Murata MEMS

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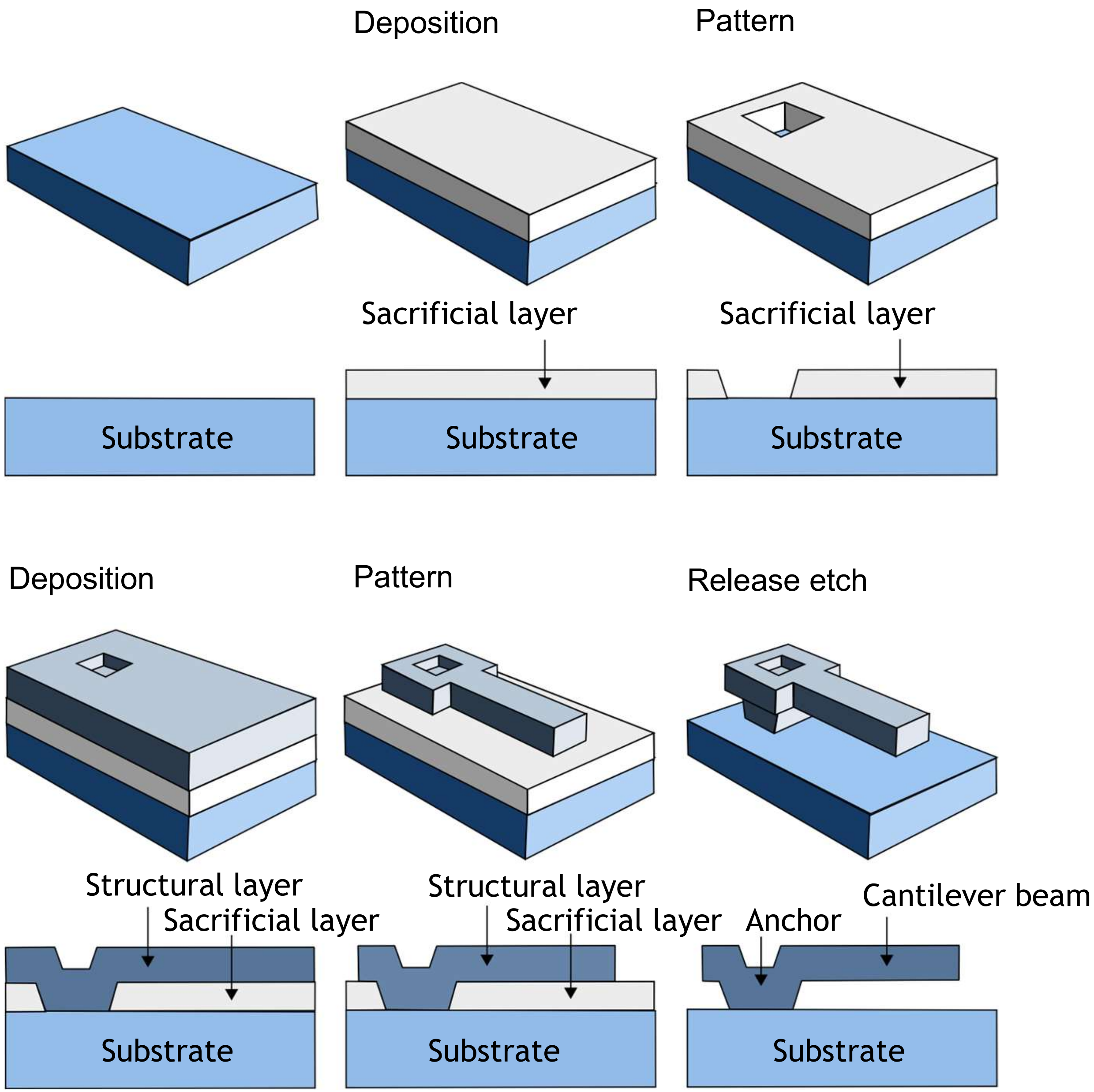
MEMS

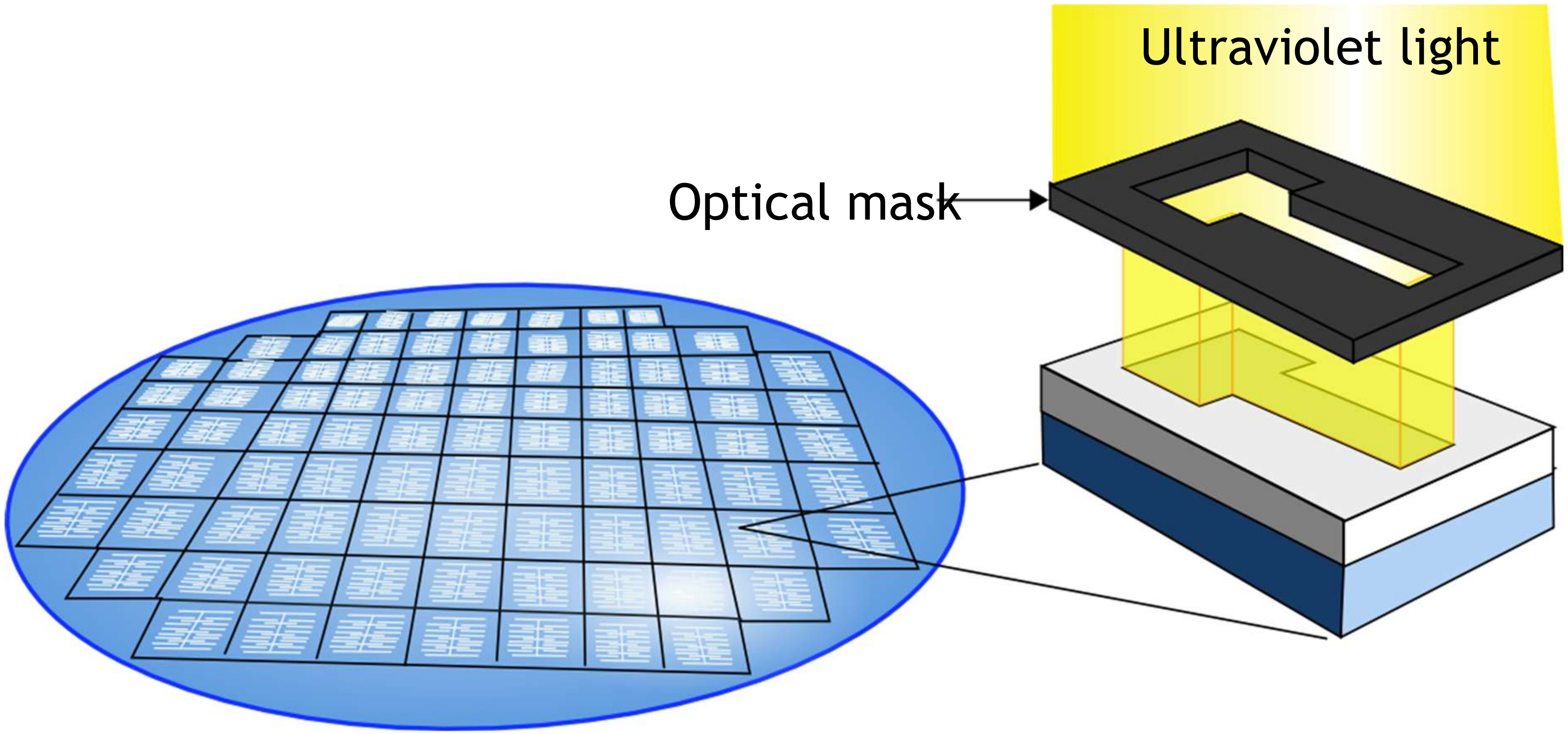
- MEMS = ‘Micro Electro Mechanical Systems’
  - Micro: micrometer scale
  - Electro: electronic control, actuation, amplification
  - Mechanical: moving structures
  - System: electronics and mechanical parts combined into an integrated system
- Other equivalent terms:
  - Micromechanics
  - Micromachines
  - Micromachining
  - Microsystems

Surface micromachining makes thin structures



Semi-3D structures are made, by repeating the steps of film deposition and film patterning.

Batch fabrication enables low cost



Thousands of devices are obtained from a single wafer!

Murata Facts & Figures

Our Business

We are worldwide leaders in the design, manufacture and supply of electronic components and solutions.

We are Innovators in Electronics.

