NAM6 GROUP

NANO and MICRO SYSTEMS

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FIELDS OF ACTIVITY AND STRATEGIC POSITIONING

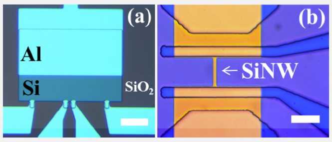
- Fields of activity: micro-actuation, micro-sensing, resonant devices and transduction schemes, cleanroom process development for MEMS/NEMS, materials/device/system characterisation and MEMS/NEMS modelling.
- Strategic positioning is based on a balance of technological/scientific-pushed and application-pulled considerations in the fields of:
  - Giant piezoresistive effects in silicon and its nanostructures,
  - MEMS resonators for high-frequency atomic force microscopy sensors,
  - MEMS devices based on gallium nitride,
  - Instrumentation for nano-characterization

PIEZORESISTANCE EFFECTS IN SILICON AND ITS NANOSTRUCTURES

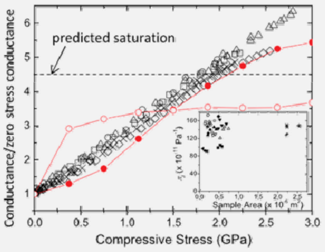
- Objective: Identifying the physical mechanism behind giant piezoresistance.
- An understanding would enable us to optimise the effect and effectively apply it to new sensor technologies.

Funding: ANR

Results reported widely in the international press (reputable scientific magazine articles and scientific news web sites).



4 terminal aluminium-silicon hybrid structure fabricated at IEMN which displays giant piezoresistance[1]. Scale bar = 20 µm. (b) Top-down silicon nanowire[2] fabricated at IEMN used for giant piezoresistance studies. Scale bar = 2 µm.

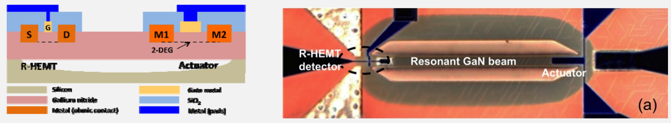


Piezoresistance in bulk p-type (110) silicon in compression up to 3 GPa.[3]

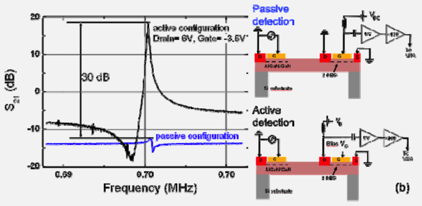
1. *Phys. Rev. Lett.* **100**, 145501 (2008)
2. *Phys. Rev. Lett.* **105**, 226802 (2010)
3. *Phys. Rev. Lett.* **108**, 256801 (2012)

GALLIUM NITRIDE MEMS

- Objective: Sensors working in a harsh environment.
- Demonstration of the first GaN MEMS resonators with integrated transducers, along with the first R-HEMT [1]
- Extensive study of the transduction physics and the piezoelectric actuation using the 2DEG of the AlGaN/GaN heterostructure as well as the piezoelectric active



Left: AlGaN/GaN MEMS resonator scheme. Right: Top view of the AlGaN/GaN MEMS resonator. On the right, the piezoelectric actuator uses the AlGaN layer sandwiched between a top electrode and the two-dimensional election gas. On the left the R-HEMT is fabricated on the resonant beam for motion detection



Measured S_{21} parameter between the input and the output of the beam resonator. black curve : signal obtained using the R-HEMT as an amplifier, blue curve : signal of the device operated as classical piezoelectric passive transducer.
The gain of 30 dB provided by the R-HEMT shows the advantage of the integration of the HEMT on the resonant beam.

