MEMS Products

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CERN

Agenda

- MEMS Applications & Market
- What is MEMS?
- MEMS Technology
  - For Accelerometer, Gyroscope, E-compass, Microphone
  - For Pressure Sensor
- Conclusion

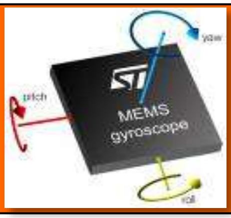
ST: ONE STOP MEMS SUPPLIER

Accelerometers

E-Compass & Inertial Module

Σ

Gyroscopes



Pressure Sensors

Microphone

MEMS Sensors - Main Applications

MEMS Sensors

Mobile, PDAs, MP4/MP3

Data access, image stabilization, MMI, Altimeter/Barometer, Personal navigation

White Goods, Industrial & Medical

Vibration & Tilt Measurement, Dead_man Function

Automotive

Navigator system, Anti-theft, Active/passive safety, TPMS

Laptop

HDD protection, anti-theft

Consumer

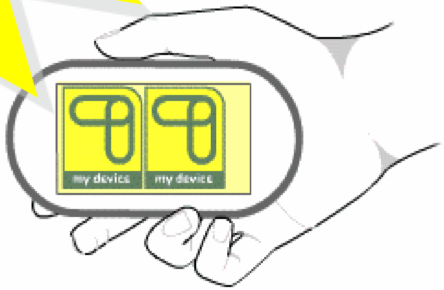
Navigation, Image scrolling, Gaming, Sport monitoring

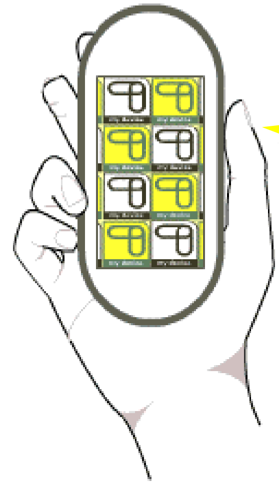
Robotics

Roll over detection, inclination measurement

Few examples: Handheld Devices Market

Portrait landscape





Menu Navigation

Picture view

Map Browsing

Pictures are used as example of application

Some ‘g’ references

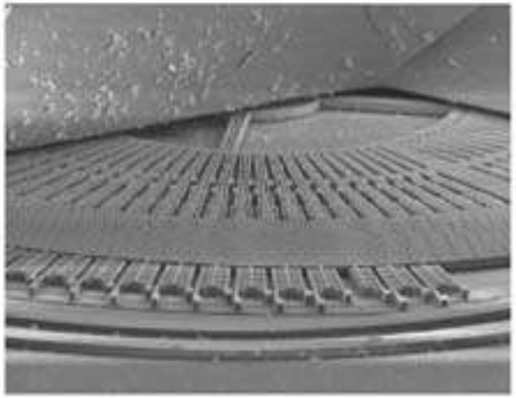
Passenger car acceleration	0.2 / 0.3g
Earth’s gravity	1g (by definition)
Emergency braking (Formula 1)	1g
Running	<5g (shock at low back level)
Bobsleigh rider in corner	5g
Human unconsciousness	7g
Walking down/up stairs	7.4/8g (shock at ankle level)
Running	8/12g (shock at ankle level)
Car Frontal choc @15Km/h	10/15g
Car Frontal choc high speed	35g (shock at head level, with Airbag)
Car Frontal choc high speed	40g (for the vehicle)
Car Frontal choc high speed	65g (shock at head level, without Airbag)
Tennis ball	500/700g

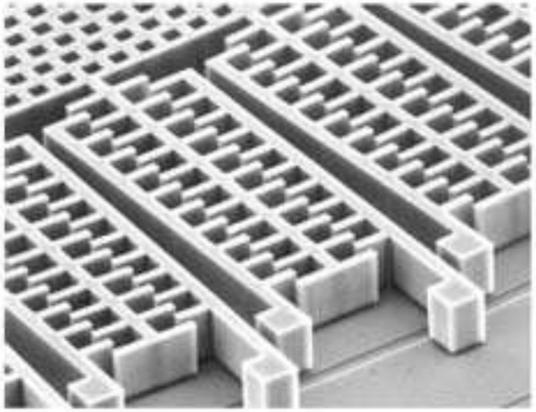
What is a MEMS?

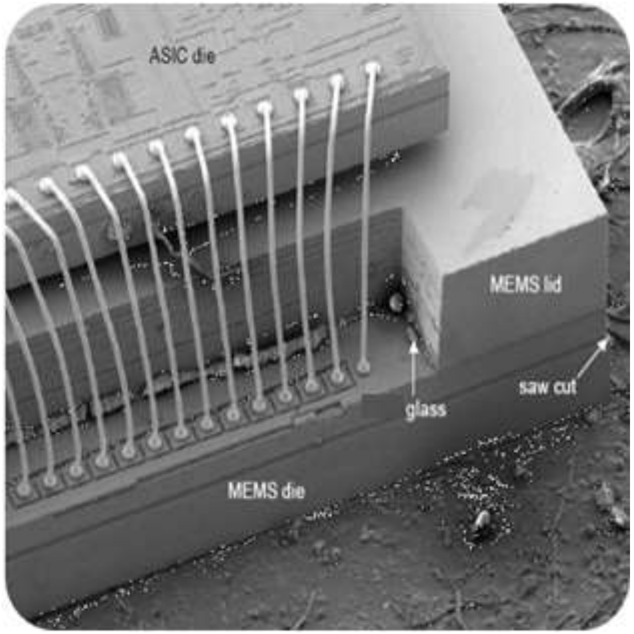
What is MEMS?

- MEMS is Micro Electro Mechanical Systems
- MEMS contain movable 3-D structure
- Structure move accordingly to external displacement

- In MEMS not only electrons are moving!





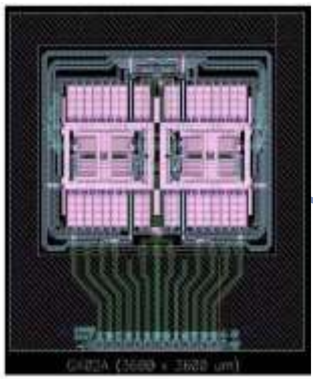


SEM pictures of a capacitive micro-machined structure manufactured with THELMA process*

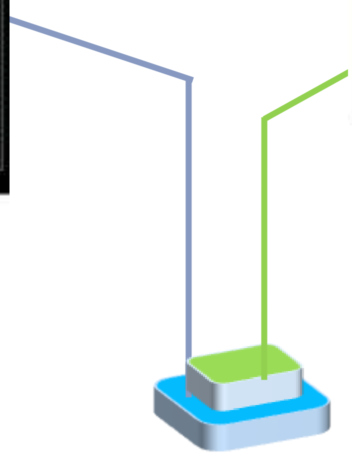
*SEM: scanning electron microscope

ST MEMS Approach

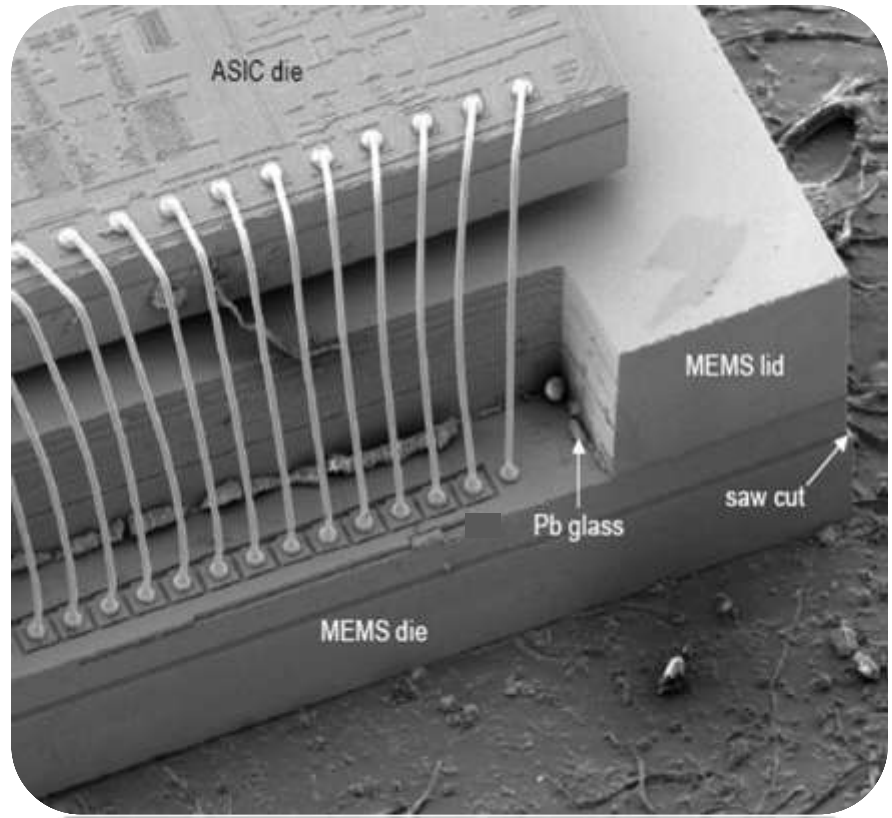
MEMS



ASIC

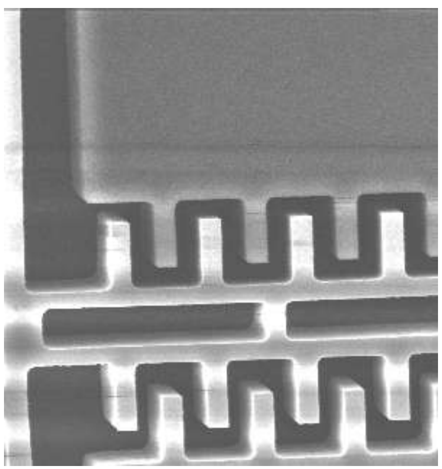


Stacked Configuration



What's inside our MEMS?

- MEMS Sensor: Motion (i.e. acceleration) → Differential Capacitance Change
- Interface Chip: Differential Capacitive Change → Output Signal



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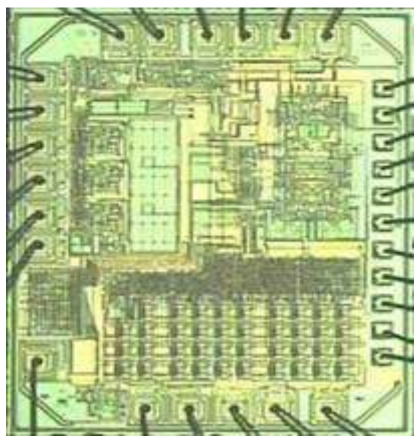

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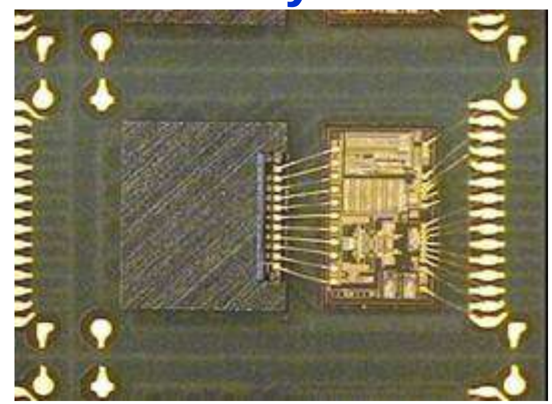
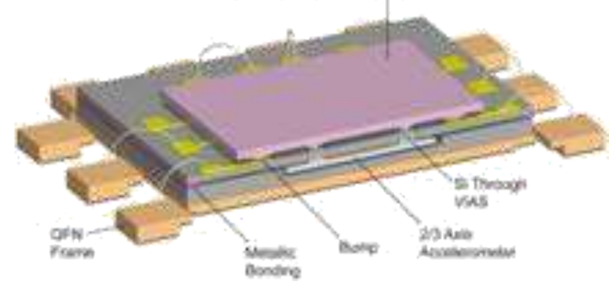
Side by side

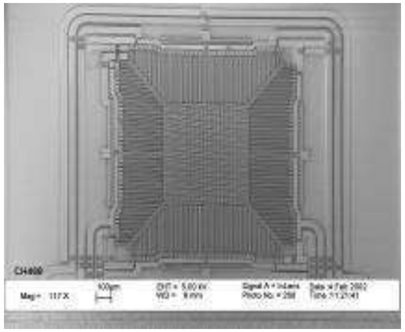


or

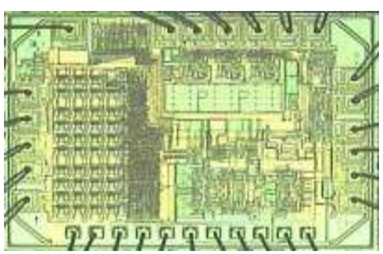
Stacked



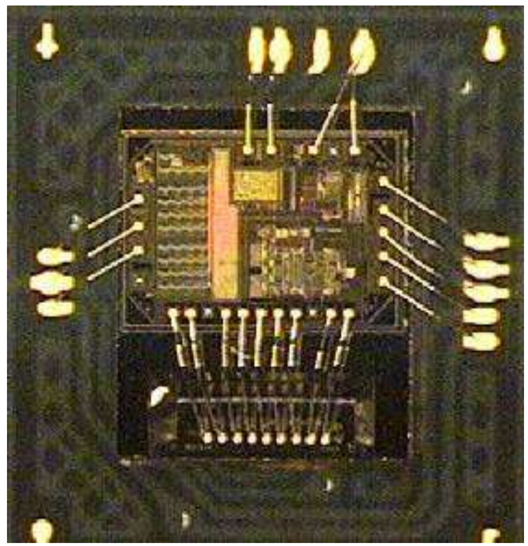
What's inside our Accelerometers?



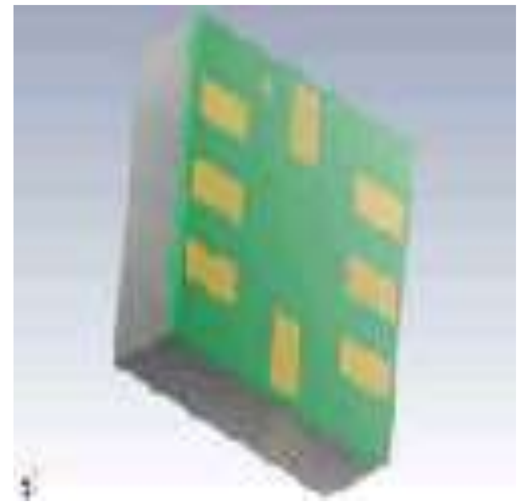
Mechanical Chip



Electrical Chip



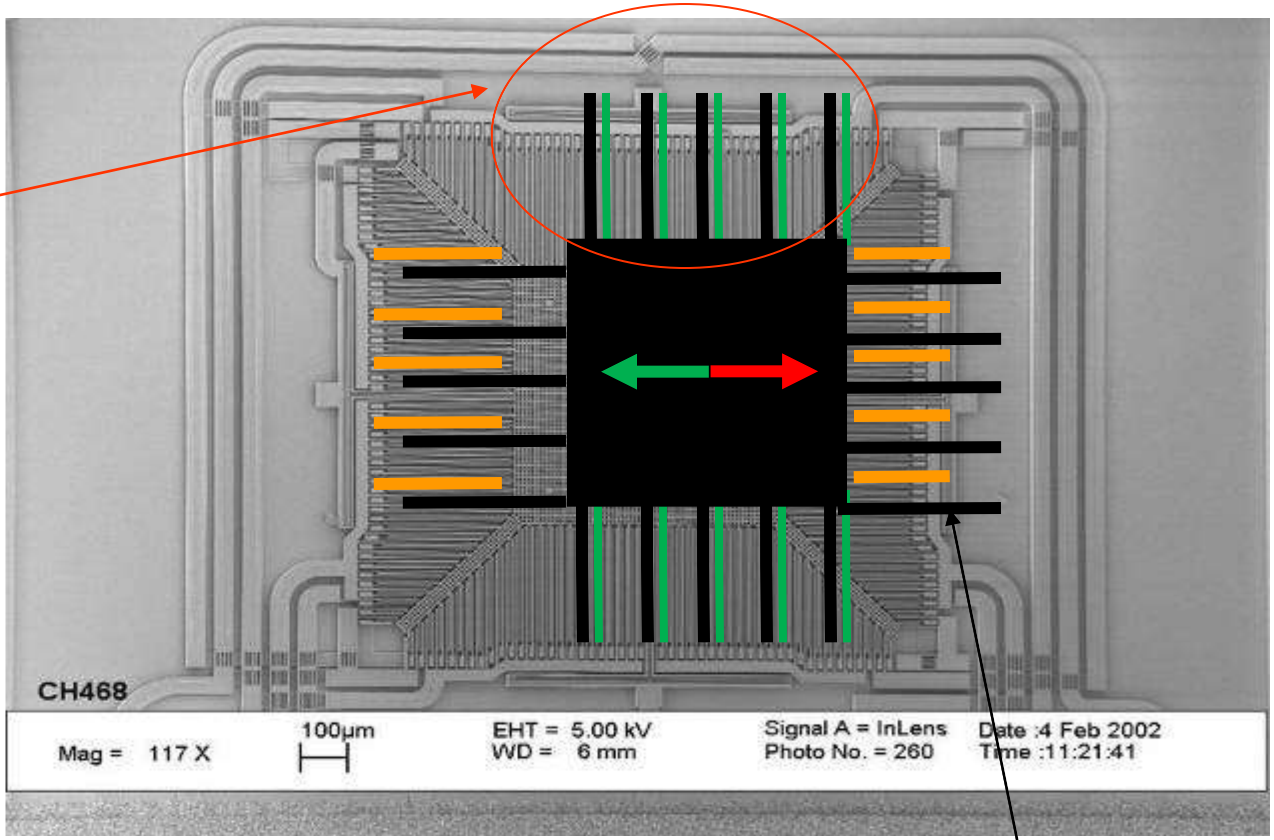
Package
(shown without Plastic Mould)

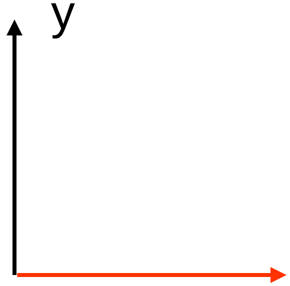


Complete Package

MEMS Accelerometer - Principle

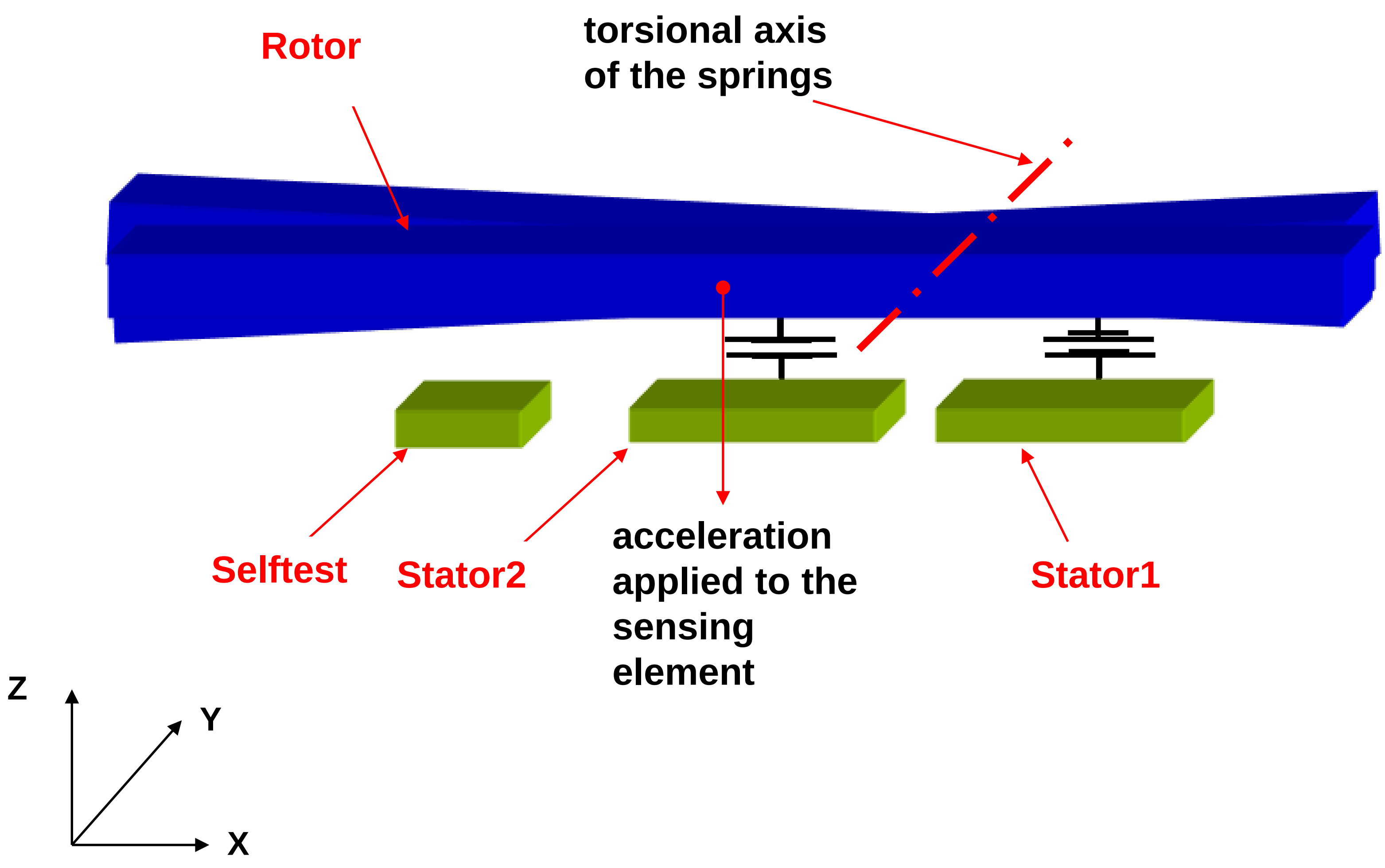
Group of inter-digitized fingers to measure the linear acceleration on X-axis



