Charge transfer and screening behaviour of bilayer graphene devices

Vishal Panchal[1,2], Arseniy Lartsev[3], Rositza Yakimova[4], Alexander Tzalenchuk[1] and Olga Kazakova[1]

[1]National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK
[2]Royal Holloway, University of London, Egham Hill, Egham, Surrey, TW20 0EX, UK
[3]Chalmers University of Technology, Göteborg, S-412 96, Sweden
[4]Linköping University, Linköping, S-581 83, Sweden
olga.kazakova@npl.co.uk

Graphene is a two-dimensional material comprised of only carbon atoms closely packed in a honeycomb crystal structure. Devices fabricated out of epitaxial graphene grown on SiC have shown great promise for commercialization [1,2]. However, due to the complicated growth procedure, even the best epitaxial samples contain ~95% mono-layer (1LG) and ~5% bi-layer (2LG) graphene coverage [3]. Due to the differences in the band structure of different graphene layer thicknesses, such samples have been shown to exhibit a work function difference of ~120±15 meV between 1LG and 2LG [4-6], which can affect the transport properties of graphene devices.

Our study of the *bulk* electrical properties of 1LG and 2LG devices reveals the carrier density for 1LG and 2LG to be $n^{1LG} \sim 2\times10^{12}$ cm^{-2} and $n^{2LG} \sim 9\times10^{12}$ cm^{-2}, respectively, in a dark environment at ambient conditions. Further, we investigate the *local* electrical properties of 1LG device with isolated 2LG islands by measuring the longitudinal (V_{xx}) and transverse voltage (V_{xy}) response to an electric field produced by a local scanning gate (Fig. 1a). Scanning gate microscopy (SGM) is performed using an electrically conductive probe to locally gate the double-cross graphene Hall bar at a constant 15 nm lift height, while a DC bias voltage (V_{probe}) is applied to the probe. V_{xx} and V_{xy} maps of the current biased device (I_{bias}) are obtained by measuring and recording the signal, pixel by pixel, with a lock-in amplifier referenced to the mechanical resonance of the cantilever. Spectroscopy is a point measurement performed by sweeping V_{probe} and measuring V_{xx} at well-defined positions.

SGM V_{xx} map of the entire device was obtained at I_{bias} = 10 μA and V_{probe} = –3 V (Fig. 1b). The image shows that gating in the central part of the device on the 1LG increases V_{xx}, whereas gating on the 2LG decreases V_{xx}. Spectroscopy measurements on 1LG, isolated 2LG and background conducted by sweeping V_{probe} and measuring $R_4 = V_{xx} / I_{bias}$ (Fig. 1c), shows that local gating on 1LG with V_{probe} = –5 V *increases* the total resistance of the channel by R_4 ~0.75 Ω. The latter can be described by the electron-electron repulsion between the probe and the sample decreasing the carrier density, thereby increasing the resistance. However, gating on the isolated 2LG *decreases* the total resistance by R_4 ~0.25 Ω, which is a result of an increase in the carrier density. This gives indication of a charge transfer occurring to/from the isolated 2LG islands in the presence of an electric field. Such effect is impossible to observe with uniform top gates, where the small inverse behaviour of the 2LG islands would be masked by the much larger contribution from the 1LG part of the device.

In addition, we study the effects of isolated 2LG islands on the V_{xy} of the Hall device (Fig. 2). Comparing the V_{xy} contrast of the 2LG island (location 1) to the SiC background (location 2), the V_{xy} map indicates that isolated 2LG islands can screen the local electric field, affecting the transport measurements of the Hall sensor. However, the screening efficiency will depend on geometry of 2LG domains and their exact position with respect to the leads. Local electric field applied at location 3 clearly shows a significantly larger response in comparison to locations 1 and 2. These measurements allow investigating the possible effect of decoupling between individual layers of graphene.

In summary, we studied the bulk and local transport properties of graphene nanodevices as well as the effects of local electric fields applied to continuous 1LG and isolated 2LG islands on the total resistance of the device. We show that the local resistance and, hence the carrier density change of the 2LG island are sensitive to the sign of the gate voltage, giving indication of charge transfer occurring to/from the isolated 2LG islands in the presence of a local electric field. In addition, in the transverse voltage measurements we also observe the effect of local screening of the electric field by the 2LG island. These nanoscale effects of isolated 2LG islands can significantly affect the performance of graphene devices. SGM techniques are ideal for observing these nanoscale effects, which otherwise are difficult to detect with bulk transport measurements alone.

