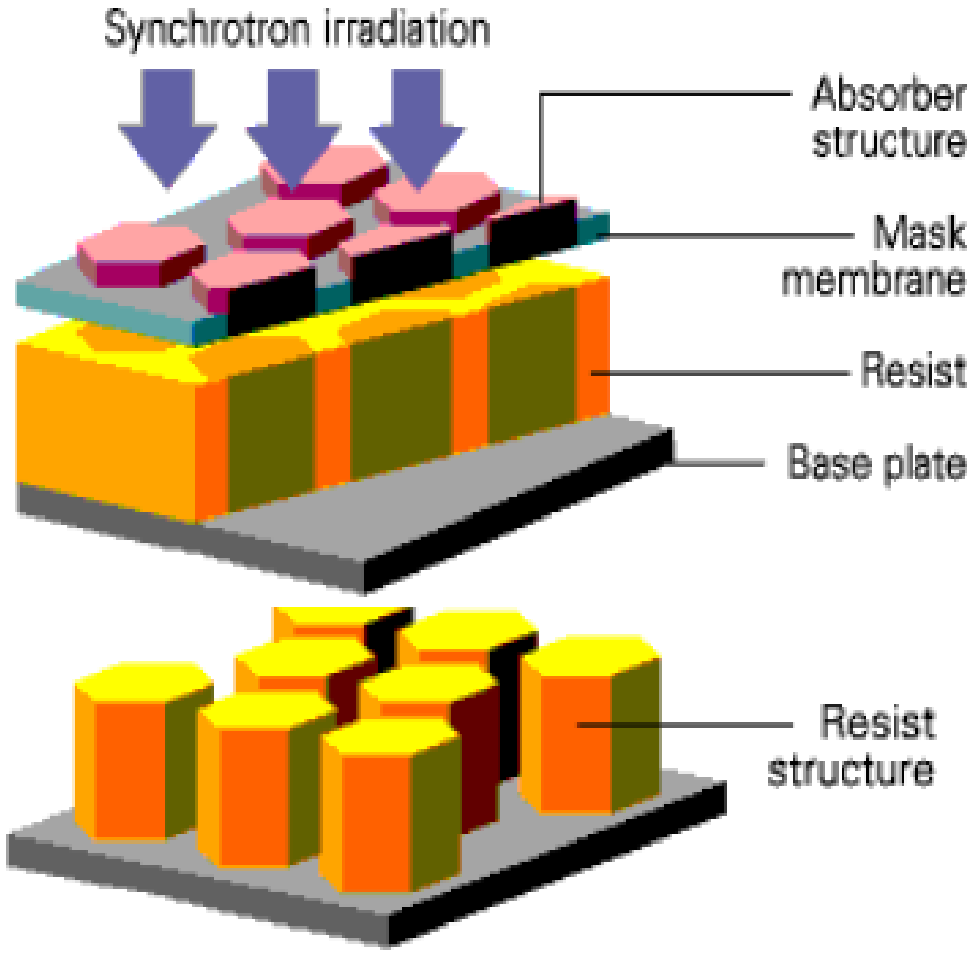




Early 1980s – Karlsruhe nuclear research center in Germany

LIGA – Lithography Step

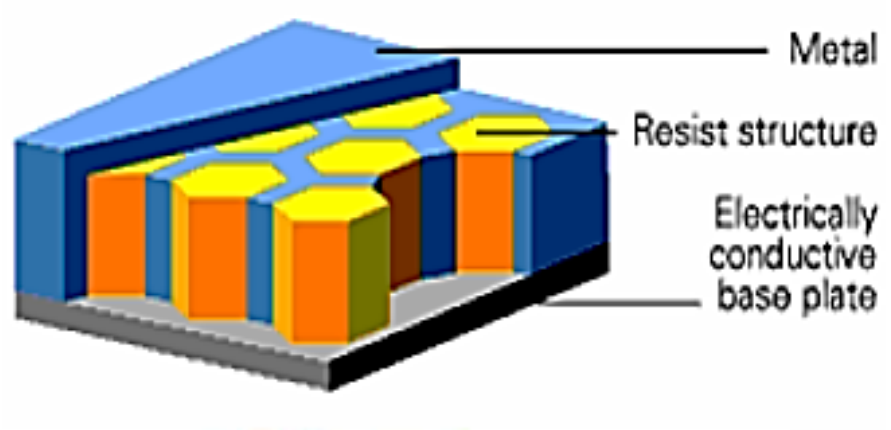
- X-ray proximity printing

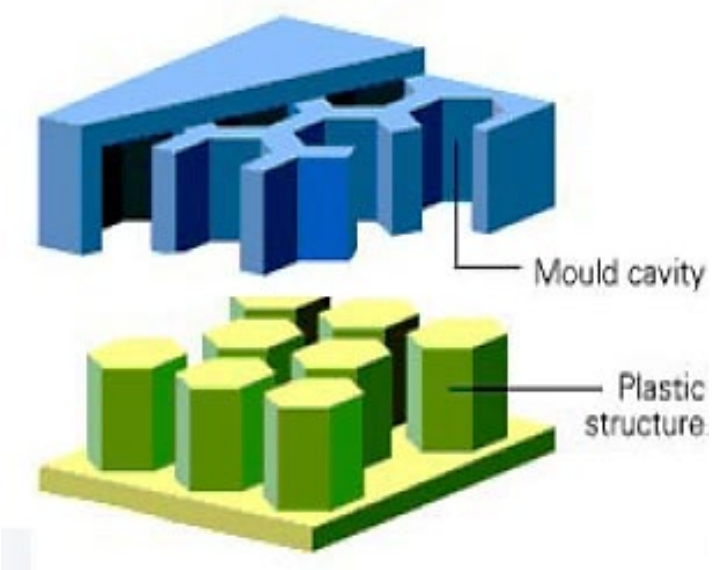


- X-ray mask
  - Thick absorber patterns and thin membrane layer
- Resist
  - PMMA
- Base plate
  - Conducting seed layer (gold/nickel)

