Impact of process variability on a frequency-addressed NEMS array sensor used for gravimetric detection

MARTIN Olivier [1], **COLINET Eric***, **SAGE Eric**, **DUPRE Cécilia**, **VILLARD Patrick**, **HENTZ Sébastien**, **DURAFFOURG Laurent** and **ERNST Thomas**

CEA-Leti, Minatec Campus, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France
** APIX Technology, Grenoble, France*

[1] olivier.martin@cea.fr

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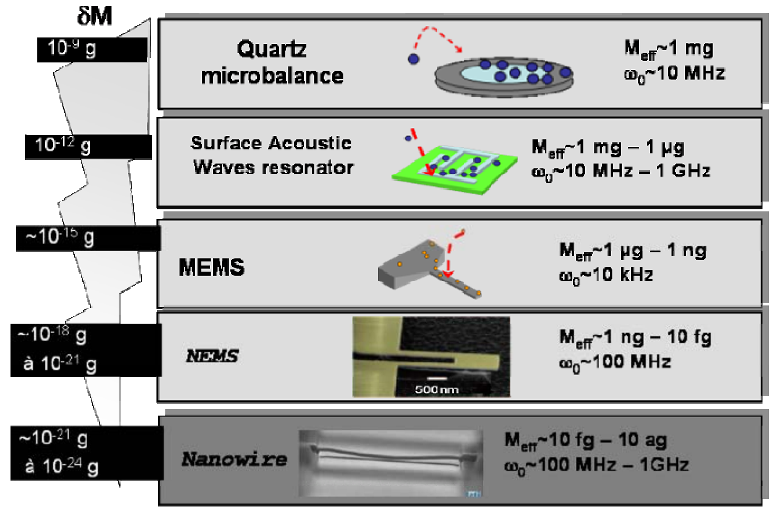
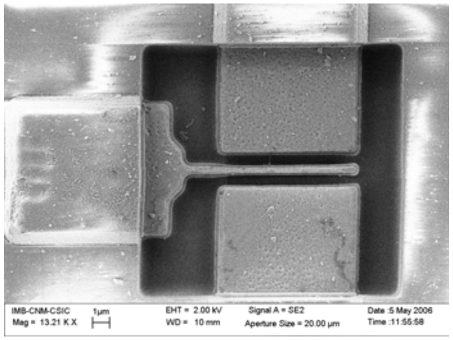
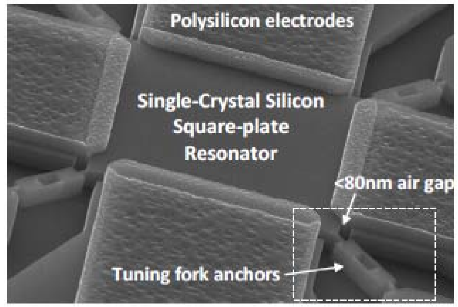
NEMS resonators





[1]



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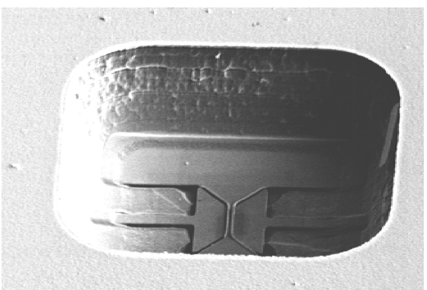

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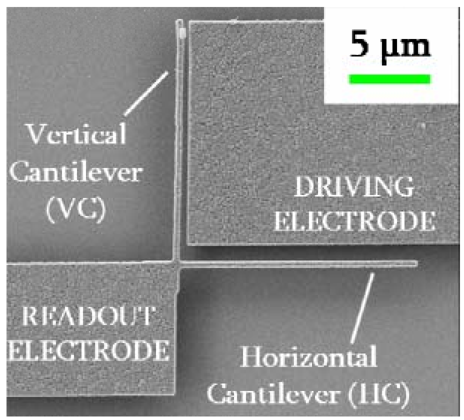

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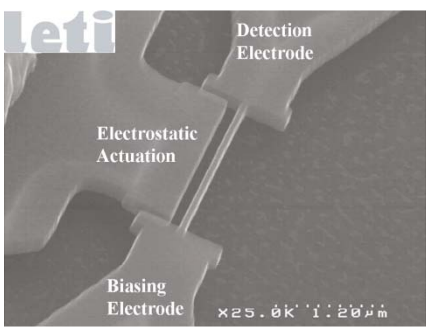

