# From CMOS to CMORE:

## innovation on a MEMS platform


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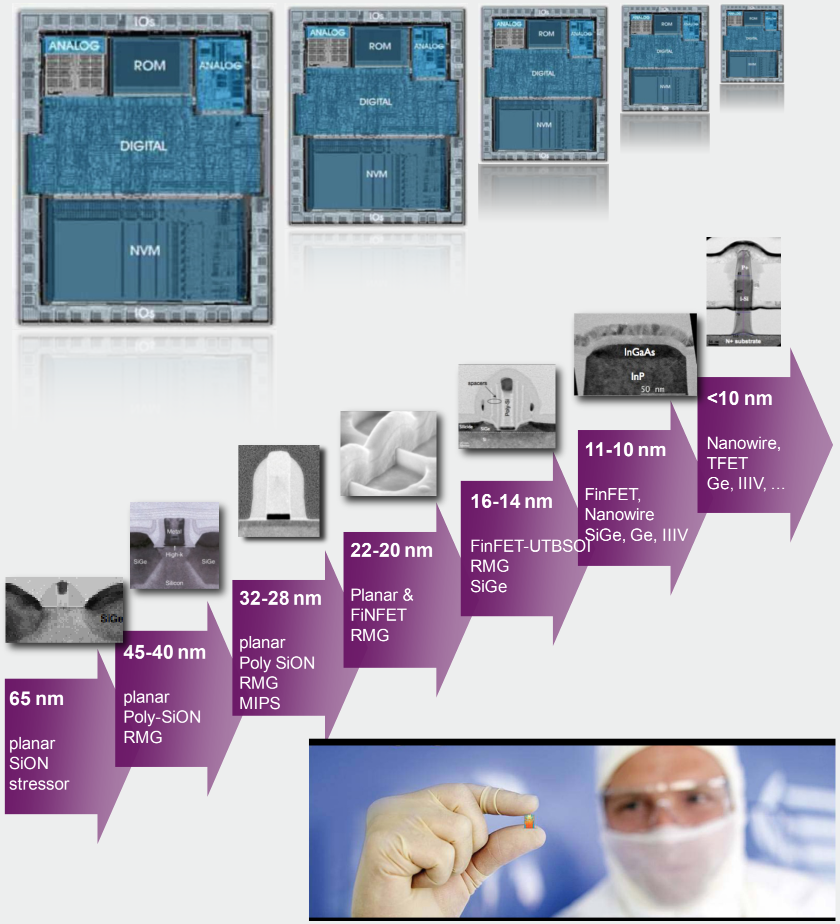
Paru Desphande, Peter Peumans,

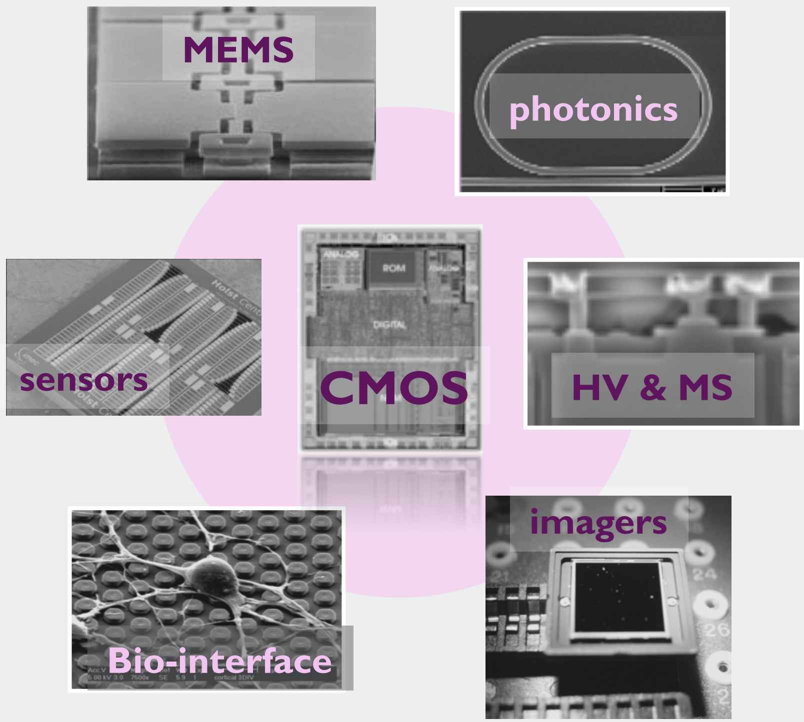
imec CMORE-Technology and Lifescience Technology teams

# FROM CMOS TO ‘CMORE’

## More Moore
CMOS Scaling




## More Than Moore
Multi-functional SOC/SIP



# CMORE
## THE ROUTE FROM SILICON CONCEPT TO A PRODUCT

(Co-)development

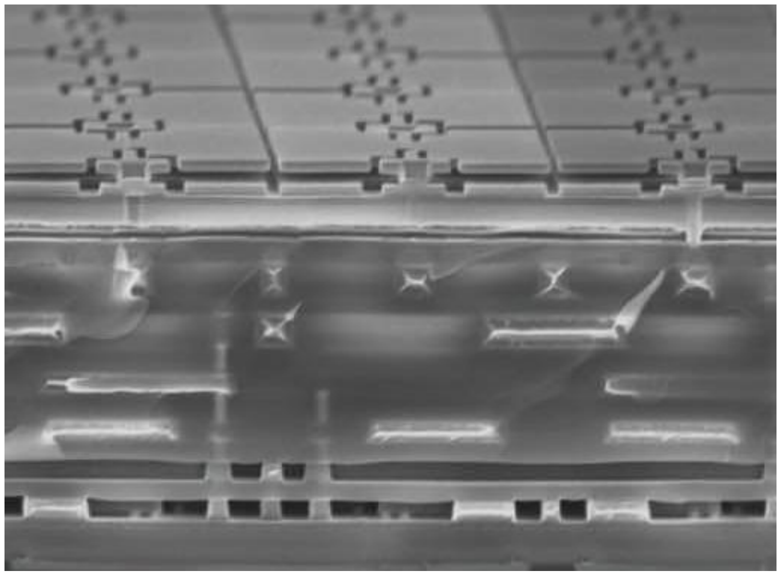
- Concept Design
- Process development, Packaging, Testing, Reliability
- Product Qualification

Prototyping

- Prototyping, Low-volume manufacturing @ imec
- Transfer

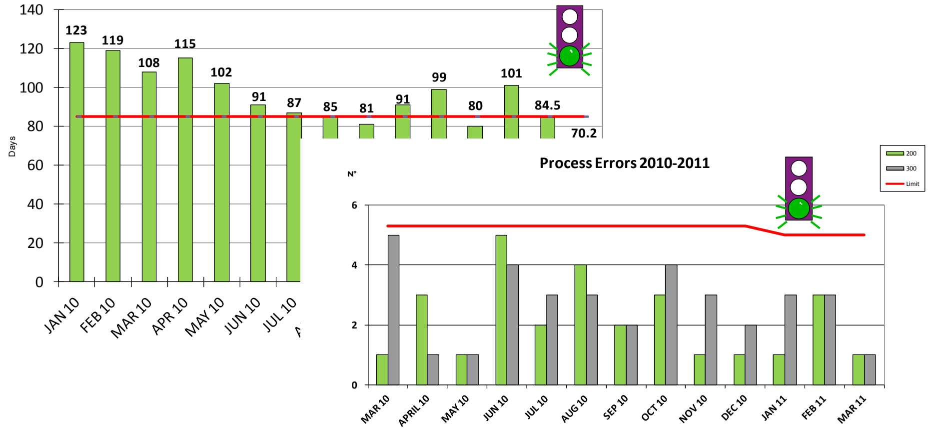
Production

- High-volume manufacturing @ foundry partner



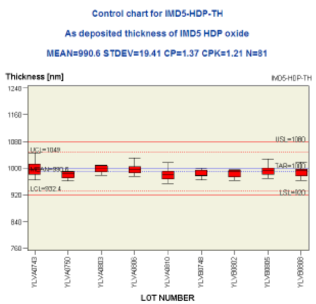
# CMORE TECHNOLOGY PLATFORMS

## Quality and cycle time KPIs

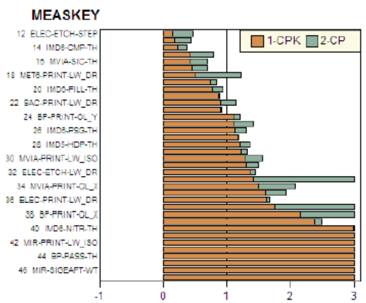



## Statistical Process Control

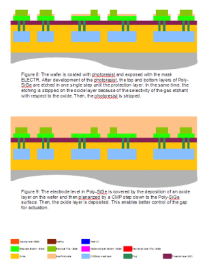
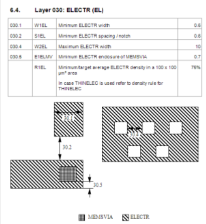
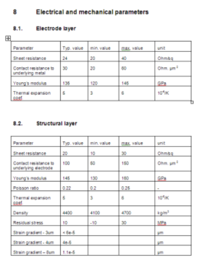
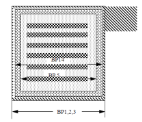
In-line SPC




