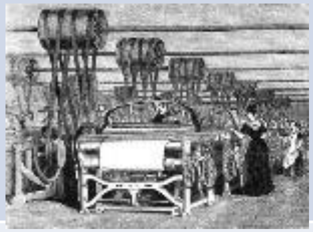
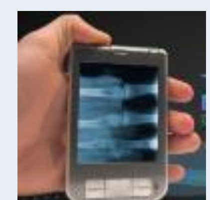
BITS Pilani

Fundamentals of MEMS and Sensors Packaging

Venkatesh KP Rao

MEMS – Motivation

Technology Evolution

Area	Yesterday	Today	Tomorrow (?)
Textile Industry			
Automobiles			
Energy		 	
Biomedical			

Accuracy | Cost | Time → ACT → How?

‘ACT’ in Today’s R&D

Accurate, Precise, within detection requirement

Dengue detection / Monitoring fuel adulteration

Affordable, Value-of-money, Competitive pricing

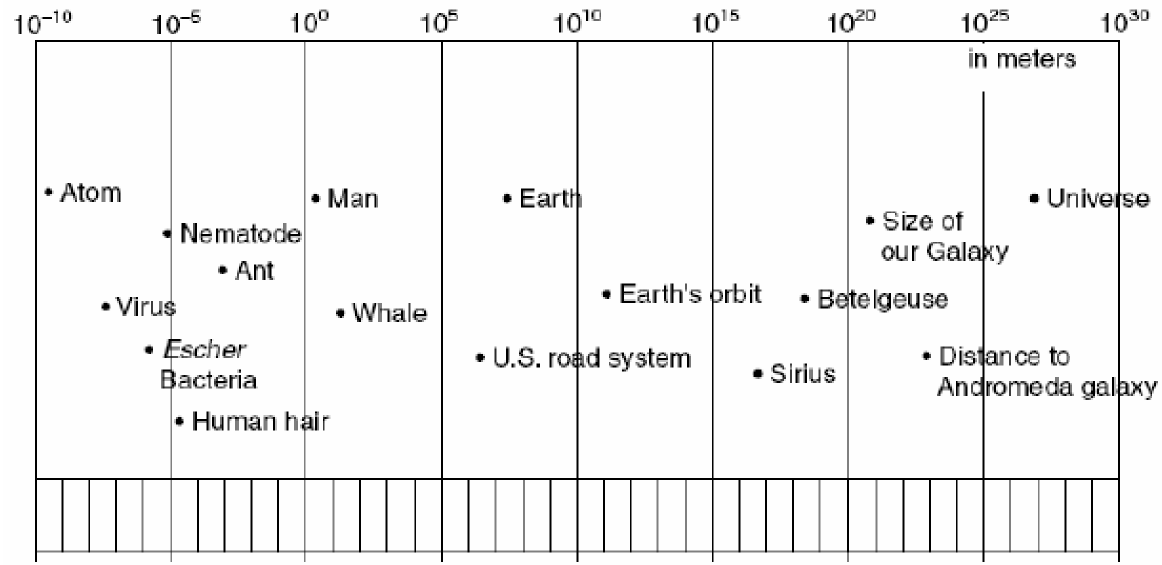
Electronic gadget / Biomedical

Ultrafast, Advance Diagnostics, Competitive

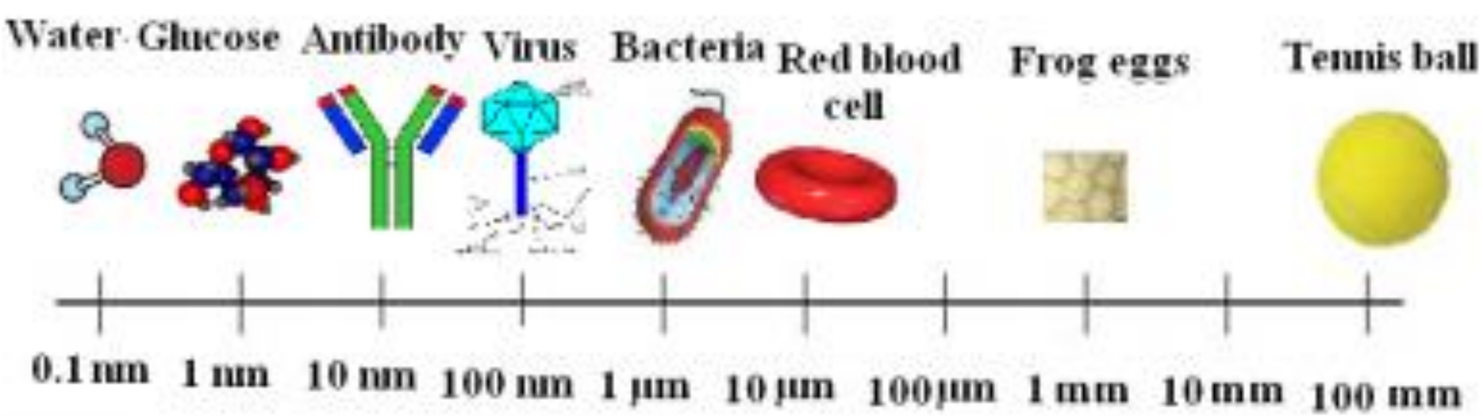
Solar / Electronic gadget

Micro-and-Nanotechnology has ‘proven’ answer

Macro to Micro to Atomic Scales

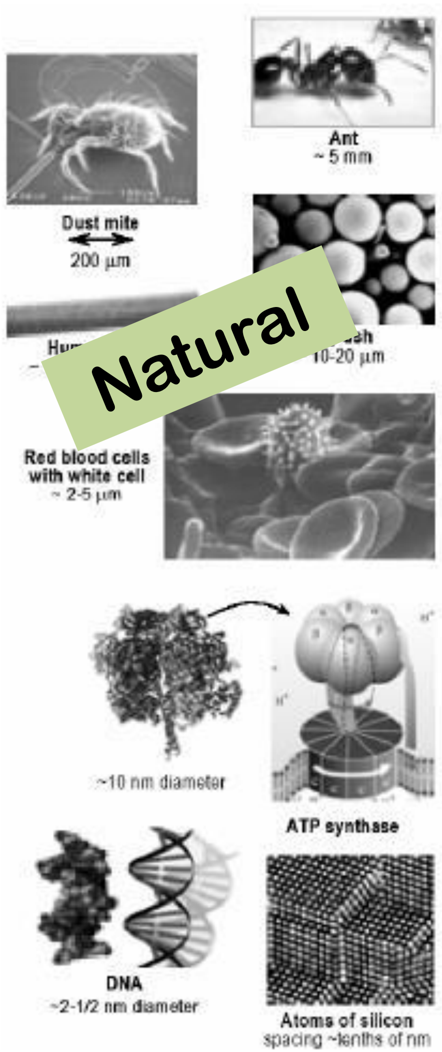


Normal or Logscale?

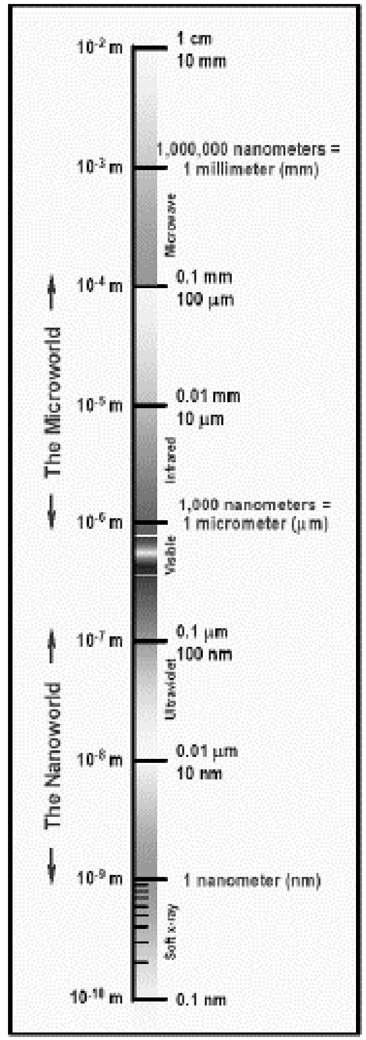


http://www.pharmainfo.net/files/u42889/figggg_1.png

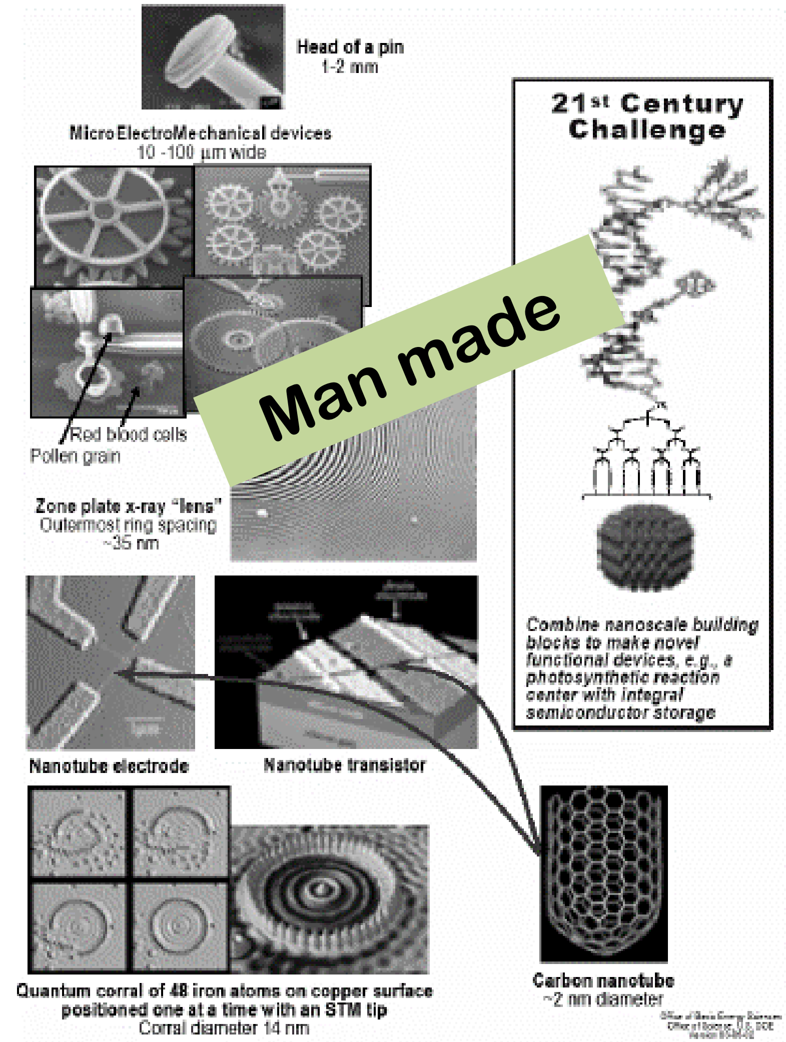
Microscale?



Ant
~ 5 mm
Dust mite
200 µm
10-20 µm
Natural
Red blood cells
with white cell
~ 2-5 µm
~10 nm diameter
ATP synthase
DNA
~2-1/2 nm diameter
Atoms of silicon
spacing ~tenths of nm



10^{-2} m
1 cm
10 mm
1,000,000 nanometers =
1 millimeter (mm)
10^{-3} m
Microwave
10^{-4} m
0.1 mm
100 µm
The Microworld
10^{-5} m
0.01 mm
10 µm
Infrared
10^{-6} m
1,000 nanometers =
1 micrometer (µm)
Visible
10^{-7} m
0.1 µm
100 nm
Ultraviolet
The Nanoworld
10^{-8} m
0.01 µm
10 nm
10^{-9} m
1 nanometer (nm)
Soft x-ray
10^{-10} m
0.1 nm



Head of a pin
1-2 mm
MicroElectroMechanical devices
10 -100 µm wide
Red blood cells
Pollen grain
Man made
Zone plate x-ray "lens"
Outermost ring spacing
~35 nm
Nanotube electrode
Nanotube transistor
Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm
21st Century
Challenge
Combine nanoscale building
blocks to make novel
functional devices, e.g., a
photosynthetic reaction
center with integral
semiconductor storage
Carbon nanotube
~2 nm diameter

Miniaturization – Enabling Technology

Microsystems Technology
(MST)
(1 µm - 1 mm)*

A top-down approach

Initiated in 1947 with the invention of transistors, but the term "Micromachining" was coined in 1982

Miniature devices

(1 nm - 1 mm)

A bottom-up approach

Nanotechnology
(NT)
(0.1 nm – 0. 1 µm)**

Inspired by Richard Feynman in 1959, with active R&D began in around 1995

There is a long way to building nano devices!

Microscale Benefits?

- Better Surface to Volume Ratio
- Automation
- Very small size, mass, volume
- Very low power consumption
- Low cost
- Easy to integrate into systems or modify
- Small thermal constant
- Can be highly resistant to vibration, shock and radiation
- Batch fabricated in large arrays
- Improved thermal expansion tolerance
- Parallelism
- Mass-Scalable

http://www.eeherald.com/section/design-guide/mems_application_introduction.html

Miniaturization?

- Tend to move or stop more quickly due to low mechanical inertia. Ideal for precision movements and for rapid actuation.
- Encounter less thermal distortion and mechanical vibration due to low mass.
- Suited for biomedical and aerospace applications due to their minute sizes and weight.
- Small systems have higher dimensional stability at high temperature due to low thermal expansion.
- Less space requirements. This allows the packaging of more functional components in a single device.
- Less material requirements → low cost of production and transportation.
- Ready mass production in batches.

