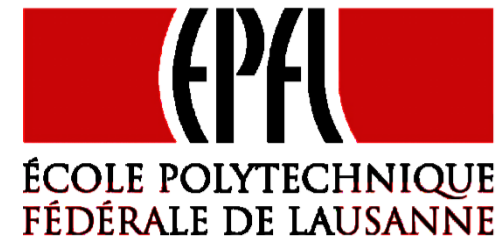# Comparison between front- and back-gating of Silicon Nanoribbons in real-time sensing experiments

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INTRODUCTION

Field-effect transistors (FETs) with opened gate structures such as Silicon Nanoribbons (SiNRs) are promising candidates to become general platforms for ultrasensitive label-free and real-time detection of biochemical interactions on surface.

A SiNR molecular sensor operates as a highly sensitive nanoscale FET in which the gate terminal is removed so that the charge distribution in the close nearby of the exposed channel directly modulate its surface potential, thus affecting the ribbon conductance.

SiNRs Sensors
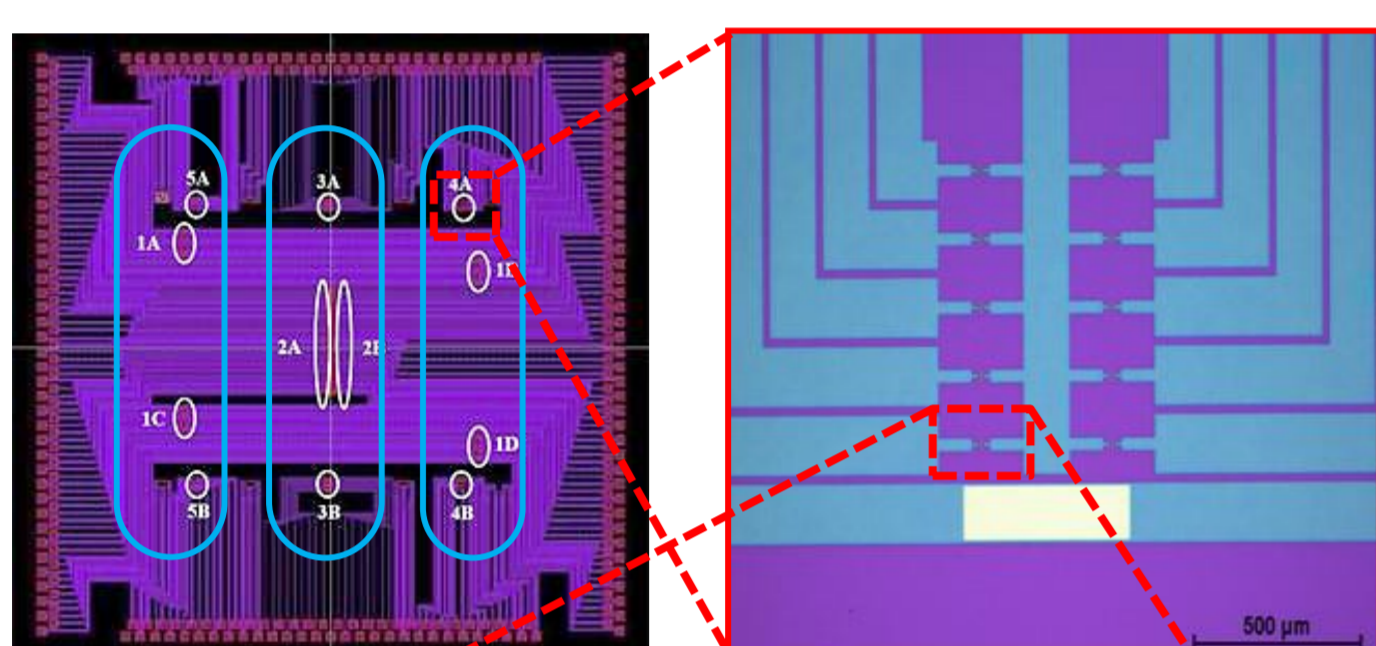
The SiNRs are fabricated on Silicon-On-Insulator (SOI) wafers and defined by means of standard top-down CMOS compatible processes, such as Deep Ultraviolet (DUV) photolithography, e-beam lithography and Reactive Ion Etching (RIE).