Our Strengths

- Advanced materials technology and expertise
- Broad product portfolio
- Extensive global manufacturing and sales network

Our Figures

- Net sales 1,575026 million JPY* (about $14B)
- Employees 77,571*
- Number of subsidiaries 92* (28 in Japan, 64 overseas)
- Established in 1944

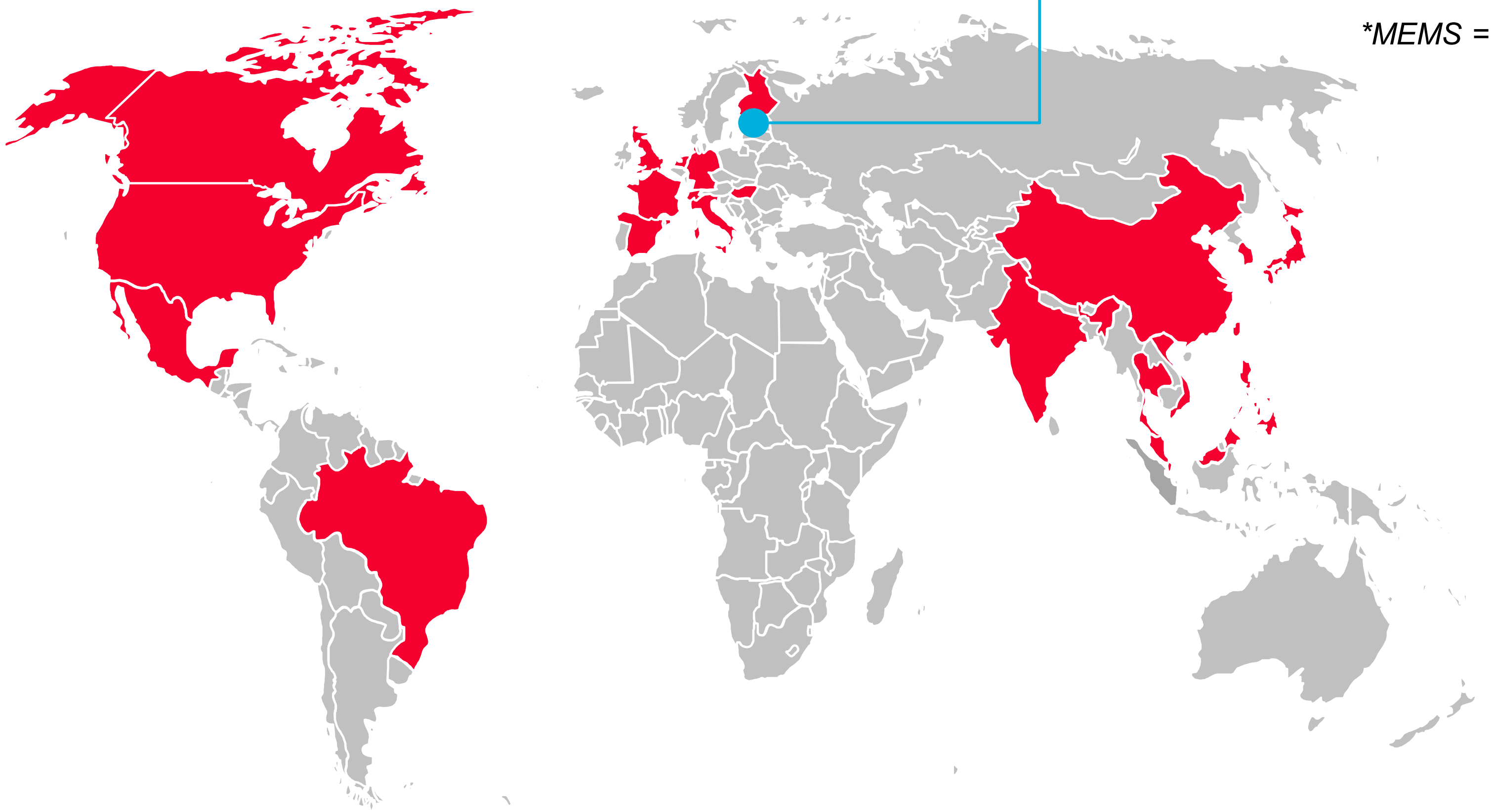
**as of March 31, 2019*

**Murata Manufacturing Co., Ltd. Is not included in the number of subsidiaries*

Murata Electronics Oy in brief

- Design and manufacturing of inertial motion sensors based on a unique 3D MEMS* technology
- State-of-the-art clean room operations (ISO 4-8)
- ISO 9001:2015, IATF16949:2016, ISO 14001:2005 (all valid through 2021)
- 1165 employees**

**MEMS = Micro Electro Mechanical Systems*
*** March 31, 2019*



In red all countries where Murata has factories, R&D centers and sales offices.

Main markets & applications

We contribute to safer driving, higher quality of life and increased efficiency

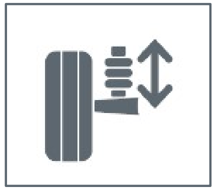
AUTOMOTIVE

#1 in acceleration sensors for automotive active safety systems

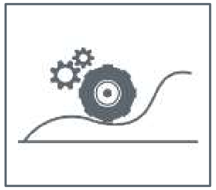
Electronic Stability Control (ESP/ESC)

Advanced Driver Assistance Systems (ADAS)

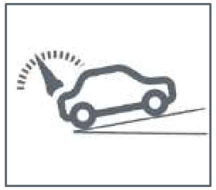
Hill Start Assistance (HSA)



Electronically Controlled Susp. (ECS)



Transmission Control (TCM)



Electric Parking Brake (EPB)

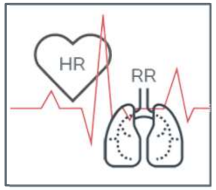
HEALTHCARE & MEDICAL

#1 in activity monitoring in Cardiac Rhythm Management

Pacemakers and ICDs

Surgery tables and medical imaging

Patient monitoring solutions



Vital signs

Bed occupancy

Sleep quality, stress, relaxation

INDUSTRIAL

Wide range of sensing solutions across industries

Construction tools and systems

Heavy machines

Structural health monitoring

Weight scales

Airplane instrument systems

Robotics

Why Silicon?

- Silicon and Si-wafer
  - Excellent mechanical properties for springs
    - Elastic - no plastic deformation
    - Brittle due to crystal structure
      - Enables self diagnostics (in-spec or broken)
  - Low cost
  - Wafers with accurate dimensions & excellent surface quality
- Manufacturing technologies “borrowed” from IC industry
  - Lithography and etching methods produce tiny structures

Accelerometer Operation Principle

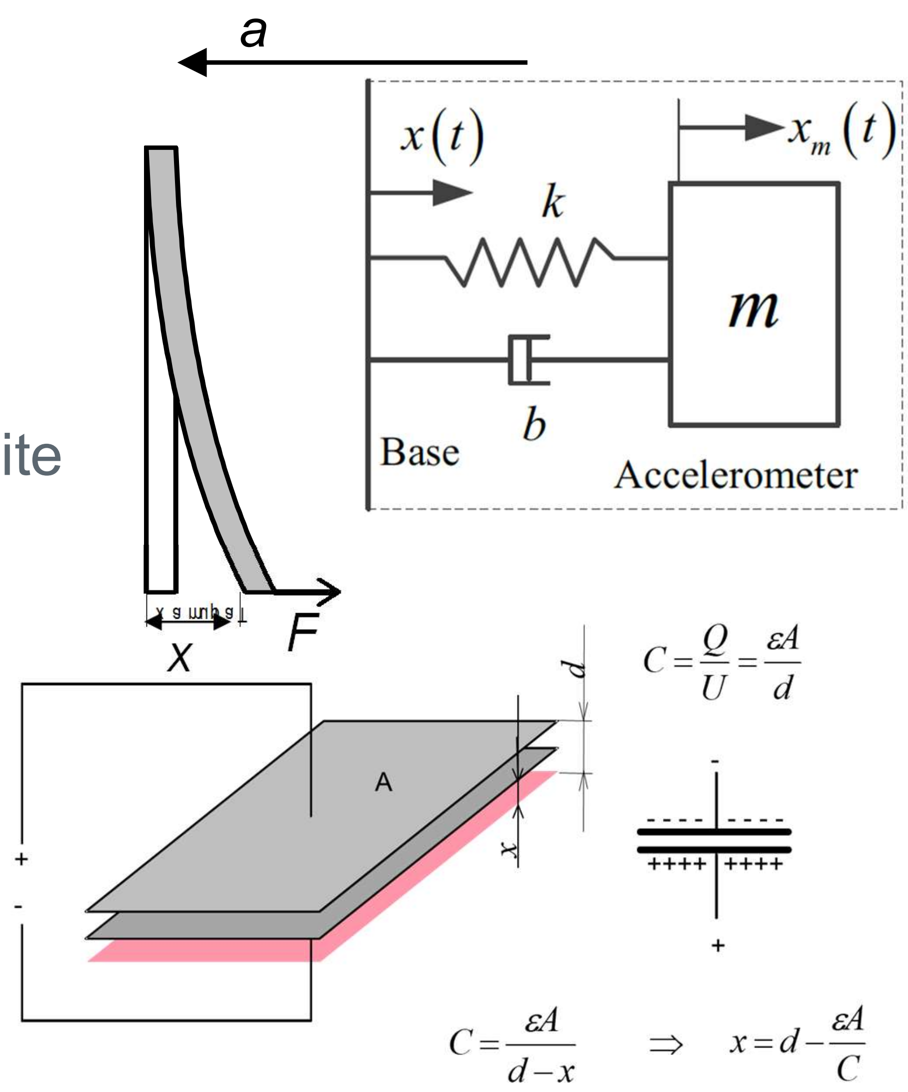
- When Base accelerates (*a*), mass *m* requires Force *F* to accelerate due to inertia