Surface-to-volume ratio

- Surface area of a sphere → $4\pi r^2$
- Volume of a sphere → $4\pi r^3/3$
- Surface to volume ratio → $3/r$
- SVR $\propto r^{-1}$

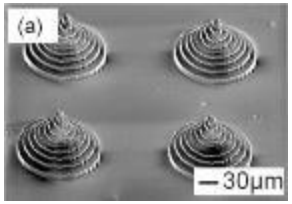
Length	*1/r (meters^{-1})*
• 1 meter	1
• 1 mm	1,000
• 1 mm	1,000,000
• 1 nm	1,000,000,000

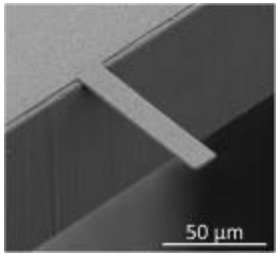
- Materials with high SVR react at much faster rates
- More surface is available to react
- Grain dust
  - Grain → nonflammable
  - Grain dust → explosive
- Finely ground salt
  - dissolves much more quickly than coarse salt

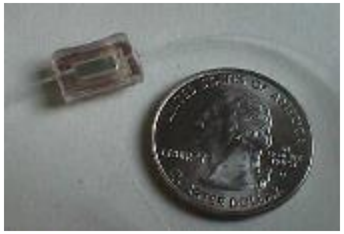
MEMS Stands for?

- **Micro** - Micro-fabricated structures
- **Electro** - Electrical signal /control (In / Out)
- **Mechanical** - Mechanical functionality (In / Out)
- **Systems** - Structures, Devices, Systems

  - Control





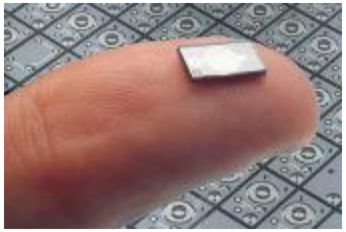
http://ase.tufts.edu/biology/labs/trimmer/news/developments.htm, http://www.buildbytes.com/assets/images/BLOG/3d_printing_carbon/4.jpg

MEMS: Features

- **MEMS** - a technology with integrated miniaturized elements
  - electrical
  - mechanical and / or
  - electro-mechanical elements

- Elements (including devices, structures and data processing unit) are developed using **Microfabrication** techniques

- **Dimensions**
  - ○ components → 1-100 μm
  - ○ device → 20-1000 μm



http://cdn.medgadget.com/img/524deb1.j

- One **unique feature** - large surface area to volume ratio,
  - ○ Surface effects such as electrostatics and wetting dominate over volume effects such as inertia or thermal mass.

MEMS: Diverse Applications

Automotive domain:
- Airbag Systems
- Vehicle Security Systems
- Intertial Brake Lights
- Headlight Leveling
- Rollover Detection
- Automatic Door Locks
- Active Suspension

Consumer domain:
- Appliances
- Sports Training Devices
- Computer Peripherals
- Car and Personal Navigation Devices
- Active Subwoofers

Industrial domain:
- Earthquake Detection and Gas Shutoff
- Machine Health
- Shock and Tilt Sensing

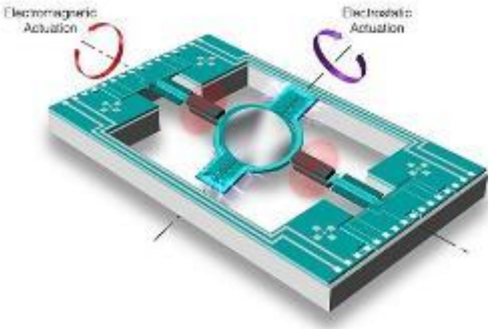
Military:
- Tanks
- Planes
- Equipment for Soldiers

Biotechnology:
- PCR
- Micromachined STM
- Biochips for chemical and biological agents
- High-throughput drug screening and selection
- Bio-MEMS biosensor & chemosensor.

http://www.eeherald.com/section/design-guide/mems_application_introduction.html

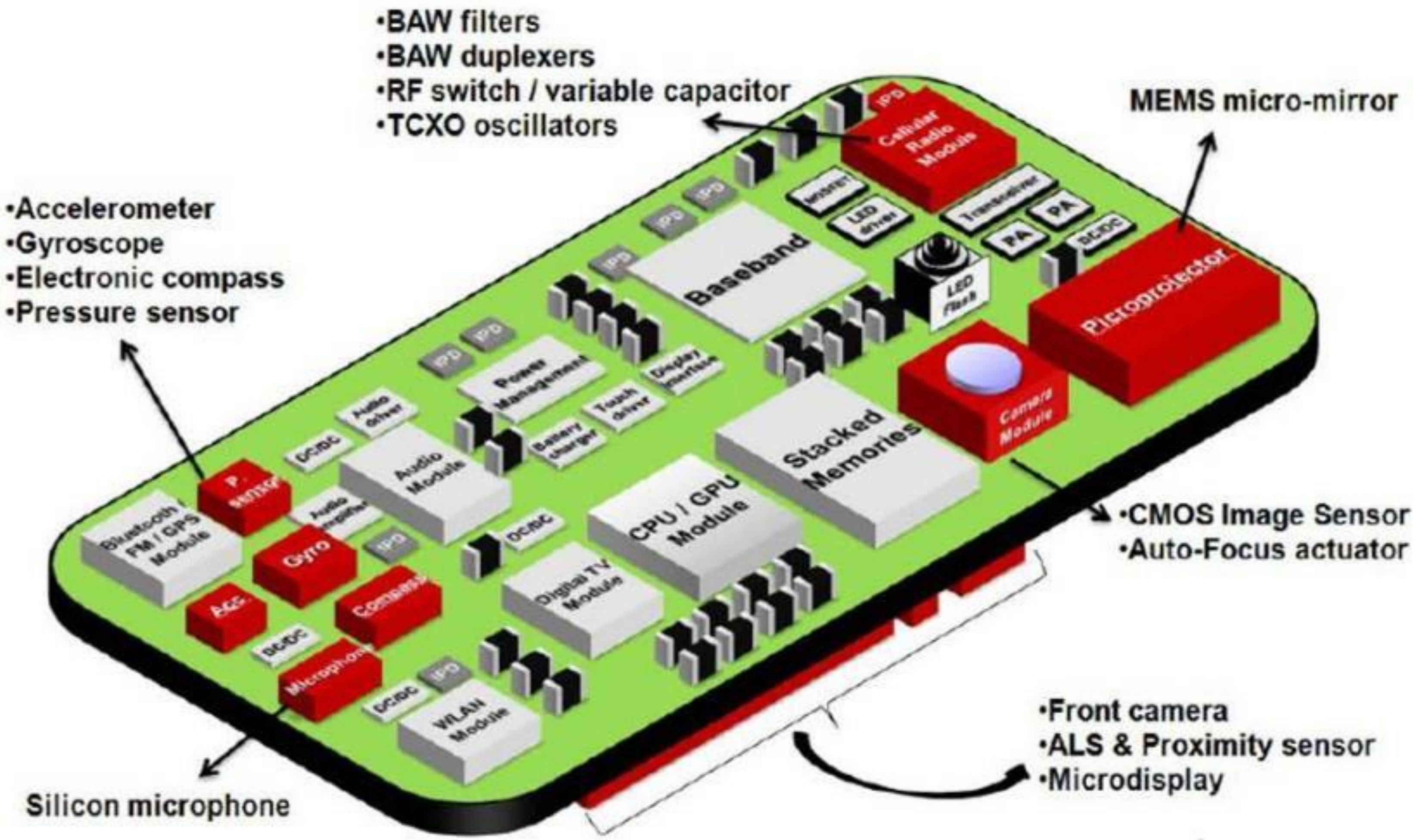
MEMS: Commercial Applications

- Inkjet printers
- Accelerometers
- Gyroscopes Pressure sensors
- Displays / micromirrors
- Optical switching technology
- Adaptive Optics for Ophthalmic Applications
- Disposable Medical Devices Micro-power sources and turbines
- Propulsion and attitude control
- Bio-reactors and Bio-sensors, Microfluidics
- Thermal control
- Atomic clocks



http://www.eeherald.com/section/design-guide/mems_application_introduction.html

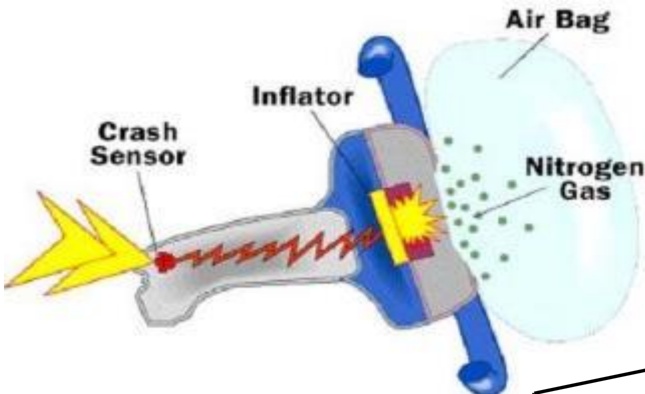
An example: MEMS in Smartphone



http://www.engineering.com/ElectronicsDesign/ElectronicsDesignArticles/ArticleID/6124/How-MEMS-Enable-Smartphone-Features.aspx

MEMS: Other Examples

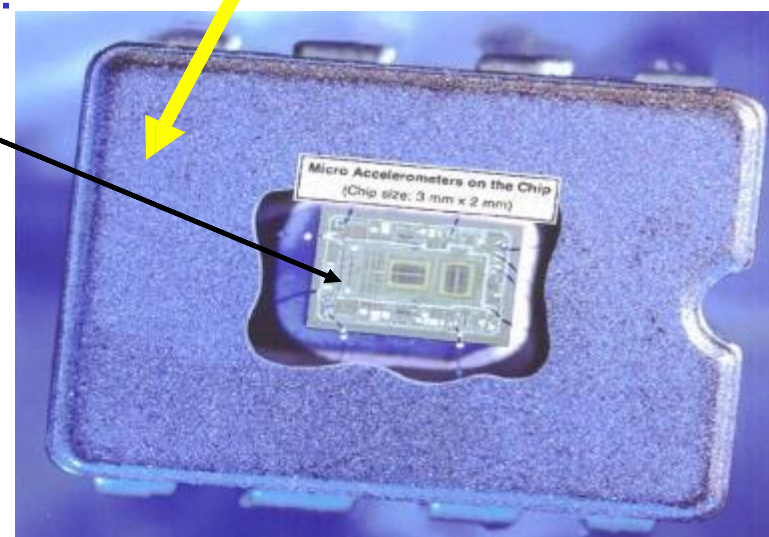
Inertia Sensor for Automobile “Air Bag” Deployment System



Micro inertia sensor (accelerometer) in place:

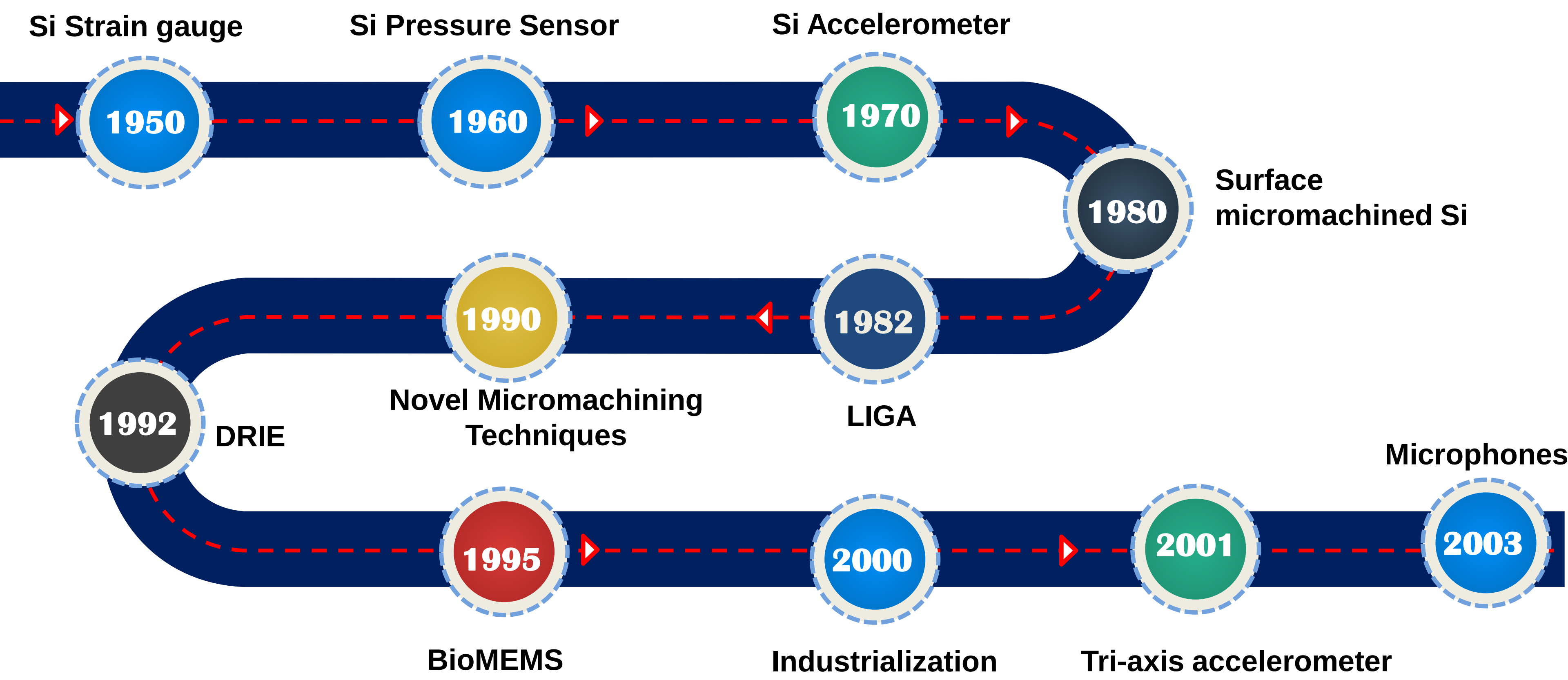
Sensor-on-a-chip: (the size of a rice grain)