[1] C. Dimitrakopoulos *et al*., J. Vac. Sci. Technol. B, **28** (2010) 985-992.
[2] Y. -M. Lin *et al.*, Science, **327** (2010) 662.
[3] V. Panchal *et al.*, 12th IEEE Conf. on Nanotechnology (2012).

[4] O. Kazakova *et al.*, Crystals, **3** (2013) 191-233.
[5] Y.-J. Yu *et al.*, Nano Letters, **9** (2009), 3430–3434.
[6] T. Filleter *et al.*, Applied Physics Letters **93** (2008), 133117.

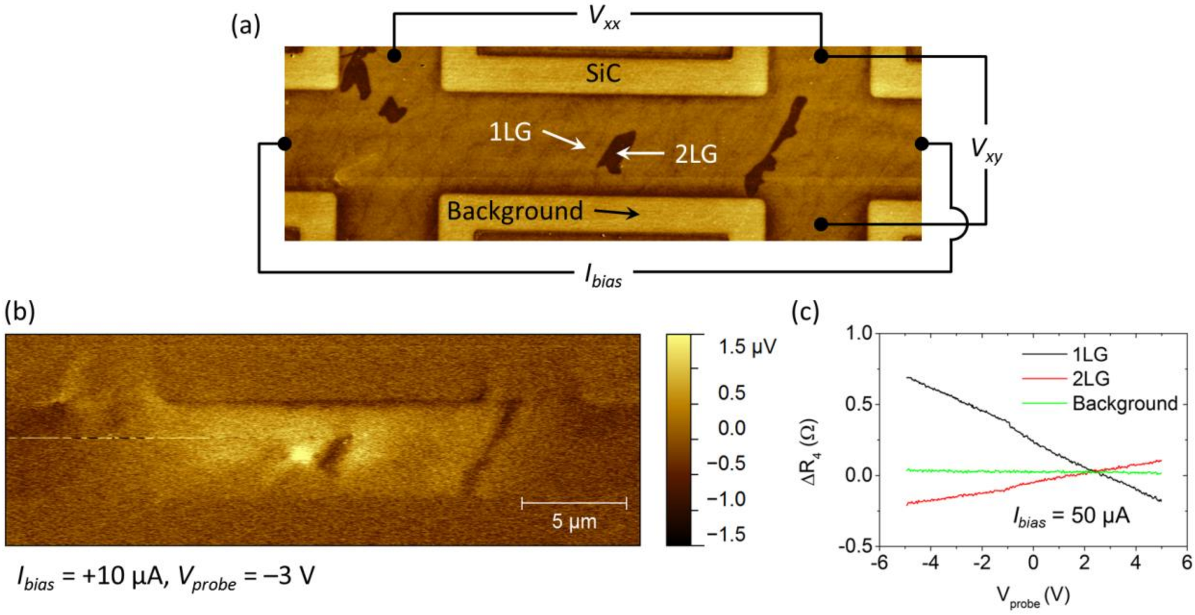

Fig. 1: (a) Electrostatic force microscopy map of the 1LG device with patches of 2LG islands. Colour scale: phase range of 0.8°. Electrical scheme of the experiment is shown. (b) SGM V_{xx} mapping of the entire device taken with I_{bias} = 10 μA and V_{probe} = –3 V. (c) Spectroscopy measurement performed by sweeping V_{probe} and recording V_{xx} at the three locations indicated by the arrows in (a).

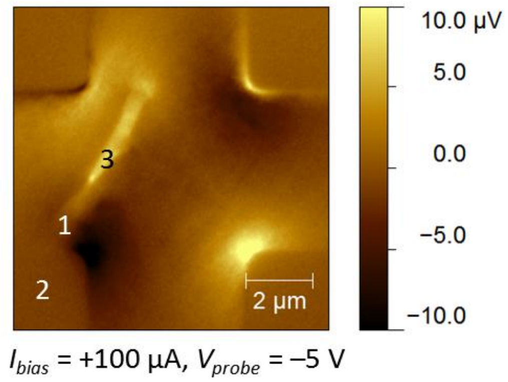

Fig. 2: SGM V_{xy} mapping of the right cross of the device shown in Fig. 1a. V_{xy} at location 1 is comparable to the background (location 2), whereas the response at location 3 is significantly larger than location 1.