DG-FinFETs for Ion and Biological Sensing Integrated Circuits

Sara Rigante and Adrian M. Ionescu

NanoLab, Ecole Polytechnique Fédérale de Lausanne, Switzerland

Abstract

In recent years, sensing applications of nanoelectronics have become increasingly prevalent in many fields. Ion Sensitive Field-Effect Transistors (ISFET), Carbon Nanotubes (CNTs) and Silicon Nanowires (SiNWs) have already been successfully exploited for sensing, although high sensitivity, integration and mass production are still challenging.
This work mainly presents a Double-Gate FinFETs (DG-FinFET) as novel label-free ion and biological sensor. This innovative approach paves the way for integrated and CMOS compatible sensing circuits in which the sensor and the driver transistor are the same structure. It also illustrates a high-k gate oxides characterization as parallel work, aimed at the optimization of the sensing performances. We present all the present collaborations in fabrication, circuit design and packaging.

The technology

A partially gated DG-FinFET with top exposed surface have been choosen as sensing unit. When an external sensing phenomena occurs, the device transfer characteristic $I_d(V_{ref})$ is shifted according to the input variation $\Delta V_{liq}(pH)$, of the order of 60mV/pH.
When such a structure is integrated in common source n-MOS amplifier, the input variation is amplified up to 1 V with linearity given by the design itself and biasing of the reference electrode.[1].

- CMOS compatible integrated circuits
- DG-FinFETs as driver transistors
- Hybrid DG-FinFETs as sensing AND driver electronic units
- Read out can be translated in an unique ON-OFF state

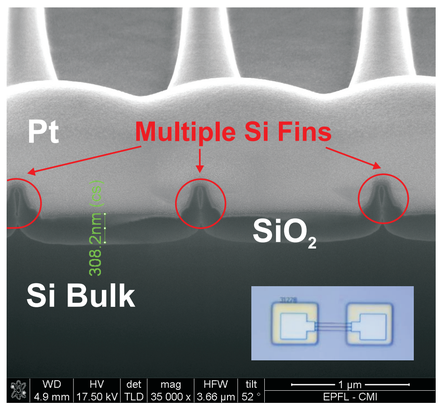

Figure 1: FIB/SEM cross-sections during the fabrication process in progress. Pictures show: multiple fins (top) after Si_3N_4 Spacer Wet Oxidation, SiNWs top view (top inset) ready for S/D implantation, single device after SiO_2/Si_3N_4 removal for Si surface exposure.

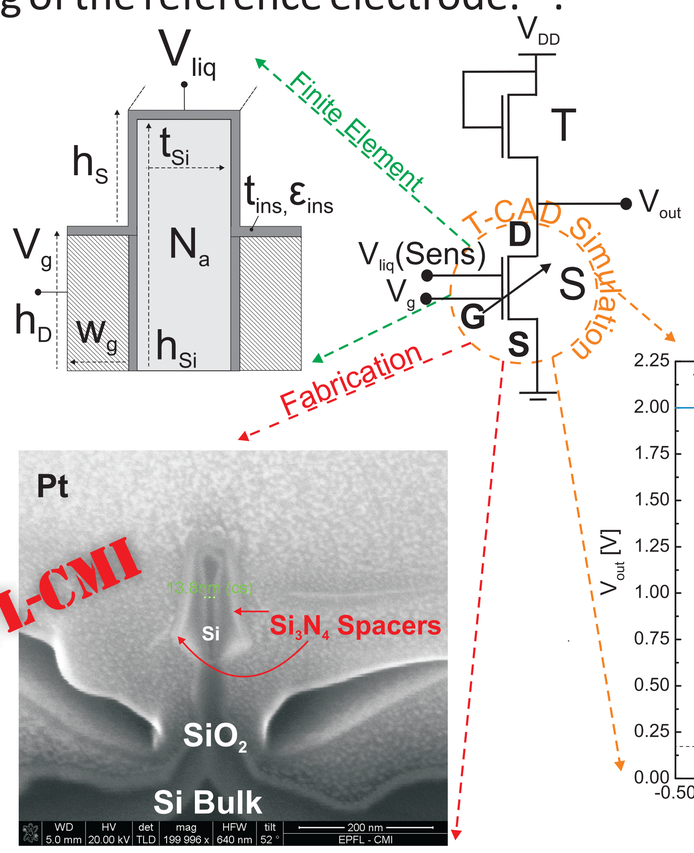

Figure 2: Electronic schematic for T-CAD simulations performed by Verilog-A 2D equations[3] for a sensing DG-FinFET (top); FIB/SEM cross-section of a fabricated 13nm fin after Wet Oxidation for BULK Isolation.

