Analytical modeling and experimental characterization of drift in graphene electrolyte-gated field-effect transistors

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Graphene field-effect transistors (gFETs) have been used as platforms for DNA, proteins, or molecule biosensing with high sensitivity. The presence of the analyte of interest modulates the Fermi level energy (E_F) of the gFET channel by doping, causing a shift in the device transfer curve. This shift is typically detected by measuring the position of the Dirac point voltage (V_{DC}), the point of minimum conductance in the curve [1]. However, electronic devices based on two-dimensional (2D) materials suffer from limited electrical stability due to the interaction of the charge carriers originating in the 2D material with the defects in the surrounding insulator layers [2]. In the case of gFETs, the charges trapped in the silicon oxide layer underneath the graphene channel can provoke hysteresis and drift of the transistor output due to unwanted and uncontrolled doping [3]. The drift prevents stable circuit operation and can be mistaken for a biodetection event.

In this work, we present a complete model for the response of an electrolyte-gated gFET, whose actuation is achieved through the electrical double layer at the graphene-electrolyte interface (λ_D). A schematic of the device is shown in Fig. 1A. The voltage applied to the gate (V_G) modulates the E_F in the gFET channel, which sits within the oxide bandgap and between the two defect bands of the silicon oxide layer [4], as illustrated in Fig. 1B. The capture and emission rates of electrons by the defect bands depend on the energy barrier between the graphene E_F and the bands. The model is validated against experiments with devices immersed in a 10 mM phosphate buffer (PB) solution. For example, Fig. 1C shows that consecutive measurements of transfer curves cause the Dirac voltage (V_{DC}) to drift to higher values due to progressive charging of the oxide layer with electrons injected from the channel. Once trapped in the oxide, the excess electrons locally gate and p-dope the graphene. When the transistor is allowed to rest, V_{DC} progressively returns to its initial value, corresponding to a slower discharge of the oxide layer. It is shown that the response of the gFETs depends on the measurement conditions and the device's history.

References

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[2] Y. Y. Illarionov et al., Nature Communications, 11 (2020) 3385
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Figures

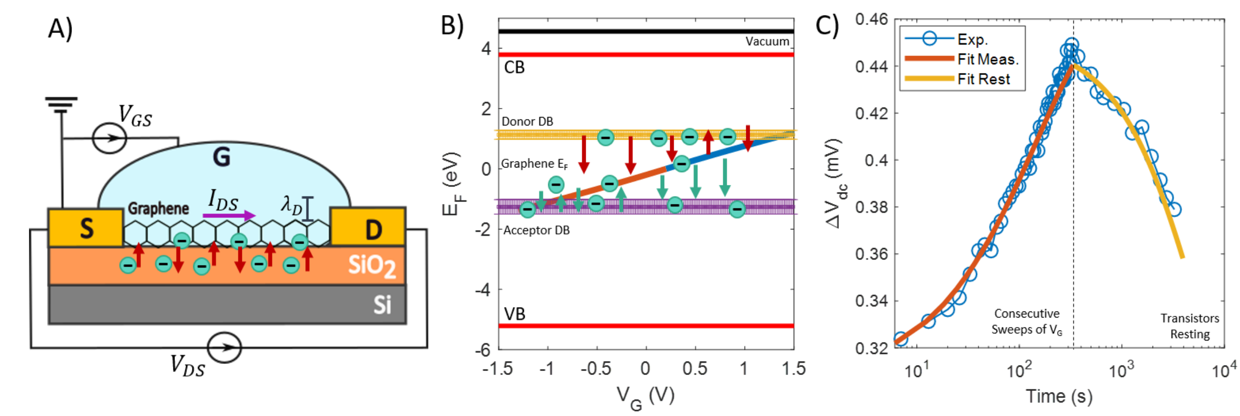

Figure 1: A) Schematic of the electrolyte-gated graphene field effect transistor; B) The model is based on the modulation of the Fermi level of the graphene by the gate voltage (V_G), which causes the capture/emission of electrons by the defect bands of the underneath SiO_2 layer; C) Experimental and fitted data of the drift of the Dirac voltage (V_{DC}) of the graphene transistor while acquiring consecutive transfer curves (sweeps of V_G) and while letting the transistor rest.