$$F = m \cdot a$$

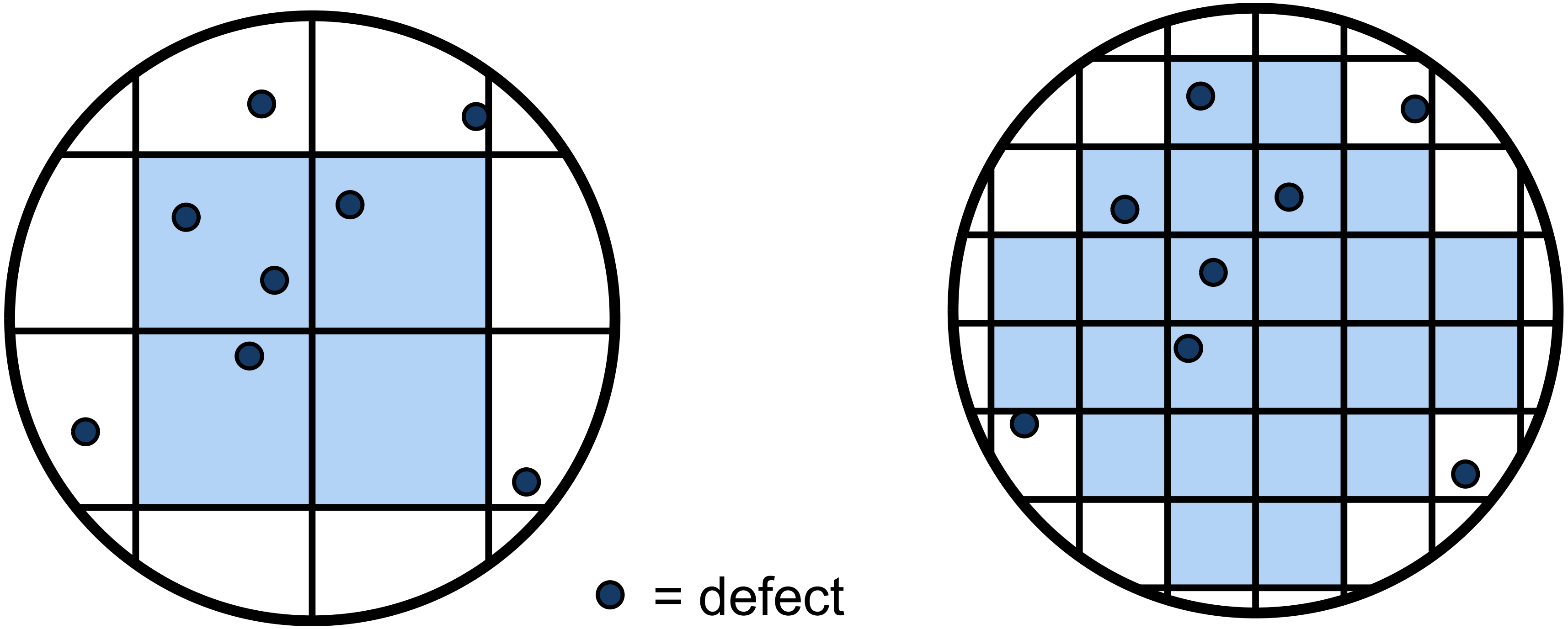
- Force displaces spring *k* to the opposite direction

$$F = k \cdot x$$

- Displacement is sensed by change in Capacitance *C*



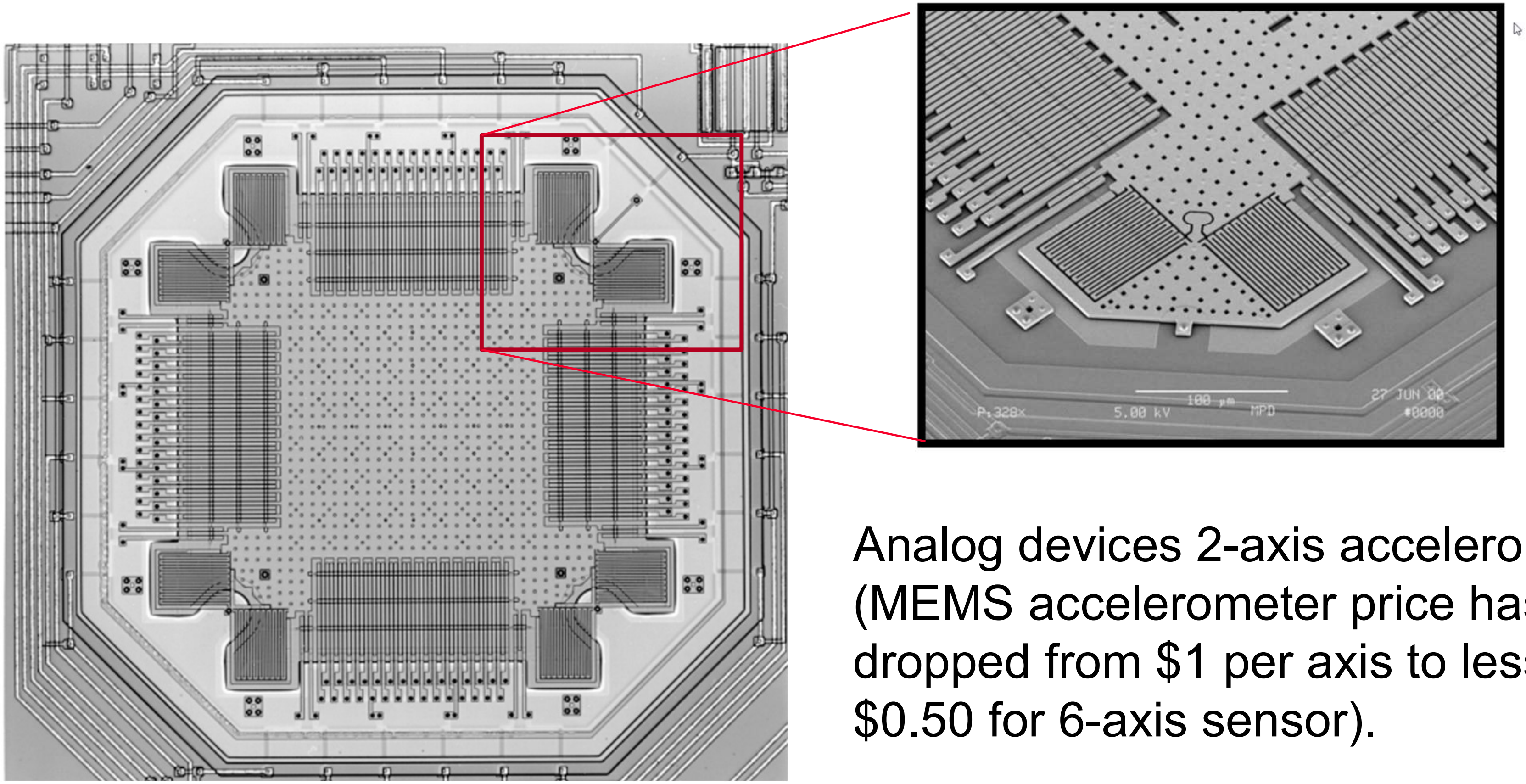
MEMS profit equation: profit = 1/size



Large dies:
- Low number of candidates (=possible working dies)
- Low number of dies without defects (=yielded dies)
- Large area lost at die edge

