Wafer-scale fabrication of planar solution-gated graphene field-effect transistors for biosensing

N.C.S.Vieira[1,3], J. Borme[1], G.M. Junior[1], M.F. Cerqueira[2], P.P. Freitas[1], V. Zucolotto[3], P. Alpuim[1,2]
[1]INL – International Iberian Nanotechnology Laboratory, Av. Mestre José Veiga, Braga, Portugal
[2]CFUM – Centre of Physics of the University of Minho, Campus de Gualtar, Braga, Portugal
[3]GNano – Nanomedicine and Nanotoxicology Group, Physics Institute of São Carlos, University of São Paulo, São Carlos-SP, Brazil
jerome.borme@inl.int

Abstract

Recently, graphene has emerged as an alternative material for application in biosensors based on field effect transistors (bio-FET) due to its unique electronic properties combined with its high chemical stability and structural uniformity [1]. Although solution-gated bio-FETs offer interesting advantages compared to other types of biosensors (high sensitivity, label-free detection and large-scale fabrication), the usually large dimensions of gate electrodes (Ag/AgCl reference electrode or a metal wire made of gold, platinum or silver) represent a hindrance for miniaturization of these devices. Since this electrode is essential for gating the transistor it may preclude technological/commercial applications where such systems must work in realistic configurations. Here, we propose the wafer-scale fabrication of solution-gated graphene FETs (SG-GFETs) in which both the metal gate electrode and the transistor array were fabricated in the same wafer. This integration is critical, aiming further applications for bio-sensing, e.g. for advanced point of care testing.
Graphene was deposited by CVD from gaseous mixtures of methane, hydrogen and argon on a 25 µm thick copper foil catalyst with 99.999% purity in a quartz tube reactor heated to 1020 °C. It was then transferred to the SiO_2/Si wafer final substrate using PMMA as a temporary substrate and dissolving the Cu in a $FeCl_3$ solution. The quality of graphene was assessed using Raman spectroscopy. Fig. 1a shows an optical image of a typical device structure: a 200 mm oxidized silicon wafer was patterned with 280 dies, each comprising three gold contacts: source, drain and a planar gate, with a source-drain gap of 25 µm and the ring-shaped gate at 50 µm around these two contacts. Several squared pieces of 25 mm of graphene were transferred to cover a large portion of the wafer. Graphene was patterned using optical lithography and oxygen plasma etch keeping the gate Au contact protected by a layer of Al_2O_3, which is removed later in a wet etch step.
The finished set of devices was characterized electrically using 0.01X phosphate buffered saline solution (PBS, pH 7.4) as the gate dielectric. The experiments were carried out by dropping a 20 µL drop of PBS onto the graphene transistor channel. Devices were gated by applying voltage to the integrated gate. A conventional Au wire was also used as gate contact in selected devices for comparison. Fig. 1b shows the transfer curves of the same device gated by conventional gold wire and using the integrated gate. The graphene is unintentionally p-doped which is related to the process and to the substrate. There is a shift in V_{Dirac} in the positive axis direction when the device is gated by the integrated gate. The gate-source leakage current is negligible (< 0.03 µA) as compared to the source-drain current of the SG-GFET at the same gate potential.
Fig. 1c shows normalized transfer curves of eleven devices, obtained by dividing each original curve by the respective I_{SD} maximum. The data show good transistor reproducibility, which is a key requirement for analytical devices. We are currently performing the functionalization of SG-FET channel with specific probes in order to detect disease biomarkers and water toxins.

G.M.J thanks CNPq for a PhD grant. N.V is thankful to FAPESP for a post-doctoral grant.

References

[1] Yan, F., Zhang, M., Li, J. Advanced Healthcare Materials 3 (2014) 313