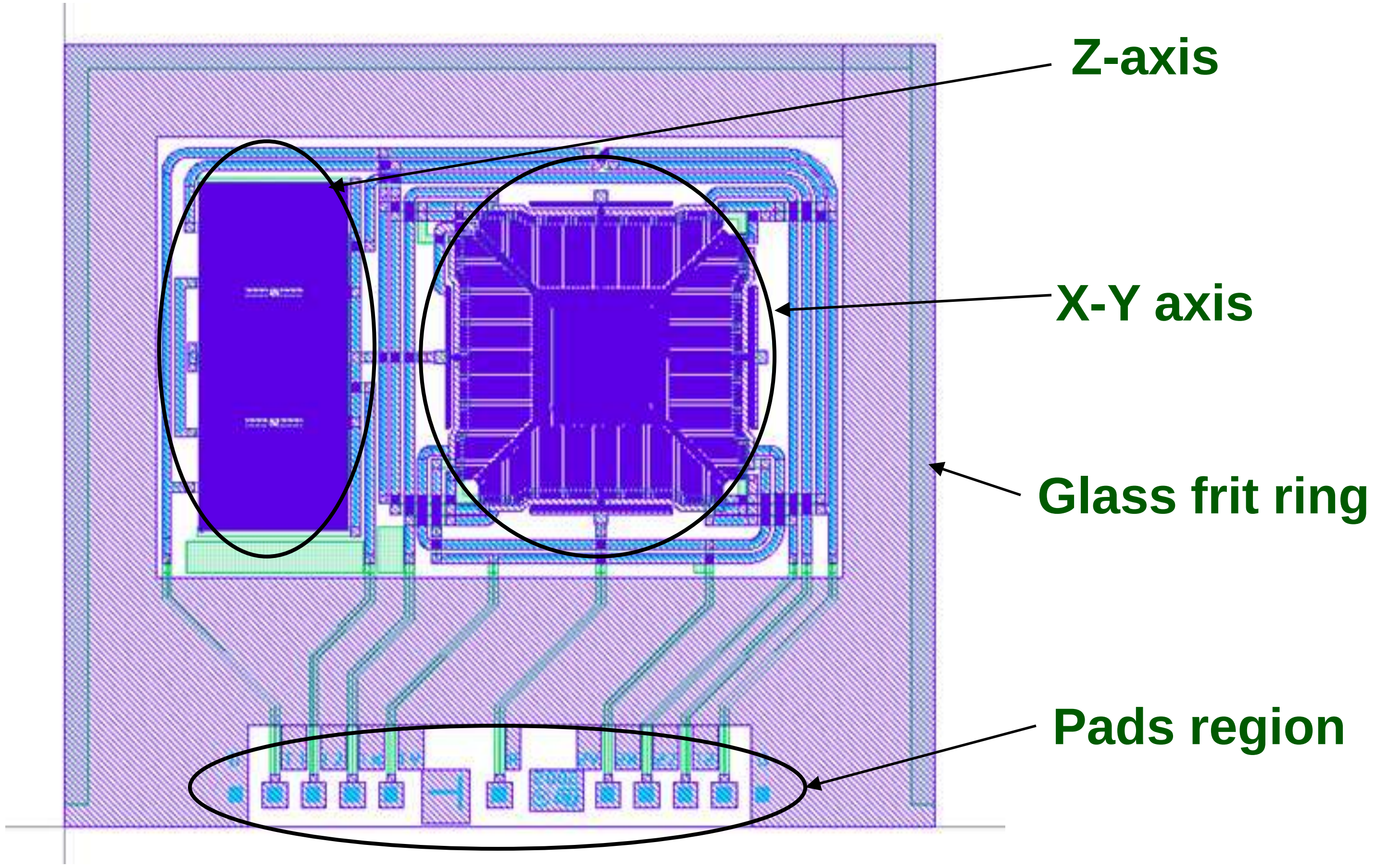


Group of inter-digitized fingers to measure linear acceleration on Y-axis

MEMS sensor Z-axis linear accelerometer

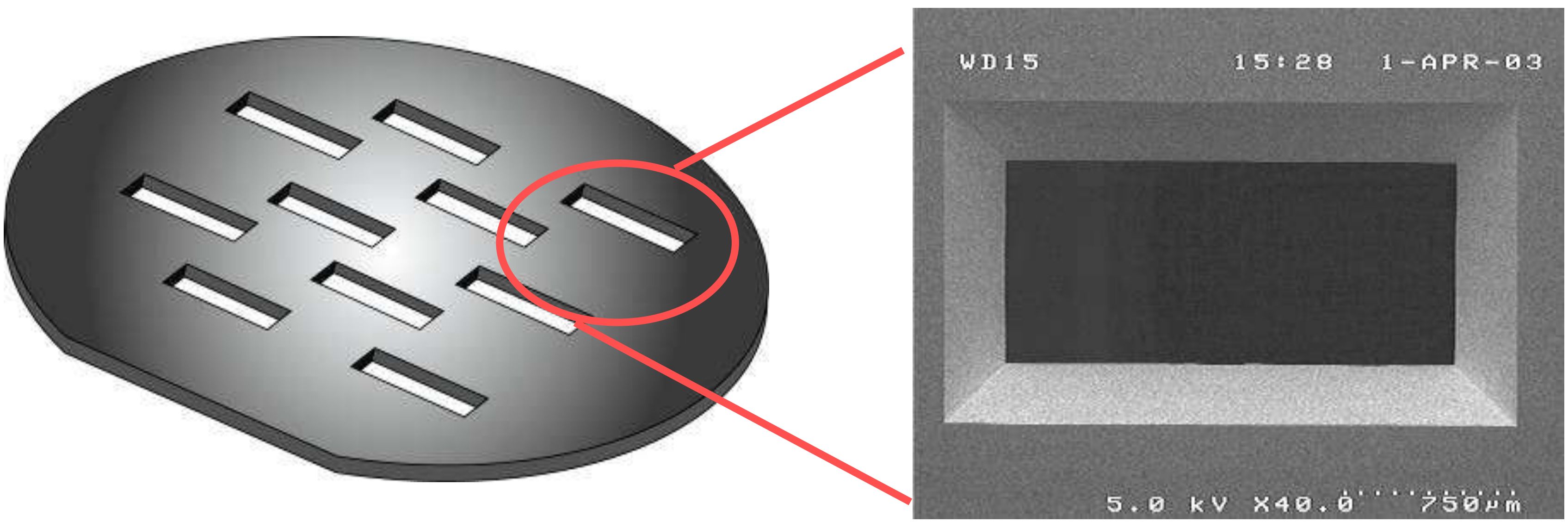


MEMS sensor XYZ -axis linear accelerometer



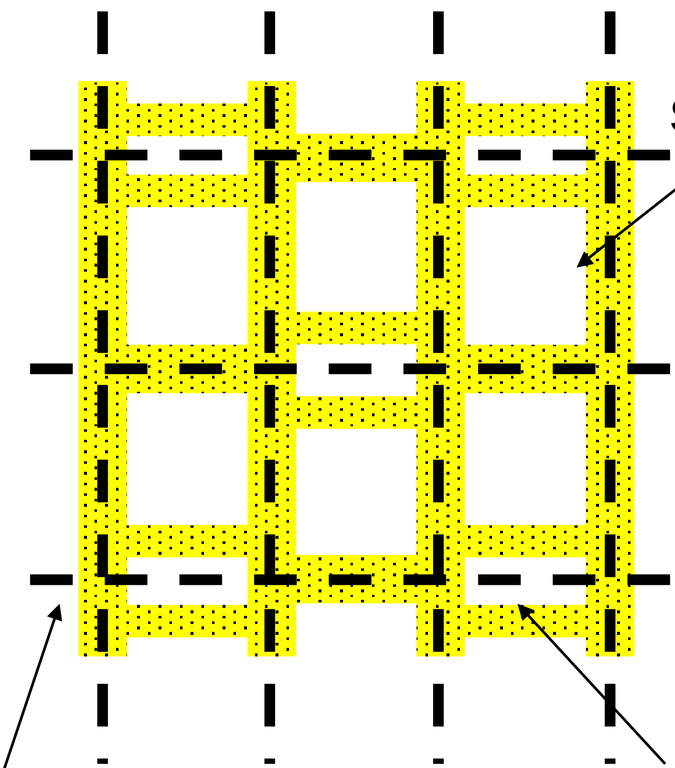
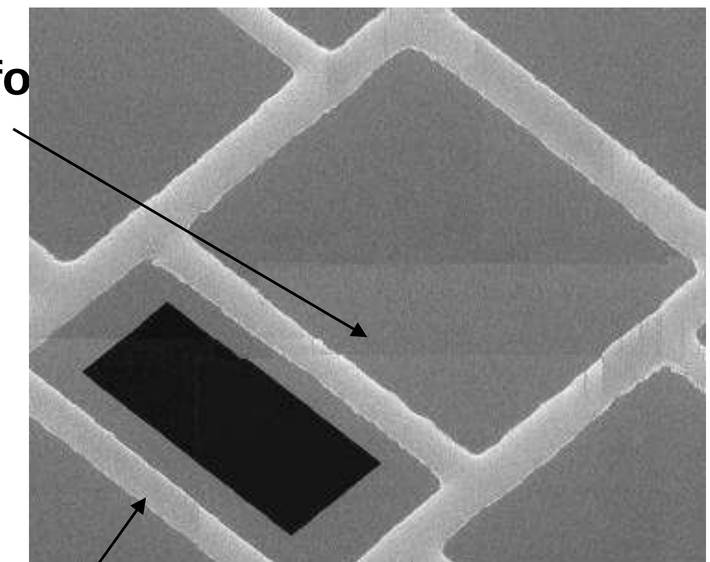
THELMA wafer cap

- MEMS sensor is protected by a cap
- Windows are etched on cap wafer
- Holes allow access to MEMS pads for bonding between sensor and IC



THELMA wafer cap

- Seal rings are realized with glass frit screen printed on cap wafer
- The glass frit printing is made in order to grant the space for sensor, pads and the scribe line
- The glass frit hermetically seals the sensor

Thelma Process description

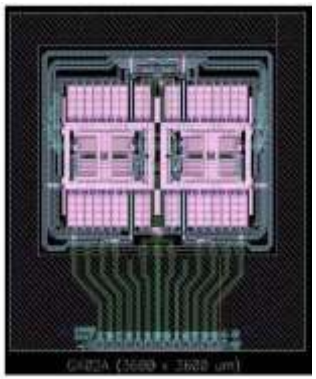
- **THELMA: THin Epitaxial Layer for Micromotor and Accelerometer**

- **Thelma is the name for our technology used for micromachining process for Accel & Gyro**

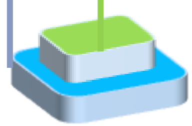
- **This process involves manufacturing of 2 wafers:**
  - **1 Sensor wafer**
  - **1 Capping wafer**