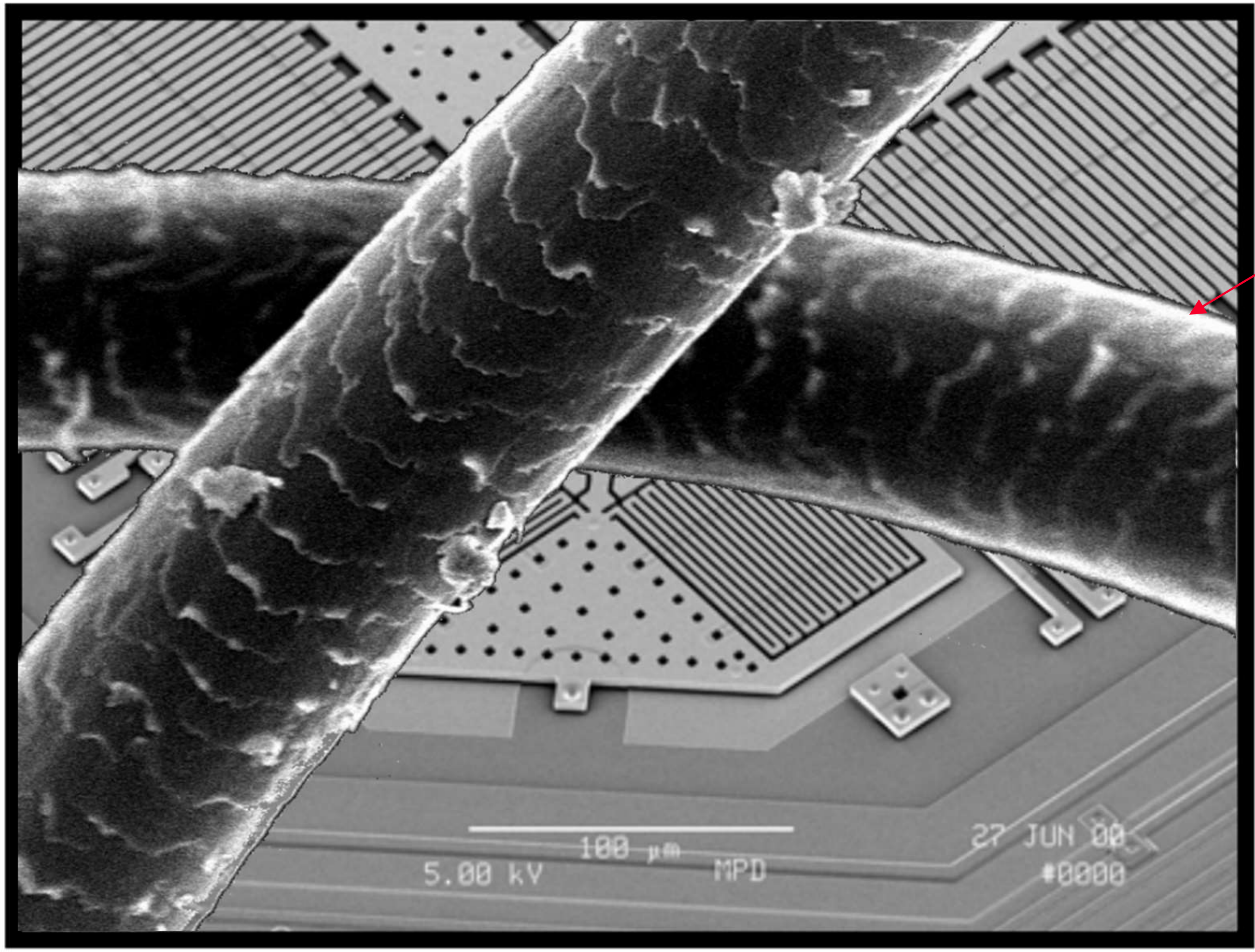
Small dies:
- Large number of candidates
- Large number of dies without defects (=> good yield)
- Less area lost at die edge

MEMS processing enables complexity …



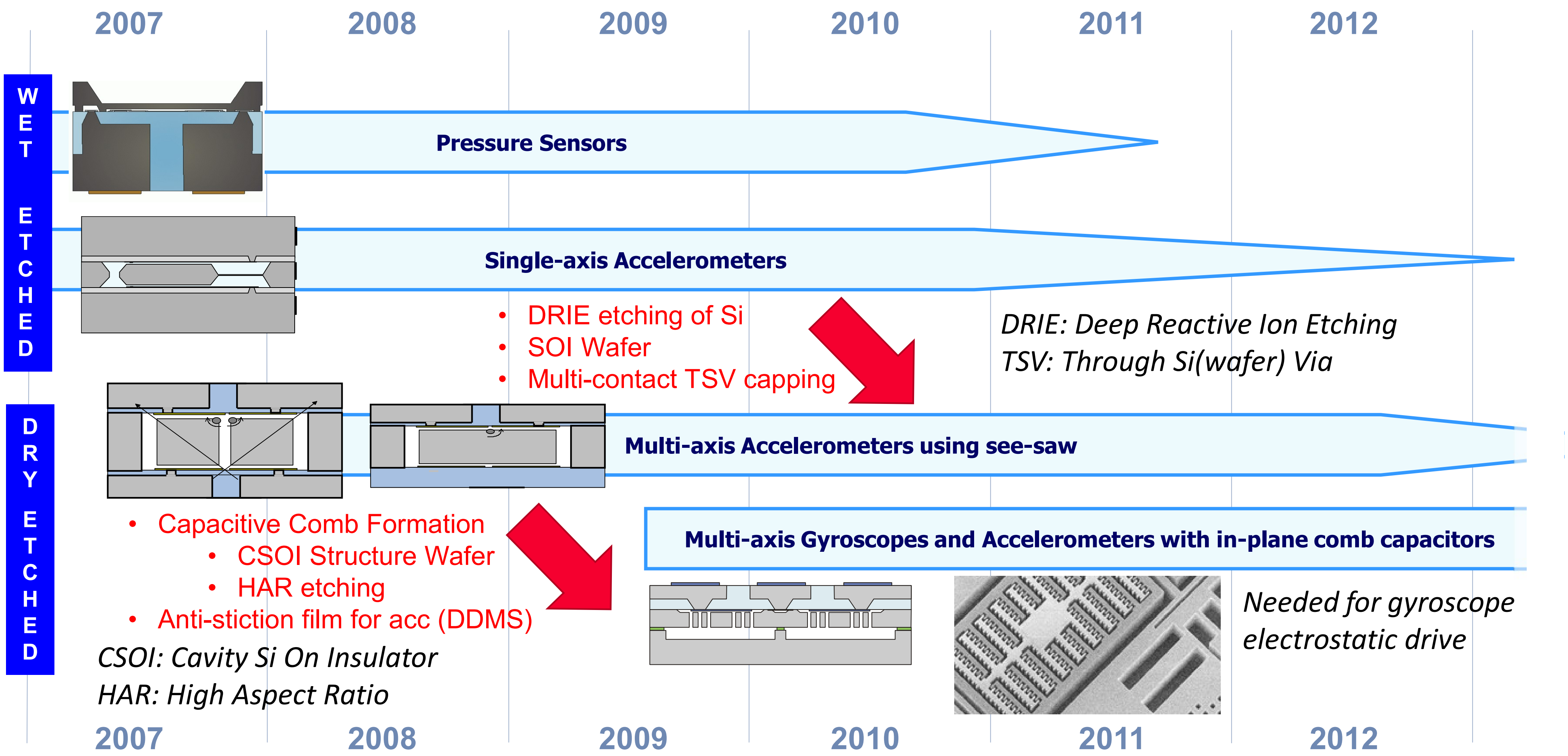
Analog devices 2-axis accelerometer (MEMS accelerometer price has dropped from $1 per axis to less than $0.50 for 6-axis sensor).

