Open PhD position – CASSINI Project – 2023

Clock And Sensor Stability Improvement in NEMS-based Instruments

Context

Resonant NEMS (Nano-Electromechanical Systems) and MEMS (Micro-Electromechanical Systems) sensors [1-2] combine several appealing features, such as small size, reduced cost, and intrinsic low power consumption compared to their macroscopic **quartz** or **optical** high-end competitors (e.g. [3-4] in the inertial sensing domain). Still, they suffer from several limitations: **(i)** their **sensitivity to temperature**, which requires elaborate **active compensation** schemes [5] that degrade their power consumption, **(ii)** their **long-term reliability**, essentially due to imperfect packaging hermeticity - the quality factor Q of the resonator decreases with time, and so does the accuracy of the device [6], **(iii)** their **sensitivity** to noise and fluctuations of their environment, and **stronger nonlinearity**. Typical beam structures fabricated at C2N are given as an illustration in Fig. 1. The generic structure of both clocks and sensors involving these MEMS/NEMS is given in Fig. 2.

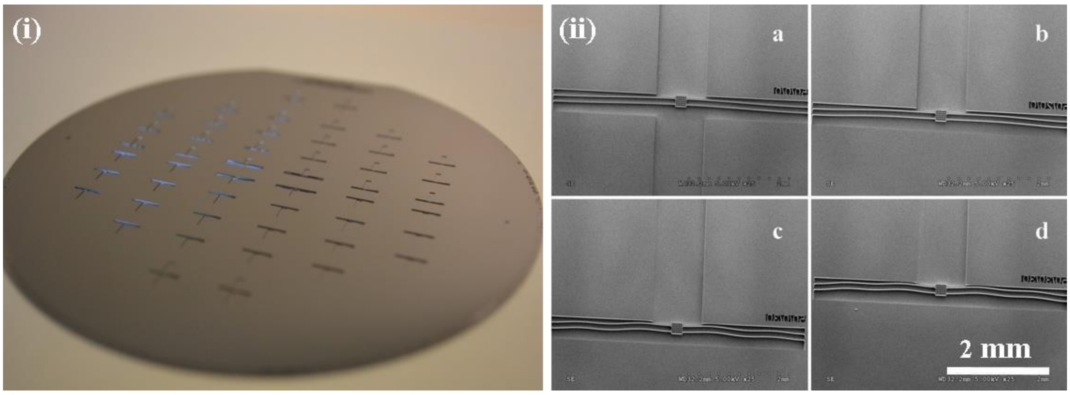

Fig. 1 – Examples of micro/nanostructures designed and manufactured at C2N, Palaiseau (PhD thesis Bogdan Vysotskyi, https://tel.archives-ouvertes.fr/tel-01968067). Left : Full wafer. Right : Microscope observations of several structures.

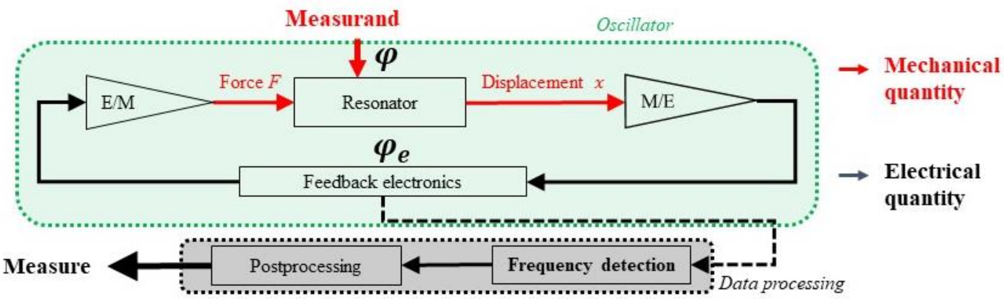

Fig. 2 – Generic structure of a MEMS/NEMS resonant sensor or clock. In sensors, the measurand is the variable of interest whereas it is considered a perturbation in clocks.

Objectives

CASSINI aims at optimizing the performance of NEMS-based clocks by finding an appropriate balance between all the constraints including the mechanical structure design, the electrical actuation of this structure and the oscillator interface, with a novel approach. This novel approach is depicted in Fig. 3.