MEMS + ASIC Description

MEMS

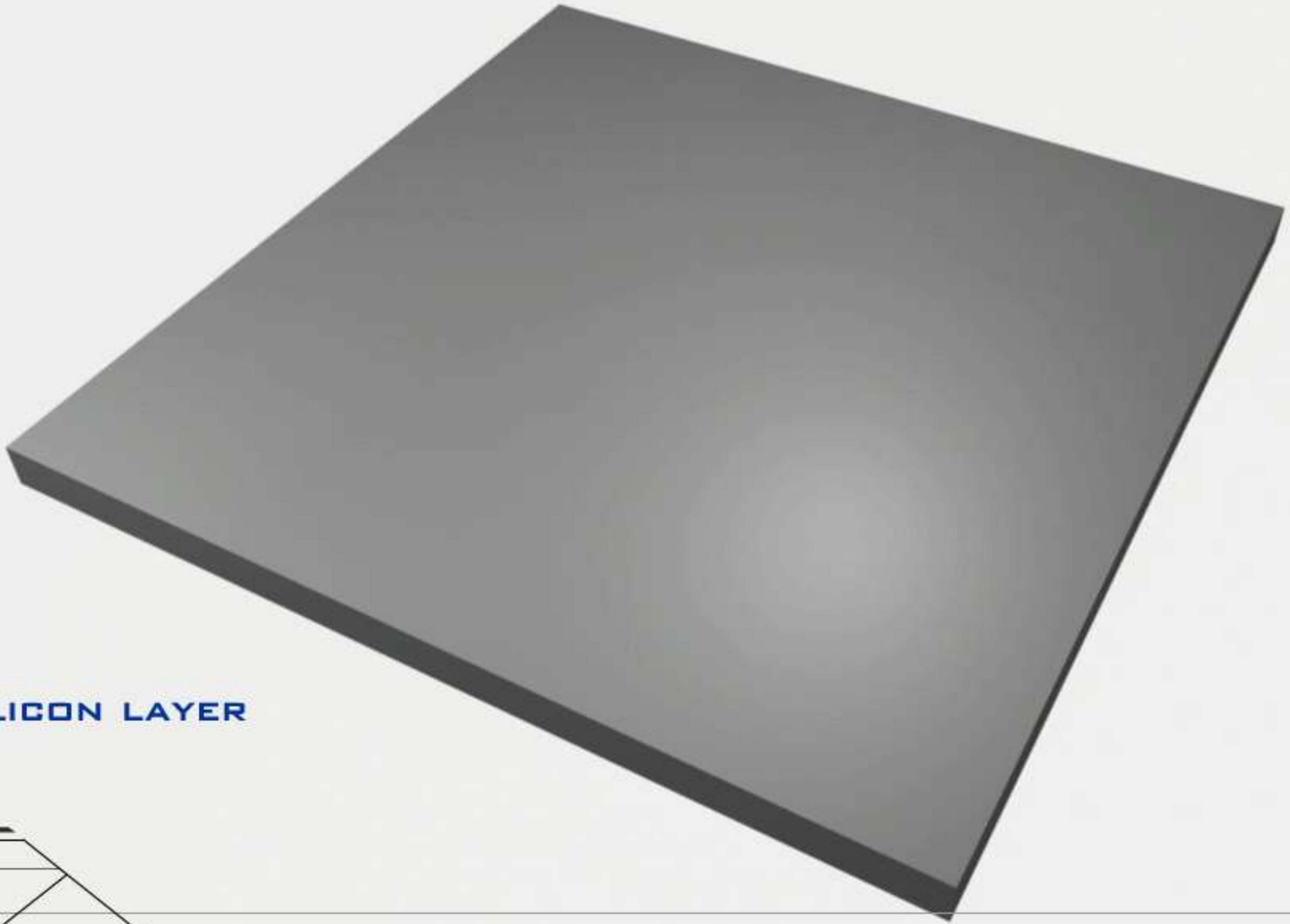


ASIC



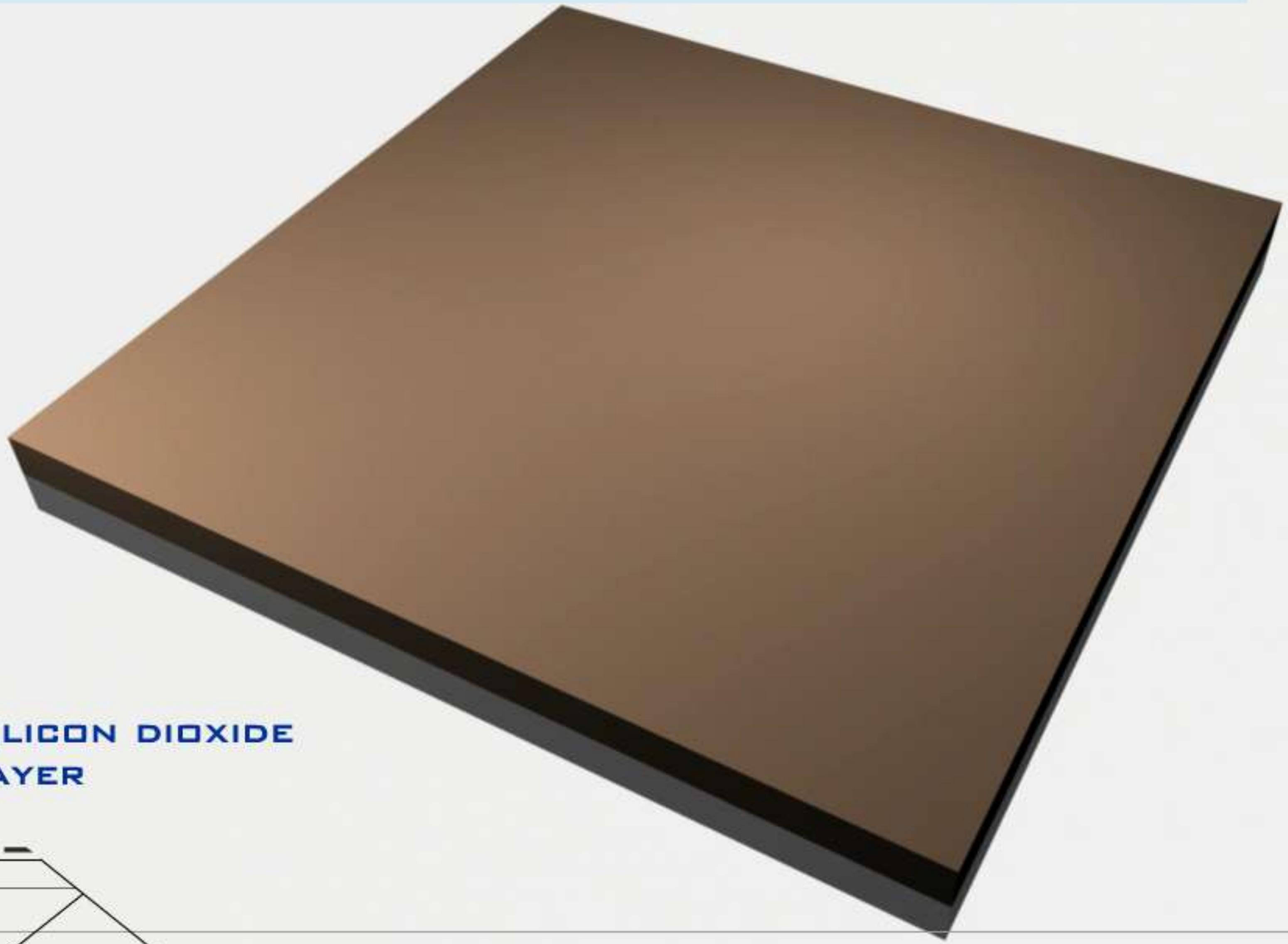
Stacked Configuration

MEMS ThELMA PROCESS



SILICON LAYER

MEMS ThELMA PROCESS

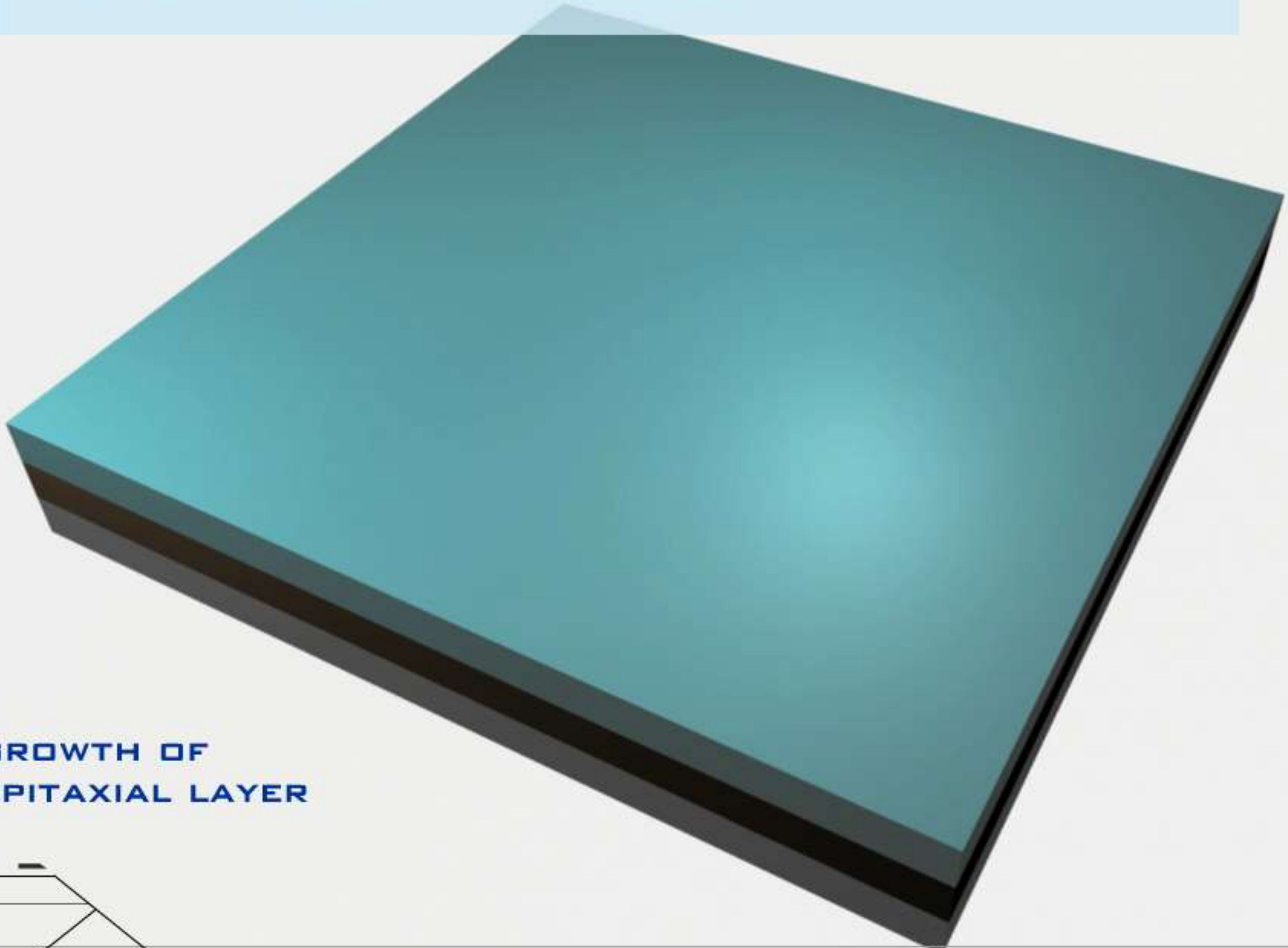


SILICON DIOXIDE
LAYER

MEMS ThELMA PROCESS

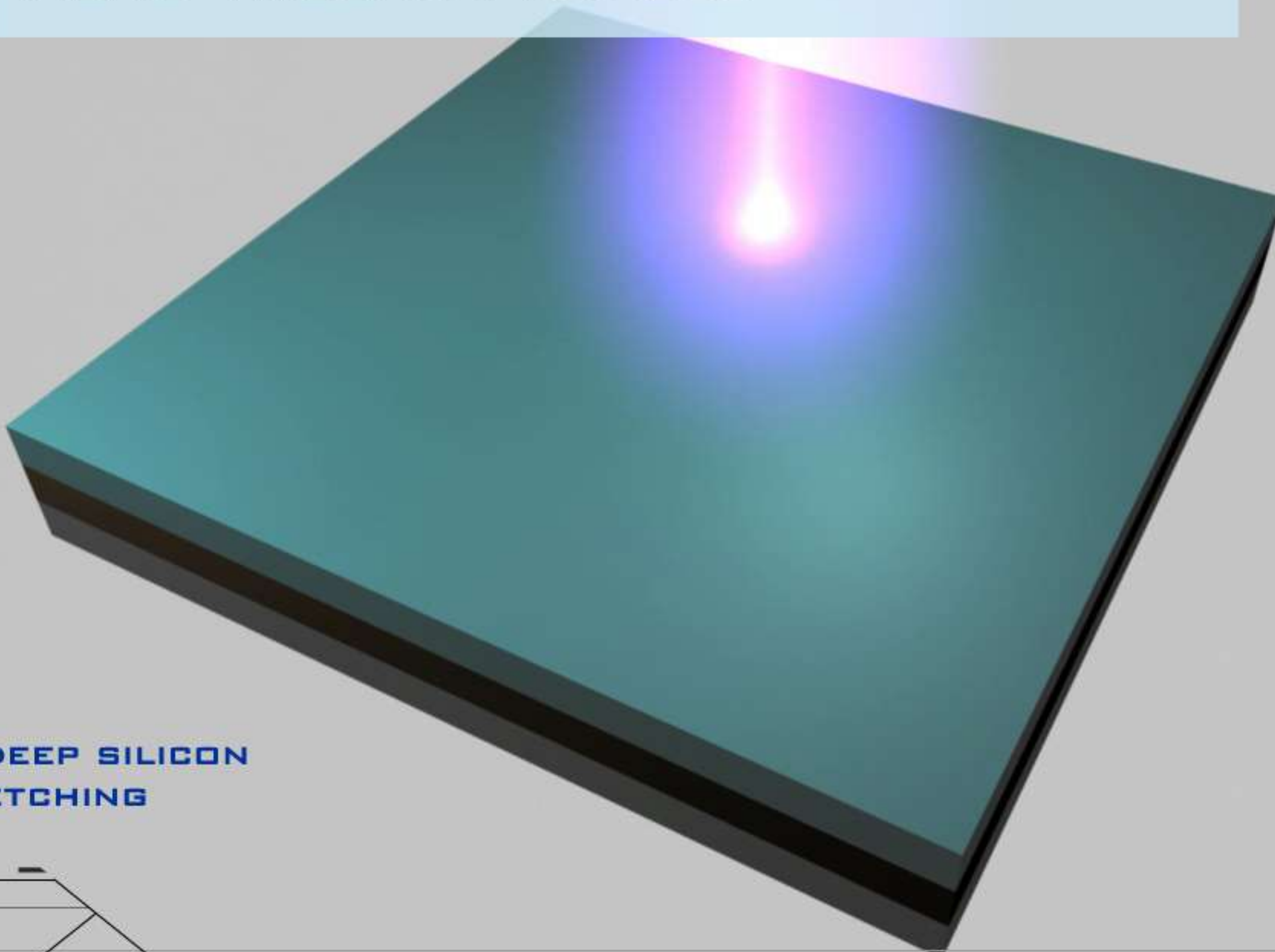
ETCHING TO CREATE
HOLES FOR ANCHORS

MEMS ThELMA PROCESS



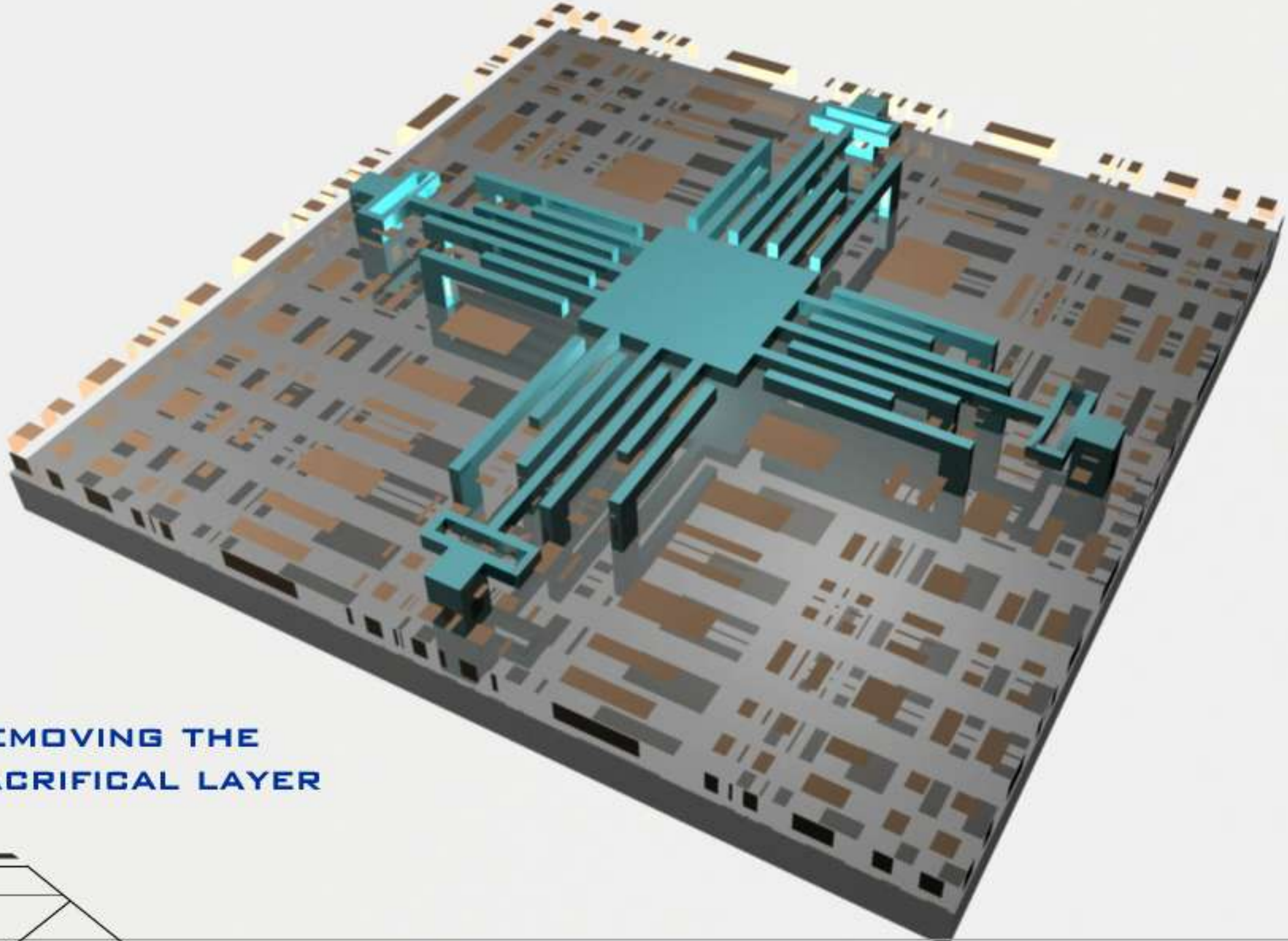
GROWTH OF
EPITAXIAL LAYER

MEMS ThELMA PROCESS



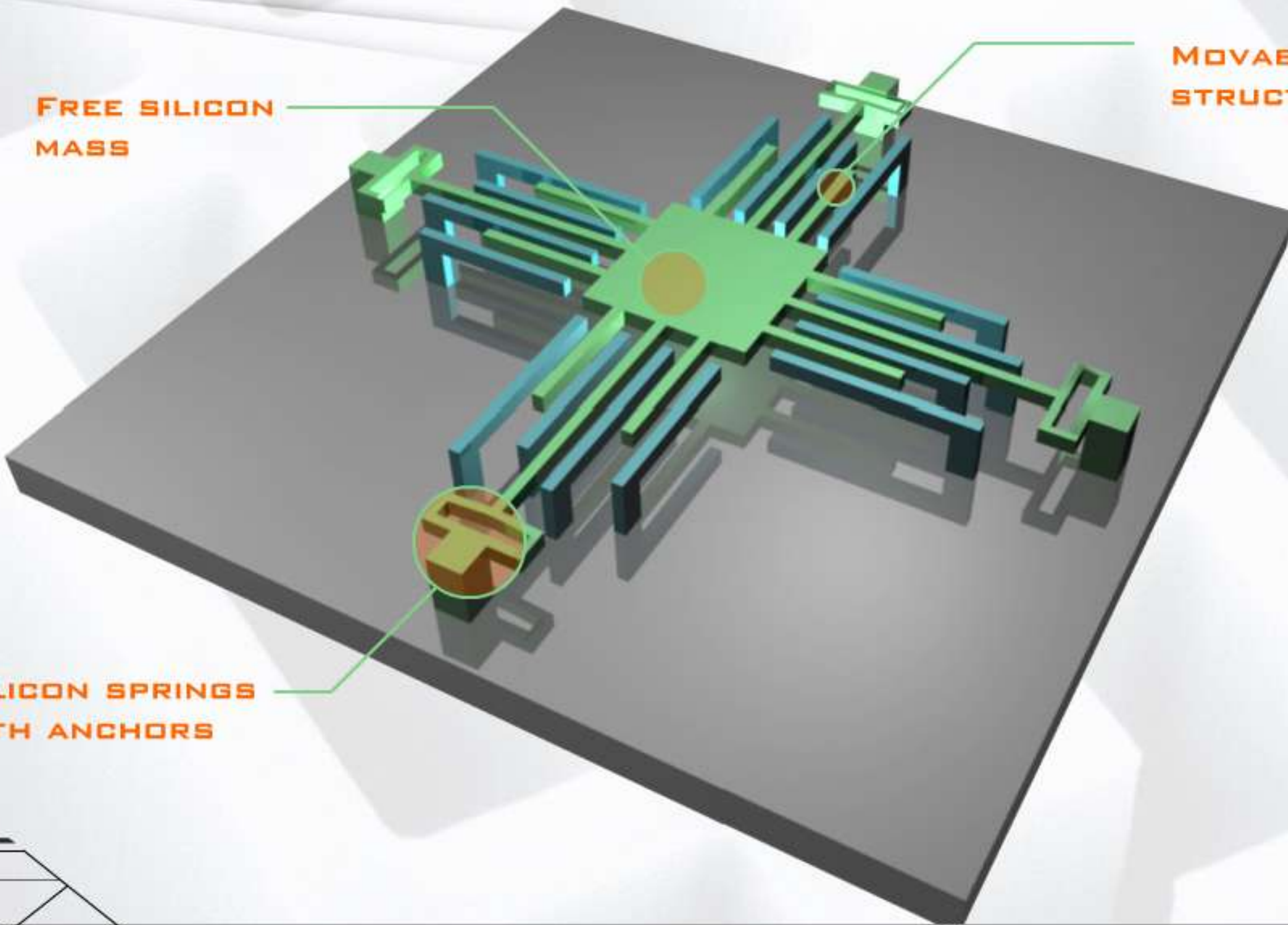
DEEP SILICON
ETCHING

MEMS ThELMA PROCESS

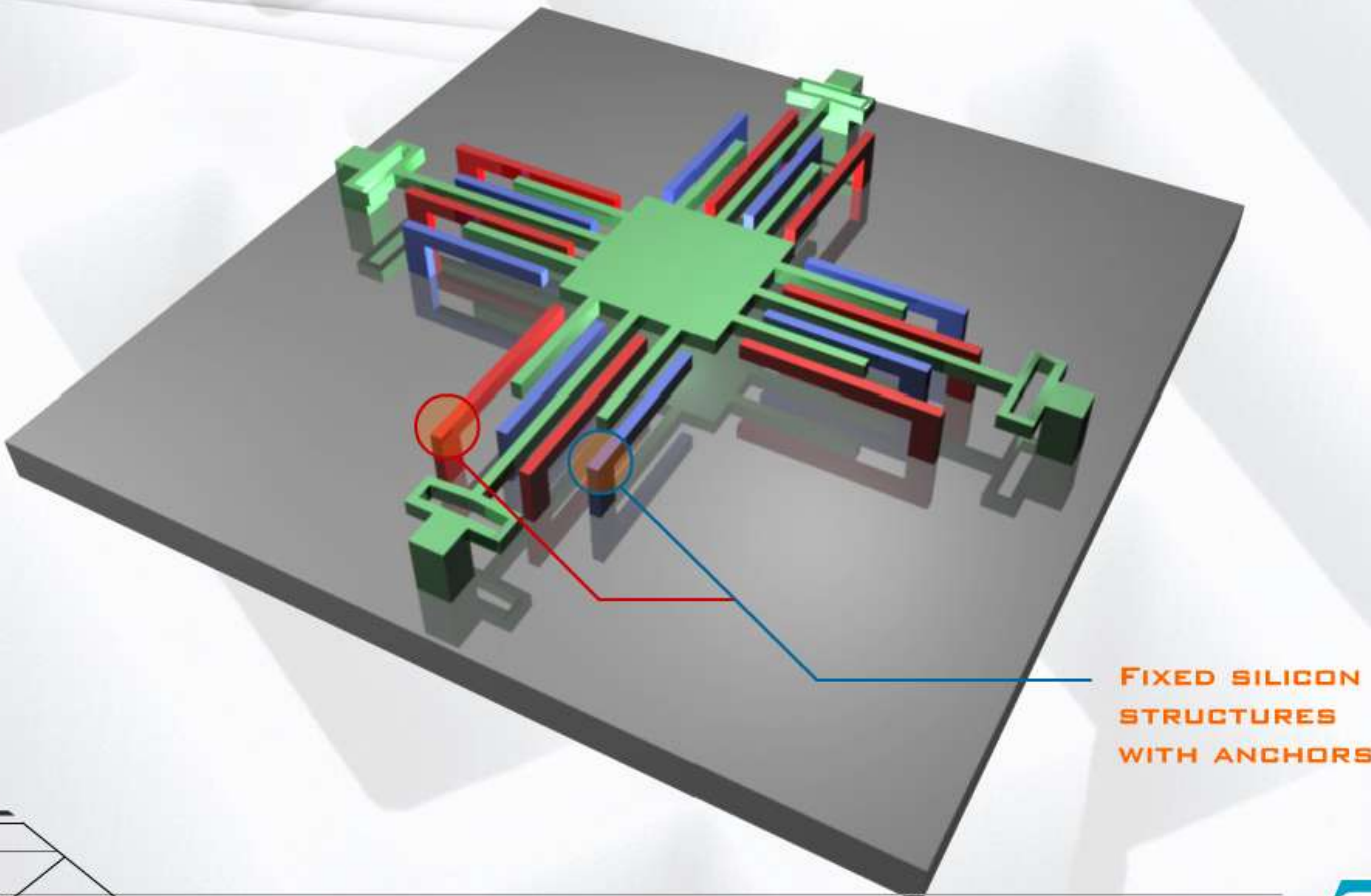


Removing the sacrifical layer

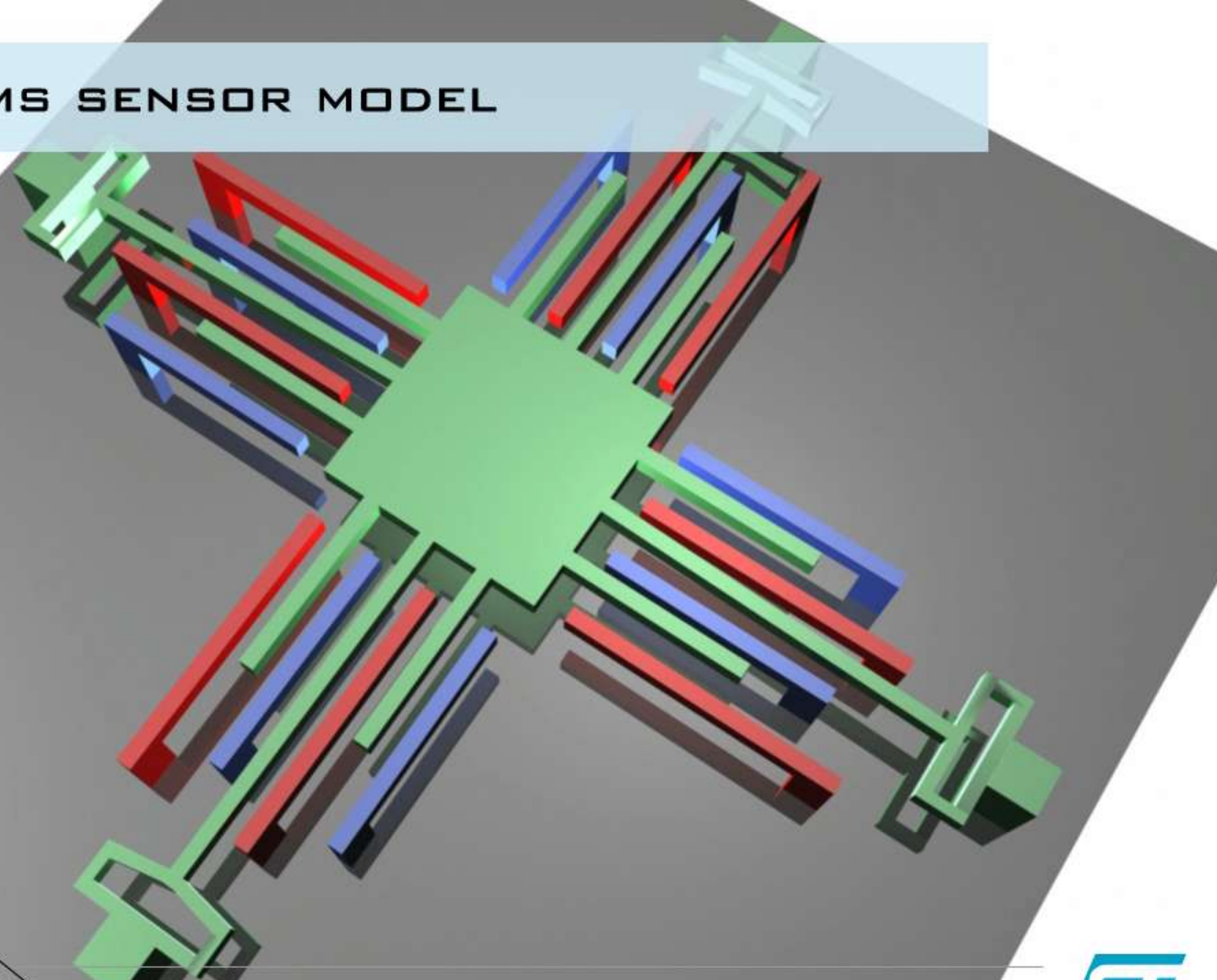
MEMS SENSOR MODEL



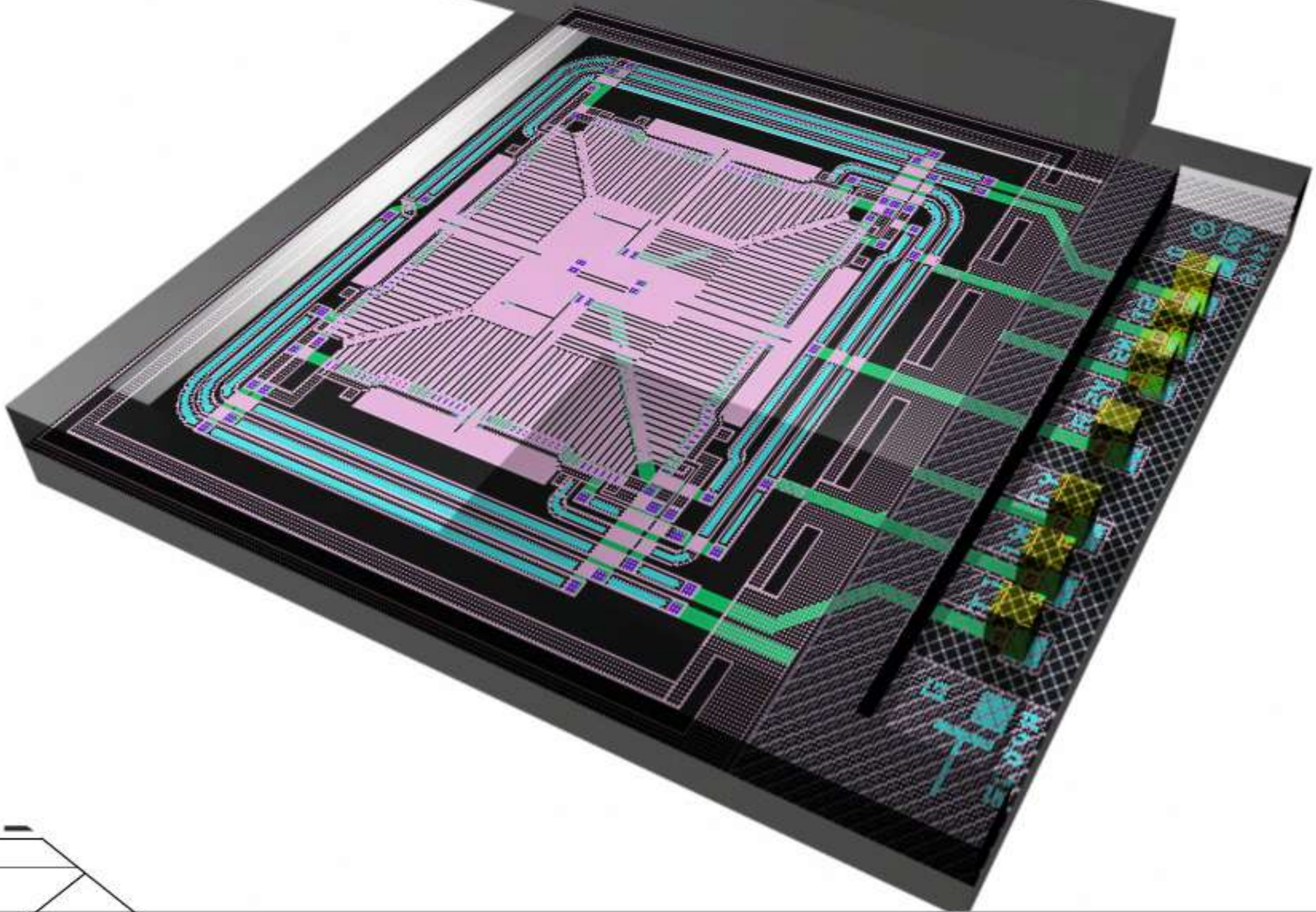
MEMS SENSOR MODEL



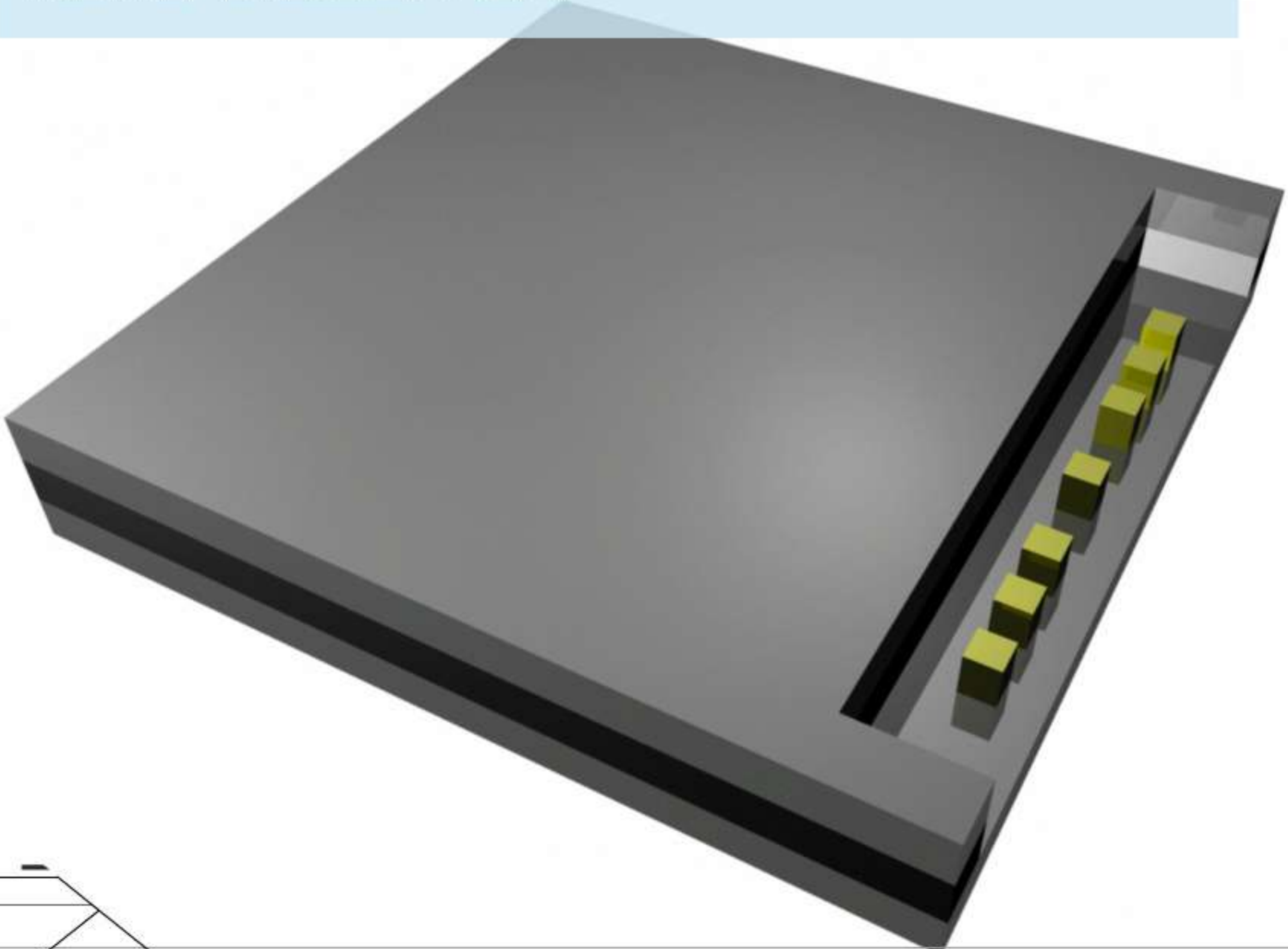
MEMS SENSOR MODEL



MEMS SILICON CAP

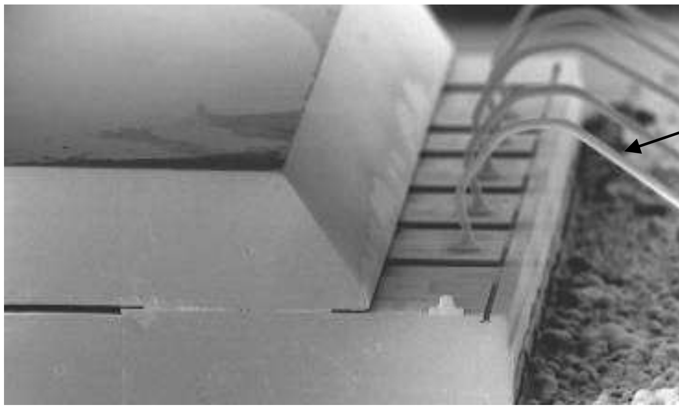


MEMS SILICON CAP



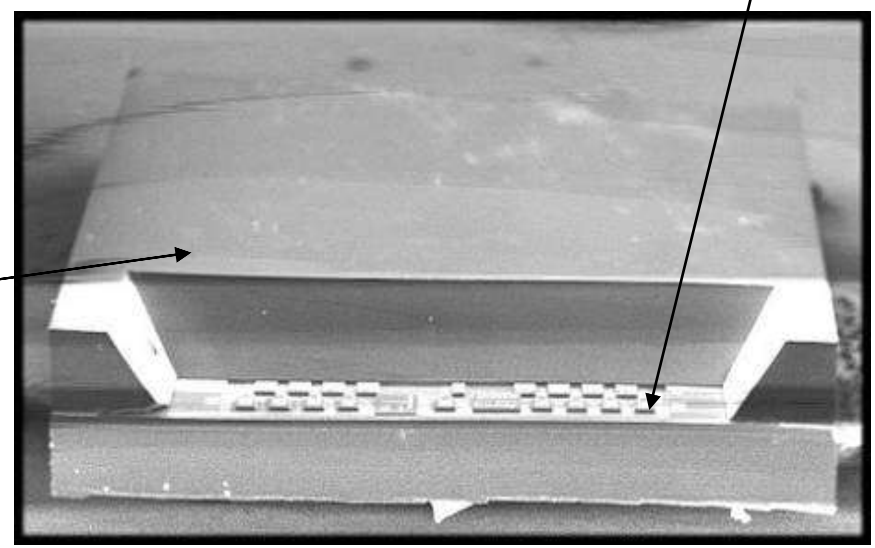
Thelma wafer cap

- The Mechanical sensor is protected by a silicon cap



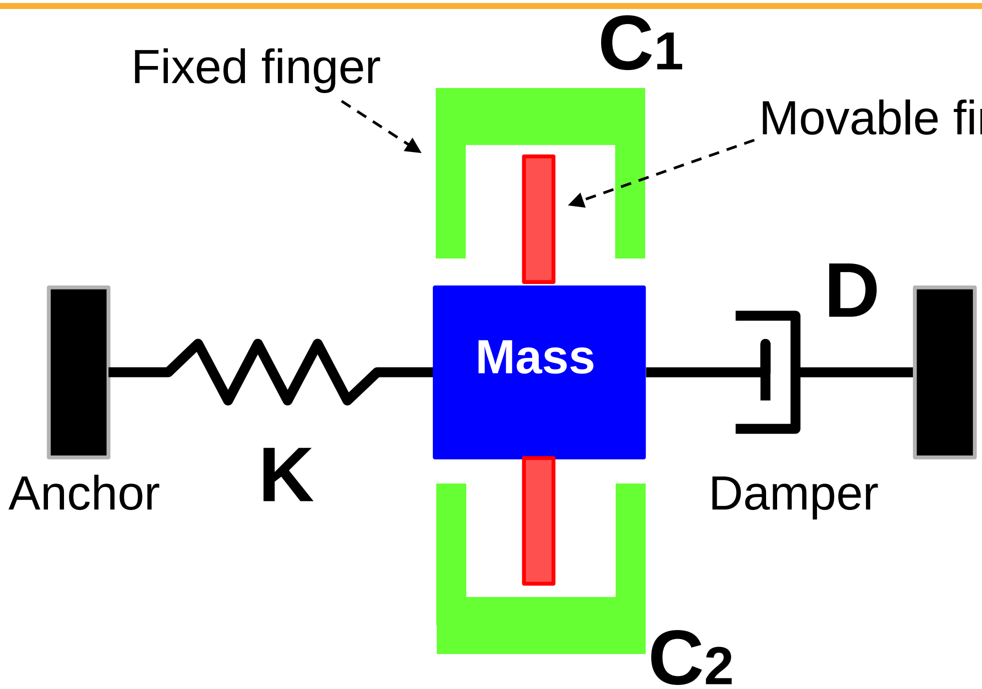
Wire bonding between sensor and IC

Sensor Pads



Sensor silicon cap

MEMS Sensor Model

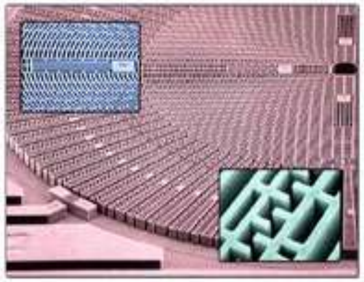


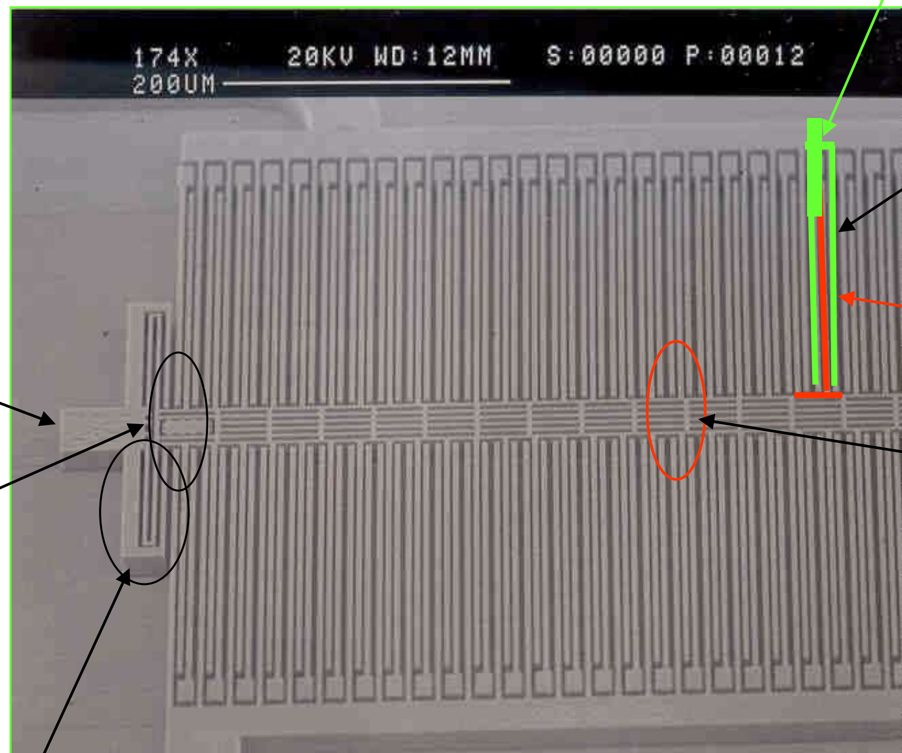
- ***Electrostatic Force*** is described by an differential equation:

$$mx'' + dx' + Kx = F$$

where **d** is linear viscous damping coefficient, **m** is the mass, **x** is the displacement, **K** is the spring constant, **mx''** electrostatic force on capacitance

