Laboratoire
d'Informatique
de Robotique
et de Microélectronique
de Montpellier

LIRMM

« Embedded Test Challenges around SiP technologies »

Pascal Nouet

SiPeX Workshop – Verbania, may 29, 2008

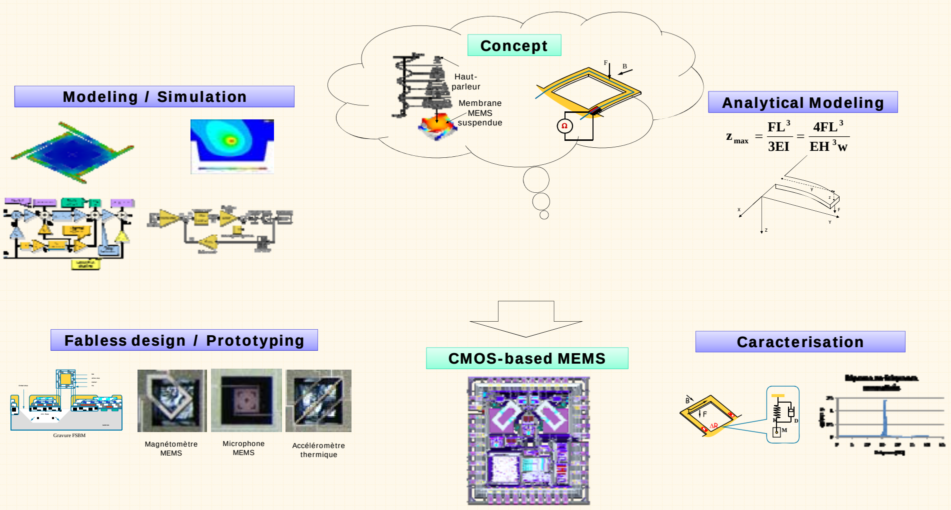
Outline

- Context, know-how and skills of the team
- Embedded Test by the example
  - ✓ MIDISPPI
    - Funded by the French Research Agency in 2006
    - Started March 2007
  - ✓ R3MEMS
    - Funded by the French Research Agency in 2007
    - Started January 2008

Context

- MEMS rather than MEMs
- Balanced development time between technology, modeling, design, test, …
- Stable technology is needed → CMOS process
  - ✓ EM Device is low performance, portable, low-cost
  - ✓ High NRE for an up-to-date CMOS process (MEMS devices + ASIC)
  - ✓ Non-planar CMOS process is prefered

Fabless design flow



CMOS-based sensors

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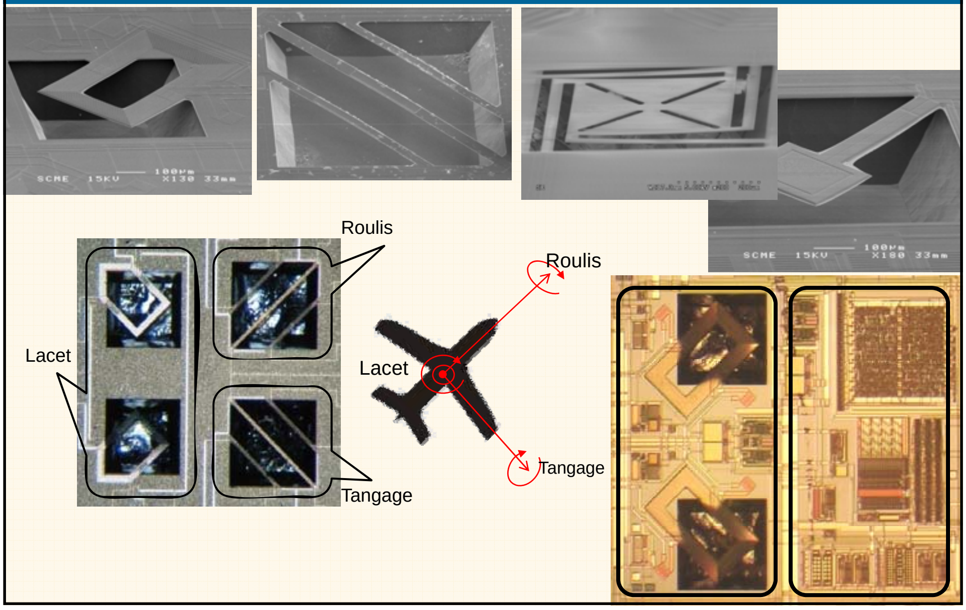

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MIDISPPI Project

« Smart Cap for Smart Sensors »