Monitoring Cp/Cpk




## Mature design kits

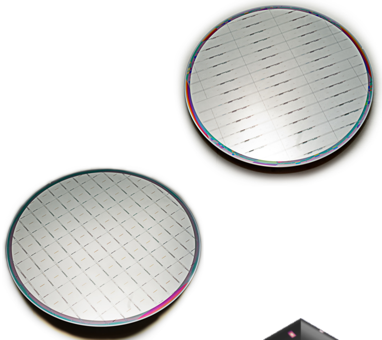
| Process description | Layout rules | Material properties | P-cells & Models |
|---|---|---|---|
|  |  |  |  P-cells on component Level<br>MEMS (limited)<br>• Bondpads<br>• Anchors<br>• Beams …<br>• Std test structures<br>• Scripts |

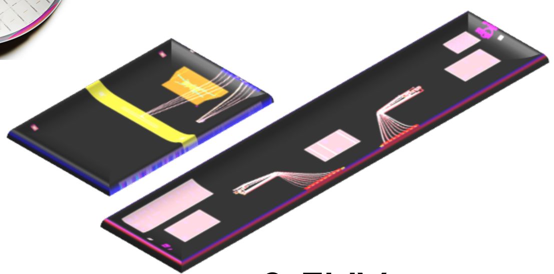
# IMEC PRODUCES HIGH-QUALITY EUV SENSORS FOR ASML'S NEXT-GENERATION LITHOGRAPHY TOOLS

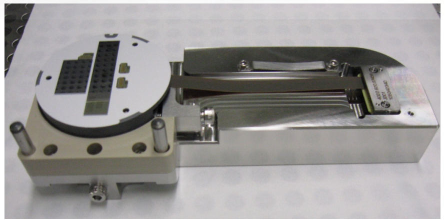
**CMORE landmark achievement in 2011: First qualified CMORE chipset installed in customer's product**

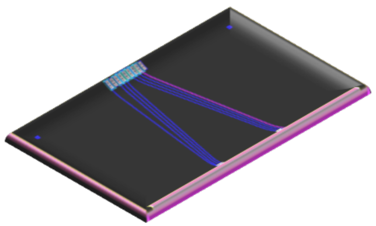

3 EUV sensors with superior lifetime and sensitivity

high and direct EUV irradiation doses









2 EUV position sensors
to calibrate, align and focus lens systems

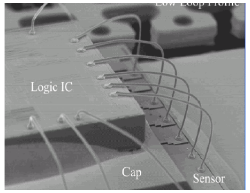
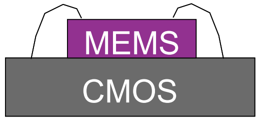
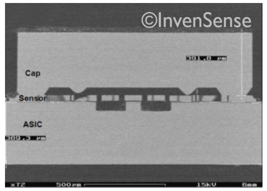
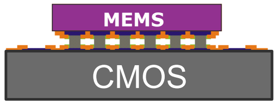
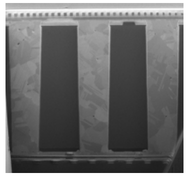
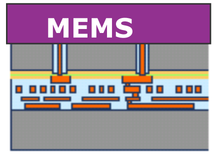
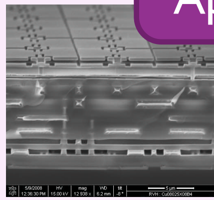
EUV Energy sensor
to monitor EUV dose

# MEMS TECHNOLOGY VISION

- Most MEMS devices are single components integrated with separate driver IC chip in multichip package.
- MEMS technologies are driven towards tighter integration with electronics for better performance, smaller form factors and packaging cost, enabled by:
  - Above IC MEMS
  - 3D Stacking

# CMORE SiGeMEMS TECHNOLOGY:
## 1. MONOLITHIC INTEGRATION WITH IC

IMEC Approach

| Different MEMS-IC Integration approaches |  SIP: Stacked die  |  SIP: F2F  |  SIP: 3D vias  |  SoC: monolithic  |
|---|---|---|---|---|
| Interconnect pitch | ~ 50 um | ~10um | ~10um | ~1um |
| Interconnect parasitics | few pF | >100fF | <100fF | few fF |
| yield | KGD | KGD (unless W2W) | KGD (unless W2W) | compound yield |

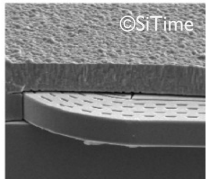
Monolithic approach:
- Most compact solution
- Better intrinsic system reliability: less components, less interconnections
- Best solution for applications that are very sensitive to parasitics
- BUT: MEMS yield is critical

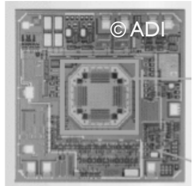
imec

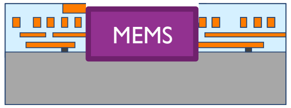
 

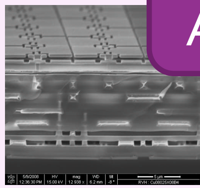
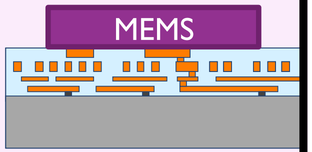
# CMORE SiGeMEMS TECHNOLOGY:
## 2. MEMS LAST (ABOVE CMOS)

IMEC Approach





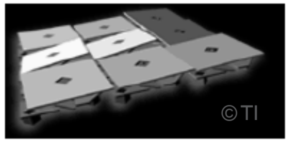
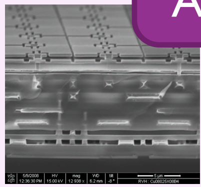

| Different Monolithic MEMS approaches | MEMS first | intraCMOS | MEMS last |
|---|---|---|---|
| MEMS processing | No thermal limitations | T-budget 800°C | T-budget 450°C |
| CMOS | Non-standard | Non-standard | any standard CMOS |
| Interconnections MEMS-IC | Peripheral around MEMS | Peripheral around MEMS | Distributed & massively parallel |

MEMS last:

- most flexible with respect to choice of CMOS technology
- very high-density and massively parallel interconnections possible
  → large arrays of MEMS (e.g. µmirror arrays)
- BUT: some loss in flexibility (e.g. material choice) due to T-budget

# CMORE SiGeMEMS TECHNOLOGY:
## 3. POLY-SiGe

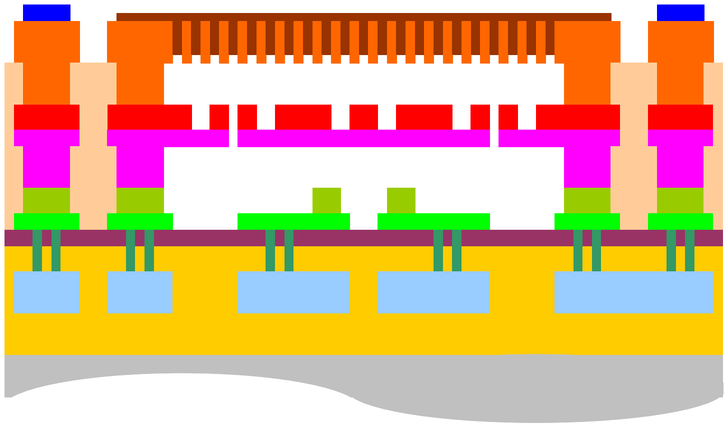
IMEC Approach

| Different Above CMOS MEMS approaches |   Al |  Poly-SiGe |
|---|---|---|
| Post CMOS integration | yes | yes |
| Fracture strength [GPa] | 0.2 | > 2 |
| Mechanical Q | low | > 10.000 |
| Reliability | creep: hinge memory effect | No creep |

Poly-SiGe:
- better mechanical properties than Al: higher strength and Q factor
- better reliability properties than Al: less creep and fatigue

# CMORE MEMS TECHNOLOGY FOCUS:
## 4. FLEXIBLE & MODULAR TECHNOLOGY FLOW

Monolithic
Above-IC
SiGe-based
Flexible MEMS technology




Surface micromachining on top of CMOS: temperature limited

450 °C for Al interconnections

Poly-SiGe deposited at 450 °C

E=140 GPa (60-70 *at.*% Ge)

Stress = ~0-70 MPa

Strain gradient = ±1 $\times 10^{-5}/\mu m$
(4 µm thick CVD+PECVD SiGe)

*Poly-Si*: 620 °C deposition, 800 °C needed for desired stress

Flexible and modular technology:
- Variable layer thicknesses
- Application-specific optimization of layer & material properties
- Application-specific functional add-on layers

# Imec's SiGe MEMS – PLATFORM

Generic poly-SiGe technology for MEMS:
- "stand-alone" MEMS, or,
- "MEMS above IC" (CMOS-MEMS)

