Graphene Nanomesh Transistors with high on/off ratio

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Abstract

Though the excellent transport properties of pristine graphene [1,2] gave rise to a lot of expectations towards high performance electronics, the possible range of applications of graphene transistors (GFET) turned out to be rather limited by the gapless character of this material. Indeed, the lack of bandgap yields a very small on/off current ratio and a poor saturation behaviour [3,4]. To open a bandgap in graphene, a possible approach consists in cutting graphene layers into nanorribons (GNRs) but fabricating narrow-enough (sub-3 nm) ribbons with good edge roughness control remains challenging. It is also possible to open a bandgap of about 130 meV in bilayer graphene by applying a strong electric field perpendicular to the bilayer plane [5], which allows enhancing the on/off ratio of transistors up to 100 at 300 K [6]. Recently, the fabrication of a new graphene nanostructure called graphene nanomesh (GNM) has been reported [7]. It consists in generating a regular array of antidots separated by a sub-10 nm distance. According to the periodicity and the neck width of GNM lattice, bandgaps of several hundreds of meV have been predicted to appear in large sheets of graphene [8,9]. A similar result can be obtained in superlattices of graphane-like islands formed by patterned adsorption of hydrogen atoms [10]. This kind of bandgap nanoengineering offers new possibilities to design improved devices delivering large currents. For instance, GNM-based PN junctions have been predicted to exhibit a negative differential conductance with high peak-to-valley ratio [11].

In the present work, we investigate GNM-based field-effect transistors (GNM-FETs) by means of 3D numerical simulation. The model is based on the Green's function approach to solving a tight-binding Hamiltonian, self-consistently coupled to 3D Poisson's equation [12]. Various GNM lattices have been considered as schematized in Fig. 1a, differing in the x and y neck widths (W_x and W_y) and filling factors. A 3D view of the simulated GNM-FETs is shown in Fig. 1b, with a gate length L_G = 30 nm and infinite width thanks to appropriate periodic boundary conditions along y direction. The results were compared to the case of pristine graphene FET (GFET). For the GNM lattice characterized by $Wx \approx 1.1$ nm / $Wy \approx 1.2$ nm and an anti-filling factor AFF of 13.3%, the bandgap reaches 553 meV. For the transistor based on this GNM we plot in Fig. 2 the local density of states (for $k_y = 0$) at the Dirac point (V_{GS} = 0.2 V) and the corresponding transmission function. The bandap widely overlaps the current transmission window [E_{fd}, E_{fs}], which results in a low off-current of 0.72 µA/µm.

The I_D-V_{GS} characteristics of four devices are plotted in Fig. 3 for V_{DS} = 0.2 V. In addition to the previous device, we consider also the case of pristine graphene ($E_G = 0$), a GNM with $Wx \approx 2.3$ nm, $Wy \approx 2.2$ nm and AFF = 10% (E_G = 268 meV) and a GNM with $Wx \approx 1$ nm, $Wy \approx 1.1$ nm and AFF = 6.25% (E_G = 508 meV). It appears clearly that when increasing the bandgap the off-current is reduced. However, the highest bandgap of 553 meV does not provide the highest on/off ratio. Indeed, for this GNM, the rather high AFF of 13.3% tends to degrade significantly the on-current. In spite of a slightly higher off-current the device with the GNM bandgap of 508 meV offers a much higher on-current thanks to a smaller AFF and finally an on/off ratio of 1460 twice as high as for the GNM with E_G = 553 meV. It is remarkably better than the performance of pristine GFET. This work shows that the GNM-FET offers a promising way of improving the performance of graphene transistors, which will be discussed in detail.

References

[1] K.I. Bolotin et al., *Solid-State Com* **146** (2008) 351-355.
[2] P.J. Zomer, S.P. Dash, N. Tombros, and B.J. van Wees, *Appl. Phys. Lett.* **99** (2011) 232104.
[3] Ph. Avouris, *Nano Lett.***10** (2010) 4285–4294.
[4] I. Meric et al., *Nature nanotechnol.***3** (2008) 654-659.
[5] J.B. Oostinga et al., *Nat. Mater.* **7** (2008) 151-157.
[6] F. Xia, D.B. Farmer, Y.-M. Lin, and Ph. Avouris, *Nano Lett.*, **10** (2010) 715-718.
[7] J. Bai, X. Zhong, S. Jiang, Y. Huang and X. Duan, *Nat. Nanotechnol.* **5** (2010) 190-194.
[8] T.G. Pedersen et al., *Phys. Rev. Lett.* **100** (2008) 136804.
[9] V. Hung Nguyen, M. Chung Nguyen, H. Viet Nguyen, P. Dollfus, J. Appl. Phys. **113** (2013) 013702.
[10] R. Balog et al., *Nature Mater.* **9** (2010) 315-319.
[11] V. Hung Nguyen, F. Mazzamuto, J. Saint-Martin, A. Bournel, P. Dollfus, *Nanotechnology* **23** (2012) 065201.
[12] V. Hung Nguyen, F. Mazzamuto, A. Bournel, and P. Dollfus, *J. Phys. D* **45** (2012) 325104 (2012).

