**Electrostatics and drain current model of bilayer graphene field-effect transistors**

**Francisco Pasadas***, David Jiménez
Departament d'Enginyeria Electrònica, Escola d'Enginyeria, Universitat Autònoma de Barcelona, Campus UAB, 08193 Bellaterra, Spain.

* Francisco.Pasadas@uab.cat

## Abstract

As predicted by Moore, the semiconductor industry has been facing an exponential growth of the number of transistors per chip during the last three decades. It is also predicted by ITRS (*International Technology Roadmap for Semiconductors*) that the gate length would scale down to 4.5 nm by 2023 [1]. However, maintaining this trend is a major challenge for both the industry and scientific community due to arising short channel effects. As a result, new device structures including FinFETs, nanowire FETs, and recently carbon nanotube field-effect transistors (CNTFETs) and graphene nanoribbon FETs have been proposed. Among them graphene based devices (either single layer graphene or bilayer graphene) have attracted the attention of scientific community due to the multitude of fascinating properties and the prospect of ultrahigh carrier mobilities exceeding those of the conventional semiconductors. This has motivated intensive work focused on the development of graphene metal-oxide-semiconductor field-effect transistors [2] (Figure 1).

On the other hand, the gapless nature of single layer graphene, which is considered as the main obstacle on its application in graphene based electronics, causes the gate voltage to lose its control on switching off the device and are not suited for logic applications. However, it seems very promising for RF and analog applications because of the high transconductance and relatively low output conductance. Cut-off frequencies up to 427 GHz and maximum frequency of oscillation of 45 GHz has been demonstrated [3], which are important figure of merits in RF. Besides the metal-graphene contact resistance issue that strongly contribute to degrade the RF performances, the lack of a gap is also a detrimental factor preventing a full saturation of the drain current. However it has been recently demonstrated that bilayer graphene might come to rescue [4-6]. In bilayer graphene, a band gap is induced either by molecular doping or by applying a potential difference between two layers as a result of an external perpendicular electric field [7-9]. Moreover, the potential difference can be realized with an applied gate field which means the band gap can be controlled by gate bias [10-11] (Figure 2).

In this work we have derived an analytical model for bilayer graphene field-effect transistors that properly accounts for the relevant physics. These kind of models are extremely useful to interpret experiments, guiding device design and exploring ultimate performances. Besides, they are key pieces of graphene-based circuit simulators, which are needed to design any circuit or calculate its figures of merit. Using this model we have demonstrated the superior saturation behavior (Figure 3) and the enhancement of the on/off current ratio (Figure 4) as compared with monolayer graphene. The physical framework applied has been a tight binding model of bilayer graphene [12-13], a field-effect model and drift-diffusion carrier transport [14-15].

## References

[1] International technology roadmap for semiconductors. http://www.itrs.net/.
[2] Wu Y, Jenkins KA, Valdes-García A, Farmer DB, Zhu Y, Bol AA, Dimitrakopoulos C, Zhu W, Xia F, Avouris P, Lin YM. Nano Lett. **12** (2012) 3062.
[3] Schwierz F. Proceedings of the IEEE **101**(7) (2013) 1567.
[4] Fiori G, Neumaier D, Szafranek B, Iannaccone G. IEEE Trans. Elect. Dev. **61**(3) (2014) 729.
[5] Xia F, Farmer DB, Lin YM, Avouris P. Nano Lett. **10** (2010) 715.
[6] Szafranek BN, Fiori G, Schall D, Neumaier D, Kurz H. Nano Lett. **12** (2012) 1324.
[7] Yu WJ, Liao L, Chae SH, Lee YH, Duan X. Nano Lett. **11** (2011) 4759.
[8] Samuels AJ, Carey JD. ACS Nano. **7**(3) (2013) 2790.
[9] Zhang W, Lin CT, Liu KK, Tite T, Su CY, Chang CH, Lee YH, Chu CW, Wei KH, Kuo JL. ACS Nano **5** (2011) 7517.
[10] Castro EV, Novoselov KS, Morozov SV, Peres NMR, Lopes dos Santos JMB, Nilsson J, Guinea F, Geim AK, Castro Neto AH. Phys. Rev. Lett. **99** (2007) 216802.
[11] Zhang Y, Tang TT, Girit T, Hao Z, Martin MC, Zettl A, Crommie MF, Shen YR, Wang F. Nature Lett. **459** (2009) 820.
[12] McCann E, Koshino M. Rep. Prog. Phys. **76** (2013) 056503.

[13] Cheli M, Fiori G, Iannaconne G. IEEE Trans. Elect. Dev. **56**(12) (2009) 2979.
[14] Jiménez D. IEEE Trans. Elect. Dev. **58** (2011) 4377.
[15] Thiele SA, Schaefer JA, Schwierz F. Journal of Applied Physics **107** (2010) 094505.