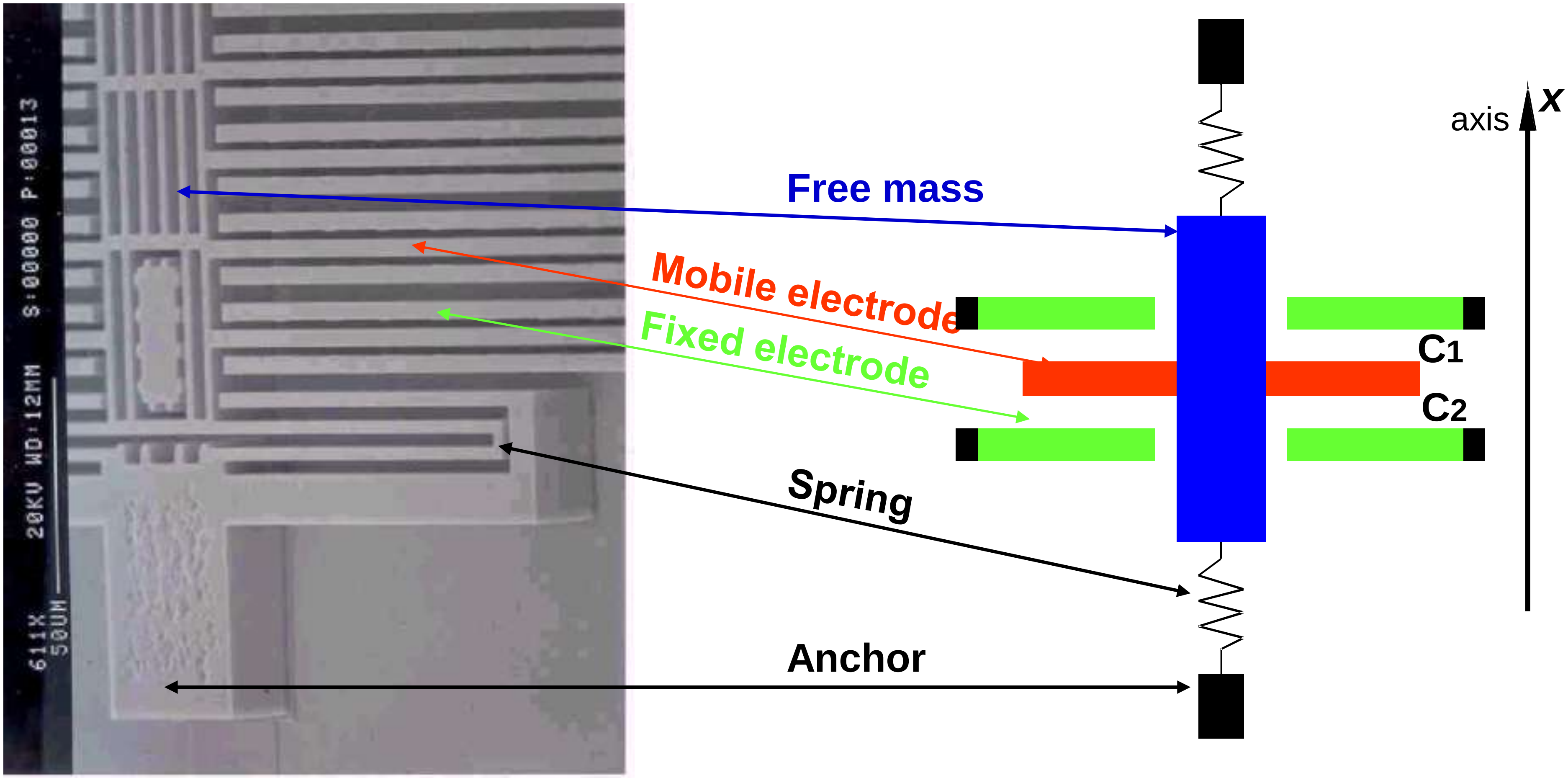
MEMS Sensor
Linear Accelerometer



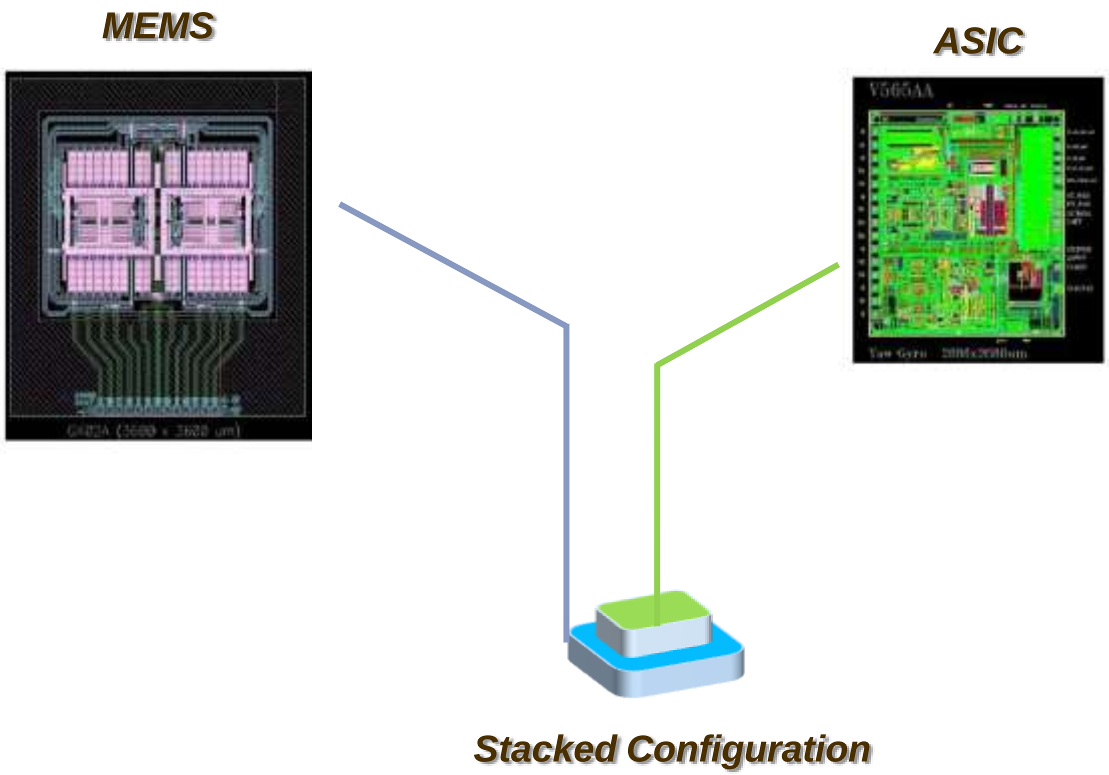


MEMS Sensor
Linear Accelerometer

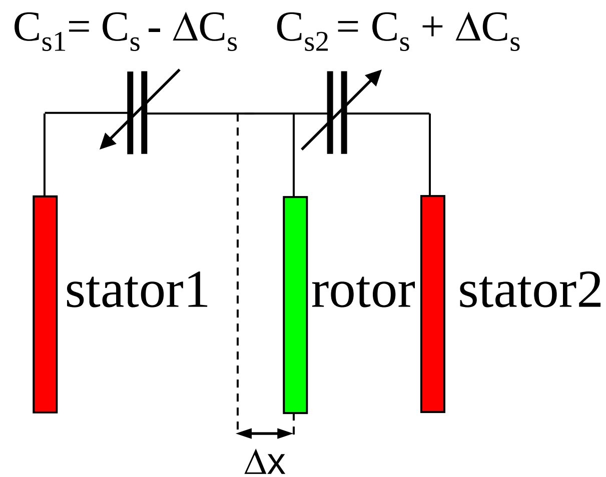
Silicon Mechanical Structure **MEMS Model**



MEMS + ASIC Description



Differential structure



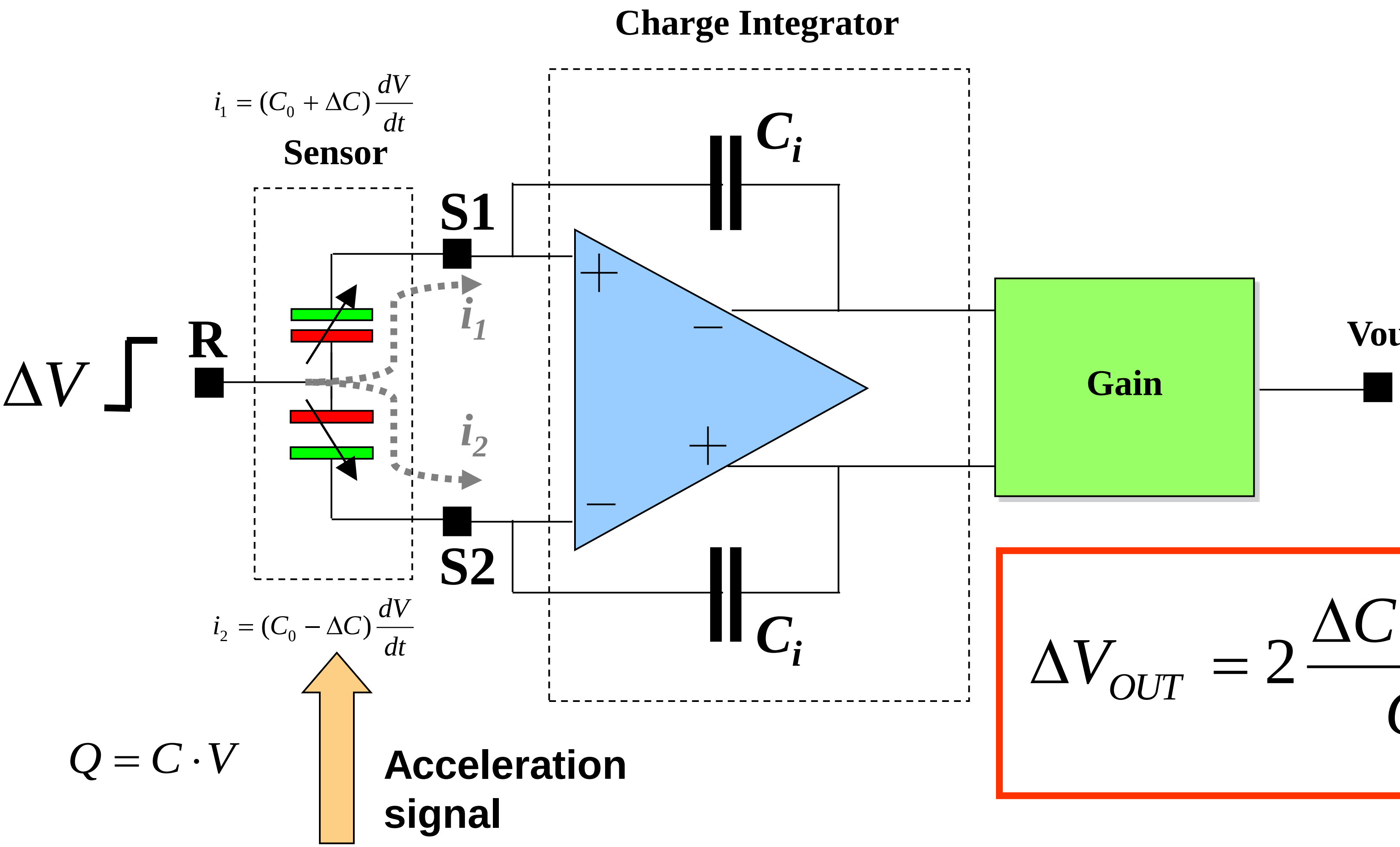
- Systematic Offset reduction

$$C_{s1} = C_s + \Delta C_s \qquad C_{s2} = C_s + \Delta C_s \qquad \Delta C_{s12} = C_{s1} - C_{s2} = 0$$

- Doubling sensitivity

$$C_{s1} = C_s - \Delta C_s \qquad C_{s2} = C_s + \Delta C_s \qquad \Delta C_{s12} = C_{s1} - C_{s2} = -2\Delta C_s$$