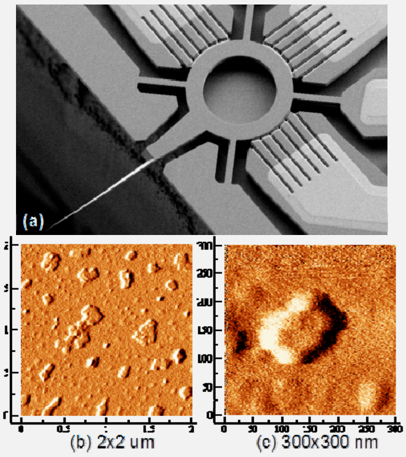
1. *Appl. Phys. Lett.*, 94, 23 (2009) 233506-1-3

Funding: ANR, DGA

MEMS BASED ATOMIC FORCE MICROSCOPY SENSORS

- Objective: High speed AFM in liquid medium by changing the AFM sensor paradigm.
- Proposed solution: ring-shaped silicon MEMS as AFM resonant probes with integrated capacitive transducers [1,2].
- Imaging of DNA origami up to 1 frame-per-second on a modified commercial AFM with a force resolution of 5 pN/√Hz [3].
- State-of-the-art for AFM probe resonance frequency. Increase in speed by a factor of 10 to 100 foreseen.

Funding: ERC starting grant (*SMART*) and ERC Proof of Concept project (*PROMISING*).

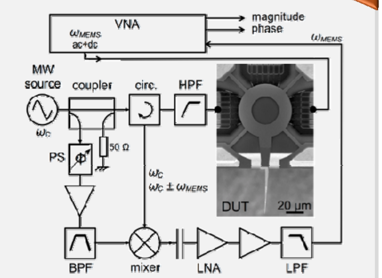


(a) SEM image of a MEMS AFM sensor based on a silicon ring resonator. Vibration is driven and sensed by integrated capacitive transducers featuring sub-100 nm air gaps. A silicon nanotip (apex radius below 10 nm) is located at a maximum of the elliptic vibration mode. (b) and (c): AFM topographic images of DNA origamis acquired by a 10.9 MHz MEMS AFM sensor. AFM tip vibration amplitude is 0.2 nm.

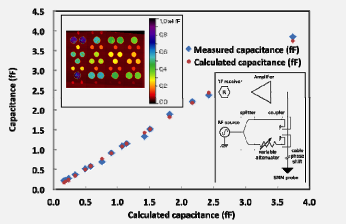
1. *Proc. IEEE MEMS* (2010)
2. *J. Microelectromech. Syst.*, **21**, 385 (2012)
3. *Proc. IEEE MEMS* (2012)

INSTRUMENTATION FOR NANOCHARACTERIZATION

- Objective: investigate microwave interferometers and reflectometers for measurement of capacitances in the femtoFarad range, far for the 50 Ω standard. Application to MEMS devices.
- Measurement of the vibration amplitude of MEMS resonators with a resolution of 10^{-14} to 10^{-15} fm/√Hz (similar or better than the optical detection).
- Electrical measurement of small capacitances with an AFM coupled with a vectorial network analyser. Calibrated detection of 100 fF capacitances limited mainly by the parasitic capacitance of the measurement probe.



Experimental set-up used to measure MEMS resonator vibration with the microwave reflectometry technique



Main: comparison between the calculated and measured capacitance values. insets: microwave interferometer and capacitance image obtained after calibration.

1. *IEEE Transducers 2013*
2. *Appl. Phys. Lett.*, 103, 053124 (2013).

ACADEMIC AND INDUSTRIAL COLLABORATIONS

- ❑ Long-term academic and industrial partnerships with: CNES, CEA (LETI/LIST), CRHEA (CNRS), Tokyo University, Leeds University, Oldenburg University, NXP Semiconductors, ST Microelectronics, Delfmems, Agilent Technologies, Ecole Polytechnique (Palaiseau) and the University of Geneva.
- ❑ 5 Ph.D. students have been jointly supervised with other groups of IEMN (BioMEMS, AIMAN, ANODE, ACOUSTIQUE). - 4 priority patents and 11 extensions from 2008 to 2013

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