(Halté, C. et al., pHealth, Valencia, 2008)

The nanometric thickness of the silicon film (ideally smaller than the Thomas-Fermi screening length), causes their electrical properties to be very dependent on the local environment, which can effectively induce a field effect that changes the carrier concentration, thus providing electrical transduction of the biochemical interaction of interest.
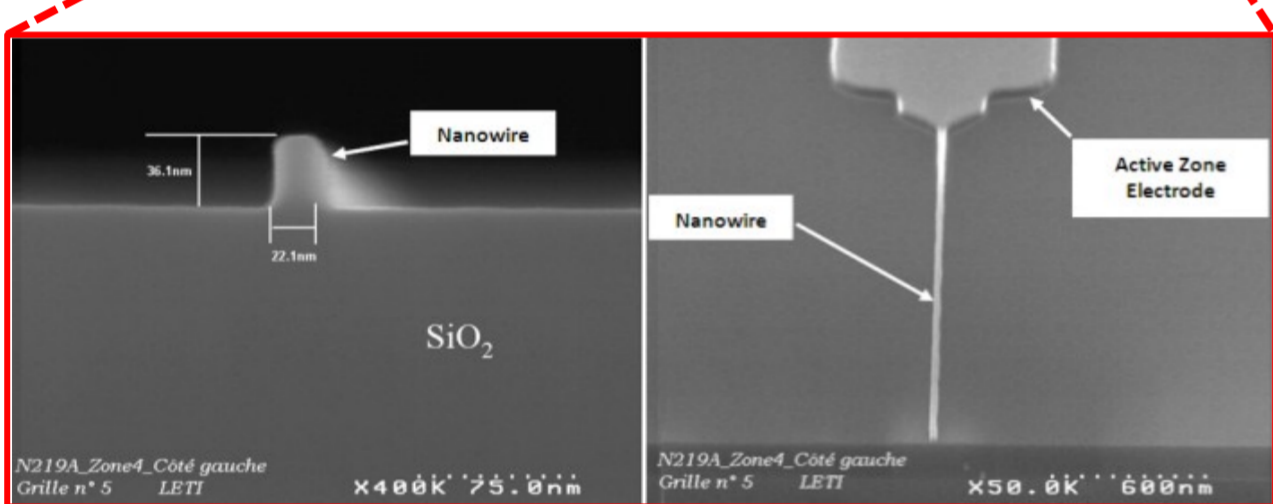
SEM pictures courtesy of CEA-LETI (Grenoble, France).

Microfluidic Setup

The developed microfluidic setup allows reduced solvents and reagents consumption, portability and ease of integration with the SiNWs chip.

