Dynamic sensing methods using microelectronic devices: *from an experimental exploration to the development of a new 'dynamic' sensor*

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Laboratory / group: IMEP-LAHC/CMNE
Advisors: Christoforos THEODOROU (christoforos.theodorou@grenoble-inp.fr)
Irina IONICA (Irina.Ionica@grenoble-inp.fr)

In the wide family of the bio-chemical sensors, the ISFETs (Ion Sensing Field Effect Transistors) occupy a place of honor thanks to their multiple advantages, for example in terms of miniaturization, sensitivity, co-integration with reading circuitry etc [1]. The working principle of such a device is based on the shift of the threshold voltage of the transistor, due to the intentional addition of charges-to-be-detected in the proximity of its channel [1]. The resulting conductivity modulation is then measured in (quasi)-static conditions, in which externally applied bias are slow enough and the device is assumed at equilibrium at every measurement point. This is the principle of the so-called 'charge-based sensors' (CBS). Despite their certain advantages and simplicity of operation, the CBS' sensitivity is by definition limited by the amount of charge of the deposited particles with regards to the minimum detectable charge, which is in turn limited by the electrical parameters of the device and by biasing. Furthermore, the selectivity of CBS, i.e. the capacity of distinguishing between different types of particles, is almost non-existing (if the surface is not chemically functionalized), because many types of particles can have exactly the same amount of charge.

To overcome these two drawbacks of CBS (minimum sensitivity and no selectivity), various alternative approaches have been suggested in the recent literature, having a core element in common: they all use dynamic effects, instead of static, as a means for detection. This thesis will address two main methods of dynamic sensing:

1) The 'out-of-equilibrium potential' method (co-developed by members of CMNE in IMEP-LAHC [2]): The interest of monitoring out-of-equilibrium instead of static current resides in the fact that the potential signature is very strong in a region where the current level is very small and noisy. This allows the creation of very low voltage/power sensors with potential sensitivity enhancement, thanks to the dynamic reading. The aim here will be to go from a simple proof-of-concept of such a response, to a realistic sensor design with improved figures of merit. From a more fundamental point of view the study involves a full understanding and modeling of the mechanisms that create the potential barriers at the contacts and that are responsible for the out-of-equilibrium response. This can be also an advantage for applications, since unlike most of the methods that need optimized ohmic contacts, for the out-of-equilibrium phenomena Schottky barriers provoke and enhance the potential response.
2) The 'fluctuation-enhanced sensing' (FES) method: This principle is based on the effects of dynamic interaction between device surface traps and electrons of deposited molecules, leading to a unique characteristic low-frequency noise spectrum for each sensing target [3], hence enabling the selectivity aspect in ISFET sensing. In other studies [4], a similar concept is used, taking advantage of the modulation in a trap's occupancy and/or electrostatic impact. This thesis aims to re-examine in a systematic way the claims of these publications, clearly identify the advantages of FES against CBS in order to avoid misconceptions, and test the feasibility of FES for a variety of microelectronic devices, both in-home fabricated ones (such as Pseudo-MOSETs on SOI) and from collaborators (such as Nanowire/NanoNet/NanoRibbon FETs, Si Nanogauges).

A whole new field of alternative sensing applications using noise or out-of-equilibrium effects as means of detection is open for exploration, while at the same time fundamental research around these phenomena is needed, in order to scientifically prove the feasibility and innovation of every approach. This thesis aims to respond to these challenges and showcase/propose the development of novel 'dynamic' sensors. Additionally, a real bench mark of these methods will allow identifying the strength and best applications of each one.

The candidate must have a very good background in semiconductor physics and characterization of semiconductor devices. Knowledge of concepts in bio-chemical sensing will be a plus. The research will cover fabrication and functionalization, electrical characterization methods, as well as modeling and simulation aspects. The thesis will benefit from a rich collaboration environment and possibility of benchmark with wide variety of methods and devices.

The candidate must have very good academic record, with high grades.

[1] N. Moser, et al, http://dx.doi.org/10.1109/JSEN.2016.2585920, P. Bergveld, http://dx.doi.org/10.1016/S0925-4005(02)00301-5
[2] L. Benea, et al, http://dx.doi.org/10.1109/JSEN.2020.3008133
[3] L. B. Kish et al, https://doi.org/10.1109/TNANO.2011.2105277, S. Rumyantsev, et al, https://doi.org/10.1109/JSEN.2013.2251627
[4] J. Li, et al, https://doi.org/10.1021/nl5010724. Y. Kutovyi et al., https://doi.org/10.1021/acs.nanolett.8b03508