… in tiny scale

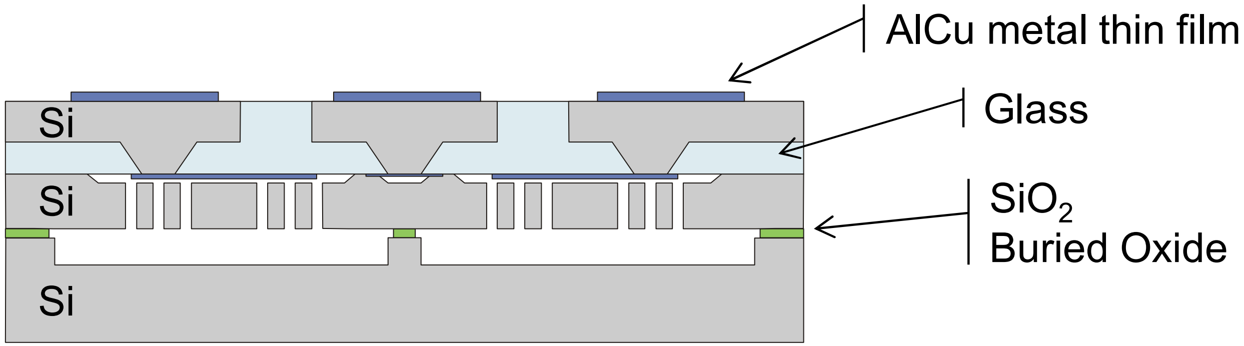


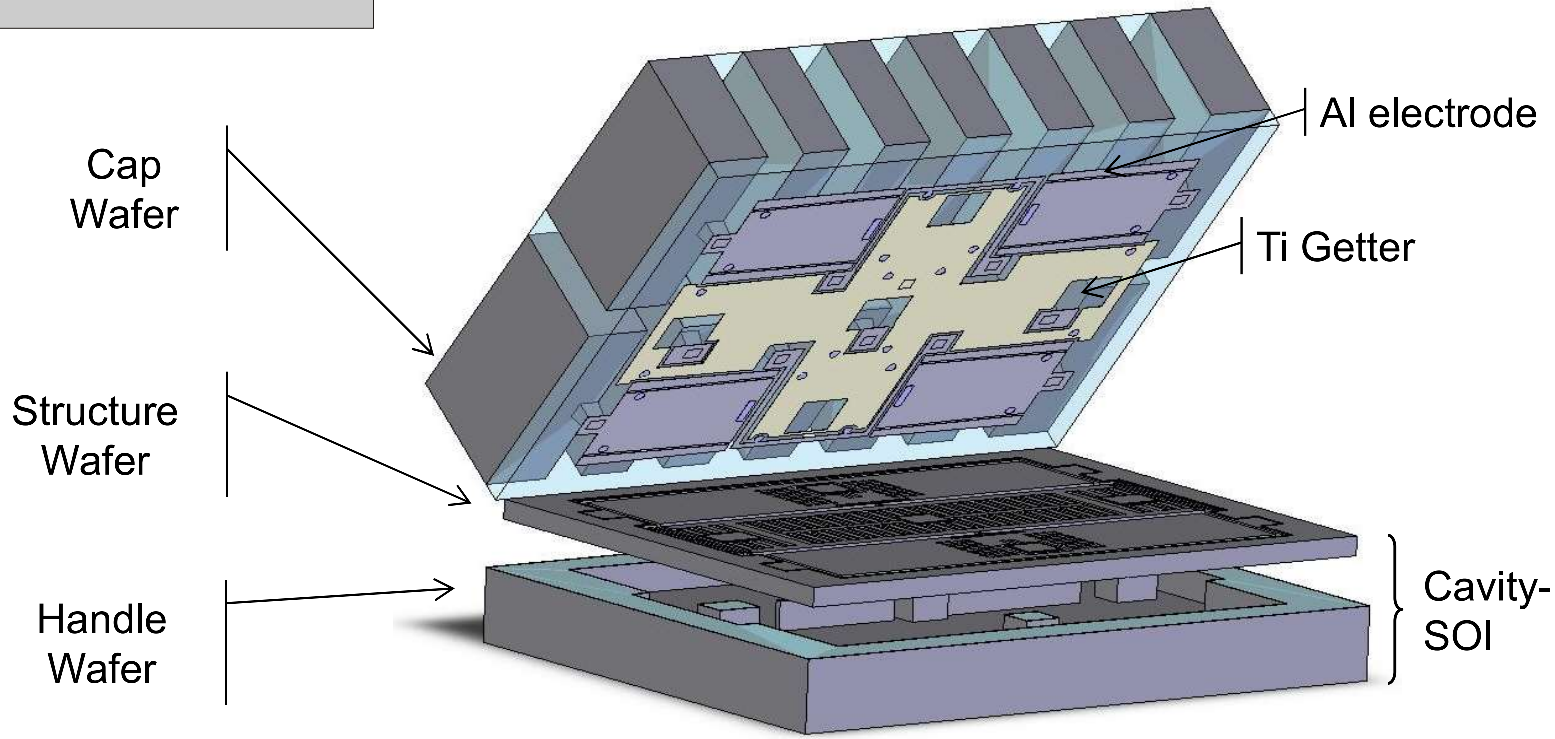
Human hair

MFI MEMS Technology Platform Evolution

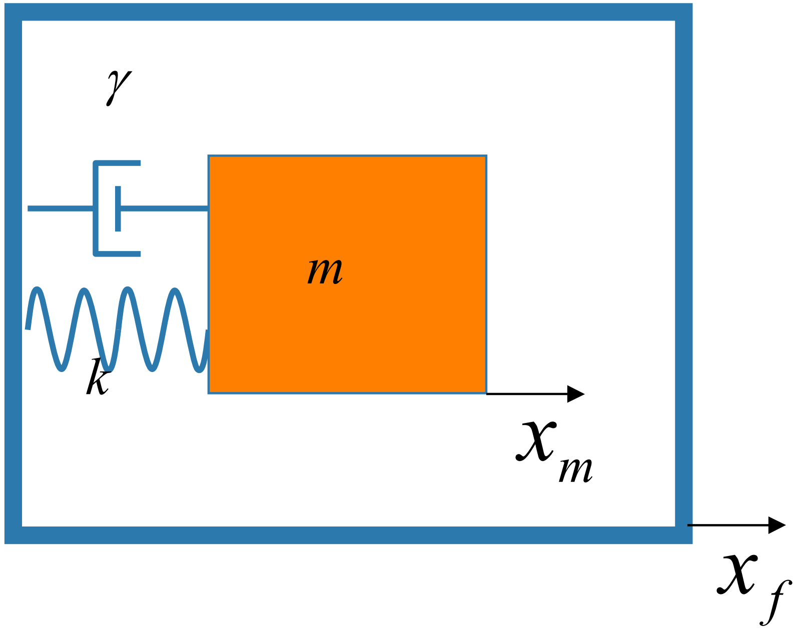


Element Structure - DEC platform (Dry-Etched Combs)





Scaling laws for accelerometers



$$x_f - x_m = \frac{m}{k}\ddot{x}_f$$

What happens when all dimensions are reduced 10x?

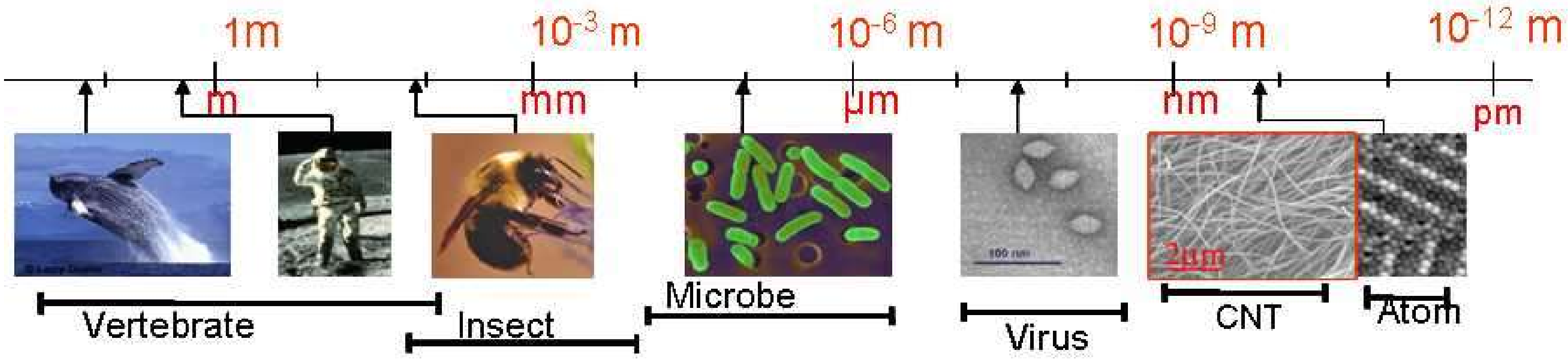
$$m \rightarrow \frac{m}{1,000}$$

$$k \rightarrow \frac{k}{10}$$

$$x_f - x_m \rightarrow \frac{x_f - x_m}{100}$$

(Analog devices accelerometers measure 0.1 Å displacements!)

Scaling of noise with size



What thermal noise???

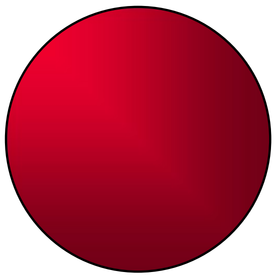
Yeh, its there if we measure carefully..

These things move under microscope!

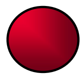
We better cool the atoms to make them stay put

Scaling laws: stiction

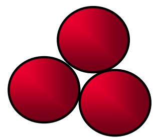
- Different forces are significant in macro and micro scale
- To obtain "microintuition", we can study scaling laws
- Example: volume scales as $V \sim l^3$ but area scales as $A \sim l^2$. The surface to volume ratio $A/V \sim l^{-1}$ increases when the object size reduce.



I am a big ball,
I have large mass!
(I am happy alone)



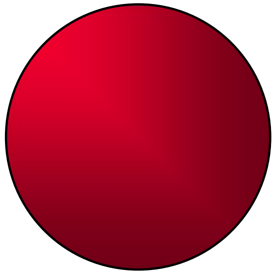
I am a small ball, I have more surface than mass!



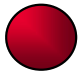
Because I am small, I like to stick to other small balls.

Scaling laws: drag force (air damping)

- Example: volume scales as $V \sim l^3$ but area scales as $A \sim l^2$. The surface to volume ratio $A/V \sim l^{-1}$ increases when the object size reduce.