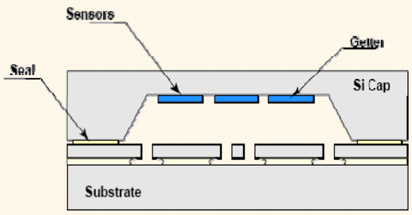
ANR Project - 2006

N. Pous, F. Mailly, P. Nouet, L. Latorre

MEMS Reliability Workshop - Toulouse, may 29-30, 2008

The MIDISPPI Project

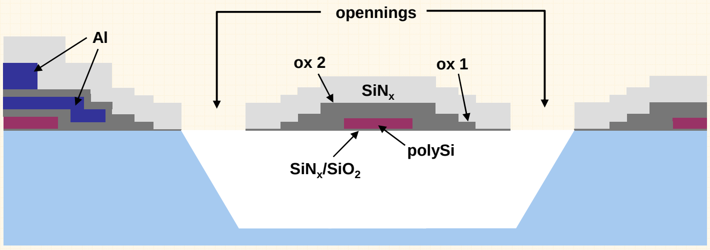
- Academic Partners:
  - ✓ IEF (Orsay)
  - ✓ IMS (Bordeaux)
  - ✓ LIRMM (Montpellier)
- Industrial Partners:
  - ✓ NXP



- Design and realization of a smart packaging : Integrating microsensors in the cap for the monitoring of the package internal environment.
- Various test devices will be integrated: Temperature, Pressure and Humidity sensor.
- The ultimate goal is to obtain a «zero-defect» final test method.
- Calibration & compensation functions

Context: The PICS substrate

- PICS
  - ✓ 25-50nm of SiN_x/SiO_2
  - ✓ One polysilicon layer
  - ✓ 2 interconnect levels (Al)
  - ✓ 2 oxides (SiO_2) layers +1 passivation (SiN_x) layer
- MEMS compatibility
  - ✓ TMAH /FSBM : fabrication of suspended structures
  - ✓ PolySi : Thermal and mechanical sensititity



Context: The PICS substrate

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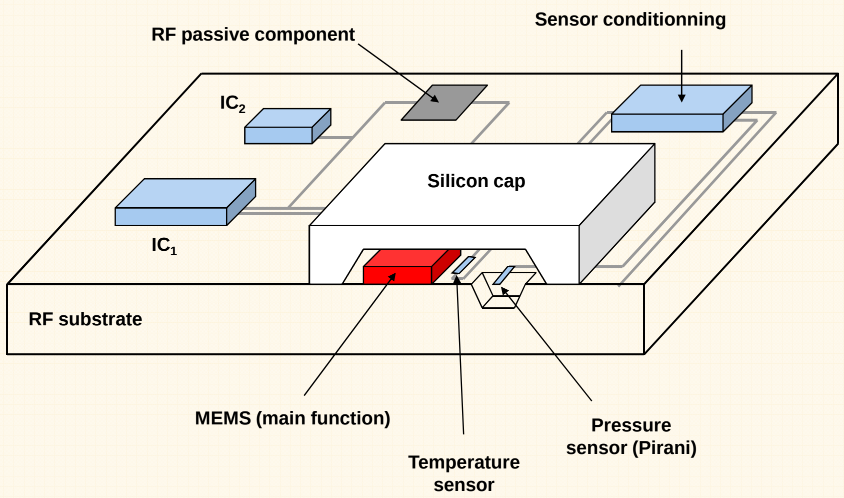
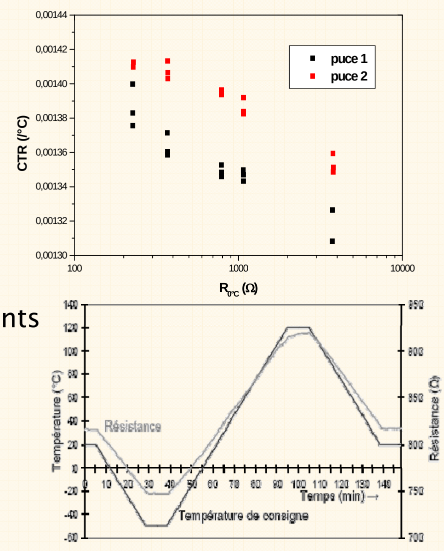


Extra-hardware must be highly reliable and low cost….

