Invited

Detrimental factors lowering the performance of graphene field-effect transistors

David Jiménez[1], Ferney A. Chaves[1], Aron W. Cummings[2], and Stephan Roche[2]

[1]Departament d'Enginyeria Electrònica, Escola d'Enginyeria, Universitat Autònoma de Barcelona, Bellaterra, Spain
[2]ICN2, Institut Català de Nanociencia i Nanotecnologia, Campus UAB, 08193 Bellaterra (Barcelona), Spain

david.jimenez@uab.cat

While graphene has emerged as a promising material for future electronic devices thanks to its unique electronic properties, the metal-graphene contact resistance (R_c) remains a limiting factor for graphene-based electronic devices. In particular, for high frequency electronics is an issue, very much influencing figures of merit like the maximum frequency of oscillation, the cutoff frequency, or the intrinsic gain. That is why there is a need to understand the intrinsic and extrinsic factors determining the contact resistance, which displays a strong variation depending on the metal contact and fabrication procedure details. To gain understanding of the intrinsic factors, a comprehensive physics based model of the contact resistance is worthy. One relevant model was already proposed by Xia et al. [1] to describe the transport in metal-graphene junctions as a sequential tunneling process from the metal to graphene underneath followed by injection to the graphene channel. The first process is responsible for the resistance between the metal and the graphene underneath (R_{mg}) and the second process includes the resistance due to the potential step across the junction formed between the graphene under the metal and the graphene channel (R_{gg}). However, there is an important ingredient determining R_c namely, the transmission from a 3D system (metal) to a 2D system (graphene), that was not properly considered in a physics basis. So, in order to improve the state-of-the-art and current understanding, we have taken this issue of the carrier transmission from 3D to 2D systems into consideration [2]. Specifically, we have developed a physics-based model where the calculation of Rmg and R_{gg} are based on the Bardeen Transfer Hamiltonian (BTH) method and the Landauer approach, respectively. The BTH method allows us to get information about the matrix elements for the transition between 3D-metal and 2D graphene states and combined with Fermi's golden rule, yields a compact expression for the specific contact resistivity. On the other hand, the Landauer approach allows to get the conductance of carriers across the potential step between the graphene under the metal and the graphene in the channel, where the angular dependence transmission of fermions have been taken into account. As an illustrative example of the predictive capability of our model we have compared our results with available experimental data from Ref. 1 for Pd-graphene contacts (see Fig. 1).

The chemical vapor deposition (CVD) technique for growing wafer-scale graphene on metallic substrates produces a polycrystalline pattern. This is because the growth of graphene is simultaneously initiated at different nucleation sites, leading to samples with randomly distributed grains of varying lattice orientations. It has recently been predicted that the electronic properties of polycrystalline graphene differ from those of pristine graphene (PG), where the mobility scales linearly with the average grain size [3]. Based on these results, we report on how the electronic properties of polycrystalline graphene (Poly-G) impact the behavior of graphene-based devices. For such a purpose, we have developed a drift-diffusion transport model for the graphene field-effect transistor (GFET), based on a detailed description of electronic transport in polycrystalline graphene [4]. This model allows us to determine how a graphene sample's polycrystallinity alters the electronic transport in GFETs, enabling the prediction and optimization of various figures of merit for these devices. Specifically, we

concentrate our study on the effect that Poly-G has on the gate electrostatics and *I-V* characteristics of GFETs. We find that the source-drain current and the transconductance are proportional to the average grain size, indicating that these quantities are hampered by the presence of grain boundaries (GBs) in the Poly-G. Besides, our simulations also show that current saturation is improved by the presence of GBs, and the intrinsic gain is insensitive to the grain size. We have found that the presence of GBs produces a severe degradation of both the maximum frequency and the cutoff frequency, while the intrinsic gain remains insensitive to the presence of GBs (Fig. 2). These results indicate that GBs play a complex role in the behavior of graphene-based electronics, and their importance depends on the application of the device. Overall, polycrystallinity is predicted to be an undesirable trait in GFETs targeting analog or RF applications.

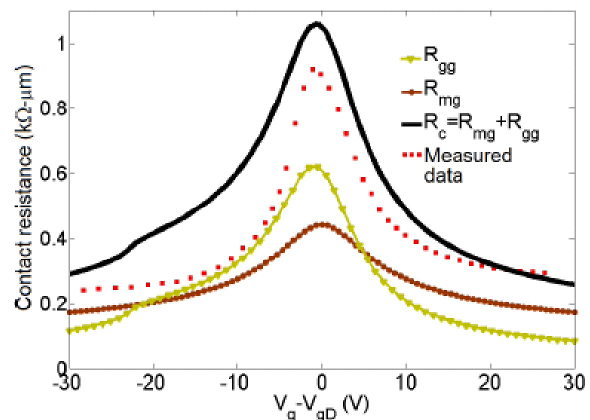

Figure 1. Experimental versus simulation of Pd-graphene junction contact resistance as a function of the gate bias overdrive.

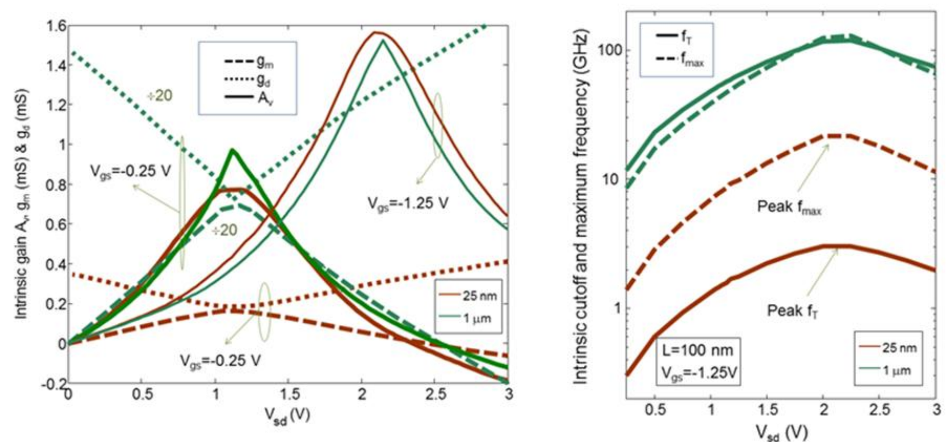

Figure 2. Left: Intrinsic gain as a function of the drain voltage. Right: Intrinsic maximum and cutoff frequency for a prototypical transistor with a channel length of 100 nm.

We acknowledge support from SAMSUNG within the Global Innovation Program. The research leading to these results has received funding from Ministerio of Economía y Competitividad of Spain under the project TEC2012-31330 and MAT2012-33911, and from the European Union Seventh Framework Programme under grant agreement n°604391 Graphene Flagship.

References

[1] F. Xia et al., Nature Nanotechnology 6, 79 (2011)

[2] F. Chaves, D. Jiménez, A. Cummings, S. Roche, Journal of Applied Physics 115, 164513 (2014),

[3] D. V. Tuan, J. Kotakoski, T. Louvet, F. Ortmann, J. C Meyer, S. Roche, Nano Lett. 13, 1730-1735 (2013).

[4] D. Jiménez, A. W. Cummings, F. Chaves, D. Van Tuan, J. Kotakoski, S. Roche, Applied Physics Letters 104, 043509 (2014).