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





LIGA – Making a mold insert for plastic molding

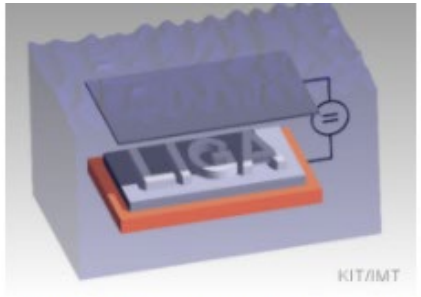


Fig. 29: Nickel electroplating in process

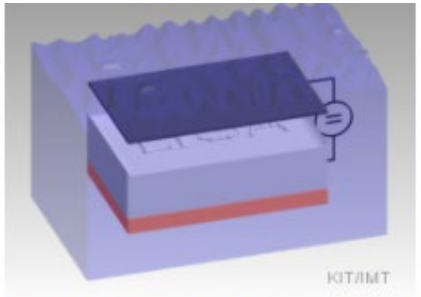


Fig. 30: Nickel electroplating finished

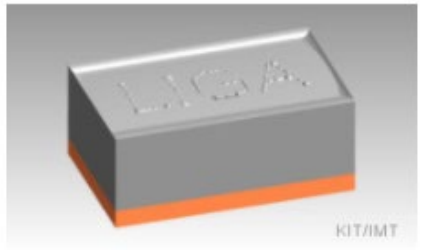


Fig. 31: Nickel mould after electroplating

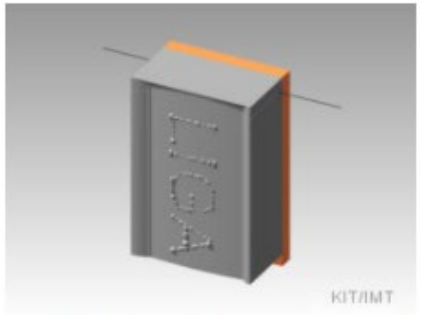


Fig. 32: Wire eroding of the mould, step 1