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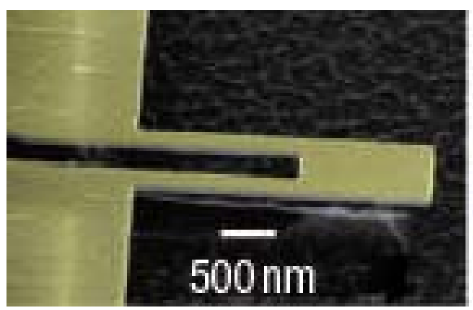

[6]

[1] Capacitive A/D, metal, BE –University of Barcelona (UAB)

[2] Capacitive A/D, Polysilicon, - UAB

[3] Capacitive A / piezoresistive D – Koumela et al. 2011 (Eurosensors)

[4] Capacitive A/D, Si+PolySi - Colinet et al. 2010 (Frequency Control Symposium)

[5] Capacitive A/D - Arcamone et al. 2008 (Journal of Physics: Conf. Ser. 100)

[6] Piezoelectric - Mo Li et al. 2008 (Nature Nanotechnology)

Applications

[8]

- Air quality
- Industrial process monitoring
  - Petrochemical industry, …
- Volatile organic compounds (VOC) identification
  - TEOX (Toluene, Ethylbenzene, Octane, Xylene)
- Security
  - chemical warfare agents detection
- Promising biomedical applications
  - Early diagnosis of illness (lung cancer, …)

[8] Max-One gas analyzer (GC/NEMS sensor), *APIX Technology*, http://apixtechnology.com