Temperature sensor

LIRMM 10

- Use of PICS polysilicon
- Measure of thermal coefficient between 20 and 90°C (LIRMM)
  - ✓ Good linearity (r > 0.999)
  - ✓ 0,13%/°C < CTR <0.14 %/°C
- Confirmed by IMS measurements between -50 et 120°C

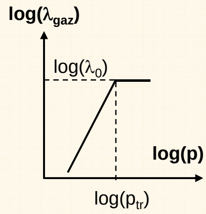


Pirani Gauge Working Principles

LIRMM 11

- ✓ Use of a suspended resistor as a heater (FSBM)
- ✓ Thermal equilibrium:
  - Heat conduction into materials to the substrate
  - Radiation losses (usually negligible)
  - Heat conduction or natural convection into surrounding gas (related to the pressure)
- ✓ Gas thermal conductivity:
  - Negligible for $p << p_{tr}$
  - Constant (λ_0) for $p >> p_{tr}$

$$\lambda_{gaz}(p) = \lambda_0 \frac{p}{p + p_{tr}}$$



- ✓ 2 techniques for pressure measurement
  - Temperature measurement at constant power
  - Power measurement at constant temperature

Transition pressure

LIRMM 12

- Related to molecule free minimal path (*l*) :

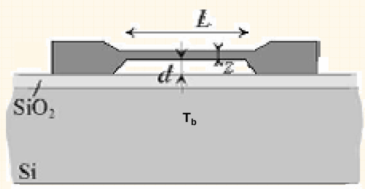
$$l = \frac{kT}{\sqrt{2}\, p \pi a^2}$$

pour N_2, πa^2=0,43nm² ⇨ L#150nm @ 20°C

- p_{tr} as a function of molecules speed and air gap:

$$p_{tr} = \lambda_0 \frac{wT_b}{(w+z)d\bar{v}}$$

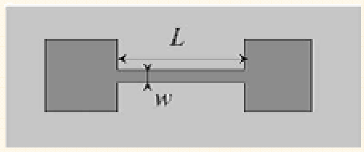
R. Puers et al, Sens. Actuators A 97-98 (2002), 280-214



- p_{tr} as a function of air gap and *l*

$$p_{tr} = \frac{\bar{v}}{2}\frac{C_v}{RT} l p \frac{d}{d + 2l(\frac{2}{\alpha_E} - 1)}$$

M. Kimura et al, Microelectronics Journal 38 (2007), 171-176

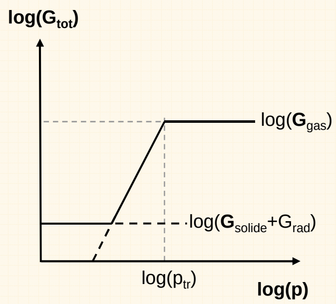


Thermal Equilibrium

LIRMM 13

$$G_{tot} = G_{solide} + G_{rad} + G_{gas}\frac{p}{p+p_{tr}}$$

- ✓ Under vaccum ($p << p_{tr}$)
  - ⇨ $G_{solide} + G_{rad}$
- ✓ At $p >> p_{tr}$
  - ⇨ G_{tot} puis G_{gas}



Prototyping

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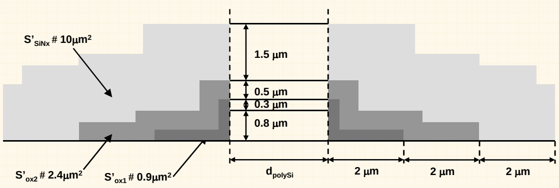
- Prototype features
  - ✓ $R_{0°C}$ = 390Ω, CTR=0,138%/°C
  - ✓ Length =1020µm, width (polysilicium): d_{polySi}=25µm
  - ✓ Cross-section area : s_{tot}~ 104µm²
  - ✓ Beam exchange surface : S_{tot}~ 78500µm²



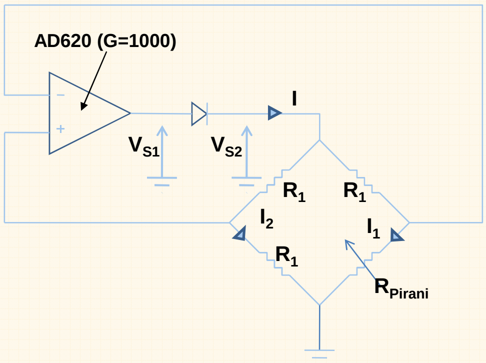
- Temperature regulation (T_c=316°C)
  - ✓ R_{Pirani} @ T_c

$$R(T) = R_{0°C}(1 + CTR.T_c) = 560\Omega$$

Conditionning Circuit

LIRMM 15

- $R_1 = 560\Omega$
- Two stable states :
  - ✓ All potentials are zero (impossible due to noises and offsets)
  - ✓ I_1 large enough to heat the Pirani resistor, giving R_{Pirani} # R_1 and T_{Pirani} # T_c et V^+ # V^-