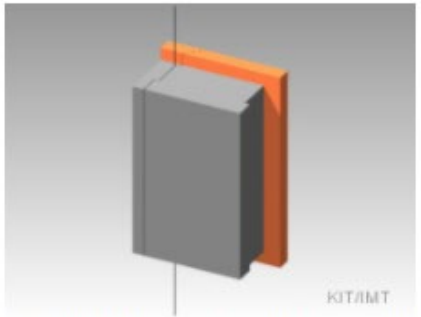


Fig. 33: Wire eroding of the mould, step 2

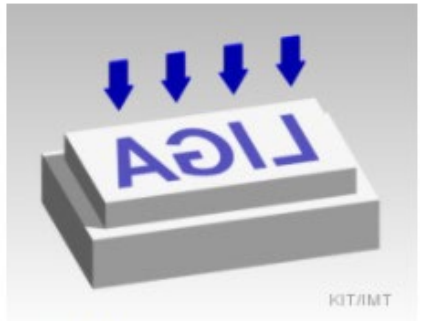


Fig. 34: Flood exposure before resist removing

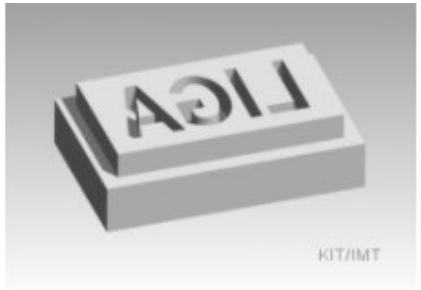


Fig. 35: Finished nickel mould

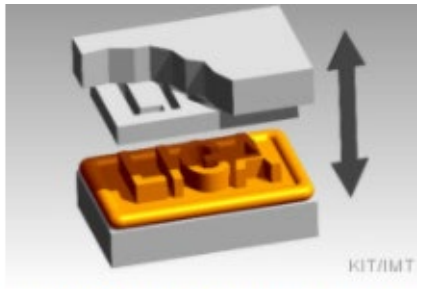


Fig. 36: Moulding for mass replication

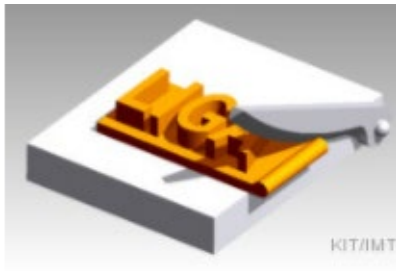
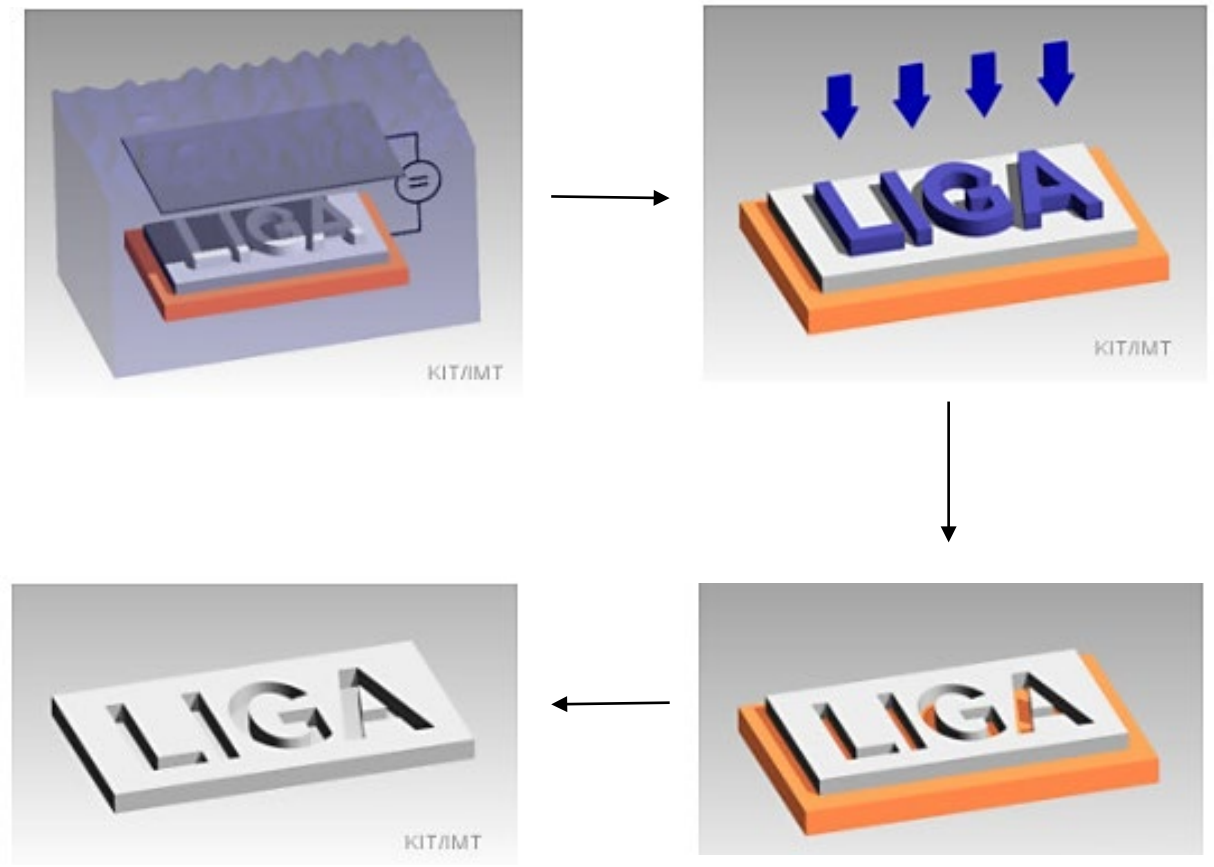


