

micro et nanoélectronique  
microsystèmes  
intelligence ambiante  
biologie et santé chaîne de l'image



## **MEMS, advanced microsystems, and their integration in the Létì's platforms .**

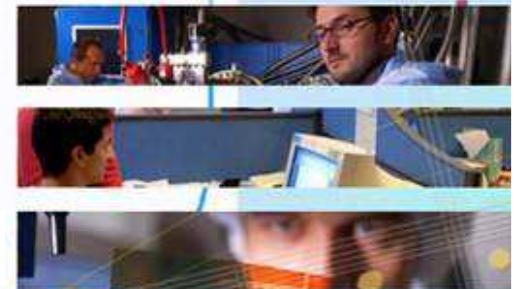
*ISIM 2011*

*February 10th, 2011, Tsukuba*

**A. Rouzaud, J.P. Polizzi**

**leti**

cea



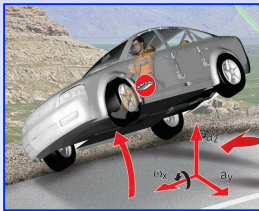
# Outline

- ❑ *Introduction: MEMS: a fast growing market*
- ❑ *Léti global approach for MEMS*
  - *Design and test*
  - *Mature components*
  - *Advanced components*
  - *Mixed components*
  - *Integration and packaging.*
- ❑ *Conclusions*

# Context : fast growing MEMS markets

## Automotive

- ESP
- Roll-over
- TPMS
- GPS
- Electric / Hybride



### Components

- Accéléromètres
- Gyromètres
- Pressure sensors
- Current sensors

## Consumer electronics

- mobile phone
- game



### Components

- 3D accelerometer
- 3D gyrometer
- Magnetometer

## bio-chemical analysis

- Bio diagnostics
- Industrial process control
- Environnemental control
- Food control



### Components

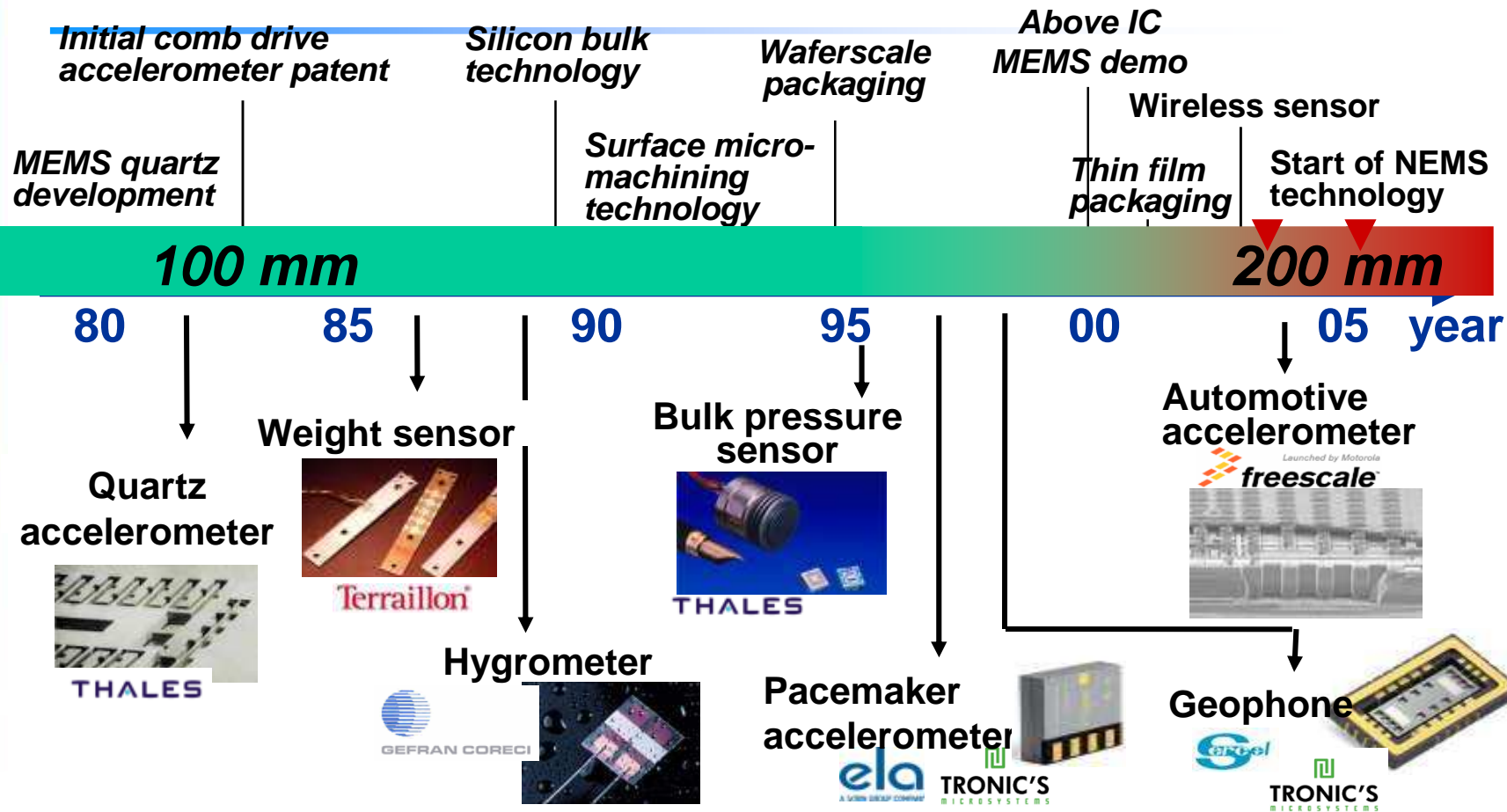
- Lab on chip
- Chemical sensors

# LETI former MEMS industrial development

Key dates

Industrial transfers

Markets



**Niche markets**

Military, aerospace...

**First mass applications**

Printing, Automotive...

**mass applications**

Consumer, Automotive...

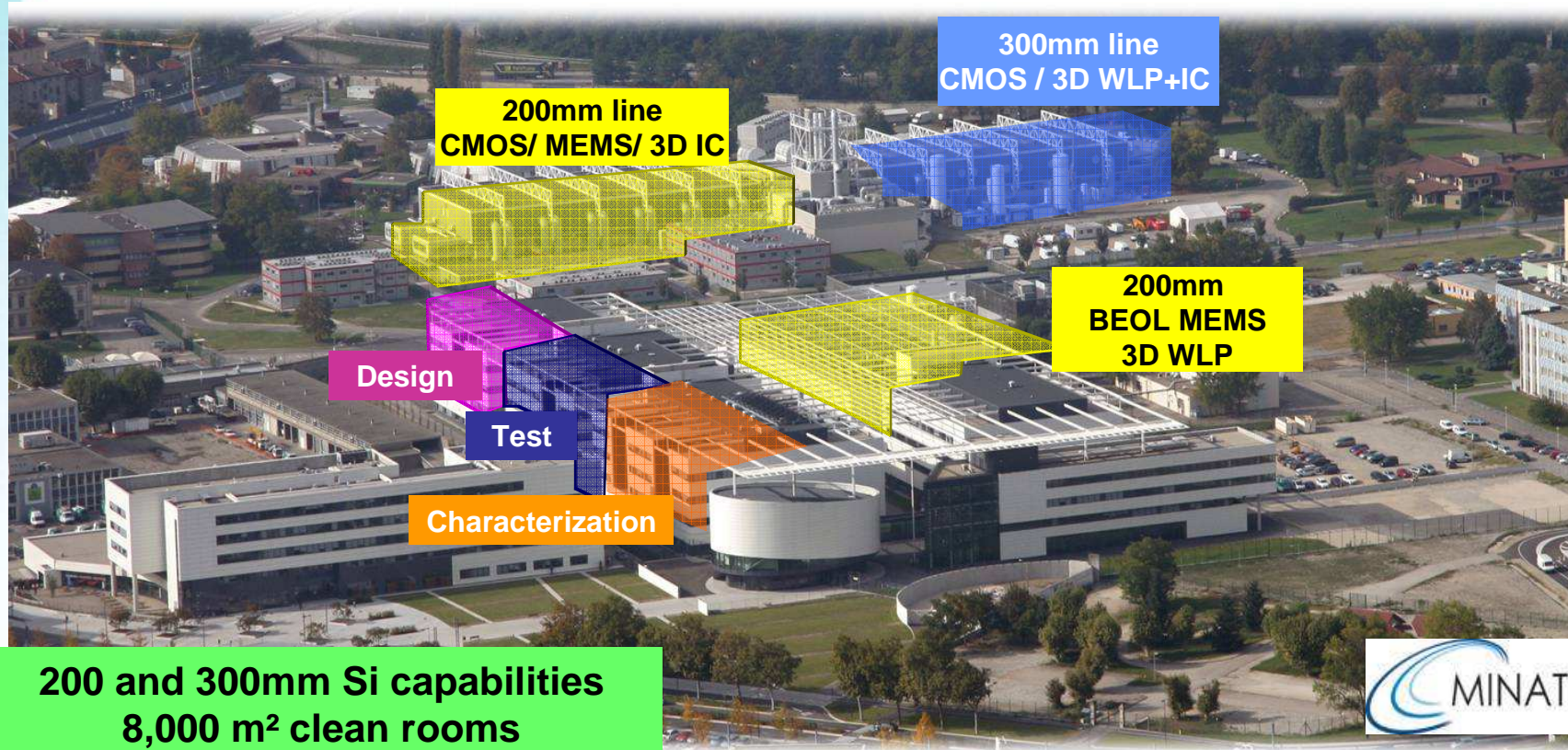


# Léti platform and environment

**Optimized 200 mm line (CMOS and MEMS), complete offer to drive MM and MtM programs from R&D to production.**

**Platform supporting 3D WLP needs / MEMS players in 200 mm**

**Platform anticipating the 3D IC integration in 300 mm**



# Léti strategy to address MEMS markets

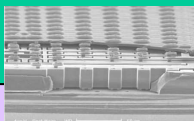
**To build a generic tools box and process flows with a complete control of the development chain *from design to system integration***