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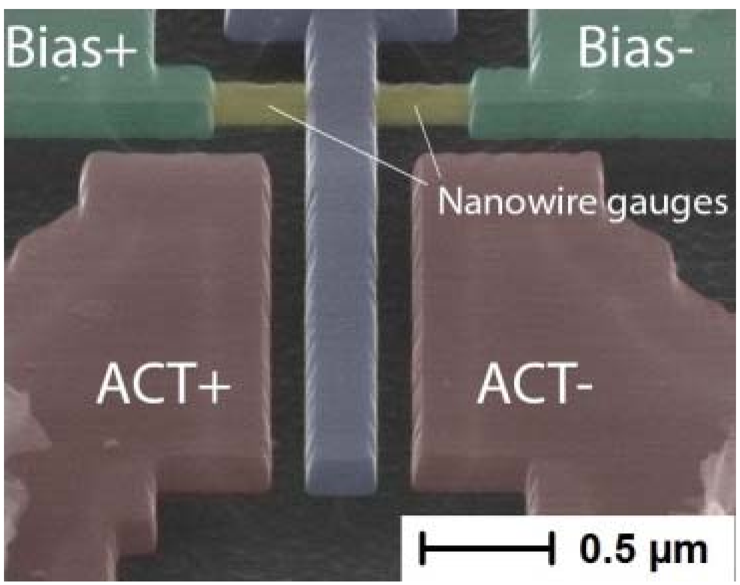
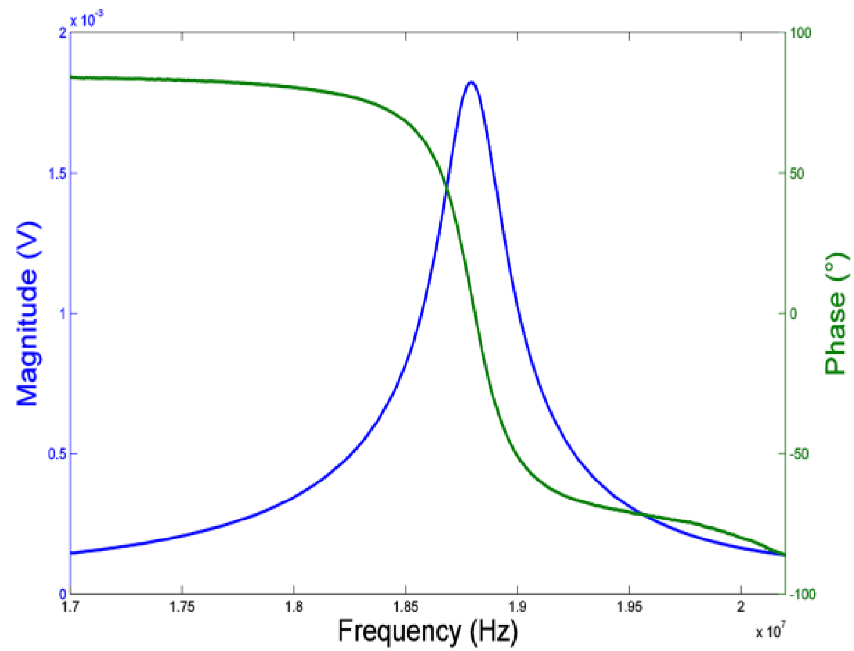
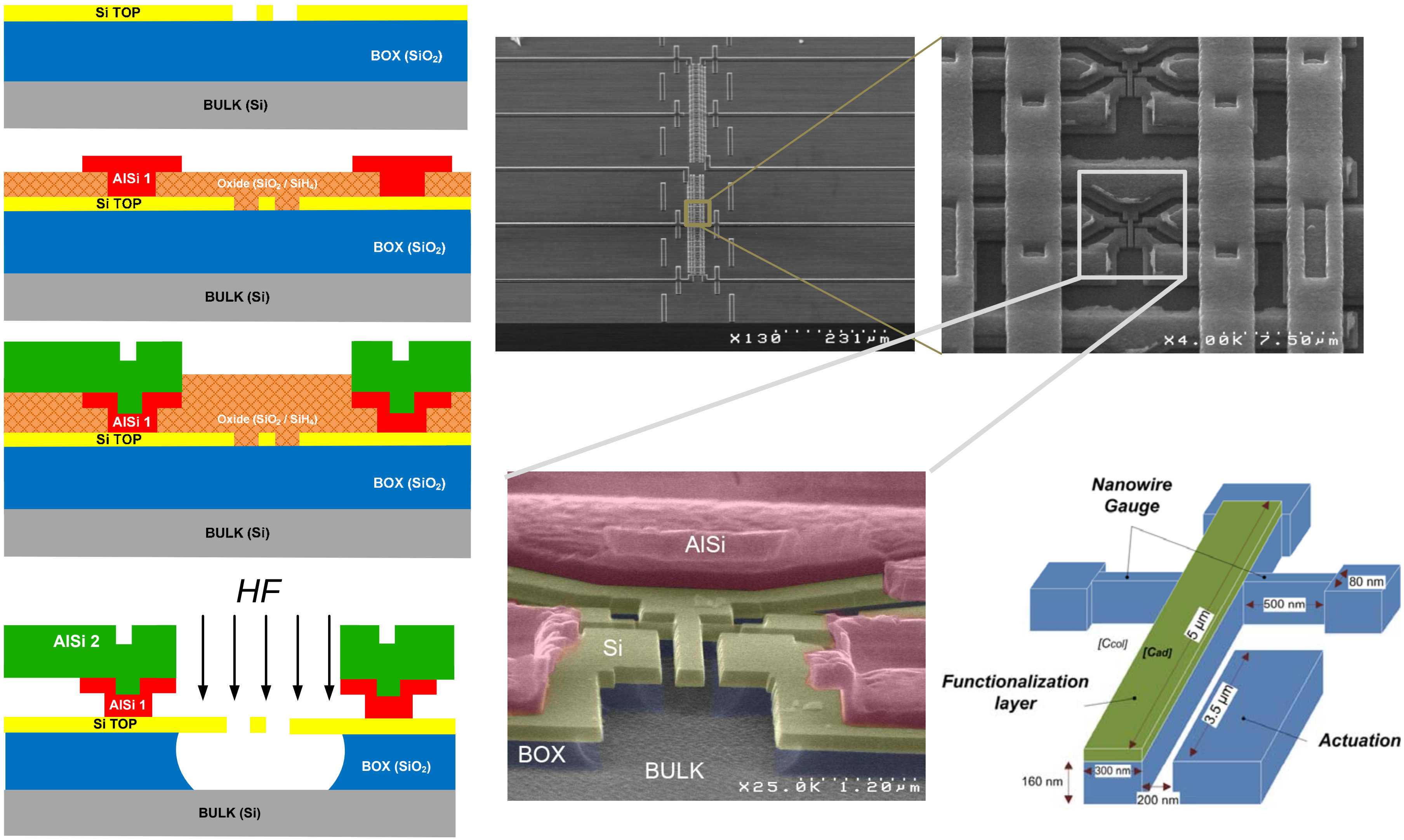
The « Crossbeam » - NEMS resonator

- In-plane motion of the beam
- Differential electrostatic actuation
- Piezoresistive detection by nanowire gauges





Process of fabrication (LETI)