The microchannels are realized with a chemical resistant double-coated tape, patterned by laser micromachining. The height of the channels are defined by the thickness of the tape (190 μm). A PMMA cap is placed to seal the channels and the inlets and outlets tubes inserted. A sealing polymer is used to avoid fluid leakages from the inlets/outlets.
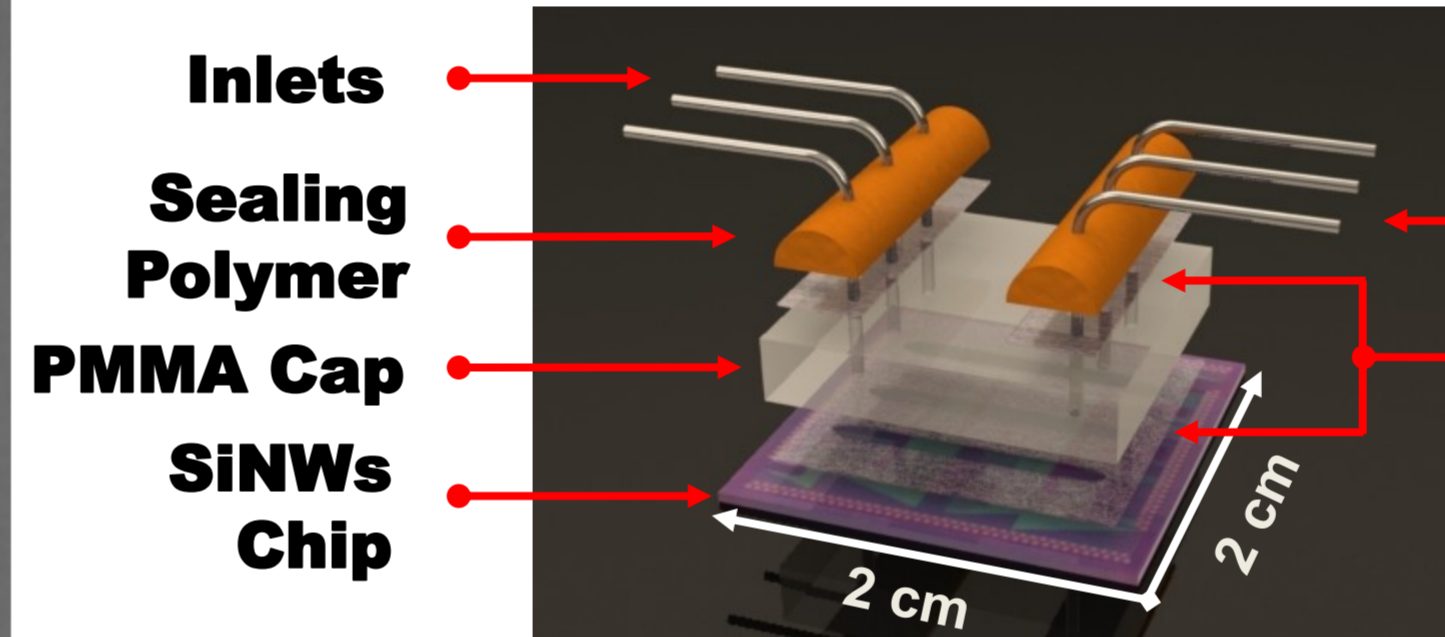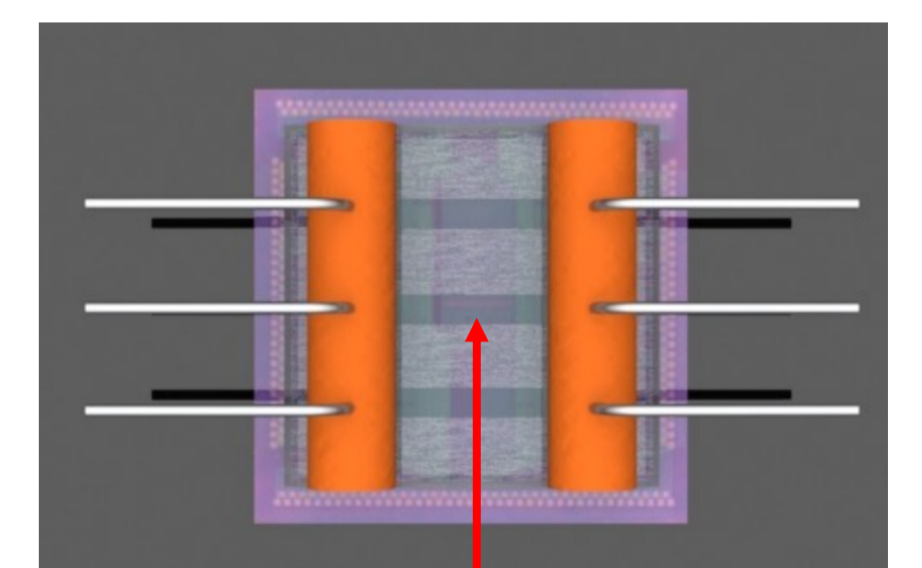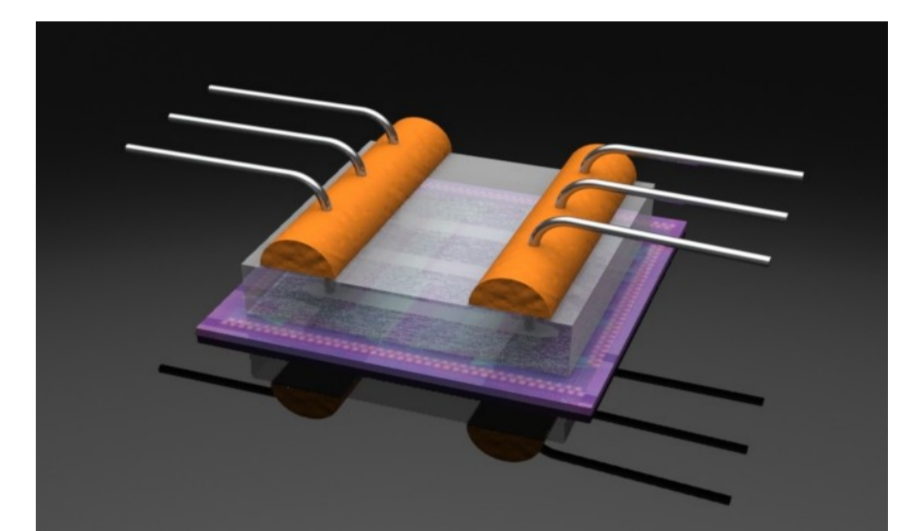
Sensitivity