## Design and test

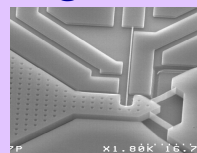
### Technology for mature components

*Developping generic process flows*

- Solutions based on generic modules.
- Adaptation to new market needs



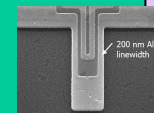
*Progressive  
integration*



### Technology for advanced components

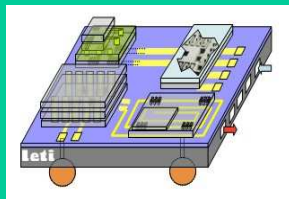
*Precising the interest*

- Alliances mixing basic knowledge and technology
- New concepts to use NEMS.



## Packaging and 3D Integration

*Investigating 3D stacking technologies. Managing MEMS specificity.*



300 mm and 200 mm lines

# *Léti global approach for MEMS*

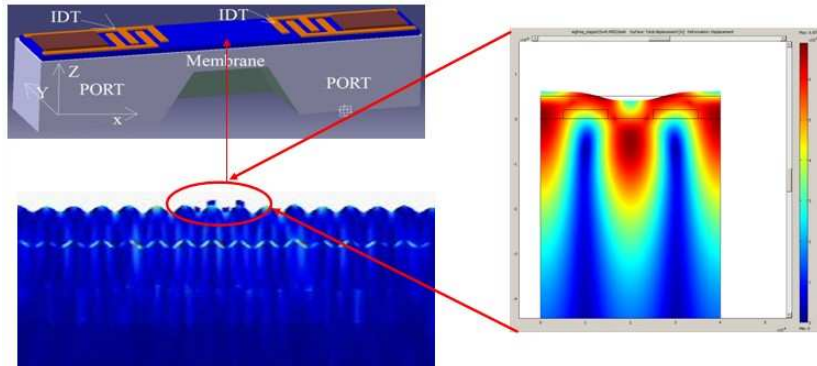
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- ***Design and test***
- *Mature components*
- *Advanced components*
- *Mixed components*
- *Integration and packaging.*



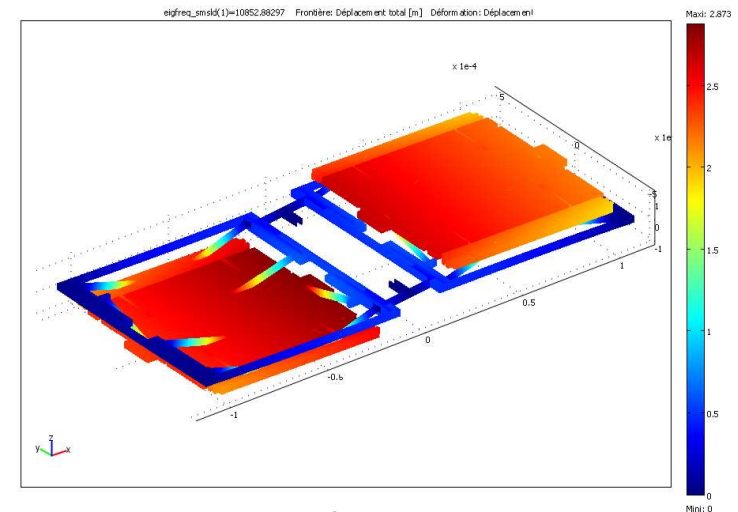
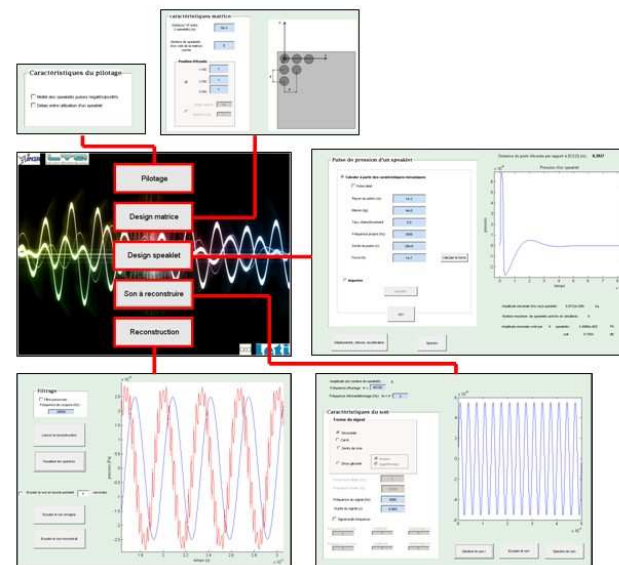
# Design and tests: mechanical modeling

**Standard FE codes for design optimization of the components.**



*Surface Acoustic Wave sensor design by FE Method*

## System design using Matlab



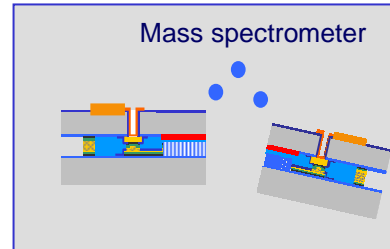
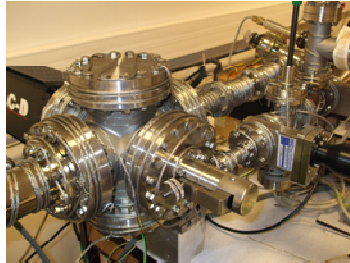
*normal modes for a gyroscope.*



# Test and Reliability of MEMS components

## Vacuum packaging

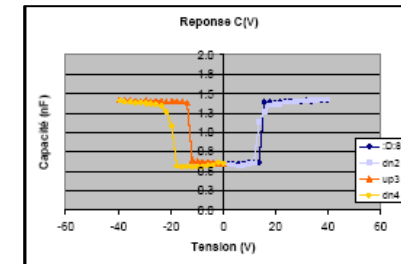
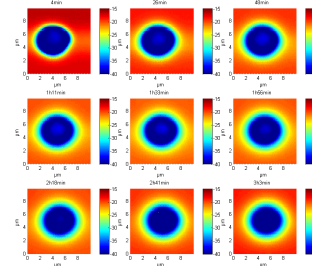
- RGA test bench for getter efficiency evaluation



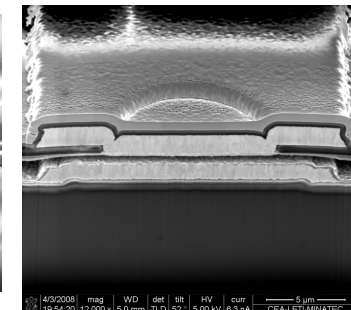
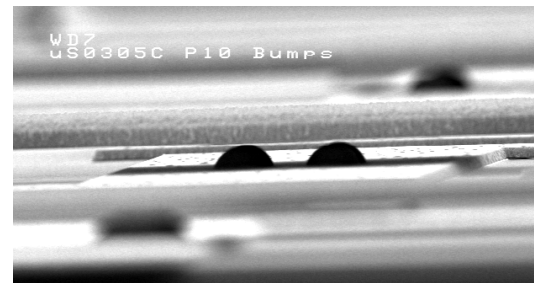
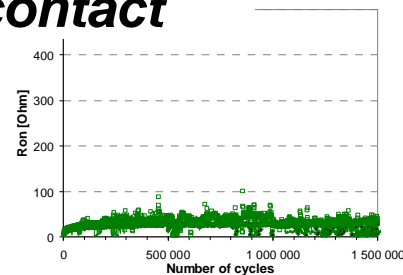
First bench available at Leti  
(Resolution  $10^{-12}$  moles)  
New bench on going (target  $10^{-15}$  moles  
 $\Leftrightarrow 10^{-3}$  mbar in a mems cavity)