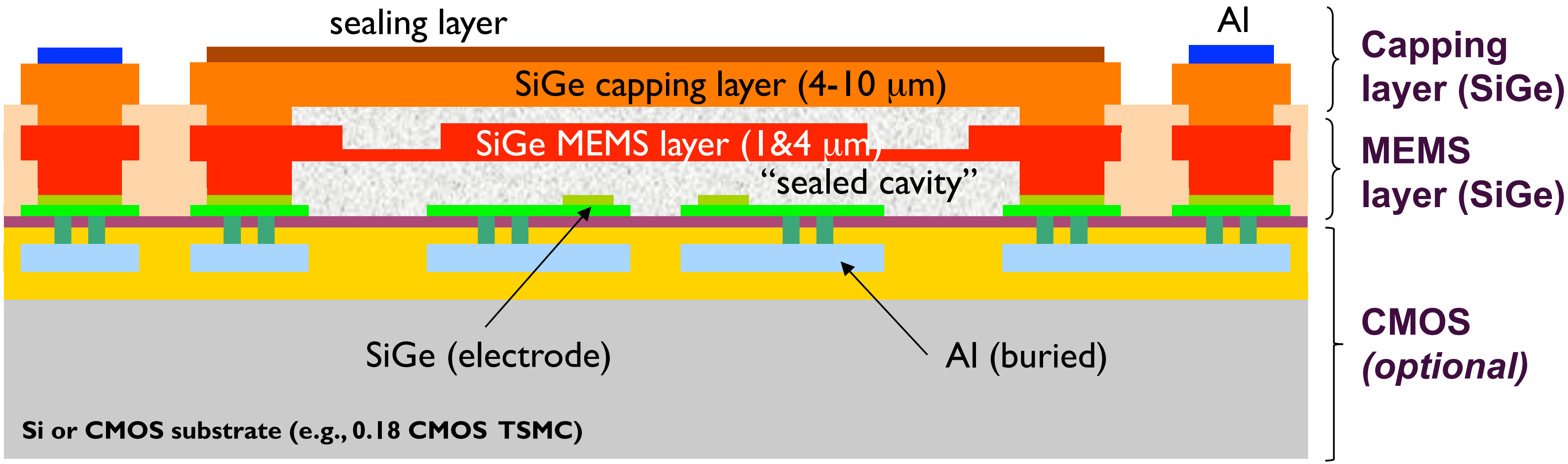
Two structural SiGe layers:
- **MEMS** structural layer (4μm standard)
- Thin film **capping/packaging** layer (4μm up to 10μm thick)

Gap in the SiGe structural layer: 0.5μm (optional: 0.2μm)

Low-T processing (< 460°C)

Hermetic package seal (1-100 Pa)

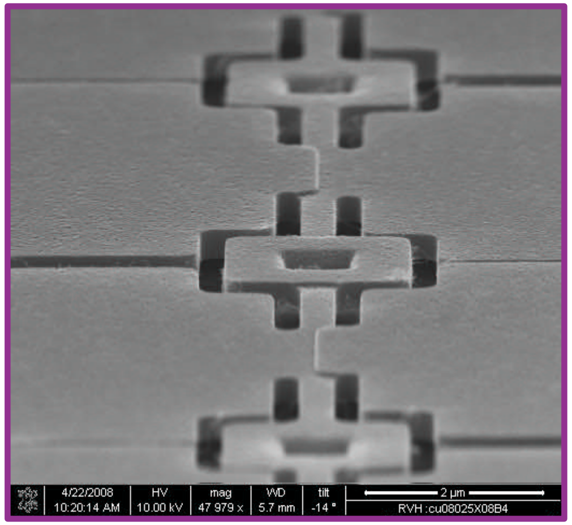
**Optional modules:**
- Optical (reflective)
- Electrical (metal trace)
- Piezo-resistive layer

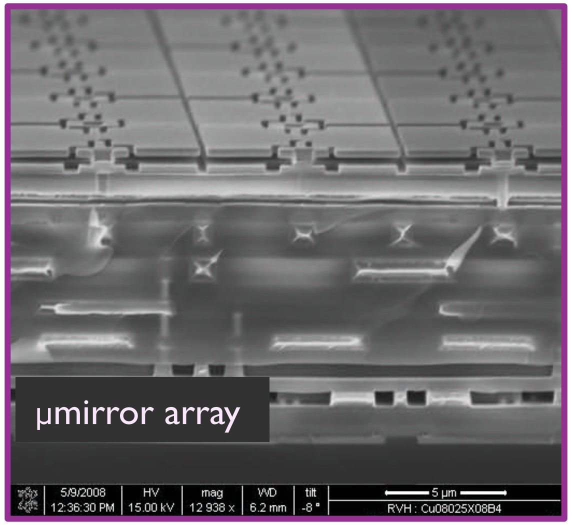


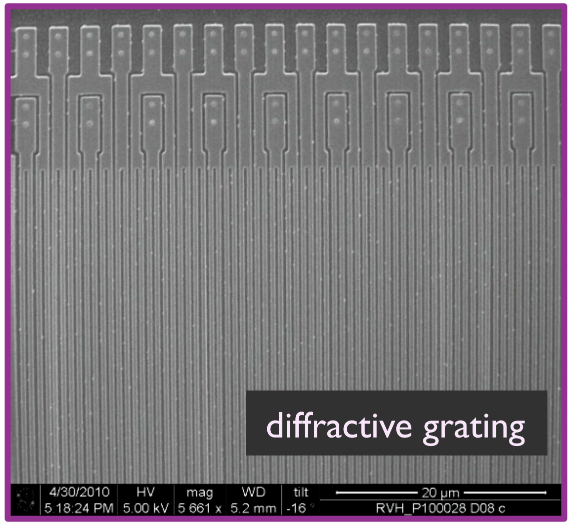
# FLEXIBILITY WITH LAYER THICKNESSES
## THIN STRUCTURAL LAYER

Thin SiGe platform
- structural layer thickness: **300nm**
- gap: 200→50 nm
- actuation gap: 300 nm
- coating for optical properties

Thin SiGe layers
- stress: 20 MPa tensile
- strain gradient: 1e-4 /μm
- resistivity: 1mΩcm



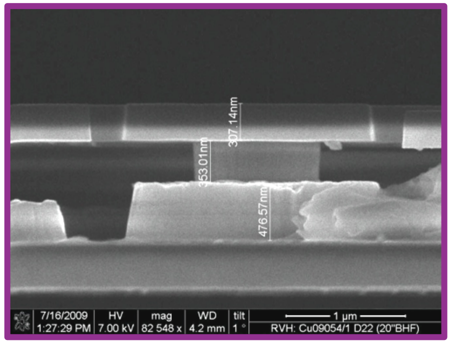



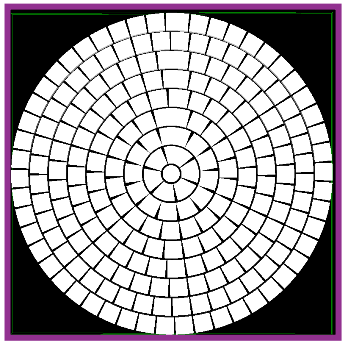

Typical applications:
- μmirror arrays
- other optical MEMS: e.g. diffractive grating

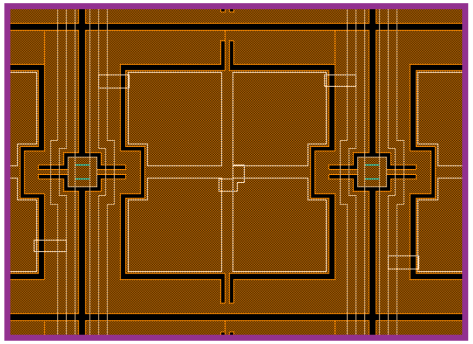
# EXPLOITING TECHNOLOGY FLEXIBILITY
## FOR OPTIMIZED MICROMIRROR DESIGNS

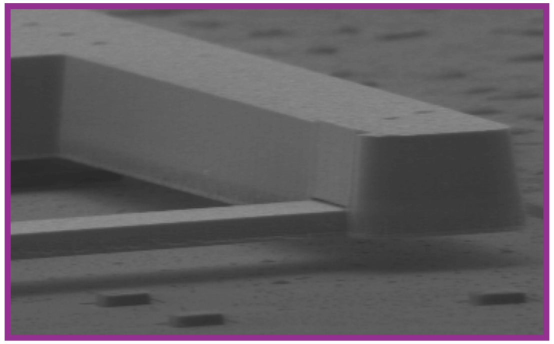
Dual electrode thickness
- mechanical stopper
- reduce actuation voltage

Dual structural layer thickness
- decoupling spring constant and stiffness



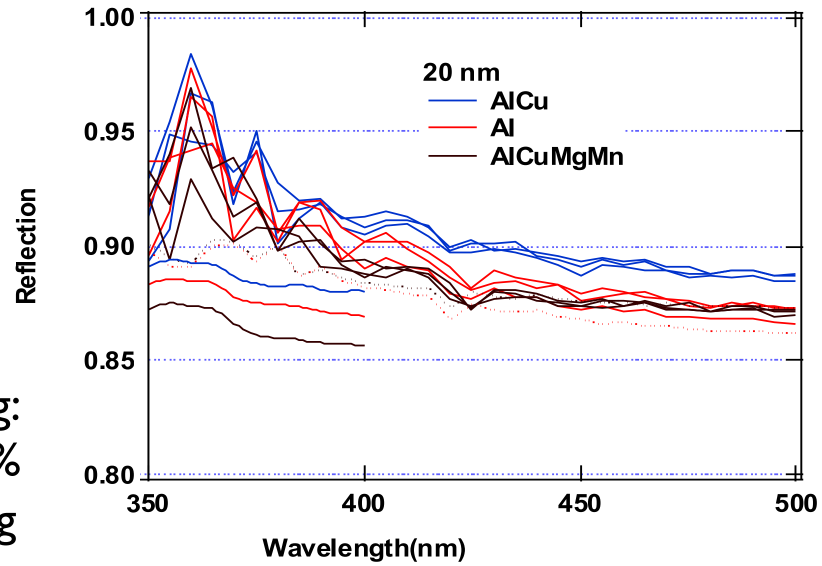




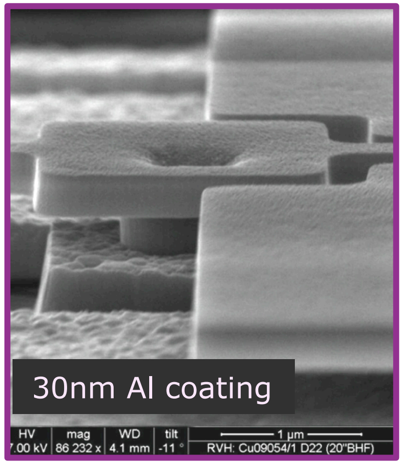
Different µmirror design variants
- Analog vs digital tilt angles
- Circular vs rectangular arrays
- Single-axis vs two-axes mirrors