Fig. 37: Final machine finishing

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

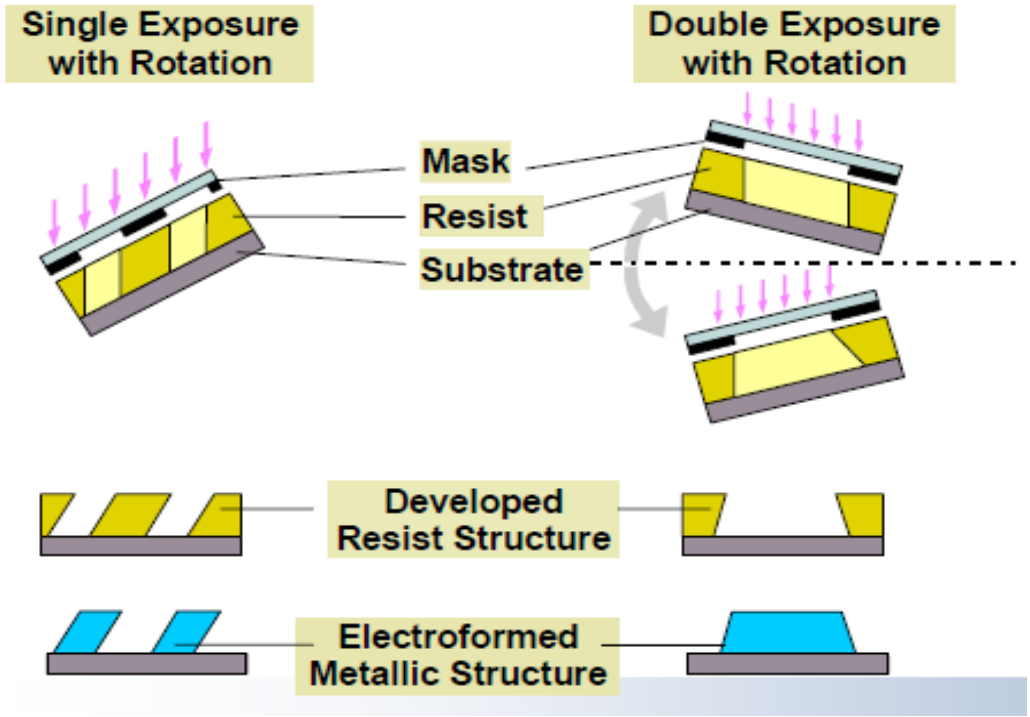
LIGA – Making a microstructure

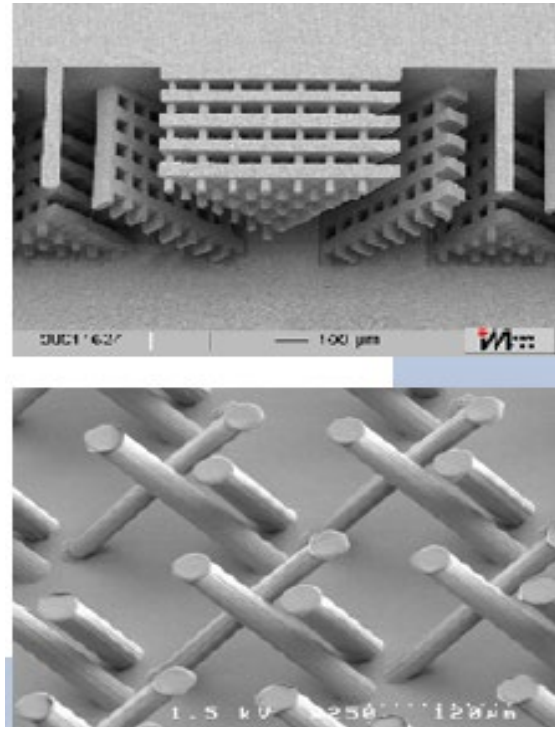


http://www.x-ray-optics.de/index.php/en/10-hauptkategorie-en/208-liga-process

LIGA – Slanted Microstructures