Measurement Chain

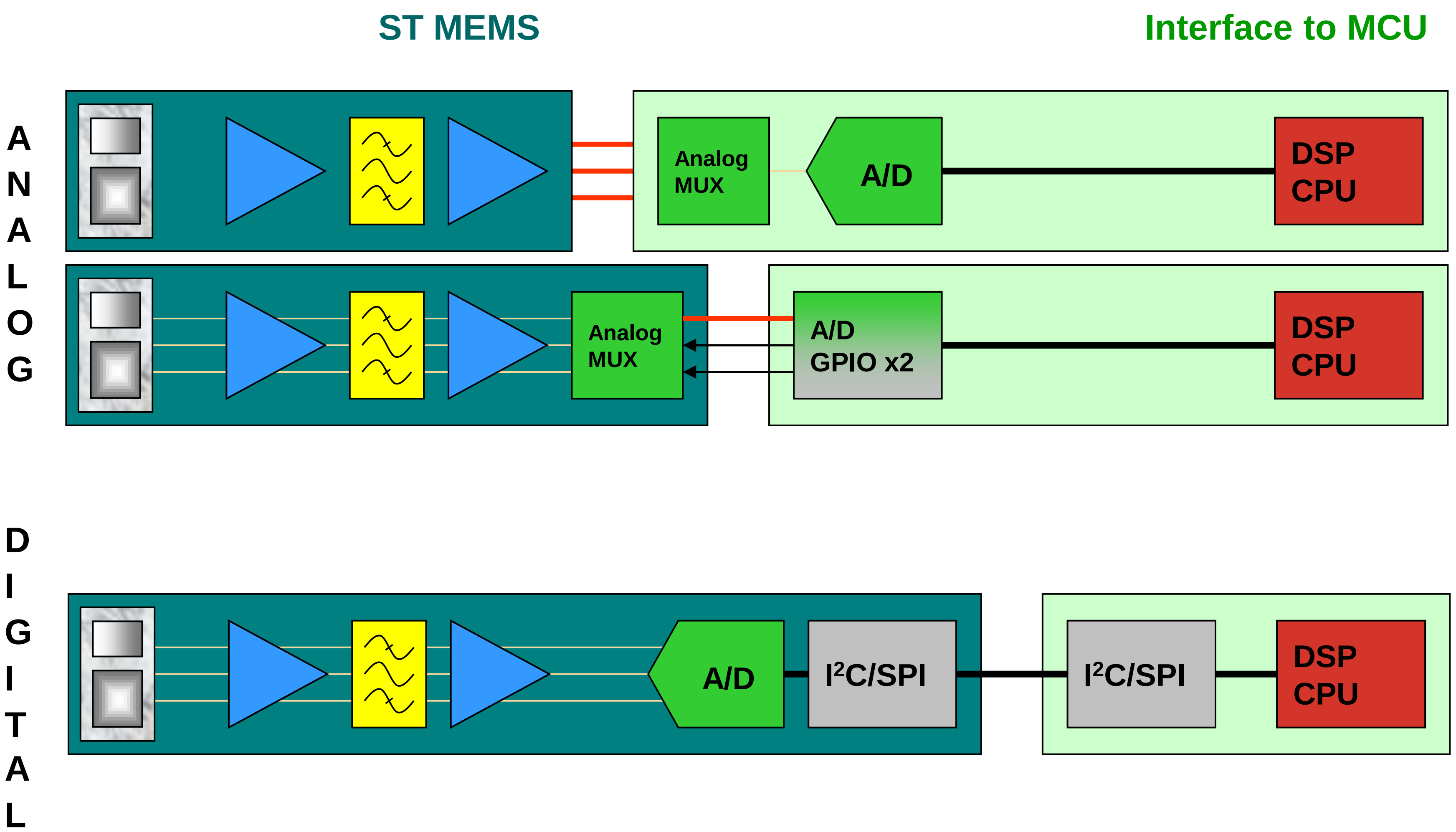


$$\Delta V_{OUT} = 2\frac{\Delta C \cdot \Delta V}{C_i}$$

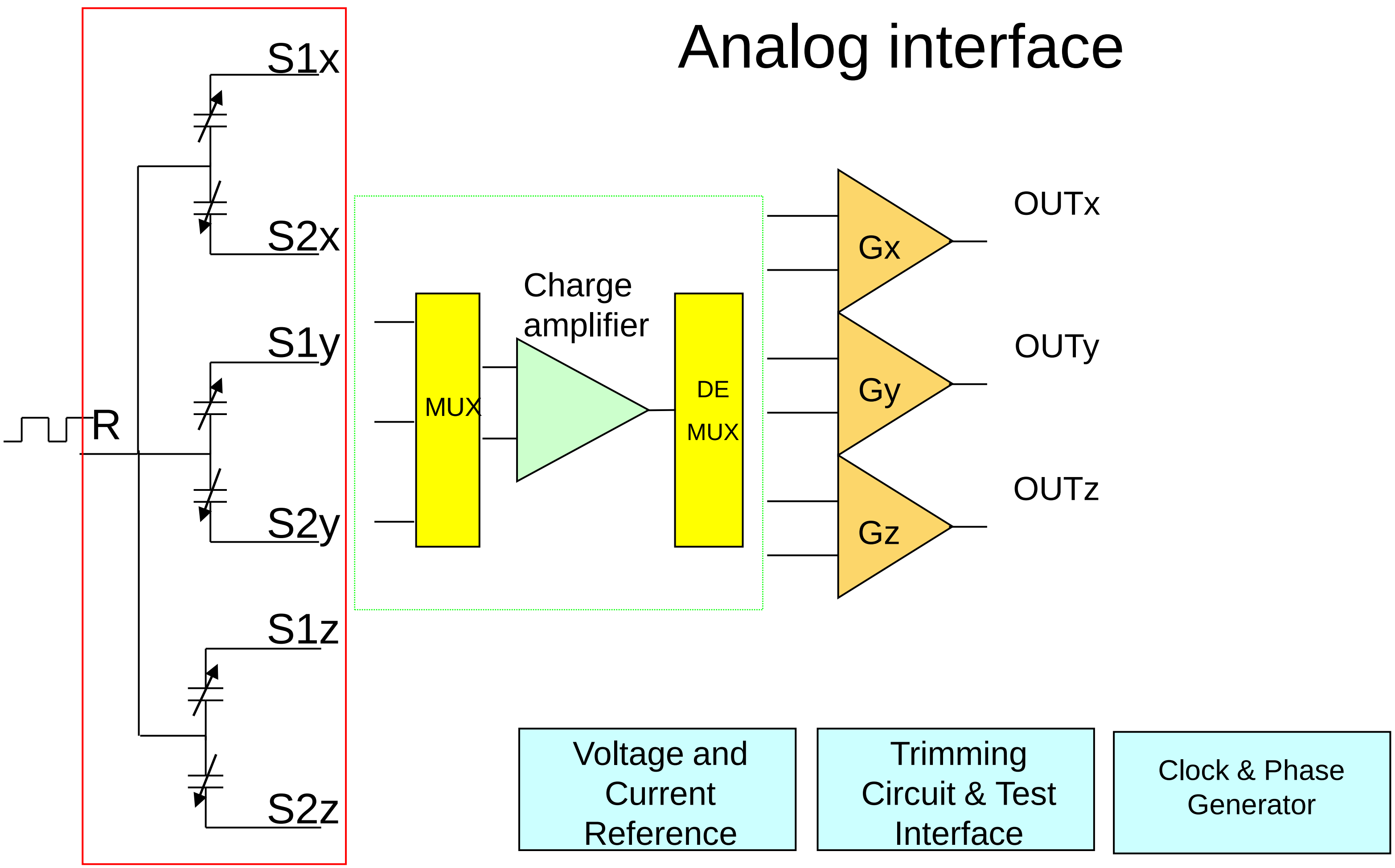
$$Q = C \cdot V$$

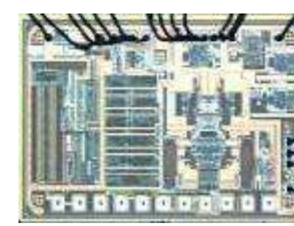
Acceleration signal

MEMS System Partitioning

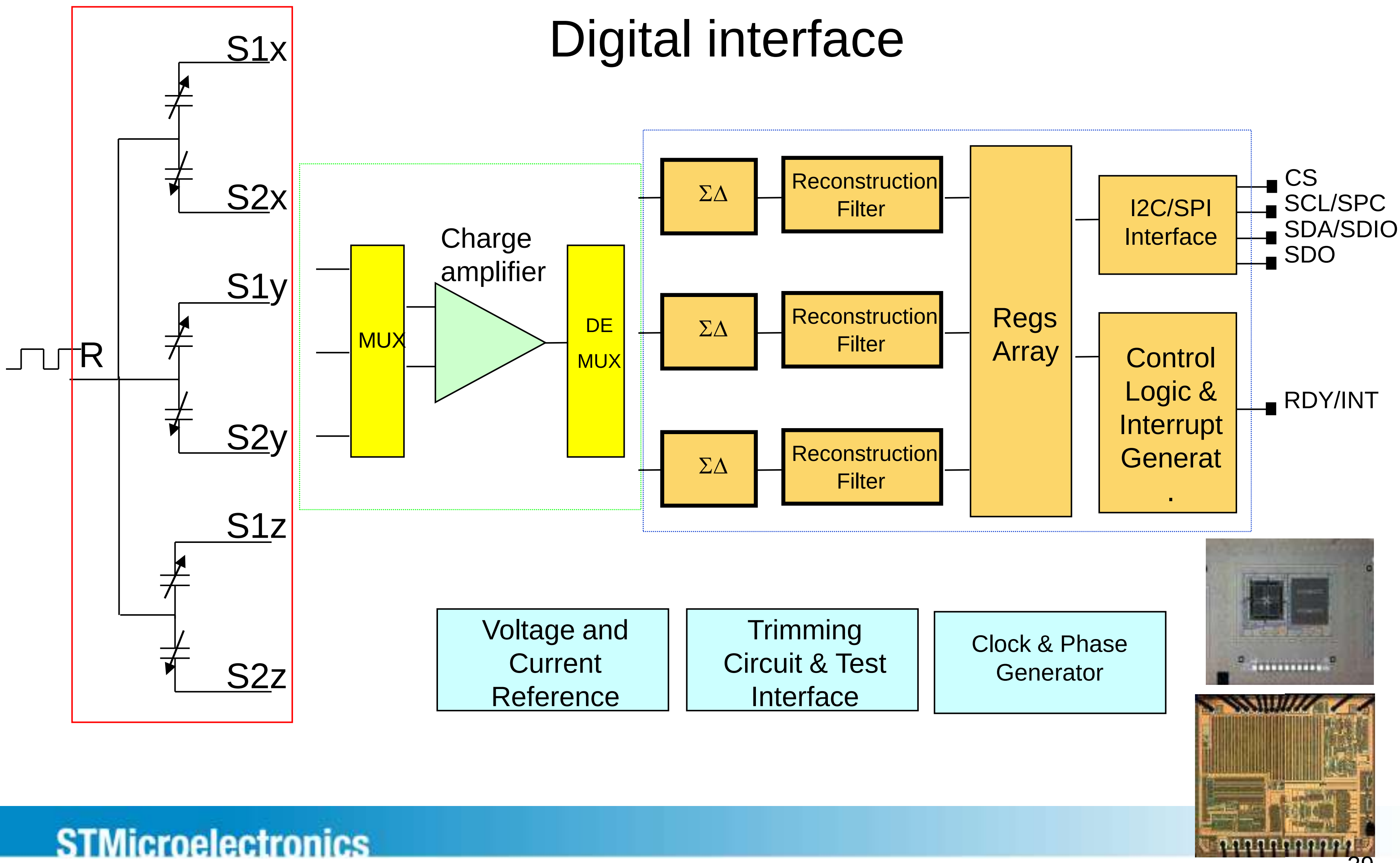


MEMS Accelerometers Interface Chip

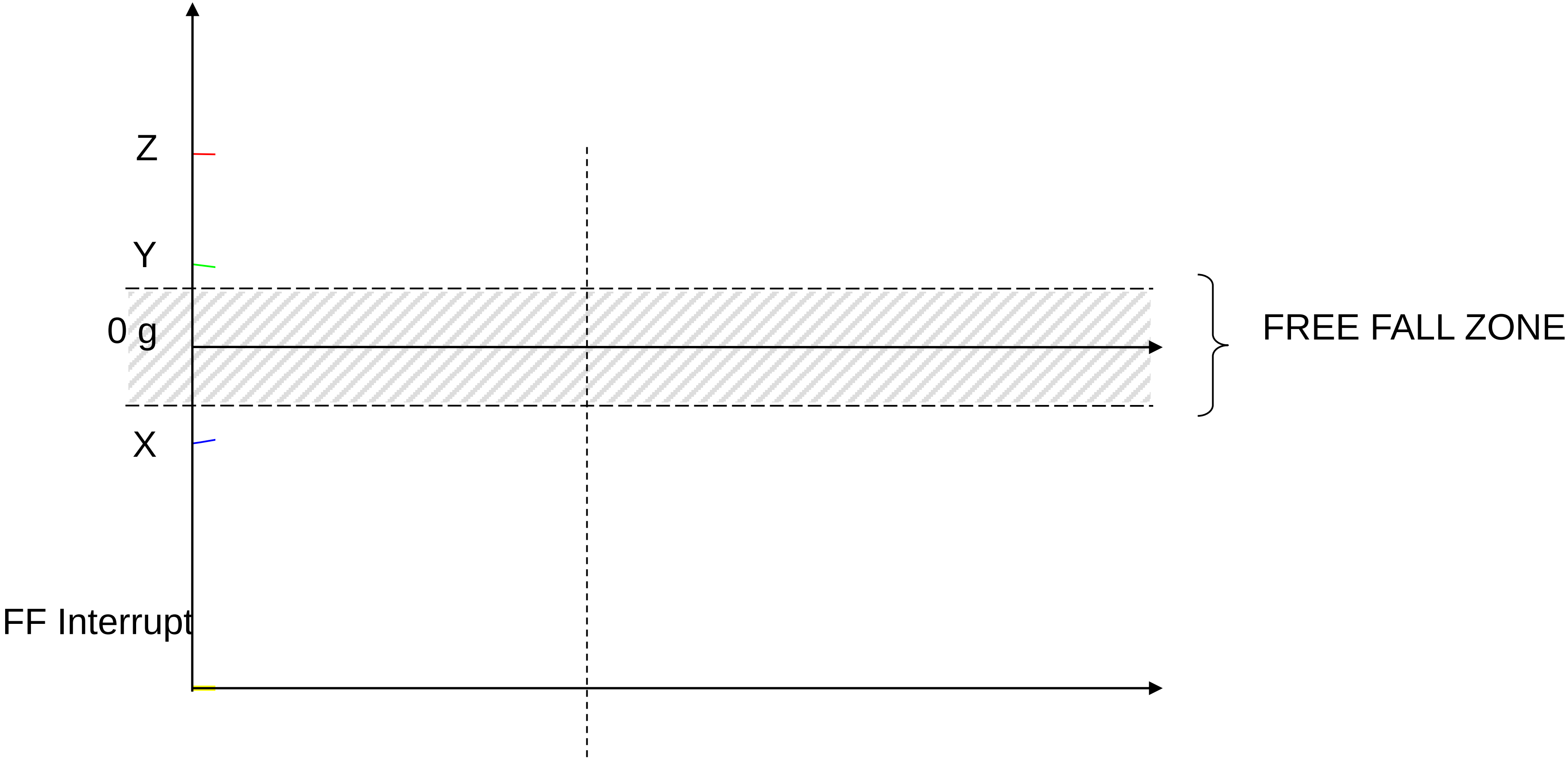




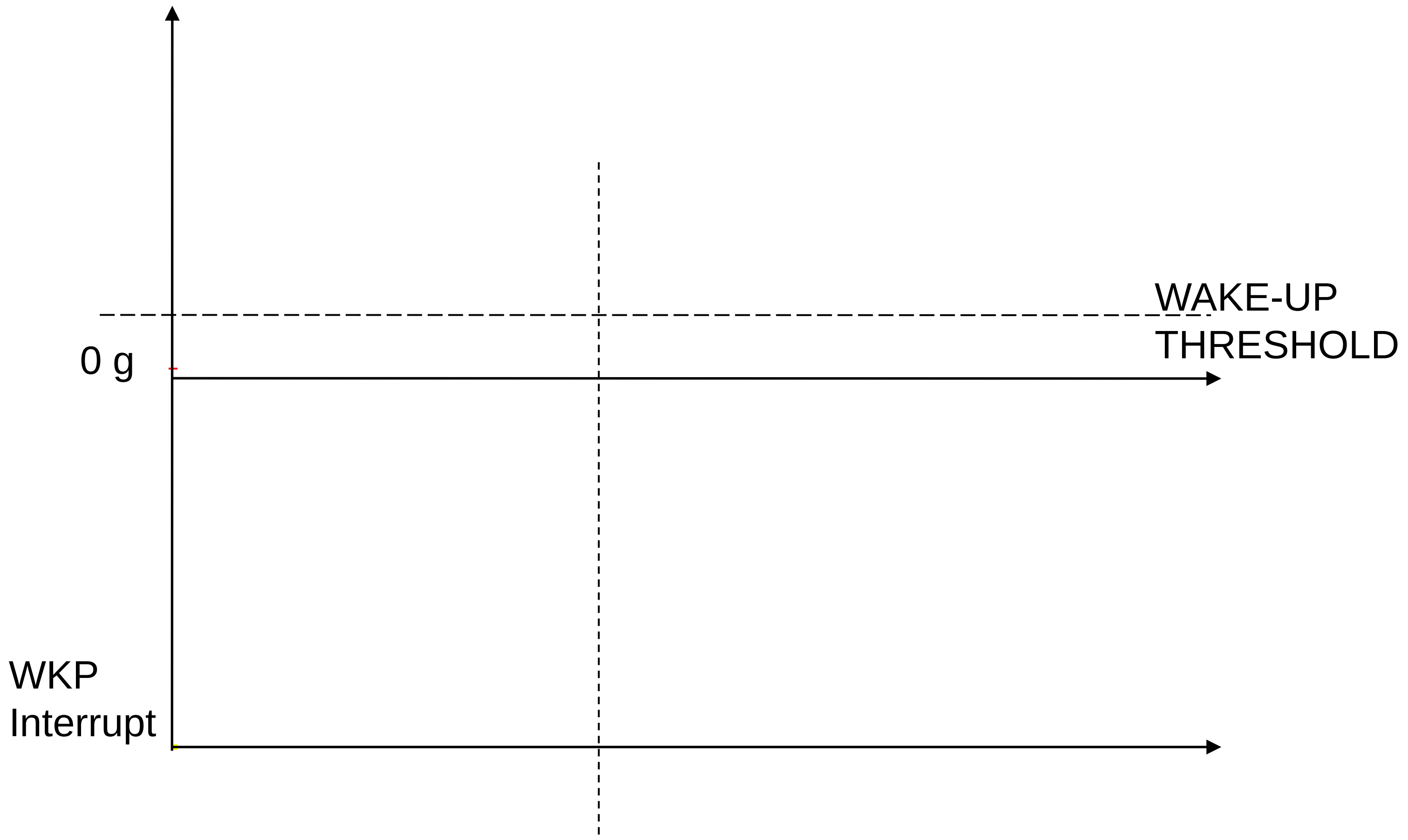
MEMS Accelerometers Interface Chip



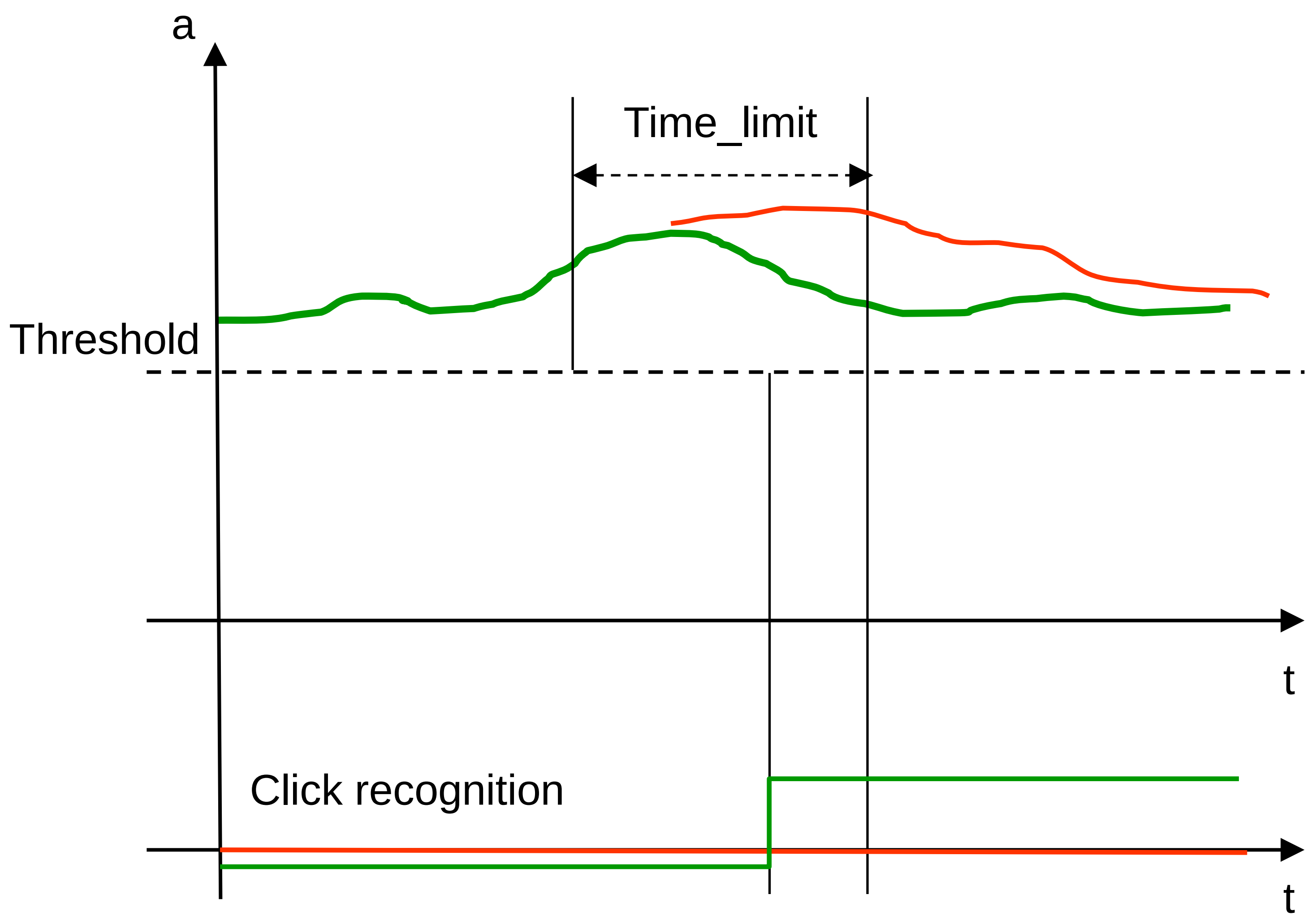
Added features for digital devices: Free Fall detection



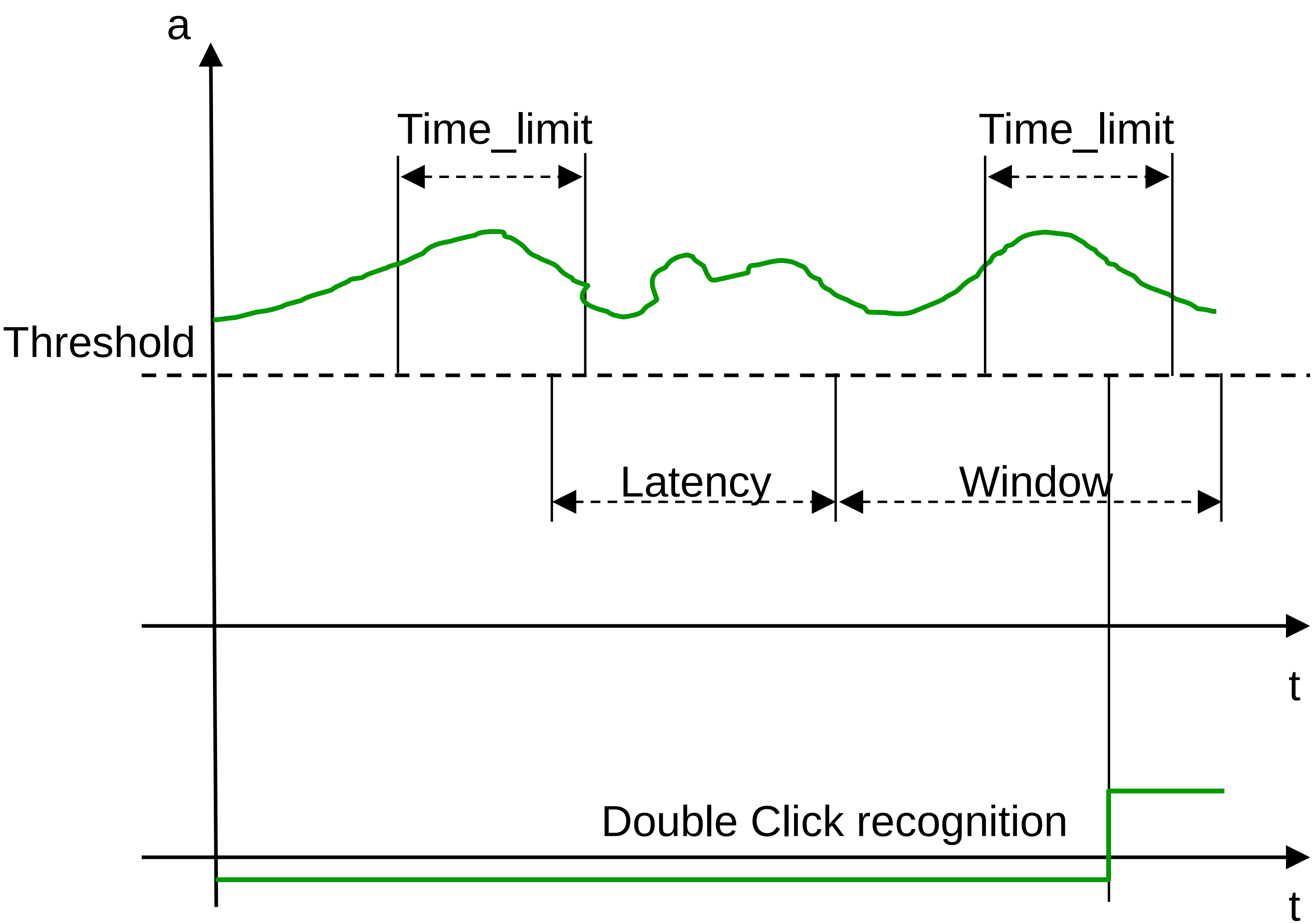
Added features for digital devices: Wake Up Detection



Added features for digital devices:
Single Click Recognition: Timing parameter

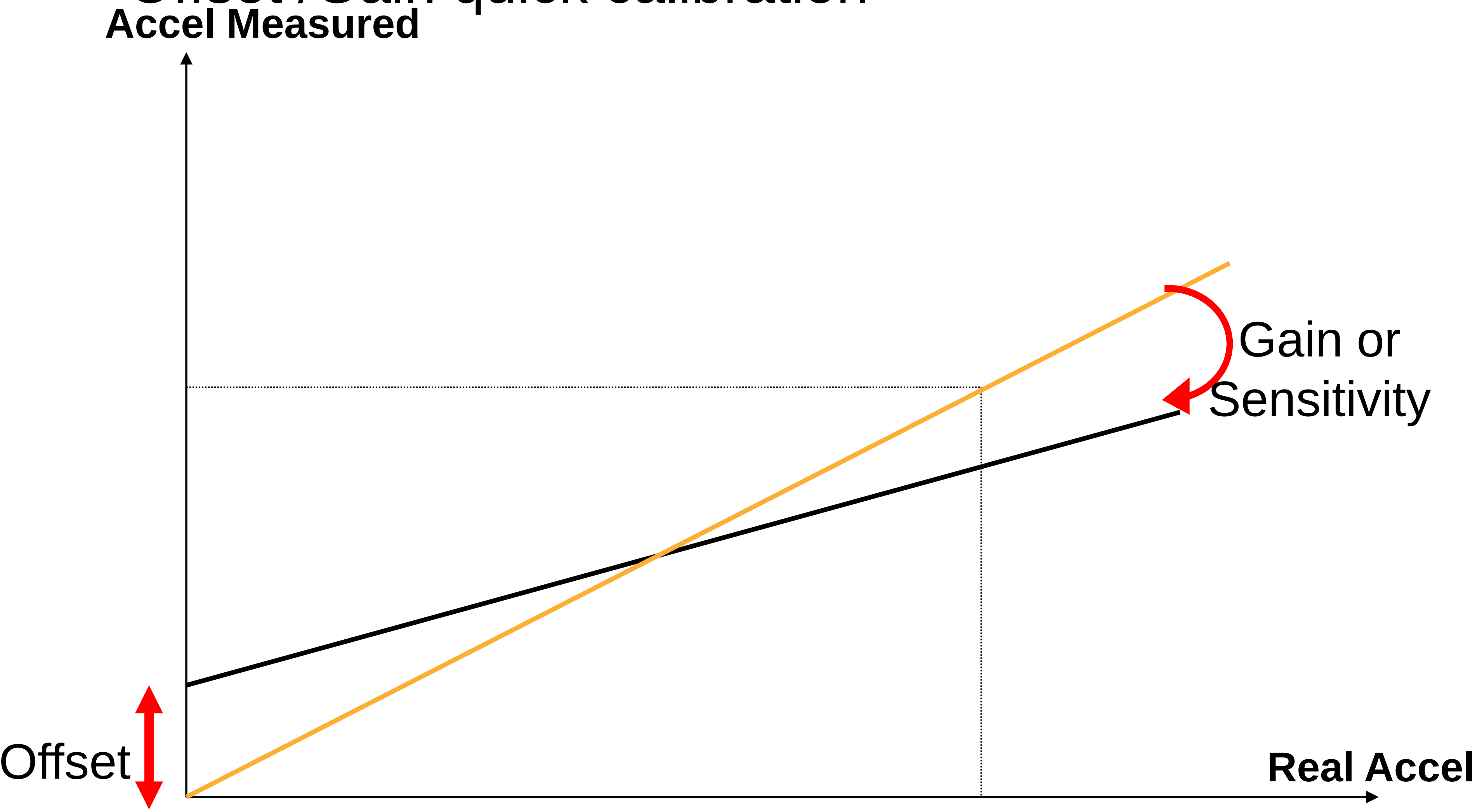


Added features for digital devices: LISxxxDx
Double Click Recognition: Timing parameters



MEMS calibration operation

- Offset /Gain quick calibration



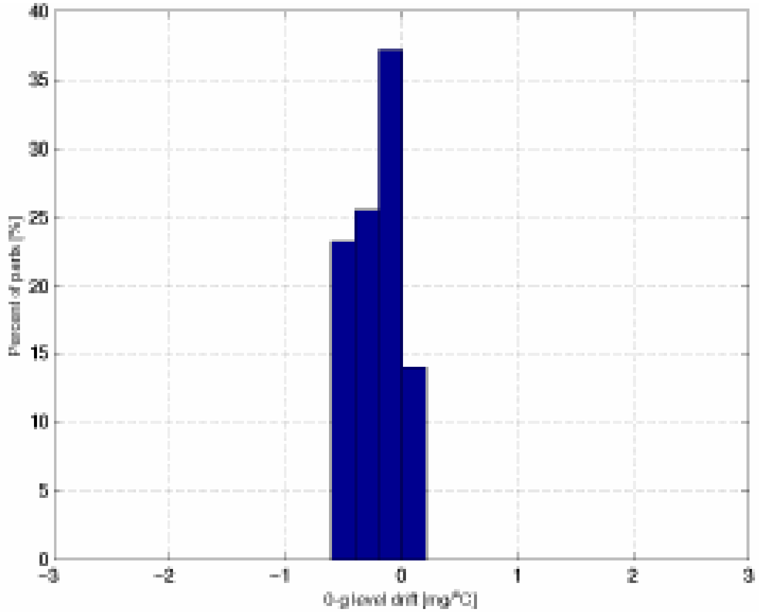
Accelerometers main parameters

Symbol	Parameter	Min	Typ	Max	Unit
Vdd	Power supply	1.71	2.5	3.6	V
Idd	Current consumption in normal mode		22		µA
ODR	Output data rate		From 1 to 5000		Hz
BW	System Bandwidth		ODR/2		Hz
Ton	Turn on time		1/ODR + 1		ms
FS	Full-scale measurement range		±2,4,8,16		g
So	Sensitivity	0.9	1	1.1	mg/LSb
TCSo	Sensitivity change vs. temperature		±0.01		%/°C
TyOff	Zero-g offset accuracy		±40		mg
TCOff	Zero-g level change vs. temperature		±0.5		mg/°C
An	Acceleration noise density		220		µg/√(Hz)

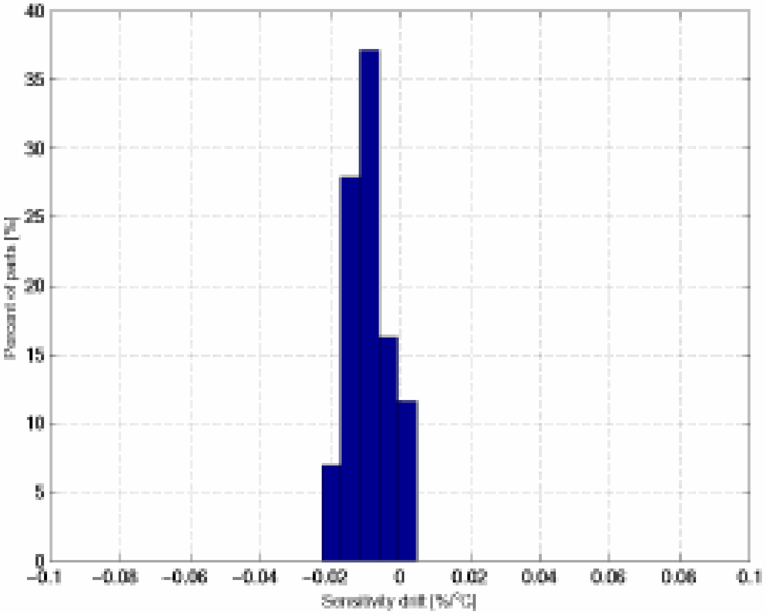
Parameters vs. temperature

- All ST MEMS sensors show outstanding stability against temperature variation of main parameters such as Zero-g offset and Sensitivity

Zero-g Offset vs. Temp.



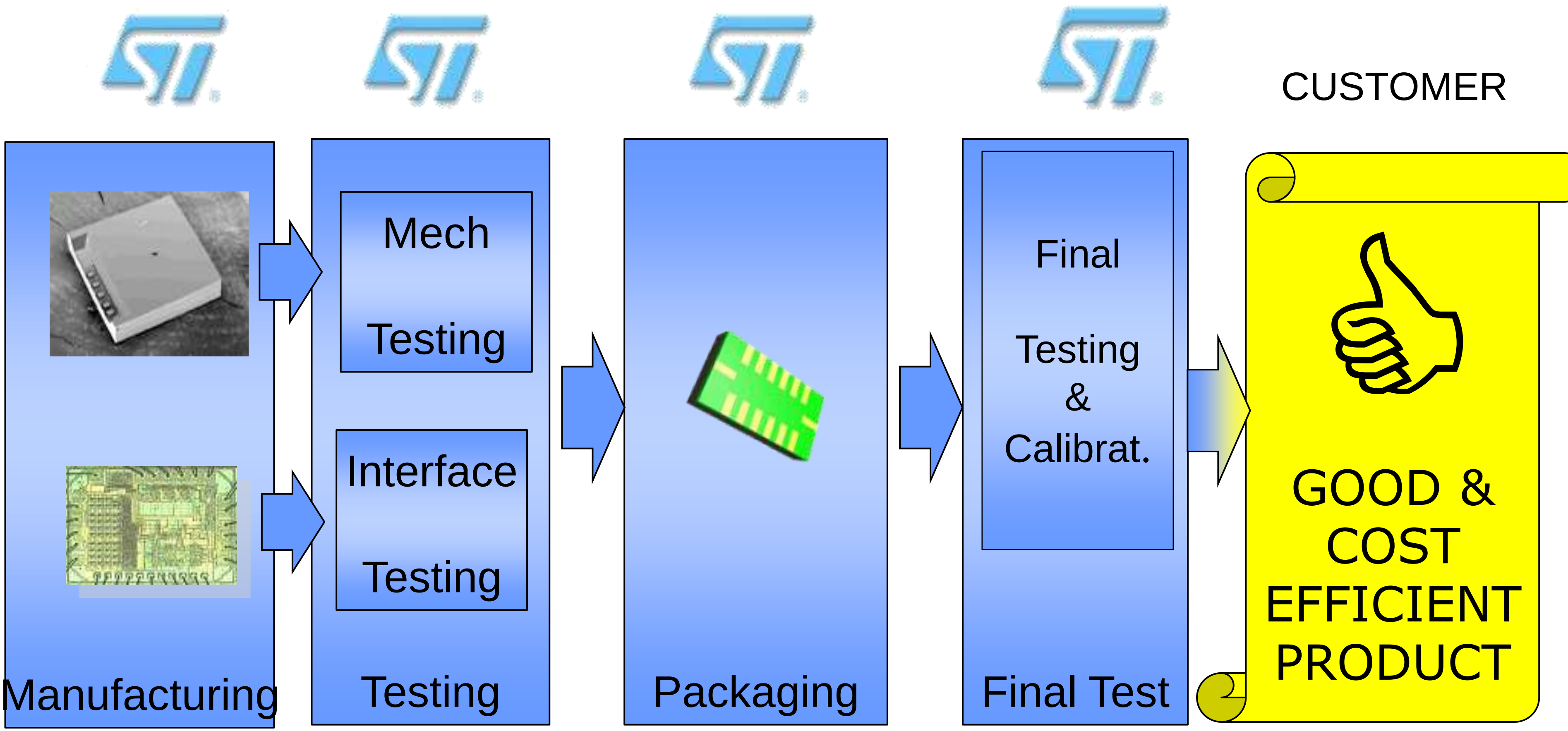
Sensitivity vs. Temp.