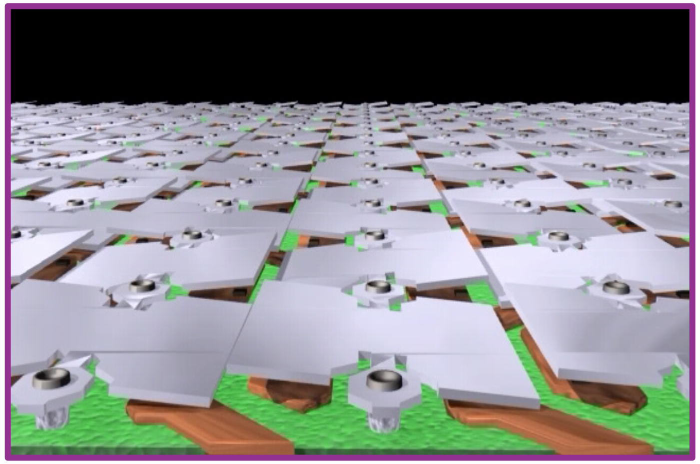
# MODULARITY VIA FUNCTIONAL LAYERS
## OPTICAL REFLECTIVITY

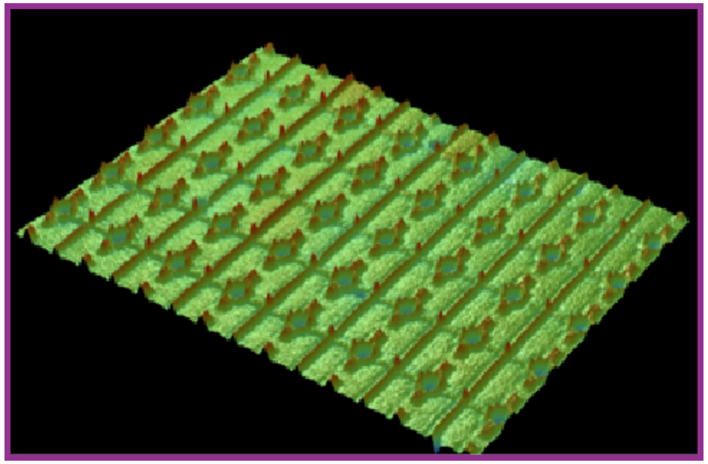
Different coatings for optical MEMS:
- visual spectrum: 30nm Al coating
- IR applications: Ag coating
- (E)UV applications: Bragg stack




Al coating:
- reflectivity > 85%
- <5nm cupping



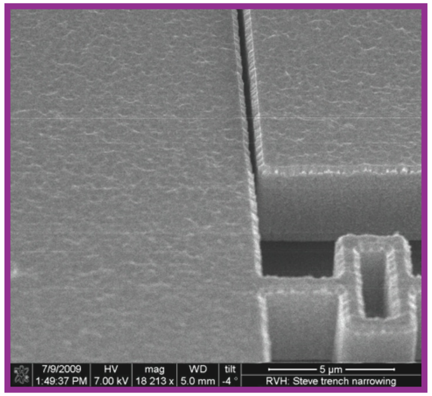
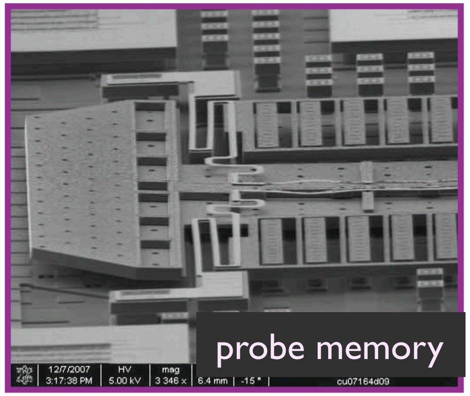



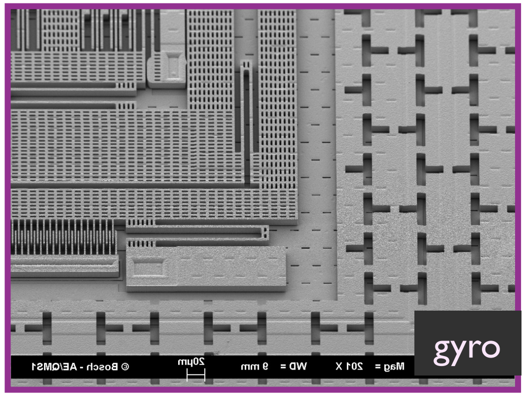


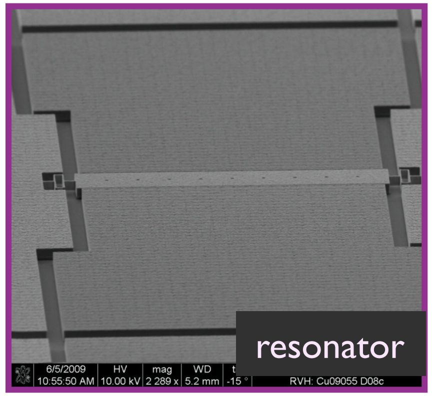
# FLEXIBILITY WITH LAYER THICKNESSES
## THICK STRUCTURAL LAYER

"Plain-vanilla" thick SiGe platform
- structural layer thickness: **4µm**
- nanogaps: 500→200 nm

Thick SiGe layers
- stress: 70 MPa tensile
- strain gradient: 1e-5 /µm
- resistivity: 1mΩcm

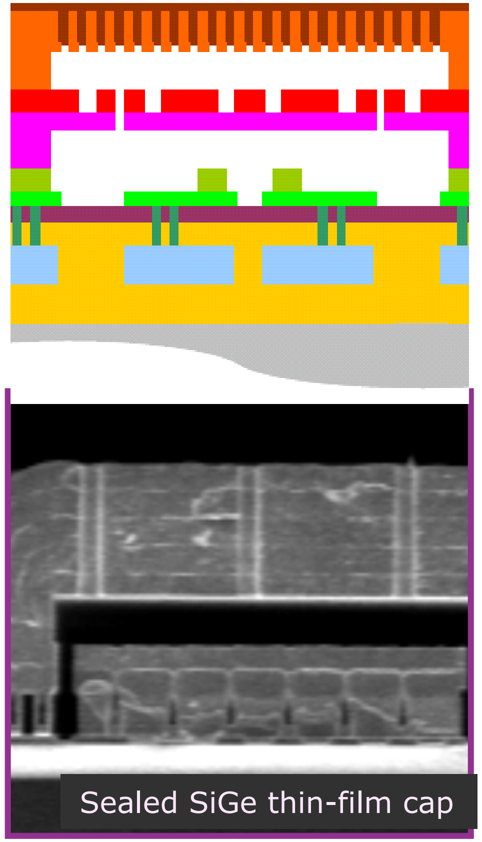





Typical applications:
- resonators, **inertial sensors**, actuators, ...
- probe-based memories