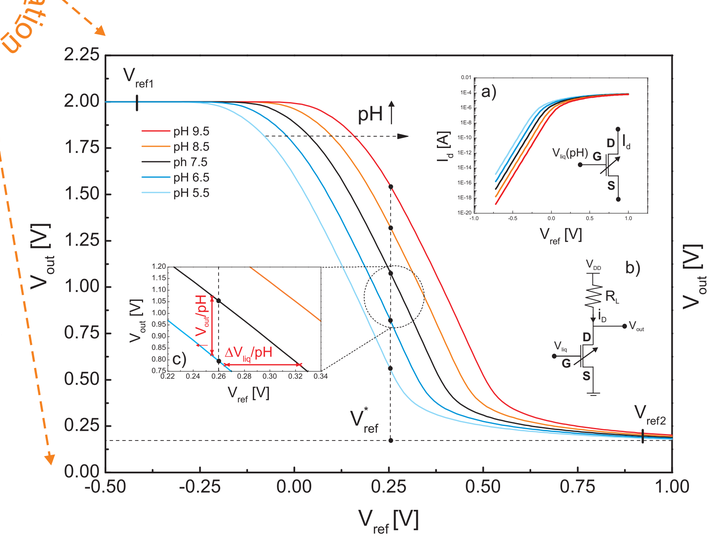

Figure 3:$I_d(V_{ref})$ curve for different pH values of one FinFET sensor. a) Circuit schematic of the common-source amplifier with resistive load. c) Common-source amplifier output voltage,V_{out}, as a function of the liquid voltage applied through a reference electrode, V_{ref}. The curve shifts according to different pH values.

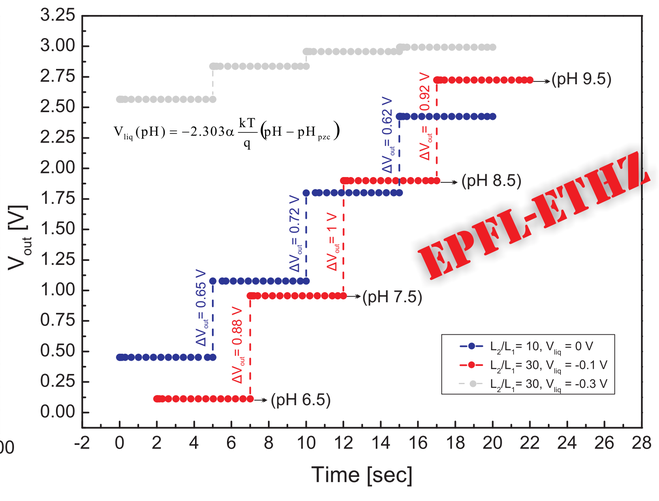

Figure 4: Simulation, as a function of time, of the output voltage,V_{out}, of a common source amplifier with the sensor FinFET as active transistor for four different pH values, different fin length ratios and different biasing points.

Testing and Packaging

In parallel to the design and fabrication process we investigate high-k gate oxides, like Al_2O_3 and HfO_2, as high quality electronic materials. In order to guarantee the correct electronic-liquid interface we collaborate for an optimized packaging procedure including SU-8 coverage for metal connections and Epoxy coverage for Aluminum bonding wires.

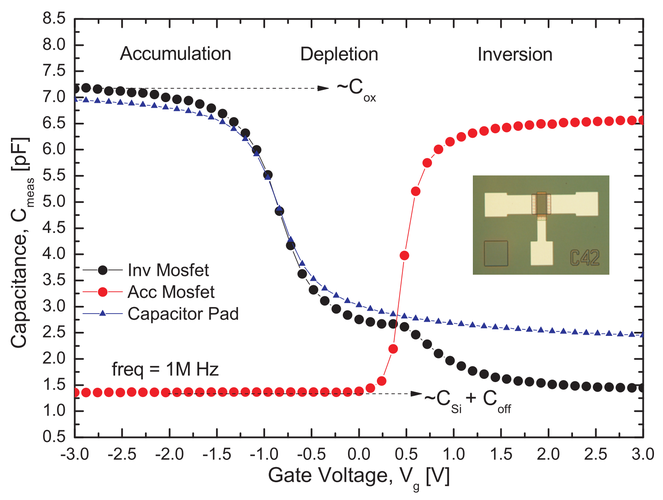

Figure 5: Capacitance of a 4.5 nm layer of SiO_2, C_{meas}, as gate oxide for a N+-p-N+ MOSFET with gate area of 80x20 µm^2 in accumulation (black) and inversion (red). Same area MOS capacitor is also shown (blue).