0.5mg/°C * 30°C = 15mg

0.015%/°C * 30°C = 0.45%

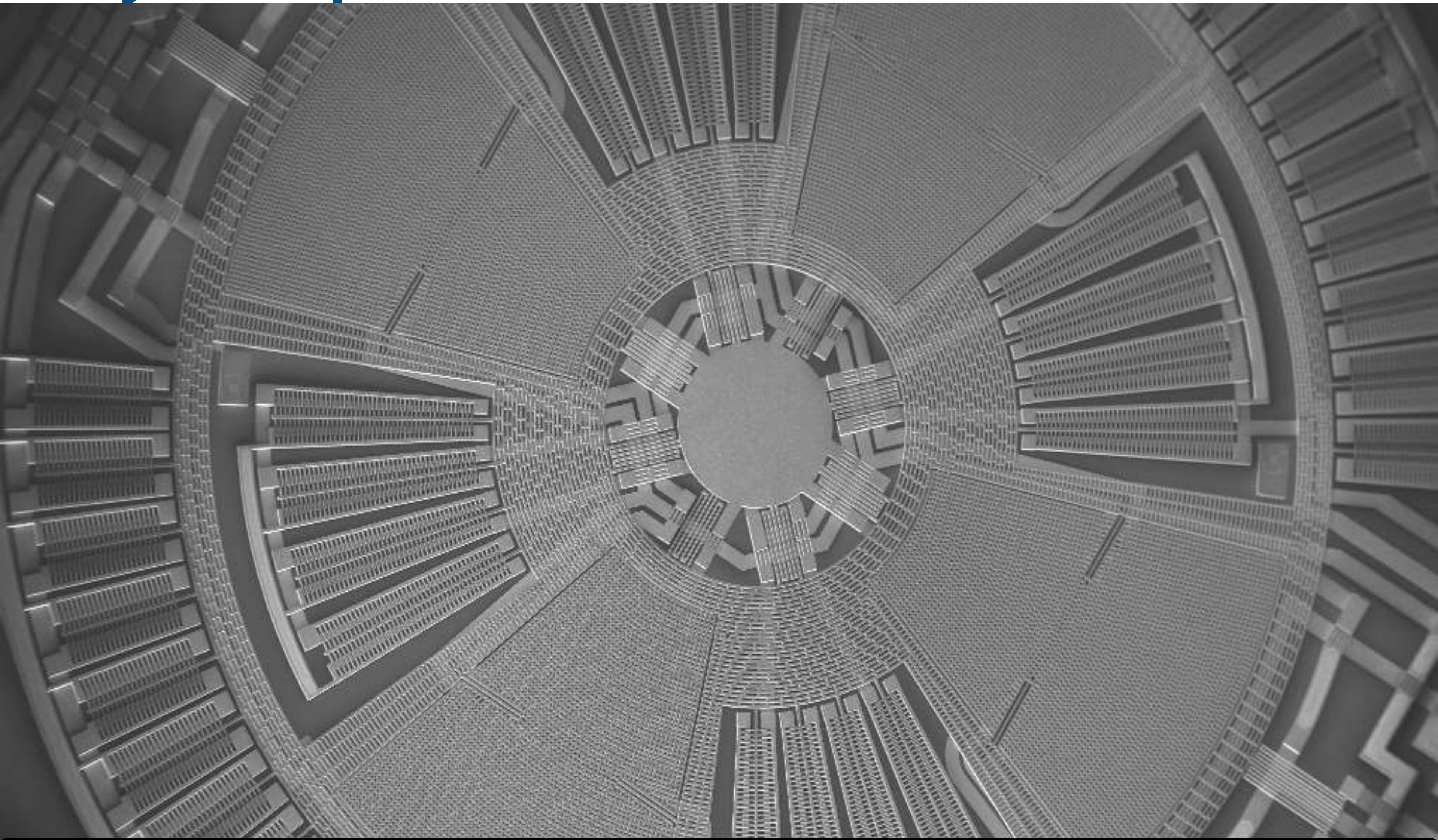
Manufacturing Flow



ST MANAGES THE COMPLETE SUPPLY CHAIN

MEMS FAB: FE + BE

Gyroscope



Pitch and Roll Coriolis Gyroscope

Accelerometer and Gyroscope

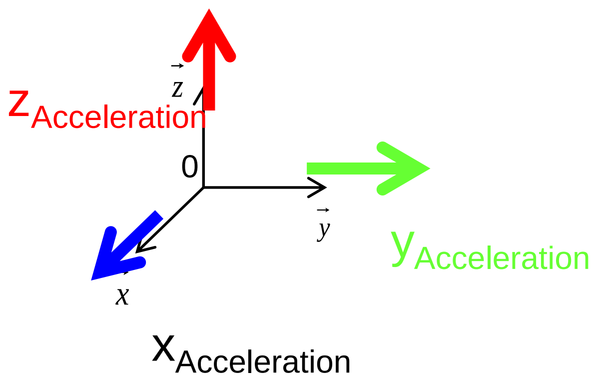
Accelerometer measure linear accelerations
Gyroscope measure angular movement (pitch, roll and yaw)

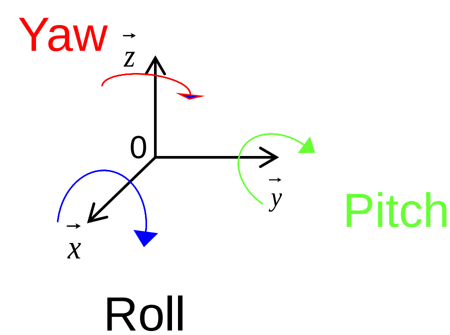
Accelerometer and Newton

$F = m A$

Gyroscope and Coriolis

$F = 2m V \times \Omega$





MEMS accelerometer and gyroscope are combined into IMU (inertial measurement unit)

Gyroscope - Principle

- **Yaw** is rotation about the vertical axis (z-Axis)

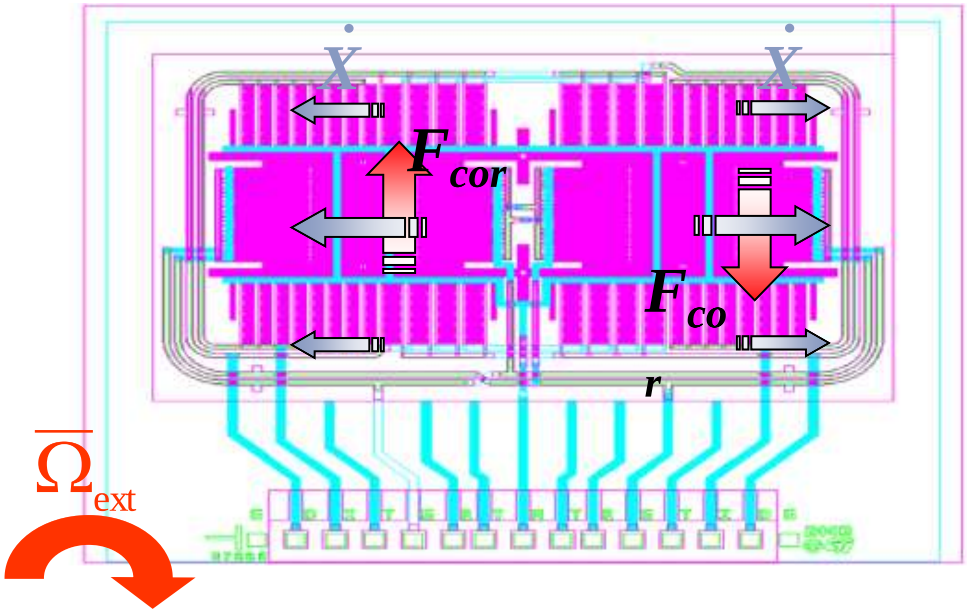
- **Roll** is rotation around the longitudinal axis, (x-Axis)

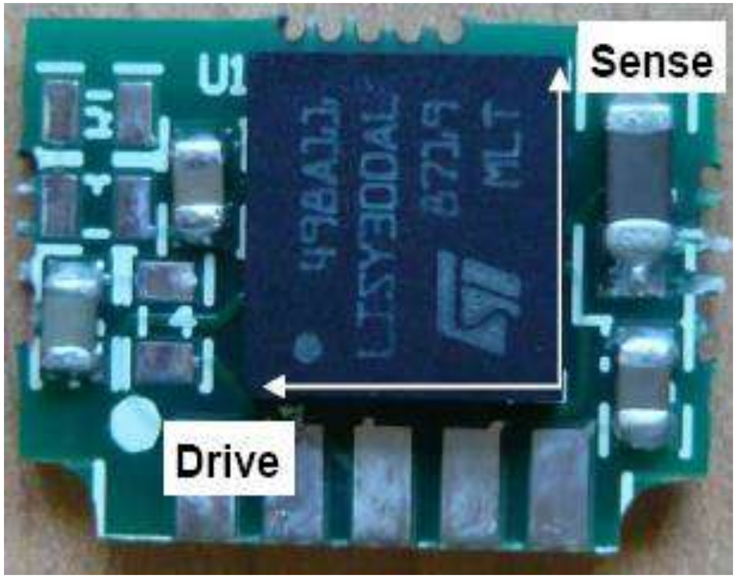
- **Pitch** is rotation around the lateral or transverse axis, (y-Axis)

MEMS - Yaw Gyroscope

- **Gyroscope** measures the rotational velocity or angular rate of an object

- **MEMS Sensor** converts Input Signal (Angular Rate) in a Differential Capacitive Change, based on the Coriolis apparent acceleration

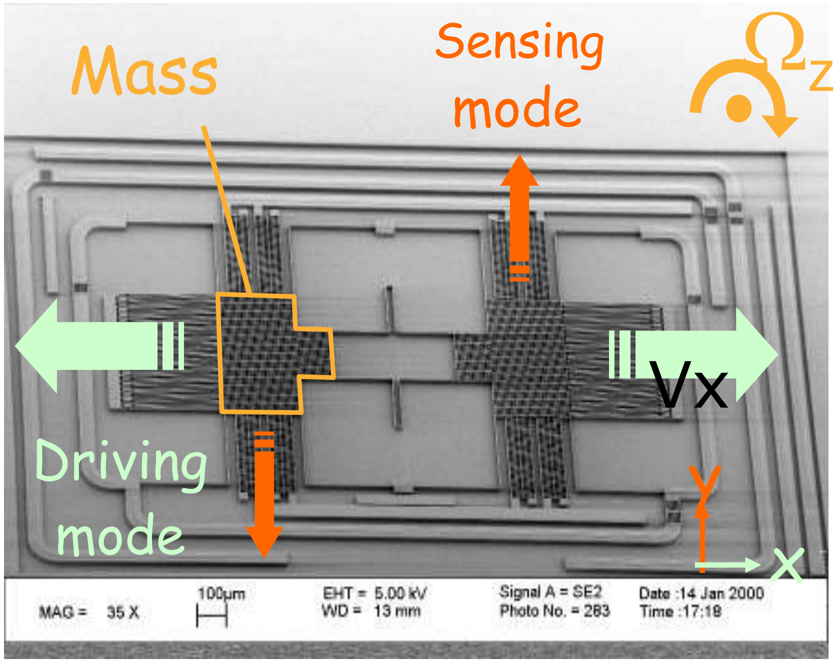




Gyroscope

Gyroscope is based on the Coriolis principle.

The force acting on the movable masses and read by the sensing interface can be expressed as:



$$Fc = 2\ M\ V_x \times \Omega_z$$

<u>Where:</u>

$X = X_o \sin(\omega_o t)$

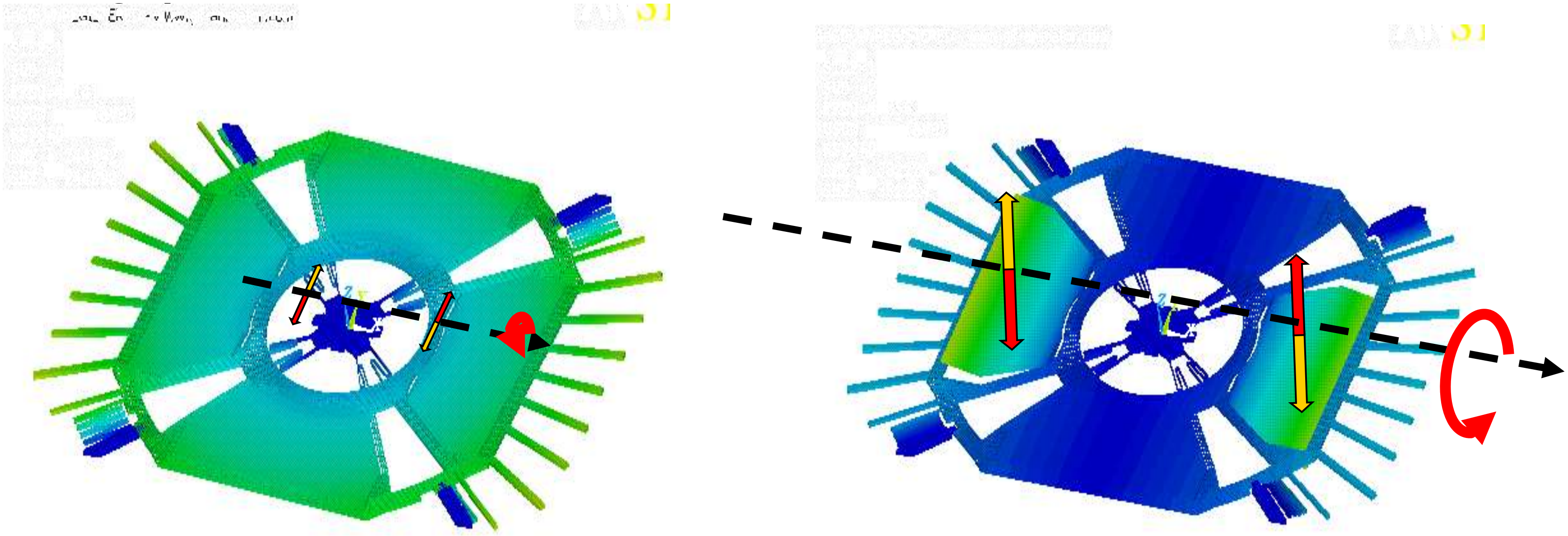
$Vx = X_o \omega_o \cos(\omega_0 t)$ = driving speed

Ω_z = angular rate

MEMS Gyroscope – Principle

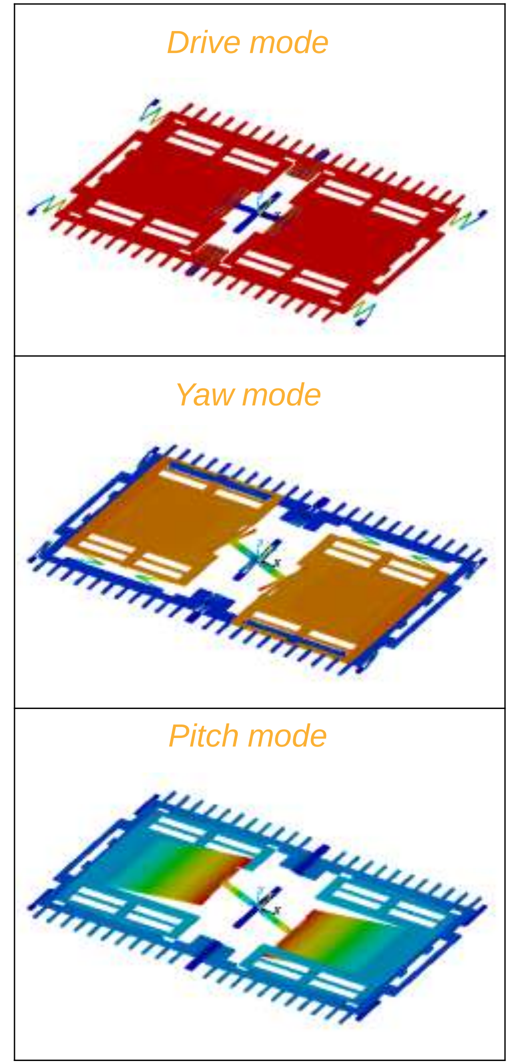
- Masses are kept moving (oscillating with capacitive drive circuitry)

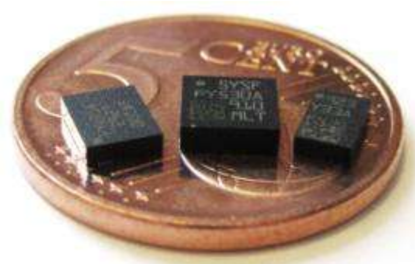
- As soon as an external angular rate is applied, capacitive sensing interface reads displacement



Gyroscopes – Key features

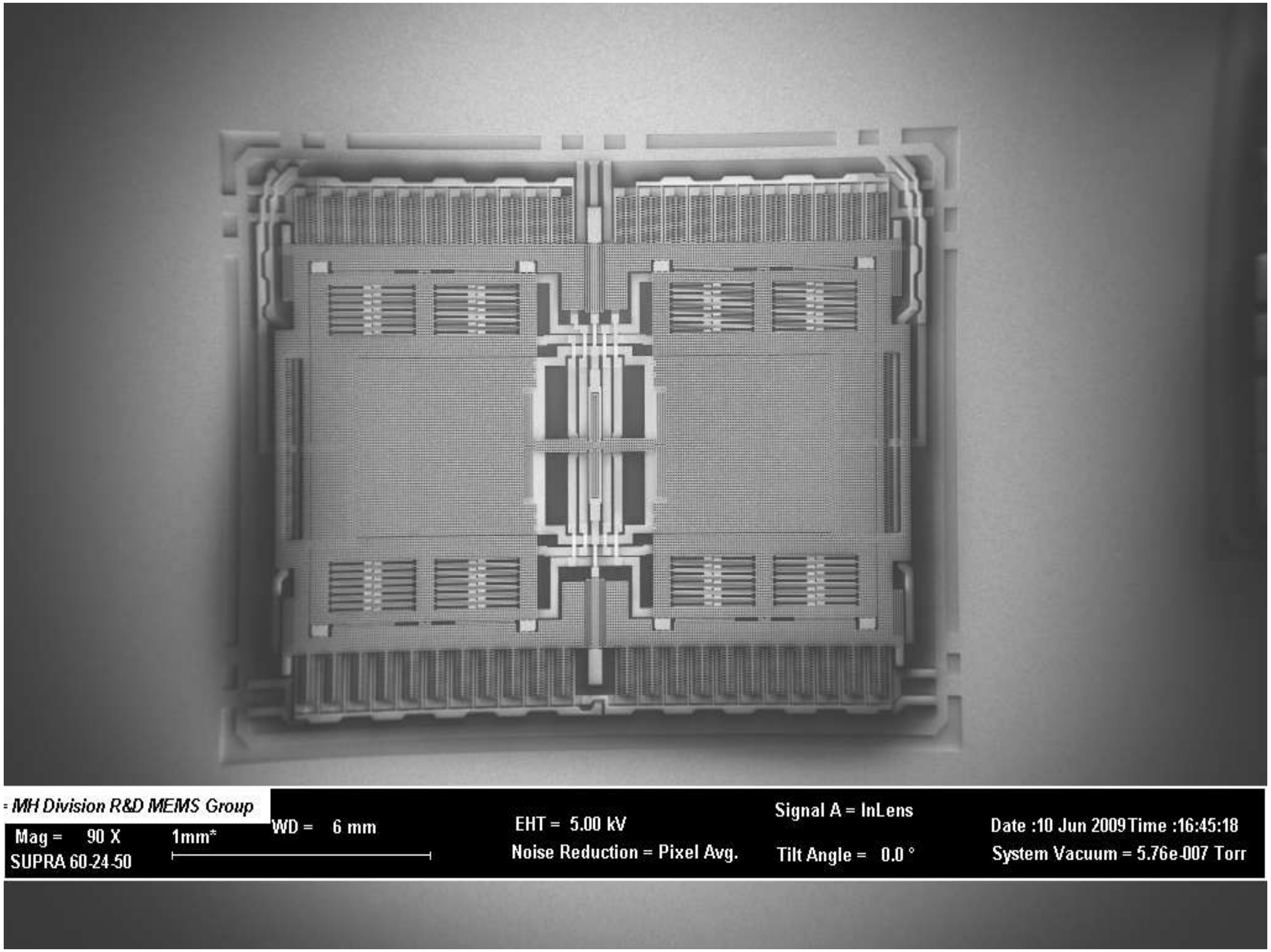
- Sensing element and ASIC in a single package
- 15 products: **1-Axis** (Yaw), **2-Axis** (Pitch/Roll and Pitch/Yaw) and **3-Axis**
- From **±30°/s** to **±6000°/s** Full scale
- **1** or **2 full scales** "out" and "4xout"
- Analog and Digital output
- Integrated low-pass filters
- Sleep & Power down modes
- Low power consumptions*:
  - 6.8mA (Normal)
  - 2.1mA (Sleep)
  - 1µA (Power down)
- Self test function
- **High resolution**: 0.01°/s/√Hz*
- **High** Thermal **Stability** (0.02°/s/°C)*
- Factory trimmed parameters
- **High shock** & **vibration** survivability
- Temperature range -40 to 85°C



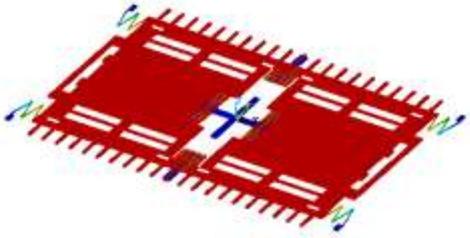


* Typ. Values for LPx403AL

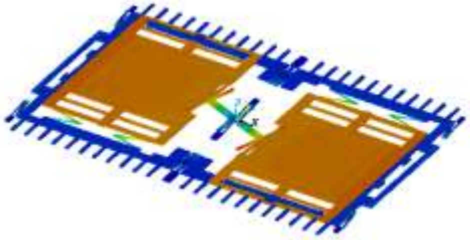
Gyroscopes – Key features



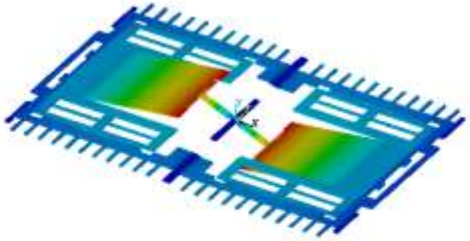
Drive mode



Yaw mode

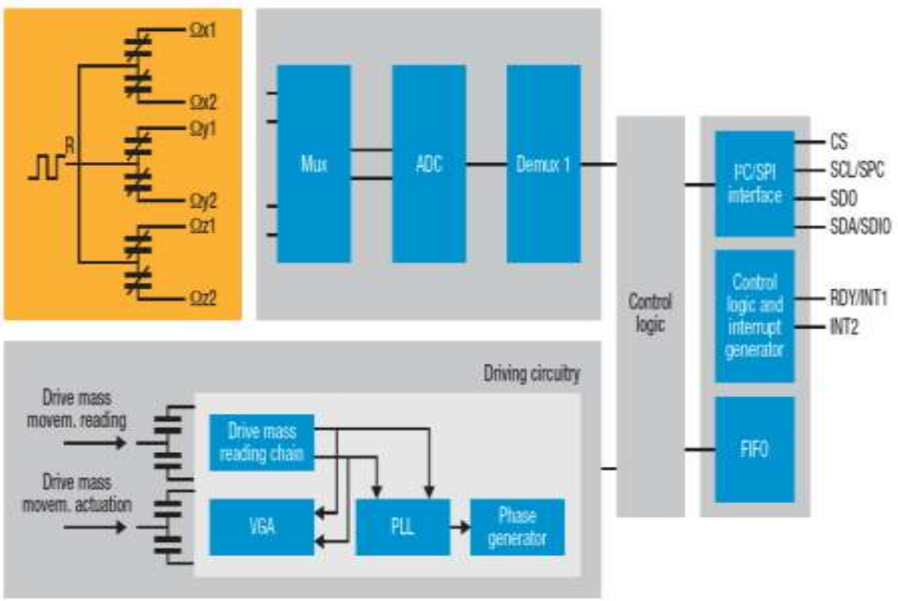


Pitch mode

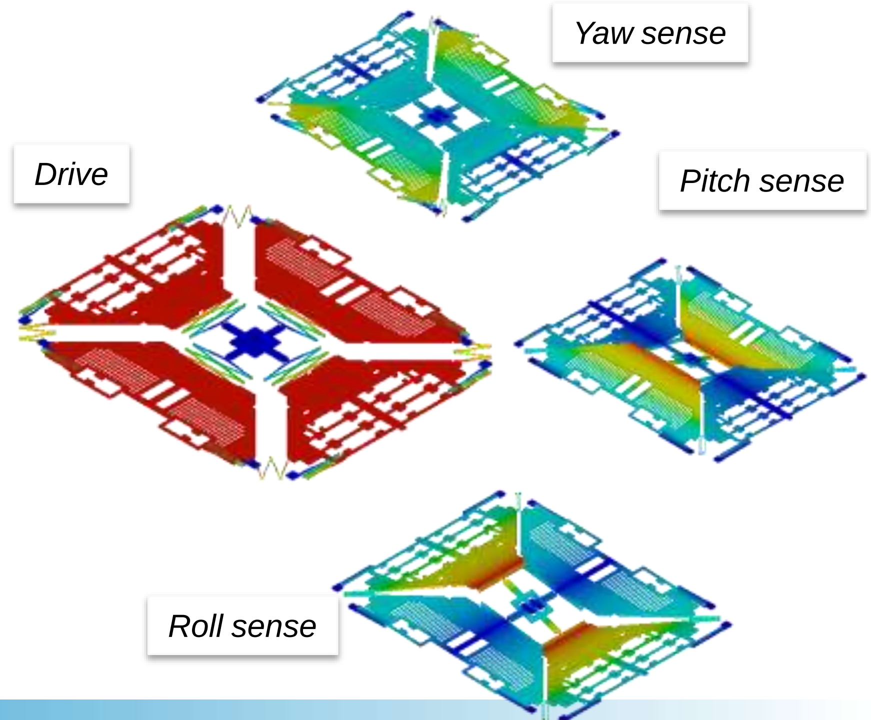


* Typ. Values for LPx403AL

3-axis Digital Gyroscope: L3G4200D



High-performance 3-axis digital-output gyroscope that embeds a FIFO (first-in first-out) memory block



ST MEMS gyroscopes employ an industry-unique concept of a single sensing structure for motion measurement along all three orthogonal axes

