Electrostatic Control of the Threshold Voltage in Graphene-GaAs Field-Effect Transistors for Digital Logic Applications

Luca Anzi[1]
Artur Tuktamyshev[2], Alexey Fedorov[3], Amaia Zurutuza[4], Stefano Sanguinetti[2], and Roman Sordan[1]
[1] *L-NESS, Department of Physiscs, Politecnico di Milano, Polo di Como, Via Anzani 42, 22100 Como, Italy*
[2] *Department of Material Science, Università di Milano Bicocca, Via Cozzi 53, 20125 Milano, Italy*
[3] *CNR-IFN and L-NESS, Department of Physics, Politecnico di Milano, Via Anzani 42, 22100 Como, Italy*
[4] *Graphenea, Avenida de Tolosa 76, 20018 Donostia/San Sebastián, Spain*

luca.anzi@polimi.it

The threshold voltage (V_{th}) of a field-effect transistor (FET) impacts its power consumption and switching speed. The undesired shift of V_{th} limits the minimum power supply voltage in digital circuits, which leads to increased static power dissipation. In conventional FETs, V_{th} cannot easily be adjusted because it is set by the work function of the metal gate. In metal-semiconductor FETs (MESFETs), V_{th} is additionally constrained by the semiconductor work function and channel thickness. All these parameters are chosen during fabrication and set V_{th} at a fixed value.
GaAs MESFETs are used in high-speed integrated circuits (ICs) because of the high carrier mobility in their semiconductor channels [1]. To limit the gate leakage current, the gate forward bias voltage should be smaller than the turn-on voltage of the gate Schottky diode. As a result, it is challenging to fabricate ICs in which MESFETs are biased by a positive gate voltage, which is required in digital logic gates.
In this talk, we will introduce a GaAs-based MESFET in which the metal gate was replaced by a monolayer graphene gate (Figure 1a). Graphene forms a Schottky junction with GaAs [2], which was used to control the conductivity of the transistor channel. An additional Al/AlO_x control gate stack was fabricated on top of the graphene gate (Figure 1b). The control gate was used to adjust the work function of the graphene gate by shifting its Fermi level. This resulted in the modulation of the graphene-GaAs Schottky barrier height (SBH) and, therefore, the modulation of the threshold voltage of the FET. Such effect has been used in the past to realize graphene barristors [3] and vertical heterostructures [4].
We exploited the modulation of the SBH to realize GaAs FETs in which V_{th} was changed from -0.8 to 0.6 V by changing the control gate voltage (V_{GC}) from 0 to 1.8 V. The transfer characteristics of such GaAs FET are shown in Figure 2. The increase of V_{th} increases the cut-in voltage of the gate Schottky diode and, therefore, allows the use of the FETs under larger gate voltages without increasing the gate leakage current.
To demonstrate the operation of the fabricated FETs, we realized digital logic gates with a positive switching threshold, which is a fundamental requirement for the realization of more complex logic circuits.

References

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Figures

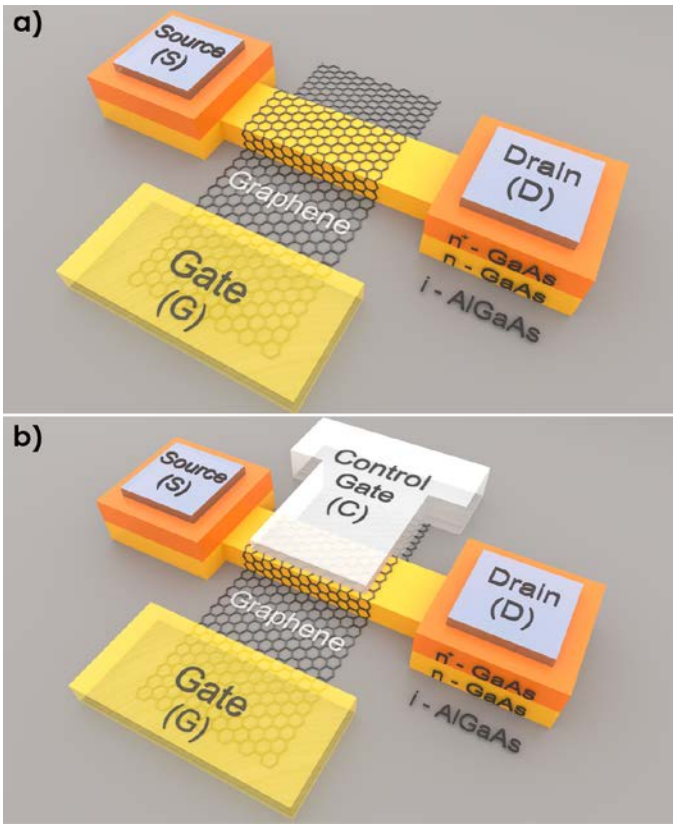

Figure 1: GaAs FETs with a graphene gate. (a) Schematic of a single-gate graphene-GaAs FET on an insulating AlGaAs substrate. The graphene gate is deposited on top of an n-GaAs layer with a donor concentration of 10^{17} cm^{-3} and connected externally by an Au gate pad (G). The graphene gate controls the conductivity of the GaAs channel, modulating the current flow between source (S) and drain (D). (b) Schematic of a dual-gate graphene-GaAs FET. The additional control gate (C) controls the graphene Fermi level and, therefore, Schottky barrier height (which affects the modulation of the current in the transistor channel).

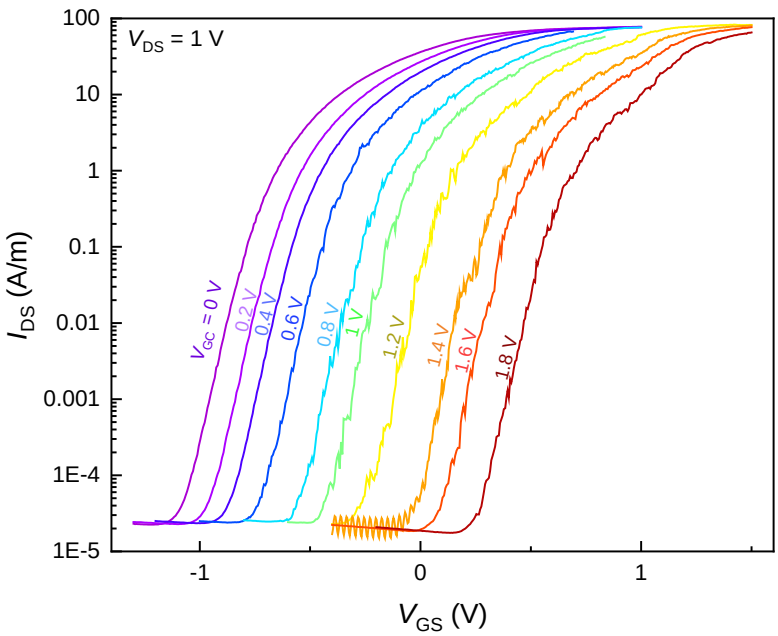

Figure 2: Transfer characteristics of a dual-gate graphene-GaAs FET where the drain current I_{DS} (normalized by the channel width) is measured as a function of V_{GS} at different V_{GC}. Increasing V_{GC} from 0 V to 1.8 V shifts the curves and V_{th} to more positive V_{GS}.