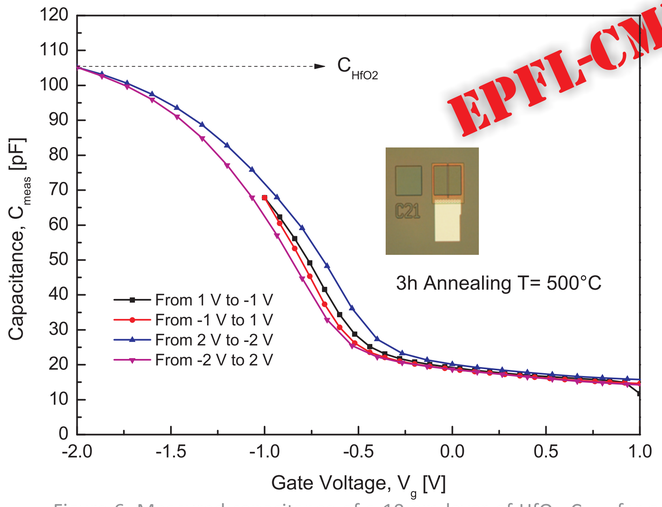

Figure 6: Measured capacitance of a 10 nm layer of HfO_2, C_{meas}, for a MOS capacitor of 80x80 µm^2, at high frequency with voltage sweep for hysteresis investigation. The inset shows the fabricated MOS device for the characterization.

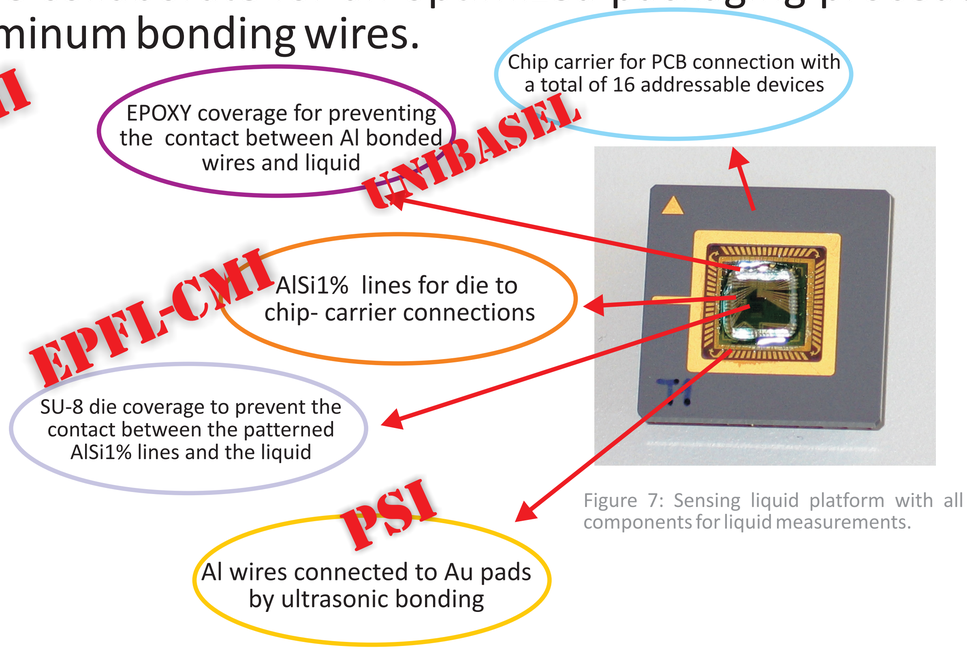

Figure 7: Sensing liquid platform with all components for liquid measurements.

Results and Conclusions

- 3D Finite Element Simulations have optimized the geometrical and electrical parameters of the single partially gated DG-FinFET
- T-CAD Simulations based on 2D Verilog-A equations have lead to the design of simple Integrated Circuits for High Sensitivity Read-out
  - → Such circuits can be fabricated at Cmi-EPFL.
- We are currently working on the fabrication process of single sensing structure on BULK
  - → We have recently succeeded in the fins wet oxidation and we are proceeding with Source and Drain implantation

[1] Hybrid DG-MOSFETS integrated circuits for enhanced ionic and biological sensing applications, work accepted at BIOSENSORS 2012
[2] FinFET for high sensitivity ion and biological sensing applications, S.Rigante, J. Microel. Eng., 2011; 88:8;
[3]Implementation of the symmetric doped double-gate MOSFET model in Verilog-A for circuit simulation, J.Alvarado, Int. J. Numer. Model. 2010; 23:88-106;

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