Collision



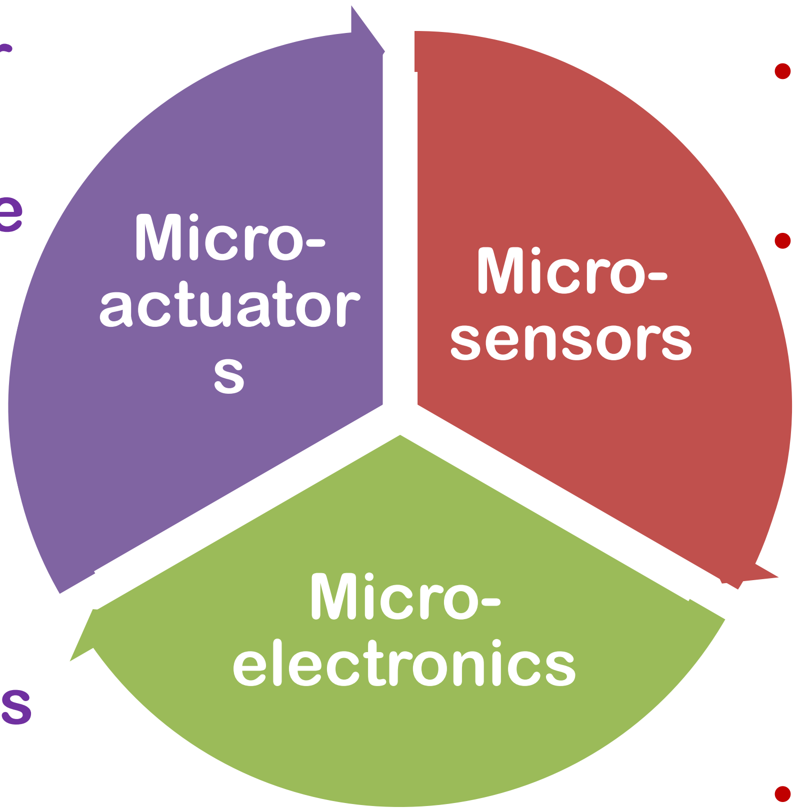
(Courtesy of Analog Devices, Inc)

Historical evolution



MEMS: Vertical Components

- Acts as a switch / trigger to activate an external device
- Makes decisions on what to do based on this data
- Micrelectronics will tell the microactuator to activate this device

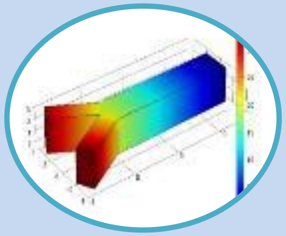


- Arms, eyes, nose
- Constantly gather data (?)
- Data?
  - Mechanical
  - Thermal
  - Biological
  - Chemical
  - Optical
  - Magnetic
- Pass to microelectronics for processing

- Brain of MEMS
- Plays smartly with data

✓ Receives
✓ Process
✓ Makes Decision

MEMS: Horizontal Components

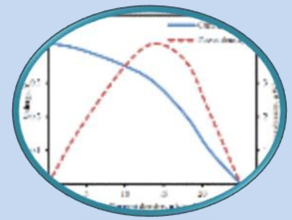


Design & Simulation

- **Aim**
  - Understand Dependent Parameters
  - Simulation to analyze practicality
  - Design finalization for fabrication and testing
- **Tools:** COMSOL, Matlab, CATIA

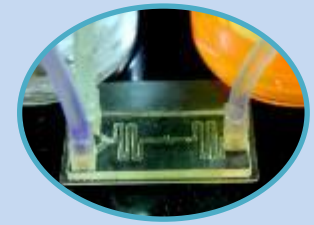
Fabrication

- **Photolithography** (Si / Glass)
- **Direct laser writing** (maskless)
- **Soft-lithography** (PDMS)
- **Laser engraving** (PMMA)
- **Paper based**
- **3D printing** (various polymers)



Detection

- **Optical** (colorimetric / image)
- **Luminescence** (chemi / bio)
- **Electrical** (impedance / amperometric)
- **Electrochemical**
- **Electrochemiluminisence**

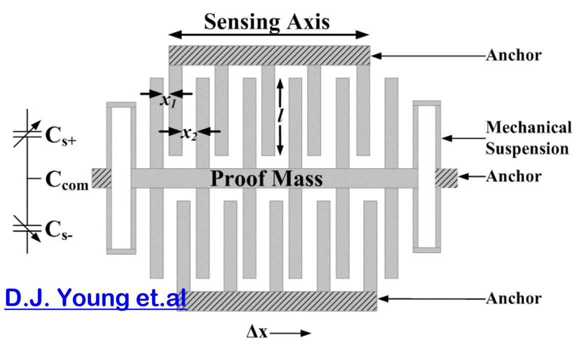


Testing and Characterization

- **Generate samples** of various parameters ratios for Testing
- **Analysis** of flow characteristics
- **Investigate** possibility for other applications