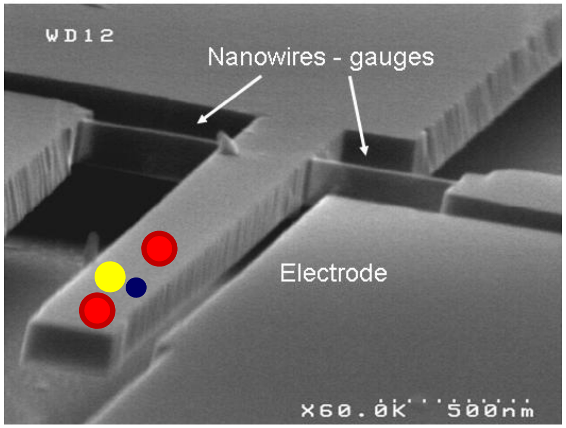
The « Crossbeam » as a mass sensor

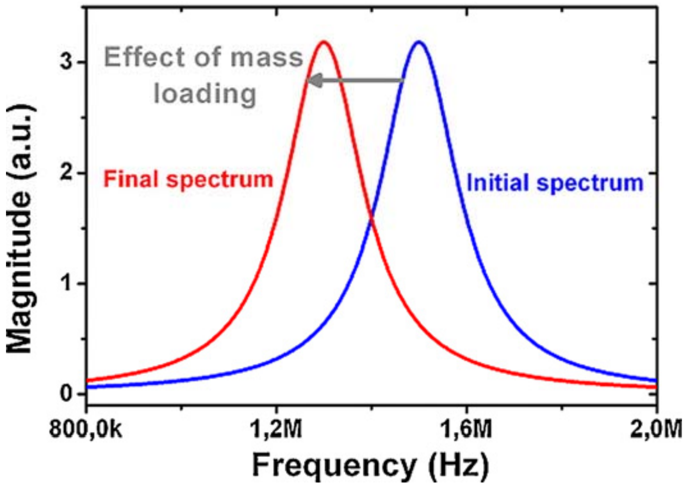
- Equation of the beam flexion :

$$H(\omega) = \frac{y(\omega)}{F(\omega)} = \frac{\frac{1}{M_{eff}}}{\omega^2 - \Omega_1^2 + j.\frac{\omega.\Omega_1}{Q}}$$

- Effect of mass loading :

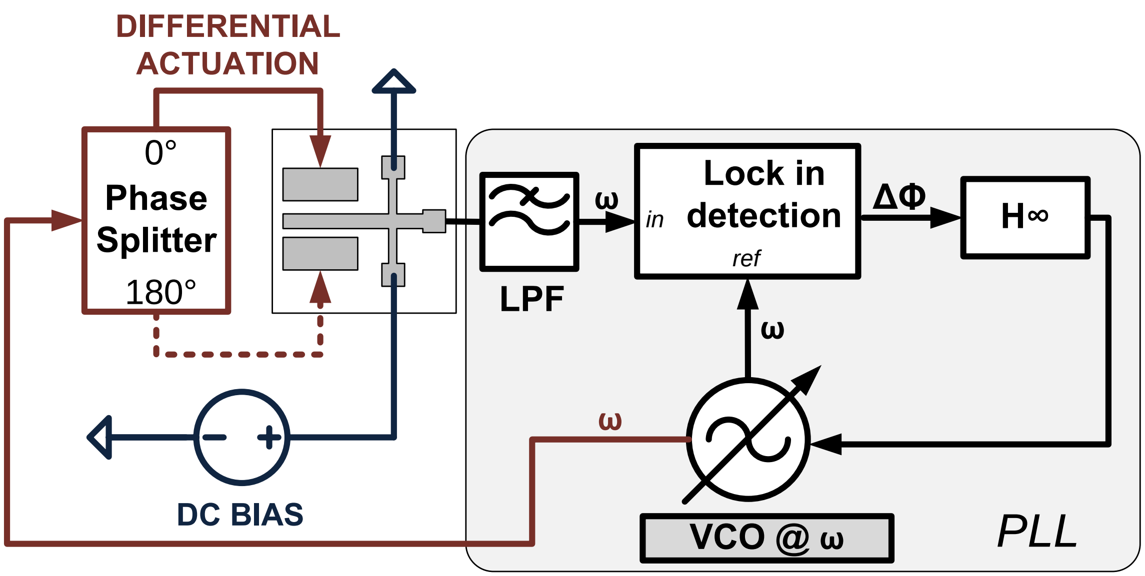
$$\Delta f = -\frac{\Delta m}{2M_{eff}} f_1$$