- Complex structures can be fabricated by multiple oblique irradiation





The tools for microfabrication

etching, deposition, lithography

http://nnfc.cense.iisc.ac.in/

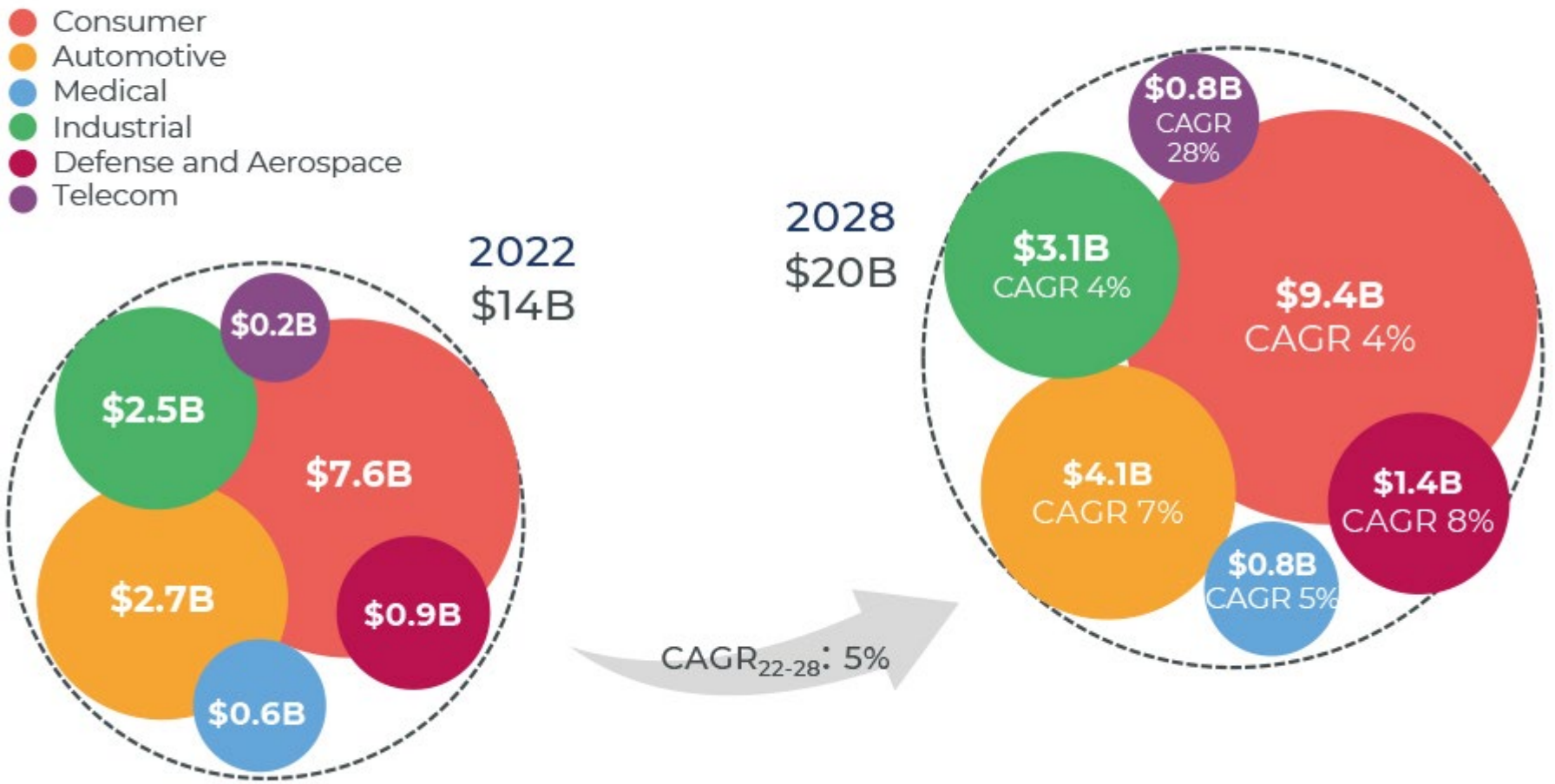
Visit to SCL, Mohali on 14th Feb, 2024

MEMS Market

How relevant is MEMS today?