I am a big ball,
I have large mass!
(I drop like a rock)

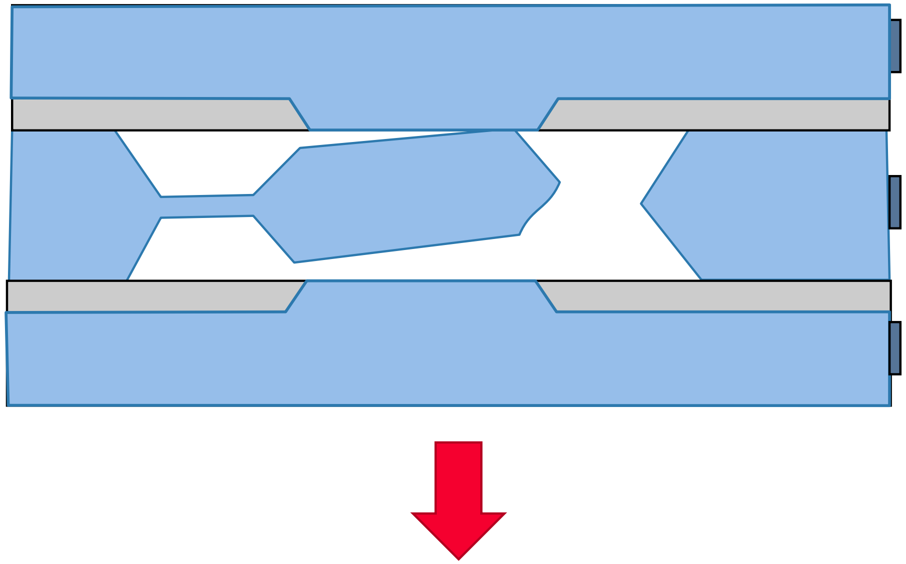


I am a small ball, I have more surface than mass!
(I can float in air)

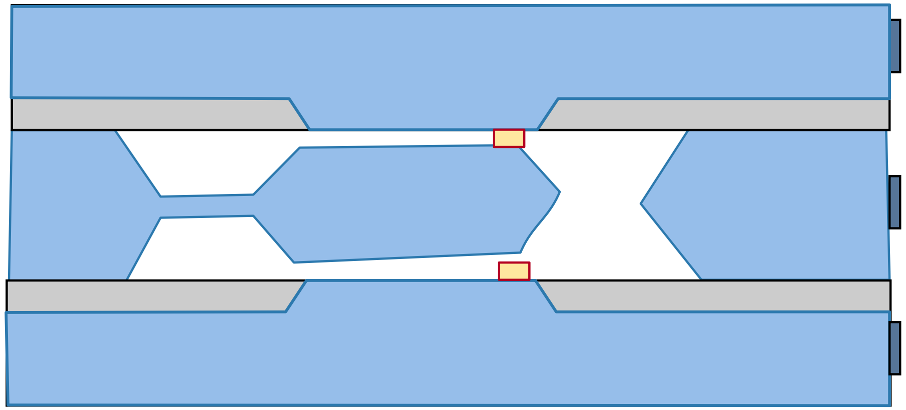
$$F_D = \frac{1}{2} C_D \rho A \dot{x}^n$$

MEMS curses

Stiction (honey, I am stuck)

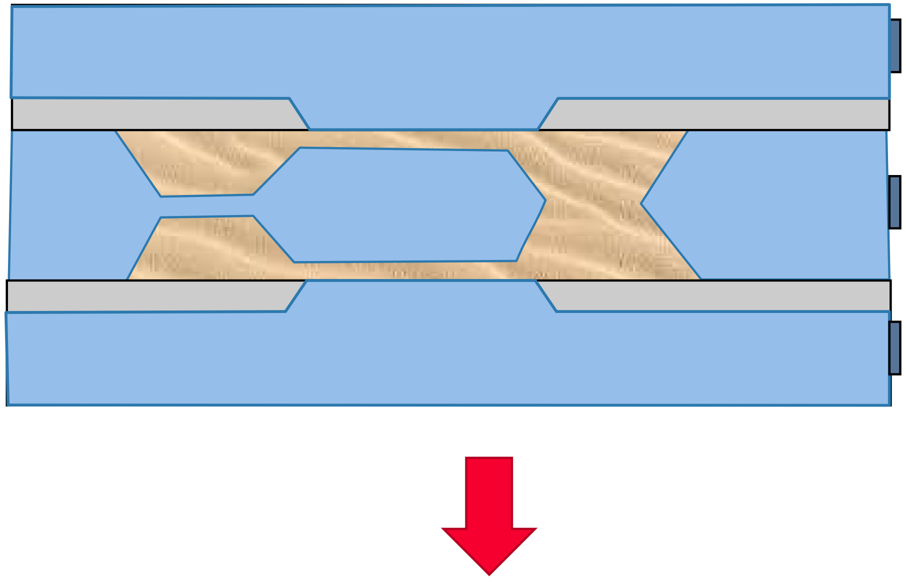


Stiction (bumps help!)



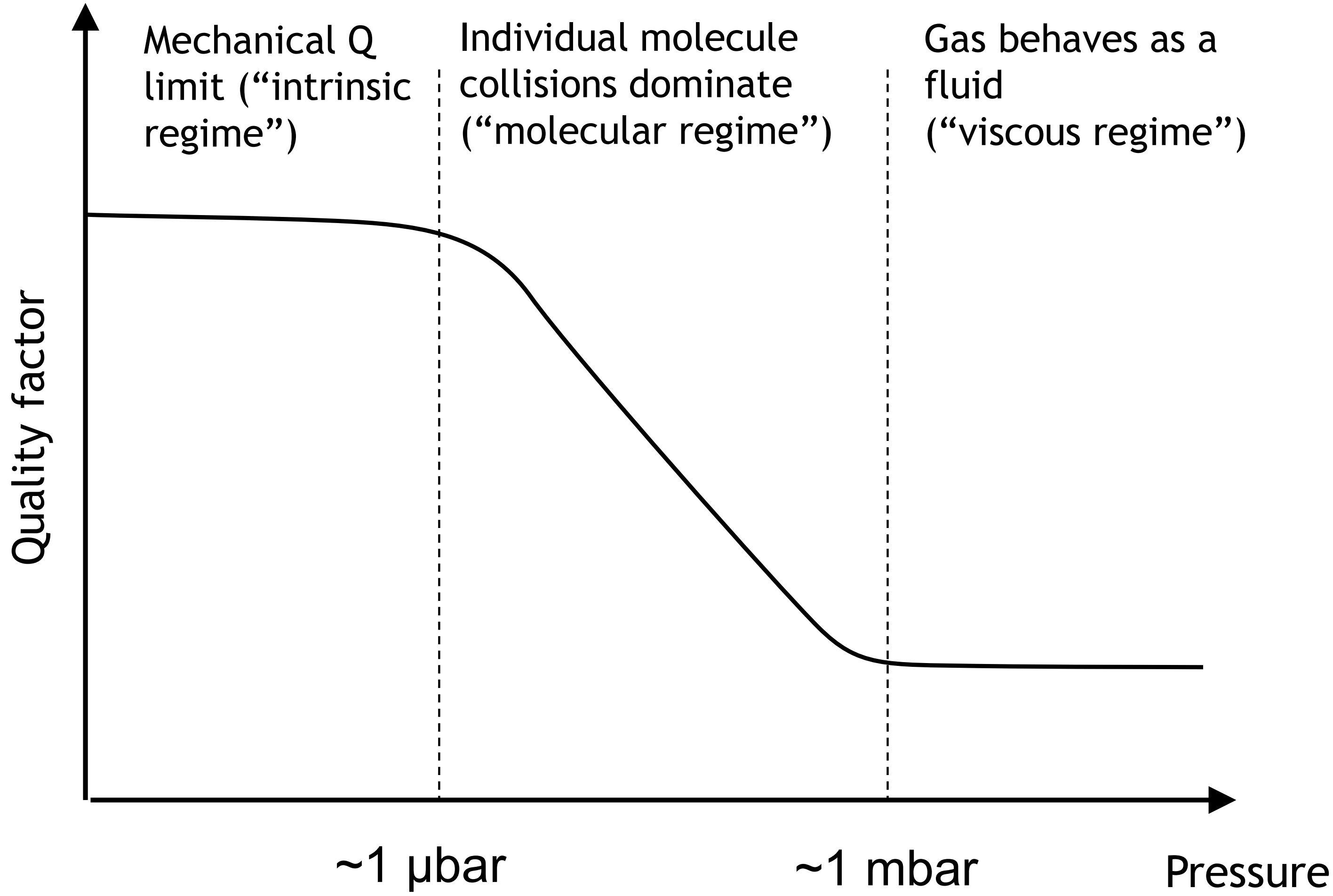
Minimize contact area

Air damping (honey, I am in quick sand)



?