According to the site binding model applied to ISFET devices, the surface of the gate oxide becomes negatively charged when in contact with electrolyte solutions characterized by pH values bigger than its isoelectric point (pI ≈ 2-3 in the case of SiO_2). This phenomenon is due to the deprotonation of the silanol groups. These negative charges increase with the pH, leading to a decrease in the conductance of an n-type SiNR. The different pH solutions were made from 10 mM phosphate buffers with 100 mM KCl.
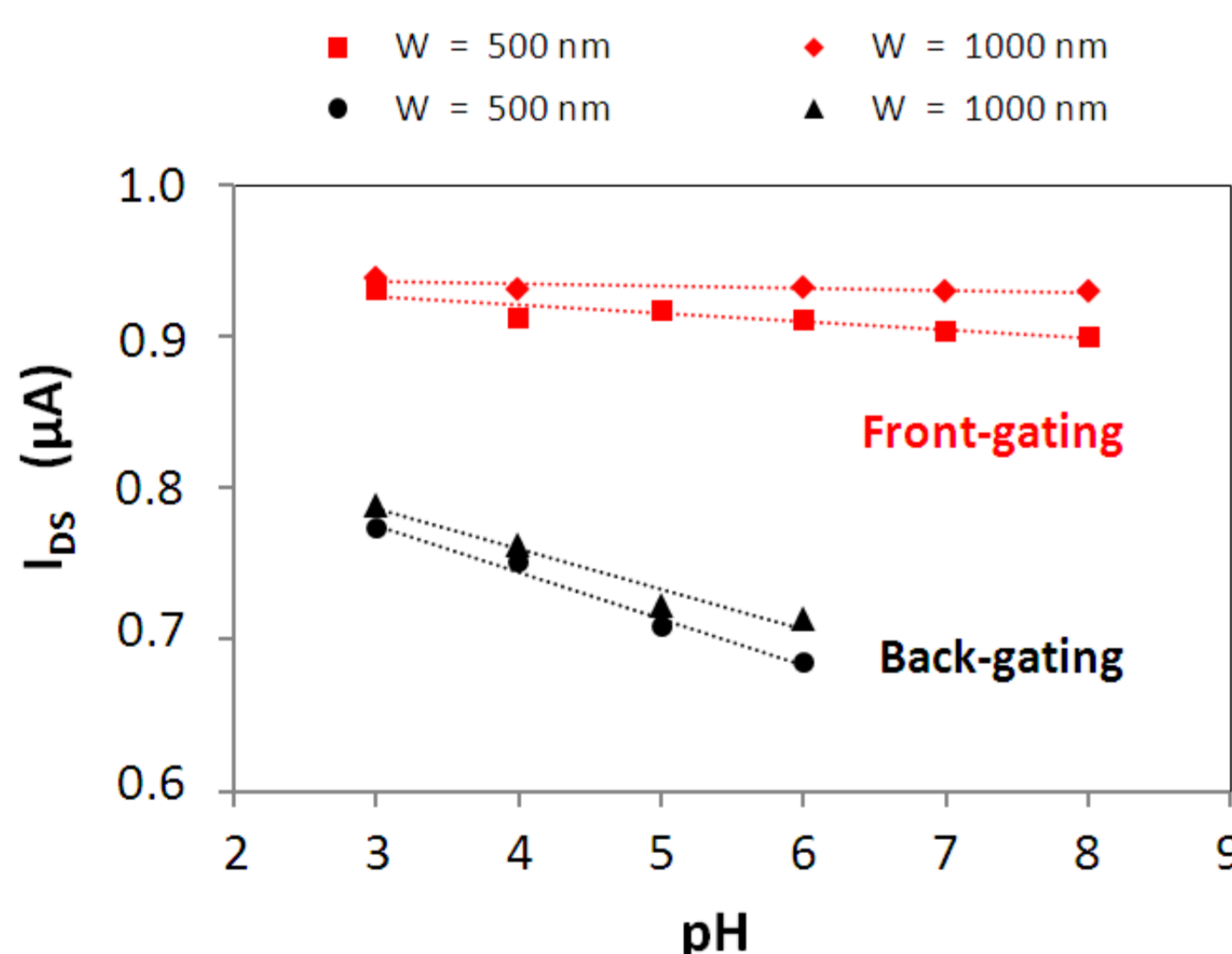
When polarized with the back gate, the devices showed enhanced sensitivities due to a different capacitive coupling ratio between the controlling gate and the charged species on surface.