MEMS Gyroscopes: Products & Applications

Increasing full scale

Yaw	*Pitch & Roll*	*Pitch & Yaw*	*Yaw ,Pitch & Roll*
LY3200ALH ±2000dps 3x5x1	LPR4150AL ±1500dps ±6000dps 4x5x1	LPY4150AL ±1500dps ±6000dps 4x5x1	L3G4200D ±250dps ±500dps ±2000dps 4x4x1
	LPR450AL ±500dps ±2000dps 4x5x1	LPY450AL ±500dps ±2000dps 4x5x1	
LY3100ALH ±1000dps 3x5x1	LPR430AL ±300dps ±1200dps 4x5x1	LPY430AL ±300dps ±1200dps 4x5x1	
LY330ALH ±300dps 3x5x1	LPR410AL ±100dps ±400dps 4x5x1	LPY410AL ±100dps ±400dps 4x5x1	
	LPR403AL ±30dps ±120dps 4x5x1	LPY403AL ±30dps ±120dps 4x5x1	
Single axis	*Dual axis*	*Dual axis*	*Tri axis*

The right portfolio to address a wide range of applications

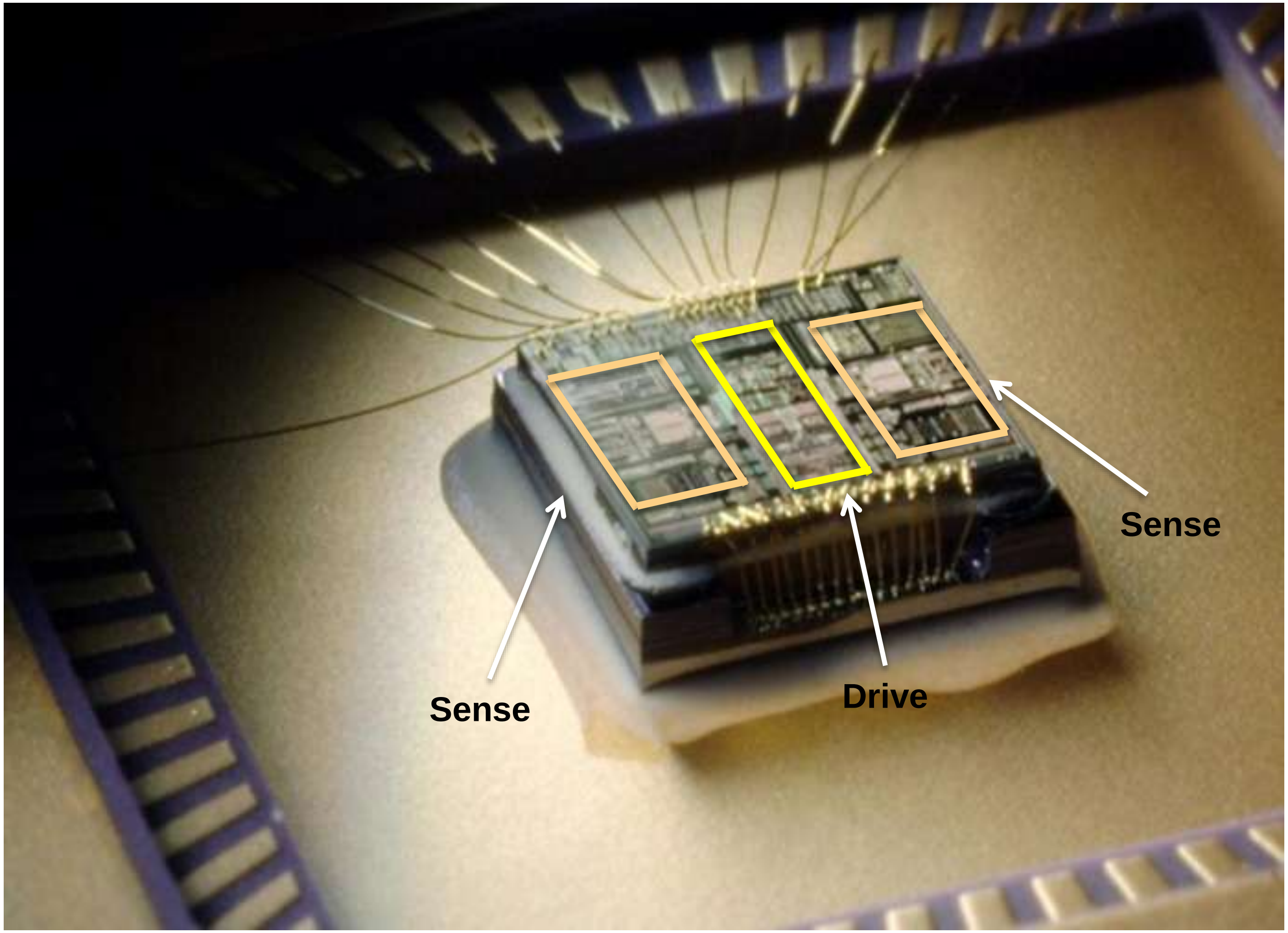
Gaming

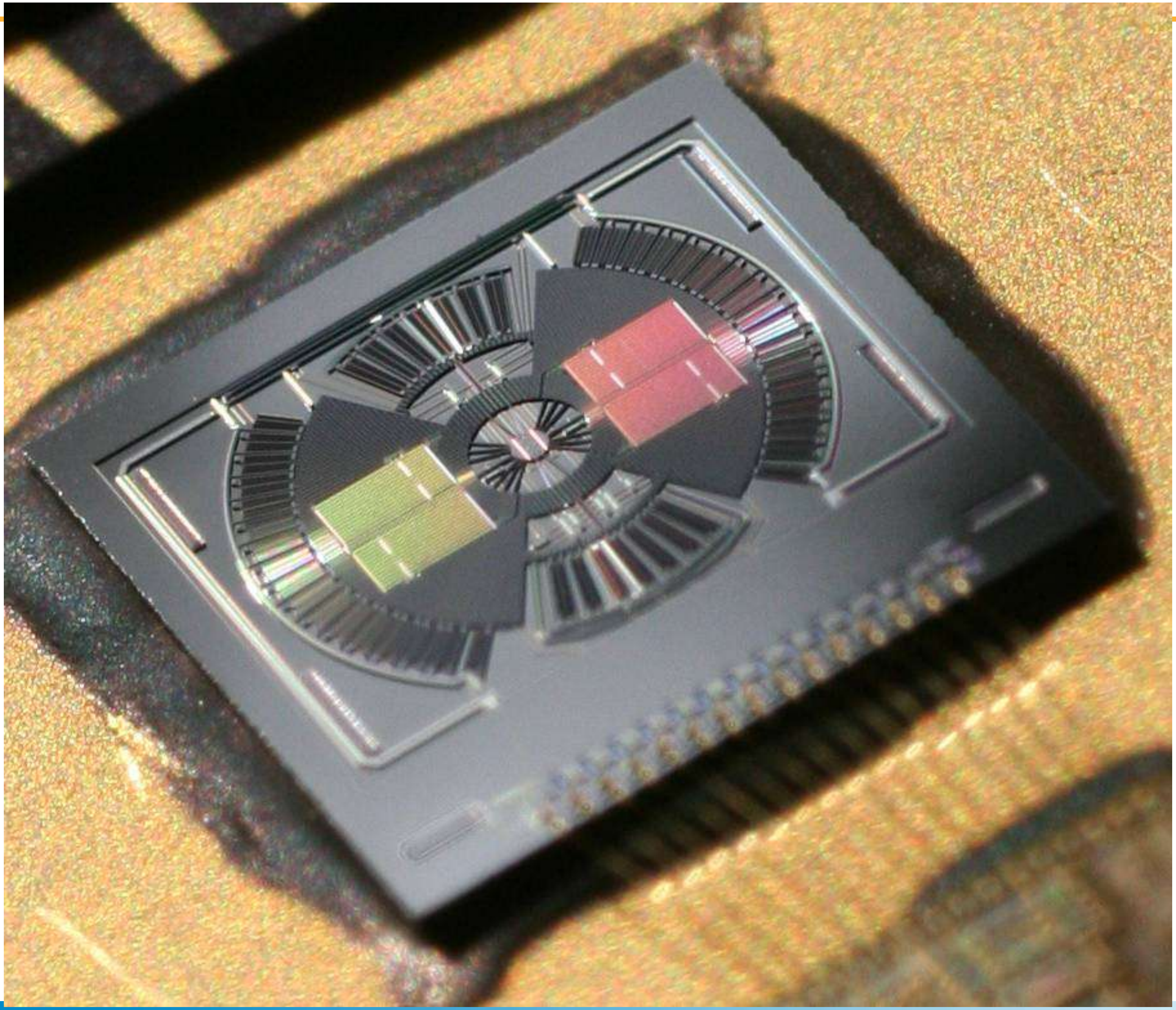
Pointing devices

Car Navigation

Image Stabilization

Stacked die assembly detail





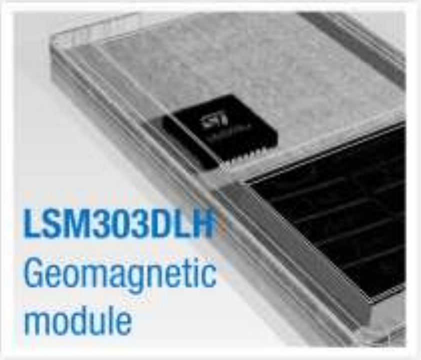
Modules - SiP

E-Compass: Magnetometer + Accelerometer

E-compass – LSM303DLH:

- MEMS Accelerometer + Magnetic sensing elements and ASIC
  - 3-axis Digital Accelerometer: ±2g/±4g/±8g full scale
  - 3-axis Digital Magneto sensor: from ±1.3 up to ±8 gauss full scale

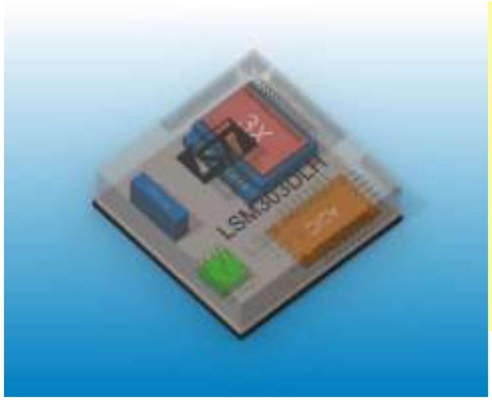
- Targeted applications
  - Compensated compass
  - Location based services (LBS)
  - Map rotation
  - Position detection
  - Point of interest (POI)
  - Motion-activated functions and intelligent power saving



LSM303DLH:
MEMS Digital
Compass Module

LSM303DLH: 6-Axis Module overview

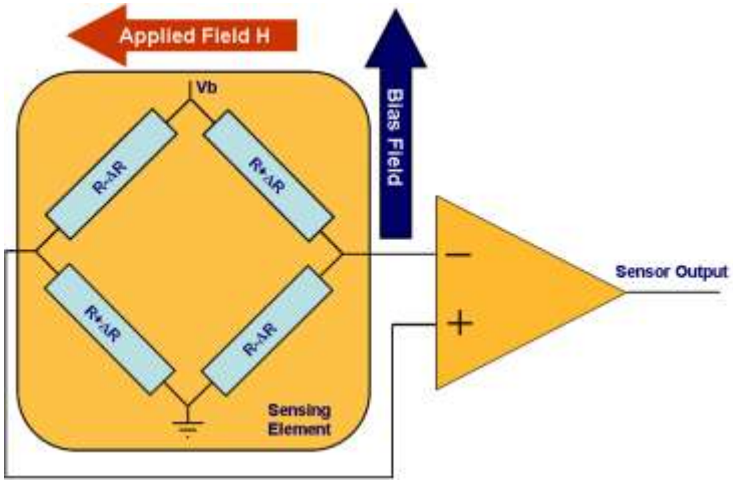
6D module: 3-Axis Accelerometer & 3-Axis Magnetometer

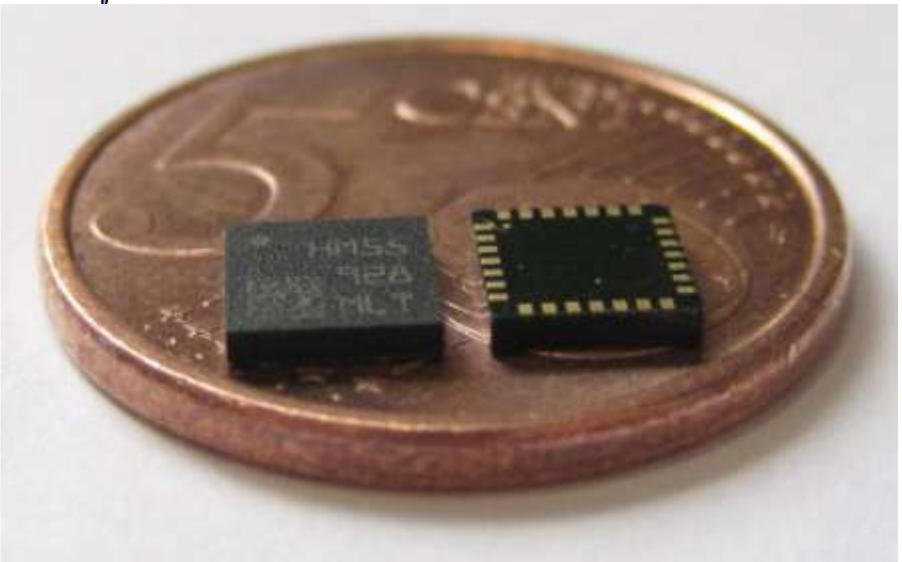


- 3A & 3M Module
- 1.0mA current consumption
- ±1.3 to 8.1 gauss MAG full scale
- ±2g/±4g/±8g Acc. full scale
- 1mg resolution (12 bit)
- Built-in Strap drive circuits
- Self test (Accel & Mag)
- I2C serial interface
- Power down mode
- LGA 28 – 5x5x1

Earth's magnetic field roughly 0.6 gauss

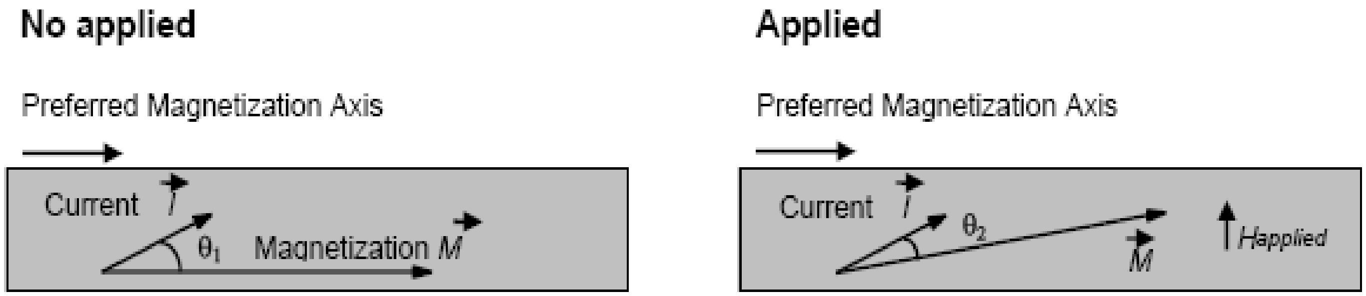
LSM303DLH cover all measurement range





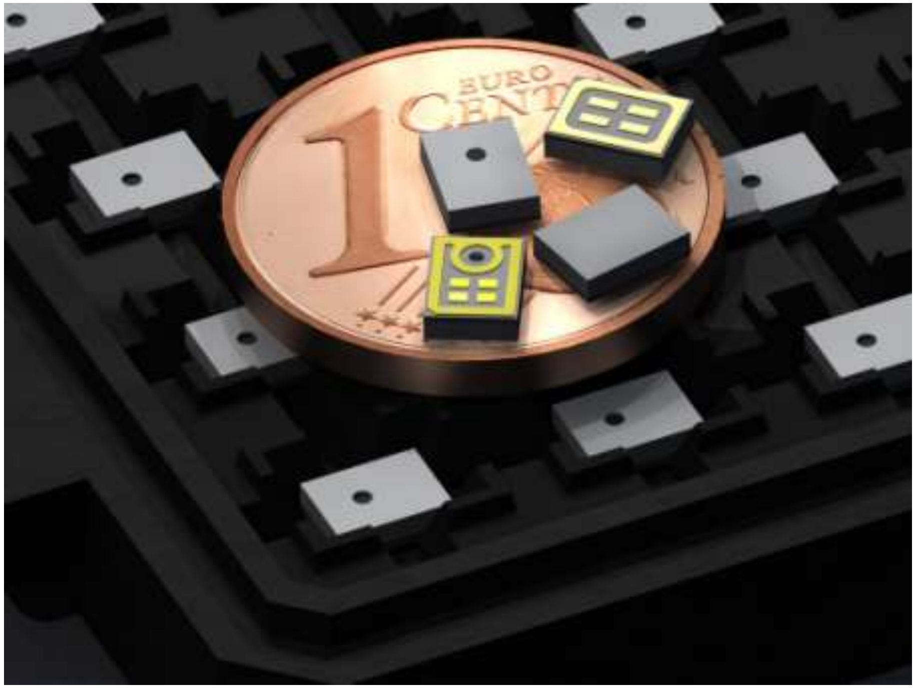
Anisotropic Magneto-Resistive Sensor

- AMR Sensor - Permalloy thin film material (NiFe alloy)



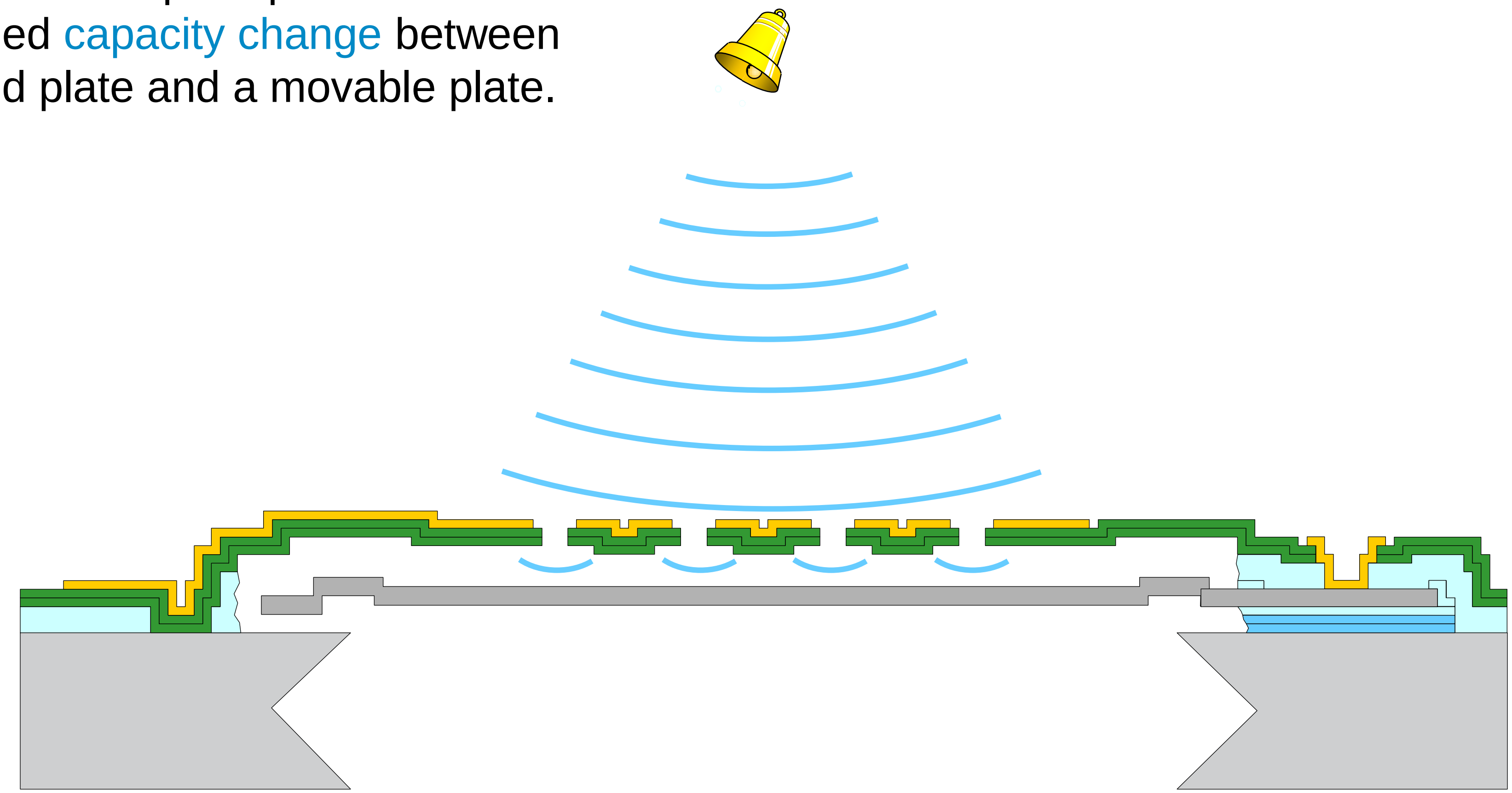
- Magneto-resistance is the property of a material to change the value of its electrical resistance when an external magnetic field is applied
- In AMR sensors, the sensing element is composed by material where a dependence of electrical resistance on the angle between the direction of electrical current and orientation of magnetic field is observed
- In Wheatstone Bridges AMR, the sensing element detects resistance change effects due to magnetic field change, that is translated into a digital word by the electronic section embedded into LSM303DLH

Microphone



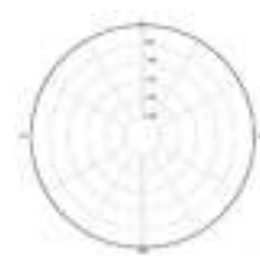
MEMS microphone structure

Transduction principle is the coupled capacity change between a fixed plate and a movable plate.



MEMS Microphone – MP45DT01

- Top Digital microphone, Pulse Density Modulation single bit output with stereo support
- Omni-directional sensitivity
- High level performance for :
  - Signal to noise ratio: 58dB (@1KHz)
  - Acoustic overload point: 120 dBSPL
  - Power supply rejection: -70 dBFS
  - 10ms wake-up time
- High Frequency response :
  - Voice / Hearing range 20Hz to 10 kHz
- Low power consumption: 650µA and 20µA
- Small Package, 4x5 HLGA package
- Single supply voltage from 1.64 to 3.6V



Omnidirectional micro

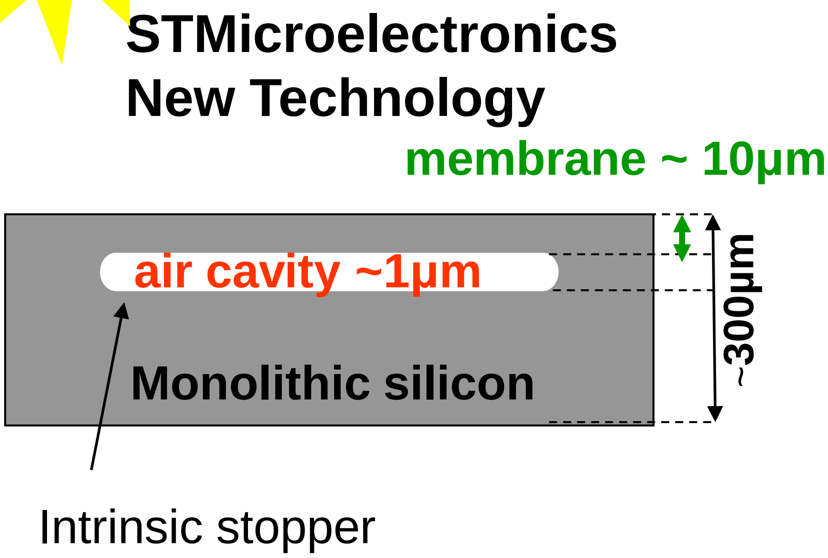
ST MEMS Microphone Benefits

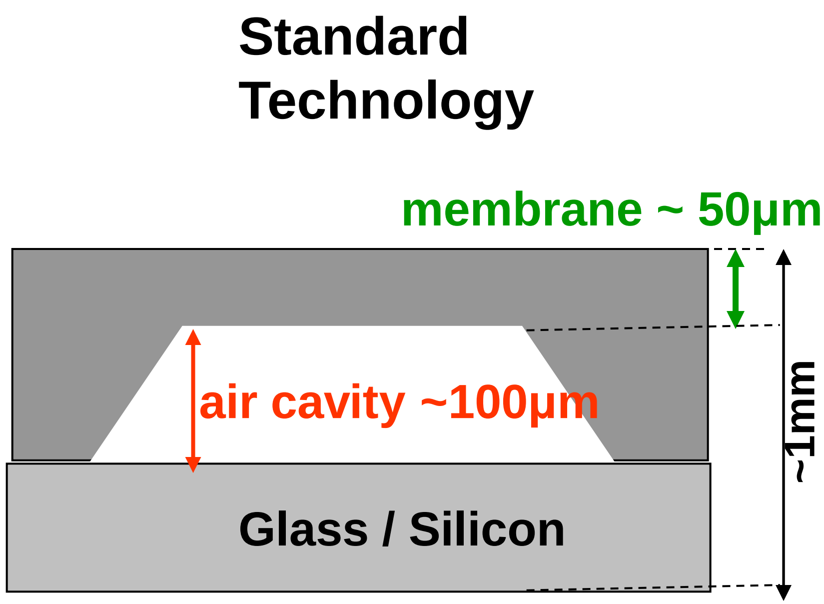
- ***Cost-efficient manufacturing in high volumes*** using standard, existing silicon processes
- Fully ***automated manufacturing line***, no manual assembly
- ***Same process and manufacturing tools*** for multiple versions of different microphone topologies and versions
- ***Whole supply chain managed by ST***
- ***New features and logic integration*** using future silicon processes
- Very good ***sensitivity vs. temperature stability***
- ***Better matching of acoustical parameters*** for beam-forming and multi microphone applications.
- Very ***good reliability*** due to MEMS element silicon properties, material does not age or fatigue
- Very good ***re-flow properties*** due to robust package and internal silicon based structure