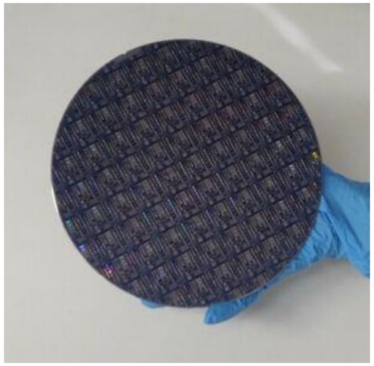
MEMS: Process Value Chain

Process chain

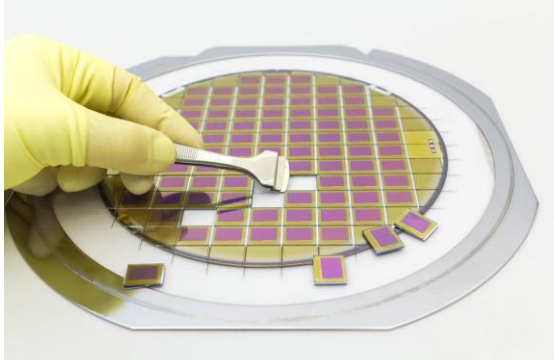


D.J. Young et.al

Design

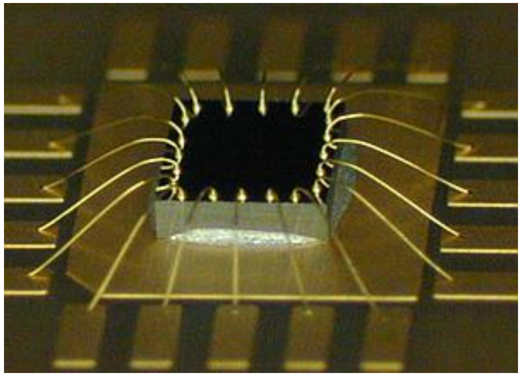


Fabrication



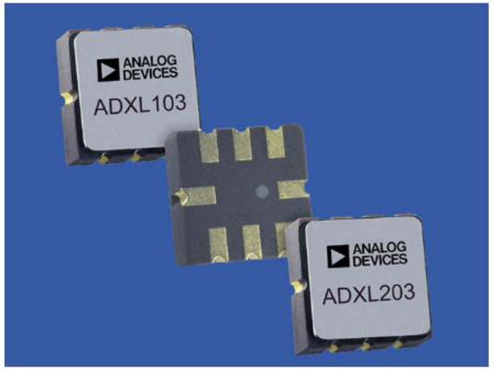
https://www.waferworld.com

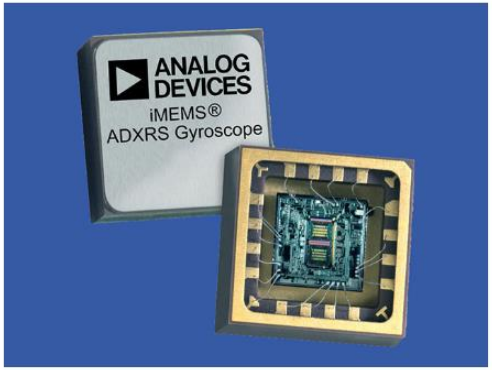
Dicing



https://firstlevelinc.com/

Die attach and wire bonding



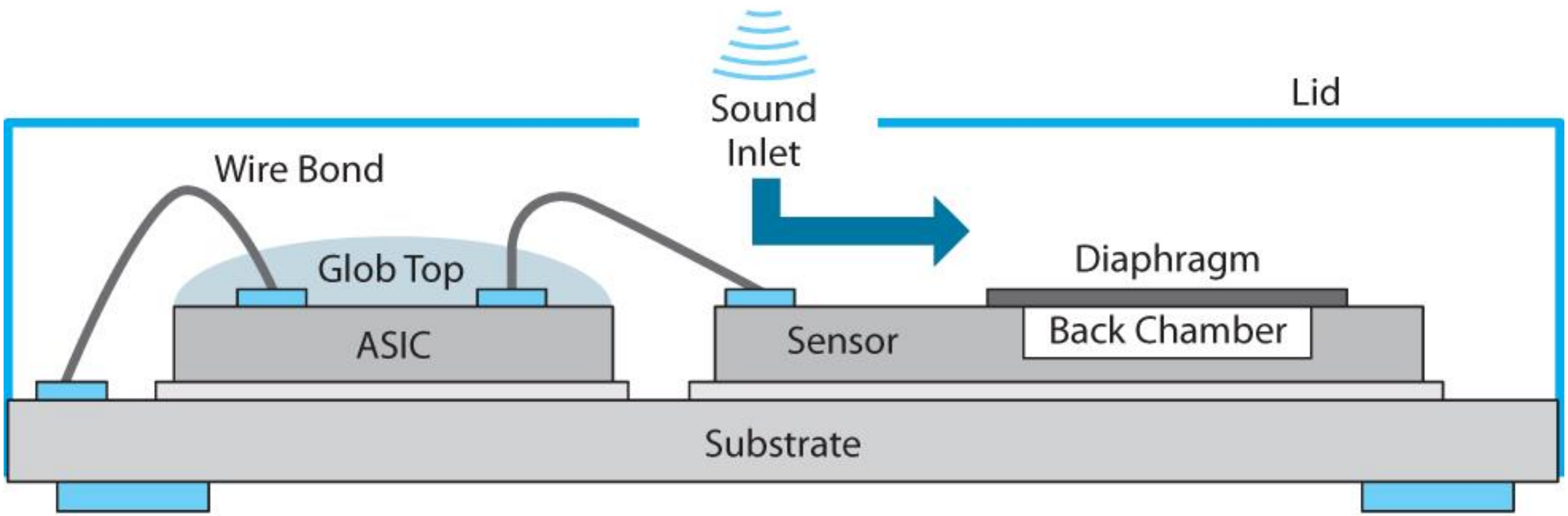


https://global.kyocera.com/

https://global.kyocera.com/

Hermetic sealing

Anatomy of MEMS Package



Fundamentals of MEMS Packaging

Protection

Electrical connection

Thermal Management

Mechanical stress

IC

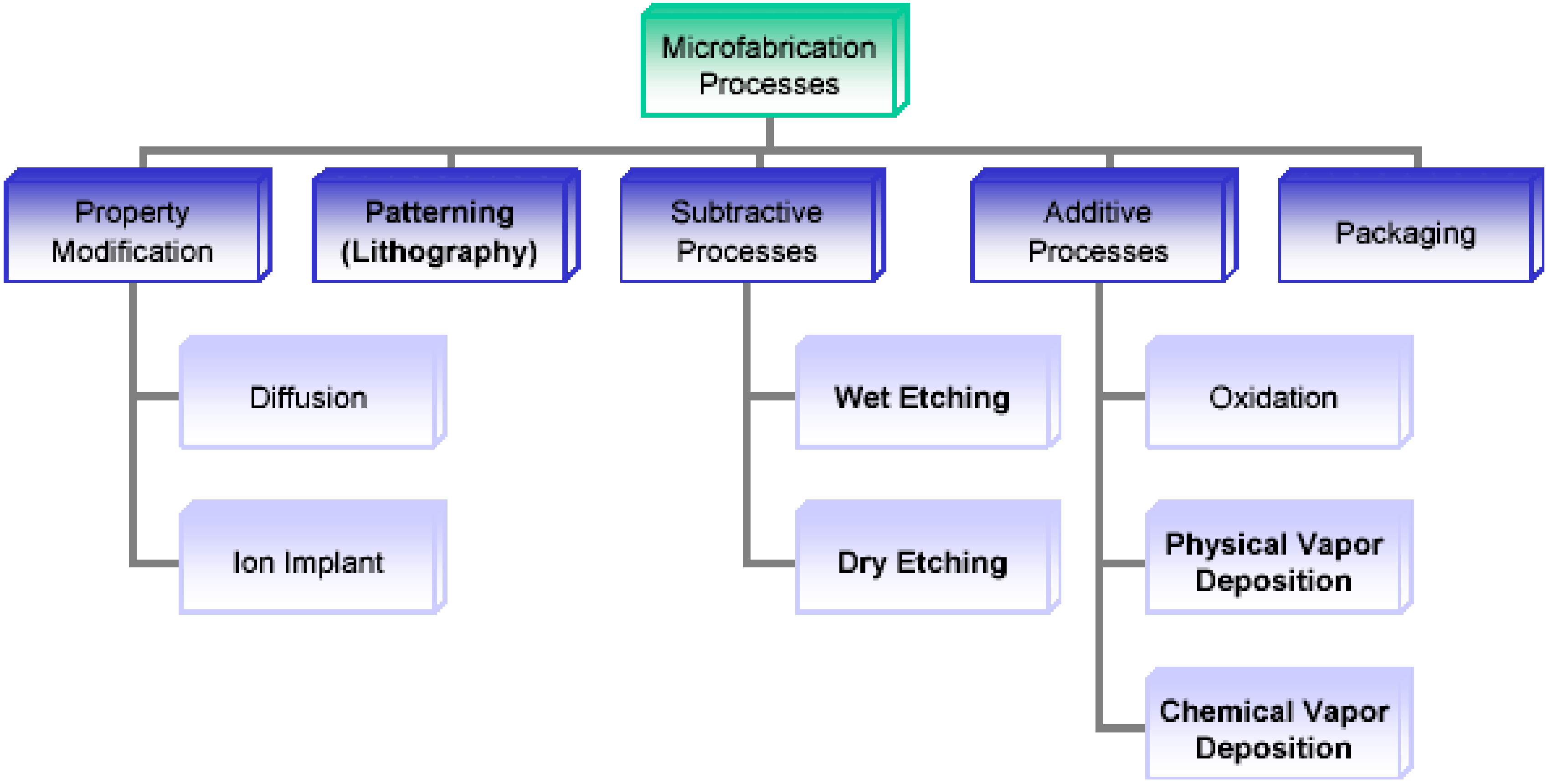
Reliability

MEMS

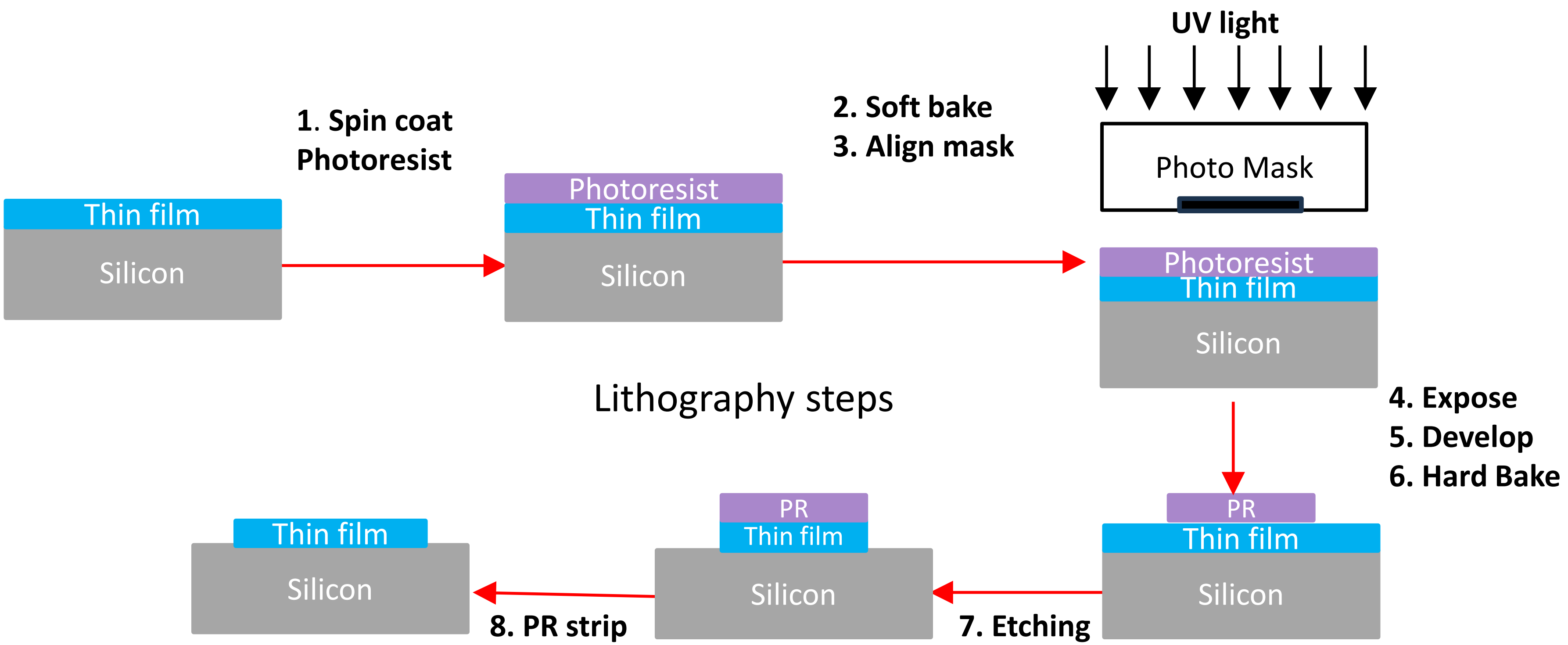
Multiphysics
Environment interaction with sensors

Fabrication

Fabrication Techniques



Photolithography

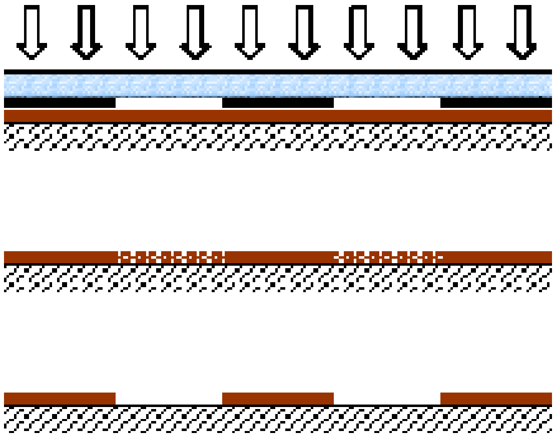


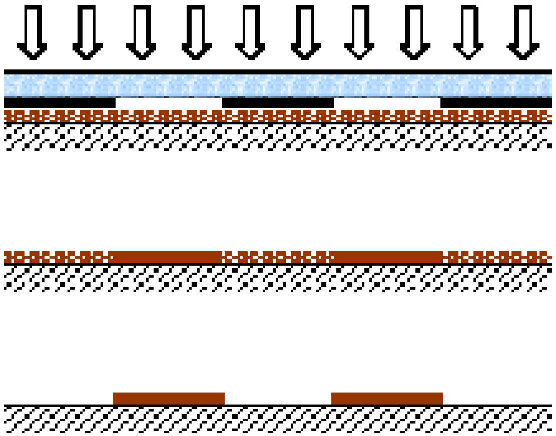
Lithography steps

Photolithography

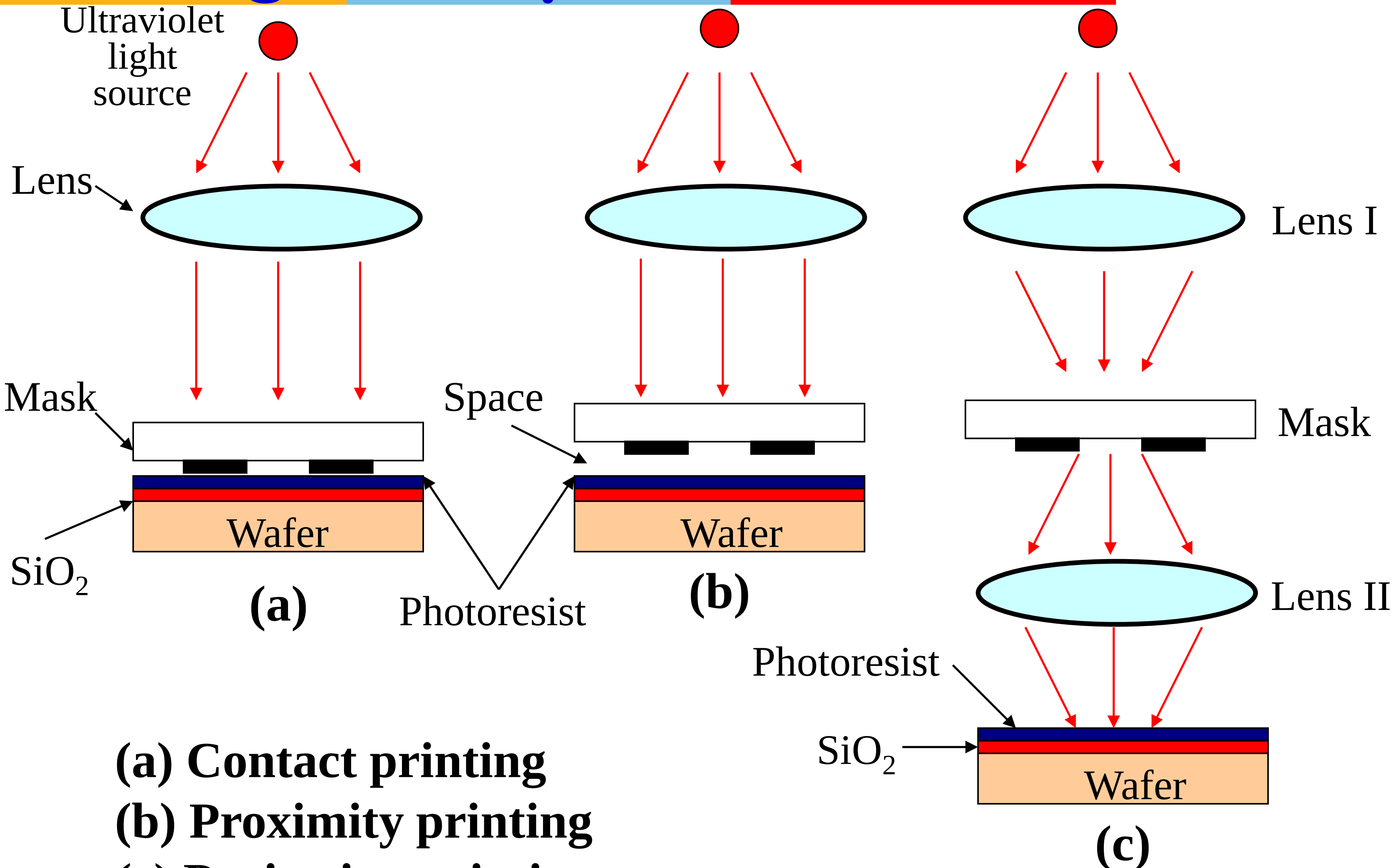
A **positive** photoresist is weakened by radiation exposure, so the remaining pattern after being subject to a developer solution looks just like the opaque regions of the mask

A **negative** photoresist is strengthened by radiation exposure, so the remaining pattern after being subject to a developer solution appears as the inverse of the opaque regions of the mask.