## Electrostatic actuator reliability

- Dielectric charging studies



## Physics of contact



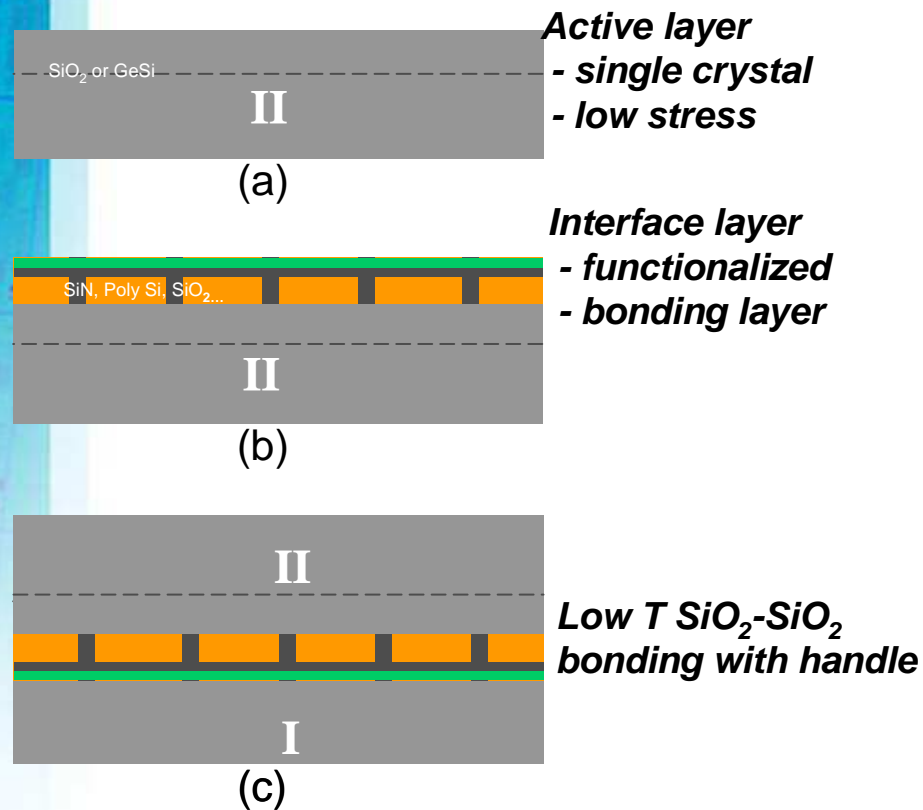
# *Léti global approach for MEMS*

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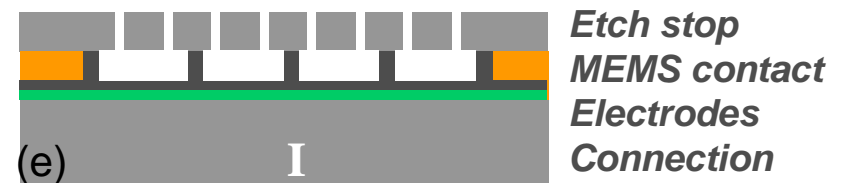
- *Design and test*
- ***Mature components***
- *Advanced components*
- *Mixed components*
- *Integration and packaging.*

# Generic process flow for mature components

**Process based on a low number of key validated modules (*transfer of Si layers, thinning, sacrificial layer functionalization, vias*)**



*Single cristal active layer  
No limit on thickness*



**great flexibility in the design**

*Electrodes, geometries, backside contacts...*



accelerometer



CMut



3D Force sensor



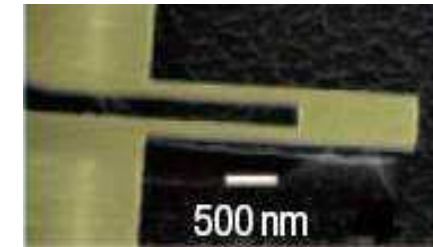
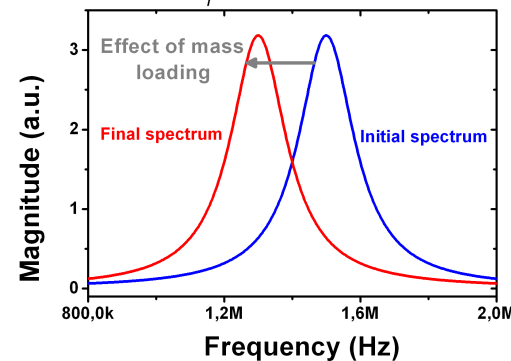
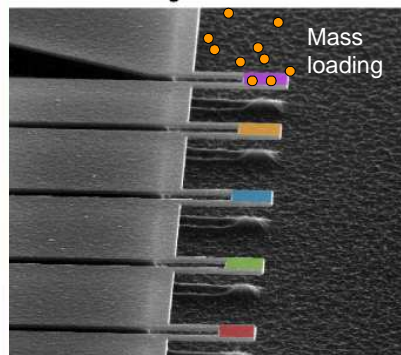
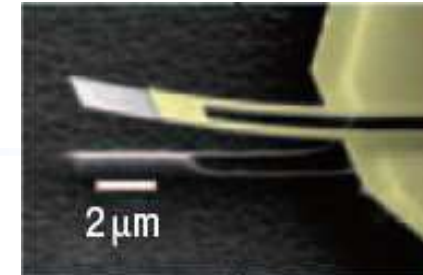
# *Léti global approach for MEMS*

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- *Design and test*
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# Advanced components: NEMS approach for mass sensing

Detection by shift of  $F_r$  due to added mass



Due to their extremely low mass, the nanoresonators allow ultra sensitive detection (below  $10^{-18}$  g in ambient air).



Highly appropriated to bio chemical applications

	Sensitivity	Resolution
	$\Re = -\frac{\delta f}{\delta m} = \frac{f_0}{2M_{eff}} \propto l^{-4}$	$\delta m = \frac{M_{eff}}{Q} 10^{-\frac{DR}{20}} \propto l^3$
$10^{-9}$ g	Quartz microbalance	$M_{eff} \sim 1$ mg $\omega_0 \sim 10$ MHz
$10^{-12}$ g	Surface Acoustic Waves resonator	$M_{eff} \sim 1$ mg – $1$ $\mu$ g $\omega_0 \sim 10$ MHz – $1$ GHz
$\sim 10^{-15}$ g	MEMS	$M_{eff} \sim 1$ $\mu$ g – $1$ ng $\omega_0 \sim 10$ kHz
$\sim 10^{-18}$ g à $10^{-21}$ g	NEMS	$M_{eff} \sim 1$ ng – $10$ fg $\omega_0 \sim 100$ MHz
$\sim 10^{-21}$ g à $10^{-24}$ g	Nanowire	$M_{eff} \sim 10$ fg – $10$ ag $\omega_0 \sim 100$ MHz – $1$ GHz

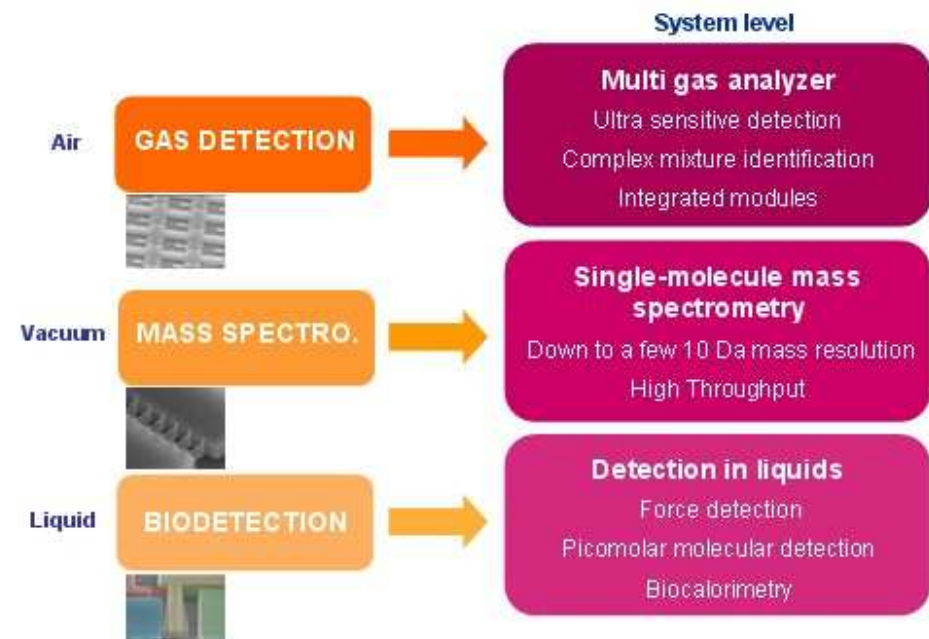
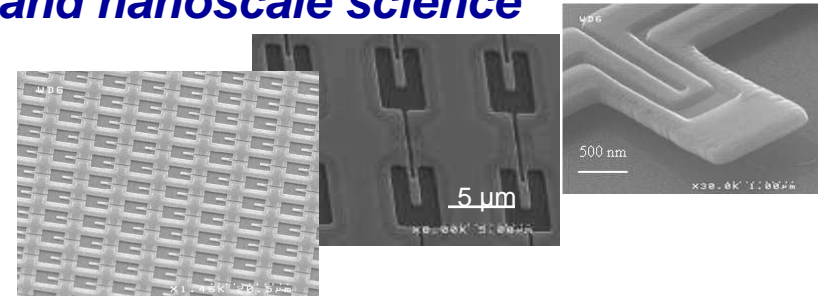
# NEMS approach for mass sensing

