Electrical model for characterizing Chemical Vapour Deposition graphene

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Abstract

Due to its extremely small thickness (0.35 nm), graphene is an intrinsic 2D nanomaterial. As in many other nanomaterials, its unique properties are derived from its exceptional dimensions. One of these properties is its linear dispersion equation that implies charge carriers with extraordinary high mobility. Therefore, the electronic properties of the material can lead to a big improvement in the performance of known electronic devices, or even result in novel devices for a post-silicon era.

In this work, we explain a method to characterize graphene using electrical measurements in graphene field-effect transistors (GFET) devices. Our goal is to obtain the material electronic properties from the output characteristics of one GFET. For the previous purpose, we will need to apply a physical model that allows us to correlate the electronic behavior of a GFET with the material properties.

There are several models used for graphene. Some of them are based strongly on solid state physics [1], [2], including even quantum effects at high magnetic fields. Others are more focused on FET devices [3]. The model used in this work is based on first principles and is described thoroughly in [4]. The main advantage of this model is that most of the equations are directly derived from the energy-momentum dispersion relation from graphene, so it is straightforward to obtain the carrier concentration and the current in terms of the gate voltage (Vg) of the transistor, and even local characteristics along the channel. Also, the temperature is an explicit parameter on the equations, and the shifts in the Dirac point are explained with a fixed surface charge. With this model we are able to obtain a quick characterization of the material electrical properties from just a transistor structure (Fig. 1).

The fitting to this model is done by using the measured IDS vs. VG curves of a real device. All the relevant parameters, such as the oxide capacitance (C_{ox}), voltage applied (V_{DS}), gate metal work function, gate length (L_g), and width (w), among others must be introduced in the model. For fitting the experimental measurements into the model, we work with the transconductance (g_m), in order to extract some fundamental values from the shape, such as the maximum and minimum transconductance, the Dirac point, or the curve slope in several voltage ranges, as detailed in Fig.2. Using these parameters from real data, we use the model to obtain the electron and hole mobilities, the total serial resistance and the total density of fixed charge.
We have used different measurements from previous publications, like suspended devices [5] (see Fig. 3), and CVD graphene transistors [3] (see Fig. 4).

Effects due to scattering produced by defects in the surface, either from the material or due to processing, are not included in this model, somewhat limiting its validity for some devices. Also, large differences between electron and hole mobilities cannot be explained properly in this theoretical framework. More work is underway to increase the physical effects taken into account, and therefore to improve the results and widen the range of devices to which the explained procedure is applicable.

Acknowledgements

References

[1] K.S. Novoselov, A.K. Geim et al., Nature, **438** (2005) 197.

[2] S. Adam, E. Hwang et al., PNAS, **104** (2007) 18392.

[3] H. Wang, A. Hsu et al., IEEE Transactions on Electron Devices, **58** (2011) 1523 .

[4] J. Champlain, Journal of Applied Physics, **109** (2011) 084515.

[5] K. Bolotin, K. Sikes et al., Physical Review Letters, **101** (2008) 1.
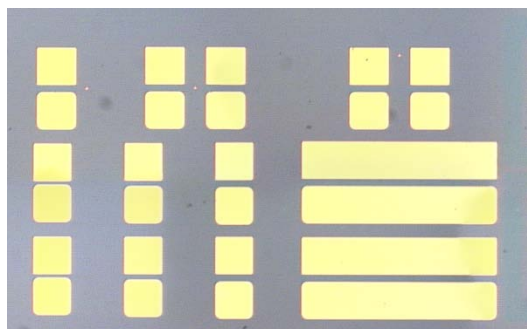
Figures

Fig. 1: Sample with CVD-graphene transistor devices used for batch-fitting to the model.
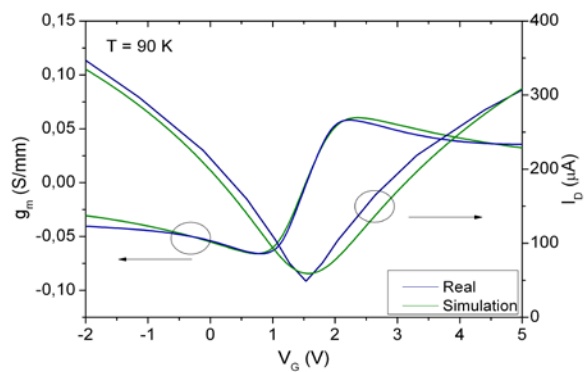

Fig. 3: Fit for a suspended graphene device in [5] at low temperature.
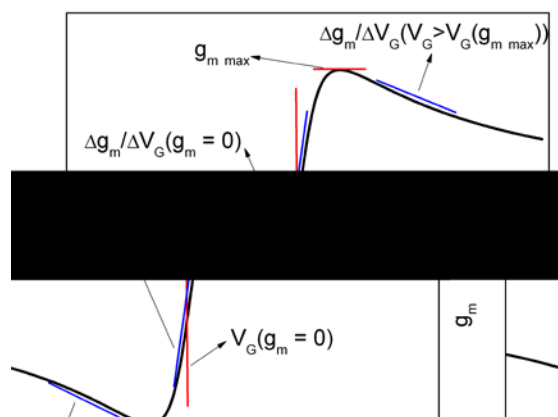

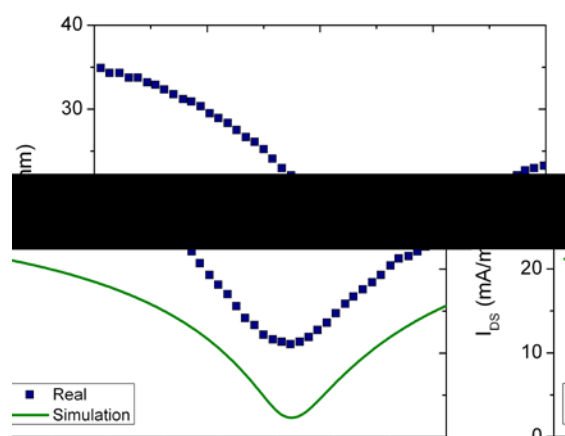Fig. 2: Relevant parameters obtained from real data transconductance.

Fig. 4: Model applied to a CVD graphene transistor from reference [3]