2022–2028 MEMS market forecast by end market

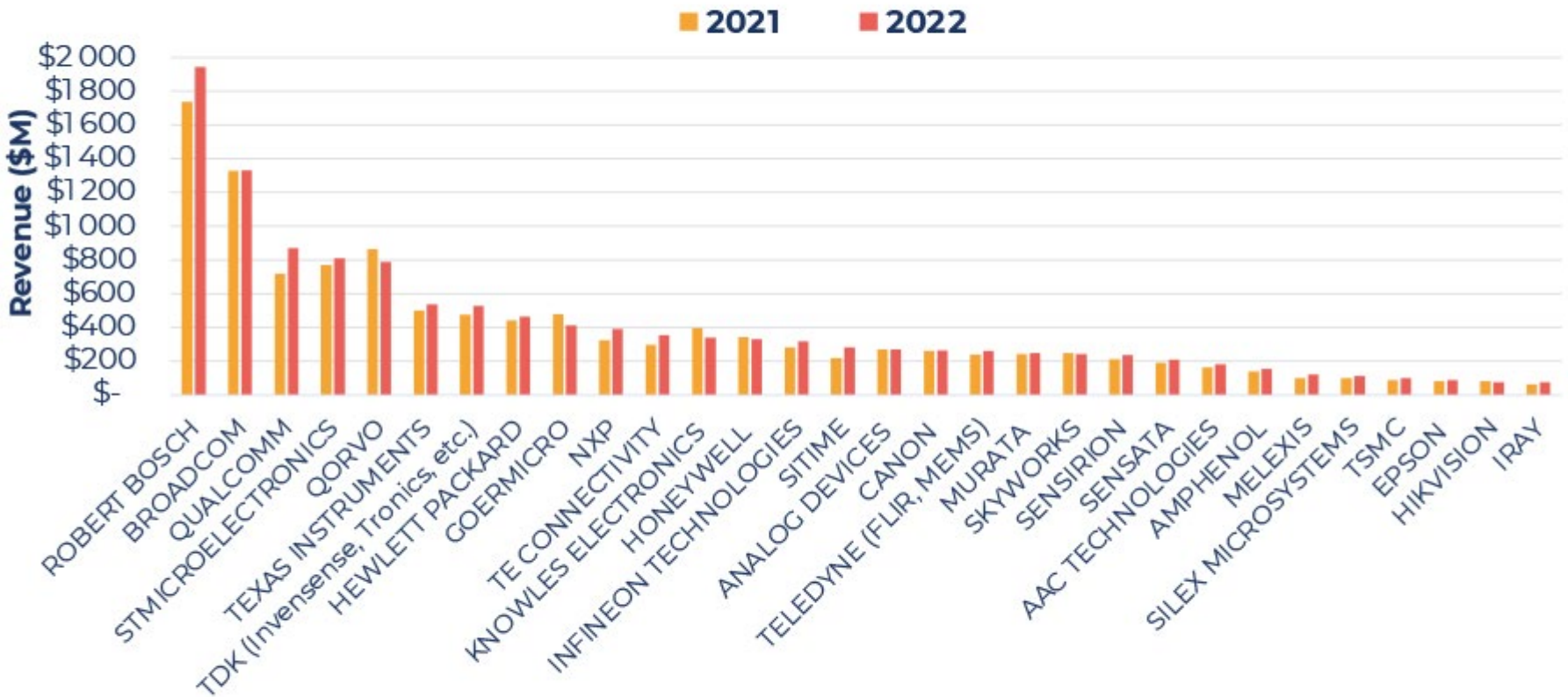
(Source: Status of the MEMS Industry 2023, Yole Intelligence, August, 2023)