- Nanoresonators for ultra sensitive measurements ( resonance frequency shift induced by mass).
- CMOS compatible fabrication process.
- Strong coupling between technology and nanoscale science



**Strong Léti-Caltech Alliance  
launched in 2007.**

*Caltech: functional validation of  
nanosystems.  
Léti: integration*





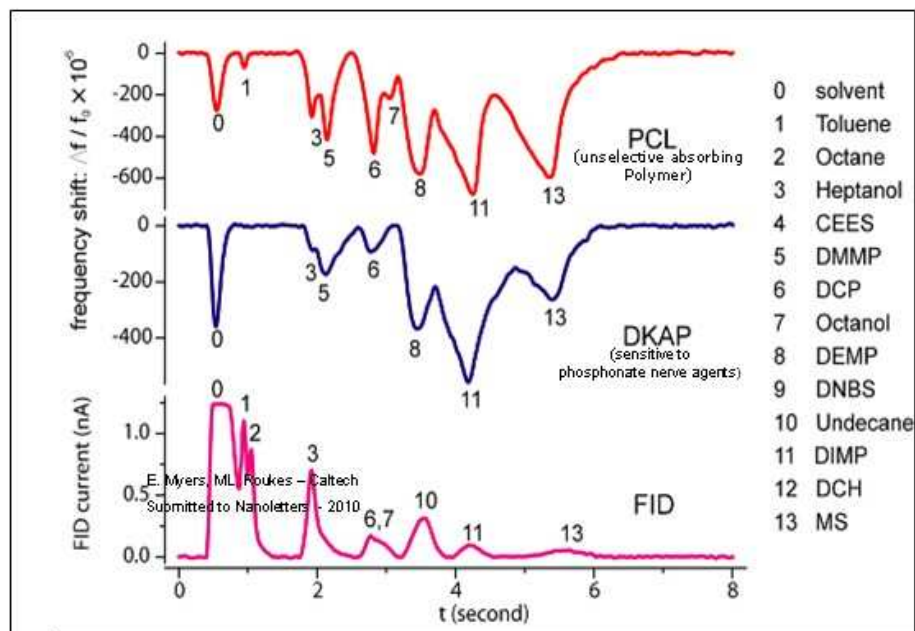
# Some proofs of concepts

## GC + functionalized NEMS array

- Total separation in < 6 sec
- LoD ~ 200 ppt demonstrated
- Security applications

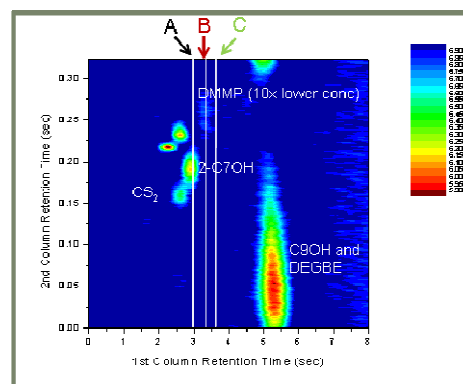
E. Myers, ML. Roukes – Caltech

Submitted to Nanoletters - 2010



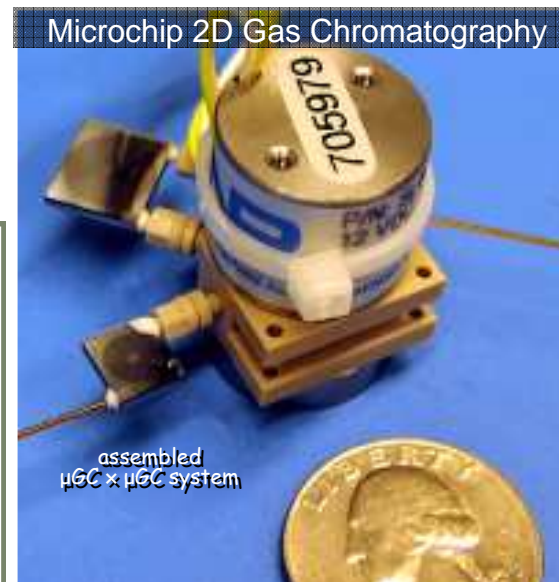
## GCxGC + NEMS

- Total separation in < 4 sec
- Measurements repeated > 20,000 times.
- NEMS ran continuously for ~6 weeks without failure



C. Fix, J. Simonson, M. Roukes,  
E. Myers, J. Whiting et al. –  
Caltech/Sandia 2009/2010

## 2D separation of a 29 component mixture

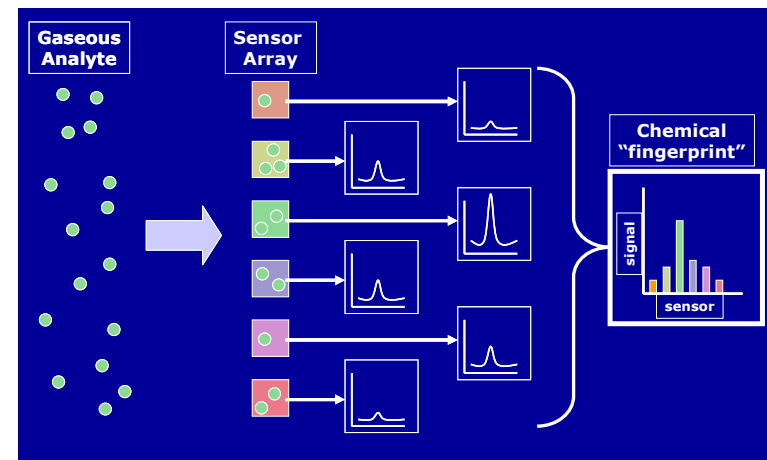
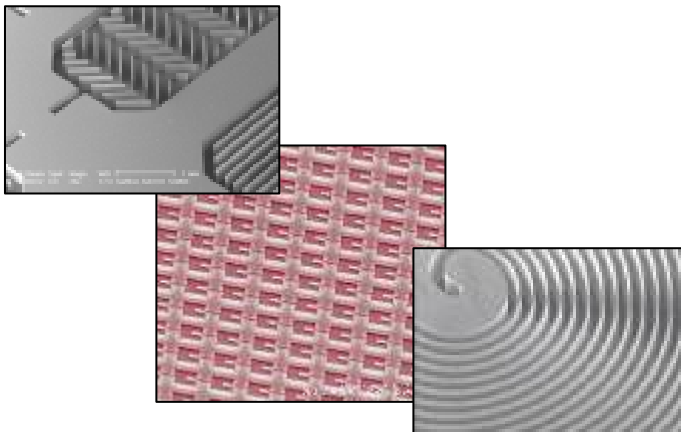


# Biological detection for earlier diagnostics

## □ *Biological detection based on metabolism changes at early stages of diseases*

- *Breath analysis can reveal specific diseases (e.g. : lung, breast, larynx cancers, ...)*
- *Method highly sensitive, even at very early stages*
- *Requires sensitive and selective chemical sensors.*