Ag/AgCl Reference Electrodes

The employment of suitable types of electrodes as RE is crucial to properly contact the electrolyte solution. They help reducing the drain current noise generated by a floating potential of the solution. The drain current ΔI_{DS} in time follows an exponential law with an associated linear drift given by the form

$$\Delta I_D(t) = \left[1 - e^{\left(-\frac{t}{\tau}\right)^{\beta}}\right](a \cdot t + b)$$

where t is the time, τ, β, a and b are fitting parameters describing the stretched-exponential time dependence and the linear time one, respectively.

The dots represent the analytical model, the line the experimental data. The fitting parameters are: $\tau = 1000$ s, $\beta = 0.22$, $a = 4.5$ pA/s and $b = 127$ nA. (Inset) Change of drain current when the electrolyte is not polarized by means of proper REs.
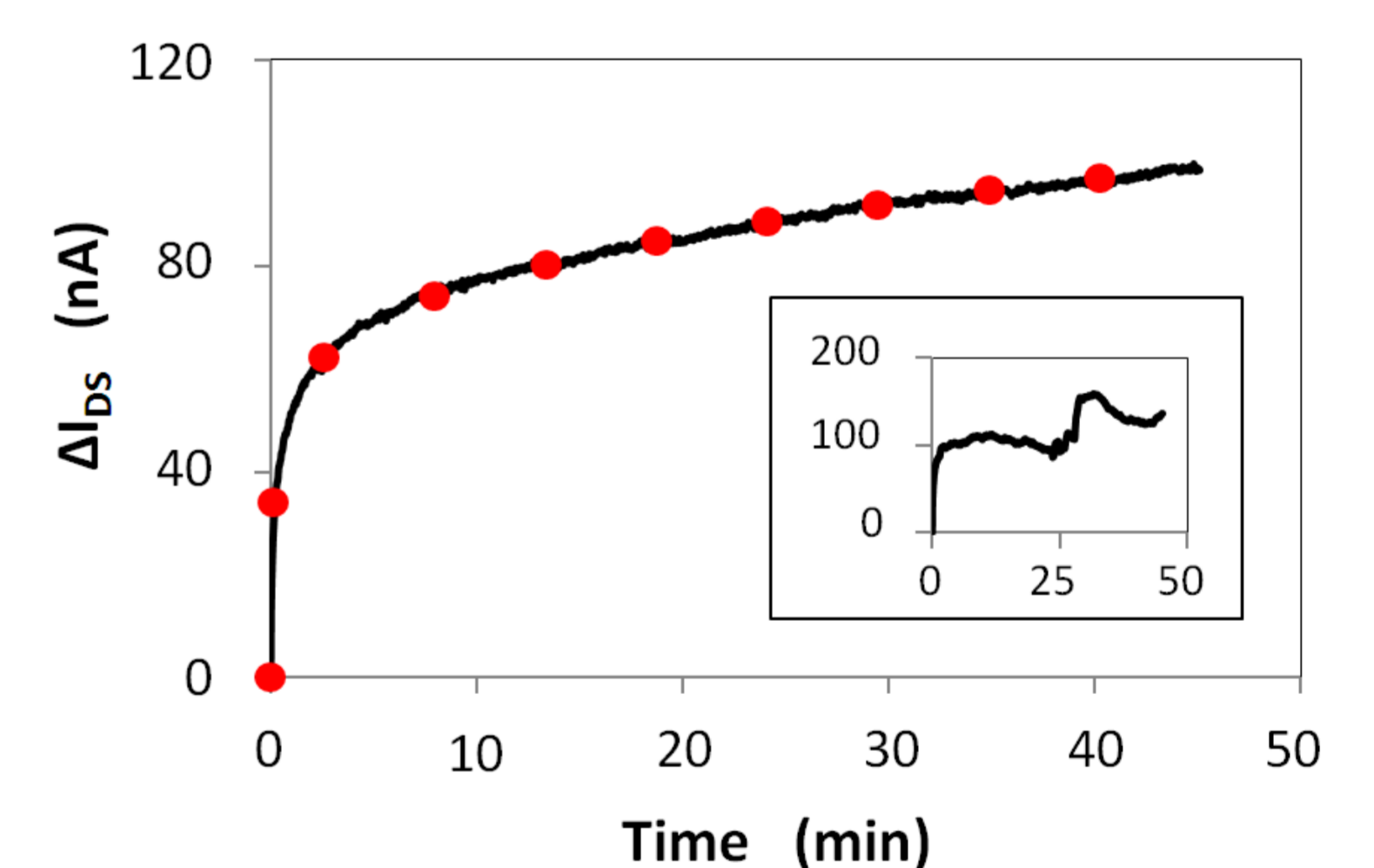