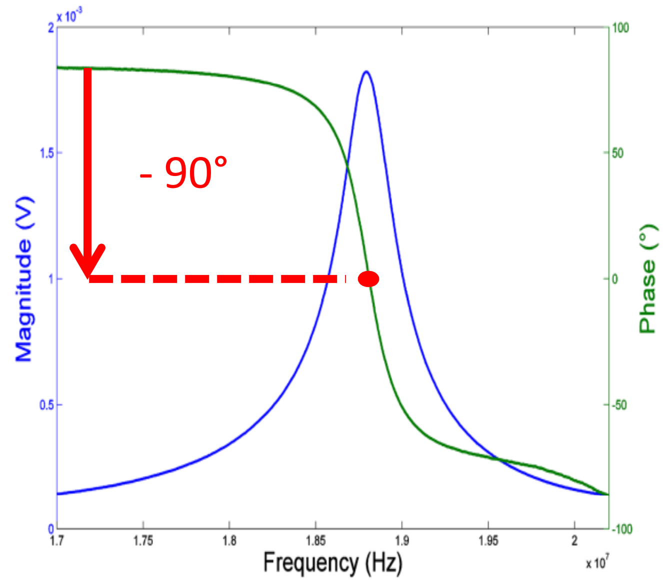




Frequency tracking readout (FLL)

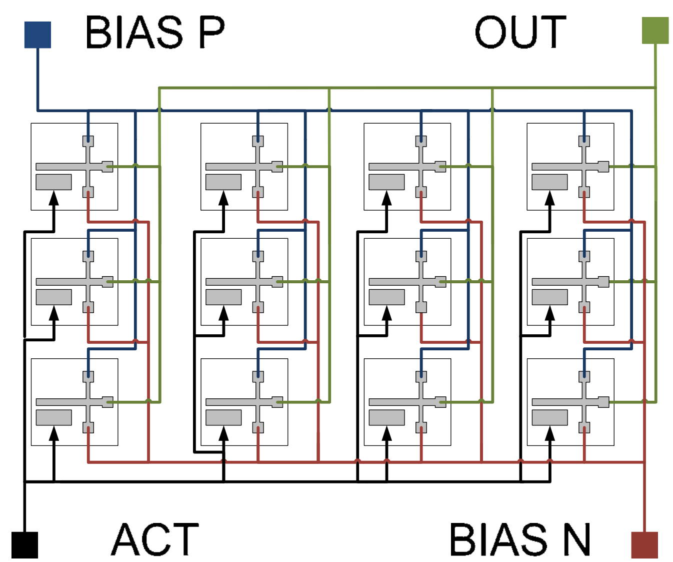
- Principle :
  - Phase shift of 90° @ resonance frequency
  - Input/Output phase shift comparison
  - Controller feeds a VCO which actuates @ the new resonance frequency

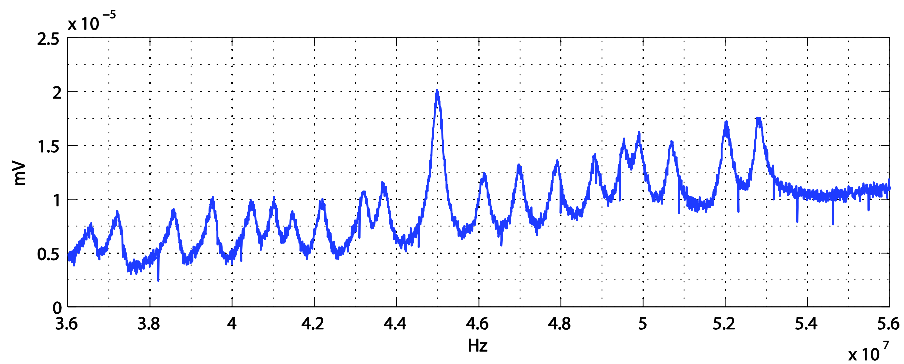




Parallel NEMS array integration scheme

- Collectively addressed resonator
  - Same resonance frequency
  - Better SNR proportional to $\sqrt{N}$
  - Global Q depends on process fluctuation
  - Same load needed on each NEMS
- Frequency addressed resonator
  - Each NEMS is readed independantly around its resonance frequency
  - Limits : frequency bandwidth / Q





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Impact of the variations (I)