## □ *A low-cost chip for routine analysis*



# *Léti global approach for MEMS*

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- *Design and test*
- *Mature components*
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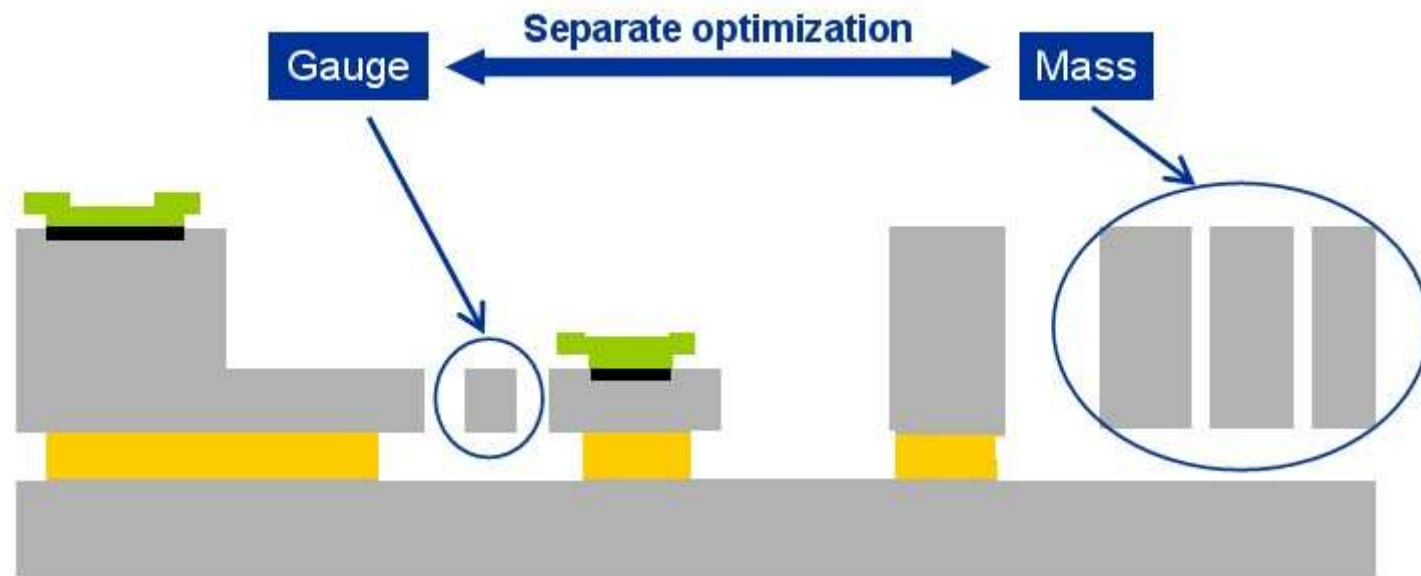
# Enabling technologies : M&NEMS

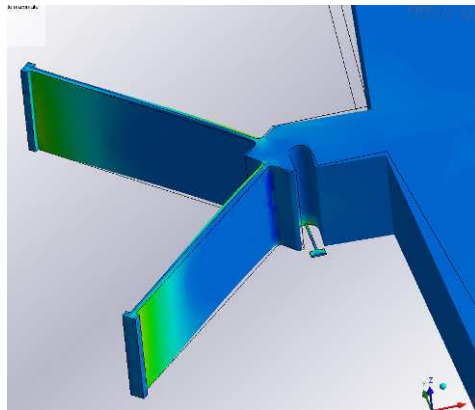
## Generic solution for decreasing MEMS size

*Use a new approach for inertial sensors : Mix on a same device two different thicknesses*

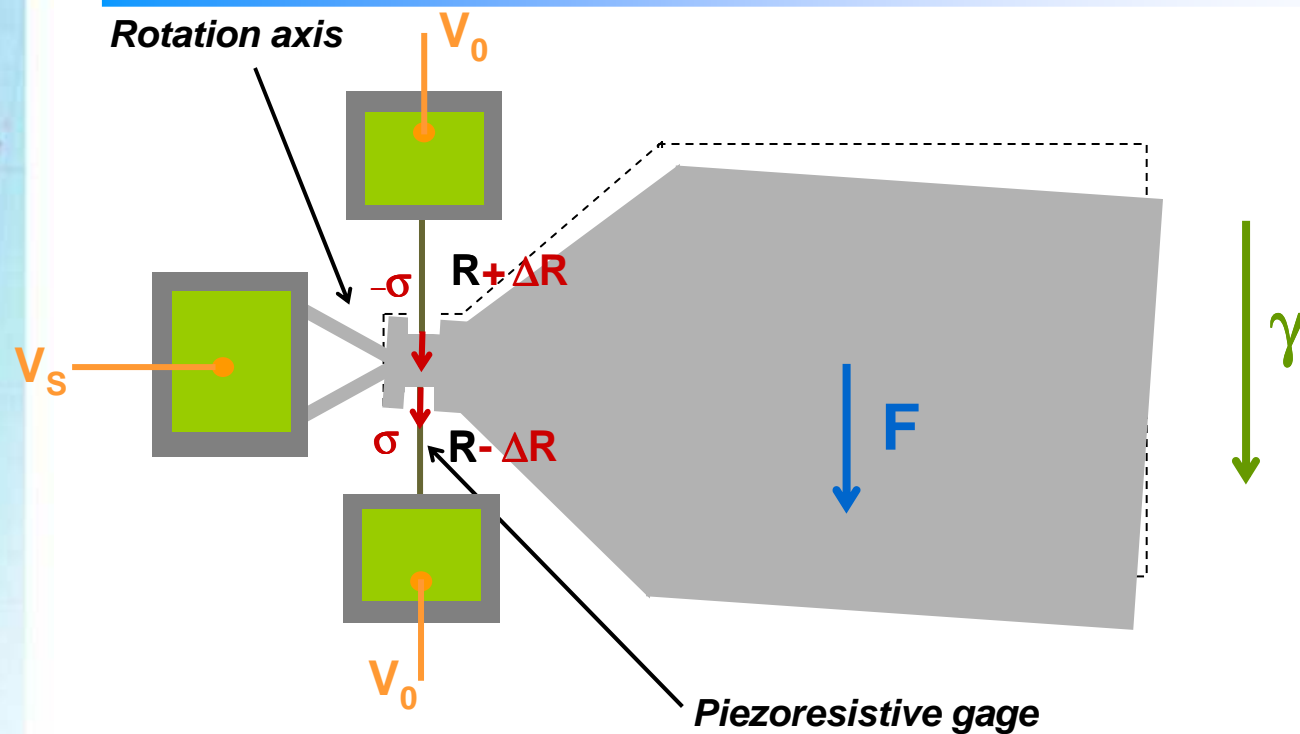
- A thick layer for the proof mass (MEMS)
- A thin layer for the gauge (NEMS) with stress magnification (design lever effect + size effect)

**Area gain : x3-5**

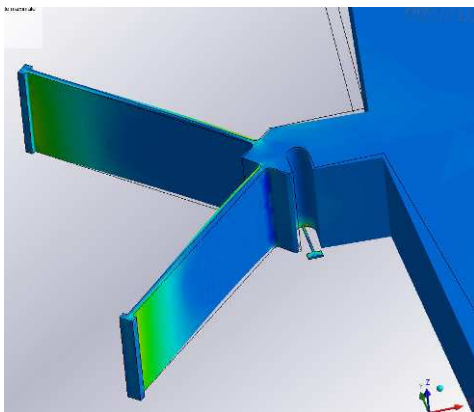




# M&NEMS principle



$$\begin{aligned} & \gamma \\ & \downarrow \\ & F = M \cdot \gamma \\ & \downarrow \\ & \sigma \\ & \downarrow \\ & \frac{\Delta R}{R} = \pi \sigma \end{aligned}$$



$S = 50 \text{ mV/V}$  full scale  
( $\sigma_{\text{max}} = 100 \text{ MPa}$ )