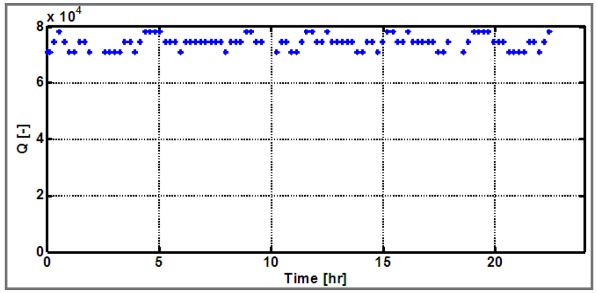
# MODULARITY VIA FUNCTIONAL LAYERS
## SEALING LAYER

SiGe membranes can be sealed:
- structural layer
- thin-film capping layer

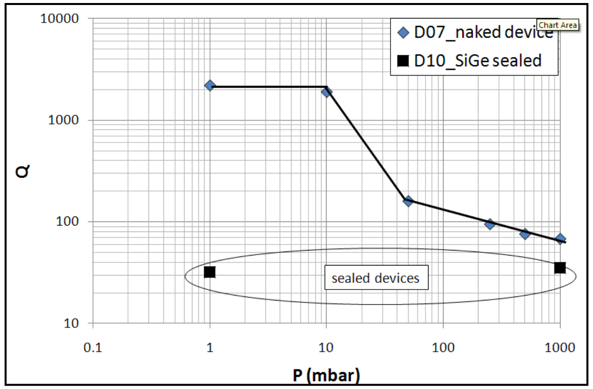


Sealed SiGe thin-film cap

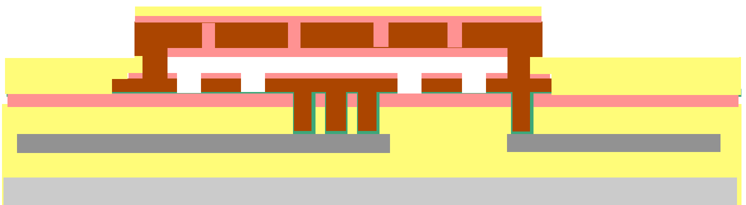
low pressure sealing of high-Q devices



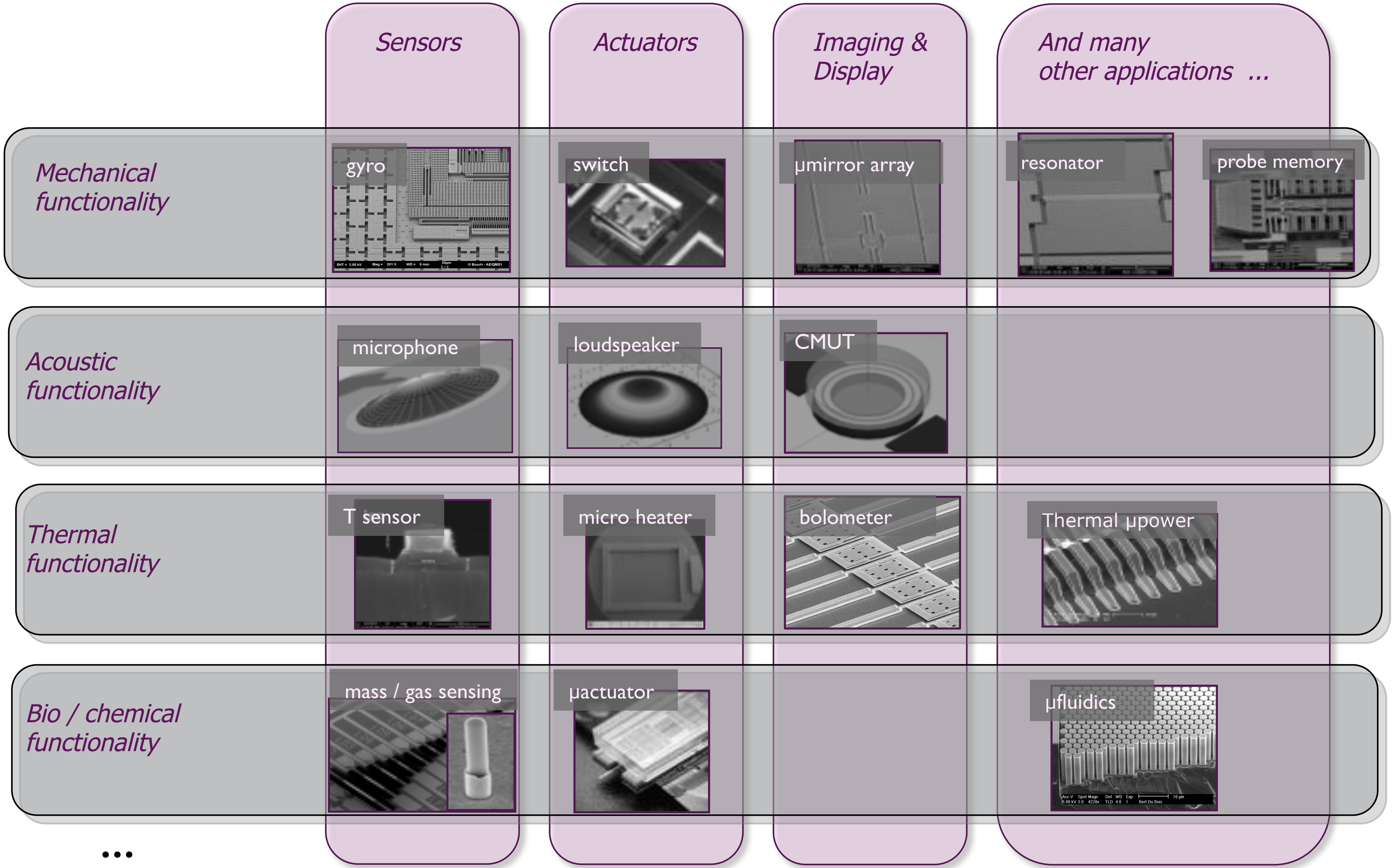

high pressure sealing for low-Q devices



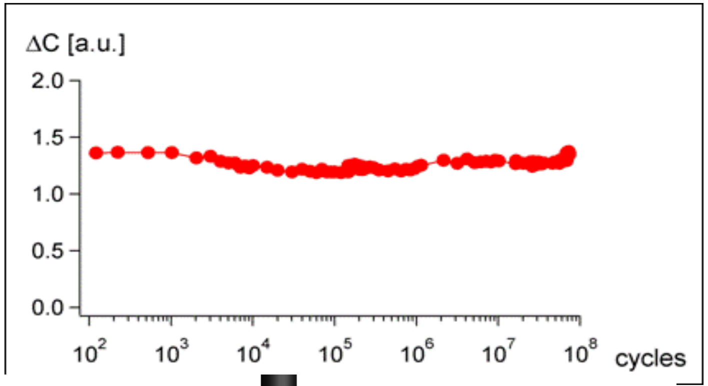

Component applications:
- Capacitive Micromachined Ultrasound Transducers (CMUT)
- Pressure sensors

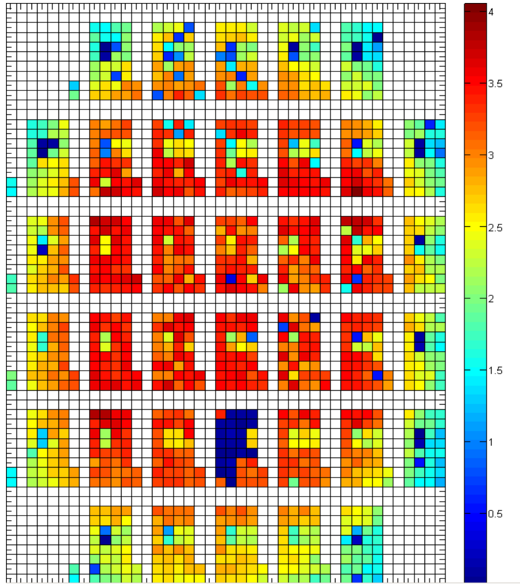


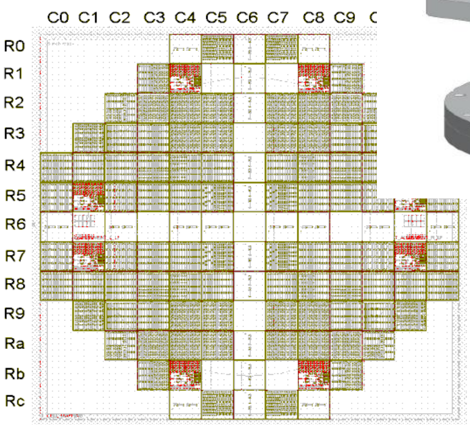
# MEMS APPLICATIONS BUILD ON PLATFORM

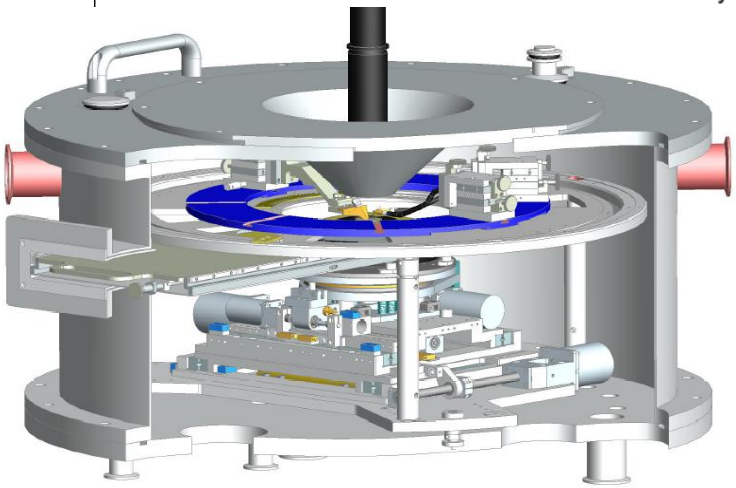


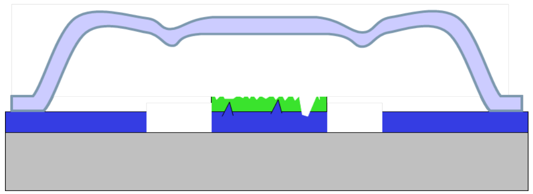
# STRONG BACKGROUND IN MEMS CHARACTERIZATION AND RELIABILITY



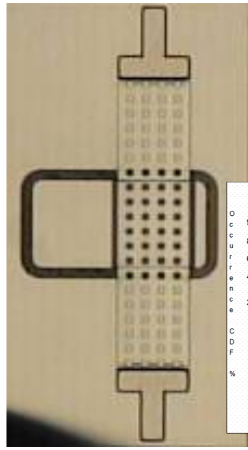



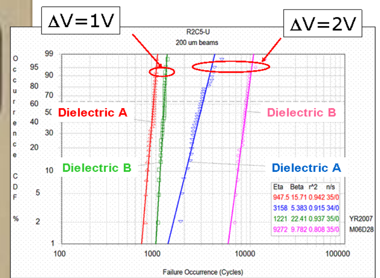





FMEA





# CONCLUSIONS
## IMEC SIGE MEMS TECHNOLOGY

Monolithic integration with IC

- Very compact & low cost
- Allows for higher performance
- Smaller footprint

SiGe-based above CMOS processing

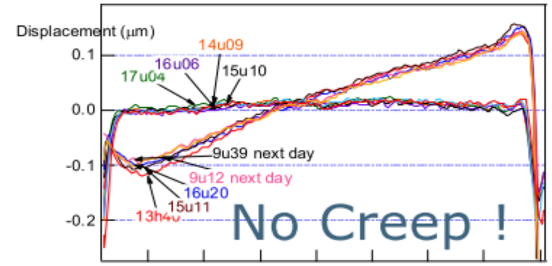
- High performance: low parasitics
- Good mechanical properties & reliability
- Extremely well suited for MEMS array applications

