Lithography-free fabrication of graphene devices

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Graphene device fabrication on large-area graphene typically involves several patterning steps using electron beam or optical lithography, followed by graphene etching and metallization. However, the resist films and lift-off chemicals used in lithography introduce compatibility issues, such as the difficulty of removing the resist from the graphene and undesired doping. The resist residue has a negative influence on the thermal and electrical properties of the graphene and interferes with functionalization of the graphene. This motivates the development of a 'bottom-up', direct-write, lithography-free fabrication method.

In this work, a lithography-free fabrication method for graphene-based devices will be demonstrated. In the first step, large-area graphene is directly patterned by a focused ion beam (FIB) in order to isolate small strips of graphene from the bulk. An *in situ* Raman microscope allowed for direct observation of the graphene before and after the ion beam processing. The Raman spectra showed that a Ga-ion dose of 10 C/m^2 is sufficient to completely remove graphene. By optimizing the pattern design, the ion beam current and the background pressure damage to the graphene by scattered ions is prevented.

In the second step Pt contacts are formed by using our novel resist-free direct-write technique [1, 2]. This approach consists of the patterning of a thin seed layer of less than 0.5 nm Pt-containing material by electron beam induced deposition (EBID), followed by selective thickening of the seed layer by area-selective atomic layer deposition (ALD). This combined approach yields virtually 100% pure Pt (resistivity of 12 μΩ.cm), while it allows for patterning of Pt line deposits of only 10 nm in width. This chemical approach to contact deposition is expected to yield lower contact resistances compared to conventional physical deposition techniques.

Preliminary electrical measurements on sub-optimal devices demonstrate contact resistances as low as (40 ± 30) Ω.

[1] A.J.M. Mackus, S,A,F, Dielissen, J.J.L. Mulders, W.M.M. Kessels, Nanoscale 4(2012), 4477

[2] A.J.M. Mackus, N.F.W. Thissen, J.J.L. Mulders, P.H.F. Trompenaars, M.A. Verheijen, A.A. Bol, W.M.M. Kessels, J. Phys. Chem. C 117 (2013), 10788

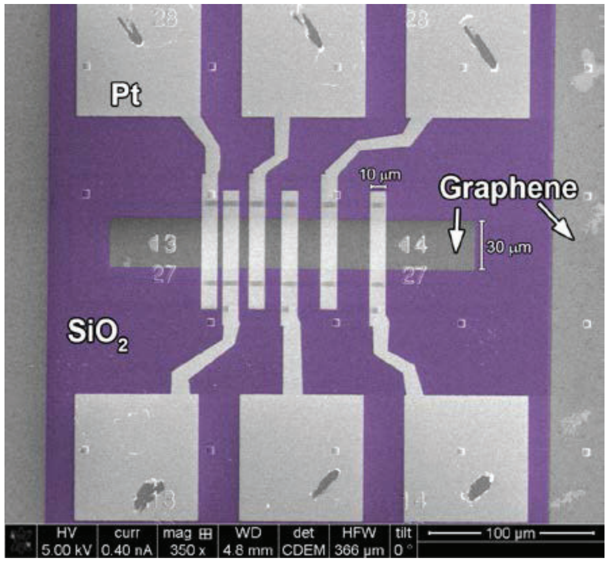

Figure 1 – Scanning electron microscope image of a completed graphene device. A focused ion beam (FIB) is used to locally remove the graphene in order to isolate a strip for contacting. Direct-write ALD is then used to deposit Pt contacts to the graphene. The SiO_2 surface is artificially coloured for clarity.

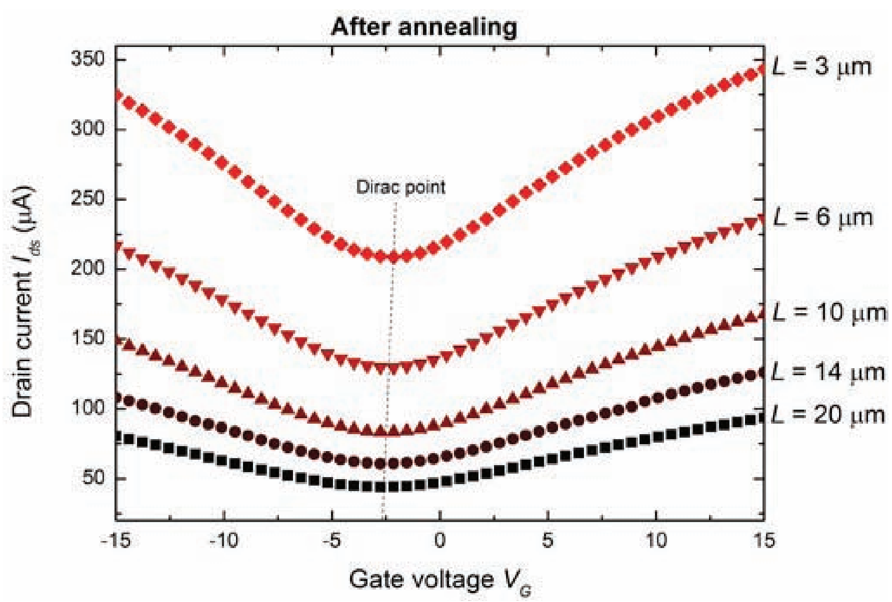

Figure 2 - Electrical characterization in vacuum (drain current vs gate voltage applied via a back-gate) of a typical device after mild annealing (200 °C) to remove adsorbents from the air. The various curves correspond to two-terminal measurements across two adjacent contacts with the specified channel length *L* between them.