(Inset) Change of drain current when the electrolyte is not polarized by means of proper REs.

Influence of front- and back-gate

The different gating properties of the front-gate and back-gate on the device have been characterized.

(a) I_{DS}-V_G characteristics of a SiNR (2375 nm in length and 500 nm in width) subjected to a front-gate sweep. Increasing the back-gate voltage leads to a shift of its isoelectric point of the device. Nevertheless, the device can neither be switched off nor be switched on through the back-gate.
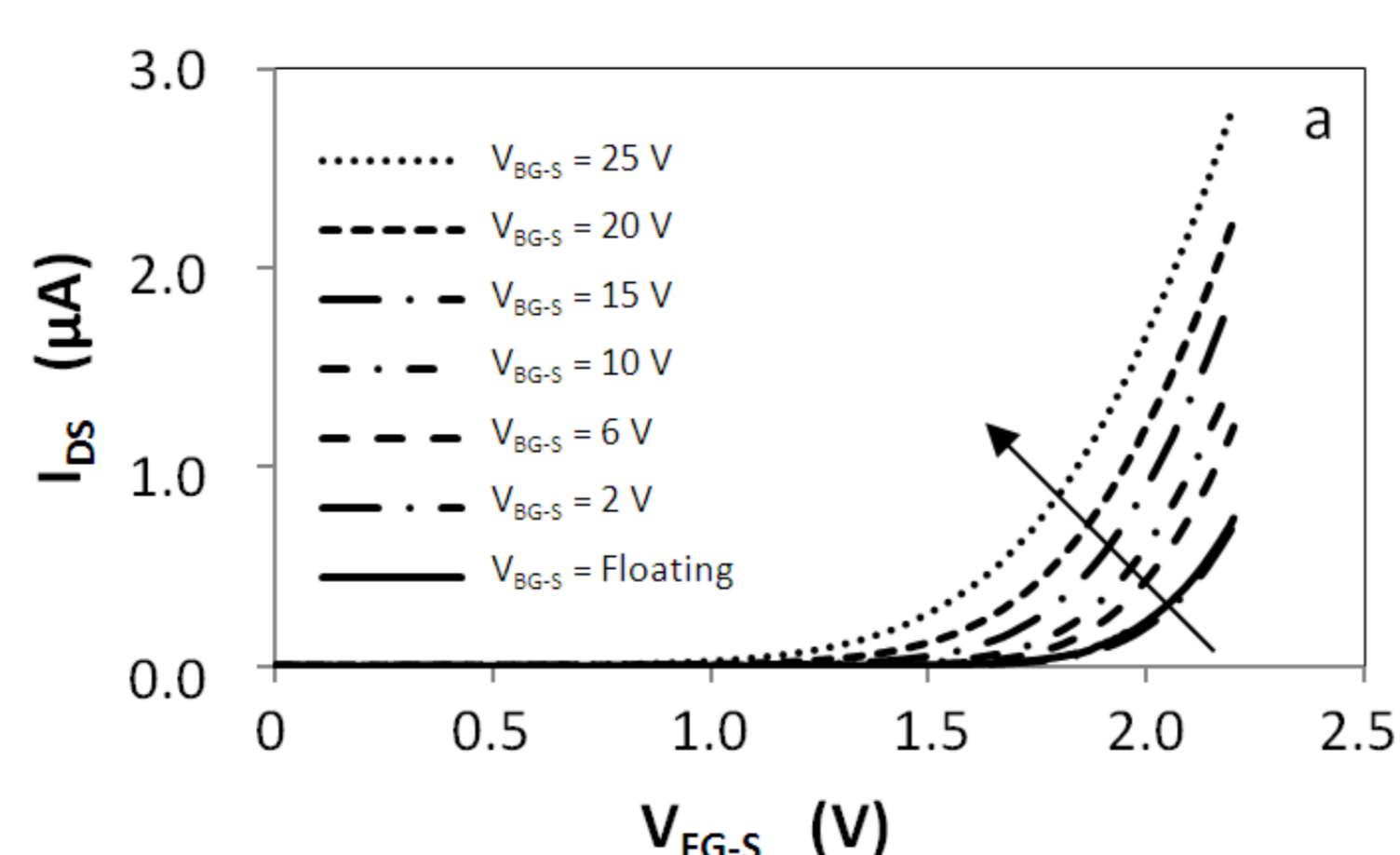
(b) On the other side, b shows that the application of a positive front-gate voltage is sufficient to switch on the device, even if the back-gate is grounded.
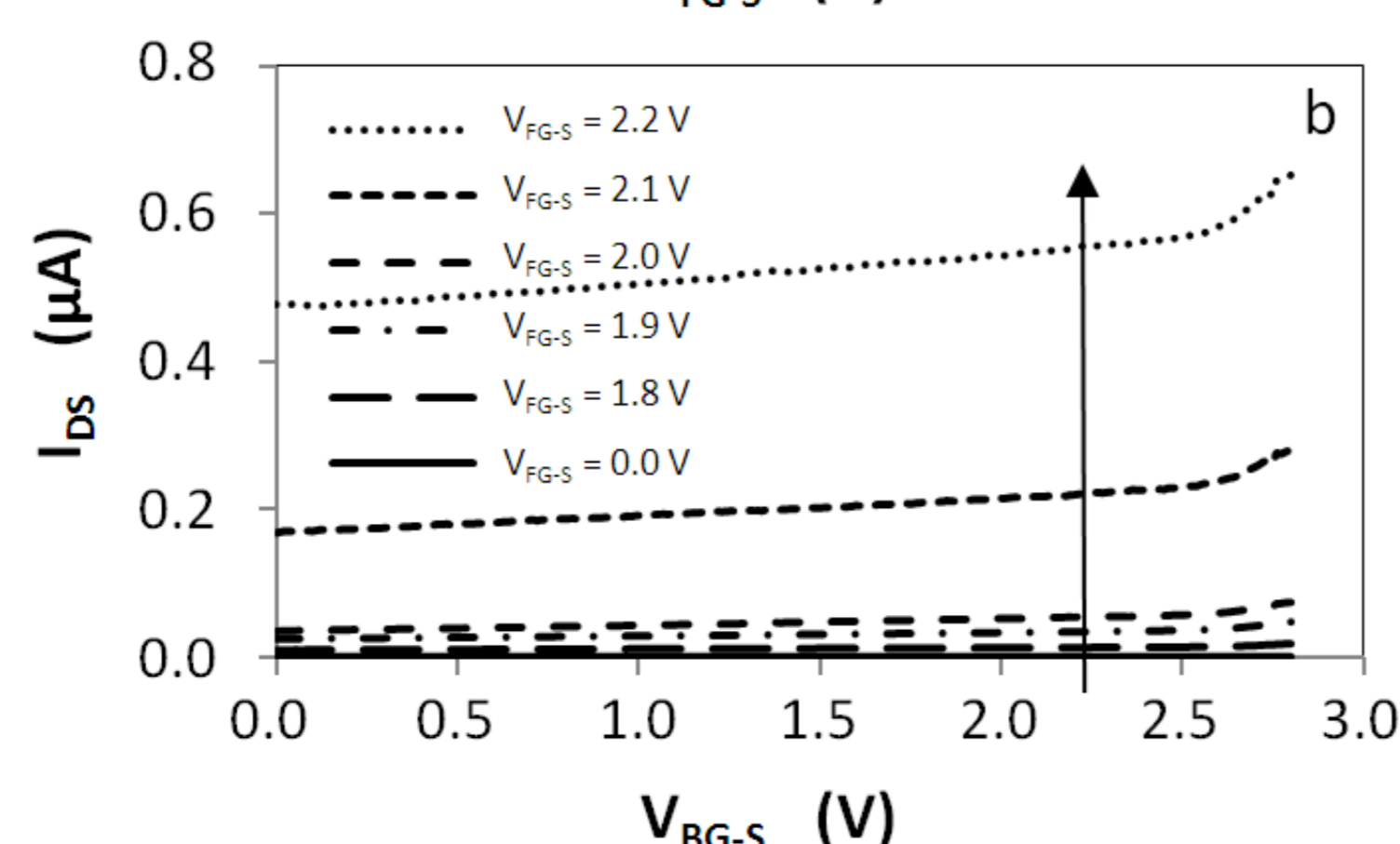
Measurement artifacts