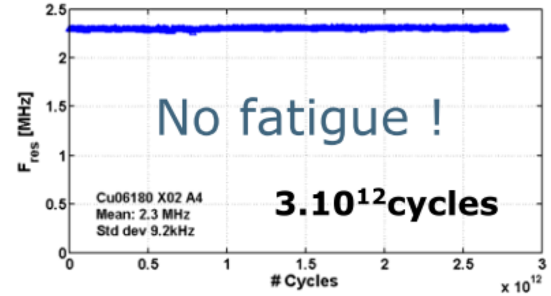
Flexible and Modular

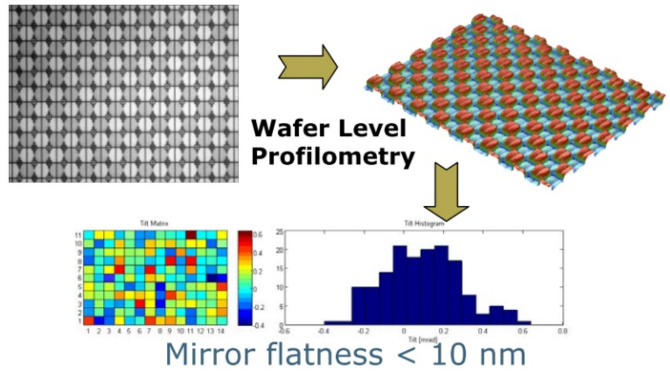
- Application-specific tuning and optimization
- Very versatile

# IMEC (TECHNOLOGY) DIFFERENTIATORS

- Support analog tilting of mirrors
- Produce micromirros with reliable performance
  - SiGe mirrors are better material in terms of flexibility than Al (TI umirrors) →
    - No creep
    - No fatigue
    - Flat mirror profiles
- Produce umirrors with higher performance
  - Smaller mirrors (8umx8um demonstrated)
  - large array sizes (> 10cm2)
  - Large number of mirrors ~ 11M
- Produce CMOS integrated umirror array
  - Efficient integration of electronic control
  - Efficient control of mirrors

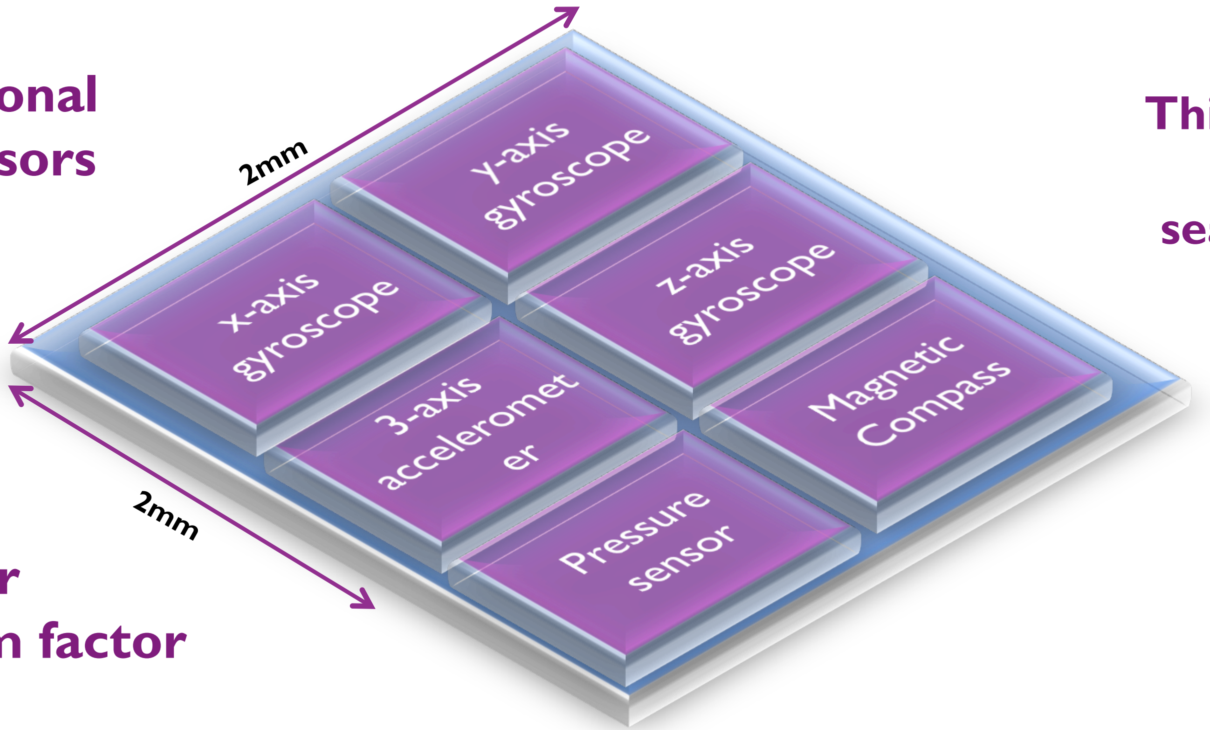


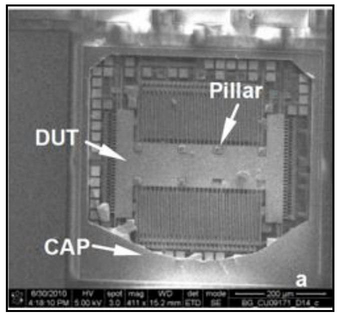



# SiGeMEMS ALLOWS FOR MONOLITHIC INTEGRATION OF 10+ DEGREES-OF-FREEDOM INERTIAL MEASUREMENT UNIT

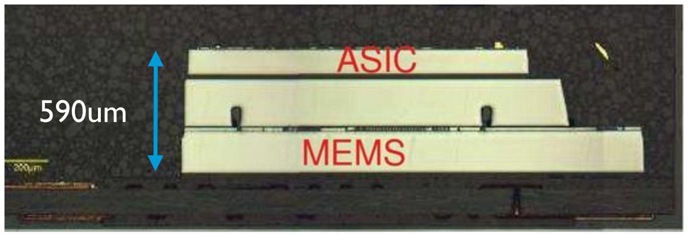
**Multi-functional array of sensors**



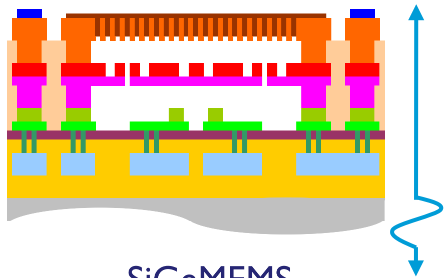

**Thin-film capping with different sealing pressures**




**Low noise**
**Low power**
**Small form factor**




Traditional Package ( ©Chipworks)



150-250um

SiGeMEMS

imec

# FROM CMOS TO LIFE SCIENCES TECHNOLOGY


**Multidisciplinary teams**

Concept development

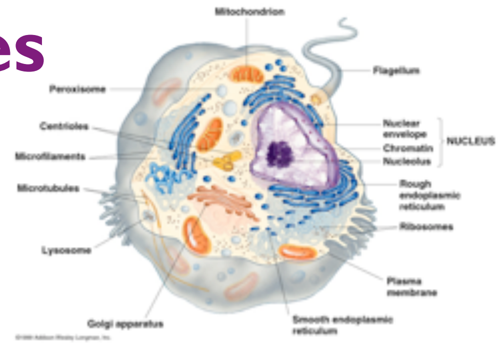
Process integration
Process technology
Fab operations