- Resonance frequency:

$$\Omega_1 = \sqrt{\frac{EI}{\rho S}} k_1^{\ 2}$$

E : Young's Modulus of elasticity (169 GPa)
ρ : the density of the silicon (2330 kg/m3)
S : the cross-section of the lever beam
k_1=2.1178/Lb : the wave vector (anchorage)
I : the bending moment of inertia

$$I = \frac{(Tsi_b . W_b^{\ 3})}{12}$$

- Dependance of the geometrical parameters

$$\begin{cases} \dfrac{\partial \Omega_1}{\partial W_b} = \dfrac{(2.1178)^2}{2L_b^{\ 2}} \sqrt{\dfrac{E}{3\rho}} \\ \dfrac{\partial \Omega_1}{\partial L_b} = -\dfrac{(2.1178)^2}{L_b^{\ 3}} \sqrt{\dfrac{E}{3\rho}} W_b \end{cases}$$

With **L_b > 15~20.W_b**

W_b is 10 times more impacting than L_b

Impact of the variations (II)

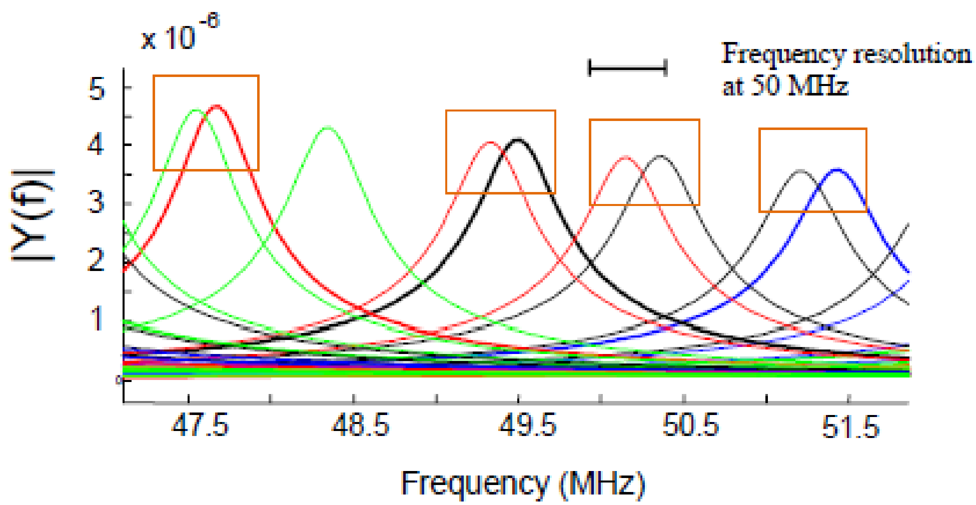
- Resonance frequency shift :
  - For NEMS resonating at 20 MHz, 40 MHz and 60 MHz
  - With a **10 nm** width fluctuation error

➔ Downshift of 1.21 MHz, 2.46 MHz and 3.63 MHz respectively

➔ A **6% variation** on the **width** leads to a **6% downshift** of the resonance frequency