Figures

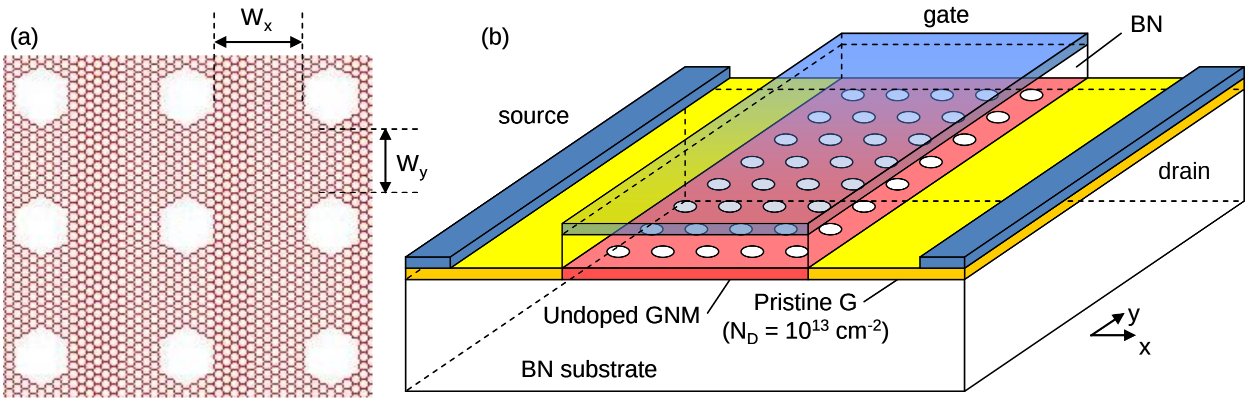

Figure 1. (a) Typical view of a GNM lattice characterized by the neck widths W_x and W_y. (b) Schematic 3D view of the GNM-FET. The gate length is L_G = 30 nm, the BN gate insulator thickness is 2 nm.

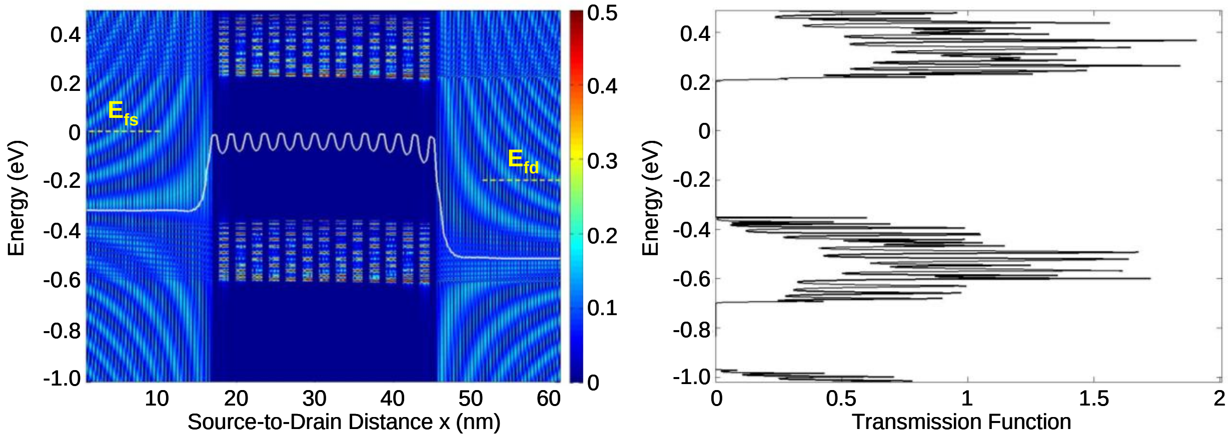

Figure 2. (left panel) Local density of states for k_y = 0 in a GNM-FET for V_{DS} = V_{GS} =0.2 V. The potential profile at the center of the device is superimposed (white line). (right panel) Corresponding transmission function. GNM considered: Wx = 1.1 nm, Wy = 1.2 nm and AFF = 13.3%.

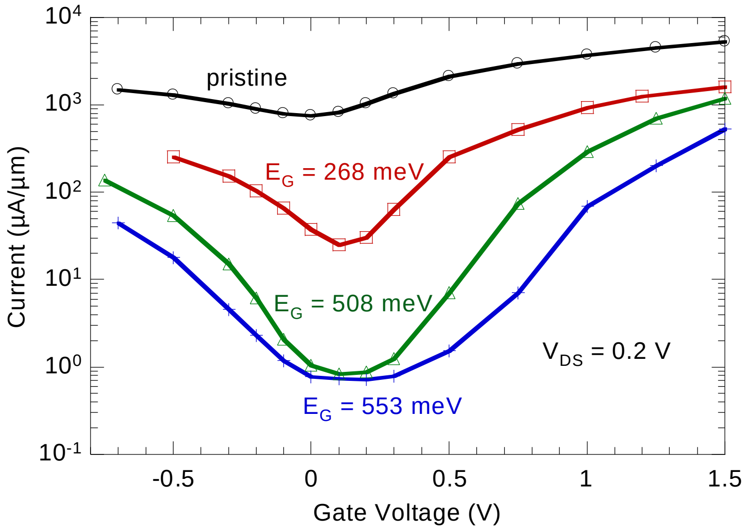

Figure 3. I_D-V_{GS} characteristics of simulated devices at V_{DS} = 0.2 V (see text for details on GNM parameters).