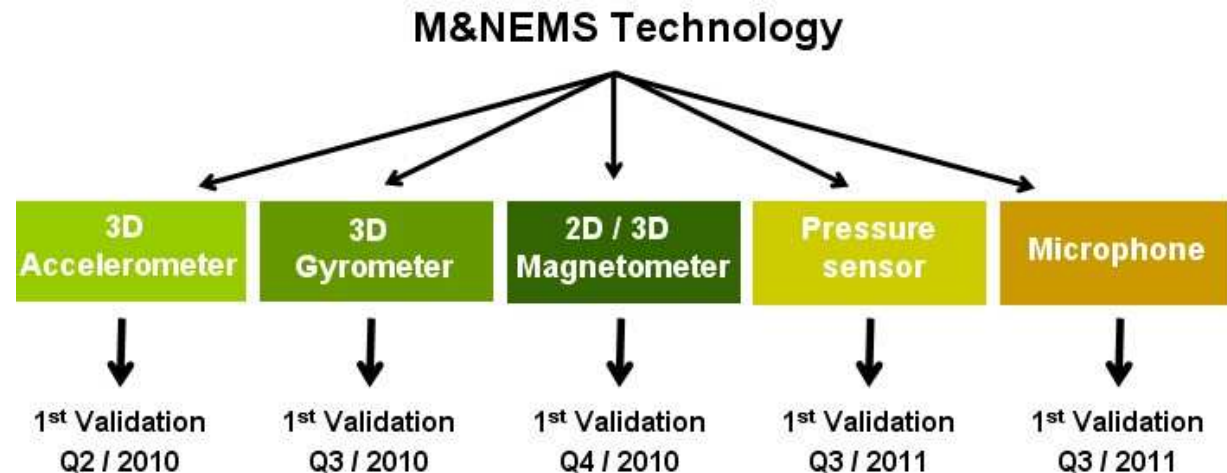


# Enabling technologies : M&NEMS

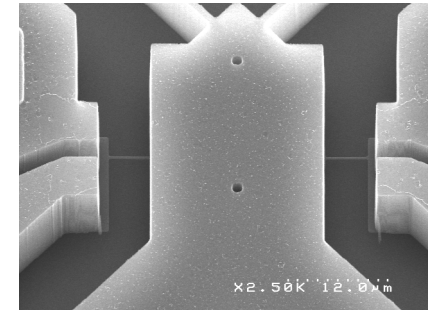
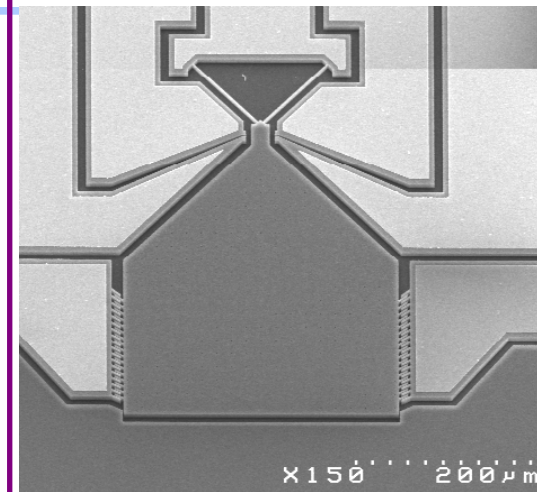
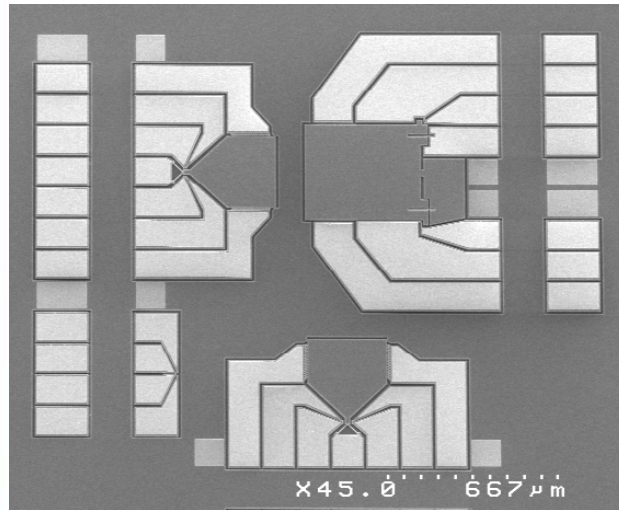
## Global interest of the technology.

- *Generic process available for many kind of MEMS.*
- *Piezoresistive or resonant differential measurement (drift limitation)*
- *In-plane and out-of-plane detection available*
- *CMOS Compatible*
- *6 mask levels (without packaging)*
- *Concepts and technology protected by +10 patents*

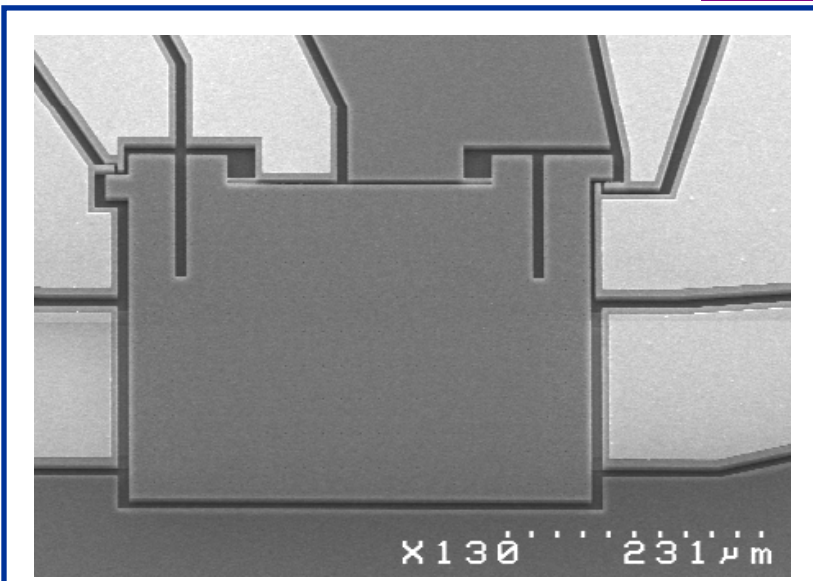
Design / modeling	: Completed
Process integration	: Validated
Electrical measurements	: In progress
Reliability (thermal drift, stability,...)	: Started



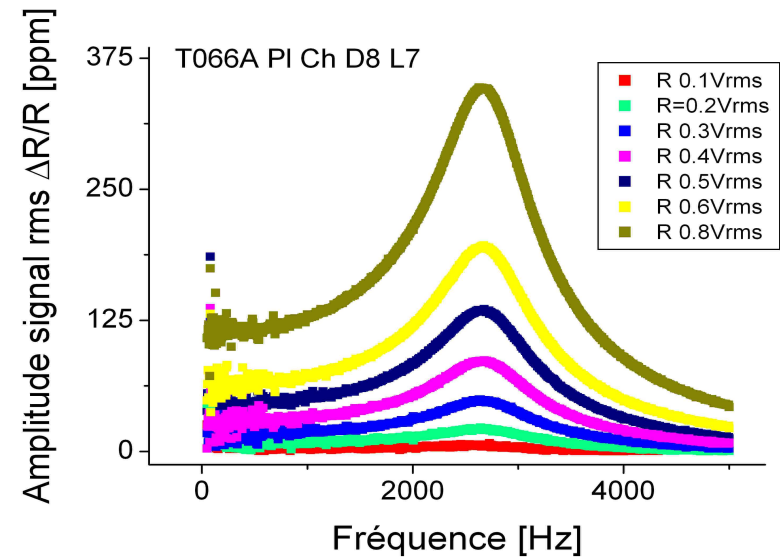
# M&NEMS demonstrators: 3 axis accelerometer



x/y accelerometer

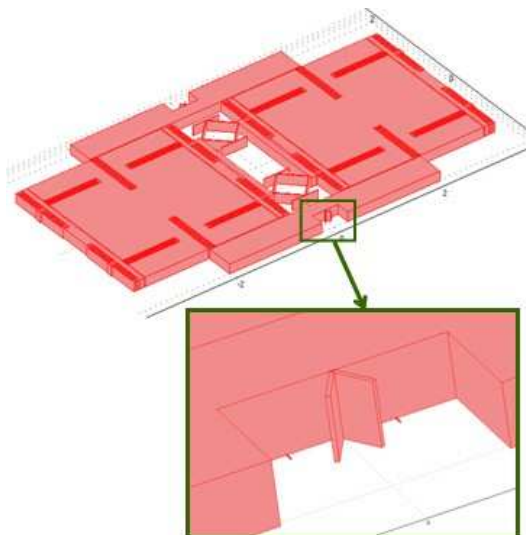


Out of plane accelerometer

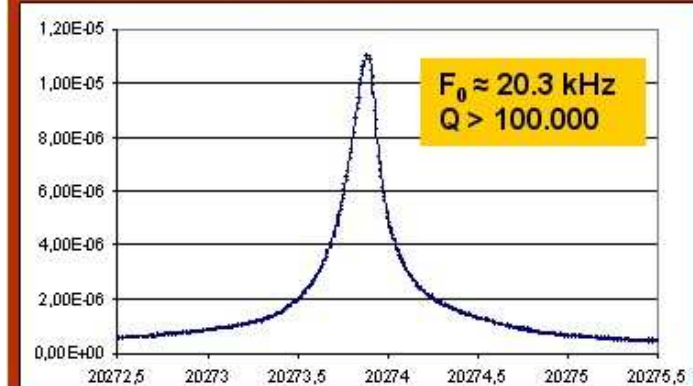


# M&NEMS demonstrators: 3 axis gyrometer

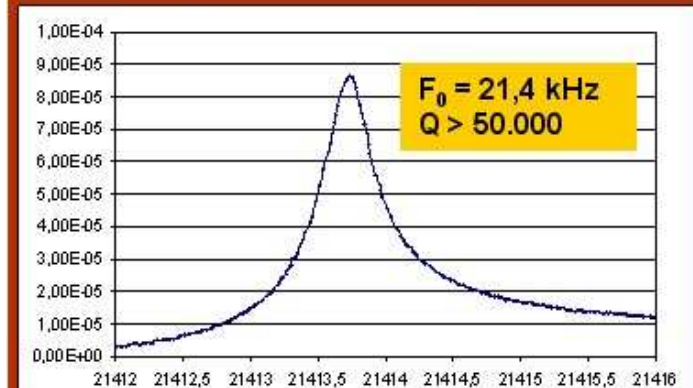
- *Typical dimensions of sensitive element :  $< 0.5\text{mm}^2/\text{axis}$*
- *3D sensor on chip*
- *1 sensitive element / axis (avoid cross sensitivity)*
- *Differential measurement (drift limitation)*
- *Open-loop detection (no need matched frequencies - process control is relaxed)*
- *Rough vacuum required (no need getter)*