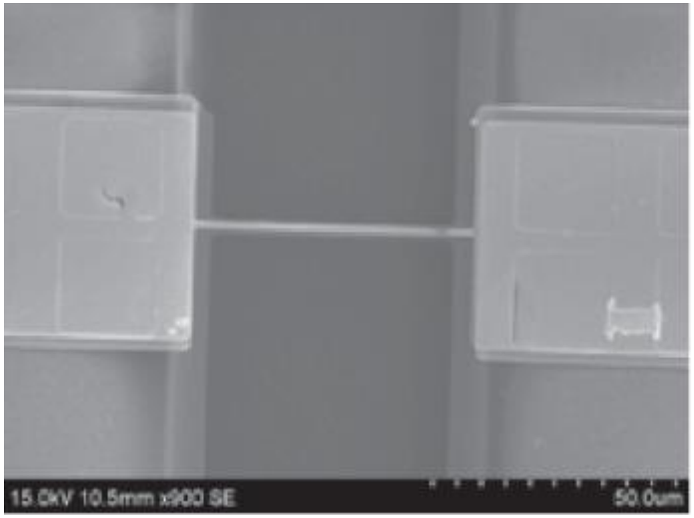
Printing techniques



(a) Contact printing
(b) Proximity printing
(c) Projection printing

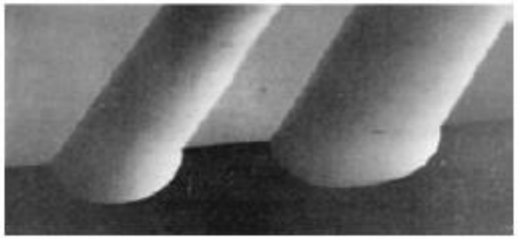
Deposition

- **CVD**
  - **LPCVD**
  - **APCVD**
  - **PECVD**
- **PVD**



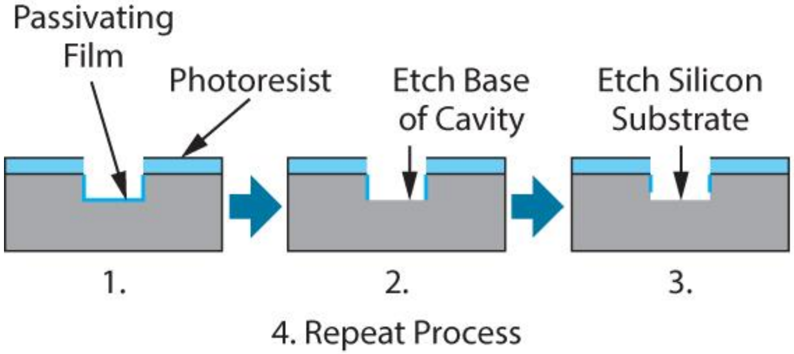
Etching

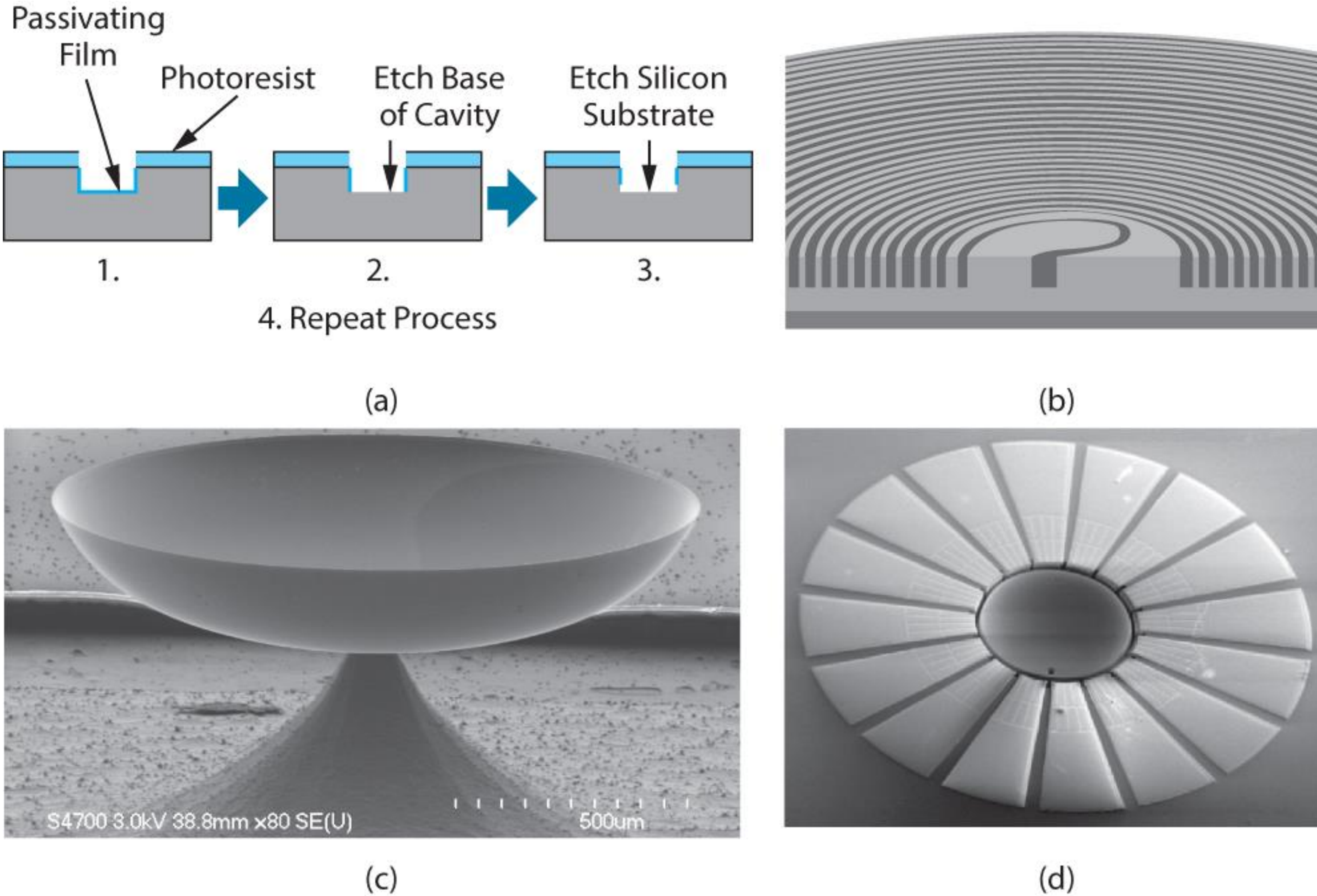
– **Wet chemical etching**
  - **Isotropic**



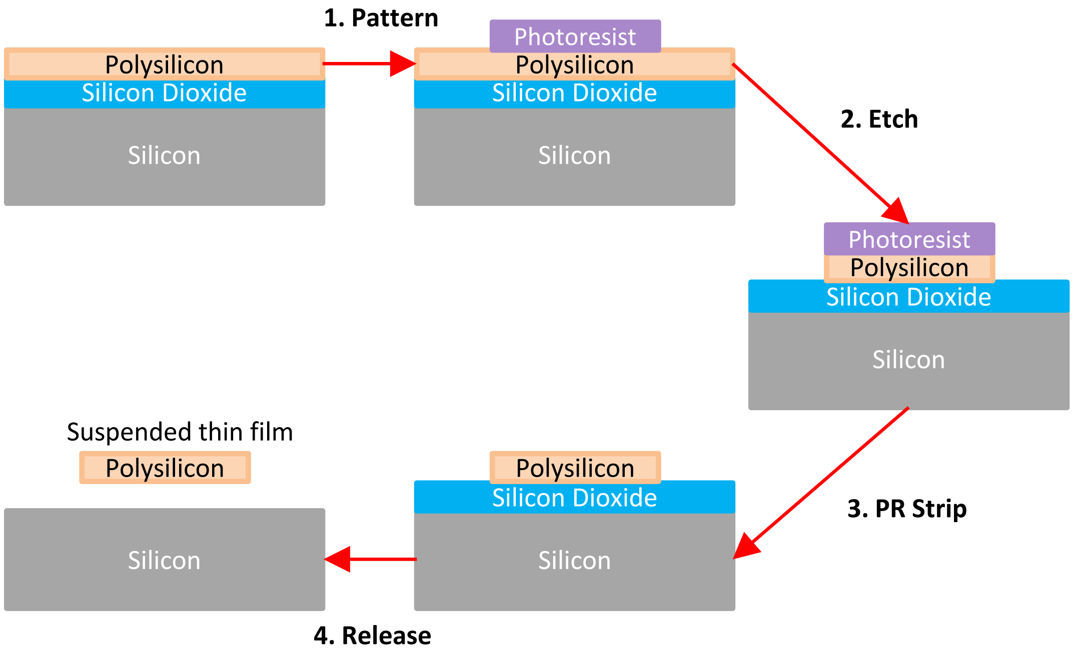
  - **Anisotropic**

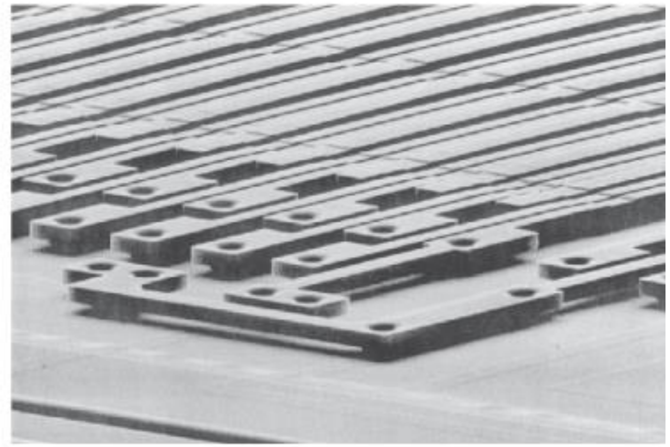
– **Dry etching**




Passivating Film
Photoresist
Etch Base of Cavity
Etch Silicon Substrate
1.
2.
3.
4. Repeat Process
(a)
(b)
S4700 3.0kV 38.8mm x80 SE(U)
500um
(c)
(d)

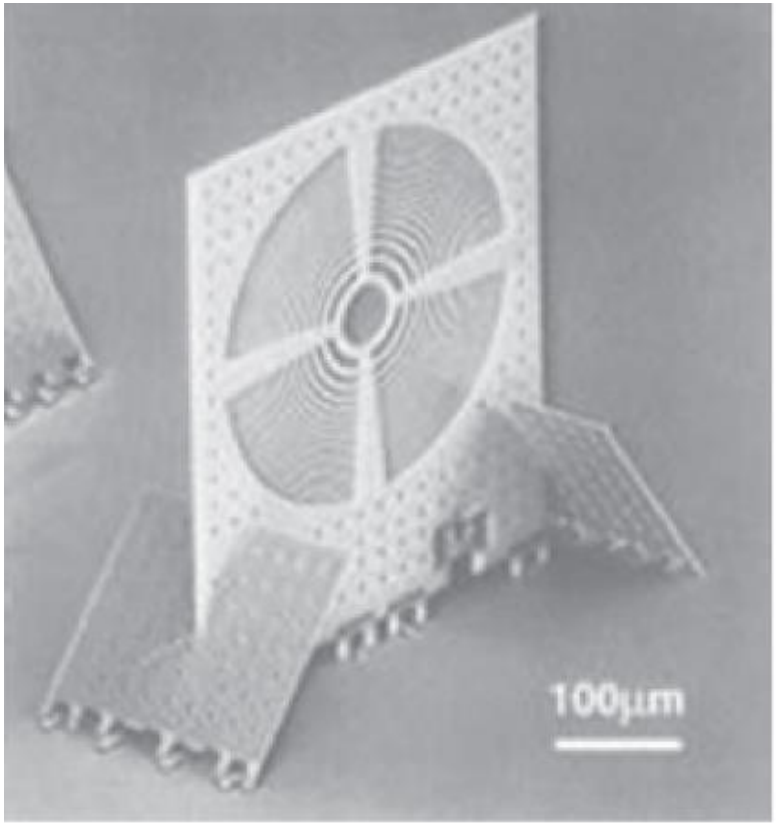
Surface Micromachining





(Analog Devices ADXL50 micro-accelerometer)