- Bandwidth of the NEMS: **ΔΩ1=Ω1/Q** with **Q ≈ 100***

→ 500 kHz for a 50-MHz resonance frequency NEMS



*** In air**

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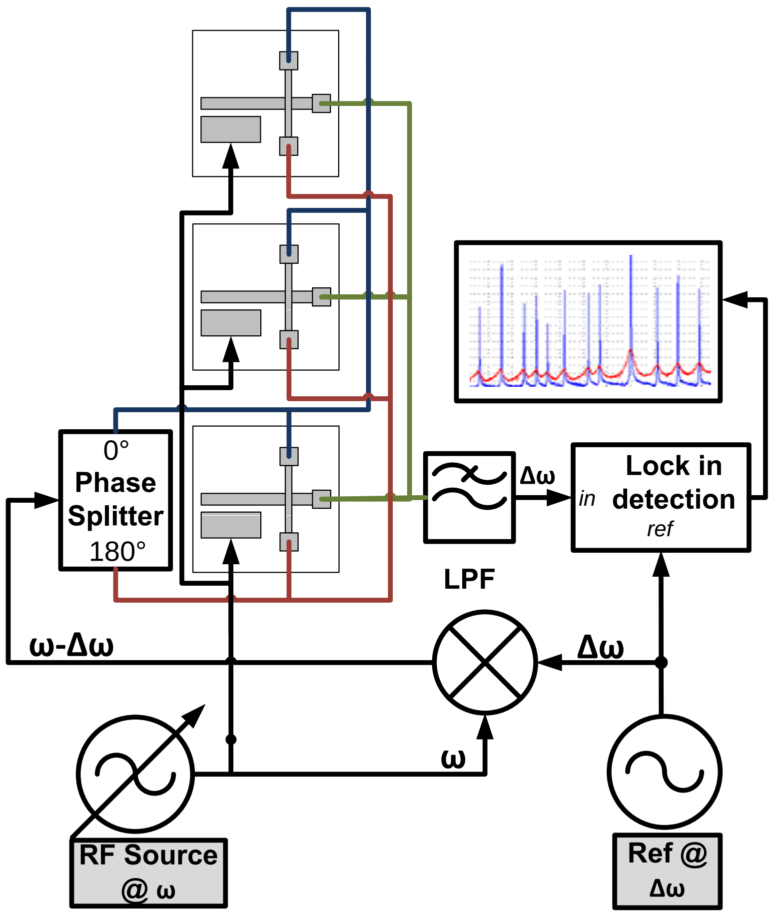
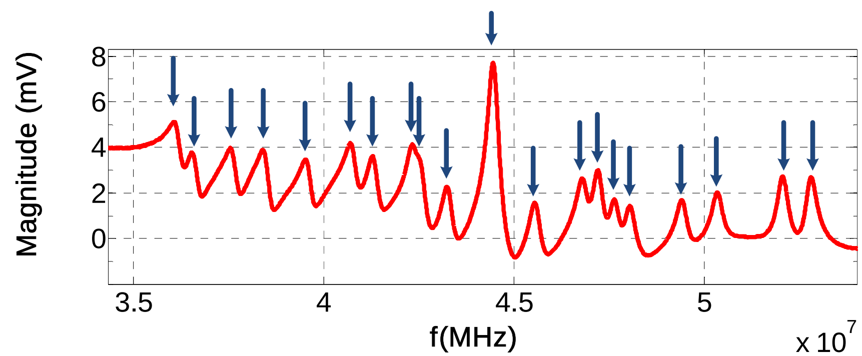
Measurement setup (I) – Open Loop

