Graphene RF Design: what really matters

G. Fiori, G. Iannaccone

Dipartimento Ingegneria dell'Informazione, Universita' di Pisa, Via Caruso 16, 56126 Pisa, Italy
gfiori@mercurio.iet.unipi.it

Abstract

It is a widely held opinion in the graphene community that radiofrequency (RF) applications are the most promising when trying to exploit graphene as device channel material, since they can harness graphene properties such as ultrahigh mobility and large saturation velocity, without suffering from the lack of a band gap [1], [2].
The main figure of merit considered so far in order to assess graphene performance for RF applications is the cut-off frequency f_T, i.e. the frequency at which the short-circuit current gain is unity. In particular, in the recent years we have been the witnesses of a kind of "gold-rush", where larger and larger f_T have been obtained at a rapid pace, reaching *few* hundred GHz [3].

However, the main relevant parameter in RF graphene electronics is not f_T*, but rather* f_{MAX}*, i.e. the maximum frequency at which one can obtain power gain. Unfortunately,* f_{MAX} *has often been neglected, while investigating graphene RF performance, and it must be put at the center of the scene.*

The absence of band gap in graphene can indeed have a negative impact in graphene short channel devices, where transport is quasi ballistic and drift velocity saturation cannot occur, interband tunneling suppresses the output differential resistance r_0, the intrinsic voltage gain A_v, and therefore f_{MAX}.

Recently, *Szafranek et al.* [4] have shown with experiments and simulation that a larger r_0 and A_v can be obtained by using bilayer graphene. The reason is that by applying an electric field perpendicular to the bilayer graphene plane it is possible to induce a gap of 100-200 meV. Even such a small gap, is sufficient to significantly improve saturation of the device output characteristics.

Here we investigate with atomistic simulations graphene bilayer FETs for radio frequency application, and show that they represent significant improvement with respect to monolayer graphene FETs. To this purpose we extensively exploit the open source device simulator *NanoTCAD ViDES* [5], based on the self-consistent solution of the three-dimensional Poisson equation and of the Schroedinger equation with an atomistic tight-binding Hamiltonian, within the non-equilibrium Green's functions formalism (NEGF).

The simulated structure is the one considered in the experiments by *Wu et al.* [1] and shown in Fig. 1, where the top oxide has been reduced to 4 nm. To isolate and understand the improvements due to bilayer graphene, we show in Fig. 2 the comparison between the output characteristics of two identical devices, biased with a back-gate voltage V_{BG} = 50 V, where the only difference is the use of monolayer graphene (left) or bilayer graphene (right) as channel. One can see the much improved current saturation and transconductance provided by bilayer graphene, even with a small bandgap (0.22 eV).

As shown in Fig. 3, the backgate voltage is key to tune the energy band gap, and the main factor responsible for the high intrinsic gain achievable with bilayer graphene. The larger the V_{BG}, the larger the bandgap, and in turn the larger the intrinsic gain.
In Fig. 4 instead we show the achievable f_T and f_{MAX}, including some non-idealities such as stray capacitances, and a varying contact resistance R_S. For the bilayer graphene device, for R_S = 0 Ω, we obtain f_T 1.5 THz and f_{MAX} 2 ÷ 4 THz. This is very promising with respect to monolayer graphene devices, where the low output resistance pushes f_{MAX} below f_T. If a finite contact resistance is considered both f_T and f_{MAX} decrease, but for R_S = 80 · μm, as required by ITRS [6], we have both in the THz range.

To conclude, bilayer graphene devices with ideal contact resistances are promising with respect to single layer graphene device. The main single performance booster is the use of bilayer graphene channel, which has a band gap of up to 220 meV, sufficient to suppress interband tunneling and provide acceptable output resistance.

References

[1] Y. Wu et al., Nature, **472** (2011) 74.
[2] G. Iannaccone et al., IEDM Tech. Dig., **1** (2009) 10.4.1.
[3] L. Liao et al., Nature, **467** (2010), 305.
[4] B.N. Szafranek et al., Nano Lett., **12** (2012), 1324.
[5] All documentation on NanoTCAD ViDES can be found at url: http://vides.nanotcad.com
[6] ITRS Roadmap, available at http://public.itrs.net