Cell biology
Molecular biology
Surface chemistry
Assay development

# From CMOS to life sciences technologies

Molecules

DNA, RNA, proteins, metabolites



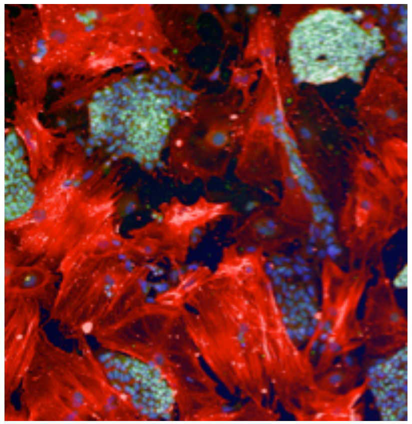

Cells

Molecular diagnostics

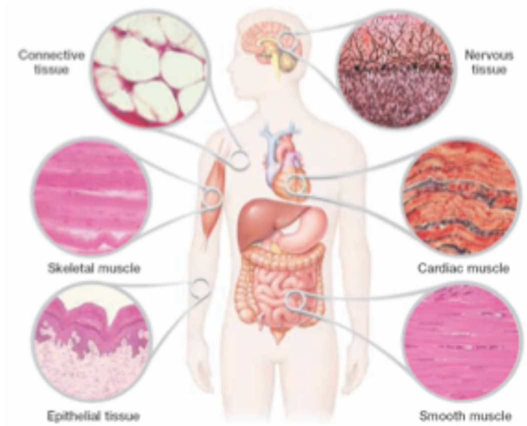
Cell-based analysis

In vitro systems

In vivo probes



Cell cultures



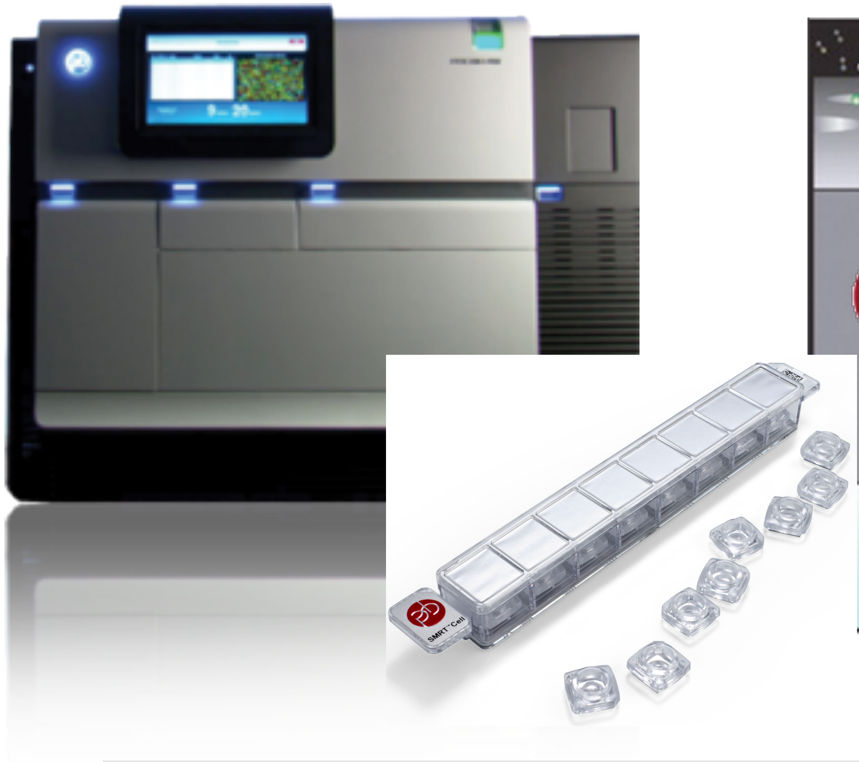

Tissue

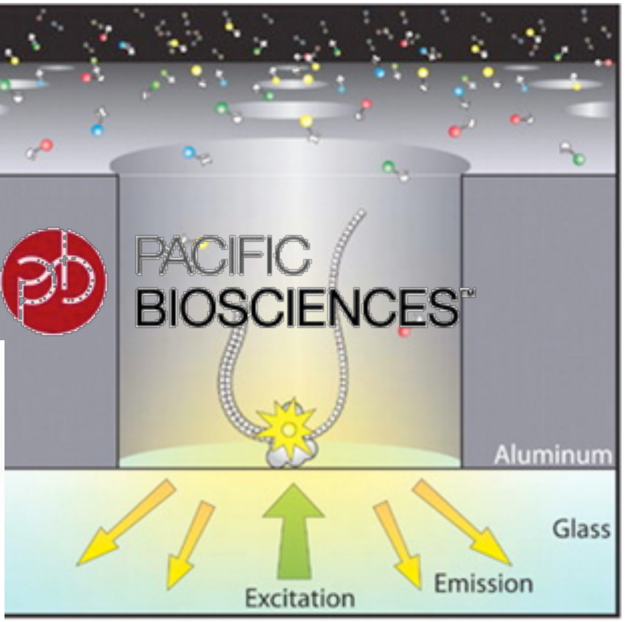
# NEXT GENERATION SEQUENCING CHIPS

July 23, 2012

**Pacific Biosciences and Imec Announce Collaboration to Develop Advanced Microchips for Single Molecule Sequencing Applications**

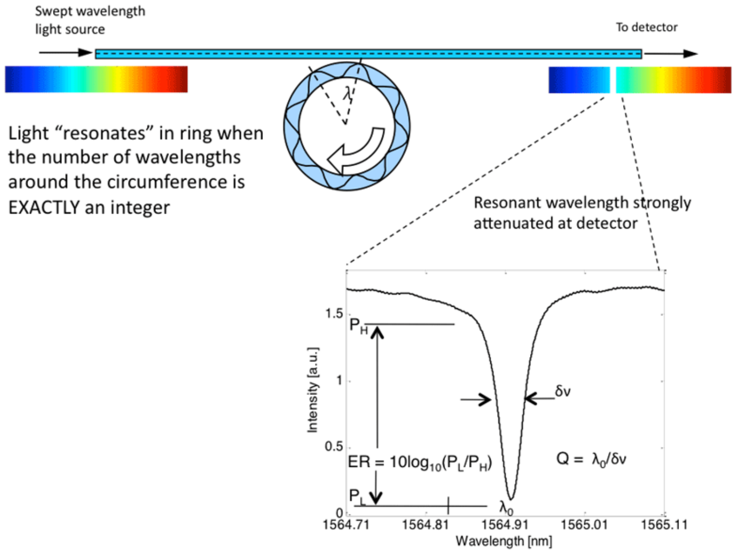
MENLO PARK, Calif., and LEUVEN, Belgium--(BUSINESS WIRE)-- Pacific Biosciences of California, Inc. (NASDAQ:PACB) provider of the PacBio® *RS* High Resolution Genetic Analyzer and Belgium-based nanoelectronics research center imec today announced a multi-year research collaboration focused on the development of advanced microchips for highly multiplexed single molecule genetic analysis. This research and development project will build on Pacific Biosciences' proprietary zero-mode waveguide (ZMW) technology and imec's world-leading expertise in nanophotonics, CMOS sensors, technology integration and fabrication.

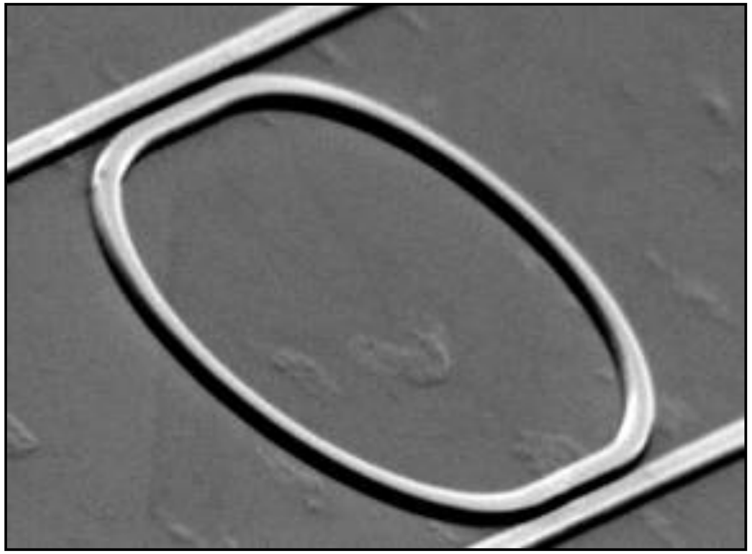




# GENALYTE BIOSENSOR

## SILICON PHOTONICS



*source www.genalyte.com*

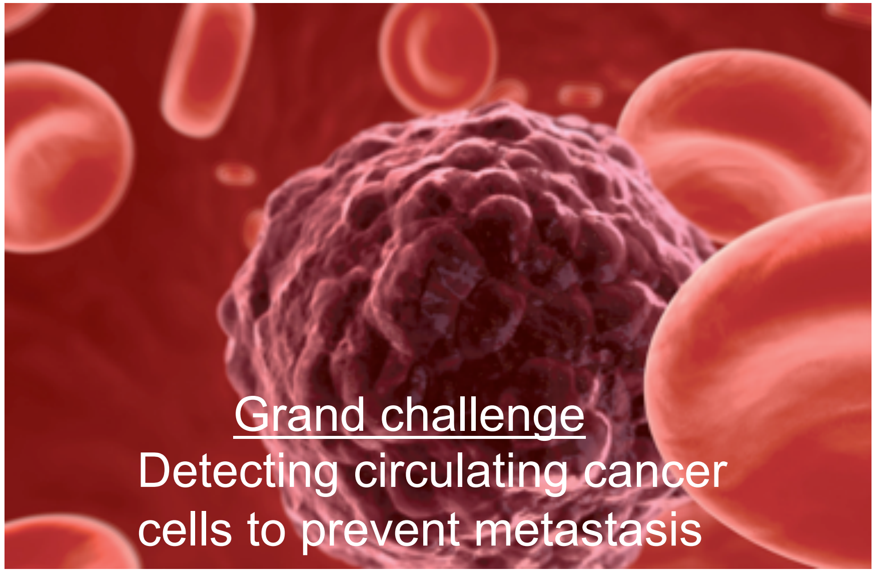
Genalyte leverages imec silicon photonics platform to develop and manufacture (low-volume production) its disposable bio-sensor chips.