https://www.yolegroup.com/product/report/status-of-the-mems-industry-2023/

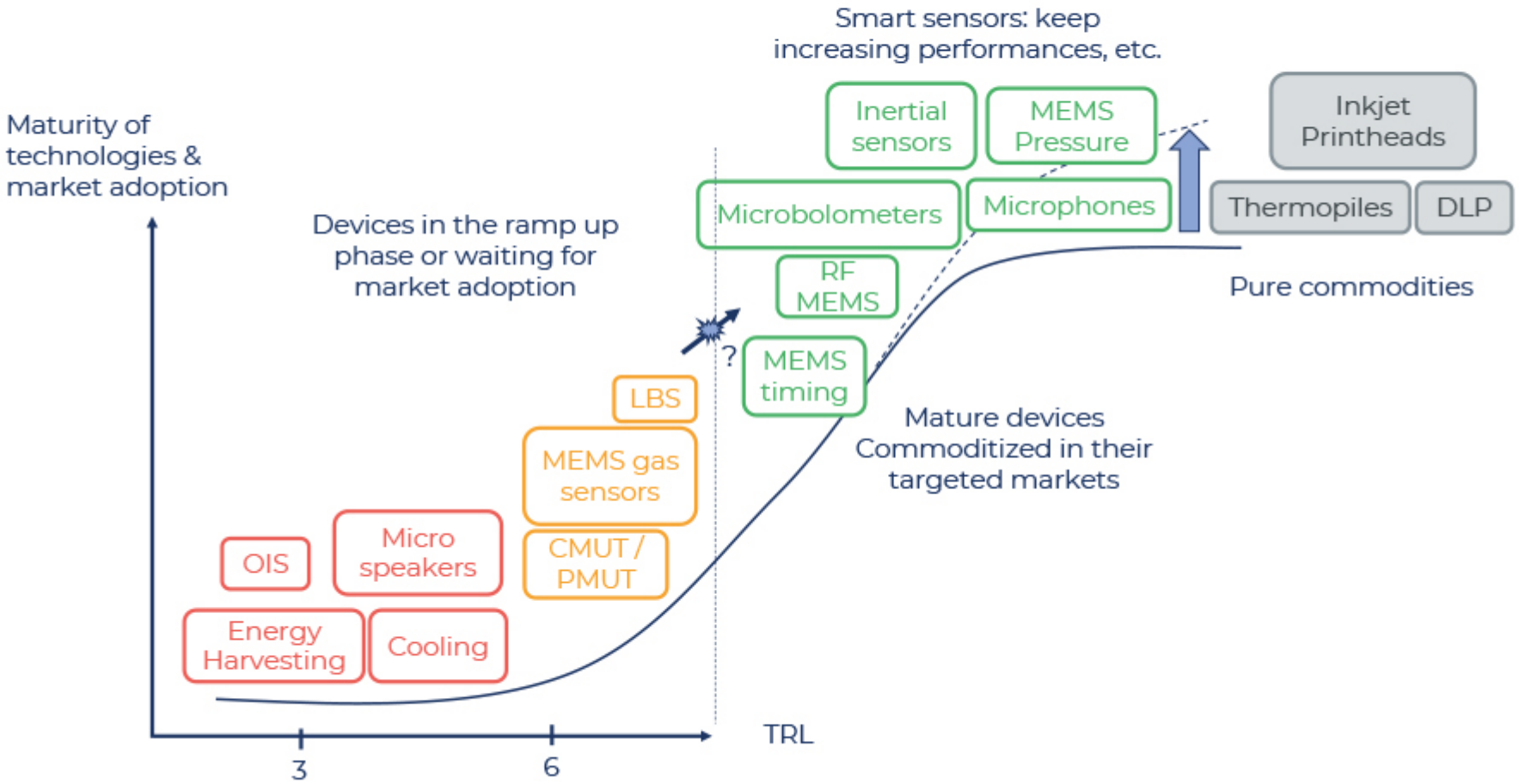
2022 Top MEMS companies ranking

(Source: Status of the MEMS Industry 2023, Yole Intelligence, August, 2023)



MEMS Industry : Who will be next to cross the chasm?

(Source: Status of the MEMS Industry 2023, Yole Intelligence, August, 2023)



Example career options in MEMS/Sensors

- https://www.bosch.de/en/career/
- https://www.indeed.com/viewjob?jk=c242e5cedd10fc3a&tk=1hdt3hn58ioll800&from=serp&vjs=3

Thank You