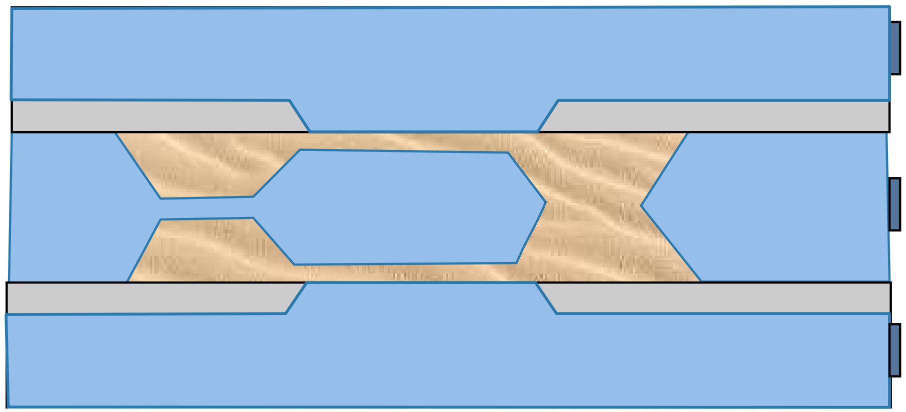
Air damping



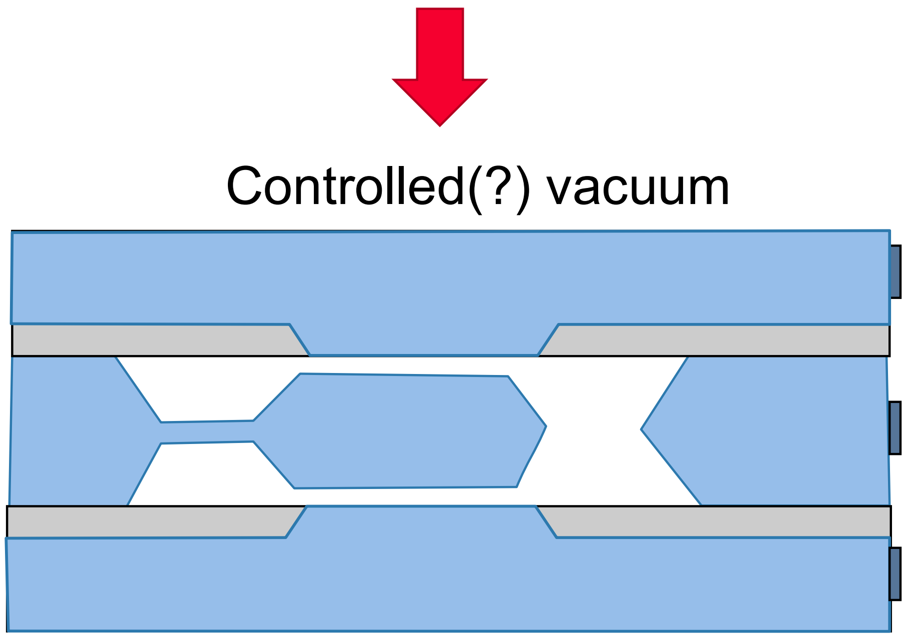
Mechanical Q limit ("intrinsic regime")
Individual molecule collisions dominate ("molecular regime")
Gas behaves as a fluid ("viscous regime")
Quality factor
~1 µbar
~1 mbar
Pressure

Solition to air damping: microvacuum

Air damping (honey, I am in quick sand)



Controlled(?) vacuum

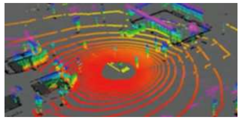
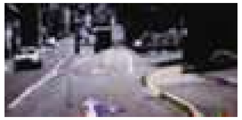
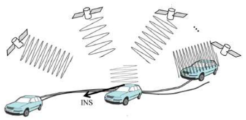
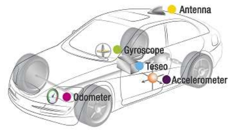


- Still one of the hardest problems in MEMS
- No such thing as perfect vacuum
- Every material outgassess
- Every material leaks (especially He)
- Packaging volumes are small (large surface to volume ratio)

Note: effective viscosity depends on the mechanical dimensions – no good way to simulate!

Why Inertial Sensor in Autonomous Driving?

Accurate positioning requires fusion of multiple sensors

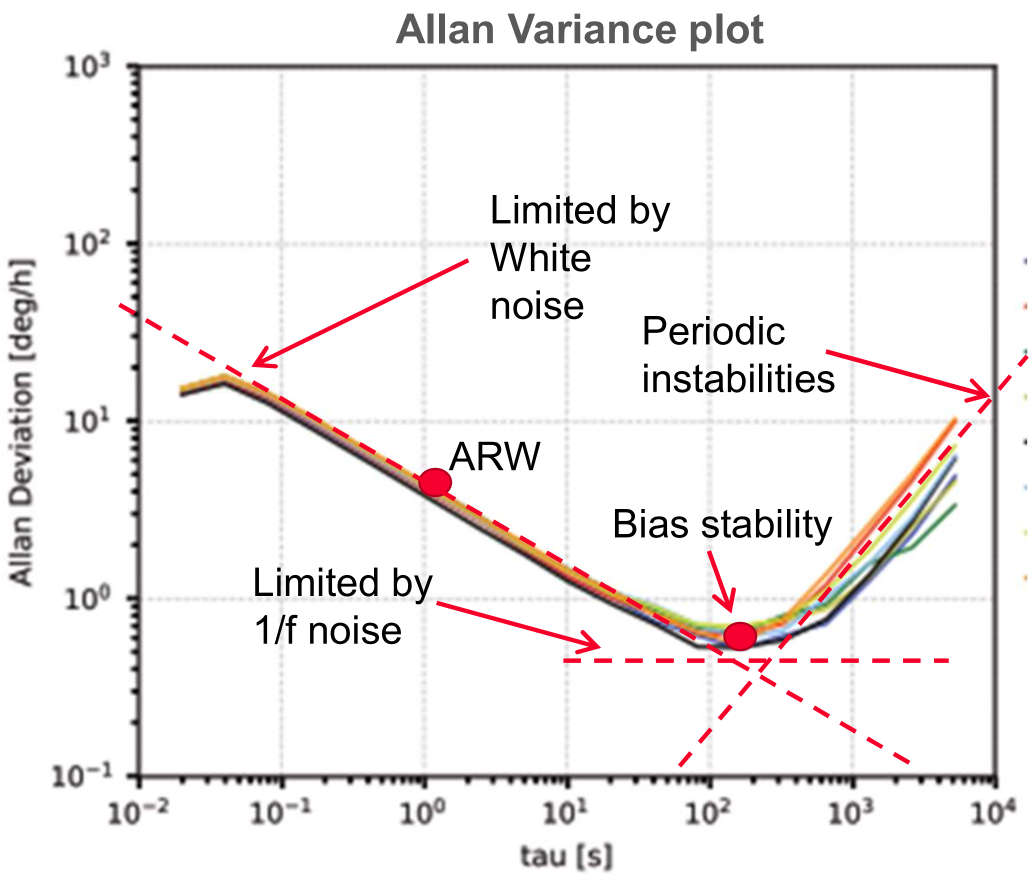
Image based		Satellite based	Inertia based
 Lidar/Radar	 Camera	 Multi band GNSS	 IMU / Vehicle Speed

GNSS ✗ Image ✓ IMU ✓

GNSS ✓ Image ✗ IMU ✓

Emerging Application – Autonomous Driving

- Gyros have been compared with performance parameters like **Offset stability over time and Temp**
- In Autonomous Driving **Relative Positioning** becomes more important
- **Allan variance** plot shows Deviation of Output (noise) vs. Averaging Time on logarithmic scale axes
- Sensor performance in one single diagram