# CELL BASED ANALYSIS

## Finding individual cells is critical for cancer detection.

- 90% of cancer patients die from metastasis -- the cancer spreads via our circulation system

**1 mL of blood contains:**
**$10^9$ blood cells**
**1 Circulating Tumor Cell**

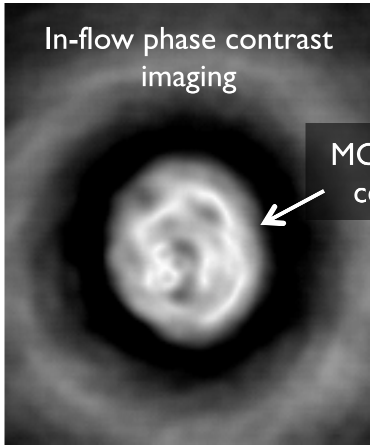


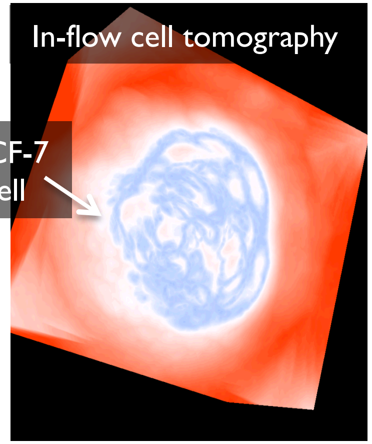

#1 predictor of cancer survival is how early it's detected

# HIGH-THROUGHPUT IMAGING FLOW CYTOMETER

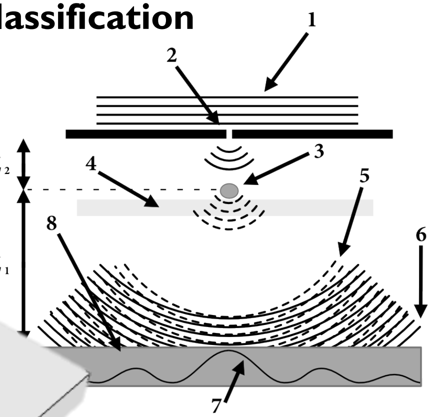
Scalable to 20,000,000 cells/s

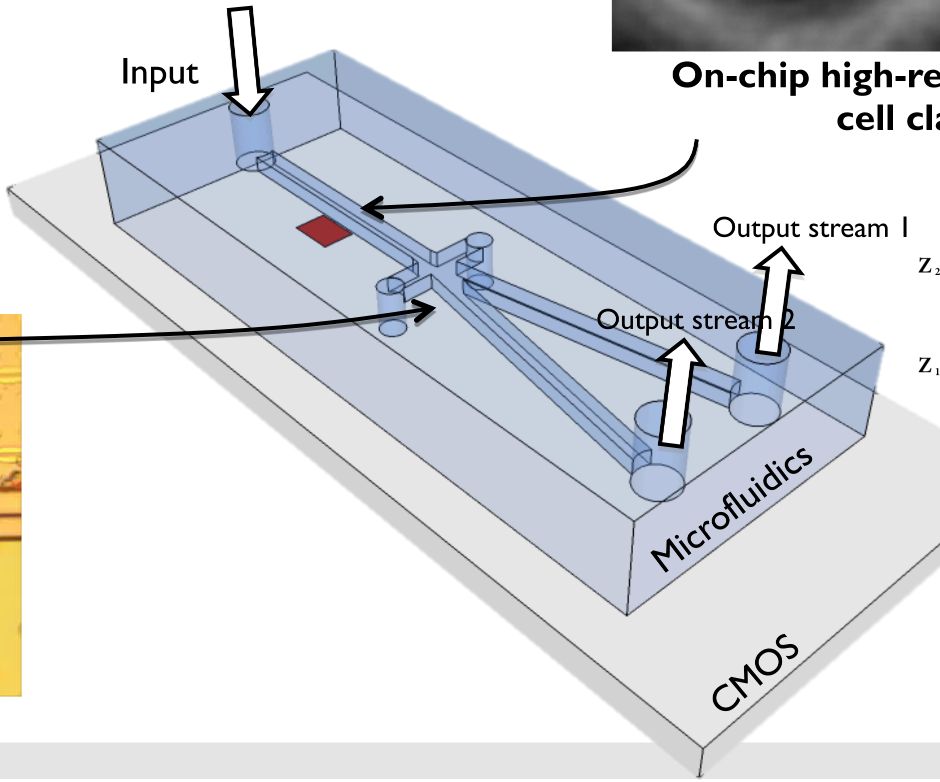
**>1000-fold improvement** over current systems



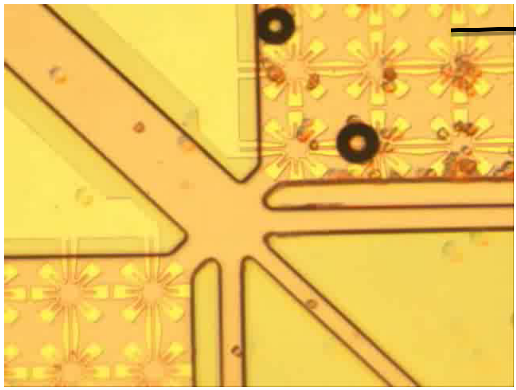




**On-chip high-resolution imaging for cell classification**

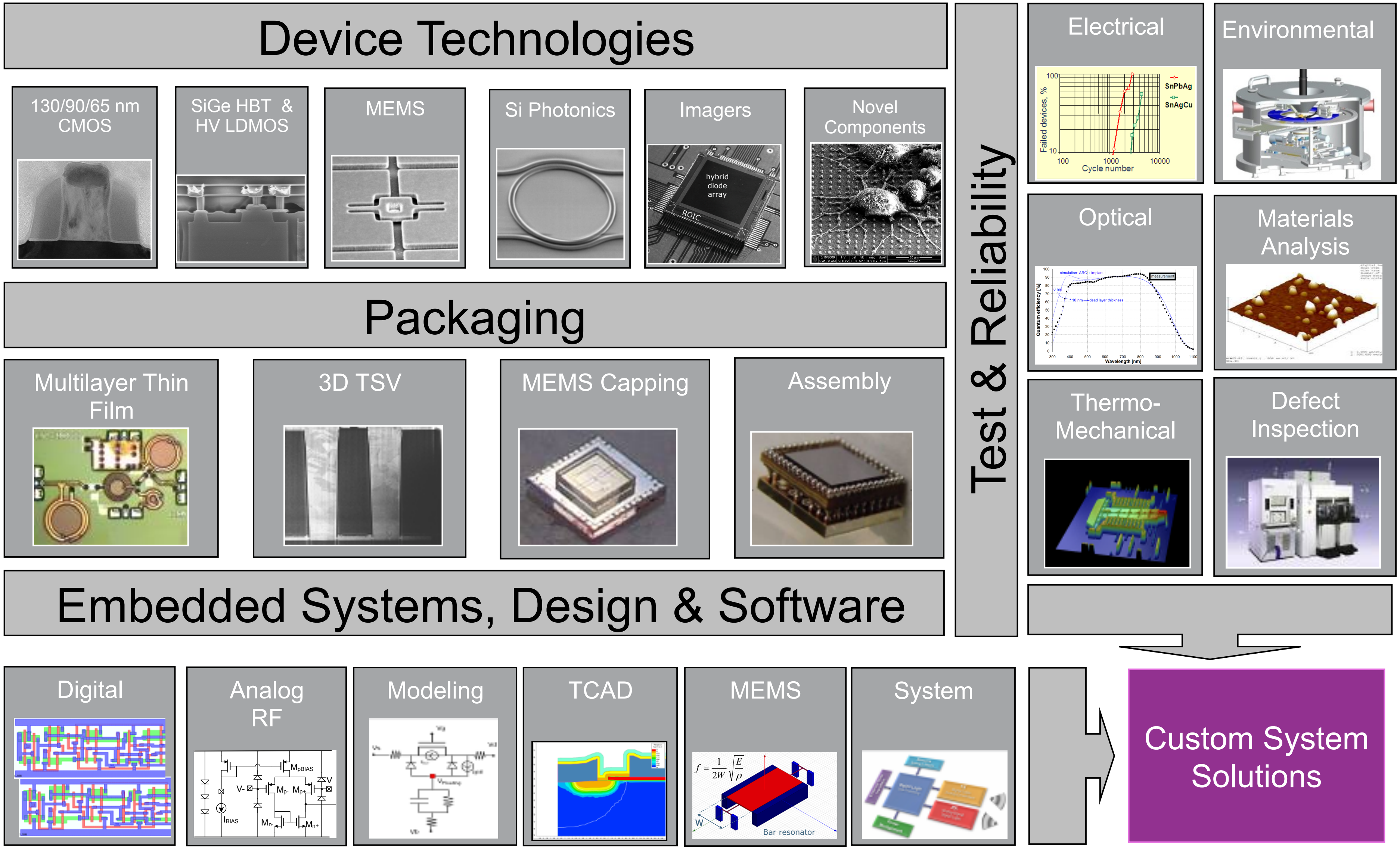



**Fast microfluidic bubble-jet cell routing**



# FROM CMOS TO CMORE PLATFORM



# THANK YOU

imec