Pressure Sensor

ST "Full Silicon" vs. Std Technology

ST patent

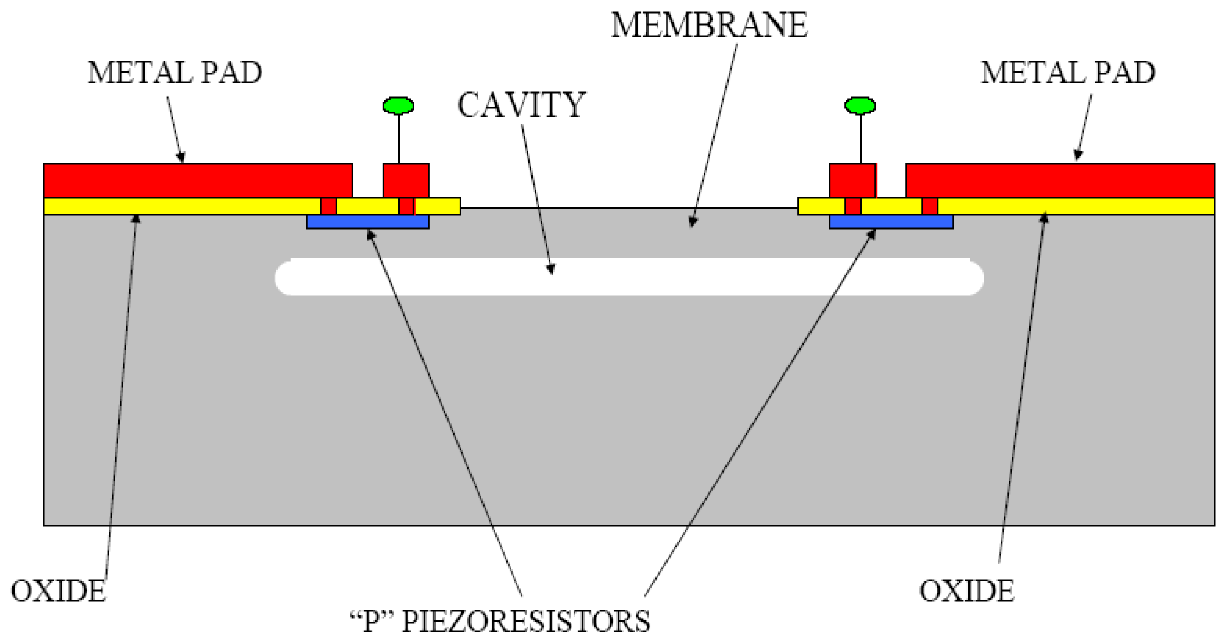




Monolithic monosilicon sensor with hermetic cavity

Silicon membrane bonding with glass/silicon wafer to create the cavity

VenSENS Process

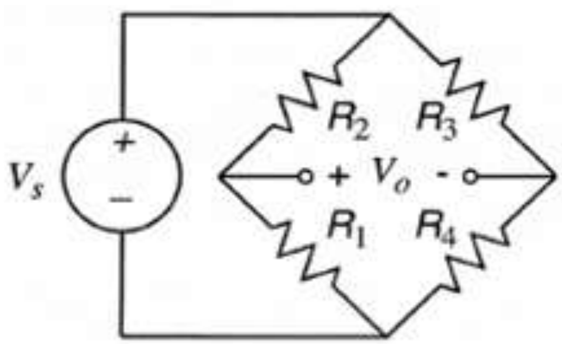


- No wafer to wafer bonding for cavity creation
- Thinner and smaller chip
- Intrinsic stoppers
- High Shock Survivability
- Stable and Reliable

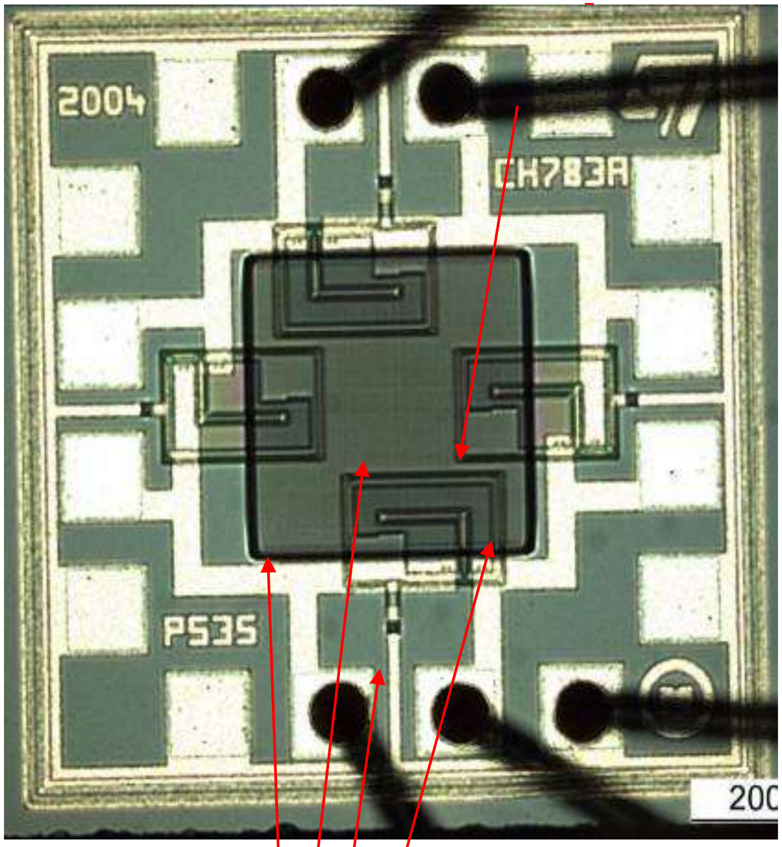
Pressure Sensor DICE

DICE:

- Integrated Wheatstone bridge
- Die size 0.8 mm X 0.8 mm
- Membrane Edge 300 µm
- Rin= 3.7 kOhm



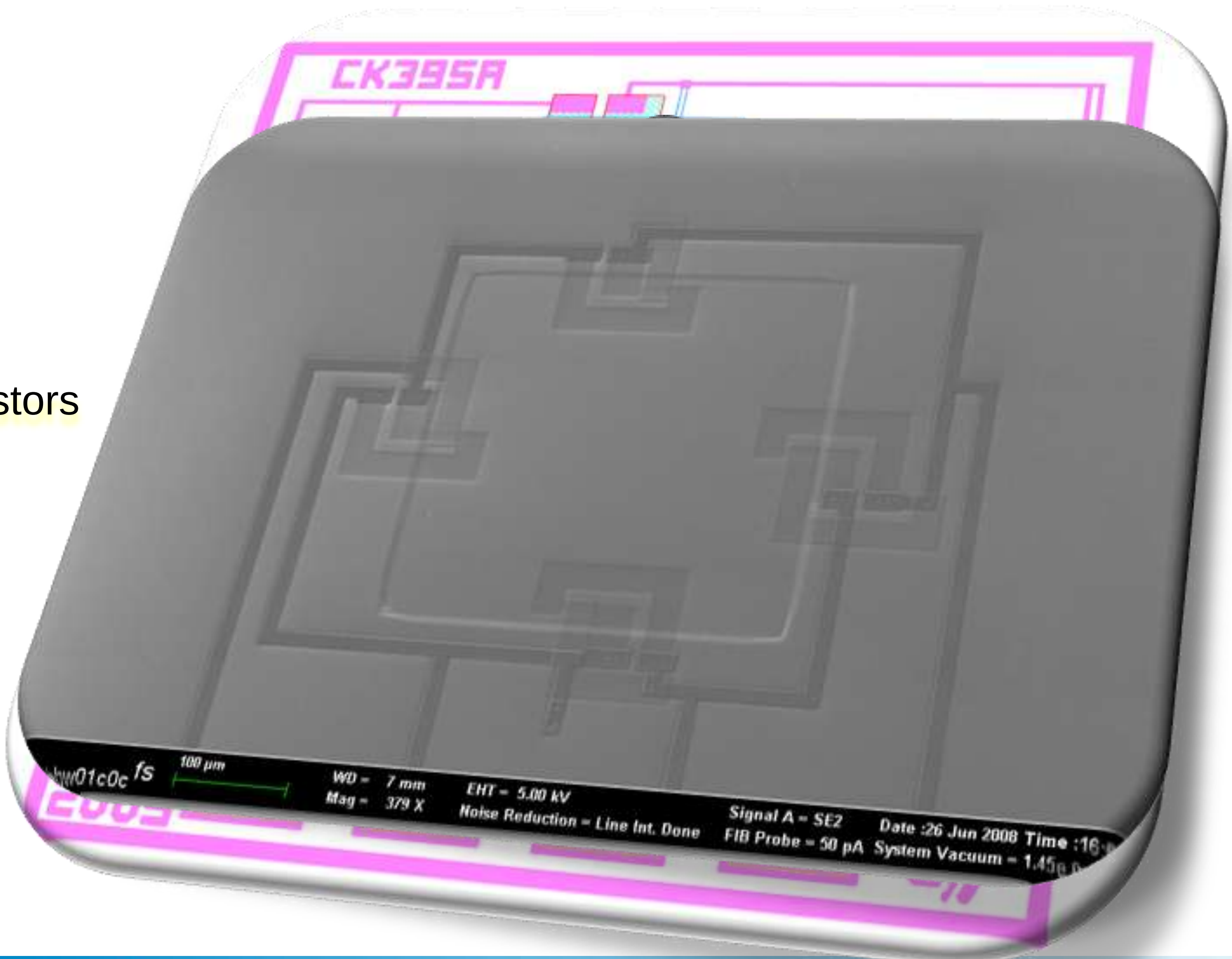
Suspended



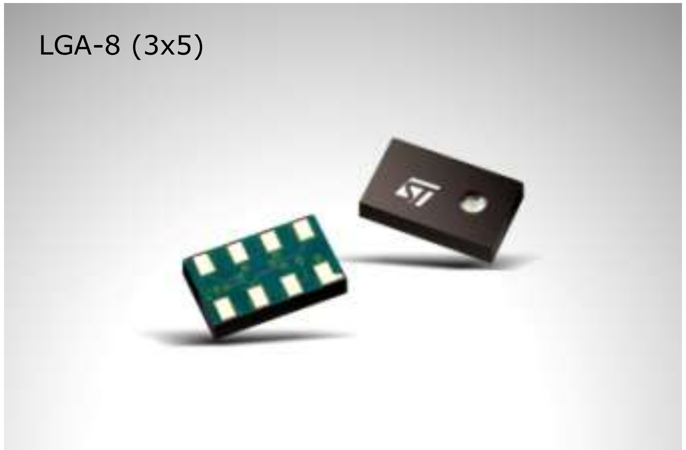
Piezoresistors

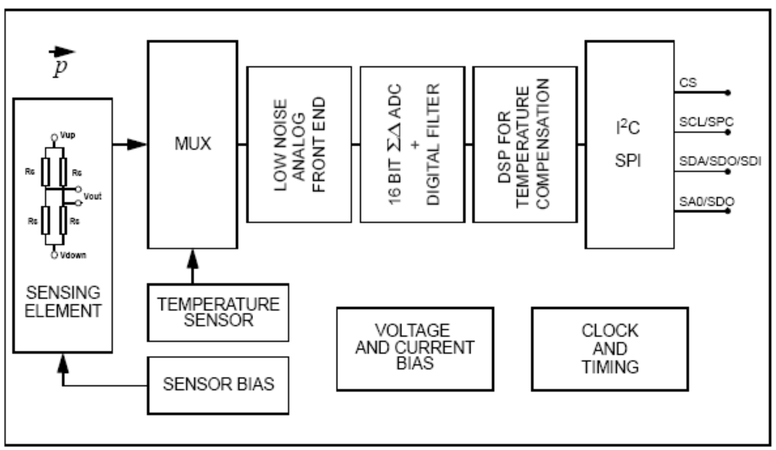
1) Piezoresistive Pressure Sensor

4 resistors



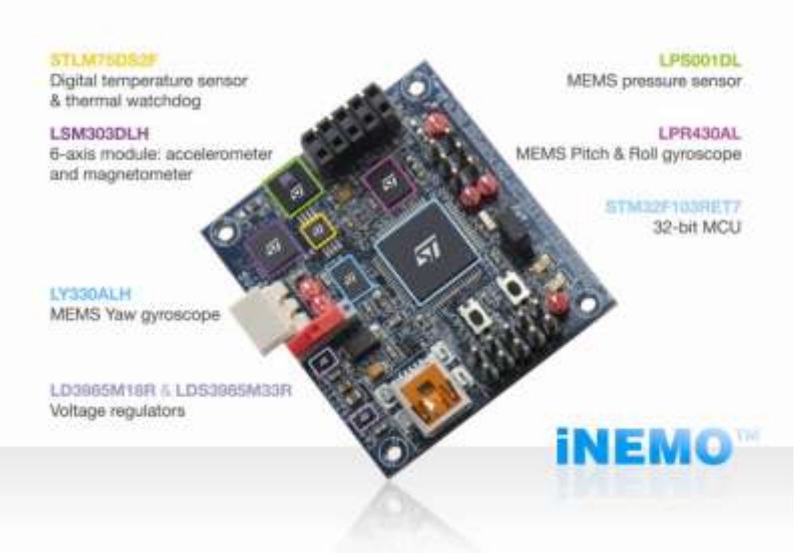
LPS001: Absolute Piezo resistive pressure sensor





- **Absolute Piezo resistive pressure sensor**
- 300-1100 mbar absolute pressure range
- **Up to 0.065 mbar resolution**
- Very low power consumption
  - 190 μA continuous mode (400 during conversion)
  - 120 μA low power mode
  - 5 μA power down
- Embedded Offset and Span temperature compensation
- Embedded 16 bit ADC
- Digital SPI and I2C interfaces
- Supply voltage 2.2 V to 3.6 V
- 1.8 V compatible Ios
- High shock survivability (10000 g)
- Small and thin package

STEVAL-MKI062V2 – iNEMO – 10-DOF

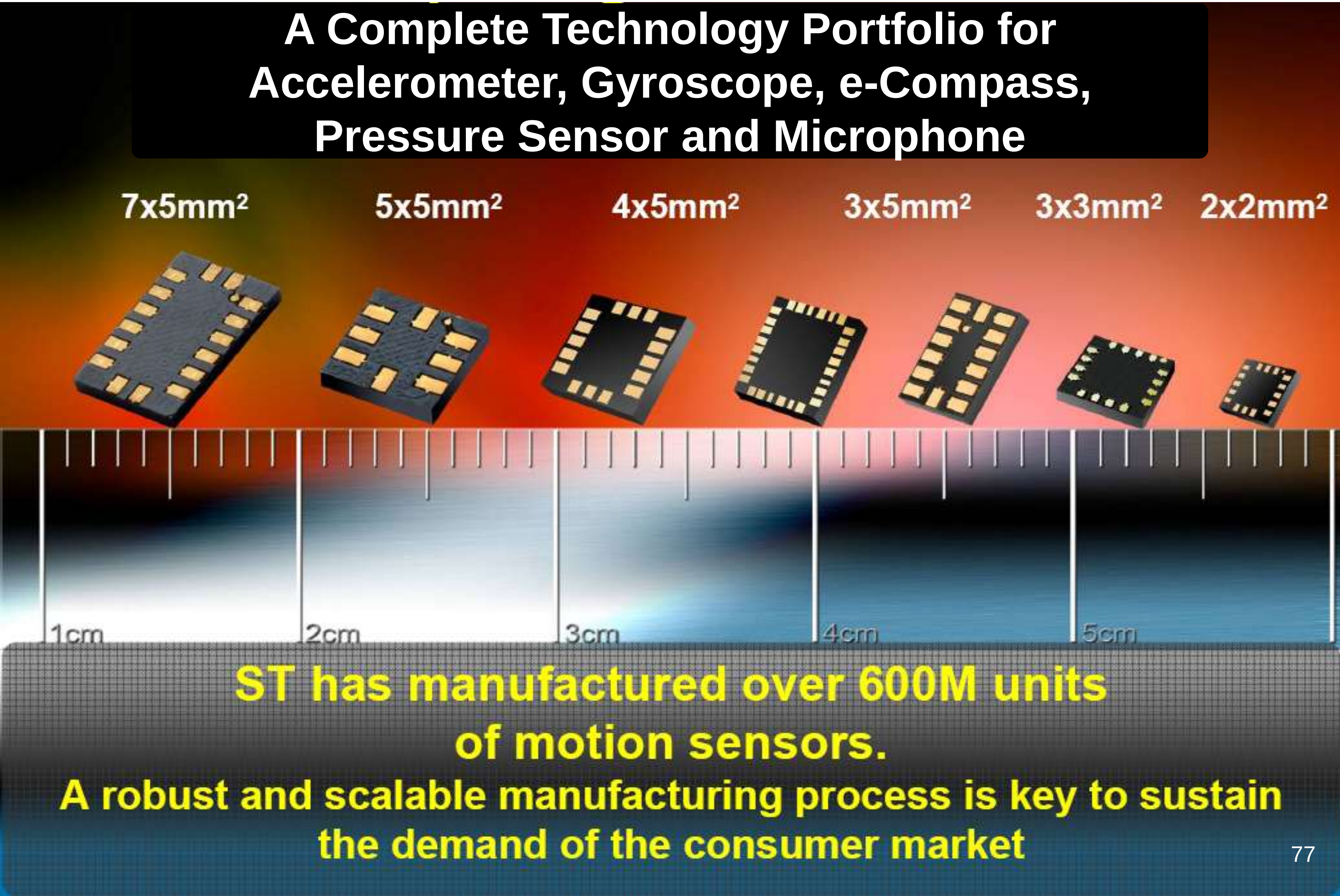


- **10-DegreesOfFreedom platform:**
  - 3-Axis Accelerometer
  - 3-Axis Gyroscopes
  - 3-Axis Magnetometer
  - 1 Dimension of pressure information
- STLM75: temperature sensor with –55 to +125°C range and I^2C
- MCU - STM32F103RE

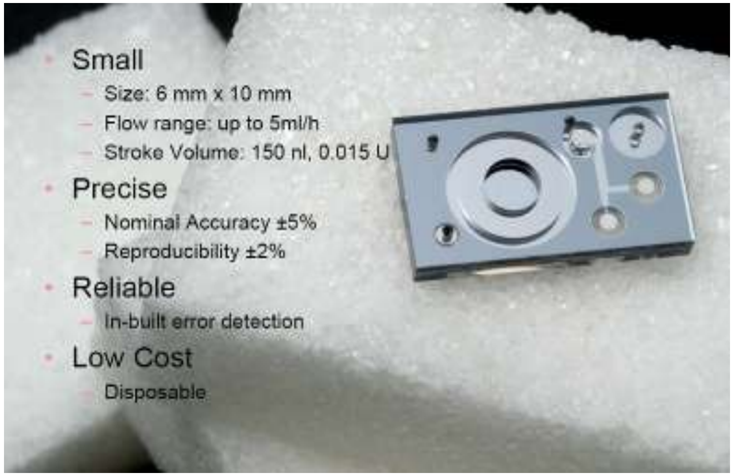
Key Messages & Conclusion

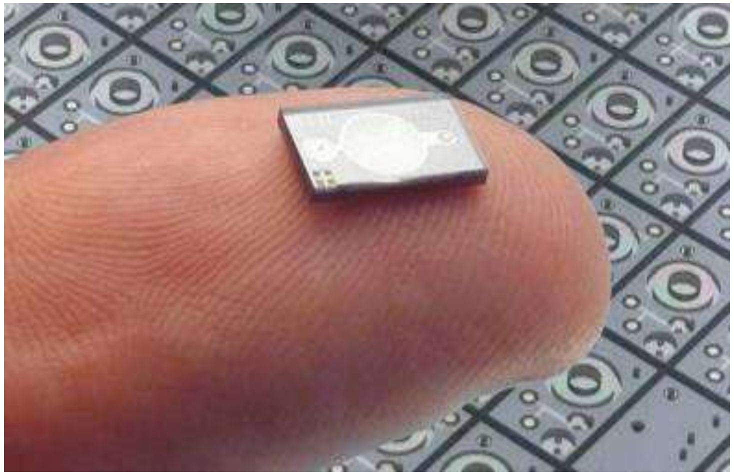
ST Leadership in MEMS:

High Volumes & Die Shrink



Insulin Nanopump in MEMS Technology





Disposable Healthcare

- Precise stroke volume of 150nl
- Max. Flow 5ml/h
- Integrated pressure sensor and error detection
- Driven by external piezo.
- Invented by Debiotech

DEBIOTECH SWITZERLAND

ST In-*Check*™ for DNA Analysis

Molecular Diagnostic

Biological Content

From ST partners

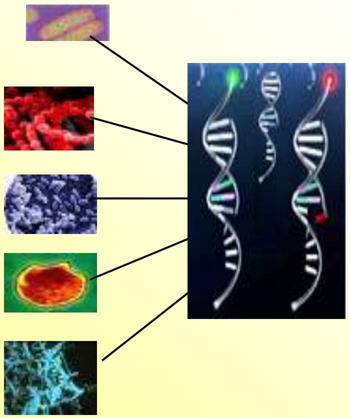
Pathogen A

Pathogen B

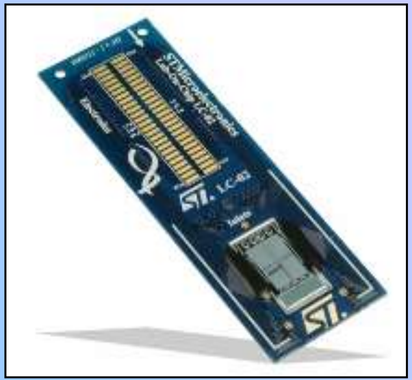
Pathogen C

Marker A

Marker B



Biochip Core



Temp. Control System

Reader

Software platform

1Bunits delivered by e/o 2010 but

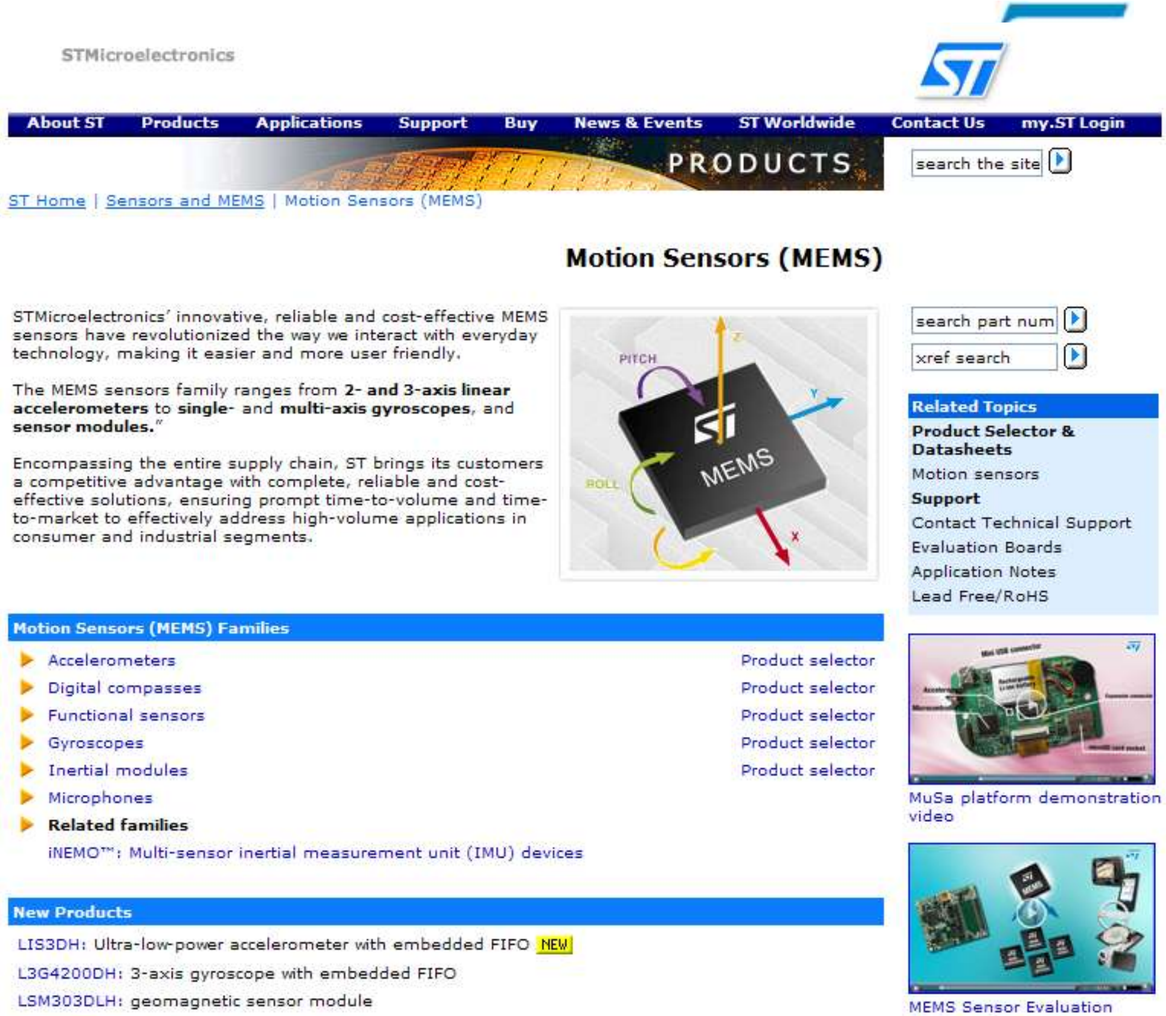
- Continuous challenges
  - MEMS Mechanical structure design
    - Die shrink with equivalent Mechanical properties
  - ASIC electronic design
    - Signals amplification
    - Reducing power consumption
  - Package manufacturing
  - Test equipment
  - Modules – System in Package
  - Embed more & more features

  - Many applications & domains are still to investigate

For more information

- Web site

www.st.com/mems



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