- **Excitation mode :**
  - Electrostatic actuation
  - Capacitive detection



- **Detection mode :**
  - Electrostatic actuation
  - Piezoresistive detection



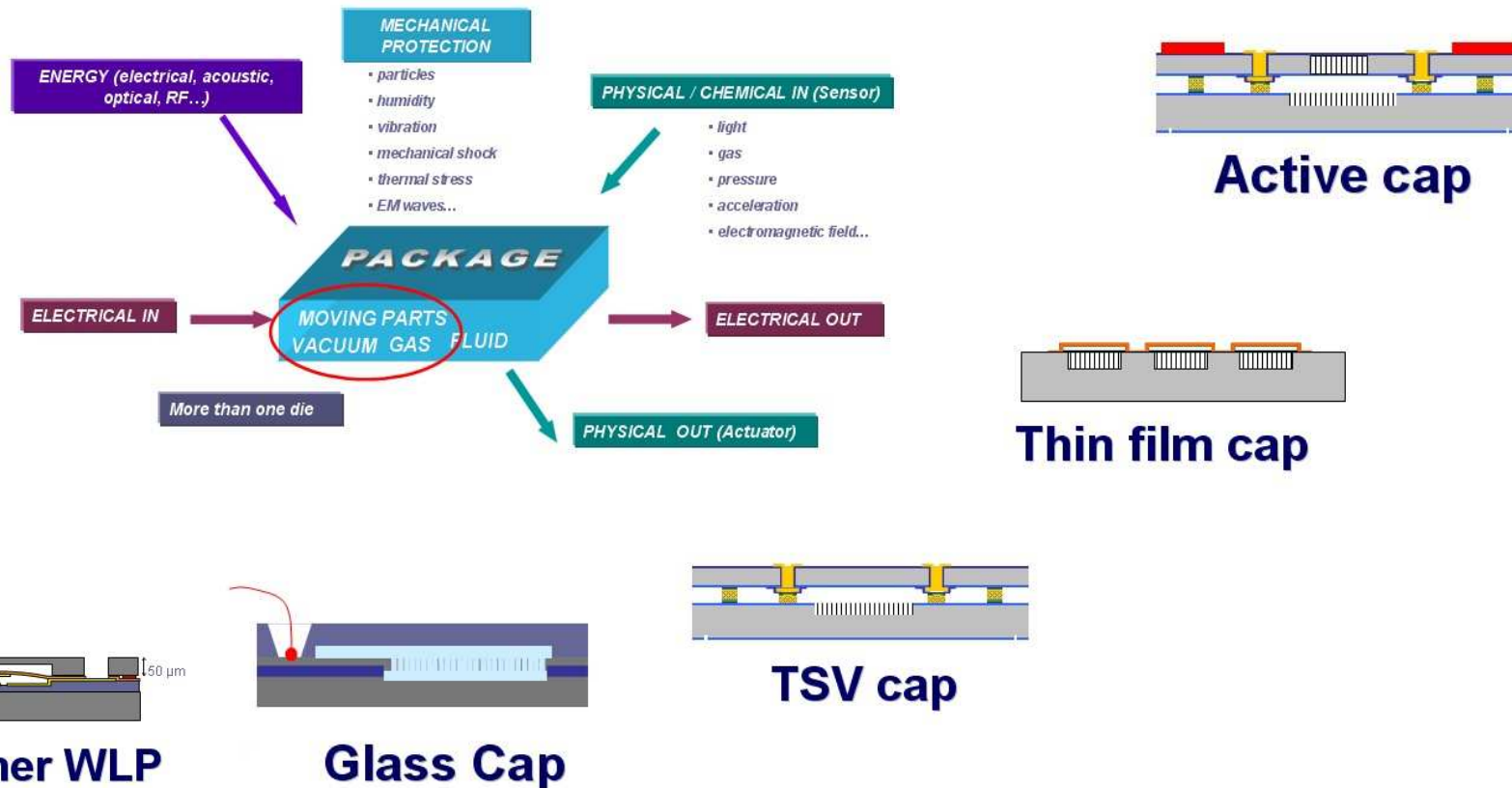
# *Léti global approach for MEMS*

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- *Design and test*
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- ***Integration and packaging.***



# Problematic of MEMS packaging



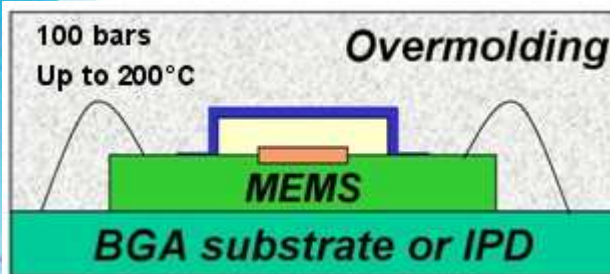
Require specific & complex packages => Important overcost  
Trend: to manage specificity at the wafer level.

Targeted solution: pre packaging low cost process compatible with subsequent standard IC packaging processes.

# Reinforced Thin film packaging

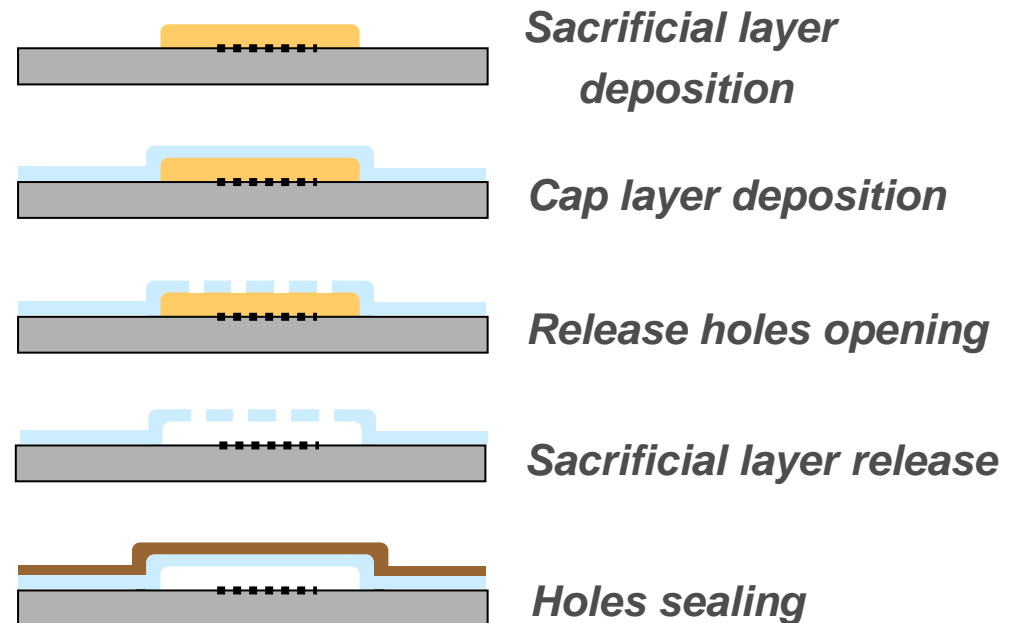
## Advantages

- Low cost process
- Ultra compact solution
- Balling compatibility
- Possibility of hermetic sealing

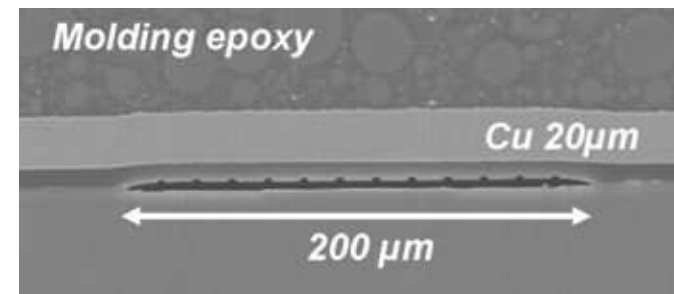


## New process developed for cap reinforcement

- Cu ECD w/wo thick resist
- No stress on the cap

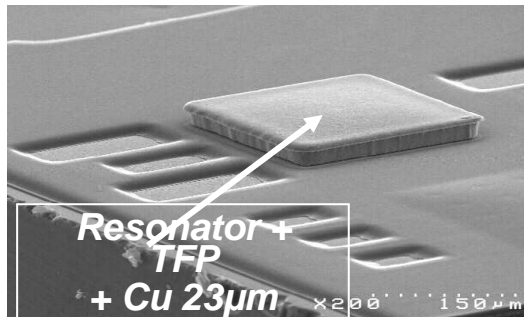


**Drawback: No overmolding compatibility for standalone components**



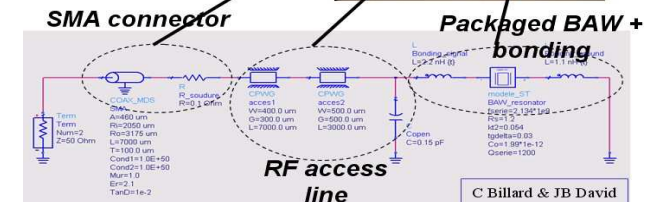
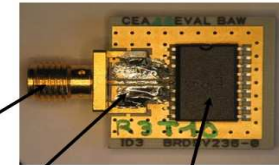
# Thin Film Packaging application to BAW RF resonator