Figures

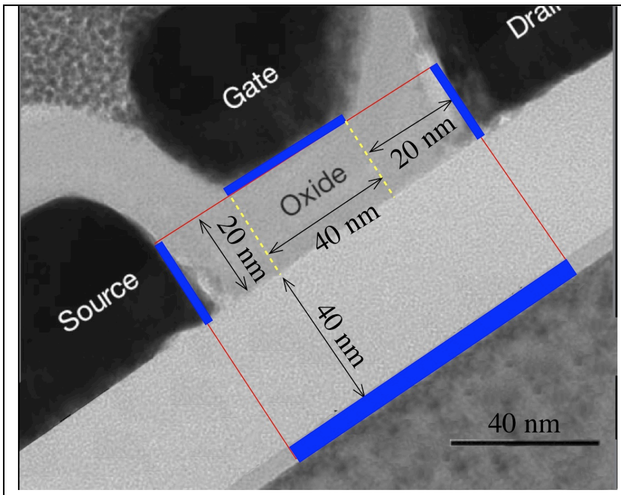

Figure 1: Device structure of Ref. [1] and simulated domain.

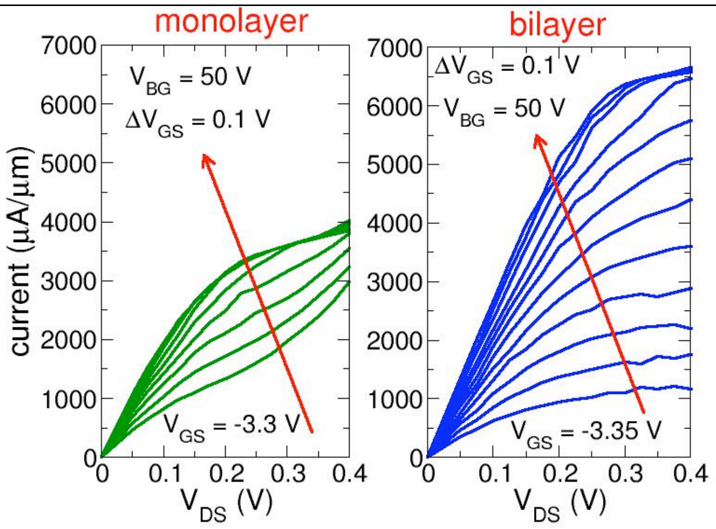

Figure 2: Output characteristics with V_{BG} = 50 V with monolayer graphene channel (left) and bilayer graphene channel (right).

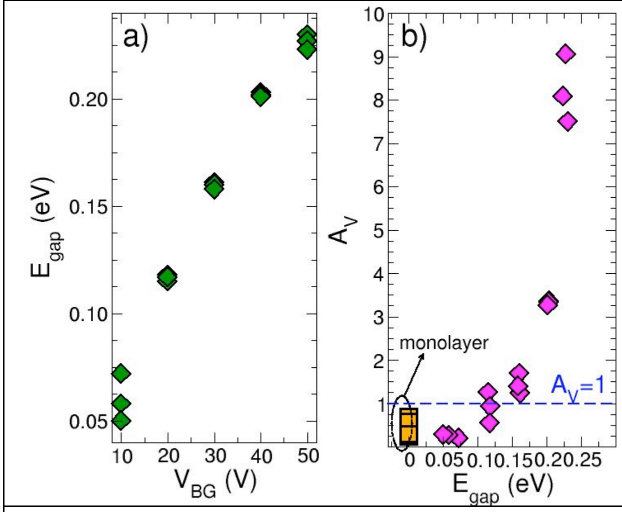

Figure 3: Left: energy gap as a function of the backgate voltage for different V_{GS}; Right: intrinsic gain A_v as a function of E_{gap} for different V_{GS}.

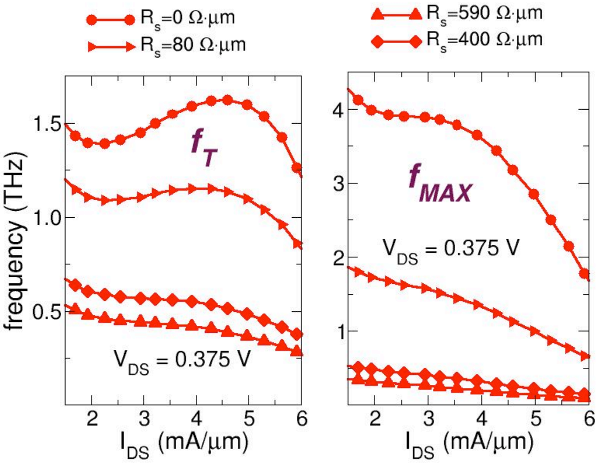

Figure 4: f_T and f_{MAX} as a function of I_{DS} for V_{GB}= 50 V and different contact resistances.