Objective 1 – Provide an **experimental demonstration of the use of specific waveforms in NEMS resonators** to evade different types of fluctuations, to enhance the frequency stability of devices such as FM (frequency-modulated) sensors, without sacrificing drive efficiency.

Objective 2 – **Design and fabrication of a new NEMS structure optimized with system-level constraints.** We will increase the number of degrees-of-freedom for phase noise minimization compared to objective 1 which only addresses the system level. In objective 2, we aim at incorporating the resonator design into the global optimization.

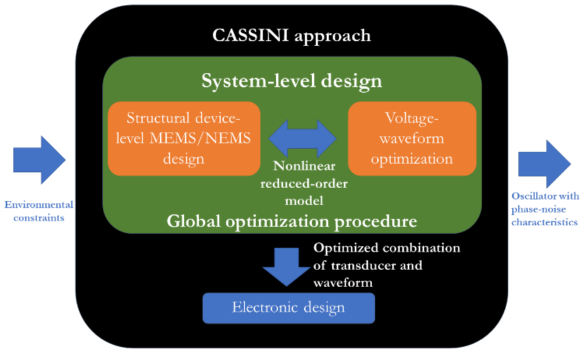

Fig. 2 –Methodology of the CASSINI project

Candidate profile

This multidisciplinary project involves several fields including:

- **Applied mathematics and signal processing**: pulsed and complex waveforms, associated spectrum.
- **Mechanics**: linear and nonlinear resonators. Analytical modeling and FEM simulations.
- **Electronics**:
    - Oscillators
    - Test benches including waveform generators, lock-in amplifiers, oscilloscopes, computer interface, etc.
    - PCB circuits design
- **Clean room fabrication processes**: lithography, etching, microscope observations, optical characterization of nanostructures in motion, etc.

It is obviously not required for the candidate to be already familiar with all these topics, but she/he must be motivated and interested to investigate all these aspects. Knowledge of programming/computing languages such as MATLAB/Simulink, Mathematica and/or Python would be a plus.

PhD director and co-advisor

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Location

The PhD thesis will fully take place at C2N, Centre for Nanoscience and Nanotechnologies, Palaiseau.

Theoretical Beginning

Budget is available to start any time. Starting by September 2023 would be ideal.

Salary and funding

The project is fully funded by the French ANR (Agence Nationale de la Recherche). PhD salary will be approx. 2000€/month (gross before taxes). We may consider an internship prior to the PhD thesis if the candidate is interested and not immediately available. If interested, the PhD student will have the possibility to teach at Université Paris-Saclay for an additional salary.

References

[1] C. T. Nguyen, "MEMS technology for timing and frequency control", in IEEE Trans. on Ultrasonics, Ferroelectrics, and Frequency Control, 54, 2, 2007 pp. 251-270, https://doi.org/10.1109/TUFFC.2007.240.
[2] G. Langfelder et al., "Frequency Modulated Mems Gyroscopes: Recent Developments, Challenges and Outlook", 20th Int. Conf. on Solid-State Sensors, Actuators and Microsyst., 2019, https://doi.org/10.1109/TRANSDUCERS.2019.8808613.
[3] O. Le Traon et al., "The fairy world of quartz vibrating MEMS", European Frequency and Time Forum, 2012, pp. 214-220, https://doi.org/10.1109/EFTF.2012.6502370.
[4] Goodall et al. "The Battle Between MEMS and FOGs for Precision Guidance", www.analog.com/en/technical-articles/the-battle-between-mems-and-fogs-for-precision-guidance.html (from Analog Devices website, 2013)
[5] J. C. Salvia et al., "Real-Time Temperature Compensation of MEMS Oscillators Using an Integrated Micro-Oven and a Phase-Locked Loop," in J. of MEMS, 19, 1, 2010, pp. 192-201, https://doi.org/10.1109/JMEMS.2009.2035932.
[6] H.A.C. Tilmans et al., "MEMS packaging and reliability: An undividable couple", Microelectronics Reliability, 52, 9–10, 2012, pp. 2228-2234, https://doi.org/10.1016/j.microrel.2012.06.029.