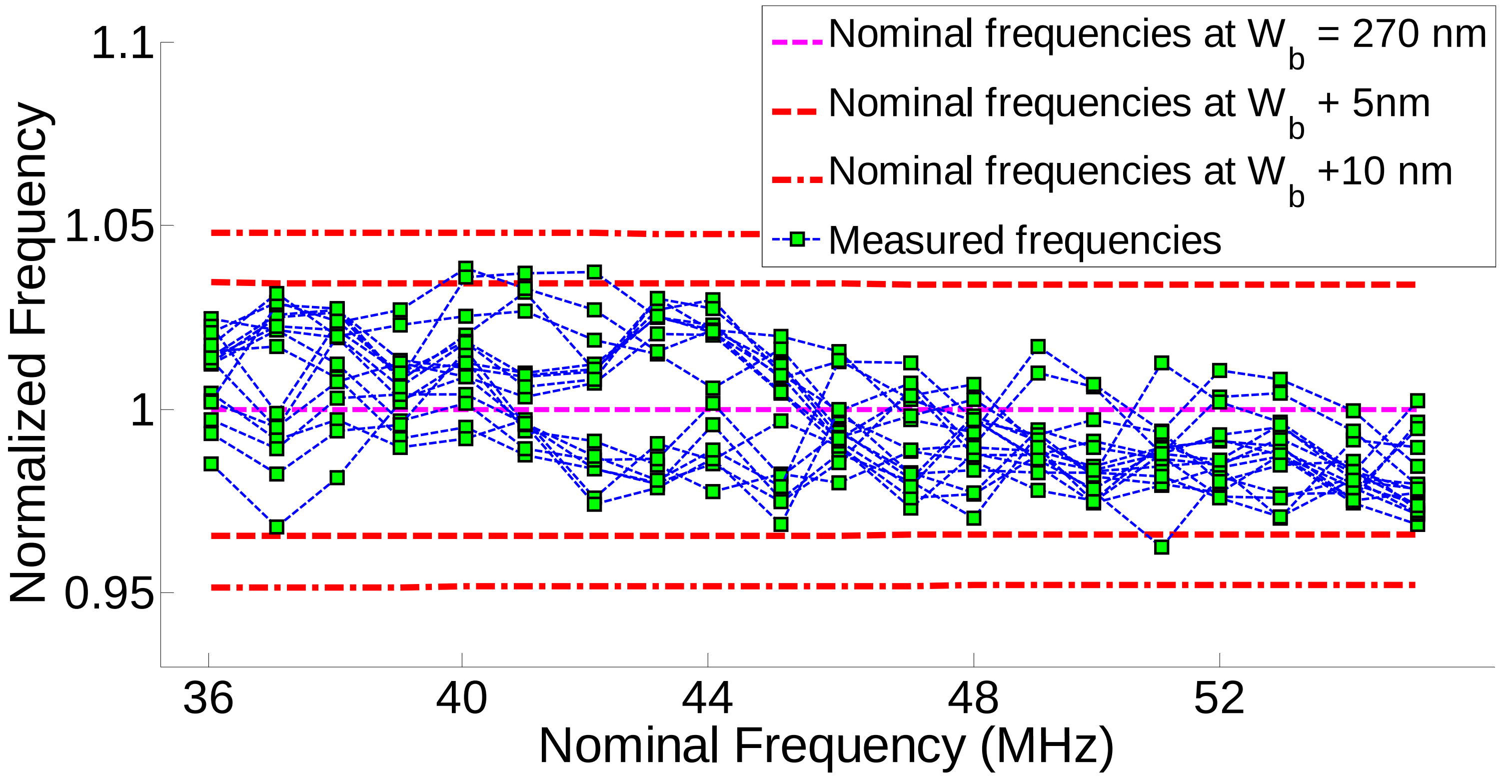


- First bench:
  - Frequency control
  - Open loop
  - Lock-in Amplifier : *SR 830*
  - Sources : *Agilent 81160A* (Double)



[9] E. Sage et al. - Transducers 2013

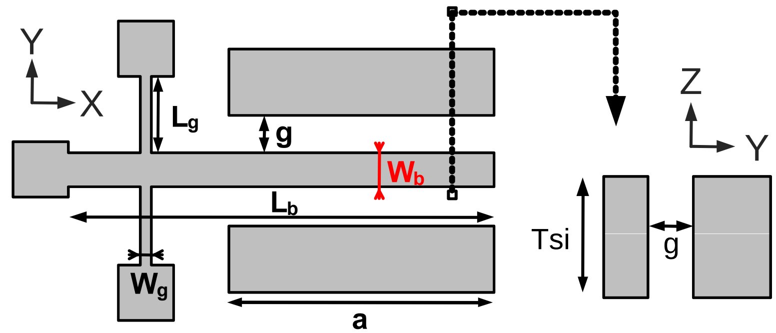
Measurement (I) - Results

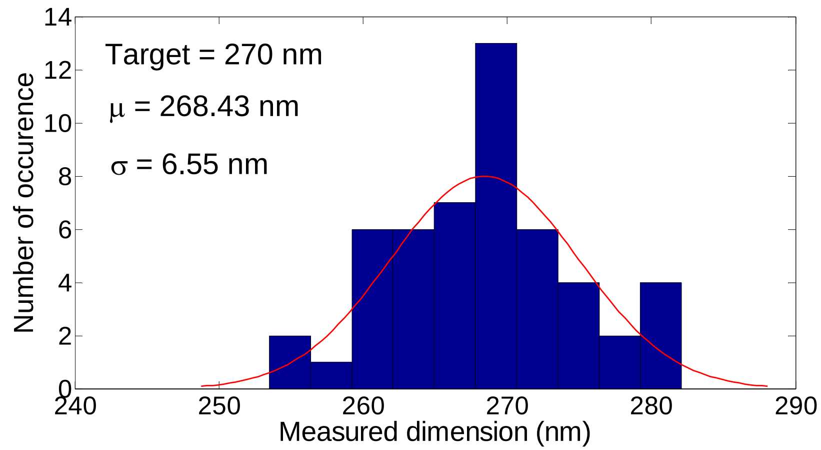


- Dispersion on the width below 10 nm

Measurement setup (II) – Optical

- Second bench:
  - **Morphology** of each NEMS characterized by **SEM** (Scanning Electron Microscopy)
  - Characterization of:
    - L_b, W_b, g
  - Exemple of W_b for a 40 MHz NEMS:
    - $\sigma_{\Omega 1}$ = 1.83 MHz (cf Bench 1)
    - σ_{W_b} should be 7 nm (Bench 1)
    - Results : 6.55 nm





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Conclusion

- Process variations impact on a new NEMS device was studied
- Most impacting parameters are indentified
- Toward VLSI sensors with a better capture area
- Design of frequency-addressed NEMS arrays
  - Without overlap of frequencies
  - More robust
  - With a maximum of density

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CEA-Leti
MINATEC Campus, 17 rue des Martyrs
38054 GRENOBLE Cedex 9
Tel. +33 4 38 78 36 25

www.leti.fr

Thank you for your attention

olivier.martin@cea.fr

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