Experimental results

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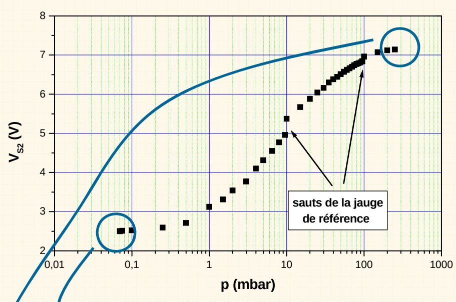


$$V^+ - V^- \approx \frac{V_{S2}\left(R_1 - R_{Pirani}\right)}{4R_1}$$

$$V_{S1} = G(V^+ - V^-) \approx V_{S2} + 0.7$$

$$\Rightarrow \quad T_{Pirani} = \frac{R_1 - R_{0°C}}{CTR.R_{0°C}} - \frac{(V_{S2}+0.7).4R_1}{G.V_{S2}.CTR.R_{0°C}}$$

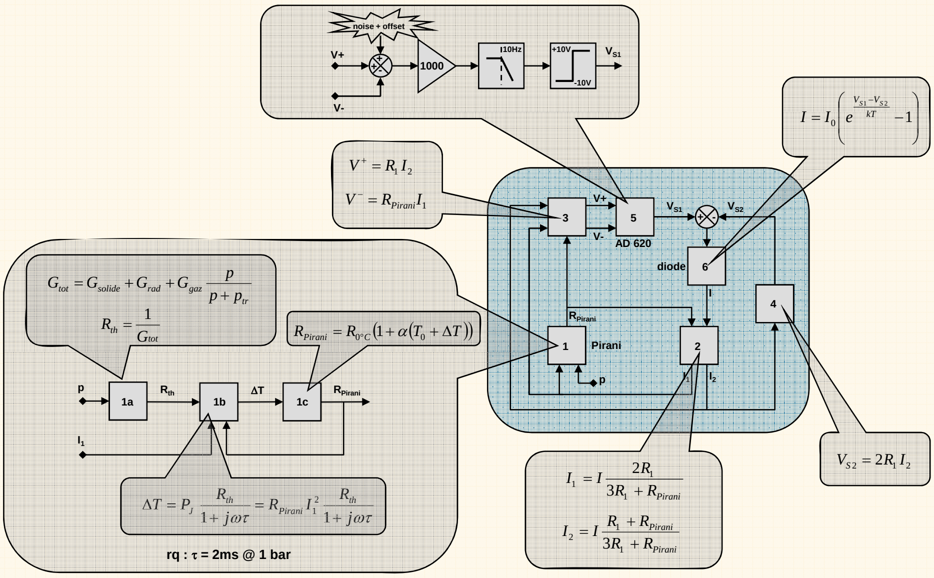
$$T_{Pirani} = 316°C - \varepsilon$$

$V_{S2} = 2{,}5V \Rightarrow \varepsilon = 5{,}3°C \Rightarrow G_{solide} + G_{rad} \approx \frac{P_J}{T_{Pirani} - 20°C} = \frac{2{,}8.10^{-3}}{290{,}5} = 9{,}65.10^{-6} W/K$

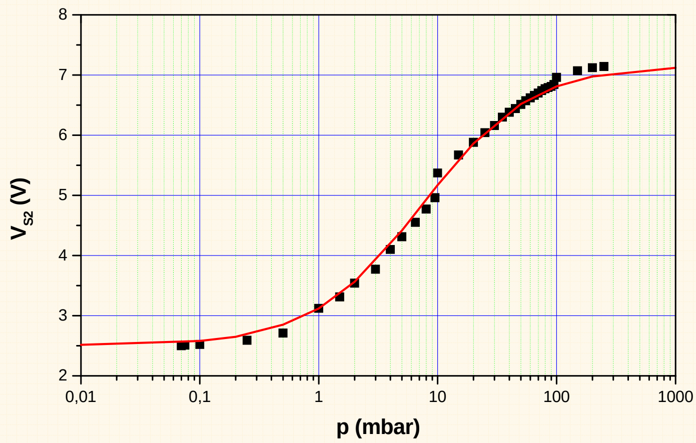
$V_{S2} = 7{,}14V \Rightarrow \varepsilon = 4{,}6°C \Rightarrow G_{tot} \approx \frac{P_J}{T_{Pirani} - 20°C} = \frac{2{,}29.10^{-2}}{291.3} = 7{,}85.10^{-5} W/K$