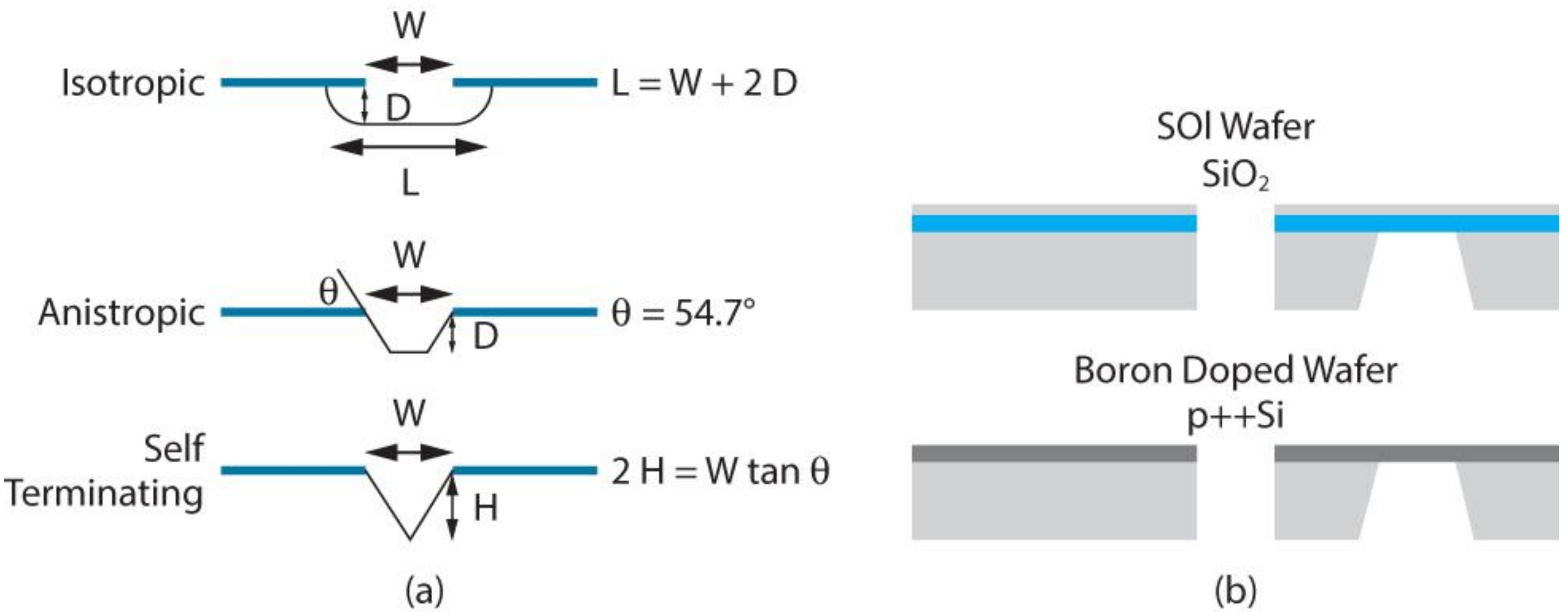
Examples



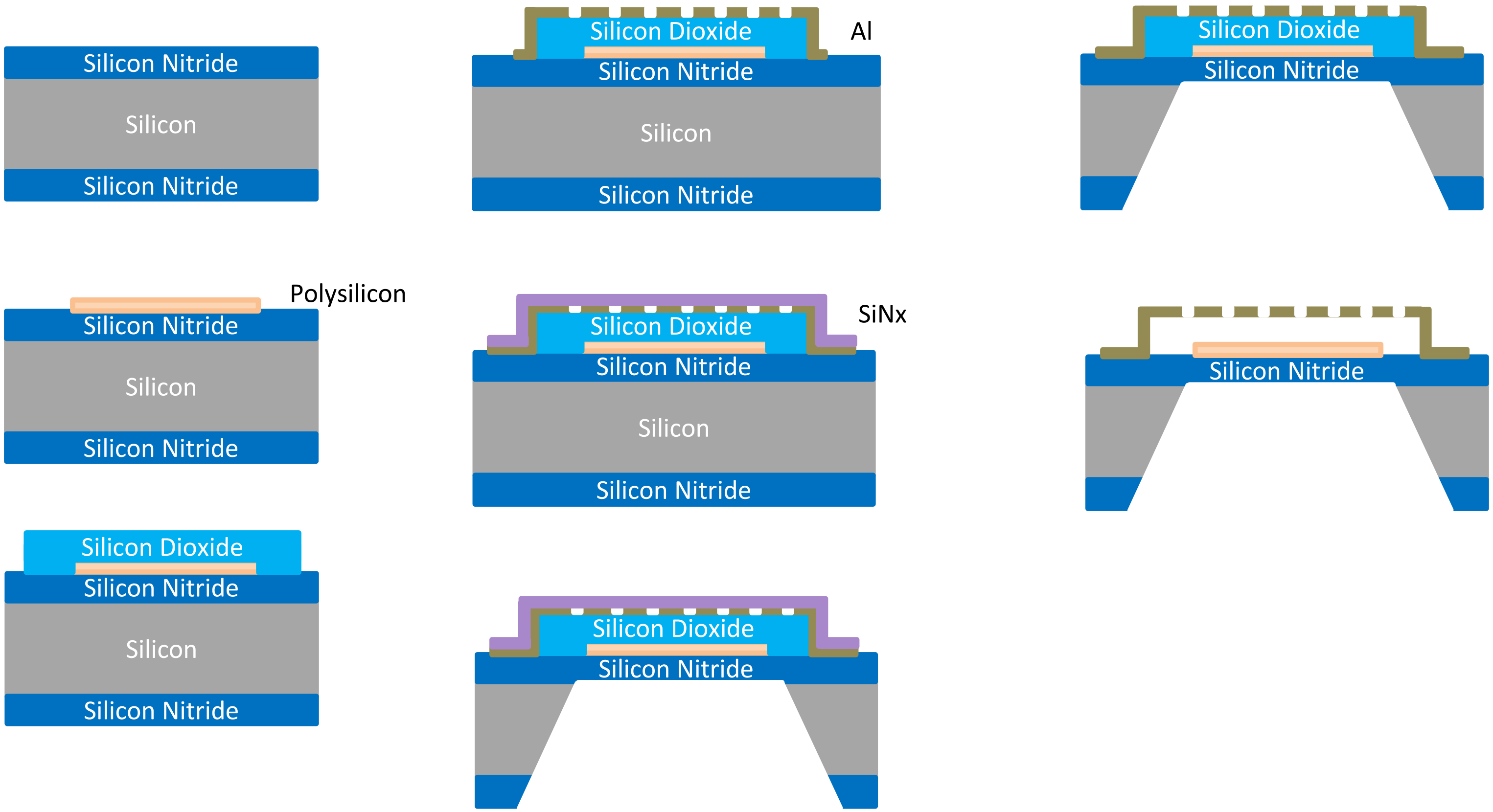
(a)

(b)

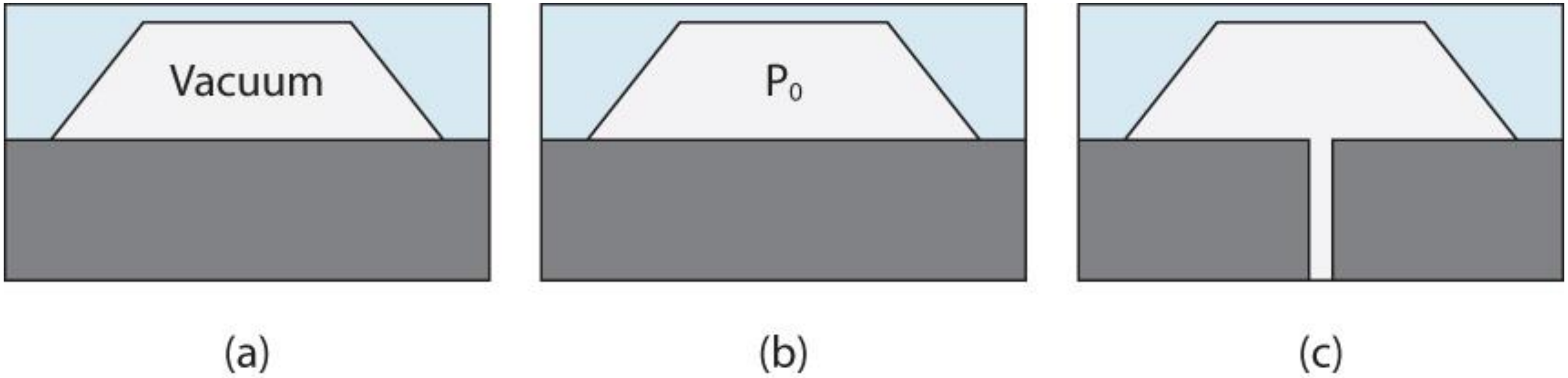
Bulk micromachining



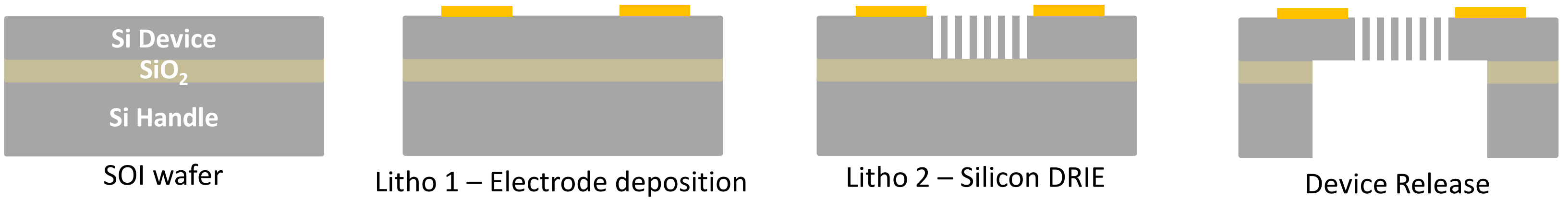
Fabrication of MEMS Microphone

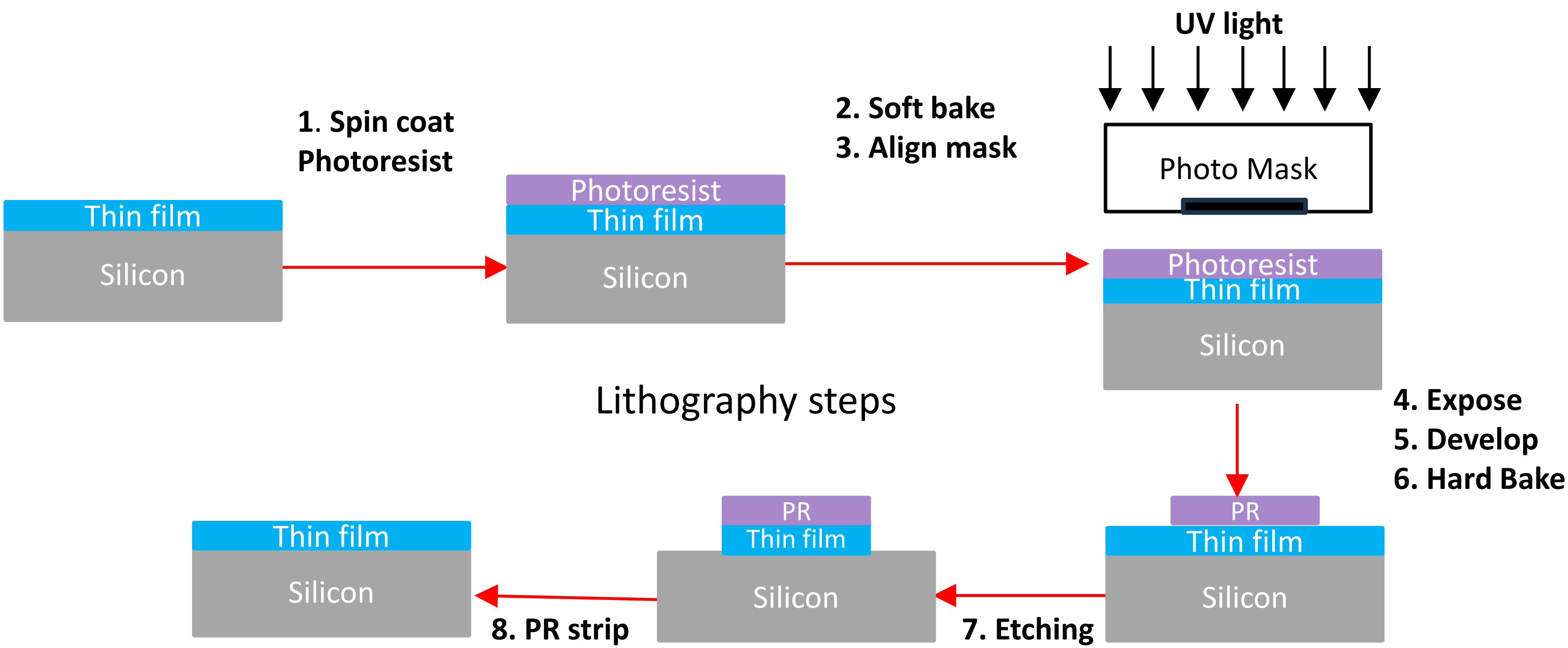


Pressure sensor



Fabrication of MEMS accelerometer





innovate achieve lead

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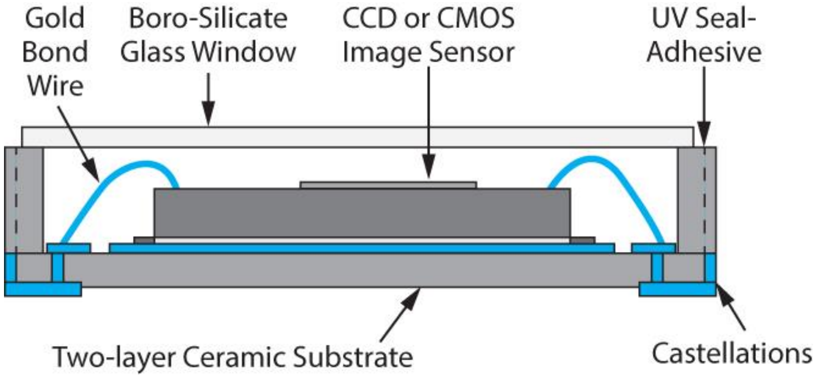
MEMS Packaging Technologies