## Figures

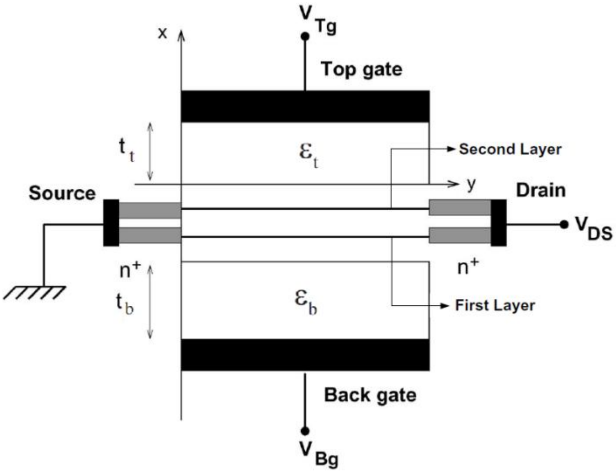


**Figure 1** Cross section of the bilayer graphene field effect transistor. Here, $t_b$ and $t_t$ are the top and back oxide thicknesses, $\varepsilon_b$ and $\varepsilon_t$ are the top and back dielectric relative permittivities, $V_{tg}$ and $V_{bg}$ are the top and back gate voltages and $V_{ds}$ is the drain-to-source voltage.

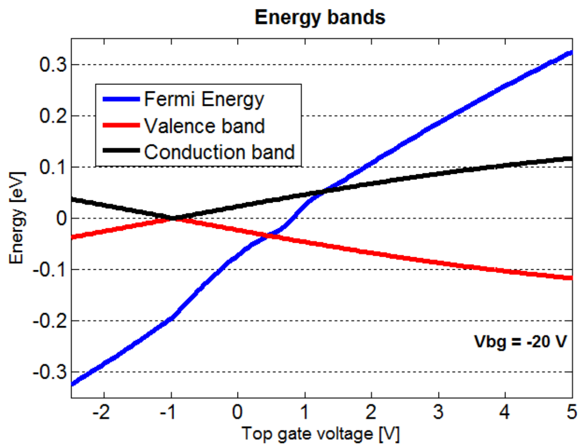


**Figure 2** Energy band diagram of a double gate bilayer graphene field effect transistor ($t_b$ = 300$nm$, $t_t$ = 10$nm$, $\varepsilon_b$ = 3.9, $\varepsilon_t$ = 3.2).

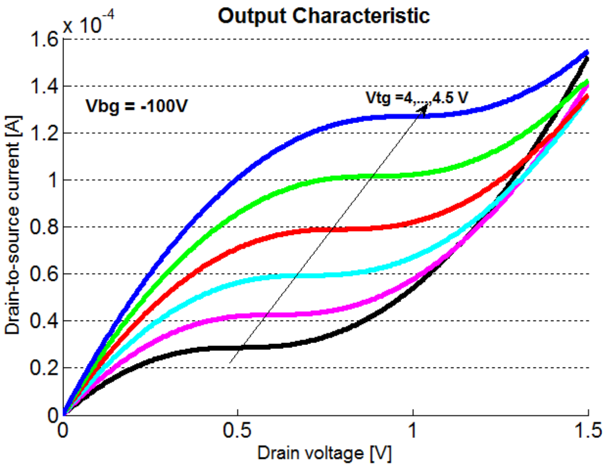


**Figure 3** Output characteristics of a double gate bilayer graphene field effect transistor ($t_b$ = 300$nm$, $t_t$ = 10$nm$, $\varepsilon_b$ = 3.9, $\varepsilon_t$ = 3.2).

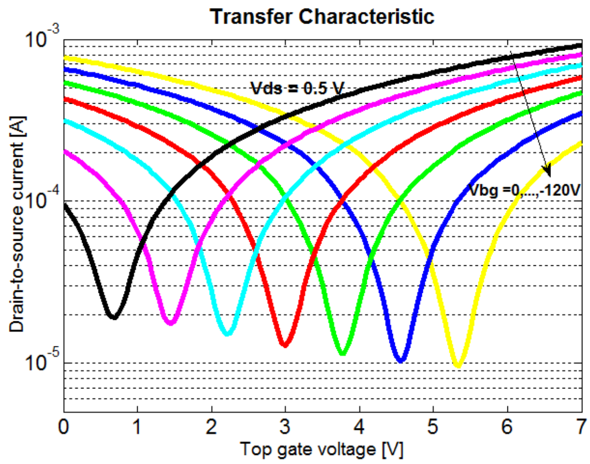


**Figure 4** Transfer characteristics of a double gate bilayer graphene field effect transistor ($t_b$ = 300$nm$, $t_t$ = 10$nm$, $\varepsilon_b$ = 3.9, $\varepsilon_t$ = 3.2).