$G_{air} \approx 6{,}88.10^{-5} W/K \Rightarrow h_{air} \approx 876 W.m^{-2}K^{-1}$

Modeling (Matlab/Simulink)



Simulation vs Measurements

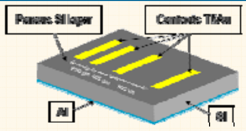


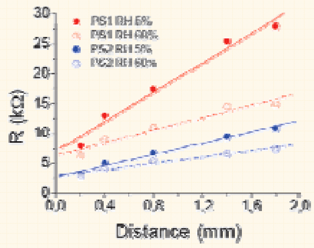
Fits @ p_{tr} = 12 mbar

Porous Silicon Humidity Sensor

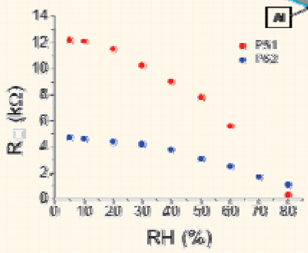
➢Resistive Humidity Sensor

- First results:





Variation of resistance of PS1 and PS2 verus distance between contacts



Sheet resistance $R_{\square}$ versus RH from 5 to 80%

At moisture levels smaller than 70% relative humidity (RH), resistance increases with specific surface.

The sample with the higher specific surface (PS1) is about 10 times more resistive than the other (PS2).

Reference: W. Luduczak, O. Garel, C. Pellet, E. Dufour-Gergam, F. Verjus, *Influence on moisture sensor performances, and characterization of different specific area porous silicon layers*, IEEE Sensors 2007 conference, 2007

Conclusion

- Approach strengths
  - ✓ Use of PICS substrate
  - ✓ Simple conditioning circuits
  - ✓ Modeling in good agreement with experiment
- Integration of the conditioning circuits
- Thermal conductivity of materials need to be studied
  - ✓ Under vacuum, using various geometries
  - ✓ Support from FEM (coventor)
- Air conductivity
  - ✓ 876 $W.m^{-2}.K^{-1}$
  - ✓ Higher than reported
  - ✓ Requires a precise knowledge of prototype geometry (e.g. air gap)

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R3MEMS Project

« MEMS-based reflect array antena »

ANR Project - 2007

N. Dumas, F. Mailly, P. Nouet, L. Latorre

Context

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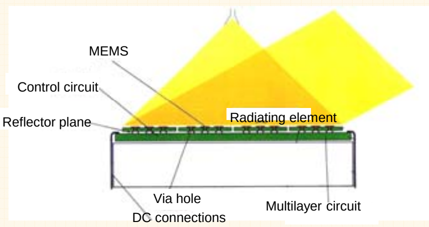

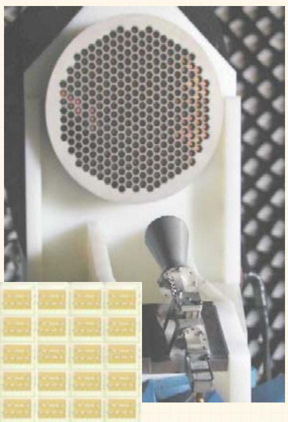

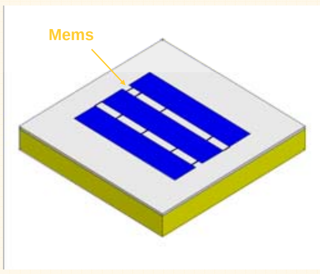

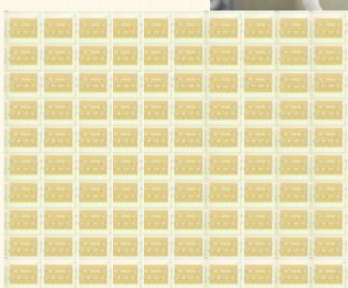

Main challenges

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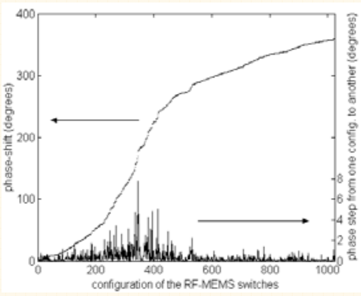
- Assembling – Packaging
- …
- Control → 10,000 electrostatic actuators
- Robustness → solved by redundancy



Embedded Test

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- No extra cost
  → use of the same infrastructure than for control
- Verify the actuation → Con/Coff

- Memory-like
- Scan-chain like

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Thank you !!!

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