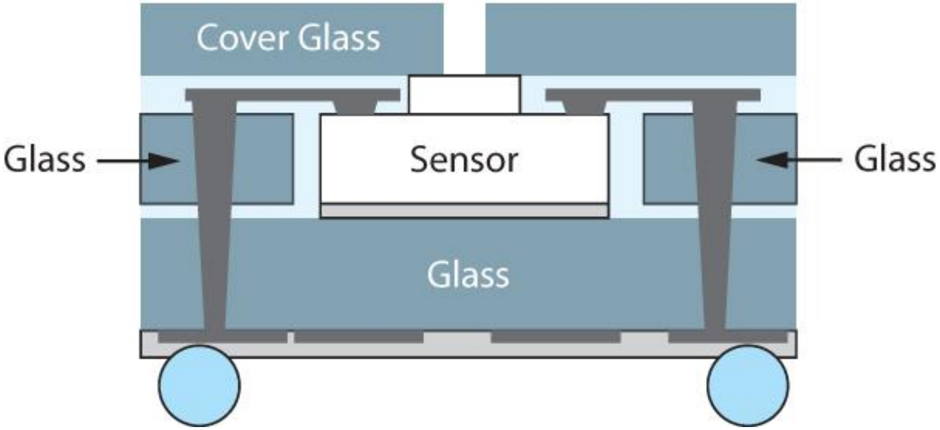
Materials

Metal



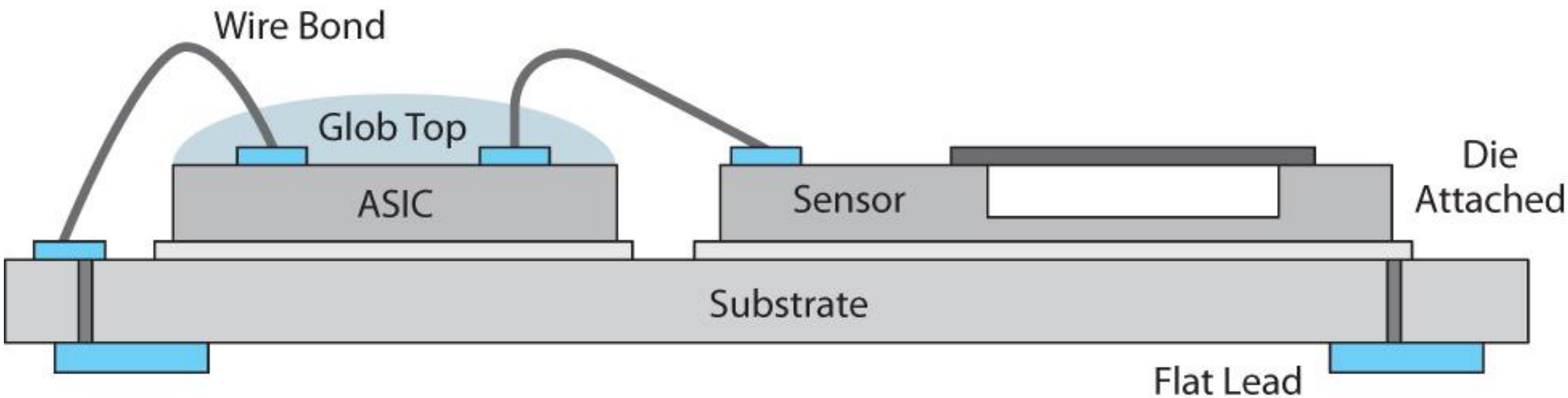
Ceramic

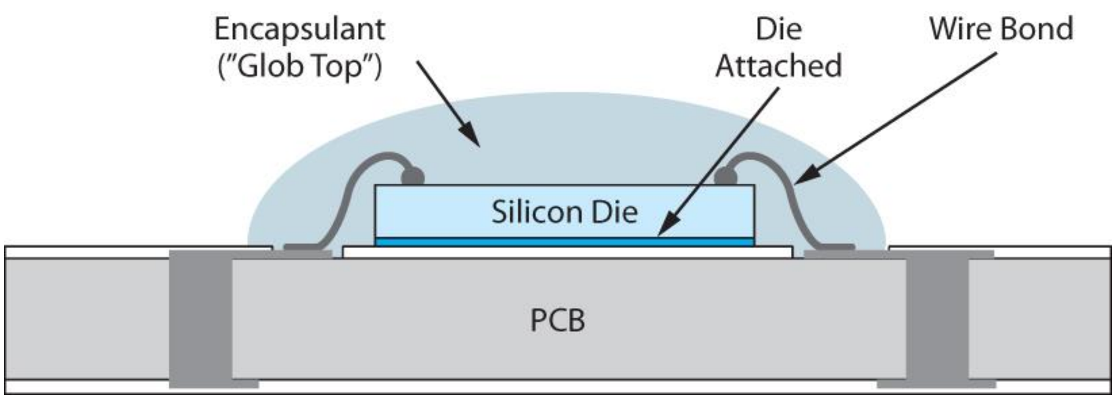
Plastic



Glass

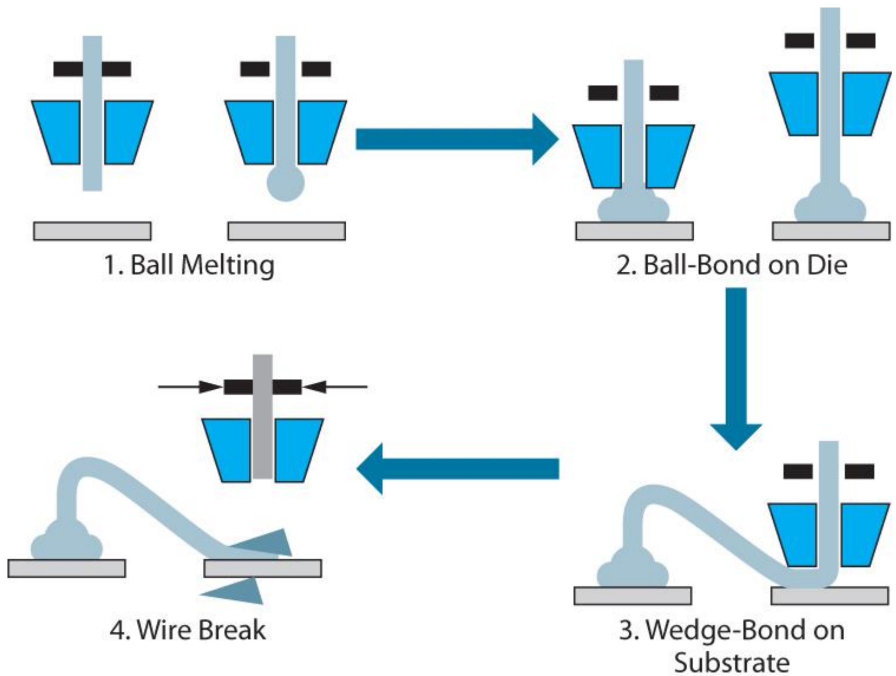
Assembly process



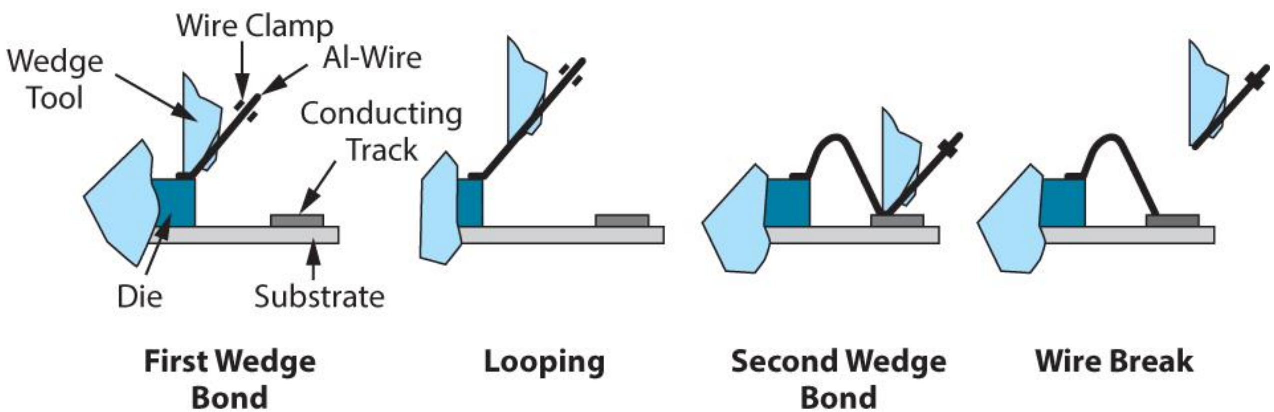


Chip on board

Wire bonding

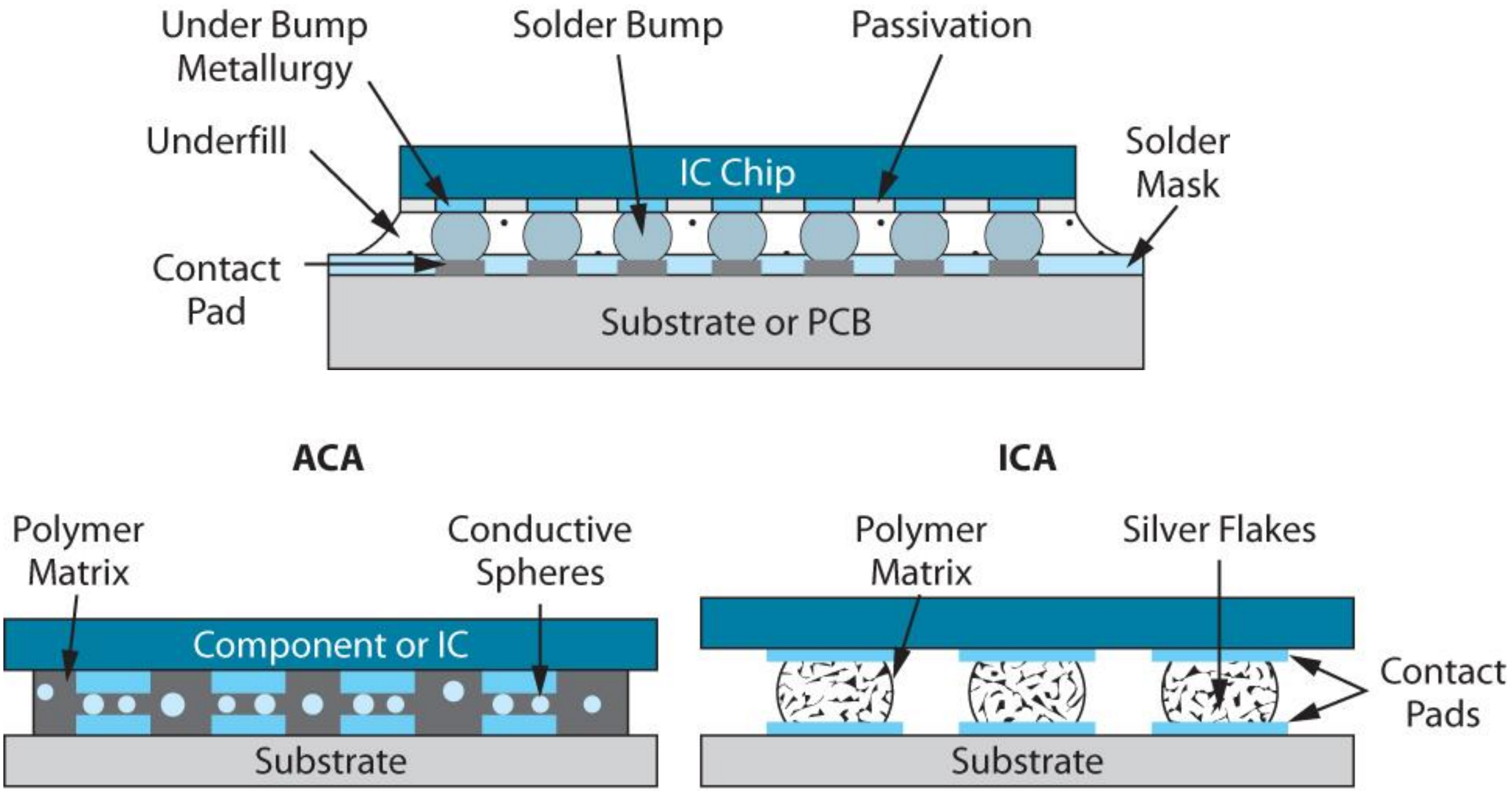


Thermosonic bonding

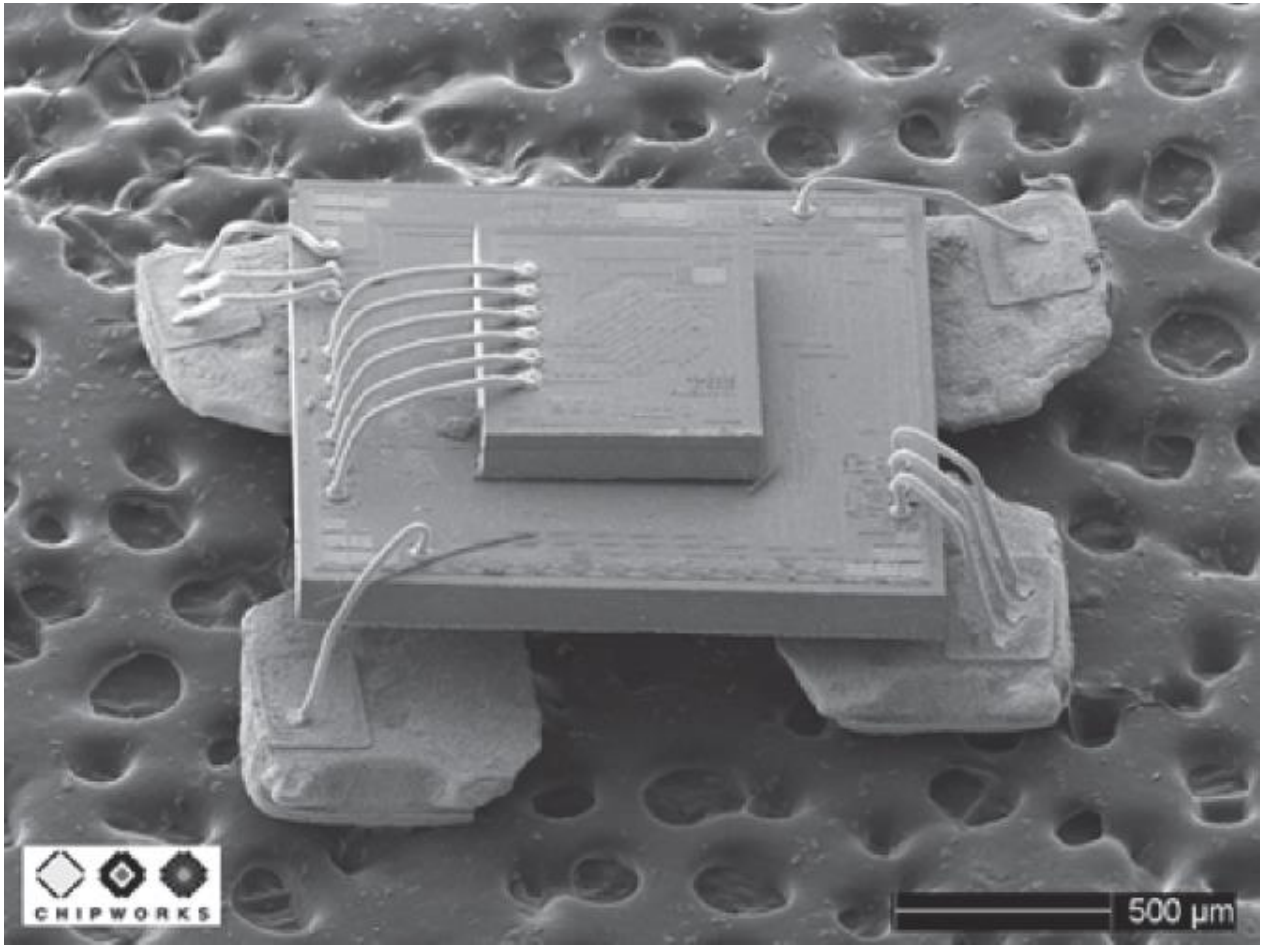


Ultrasonic bonding

Flip-chip bonding



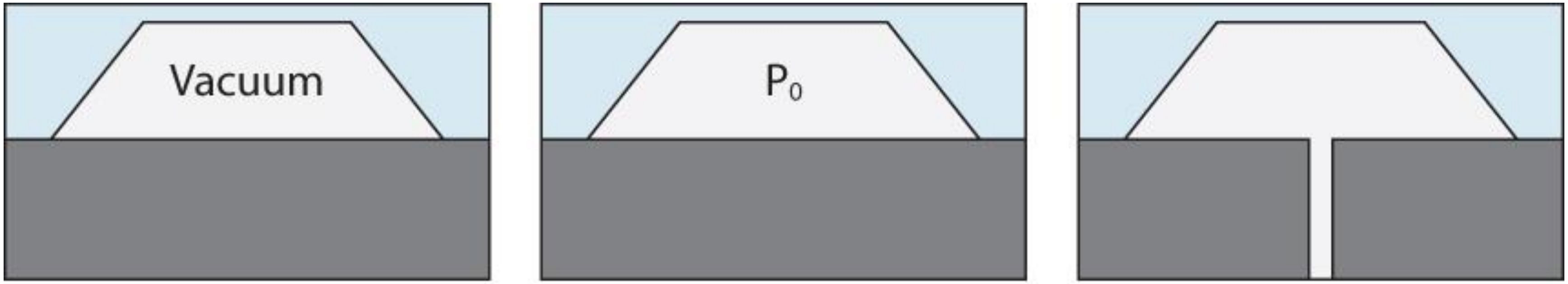