Due to the strong impact of the front-gate on the SiNR behavior, a proper polarization of the electrolyte is crucial to avoid measurement artifacts. When back-gating with electrolyte solution left electrically floating, the device current is subjected to noise in particular in correspondence of the change of the buffer solution by injection in the microfluidics.
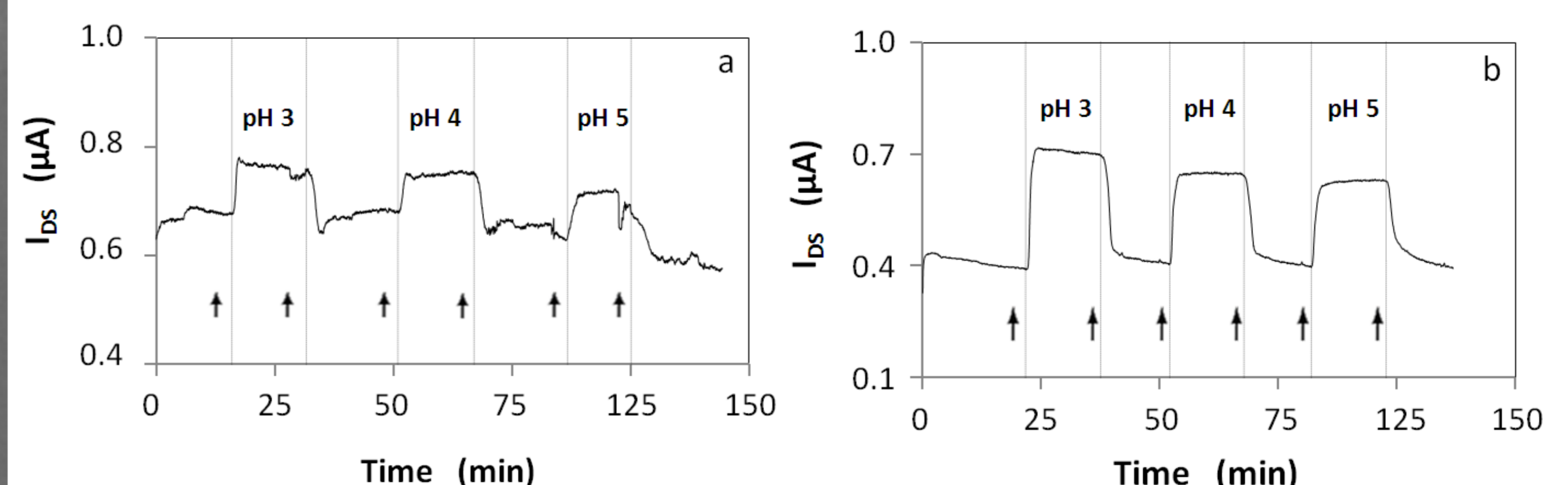
Real-time drain current measurement in the case of back-gating (a) and front-gating (b). The arrows and dotted vertical lines indicate the injection of the solution and the actual moment when the solution reaches the sensing area, respectively.