*ARW= Angular Random Walk

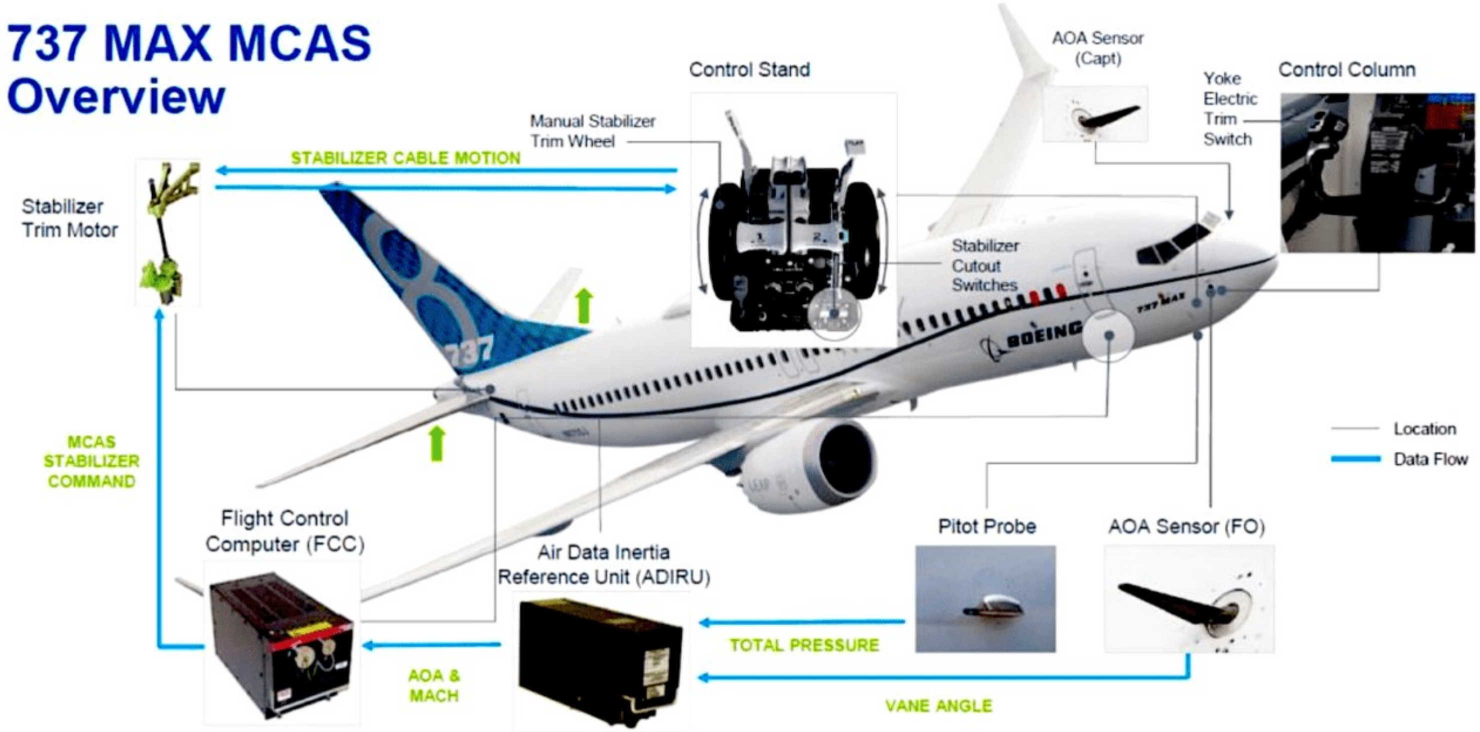
The Effect of ARW in Vehicle Positioning

- IMU usage in navigation requires continuous error correction by the system based on GPS position
- **Accumulated mean error is given by the gyro Angular Random Walk, directly related to gyro white noise level**
- Calculated errors (1 sigma) in case of 80km/h 1 min driving

1. ESC standard spec performance	ARW 1.7deg/sqrt(h)	→ error 5 m
2. Murata Combo 2 ESC sensor	ARW 0.4 deg/sqrt(h)	→ error 1.2 m
3. Murata Combo 3 ESC sensor	ARW 0.2 deg/sqrt(h)	→ error 0.6 m
Future AD target	ARW 0.04 deg/sqrt(h)	→ error 12 cm

Functional safety = failing in a safe way

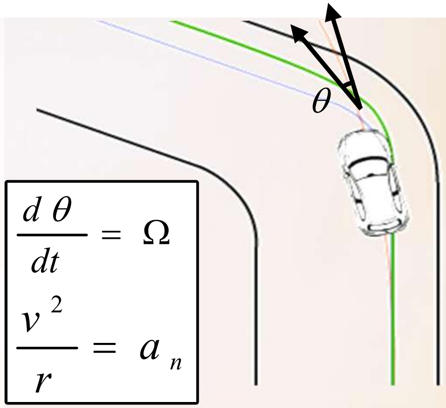
Example: Airbus uses 3 airflow sensor for autopiloting
Counter example: Boeing 737 max relied on one sensor



MEMS fail (seldom but it happens). How to guarantee a safe failure?

Safety illustrated: Electronic Stability Control

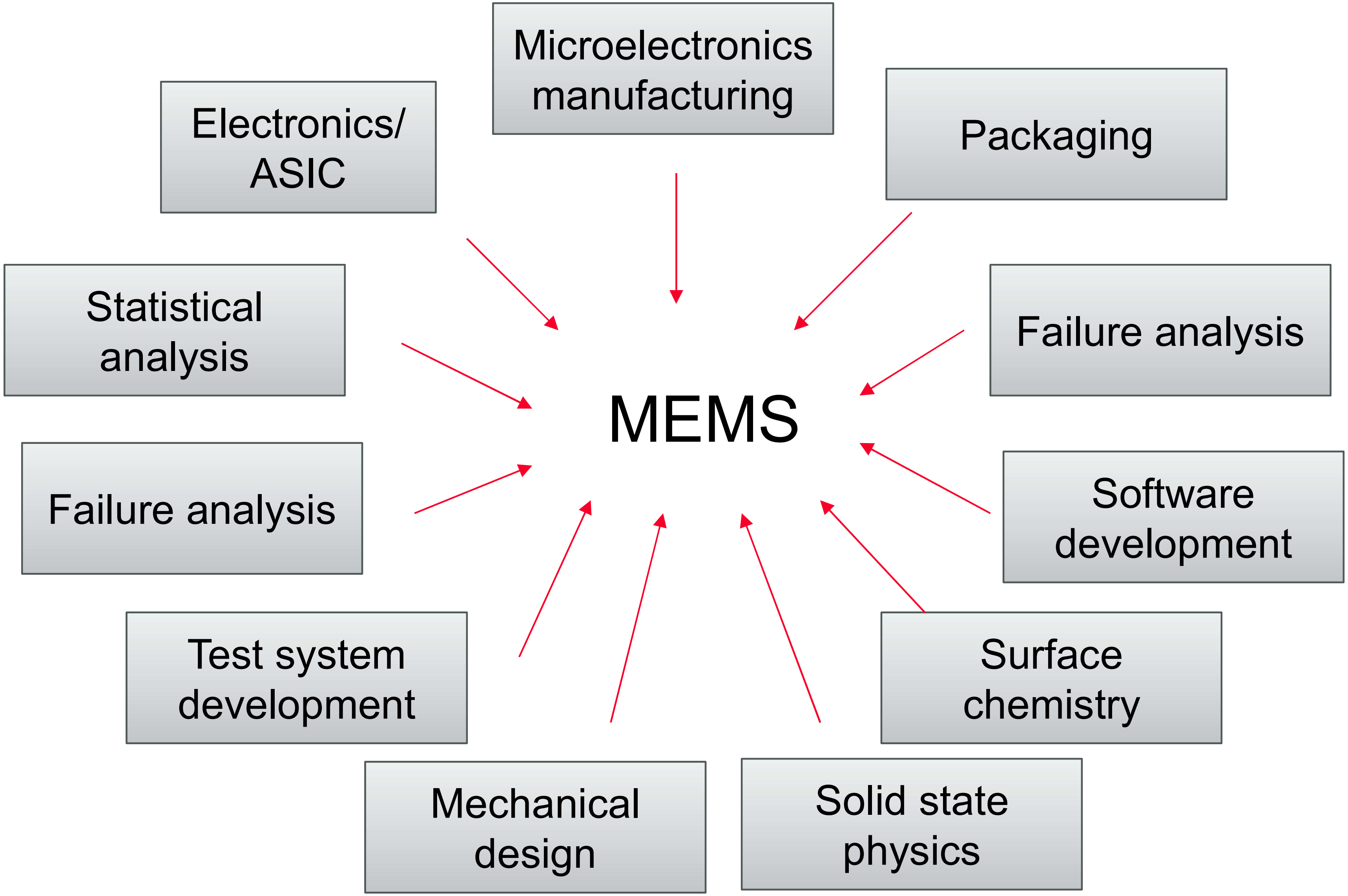
- ABS is not enough in a curve
- Electronic Stability Control (ESC) corrects for under- and over- steering
- Yaw rate (Ω) from angular rate sensor and centripetal acceleration (a_n) from lateral accelerometer are compared to calculated trajectory from wheel speed and steering wheel angle
- Control by applying brake force on individual wheels



$$\frac{d\theta}{dt} = \Omega$$

$$\frac{v^2}{r} = a_n$$

MEMS experts needed in:



Solid state physics

- Metal – semiconductor junction
  – When is it diode and when ohmic contact?
- Force between electrodes
  – What is the difference between silicon-air-silicon and silicon-air-metal capacitor?
- Carrier density and resistivity
- Material engineering
  – Effect of doping on mechanical properties of silicon
- New materials
  – Piezoelectric
  – ALD
  – …

Thank You

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