Die Stacking

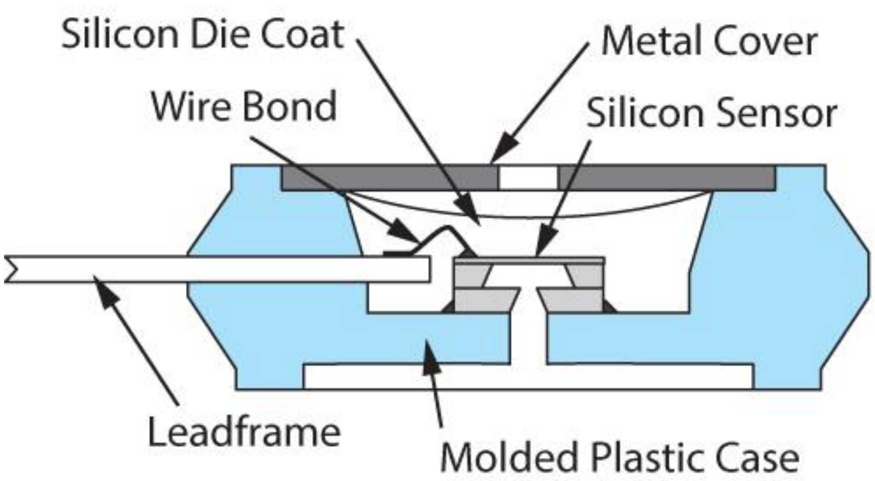


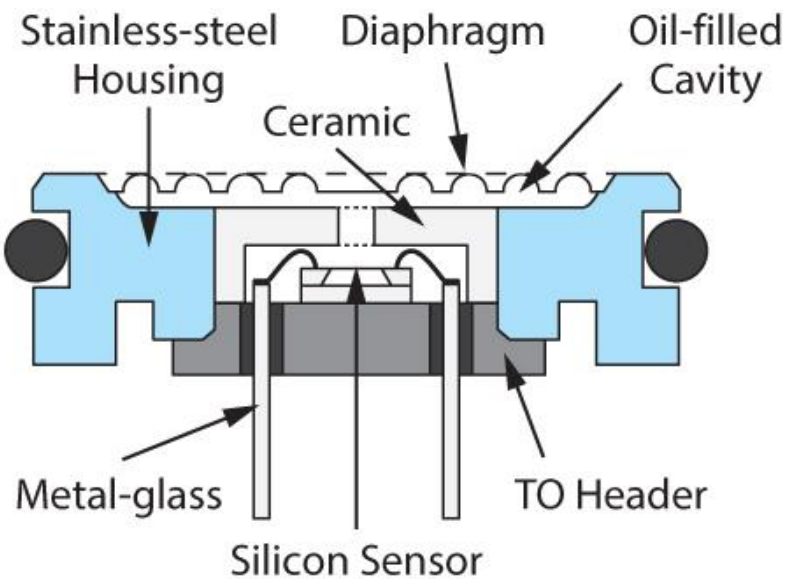
(Courtesy of Chipworks)

Applications

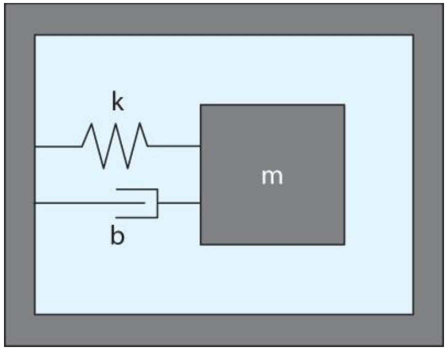
Pressure Sensor

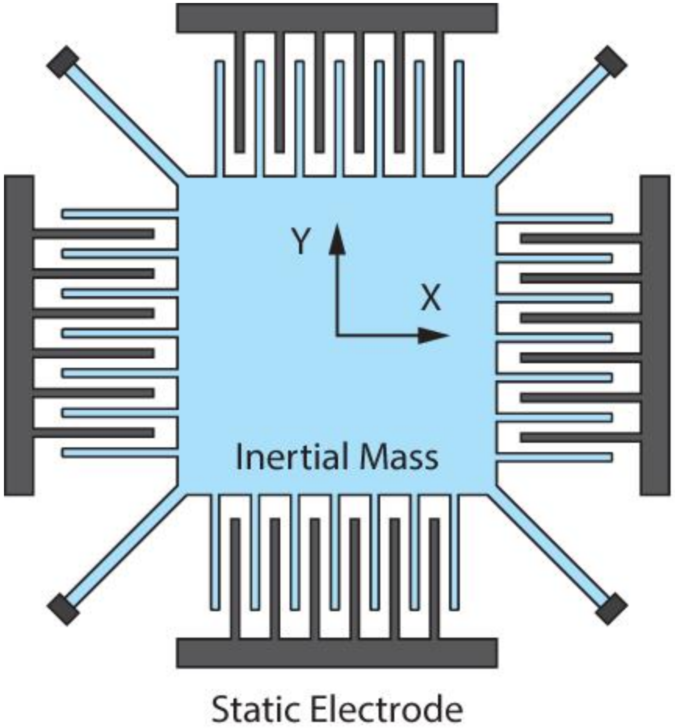


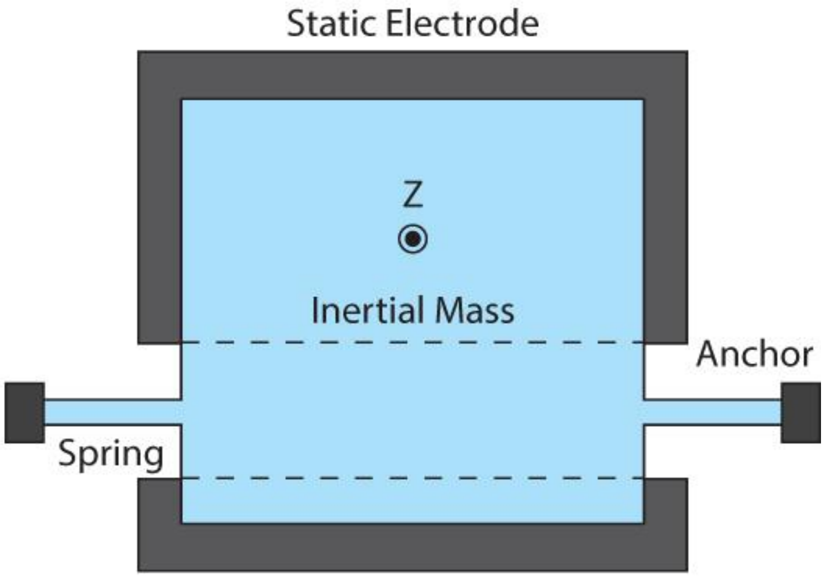




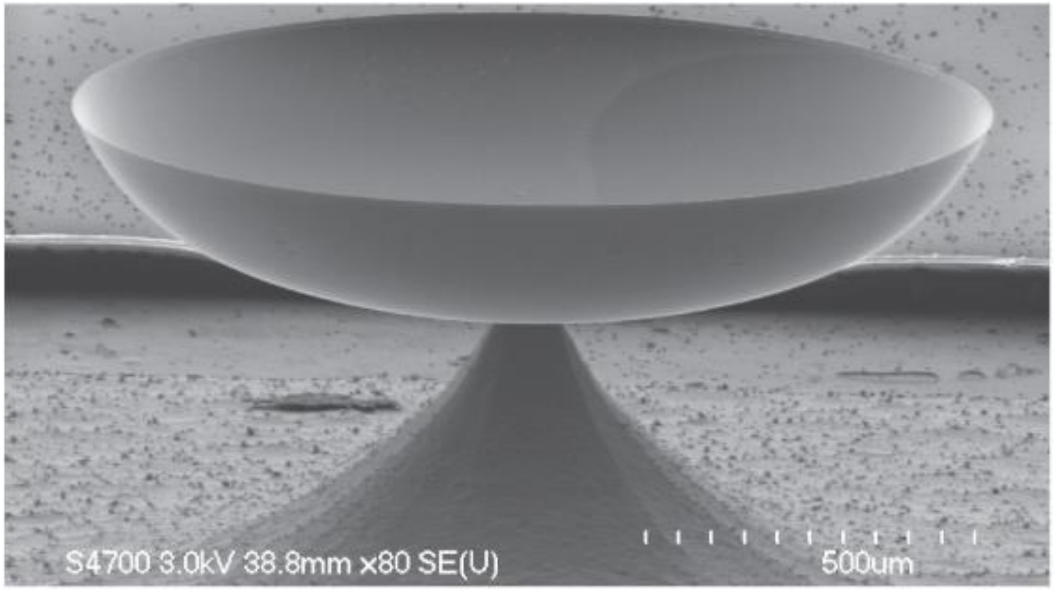
Accelerometer

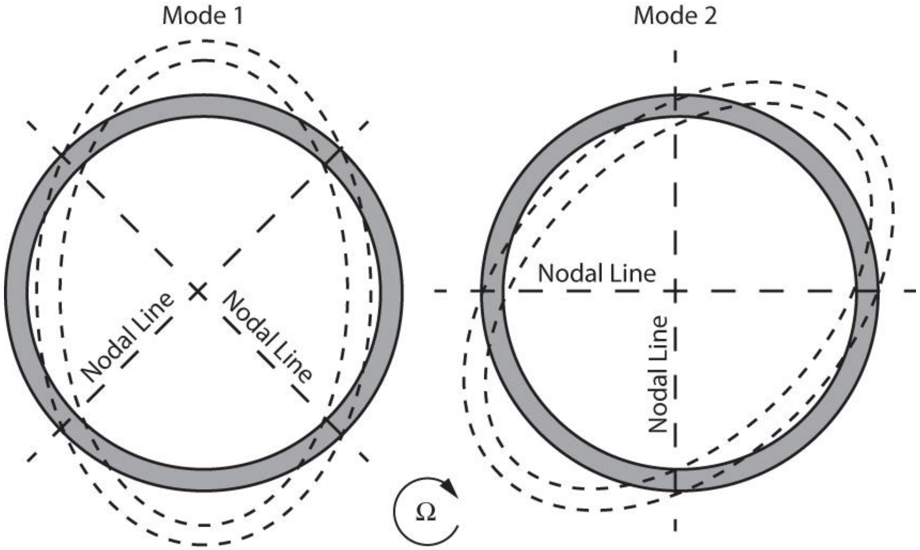






Gyroscope


S4700 3.0kV 38.8mm x80 SE(U)
500um


Mode 1
Nodal Line
Nodal Line
Mode 2
Nodal Line
Nodal Line
Ω

Thank You