## Electrical measurements on overmolded BAW resonators



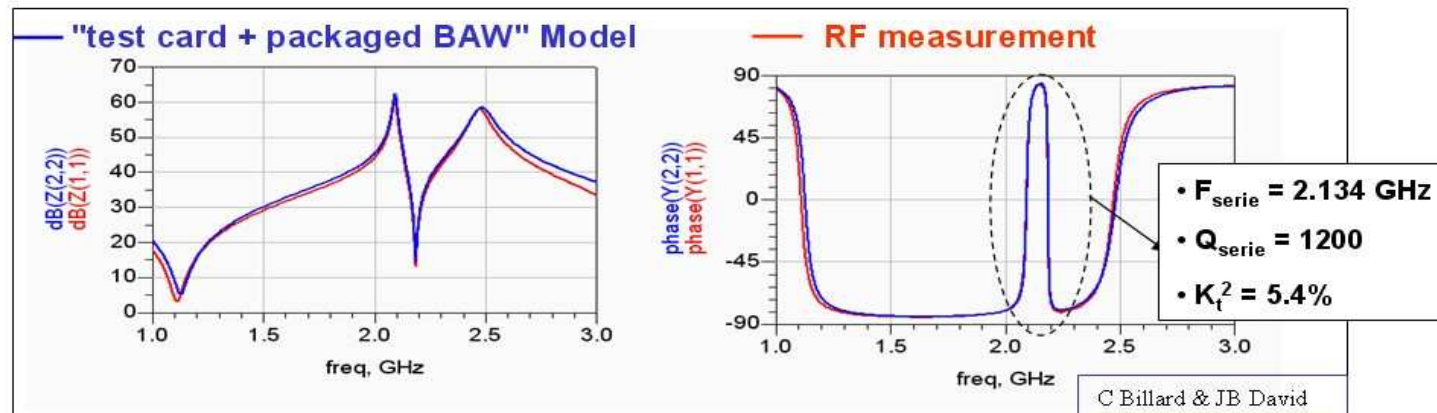
RF Measurement up to 10 GHz.

Over molding at  
100 Bars 185°C



Very good agreement obtained with standard model

## Electrical performances not affected



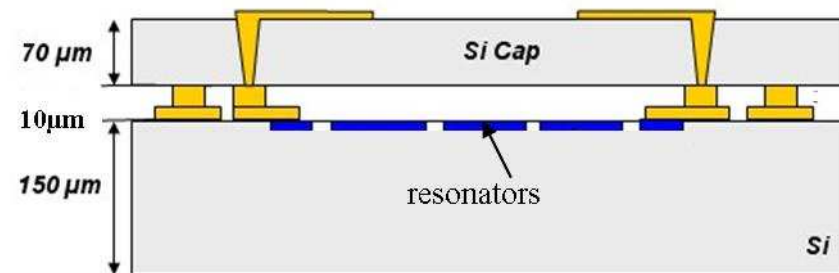
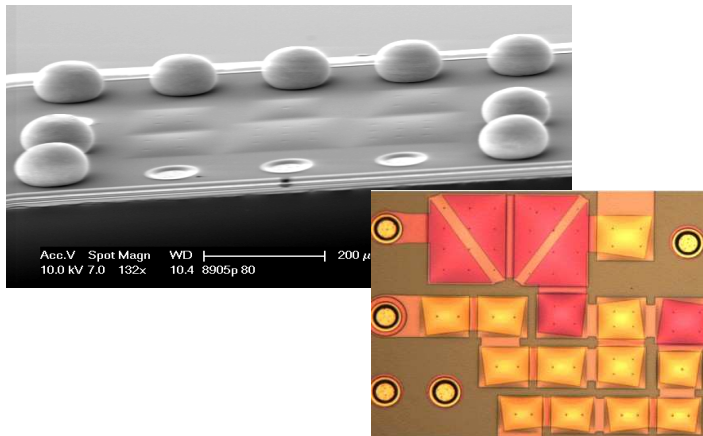
## Reliability analysis on going:

1000h @ 85°C & 85% moisture, -55/+150°C thermal cyc ling, hold @ 120°C

# Comparative cost analysis for packaging technologies

## Comparing between Wafer Level Packaging methods

- Thin film packaging (standard).
- Thin film packaging (with reinforcement).
- Si cap packaging (polymer bonding).
- Si cap packaging (with TSV).

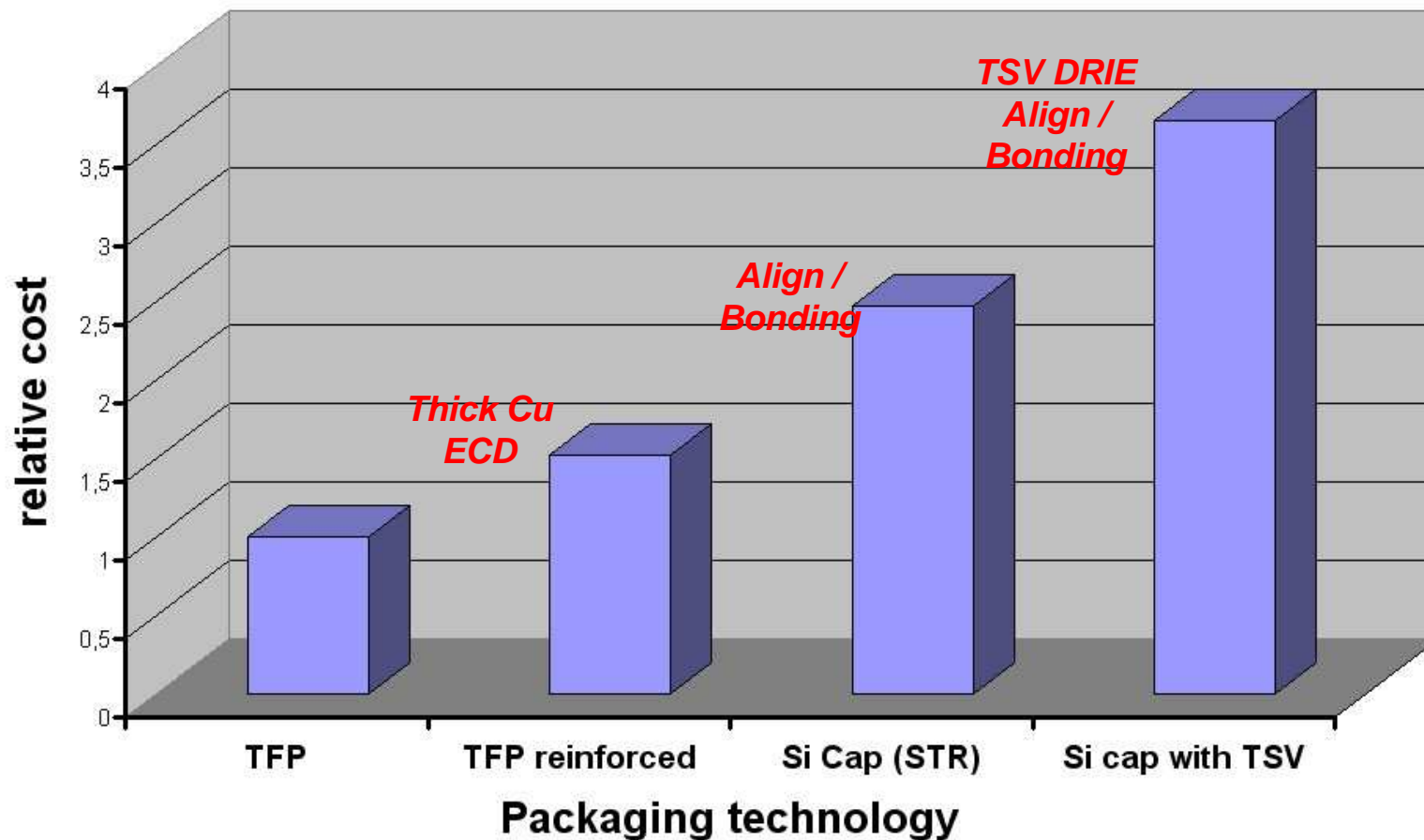


**Evaluations based on a cost model taking into account the global process (die area, yields...), process flows (equipments CoO, operator time, consumables,...), the clean room environment (HU, depreciation, footprint, production capacities...), ...**



# Comparative cost analysis : results

## Relative cost analysis



## Conclusions

- ***MEMS platform at LETI has been updated to integrate the international MEMS landscape, putting in coherence short-term, mid-term, and long-term applications.***
- ***Short-term developments based on few key modules and generic technologies.***
- ***Same approach initiated for mid-term and long-term developments.***
- ***High focus on the wafer level key technologies for packaging and heterogeneous integration.***



***THANK YOU FOR  
YOUR ATTENTION***





micro and nanoelectronics  
microsystems  
ambient intelligence  
biology and health  
image chain



# Innovation for industry

Loyalty  
Entrepreneurship  
Team work  
Loyalty  
Entrepreneurship  
Team work  
Innovation

leti

