Influence of individual process steps on graphene device characteristics

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Abstract

The electrical properties of graphene-based electronic devices may be significantly affected by complex fabrication processes [1], including photolithography and electron-beam lithography (EBL). These involve chemicals, polymers, heating in various atmospheres, electron irradiation etc. [2]. Since electrical measurements are most often performed after the device has been subjected to several physical processes and chemicals, the role of individual processing steps on features like gate voltage hysteresis and residual doping can be difficult to assess.

Stencil lithography enables the production of devices entirely without the use of resist, chemicals or heat [3]. We use stencil shadow masks for deposition of electrical contacts on mechanically exfoliated graphene flakes to form two-terminal electrical devices, see Fig. 1 (a-b). The great advantage of this strategy is the avoidance of additional contamination, which creates a clean starting point and makes it possible to investigate the change in the electrical behavior due to individual processing steps. We have systematically tested the effect on charge carrier mobility, doping level and gate voltage hysteresis due to various chemicals, heating and polymers such as polymethyl methacrylate (PMMA), see Fig. 1 (c). PMMA is a polymer often used as resist in EBL processes and for transfer of graphene between different substrates [4].

We find that the p-type doping and hysteresis induced by this EBL-like process can be strongly reduced by thermal annealing. This approach enables systematical, well-controlled study of individual process steps in a graphene fabrication cycle, which is critical for optimization, fault-finding and commercialization of graphene-based electronic devices.

References

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Figures

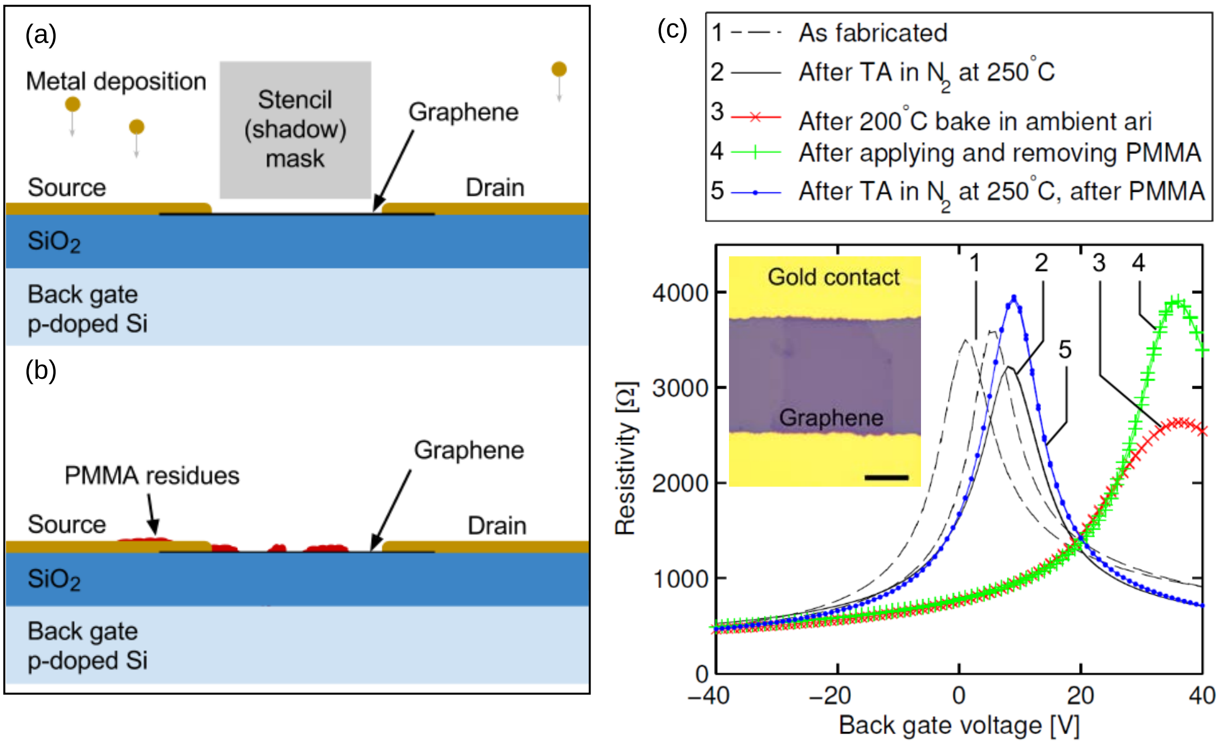

Figure 1: Schematic drawing of (a) the fabrication of stencil devices and (b) the devices after dissolution of polymer. In (c) the effect of electron-beam lithography with PMMA as resist is mimicked. Electrical measurements are performed between every fabrication step. 1: A hysteresis of 5 V is observed after deposition of stencil electrodes. 2: The hysteresis is reduced after a 30 minutes temperature anneal (TA) in nitrogen atmosphere, at 250°C. 3: After a bake in ambient air at 200°C the graphene is found to be heavily p-doped. This step is typically used in electron-beam lithography fabrication to create better adhesion between substrate and PMMA. 4: The PMMA is applied and removed, which leaves PMMA residues on the graphene. 5: Doping and hysteresis is reduced after temperature anneal with same parameters as in 2. The optical image in (c) shows the measured graphene stencil device. The scale bar is 10µm.